

Book of Abstracts

I International Conference

Advanced functional materials for digital and quantum electronics 2025

Moscow Institute of Physics and Technology

(MIPT / PhysTech)

September 15-20, 2025



Dolgoprudny, Russia
2025

Contents

Monday, September 15: Superconductivity	18
1 DORIA Mauro: A Quantum Plasmonic approach for the topological insulators	18
2 KUPRIYANOV Mikhail: Quasiparticle Conversion in SN-N-NS Josephson Junctions	19
3 BAKURSKIY Sergey: Crucial role of electrode dimensions in Josephson SNS bridges	20
4 ZADOROSNY Rafael: Fibrous Ceramic Superconductors and Their Production Using the Solution Blow Spinning Structuring Technique	21
5 VAGOV Alexei: Localization in Materials with Several Conducting Bands to Enhance Superconductivity	22
6 BURMISTROV Igor: Spatially Resolved Dynamics of the Amplitude Schmid-Higgs Mode in Disordered Superconductors	23
7 BENITES Talles: Resistive States due to the Interplay of Flux Flow and Vortex Dynamics in Artificially Defected Granular Superconductors within the Ginzburg-Landau Theory	24
8 POLEVOY Konstantin: Proximity Effect Engineering in Al-Based SNS Junctions with Intrinsic Superconductivity	25
9 BRAMBILLA Matheus Paniago: A Novel Route to Nickelate Superconductors through the Synthesis of $\text{La}_3\text{Ni}_2\text{O}_7$ Nanofibers via Solution Blow Spinning	26
10 MARYCHEV Pavel: Crossover between Types I and II in Diffusive Superconductors: Perturbative Study	27
11 DURAN Edimar Aparecido dos Santos: Systematic Analysis of Silver Interaction in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Ceramic Nanowires	28
Tuesday, September 16: Functional Materials	29
12 NIKITOV Sergey: PT symmetry and Exception Points in spintronics, magnonics and photonics	29
13 ZHAO Ya-Xin: Realization of fractional-layer transition metal dichalcogenides	30
14 GORSHUNOV Boris: Thin films at terahertz frequencies: physics and applications	31
15 HU Qingmei: Graphene Based Room-Temperature Terahertz Detector with Integrated Bow-Tie Antenna	32
16 MEL'NIKOV Alexander: Impurity-induced Inverse Faraday Effect	33
17 VODOLAZOV Denis: Vortex nucleation in type I superconducting layer covering type II superconductor	34
18 TARASOV Artem: Electronic spin structure of quasi-two-dimensional systems with combined spin-orbit and exchange interactions	35
19 MA Junli: Asymmetric Evaporator for Simultaneous Generation of Clean Water and Electrical Power	36
20 MELENTEV Alexander: Enhancing permittivity of SrTiO_3 thin film via intermediate AlFeO_3 layers incorporation	37

21 ANCHICO Brian: Ferroelectric phase transition and topological properties in two-dimensional CuVP_2Se_6	38
22 ANNENKOV Dmitry: Domain-wall superconductivity in van der Waals structures with ferroelectric ordering	39
23 LIANG Qingrong: Multidirectional sliding ferroelectricity of rhombohedral-stacked InSe for reconfigurable photovoltaics and imaging applications	40
24 SEMIN Viktor: Structure, residual stresses and properties of Al superconducting thin films fabricated by magnetron sputtering	42
Wednesday, September 17: Moscow Sightseeing Tour, Visit to the Kremlin	43
Thursday, September 18: Digital and Quantum Technology	43
25 WU Hao: EPR in the high-cooperativity regime: a playground for microwave quantum electronics	43
26 MAKHLIN Yury: Planar topological Josephson junctions and Majorana zero modes	44
27 SU Wenyong: Fabrication and application of optical synaptic devices based on two-dimensional materials	45
28 FOMINOV Yakov: All fractional Shapiro steps in the RSJ model with two Josephson harmonics	46
29 BELOTELOV Vladimir: Ultra-Low-Damping Epitaxial YIG Films Grown by LPE with a Buffer Layer for Quantum Applications	47
30 ALADYSHKIN Alexey: Analysis of periodicity in arrays of triple steps on vicinal surfaces: Period-dependent suppression of Fourier peaks	48
31 PANKRATOV Andrey: Studying photon statistics and noise with quantum sensors	50
32 ESTYUNIN Dmitriy: Precise Control of the Electronic Structure in AB_2C_4 -Type Topological Compounds	51
33 YUHE Yang: Research on Multimodal Sensors Based on Two-Dimensional MXene Materials	52
34 NEVEROV Vyacheslav: Enhancing the visibility of Majorana Zero Modes via non-magnetic impurity	53
35 WANG Pengfei: Observation of the Superconductivity and Vortex in In-doped SnBi_2Te_4 by Scanning Tunneling Spectroscopy	54
36 KALASHNIKOV Dmitrii: Nonreciprocal phenomena in the asymmetric superconducting interferometer with external microwave irradiation	55
37 WANTING Xu: Quantum Transport in Graphene-Based van der Waals Heterostructures	56
Friday, September 19: New Materials & Spintronics	57
38 MAGALHAES Sergio: Heterostructures and Spins Clusters	57
39 WAN Caihua: Advanced Spintronic True Random Number Generators and Their Applications	58

40 BOBKOVA Irina: Theory of hybrid collective excitations in topological superconductor/ferromagnetic insulator heterostructures	59
41 VYALYKH Denis: Unusual magnetic phenomena at the surfaces of lanthanide materials: Insights from ARPES and XAS experiments	60
42 USACHOV Dmitry: Photoelectron diffraction for probing structural, electronic and magnetic properties of 4f materials	62
43 BOZHKO Sergey: Electric field induced spin polarized tunneling current	63
44 GOLUBOV Alexander: tba	64
45 KLINOV Dmitry: High-Resolution Visualization of Single Melanin Molecules Using Atomic Force Microscopy	64
46 LI Fachao: Facet-Controlled Film Growth and Magnetism in YBaCo ₂ O ₆ Epitaxial Thin Films	65
47 GORDEEVA Valeria: Composite excitations in S/AF/S systems	66
48 ZHIYUAN Wang: Dual-Cation Co-Intercalation Strategy for Enhanced Electrochemical Performance of Ti ₃ C ₂ T _x MXene Membranes	67
49 VASYAKIN Maxim: Disorder-enhanced superconductivity in altermagnet-superconductor hybrids	68
50 ZHOU Fudi: Strain-Induced One-Dimensional Magnetic Stripe in Metallic Monolayer H-NbSe ₂	69
Friday, September 19: Poster section	70
51 KUZNETSOVA Polina: Research of Superconducting Properties of S/NFN/S-Structures Based on Segmented Nanowires	70
52 BELKOVICH Ivan: Proximity effect in SSH-superconductor junction	71
53 STADNIK Edward: $0 - \pi$ transition in planar Josephson S-N-S junction on a ferromagnetic insulator substrate	72
54 IANOVSKAIA Anastasia: Spin-valve effect in ferromagnet/superconductor/ferromagnet van der Waals heterostructures	73
55 KINZIBAEV Ruslan: High Frequency Dynamic Response of Abrikosov Vortices: Time-Dependent Ginzburg-Landau Approach	74
56 KOVALENKO Maria: Photoinduced magnetic moment of the superconducting disk	75
57 LARIONOV Semyon: Peculiarities of the vortex dynamics in a narrow granular niobium bridge	76
58 LYCHAGINA Anna: Optical and structural properties of niobium oxide nanostructures fabricated by femtosecond laser irradiation	77
59 MURAVEV Matvey: Magnetic Resonance Spectroscopy of Topological Insulator MnSb ₂ Te ₄	78
60 NAUMOV Arsenii: A modified Bridgman method for growing single crystals of magnetic topological insulators based on MnBi ₂ Te ₄	79
61 PANOV Dmitry: Reconstruction of the spatial and temperature dependence of the superconducting gap from scanning tunneling spectroscopy data	80

62 TYUMENEV Radik: Study of multilayer SRRs as Magnetic-memory inductance in superconducting circuits	81
63 SOLOVEV Artem: Quantum enhanced magnetometry on a transmon qutrit based on phase estimation algorithm	82
64 STAVISSKII Georgii: Non-stationary theory of charge transport based on many-body wavefunction theory and its application to SIS-junctions	83
65 YAROLOV Terentii: High-Precision State Discrimination of a Transmon Qutrit Using a Feedforward Neural Network	85
66 ZUEV Oleg: Superconducting photocurrents induced by structured electromagnetic radiation	86
67 PETROVA Anastasia: Spin Waves in Easy-Plane Canted Antiferromagnets	87
68 BOGDANOVA Tatiana: Influence of unidirectional and uniaxial anisotropy in Pt/Co/FeMn/Pt heterostructures on the antiferromagnetic layer thickness	89
69 ELISTRATOVA Anna: Experimental implementation of elements of superconducting bio-like neurons based on Nb/Au/Nb Josephson junctions	91
70 PONAMAREV Evgenii: Surface spin-flop in antiferromagnetic topological insulator	92
71 MINAEV Artem: Investigation of superconductivity in In doped PbBi_2Te_4 using a scanning tunneling microscope	94
Saturday, September 20: Advanced Microelectronics	95
72 ZENKEVICH: Operando synchrotron studies of prototype non-volatile memory devices for nanoelectronics and spintronics	95
73 CHERNIKOVA Anna: Ferroelectric field-effect memory transistor with $\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$ and 2D MoS_2	97
74 KHANAS Anton: Memory transistors for neuromorphic computing: a perspective	99
75 KORNEEV Alexander: Multistep atomic layer deposition process for ultrathin superconducting NbN films with high critical current density on different substrate	100
76 KALININ I. A.: High performance microheater-based catalytic hydrogen sensors fabricated on porous anodic alumina substrates	101
77 SAFIN Ansar: Electrically tunable sub-terahertz resonance in antiferromagnet-normal-metal heterostructure	102
78 KALYABIN Dmitry: Voltage controlled magnetic anisotropy of antiferromagnetic modes of bulk $\alpha\text{-Fe}_2\text{O}_3$	104
79 Frolov Alexander: Electronic Structure and Topological Properties of Natural Superlattices Based on Tetradymite-like Structural Blocks	106
80 VASENKO Andrey: Schottky Defects Suppress Nonradiative Recombination in $\text{CH}_3\text{NH}_3\text{PbI}_3$ through Charge Localization	107

Conference Information

This Conference is organized within the framework of the **Megagrant** (Agreement No. 075-15-2025-010, dated 02.28.2025) *Advanced functional materials for digital and quantum electronics*.

A special session will be held as part of the conference, focusing on the scope and activities of the **World-Class Research Center "Advanced Microelectronics."**

The Conference will be held in offline and online formats at the Center for Advanced Mesoscience and Nanotechnology at MIPT.

No registration fee is required.

The conference language is English.

The participants will get Letters of Attendance.

Main topics

- Functional quantum materials based on topologically protected electronic subsystems;
- Physics of magnetic topological insulators, hybrid superconducting-ferromagnetic systems;
- Development of control elements for superconducting quantum circuits and devices;
- Magnetic resonance spectroscopy;
- Topological quantum phenomena in superconducting systems.

Key dates

- Conference dates: September 15-19, 2025
- Submission of abstracts in English by August 30, 2025

Program Committee:

- Prof. **STOLYAROV Vasily** – Director of the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **GOLUBOV Alexander** – Head of the Laboratory of Topological Quantum Phenomena in Superconducting Systems at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **NIKITOV Sergei** – Academician of the Russian Academy of Sciences (RAS); Director of the Kotelnikov Institute of Radio Engineering and Electronics Russian Academy of Sciences (Moscow, Russia)
- Prof. **BOBKOVA Irina** – Head of the Laboratory of Spin Phenomena in Superconducting Nanostructures and Devices at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **MELNIKOV Alexander** – leading researcher of the laboratory of spin phenomena in superconducting nanostructures and devices at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **VAGOV Alexey** – Director of the Center for Quantum Metamaterials, HSE University (Moscow, Russia)
- Dr. **FROLOV Alexander** – head of the laboratory of photoelectron spectroscopy of quantum functional materials at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **GORSHUNOV Boris** – Head of the Laboratory of Terahertz Spectroscopy, MIPT (Moscow, Russia)

- Prof. **LI Jiafang** – deputy director of the School of Physics, Beijing Institute of Technology (Beijing, China)
- Prof. **YU Geliang** – Nanjing University (Nanjing, China)
- Prof. **ALADYSHKIN Alexey** – leading researcher of the Laboratory of Topological Quantum Phenomena in Superconducting Systems at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)

Organizing Committee:

- Prof. **STOLYAROV Vasily** – Director of the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **GOLUBOV Alexander** – Head of the Laboratory of Topological Quantum Phenomena in Superconducting Systems at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Prof. **BOBKOVA Irina** – Head of the Laboratory of Spin Phenomena in Superconducting Nanostructures and Devices at the Center for Advanced Mesoscience and Nanotechnology, MIPT (Moscow, Russia)
- Dr. **SEDOV Egor** – Technical support
- **DOBROVOLSKAYA Ekaterina** – Administrator
- **OBUKHOVA Irina** – Coordinator
- **EGOROVA Irina** – Technical support

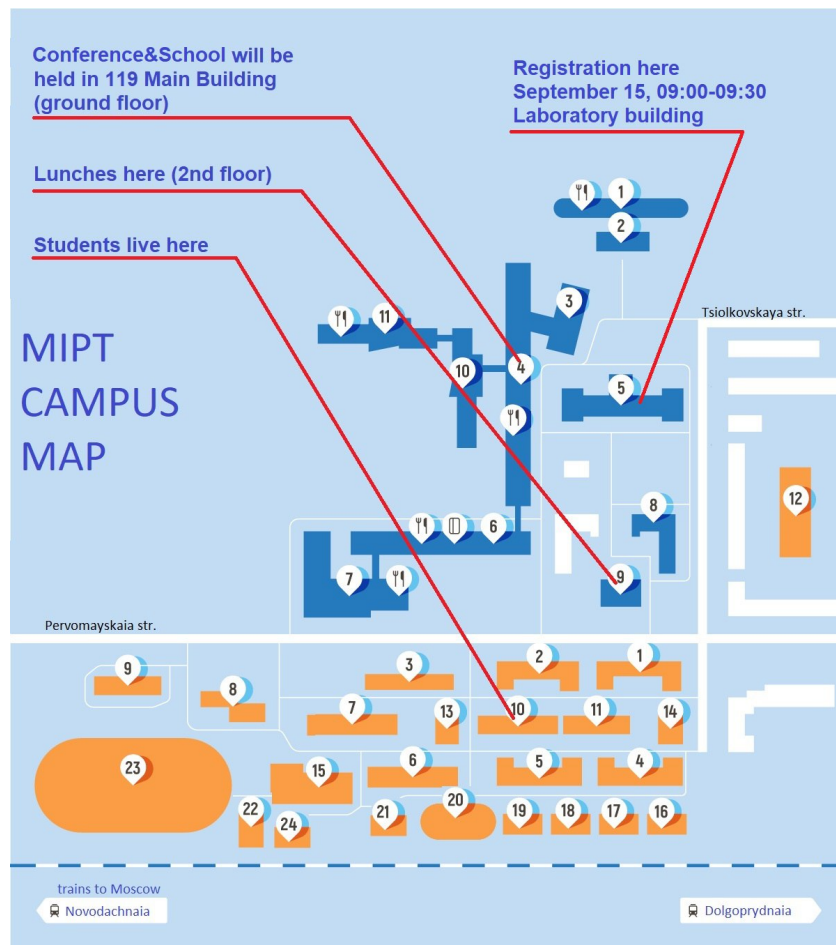


Figure 1: Schematics of the MIPT campus.

Monday, September 15, 2025

Location: Room 119, Main Building, MIPT

Session Chairman: Vasily STOLYAROV

09:00-09:30	Registration. Laboratory building.
09:30 – 09:45	Assembling and gathering in Room 119.
09:45- 09:50	MIPT Vice Rector for Scientific Work Vitaly BAGAN Opening Ceremony. Welcome remarks.
09:50-10:00	Prof. Vasily STOLYAROV (MIPT) Opening Ceremony. CMN’ review of scientific activity
10:00-10:25	Minister of the Embassy of the Federative Republic of Brazil in the Russian Federation Marcelo Böhlke Overview Russian-Brazilian cooperation in Science
10:25-10:40	Anastasia Zadorina (International Centre for Innovations in Science, Technology and Education)
10:40-10:55	Yang GAO (Program Coordinator, Office of International Affairs, BIT) BIT’ review of scientific activity
10:55 – 11:00	Prof. Alexander GOLUBOV (MIPT) Opening Ceremony. Welcome remarks.
11:00-11:30	Prof. Mauro DORIA (UFRJ) A Quantum Plasmonic approach for the topological insulators
11:30-12:00	Coffee Break & Take Photos
Session Chairman: Vasily STOLYAROV	
12:00-12:30	Prof. Mikhail KUPRIYANOV (MSU, MIPT) Quasiparticle Conversion in SN-N-NS
12:30-12:55	Dr. Sergey BAKURSKIY (MSU, MIPT) Crucial role of electrode dimensions in Josephson SNS bridges
12:55-13:20	Prof. Rafael ZADOROSNY (UNESP) Fibrous Ceramic Superconductors and Their Production Using the Solution Blow Spinning Structuring Technique

13:20-13:45	Prof. Alexei VAGOV (HSE) Localization-Enhanced Superconductivity in Multi-Band Materials
13:45-15:00	Lunch at MIPT Cafe
Session Chairman: Rafael ZADOROSNY	
15:00-15:30	Prof. Igor BURMISTROV (ITP) Spatially Resolved Dynamics of the Amplitude Schmid-Higgs Mode in Disordered Superconductors
15:30-15:50	Talles BENITES (UNESP) Resistive States due to the Interplay of Flux Flow and Vortex Dynamics in Artificially Defected Granular Superconductors within the Ginzburg-Landau Theory
15:50-16:10	Konstantin POLEVOY (VNIIA, MIPT) Proximity Effect Engineering in Al-Based SNS Junctions with Intrinsic Superconductivity
16:10-16:25	Coffee Break
Session Chairman: Alexei VAGOV	
16:25-16:45	Matheus PANIAGO BRAMBILLA (UNESP) A Novel Route to Nickelate Superconductors through the Synthesis of $\text{La}_3\text{Ni}_2\text{O}_7$ Nanofibers via Solution Blow Spinning
16:45-17:05	Dr. Pavel MARYCHEV (HSE) Crossover between Types I and II in Diffusive Superconductors: Perturbative
17:05-17:25	Aparecido DOS SANTOS DURAN EDIMAR (UNESP) Systematic Analysis of Silver Interaction in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Ceramic Nanowires
18:00-20:00	Reception (2nd floor of Concert Hall)

Tuesday, September 16, 2025	
Location: Room 119, Main Building, MIPT	
Session Chairman: Mauro DORIA	
10:00-10:30	Prof. Sergey NIKITOV (IRE RAS, MIPT) PT symmetry and Exception Points in spintronics, magnonics and photonics
10:30-11:00	Prof. Yaxin ZHAO (BIT) Realization of fractional-layer transition metal dichalcogenides
11:00-11:30	Prof. Boris GORSHUNOV (MIPT) Thin films at terahertz frequencies: physics and applications
11:30-12:00	Coffee Break & Take Photos
Session Chairman: Boris GORSHUNOV	
12:00-12:30	Prof. Qingmei HU (BIT) Graphene Based Room-Temperature Terahertz Detector with Integrated Bow-Tie Antenna
12:30-12:55	Prof. Alexander MELNIKOV (MIPT) Impurity-induced Inverse Faraday Effect
12:55-13:20	Prof. Denis VODOLAZOV (IPM RAS, MIPT) Vortex nucleation in type I superconducting layer covering type II superconductor
13:20-13:45	Dr. Artem TARASOV (SPbSU) Electronic spin structure of quasi-two-dimensional systems with combined spin–orbit and exchange interactions
13:45-15:00	Lunch at MIPT Cafe
Session Chairman: Qingmei HU	
15:00-15:30	Prof. Junli MA (BIT) Asymmetric Evaporator for Simultaneous Generation of Clean Water and Electrical Power
15:30-15:50	Valeria GORDEEVA (MIPT) Composite excitations in S/AF/S systems
15:50-16:10	Brian ANCHICO (BIT) Ferroelectric phase transition and topological properties in two-dimensional CuVP ₂ Se ₆

16:10-16:25	Coffee Break
Session Chairman: Denis VODOLAZOV	
16:25-16:45	Dmitry ANNENKOV (MIPT) Domain-wall superconductivity in van der Waals structures with ferroelectric ordering
16:45-17:05	Qingrong LIANG (BIT) Multidirectional sliding ferroelectricity of rhombohedral-stacked InSe for reconfigurable photovoltaics and imaging applications
17:05-17:25	Dr. Victor SEMIN (MIPT) Structure, residual stresses and properties of Al superconducting

Wednesday, September 17, 2025

Excursion day

Thursday, September 18, 2025	
Location: Room 119, Main Building, MIPT	
Session Chairman: Yakov FOMINOV	
10:00-10:30	Prof. Hao WU (BIT) EPR in the high-cooperativity regime: a playground for microwave quantum electronics
10:30-11:00	Prof. Andrey PANKRATOV (IPM RAS, MIPT) Studying photon statistics and noise with quantum sensors
11:00-11:30	Prof. Wenyong SU (BIT) Fabrication and application of optical synaptic devices based on two-dimensional materials
11:30-12:00	Coffee Break & Take Photos
Session Chairman: Hao WU	
12:00-12:30	Prof. Yakov FOMINOV (ITP RAS) Title: All fractional Shapiro steps in the RSJ model with two Josephson harmonics
12:30-12:55	Prof. Vladimir BELOTELOV (RQC, Skoltech) Ultra-Low-Damping Epitaxial YIG Films Grown by LPE with a Buffer Layer for Quantum Applications
12:55-13:20	Prof. Alexey ALADYSHKIN (IPM RAS, MIPT) Analysis of periodicity in arrays of triple steps on vicinal surfaces: Period-dependent suppression of Fourier peaks
13:20-13:45	Dr. Vyacheslav NEVEROV (MIPT, HSE) Enhancing the visibility of Majorana Zero Modes in vortex core via nonmagnetic impurity
13:45-15:00	Lunch at MIPT Cafe
Session Chairman: Yuriy MAKHLIN	
15:00-15:30	Yuhe YANG (Nanjing University) Research on Multimodal Sensors Based on Two-Dimensional MXene Materials
15:30-16:00	Prof. Yuriy MAKHLIN (ITP RAS, HSE) Planar topological Josephson junctions and Majorana zero modes
16:00-16:20	Dr. Dmitriy ESTIUNIN (SPbGU) Precise Control of the Electronic Structure in AB ₂ C ₄ -Type Topological Compounds

16:20-16:35	Coffee Break
Session Chairman: Wenyong SU	
16:35-16:55	Pengfei WANG (BIT) Observation of the Superconductivity and Vortex in In-doped SnBi ₂ Te ₄ by Scanning Tunneling Spectroscopy
16:55-17:15	Dmitriy KALASHNIKOV (MIPT) Diode effect in Shapiro steps in asymmetric SQUID with a superconducting nanobridge
17:15-17:35	Wanting XU (School of Physics, Nanjing University) Quantum Transport in Graphene-Based van der Waals Heterostructures

Friday, September 19, 2025	
Location: Room 119, Main Building, MIPT	
Session Chairman: Denis VYALYKH	
10:00-10:30	Prof. Sergio MAGALHAES (UFRGS) Heterostructures and Spins Clusters
10:30-11:00	Prof. Caihua WAN (Insitute of Physics CAS) Advanced Spintronic True Random Number Generators and Their Applications
11:00-11:30	Prof. Irina BOBKOVA (MIPT) Theory of hybrid collective excitations in topological superconductor/ferromagnetic insulator heterostructures
11:30-12:00	Coffee Break & Take Photos
Session Chairman: Irina BOBKOVA	
12:00-12:30	Prof. Denis VYALYKH (DIPS) Unusual magnetic phenomena at the surfaces of lanthanide materials: Insights from ARPES and XAS experiments
12:30-12:55	Prof. Dmitrii USACHOV (SPbSU, MIPT) Photoelectron diffraction for probing structural, electronic and magnetic properties of 4f materials
12:55-13:20	Dr. Sergey BOZHKO (ISSP RAS) Electric field induced spin polarized tunneling current
13:20-13:45	Prof. Alexader GOLUBOV (MIPT)
13:45-15:00	Lunch at MIPT Cafe
Session Chairman: Sergio MAGALHAES	
15:00-15:30	Dr. D. Klinov (MIPT) High-Resolution Visualization of Single Melanin Molecules Using Atomic Force Microscopy
15:30-15:50	Fachao LI (BIT) Facet-Controlled Film Growth and Magnetism in YBaCo ₂ O ₆ Epitaxial Thin Films
15:50-16:10	Dr. Alexandr MELENTEV (MIPT) Enhancing permittivity of SrTiO ₃ thin film via intermediate AlFeO ₃ layers incorporation

16:10-16:25	Coffee Break
Session Chairman: Caihua WAN	
16:25-16:45	Zhiyuan WANG
16:45-17:05	Maxim VASYAKIN (MIPT) Disorder-enhanced superconductivity in altermagnet-superconductor hybrids
17:05-17:25	Fudi ZHOU (BIT) Strain-Induced One-Dimensional Magnetic Stripe in Metallic Monolayer H-NbSe ₂
Poster Session 17:30-19:00	

Saturday, September 20, 2025	
Location: Room 119, Main Building, MIPT	
Session Chairman: KORNEEV	
10:00-10:30	Prof. Ansar SAFIN (IRE RAS, MIPT) Electrically tunable sub-terahertz resonance in antiferromagnet-normal-metal heterostructure
10:30-11:00	Dr. Andrey ZINKEVICH (MIPT) Operando synchrotron studies of prototype non-volatile memory devices for nanoelectronics and spintronics
11:00-11:30	Dr. Anna CHERNIKOVA (IRE MIPT) Ferroelectric field-effect memory transistor with Hf _{0.5} Zr _{0.5} O ₂ and 2D MoS ₂
11:30-12:00	Coffee Break & Take Photos
Session Chairman: Andrey ZINKEVICH	
12:00-12:30	Dr. Anton HANOS (MIPT) Memory transistors for neuromorphic computing: a perspective
12:30-12:55	Prof. KORNEEV (IMN RAS) Multistep atomic layer deposition process for ultrathin superconducting NbN films with high critical current density on different substrate
12:55-13:20	Dr. I. A. KALININ (MSU) High performance microheater-based catalytic hydrogen sensors fabricated on porous anodic alumina substrates
13:20-13:45	Dr. Dmitry KALYABIN (IRE RAN) Voltage controlled magnetic anisotropy of antiferromagnetic modes of bulk α -Fe ₂ O ₃
13:45-15:00	Lunch at MIPT Cafe
Session Chairman: Sergio MAGALHAES	
15:00-15:30	Dr. Alexander FROLOV (MIPT) Electronic Structure and Topological Properties of Natural Superlattices Based on Tetradymite-like Structural Blocks
15:30-15:50	Dr. Polina UYMINA (MIPT) Vertically aligned MoS ₂ structures: synthesis, morphology and properties

Monday, September 15

Welcoming Address

Dear Colleagues, Guests, and Participants,

On behalf of the Program and Organizing Committees, it is my great pleasure to welcome you to the **First International Conference on Advanced Functional Materials for Digital and Quantum Electronics 2025**, held at the Moscow Institute of Physics and Technology.

We are delighted to host this gathering of brilliant minds from across the globe, bringing together leading scientists, researchers, and students to discuss the latest breakthroughs and future directions in quantum materials, superconductivity, spintronics, topological phenomena, and novel device architectures. The interdisciplinary nature of this conference reflects the collaborative spirit essential for tackling the complex challenges at the forefront of modern technology.

This Book of Abstracts showcases the diverse and high-quality research that will be presented over the coming days. It is a testament to the vibrant activity and significant progress being made in our field. We are confident that the exchange of ideas and discussions that will take place here will foster new collaborations and inspire innovative research pathways.

We extend our sincere gratitude to all authors for their valuable contributions, to the members of the Program Committee for their diligent work in reviewing the submissions, and to the Organizing Committee for their tremendous efforts in preparing this event. Special thanks are due to the Ministry of Science and Higher Education of the Russian Federation for their support through the Megagrant program.

We wish you all a productive, stimulating, and enjoyable conference here in Moscow.

Sincerely,

Prof. Vasily Stolyarov
Director, Center for Advanced Mesoscience and Nanotechnology
Moscow Institute of Physics and Technology (MIPT)
Chairman of the Program and Organizing Committees

Section: Superconductivity

1 A Quantum Plasmonic approach for the topological insulators

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**e-mail:*

Abstract

Several common features are emerging in Condensed Matter Physics bringing new paradigms to the field. They are the Dirac linear spectrum, the Rashba term, the pseudo gap, the presence of narrow and wide bands, the spin-momentum locking, the magnetic monopole behavior of carriers and the topological nature of excitations. Here we propose that the origin of these features is found on some common properties shared by the topological insulators and the type II superconductors. They can be tracked back to Abrikosov's 1957 seminal work when the magnetic properties of superconducting alloys were determined from topological excitations, the so-called vortices. Alexey Abrikosov and later Evgeniy Bogomolny have shown that the fundamental structure behind vortices is a set of linear equations and here we sustain that the inclusion of the electronic spin into these equations provides the simplest framework to describe the topological insulators. The first of such Abrikosov-Bogomolny equations is a zero helicity condition which is essentially the spin-momentum locking condition [1,2,3] and gives the simplest explanation for the existence of the Dirac linear spectrum. The second one implies a plasmonic nature for the topological insulator state, a consequence of the evanescence of the magnetic field away from the layer. Here we show that the stacking of several topological insulating layers generates a semi-metal spectrum with the onset of a pseudo gap and of several conducting bands associated to different masses. This scenario of coexisting narrow and wide bands may provide a route to obtain a high critical superconducting temperature which makes us conjecture a deep connection between the topological insulators and the high temperature superconductors.

Keywords: SN-N-NS Josephson bridge, proximity effect, non-equilibrium processes, quasiparticle conversion length

References:

1. Mauro M. Doria and Andrea Perali, Weyl states and Fermi arcs in parabolic bands, Europhys. Lett. 119 (2017) 21001.
2. M. M. Doria, The linear Dirac spectrum and the Weyl states in the Drude-Sommerfeld topological model, The European Physical Journal B 92, 64 (2019)
3. Edinardo I.B. Rodrigues and Mauro M. Doria, The local magnetic field of spin-momentum locked states and fractional effects, Physics Letters A 448 (2022) 128289.

2 Quasiparticle Conversion in SN-N-NS Josephson Junctions

S. V. Bakurskiy^{1,2,3}, O. V. Skryabina^{2,1}, V. I. Ruzhickiy^{3,1,2}, A. A. Elistratova^{3,2}, K. B. Polevoy^{3,2}, A. G. Shishkin^{2,3}, N. V. Klenov^{4,3}, I. I. Soloviev^{1,2,3}, **M. Yu. Kupriyanov**^{1,2}, A. A. Golubov², V. S. Stolyarov^{2,3,5}

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Abstract

The miniaturization of superconducting electronics demands precise control over quasiparticle dynamics at the nanoscale. Understanding and controlling quasiparticle dynamics is essential for advancing superconducting electronics, particularly as device dimensions approach the nanoscale. Here we present direct experimental evidence for the quasiparticle-to-supercurrent conversion in planar SN-N-NS Josephson nanobridges with submicron electrodes. By employing a versatile measurement platform, we demonstrate that the injection geometry—through either superconducting or normal-metal leads—dramatically alters the critical current and resistance of the junction. Using a tunable measurement setup that allows current injection through either superconducting or normal-metal leads, we uncover marked changes in critical current and resistance depending on the injection geometry—effects that become significant when electrode widths fall below the characteristic conversion length of ~ 400 nm. These observations are quantitatively explained by a phenomenological model that accounts for nonequilibrium transport and incomplete quasiparticle conversion in narrow electrodes. These results point to the emergence of non-equilibrium transport governed by an intrinsic conversion length. We develop and apply a method for extracting this length from standard transport measurements, offering a practical diagnostic for nanoscale superconducting circuits. Our findings enable optimized design of compact Josephson junctions and support the integration of proximity-based weak links into scalable superconducting logic and sensing architectures.

Keywords: SN-N-NS Josephson bridge, proximity effect, non-equilibrium processes, quasiparticle conversion length

Acknowledgments: The work was supported by the Russian Science Foundation (project no. 25-19-00057; <https://rscf.ru/project/25-19-00057/>).

References:

1. V. Ruzhickiy, S. Bakurskiy, M. Kupriyanov, N. Klenov, I. Soloviev, V. Stolyarov, and A. Golubov. Contribution of processes in sn electrodes to the transport properties of sn-n-ns josephson junctions. *Nanomaterials*, 13:1873, 2023.
2. O. V. Skryabina, S. V. Bakurskiy, V. I. Ruzhickiy, A. Shishkin, N. V. Klenov, I. I. Soloviev, M. Yu Kupriyanov, and V. S. Stolyarov. Anomalous influence of electrode width on the critical current of nb/au josephson junctions. *Superconductor Science and Technology*, 37(12):125018, 2024.

3 Crucial role of electrode dimensions in Josephson SNS bridges

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Abstract

We studied electronic transport in Josephson bridges of variable thickness Superconductor-Normal Metal-Superconductor (SNS) theoretically and experimentally. We found a significant influence of the electrode size on the critical current, current-phase ratio, and critical temperature of the Josephson junction. The microscopic description of the Josephson SNS bridge was modified in the framework of the Usadel equations, taking into account inhomogeneous supercurrent spatial distribution in the electrode and phase drop at the boundary between the normal metal region and the superconducting electrode. We have shown that these factors lead to an increase in the characteristic length of the current flow between the superconducting electrode and the normal metal layer.

Keywords: Josephson junction, proximity effect, superconductor electronics

Acknowledgments: The work was supported by the Russian Science Foundation (project no. 25-19-00057; <https://rscf.ru/project/25-19-00057/>).

References:

1. V. Ruzhickiy, S. Bakurskiy, M. Kupriyanov, N. Klenov, I. Soloviev, V. Stolyarov, and A. Golubov. Contribution of processes in sn electrodes to the transport properties of sn-n-ns josephson junctions. *Nanomaterials*, 13:1873, 2023.
2. O. V. Skryabina, S. V. Bakurskiy, V. I. Ruzhickiy, A. Shishkin, N. V. Klenov, I. I. Soloviev, M. Yu Kupriyanov, and V. S. Stolyarov. Anomalous influence of electrode width on the critical current of nb/au josephson junctions. *Superconductor Science and Technology*, 37(12):125018, 2024.

4 Fibrous Ceramic Superconductors and Their Production Using the Solution Blow Spinning Structuring Technique

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Abstract

Since their discovery, ceramic high-temperature superconductors (HTS) have been extensively studied to understand their mechanisms and improve applications. Their use is limited by high production costs, AC losses, inhomogeneous trapped field distribution, and fragility. Some of these issues can be mitigated by scalable, low-cost methods that yield materials with high and uniform critical current density (J_c). Additionally, highly porous superconductors produced by solution blow spinning (SBS) [1–3] enhance cooling efficiency thanks to their larger specific surface area. With the aim of improving the mechanical properties of ceramic fibers and enhancing their handling characteristics, we investigated the incorporation of silver into the $\text{YBa}_2\text{Cu}_3\text{O}_7$ (YBCO) matrix using a more sustainable chemical route. In this approach, the precursor solution was prepared via a one-pot-like synthesis, where yttrium, barium, copper, and silver acetates were dissolved in propionic acid (12 wt%), ammonium hydroxide (26.5 wt%), and methanol (61.5 wt%). Polyvinylpyrrolidone (PVP, $M_w \simeq 1,300,000$ g/mol) was also added in a weight ratio of 4:1 (acetates:PVP) to stabilize and reduce the solution. The resulting solution was processed via SBS to produce fibrous polymer composite mats. These mats underwent sequential heat treatments: solvent evaporation at approximately 150°C for 3 hours; polymer degradation at 600°C for 3 hours; and finally, crystallization and grain growth at temperatures ranging from 895°C to 950°C for 1 hour. Further details can be found in Refs. [1–4]. We demonstrate that ceramic fibers can be obtained with average diameters as low as 160 nm, and that the addition of silver can reduce the crystallization temperature by about 30°C . Preliminary XRD and magnetic measurements confirm the superconducting nature of the fibers and indicate promising properties for further investigation.

Keywords: nanofibers, solution blow spinning, YBCO

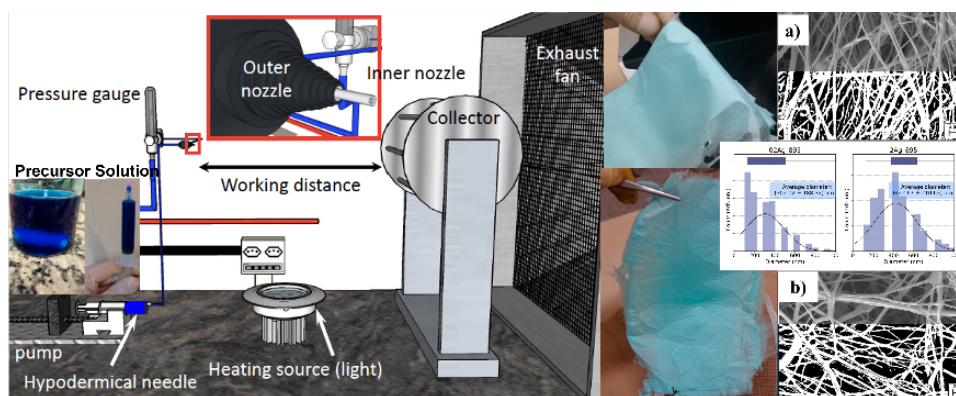


Figure 1: From left to right: the solution blow spinning system; the as-collected fibrous mats; and SEM images processed to determine the fiber diameter distribution.

References:

1. M. Rotta et al., *Ceramics International* 42, 16230 (2016).
2. A. L. Pessoa et al., *Ceramics International* 46, 24097 (2020).
3. A. M. Caffer et al., *Supercond. Sci. Technol.* 34, 025009 (2021).
4. E. A. S. Duran et al., to be published elsewhere.

5 Localization in Materials with Several Conducting Bands to Enhance Superconductivity

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Abstract

Strong disorder exerts two opposing effects on a superconducting material [1]. On one hand, it leads to localization of electrons and Cooper pairs, resulting in spatial fragmentation of the condensate state. It enhances the local density of single-particle states, increasing the binding energy of Cooper pairs and the critical temperature at which the condensate state appears. On the other hand, it destroys the long-range coherence, suppressing superconductivity and reducing the corresponding critical temperature. This work demonstrates that if such a disordered superconductor is coupled to a clean or weakly disordered conducting material, the long-range coherence is restored via the proximity effect. As a result, the coexistence of the two subsystems combines the advantages of the high critical temperature of the disordered superconductor and the global supercurrent of the clean one. This synergy effect is robust and can occur in superconducting multi-band and heterostructures, whether they are disordered or have artificial superstructures.

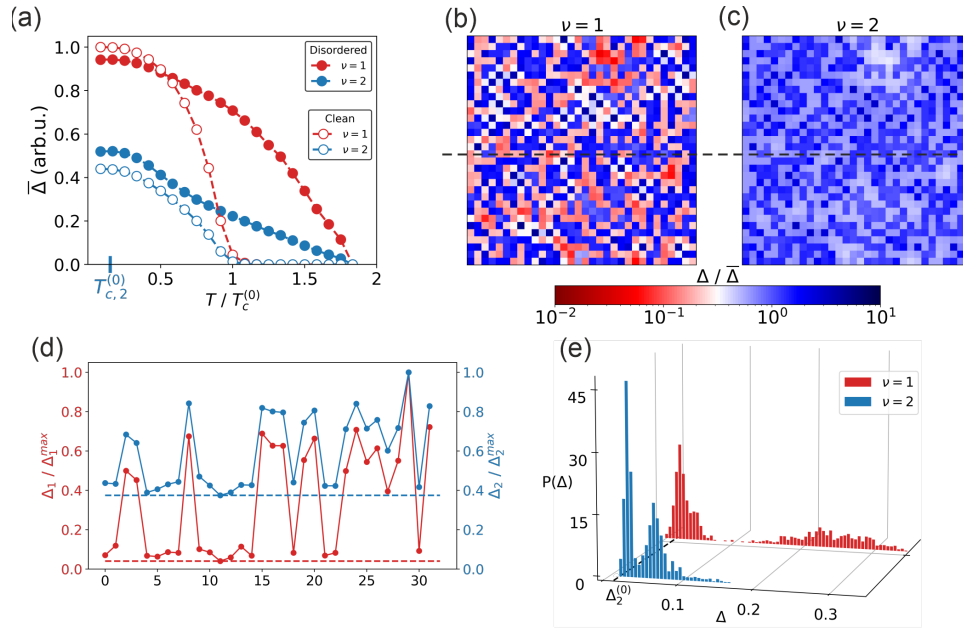


Figure 1: (a) Temperature dependence of the sample-averaged gap function for the strong band (red) and the weak band, showing results for the cases when strong band is disordered (filled circles) and in its clean limit (empty circles). Low temperature $T_{c,2}^{(0)}$ is the critical temperature of the second band in the absence of inter-band coupling. (b)–(c) Color density plot with the spatial distribution of the band gap function. (d) Profile of the gap function for strong band (red) and weak band (blue), calculated along the dashed lines shown in panels (b) and (c). (e) Histograms of the absolute value of the gap function for the strong band (red) and the weak band (blue).

References:

1. A. Vagov et al., Comm. Physics 5, 177 (2022).
2. V. Neverov et al., Comm. Physics 8, 310 (2025).

6 Spatially Resolved Dynamics of the Amplitude Schmid-Higgs Mode in Disordered Superconductors

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Abstract

We investigate the spatially resolved dynamics of the collective amplitude Schmid-Higgs (SH) mode in disordered s -wave superconductors and fermionic superfluids. By analyzing the analytic structure of the zero-temperature SH susceptibility in the complex frequency plane, we find that, when the coherence length greatly exceeds the mean free path, (i) the SH response at fixed wave vectors exhibits late-time oscillations decaying as $1/t^2$ with frequency 2Δ , where Δ is the superconducting gap; (ii) subdiffusive oscillations with a dynamical exponent $z = 4$ emerge at late times and large distances; and (iii) spatial oscillations at a fixed frequency decay exponentially, with a period that diverges as the frequency approaches 2Δ from above. When the coherence length is comparable to the mean free path, additional exponentially decaying oscillations at fixed wave vectors appear with a frequency above 2Δ . Furthermore, we show that the SH mode induces an extra peak in the third-harmonic generation current at finite wave vectors. The frequency of this peak is shifted from the conventional resonance at Δ , thereby providing an unambiguous signature of order parameter amplitude dynamics. The results are published in [1].

Keywords: dirty superconductors, Higgs mode, nonlinear response

References:

1. P. A. Nosov, E. S. Andriyakhina, I. S. Burmistrov, Spatially-resolved dynamics of the amplitude Schmid-Higgs mode in disordered superconductors, *Phys. Rev. Lett.* **135**, 056001 (2025).

7 Resistive States due to the Interplay of Flux Flow and Vortex Dynamics in Artificially Defected Granular Superconductors within the Ginzburg-Landau Theory

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Abstract

In granular superconductors, grain boundaries act as Josephson junctions, affecting the global critical current density. Although granular superconductivity is widely studied, the impact of engineered mesoscopic grains with tailored pinning centers on vortex matter remains underexplored. In this work, we simulate a semi-infinite superconducting tape using the generalized time-dependent Ginzburg-Landau (GTDGL) framework. The system consists of intra- and inter-grain regions, where the grain boundaries present a lower T_c than the superconducting matrix. Moreover, the intra-grain regions are artificially defected with 1 (S01), 4 (S04), or 0 (S00) defects. Our results show that although the intra-grain defects are not effective at trapping vortices, they significantly influence the local supercurrent distribution, delay vortex motion, and can guide vortex trajectories. Two distinct flux flow regimes were observed: one confined to the weak link region and, at certain currents, a shared flux flow regime. Additionally, at lower fields, the interaction between vortices and defects in S04 promotes the coalescence of intra-grain vortices with those in the inter-grain region. These insights may help guide the design and application of granular superconductors in sensors and emerging quantum technologies.

Keywords: granular superconductors, vortex dynamics, flux flow, Ginzburg-Landau theory

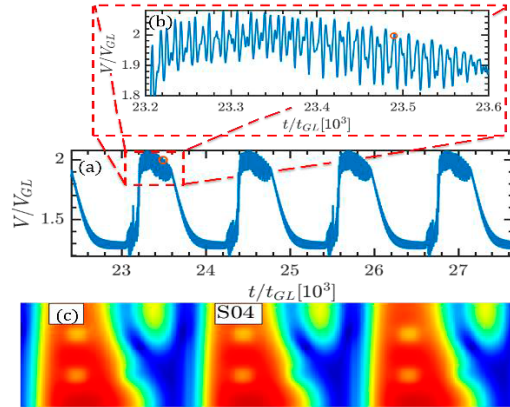


Figure 1: (a) time-voltage curve for $I_{tr} = 0.30750 I_{GL}$ at $H = 0.1 H_{c2}$, (b) Zoomed-in view, and (c) colormap of $|\psi|$.

References:

1. P Sunwong et al., *Supercond. Sci. Technol.* **26**, 095006 (2013).
2. J. Bardeen and M. J. Sephen, *Phys. Rev.* **140**, 1197 (1965).
3. Y. B. Kim et al., *Rev. Mod. Phys.* **36**, 43 (1964).
4. W. D. Gropp, *Journal of Computational Physics* **123**, 254 (1996).

8 Proximity Effect Engineering in Al-Based SNS Junctions with Intrinsic Superconductivity

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Abstract

This work investigates planar Nb-Al-Nb Josephson junctions with submicron dimensions, where the intrinsic superconductivity of aluminum significantly enhances device performance. We demonstrate that the aluminum interlayer substantially increases the critical current ($I_c \approx 50 \mu\text{A}$) and characteristic voltage ($V_c \approx 1 \text{ mV}$) at $T = 4 \text{ K}$, while preserving non-hysteretic current-voltage characteristics crucial for digital applications. Our theoretical framework, based on self-consistent solutions of the Usadel equations, shows that this performance improvement results from the synergistic combination of proximity-induced superconductivity and intrinsic pairing in aluminum, optimized at specific boundary resistance values. Structural characterization reveals epitaxial Nb/Al interfaces with minimal interdiffusion, ensuring reproducible fabrication of compact junctions. The developed Nb-Al-Nb bridges represent promising components for high-density superconducting electronic circuits operating at cryogenic temperatures.

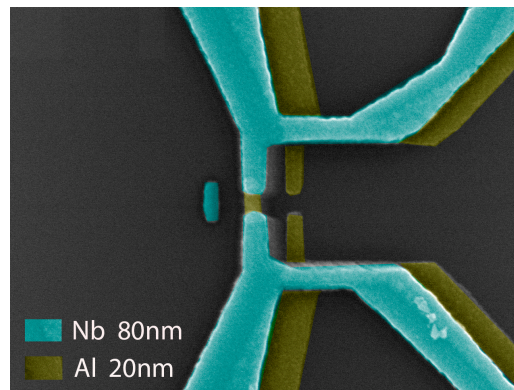


Figure 1: SEM image of one of studied junctions. Al layer painted as green, Nb layer painted as blue.

Keywords: Josephson junctions, proximity effect, superconducting electronics, Usadel equations

References:

1. O. A. Mukhanov, *IEEE Transactions on Applied Superconductivity* **21**, 760 (2011).
2. I. I. Soloviev et al., *Physical Review Applied* **16**, 044060 (2021).
3. O. Skryabina et al., *Superconductor Science and Technology* **37**, 125018 (2024).

9 A Novel Route to Nickelate Superconductors through the Synthesis of $\text{La}_3\text{Ni}_2\text{O}_7$ Nanofibers via Solution Blow Spinning

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Abstract

The quest for high-critical-temperature superconductors has identified nickelates as a promising frontier due to their structural and electronic similarities with cuprates [1]. Among them, $\text{La}_3\text{Ni}_2\text{O}_7$, which exhibits superconductivity at 80 K under pressure, stands out as a key candidate for exploring superconducting mechanisms in nickel-based systems. However, a major challenge for their application lies in achieving samples with a high superconducting volume fraction [2]. This study tackles this limitation through a distinctive two-fold strategy: (i) the development of a novel one-pot synthesis protocol and (ii) the implementation of an innovative fiber-formation technique. The synthesis begins with the dissolution of nickel and lanthanum acetates in a mixture of propionic acid, ammonium hydroxide, and methanol, stabilized and reduced using polyvinylpyrrolidone (PVP), to produce a highly homogeneous precursor solution with precise stoichiometric control. This solution is subsequently processed into polymeric mats composed of nanofibers using the Solution Blow Spinning (SBS) technique. The central hypothesis is that the high surface-area-to-volume ratio of the fibers promotes enhanced reaction kinetics, leading to improved phase formation and, consequently, a higher superconducting volume fraction in the final material.

Acknowledgements: We thank the FAPESP grant 2024/21097-7, CAPES - Finance Code 001.

References:

1. Sun, Hualei, et al. Nature 621, 7979 (2023)
2. ZHOU, Yazhou et al. Matter Radiat. Extremes 10, 027801 (2025)

10 Crossover between Types I and II in Diffusive Superconductors: Perturbative Study

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Abstract

A common feature of both single- and multiband superconductors is the presence of a crossover between conventional type I and type II superconductivity through an intertype (IT) domain in the magnetic response phase diagram. In diffusive single-band superconductors, this domain is extremely narrow due to scattering by nonmagnetic impurities. Recent work [1] has shown that in multiband superconductors the IT domain can significantly expand when the band diffusion coefficients differ substantially. In our research we demonstrate that this expansion is a general feature of diffusive multiband superconductors and is accompanied by a qualitative change in vortex-vortex interaction. This interaction shifts from the combination of short-range attraction and long-range repulsion, typical of diffusive single-band IT superconductors, to the inverse configuration of short-range repulsion and long-range attraction (see Fig.1). Strikingly, this latter behavior resembles the vortex interaction in clean IT superconductors. Consequently, a corresponding rearrangement of vortex configurations is expected – from the mixtures of Abrikosov and giant vortices, expected in diffusive single-band IT superconductors, to vortex chains and clusters, which are characteristic of vortex matter in clean IT superconducting materials [2].

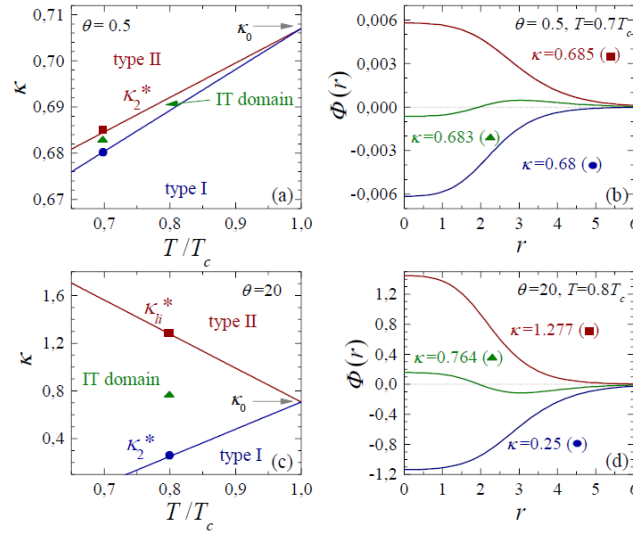


Figure 1: The IT domain for a diffusive two-band system with the microscopic parameters of MgB₂. (a) and (c) The upper and lower boundaries of the IT domain for the ratio of the band diffusivities $\theta = 0.5$ and $\theta = 20$, correspondingly. (b) and (d) The vortex-vortex potential $\Phi(r)$ for the three points marked in panel (a) and (c) by the circle, triangle, and square, respectively.

Keywords: intertype superconductivity, multiband superconductivity, phase diagram

References:

1. P. M. Marychev, A. A. Shanenko, A. V. Vagov, *Front. Phys.*, **19**, 43205 (2024).
2. P. M. Marychev, E. G. Nikonov, V. S. Stolyarov, A. Vagov, *Phys. Rev. B* **111**, 134501 (2025).

11 Systematic Analysis of Silver Interaction in $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$ Ceramic Nanowires

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Abstract

The incorporation of silver (Ag) into YBCO ceramics is widely studied due to its improvements in mechanical and superconducting properties. However, most research focuses on bulk materials using solid-state reaction techniques, with few approaches focusing on thin films, nanowires, and chemical routes. This study employs both experimental and theoretical approaches to investigate Ag interaction in YBCO ceramic nanowires. Experimentally, nanowires were synthesized via a one-pot chemical route and processed by solution blow spinning (SBS) using a wing-shaped collector to reduce average fiber diameters by about 50 nm and align them. Characterizations by XRD, Raman spectroscopy, and XPS revealed that high Ag concentration alters vibrational modes and causes asymmetry, while bond energy remained constant. Theoretically, preliminary results suggest that van der Waals corrections in the YBCO DFT model should be considered to improve the accuracy of lattice parameters. Our findings contribute to understanding the effects of Ag on ceramic structure, including composite formation, Ag localization at grain boundaries, and/or substitution of structural sites by Ag, with potential applications in superconducting nanowire single-photon detectors (SNSPDs).

Keywords: YBCO, Nanowires, Solution Blow Spinning

References:

1. P. Diko, G. Fuchs, G. Krabbes, *Physica C: Superconductivity* **363**(1), 60–66 (2001).
2. B.A. Malik, M.A. Malik, K. Asokan, *Current Applied Physics* **16**(10), 1270–1276 (2016).
3. A.L. Pessoa et al., *Ceramics International* **46**(15), 24097–24101 (2020).

Tuesday, September 16

Section: Functional Materials

12 PT symmetry and Exception Points in spintronics, magnonics and photonics

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13 Realization of fractional-layer transition metal dichalcogenides

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Abstract

Layered van der Waals transition metal dichalcogenides (TMDCs), generally composed of three atomic X-M-X planes in each layer (M = transition metal, X = chalcogen), provide versatile platforms for exploring diverse quantum phenomena. In each MX_2 layer, the M-X bonds are predominantly covalent in nature and, as a result, the cleavage of TMDC crystals normally occurs between the layers. Here we report the controllable realization of fractional-layer WTe_2 via an in-situ scanning tunneling microscopy (STM) tip manipulation technique. By applying STM tip pulses, hundreds of the topmost Te atoms are removed to form a nanoscale monolayer Te pit in the $1\text{T}'\text{-WTe}_2$, thus realizing a $2/3$ -layer WTe_2 film. Such a configuration undergoes a spontaneous atomic reconstruction, yielding a unidirectional charge density redistribution with the wavevector and geometry quite distinct from that of pristine $1\text{T}'\text{-WTe}_2$. Our results expand the conventional understanding of the TMDCs and are expected to stimulate further research on the structure and properties of fractional-layer TMDCs [1].

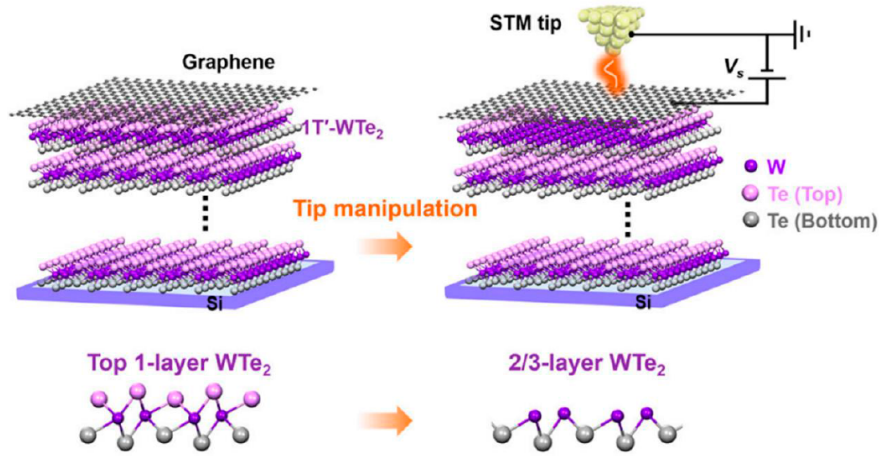


Figure 1: Structural schematics of $2/3$ -layer WTe_2 .

Keywords: Fractional-layer, transition metal dichalcogenide, scanning tunneling microscopy

References:

1. Ya-Xin Zhao, Heng Jin, Zi-Yi Han, Xinlei Zhao, Ya-Ning Ren, Ruo-Han Zhang, Xiao-Feng Zhou, Wenhui Duan, Bing Huang, Yu Zhang, Lin He. *Realization of fractional-layer transition metal dichalcogenides*. Nat Commun **16**, 3659 (2025).

14 Thin films at terahertz frequencies: physics and applications

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Abstract

It is widely accepted that thin films prepared from various materials (insulators, semiconductors, conductors, superconductors), as well as various types of structures based on them, form the basis for modern and future applications in microelectronics and other areas of the national economy (e.g., [1]). A key role in the development of new micro- and nano-electronic equipment belongs to experimental studies of the characteristics of films and structures. They are determined by the fundamental properties of the materials used, and also depend on synthesis methods and deposition procedures of thin functional layers, which provide additional opportunities for controlling these characteristics. Among the most efficient tools in this regard, it is necessary to highlight optical (in the broad sense) spectroscopy, which ensures the determination of the most important fundamental and macroscopic electrodynamic properties of films and film structures in a contactless (in most cases) manner. In addition, optical spectroscopy allows the determination of relevant characteristics of the objects at sub-terahertz and terahertz frequencies, which are promising in the development of modern and advanced telecommunication systems (e.g., [2]). This presentation will review the latest results of our terahertz spectroscopic investigations into the fundamental physical properties of ferroelectric and superconducting (conventional and high-temperature) thin films, the materials that are considered to be among the most promising for designing electronic devices with exceptional characteristics. We will also present a few examples showing how spectroscopic data can be used efficiently to enhance the performance of devices operating at terahertz frequencies.

Keywords: thin films, terahertz spectroscopy

Acknowledgments: The results presented were obtained with the support of the Russian Science Foundation, projects No. 25-42-00058 (spectroscopic experiments and data analysis), No. 22-72-10082-P (preparation of $\text{Ba}(\text{Fe}_{1-x}\text{Ni}_x)_2\text{As}_2$ superconducting films and data analysis), No. 23-79-00019 (fabrication of NbTiN superconducting films and structures, data analysis), the state program of IPM RAS No. FFUF-2024-0023 (YBCO films deposition and analysis). We are also grateful to all our colleagues whose hard work made it possible to obtain the presented results.

References:

1. Hyuk-Jun Kwon, *Electronics* **11**, 931 (2022).
2. Jia Du, Xiang Gao, Ting Zhang and He Zhu, *J. Phys. D: Appl. Phys.* **58**, 313001 (2025).

15 Graphene Based Room-Temperature Terahertz Detector with Integrated Bow-Tie Antenna

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Abstract

In electromagnetic spectrum, terahertz (THz) wave is between light and microwave. Its photon energy is much lower than normal infrared light and its frequency is higher than microwave. Therefore, it is hard to implement techniques of these two spectral ranges into THz spectrum, especially techniques in generation, modulation and detection. This has hindered the exploitation of THz spectrum although recent studies have shown its promising potentials in industries such as semiconductors, biotechnology, communications, imaging and so on. We have designed a bow-tie antenna and integrated it into a graphene photodetector. In this device geometry, the absorption enhancement region overlaps with photocarrier separation regions in graphene, which therefore greatly increases photocurrent generation. In addition to the antenna, we also design the channel. Firstly, we use BN-encapsulated graphene which has shown low residual doping (residual doping concentration of $1.3 \times 10^{11} \text{ cm}^{-2}$) and high mobility (μ up to $20000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ at room temperature) in the device. The high-quality graphene as channel guarantees a large Seebeck-coefficient difference at the pn junction and fast photoresponse. The corresponding noise equivalent power (NEP) is calculated as about $1 \text{ nW} \cdot \text{Hz}^{-1/2}$ if Johnson-Nyquist noise is assumed as the dominating noise. Moreover, the operating frequency is measured as larger than 5 kHz, which, together with the enhanced photoresponse, indicates that our design is a promising candidate for THz detection.

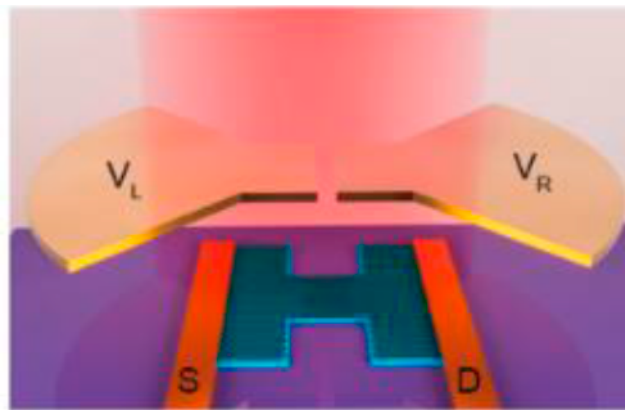


Figure 1: Schematic diagram of an antenna integrated graphene THz detector.

Keywords: Graphene; Bow-tie antenna; Terahertz detector; pn junction

References:

1. Jiawei Yang, Chunyang Zheng, Yahui Pang, Zhongyang Ji, Yurui Li, Jiayi Hu, Jiangrui Zhu, Qi Lu, Li Lin, Zhongfan Liu, Qingmei Hu, Baolu Guan, Jianbo Yin, *Acta Phys.-Chim. Sin.* (2023), 2307012.
2. Mingjia Jiang, Denan Kong, Minghao Zhang, He Lan, Qingmei Hu, Yao Zhou, Jiadong Zhou, *Advances in Two-Dimensional Materials for Infrared Photodetection: Synthesis, Heterostructures, and Device Innovations* [J]. Advanced Physics Research (2025).

16 Impurity-induced Inverse Faraday Effect

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Abstract

We provide a quantum-mechanical description of the photoinduced dc current states and magnetic fields around nonmagnetic point impurities in a two-dimensional (2D) electron gas irradiated by a circularly polarized electromagnetic wave (see Fig). Based on the solution of the corresponding time dependent Schrödinger equation within the second-order perturbation theory in the electromagnetic wave amplitude, we find that the resulting dc magnetic field component perpendicular to the plane of the 2D system is distributed like in a set of random magnetic fluxes bound to the positions of impurities. As a result, the spatially averaged dc magnetic field does not vanish far from the sample edges and, thus, our scenario of the inverse Faraday effect in disordered systems differs strongly from the standard one based on the relaxation time approximation within the hydrodynamic or kinetic equation approaches, which would give only the photoinduced currents flowing along the sample edges. The internal dc magnetic field can give rise to the photoinduced Hall effect and Faraday rotation for a probing electromagnetic signal.

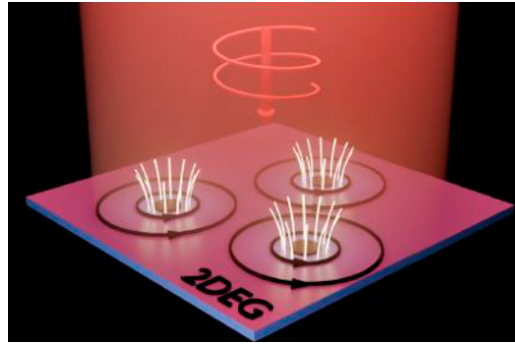


Figure 1: Schematic picture illustrating the suggested mechanism of the inverse Faraday effect. We show the lines of the dc currents flowing around each impurity center and magnetic field generated by a circularly polarized light incident on the two-dimensional electron gas (2DEG).

Keywords: inverse Faraday effect, impurities, two-dimensional electron gas

Acknowledgments: This work was supported by the Federal Academic Leadership Program Priority 2030 (NUST MISIS Strategic Technology Project “Quantum Internet”) in part of quantum-mechanical calculations of the magnetic moment, by the Russian Science Foundation (Grant No. 25-1200042) in part of the analysis of electrodynamics of the considered systems, and by the Grant of the Ministry of Science and Higher Education of the Russian Federation No. 075-15-2025-010 in part of numerical calculations. A.A.K. acknowledges the financial support of the Foundation for the Advancement of Theoretical Physics and Mathematics BASIS (Grant No. 23-1-2-32).

17 Vortex nucleation in type I superconducting layer covering type II superconductor

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Abstract

Within the framework of the Ginzburg-Landau model, it has been shown that in a composite system consisting of type I and type II superconductors with a large coherence length difference $\xi_I \gg \xi_{II}$, Abrikosov vortices may appear in the type I superconductor as superconductivity is restored upon decreasing the magnetic field. The vortices enter the type I superconductor through its boundary with the vacuum and reach the boundary with the type II superconductor, which is in the Meissner state. We have found conditions under which the chain of vortices can exist at the I/II interface even at zero magnetic field.

Keywords: type I superconductor, Abrikosov vortices

18 Electronic spin structure of quasi-two-dimensional systems with combined spin-orbit and exchange interactions

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Abstract

Quasi-two-dimensional materials are a promising platform for spintronics and quantum computing. Graphene and topological insulators (TIs) are of particular interest due to their unique interplay of electronic structure, magnetism, and the Rashba effect. The combination of strong spin-orbit coupling (SOC) and magnetism can induce non-trivial topological phases and complex spin textures, enabling control over electronic and spin properties. In TIs, SOC plays a decisive role in band inversion, which gives rise to bulk topological order and topological surface states (TSS). At the same time, Rashba states may emerge on the surface, as observed in $\text{Mn}_{1-x}\text{A}_x\text{Bi}_2\text{Te}_4$ ($\text{A} = \text{Ge}, \text{Sn}, \text{Pb}$), where magnetic and non-magnetic TI properties are combined. Our results show that hybridization of Te-pz and Bi-pz orbitals with those of the substituting element leads to distinct topological phases and possible topological phase transitions. Ab initio calculations and ARPES confirm the presence of Rashba-like surface states (RSS), which evolve systematically with increasing A concentration. RSS shift towards the Fermi level, enhancing their interaction with TSS, and at higher concentrations penetrate deeper into the crystal with a strong orbital contribution from the dopant [1]. These findings establish $\text{Mn}_{1-x}\text{A}_x\text{Bi}_2\text{Te}_4$ as a universal platform for studying RSS-TSS interaction and controlled topological transitions. Unlike TIs, free-standing graphene is non-magnetic and exhibits weak SOC. However, interaction with heavy and magnetic substrates can strongly modify its properties, providing conditions for spin current generation and quantum Hall effects. In the Gr/Au/Co(0001) heterostructure, the substrate induces strong SOC and ferrimagnetic ordering in graphene, accompanied by A/B sublattice asymmetry and the opening of a 30-40 meV gap at the K-point, confirmed by STM/STS and DFT calculations [2]. Moreover, ARPES and spin-ARPES reveal spin-polarized states with conical dispersion near the Γ -point, localized around triangular dislocations from Au-Co lattice mismatch. These states exhibit magnetic dichroism and remain stable under graphene coverage and gold clusters, underlining the technological relevance of this system. Therefore, Gr/Au/Co(0001) represents a promising platform for realizing the quantum anomalous Hall effect and for spintronic applications.

Keywords: topological insulators, graphene, spin-orbit coupling, Rashba effect, spintronics

Acknowledgments: This work was supported by St. Petersburg State University (project 125022702939-2).

References:

1. A.V. Tarasov et al. *Phys. Rev. B* 111, 165115 (2025).
2. A. G. Rybkin et al., *Phys. Rev. Lett.* 129, 226401 (2022).

19 Asymmetric Evaporator for Simultaneous Generation of Clean Water and Electrical Power

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Abstract

Energy shortage and environmental pollution have become global problems to be solved urgently. Therefore, continuously seeking and developing new and green renewable energy generation methods to gradually replace high-pollution and depleting fossil energy is one of the most concerning issues in the current and future development of human society. The promising solar photothermal evaporation technology has attracted more and more attention. Solar-driven interfacial evaporation technology, using renewable solar energy to drive water evaporation, can alleviate these two problems. However, the traditional solar thermal evaporation does not make full use of environmental resources, and most solar thermal evaporation devices will put their work on hold without solar illumination. To comprehensively utilize solar energy, a new type of green and sustainable technology, water-induced electricity generation technology, has been proposed. This kind of utilization of solar energy generates both clean water and electricity, and the devices can still output electric energy in the absence of light. The overall design of full-time work not only enriches the solar-driven photothermal evaporation technology but also provides more possibilities for the comprehensive utilization of environmental resources. However, the evaporator and generator are two separate modules that need to be isolated while each operates separately, and the design/preparation process is complex, resulting in the impaired integrated use of solar energy. Moreover, the transport of fluid in solar evaporation systems is uniformly distributed in photothermal materials. Therefore, the reporter

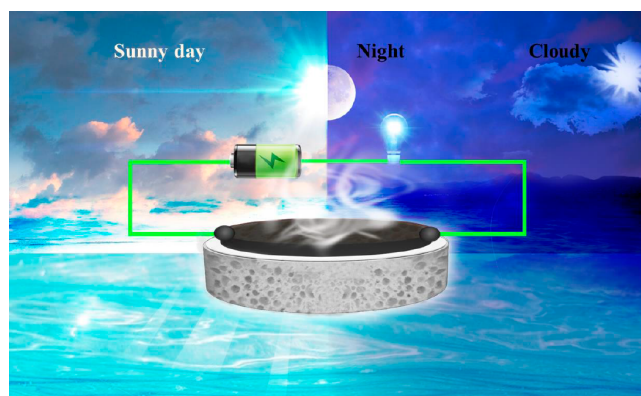


Figure 1: Asymmetric evaporator for simultaneous generation of clean water and electrical power.

proposed a method to adjust the ion concentration gradient and non-uniform distribution of the transport fluid in the nanochannels of photothermal materials to achieve simultaneous and efficient photothermal evaporation and electricity generation. 1) A preparation method of RGO/FeOOH composite photothermal materials with full solar spectral absorption was developed, and the thermal conductivity of the composites was improved by aluminum powder doping. 2) An asymmetric film deposition strategy based on vacuum filtration method was proposed. By introducing stacked asymmetric graphene oxide layers, the asymmetry of the device is enhanced and its power generation performance is improved. 3) The preparation of multifunctional photothermal devices enables simultaneous photothermal evaporation and power generation, demonstrating the potential of generators for seawater desalination and full-time power generation. Therefore, this design provides a new direction for the simple and efficient preparation of solar thermoelectric integrated evaporation devices.

Keywords: Asymmetric evaporator, Solar-driven evaporation, Water-induced power generation

20 Enhancing permittivity of SrTiO₃ thin film via intermediate AlFeO₃ layers incorporation

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Abstract

Strontium titanate is a quantum paraelectric used in novel energy storage, memory and microwave optical devices for its high permittivity and low losses. In polycrystalline films, however, the dielectric strength $\Delta\epsilon$ of the TO1 phonon soft mode (SM) is significantly lower than in bulk crystals. In this study, we investigated the structural and dielectric properties of polycrystalline SrTiO₃ thin films (50 nm and 250 nm thick) and SrTiO₃/AlFeO₃ multilayer heterostructure grown by pulsed laser deposition on Al₂O₃ substrates. Terahertz time-domain spectroscopy measurements reveal that all samples remain in a quantum paraelectric state down to 5 K. Crucially, the SM dielectric strength $\Delta\epsilon$ in the thin SrTiO₃ single layer and SrTiO₃/AlFeO₃ multilayer reaches $\Delta\epsilon = 450$, while for the thick SrTiO₃ single layer the value is lower ($\Delta\epsilon = 320$). In agreement with the Lyddane-Sachs-Teller relation, the measured soft mode central frequency in the thick film is higher, indicating an intrinsic mechanism of soft mode stiffening. Our results demonstrate that the incorporation of intermediate AlFeO₃ layers helps preserve high permittivity values in thicker SrTiO₃ films, enabling their use in electronic applications.

Keywords: Terahertz Spectroscopy, Strontium Titanate, Thin Films

Acknowledgments: The study was supported by the Ministry of Science and Higher Education of Russia (contract No. 075-15-2025-010) and the Russian Science Foundation (project No. 25-42-00058).

References:

1. A. K. Tagantsev et al., Ferroelectric materials for microwave tunable applications, *J Electroceram* 11, 5 (2003).
2. A. Tumarkin et al., SrTiO₃ Thin Films on Dielectric Substrates for Microwave Applications, *Coatings* 14, 3 (2023).
3. J. Petzelt, S. Kamba, Far infrared and terahertz spectroscopy of ferroelectric soft modes in thin films: A review, *Ferroelectrics* 503, 19 (2016).

21 Ferroelectric phase transition and topological properties in two-dimensional CuVP_2Se_6

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Abstract

Recent studies have shown out of plane ferroelectric (OP-FE) behavior in CuVP_2Se_6 . In this theoretical work, we show the Paraelectric phase (PE) of CuVP_2Se_6 , which is equally or even more stable than the OP-FE phase. More interestingly, we found the phase transition from OP-FE to PE is accompanied by a Metal-Insulator transition with non-trivial topology. Also, the tunability of the FE-OP to PE transition is shown based on strain and electric field. Additionally, a new phase corresponding to In-Plane Ferroelectricity (IP-FE) is reported in the family of Transition Metal Phosphorus Chalcogenides (TMPCs) and this phase is the ground state for monolayer CuVP_2Se_6 at $T = 0$.

Keywords: Ferroelectricity, TMPCs, Two-Dimensional, Multiferroics, Flat band

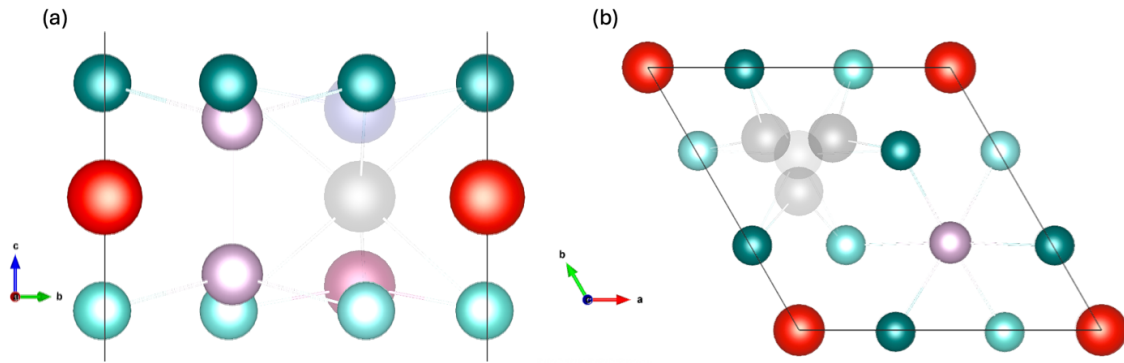


Figure 1: a) Unit Cell of CuVP_2Se_6 view from the a axis, the grey Cu in the middle of the Se_3 layers indicate the PE state and the change of color when the Cu is located on top or bottom indicates the OP-FE states of negative and positive polarization respectively b) Unit Cell of CuVP_2Se_6 view from the c axis, the grey Cu is located in the middle of the Se_3 layers, but in this case the IP-FE takes place when the Cu gets closer to any of the Vanadium (red spheres) sites.

References:

1. Qi, Jingshan et al. Applied Physics Letters 113, 043102 (2018).
2. Neumayer, Sabine M. et al. Advanced Materials 35.20, 2211194 (2023).
3. Zhao, Chunyu et al. Nature Communications 16.1, 6264 (2025).
4. Boris A. Strukov and Arkadi P. Levanyuk. Ferroelectric phenomena in crystals: physical foundations. Springer Science & Business Media (1998).

22 Domain-wall superconductivity in van der Waals structures with ferroelectric ordering

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Abstract

Recently there has been huge interest in the physics of low-dimensional van der Waals structures, and one possible reason for this interest is the possibility of controlling various types of ordering (superconductivity, ferroelectricity) through the electric field effect. This work demonstrates that the structure of superconducting correlations in van der Waals systems significantly depend on the nonlocal nature of electron attraction, which can lead to the formation of Cooper pairs composed of electrons localized in different layers of a hybrid structure [1–5]. These issues are explored for a model bilayer system in the presence of tunneling and relative shifts of the energy bands in the layers caused by spontaneous polarization oriented perpendicular to the layers [6].

We found that for a stepwise relative band shift, there exist superconducting states, which are localized at such a domain wall and have critical temperature higher than uniform superconducting state. It is shown, that the tunneling between the layers strongly modifies the system phase diagram suppressing the domain wall superconductivity. We also show that the in-plane magnetic field can suppress the tunneling between the layers providing a specific depairing mechanism for interlayer pairing. Joint impact of the orbital and the Zeeman pair breaking effects is discussed for spin-singlet and spin-triplet interlayer superconducting correlations.

The obtained results are discussed in the context of recent experimental data on the coexistence of ferroelectricity and superconductivity in van der Waals bilayers [7, 8].

Keywords: superconductivity, ferroelectricity, Van der Waals systems

Acknowledgements: This work was supported by the Ministry of science and higher education of the Russian Federation (Grant No. 075-15-2025-010) in part of analytical calculations for the spin-singlet case, by the Russian Science Foundation (Grant No. 24-12-00152) in part of analytical calculations for the spin-triplet case, and by the Federal Academic Leadership Program Priority 2030 (NUST MISIS Strategic Technology Project "Quantum Internet") in part of numerical calculations. A.A.K. acknowledges the financial support of the Foundation for the Advancement of Theoretical Physics and Mathematics BASIS (Grant No. 23-1-2-32).

References:

1. M. H. Cohen and D. H. Douglass, Jr., Phys. Rev. Lett. 19, 118 (1967).
2. K. B. Efetov and A. I. Larkin, JETP 41, 76 (1975).
3. M. V. Hosseini and M. Zareyan, Phys. Rev. Lett. 108, 147001 (2012).
4. C.-X. Liu, Phys. Rev. Lett. 118, 087001 (2017).
5. M. Alidoust, M. Willatzen, and A.-P. Jauho, Phys. Rev. B 99, 155413 (2019).
6. A. A. Kopasov and A. S. Mel'nikov, Phys. Rev. B 110, 094503 (2024).
7. A. Jindal, A. Saha, Z. Li et al., Nature 613, 4852 (2023).
8. Z. Li, A. Jindal, A. Strasser, Y. He, W. Zheng, D. Graf, T. Taniguchi, K. Watanabe, L. Balicas et al., Phys. Rev. Lett. 133, 216002 (2024).

23 Multidirectional sliding ferroelectricity of rhombohedral-stacked InSe for re-configurable photovoltaics and imaging applications

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Abstract

Through stacking engineering of two-dimensional (2D) materials, the interfacial polarization can be switched via interlayer sliding along armchair directions, so called sliding ferroelectricity, which is advantageous on ultra-thin thickness, high switching speed and high fatigue resistance. However, unveiling the relationship between the sliding pathway and polarization state in rhombohedral-stacked materials, which is the key for 2D sliding ferroelectricity, remains challenging. Here, we report layer-dependent multidirectional sliding ferroelectricity in rhombohedral-stacked InSe (γ -InSe) via dual-frequency resonance tracking piezoresponse force microscopy and conductive atomic force microscopy. The graphene/ γ -InSe/graphene tunneling device exhibits a tunable bulk photovoltaic effect with a photovoltaic current density of ~ 15 mA/cm² due to multiple polarization states. The dome-like domain wall generation is experimentally observed and a multidirectional sliding pathway model is proposed based on our theoretical calculations. Moreover, the intrinsic polarization of γ -InSe guarantees the tunneling device to have a high photo responsivity of ~ 255 A/W and a fast response time for real-time imaging. Our work not only elucidates multidirectional sliding ferroelectricity of rhombohedral-stacked 2D materials, but also sheds light on their potential for tunable photovoltaics and imaging applications.

Keywords: two-dimensional materials, van der Waals heterostructures, sliding ferroelectricity, γ -InSe, bulk photovoltaic effect, photodetection

References:

1. Y. Zhang, T. Ideue, M. Onga, F. Qin, R. Suzuki, A. Zak, R. Tenne, R. Tenne, J. Smet, Y. Iwasa, Enhanced intrinsic photovoltaic effect in tungsten disulfide nanotubes. *Nature* **570**, 349-353 (2019).
2. D. Yang, J. Wu, B. T. Zhou, J. Liang, T. Ideue, T. Siu, K. M. Awan, K. Watanabe, T. Taniguchi, Y. Iwasa, Spontaneous-polarization-induced photovoltaic effect in rhombohedrally stacked MoS₂. *Nat. Photon.* **16**, 469-474 (2022).
3. L. Li, M. Wu, Binary Compound Bilayer and Multilayer with Vertical Polarizations: Two-Dimensional Ferroelectrics, Multiferroics, and Nanogenerators. *ACS Nano* **11**, 6382-6388 (2017).

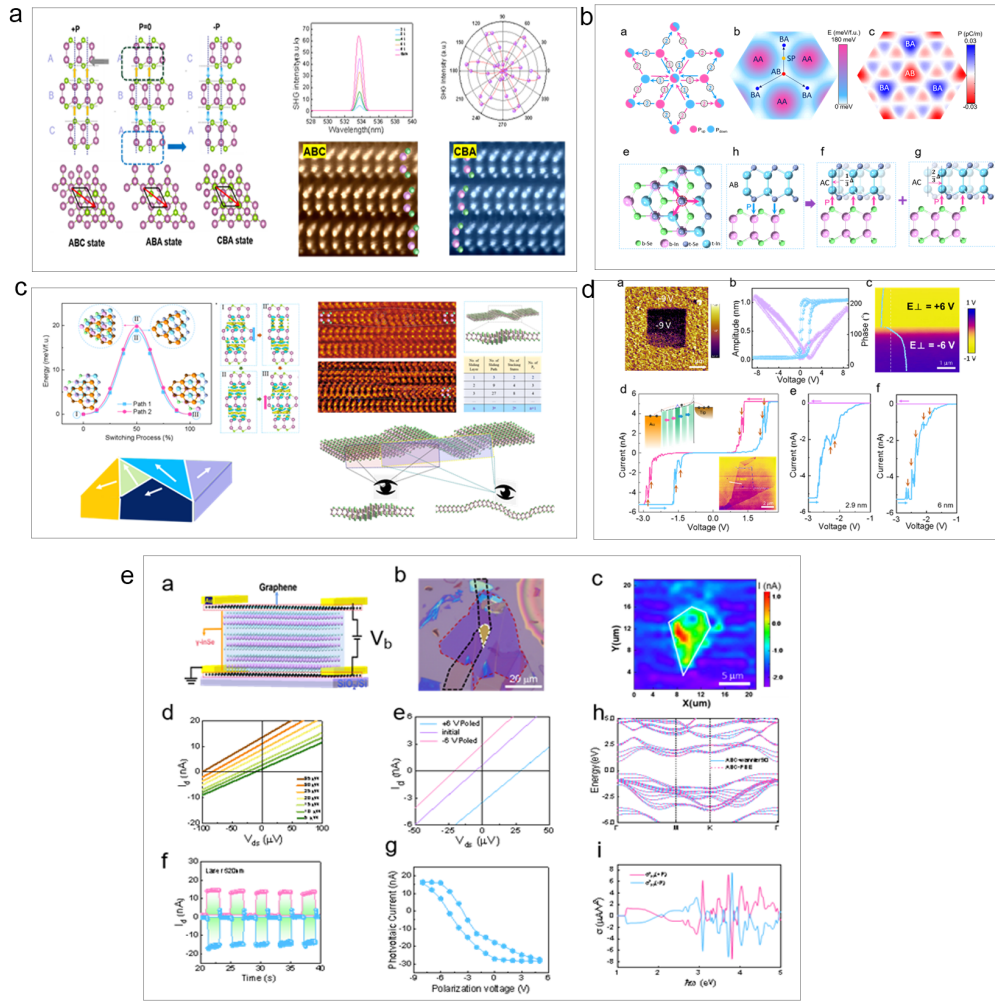


Figure 1: (a) The broken inversion symmetry and C_{3V} rotational symmetry of γ -InSe confirmed by SHG. The phase structure of γ -InSe characterized by STEM. (b) Energy and polarization mapping showing three equivalent sliding directions for each layer. Observation through partial side views reveals pseudo-AA stacking visual effect. (c) Two types of intermediary states among the 9 anisotropic sliding paths of three-layer γ -InSe. Phase structure pinned by a certain sliding path after polarization. (d) Ferroelectricity characterization by PFM, KPFM, and C-AFM showing multiple conductance states during the sliding path. (e) Bulk photovoltaic short-circuit current under different light powers showing tunable bulk photovoltaic effect. Calculated bulk photovoltaic conductances of ABC and CBA stackings by DFT are opposite, consistent with experiment.

24 Structure, residual stresses and properties of Al superconducting thin films fabricated by magnetron sputtering

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Abstract

Superconductors attract a great potential for high-performance applications: electrical power transmission, eliminating the Joule effect; medical diagnostics; quantum interference devices and quantum computing, etc. Recent studies [1] have focused on finding new technological approaches allowing us to sustain a stable superconductivity in thin films. Significant efforts were made in order to improve the scalability and robustness of thin (< 100 nm) film superconductors. However, the numerous fabrication issues still remain unsolved. In particular, the Al-based superconducting thin films, obtained via molecular-beam epitaxy [2], PVD [3] and magnetron deposition [4] exhibit different structural features and, as a consequence, various temperature ranges of a superconducting transition. The possible reasons responsible for the shifting of T_c could be related to either grain structure or electron-phonon interaction. In order to reveal this issue, a series of Al magnetron-sputtered thin films were fabricated onto a Si substrate under different sputtering modes. The purpose of this work is to examine the effect of residual mechanical macro-stresses, distributed within Al thin films, on the critical superconducting temperature. Thin (< 100 nm thick) film deposition was carried out using a magnetron sputtering setup (developed by V. Stolyarov) onto [100]-Si substrate. Prior to the deposition, the substrate was precleaned by Ar^+ ions at low (< 3 keV) energy. The parameters of the magnetron sputtering were as follows: the power of discharge was 50-200 W, the magnetron voltage was 173–571 V, and the argon pressure varied between $2 \cdot 10^{-2}$ Pa and $6 \cdot 10^{-3}$ Pa. Under these conditions, the estimated sputtering rate of 0.02–0.4 nm/s could be achieved. The XRD studies were performed by Panalytical Aeris X-ray diffractometer in the « Ω - 2θ » mode in Cu-K α radiation. TEM characterization was done by JEM 2100 at 200-kV accelerating voltage. The critical superconducting temperatures were measured by a four-probe method using the Coolab LD500 dilution refrigerator. It has been found that the typical structure of the synthesized Al films is nanocrystalline (63 ± 20 nm) and possesses many inner defects (dislocation and twins). The comprehensive XRD examination has revealed a strong $\langle 111 \rangle$ Al texture and the appearance of the residual compressive stresses (~ 150 MPa) oriented along the sample's surface. In turn, the critical T_c temperatures were measured to be around 1.2 K within a certain variation ± 0.2 – 0.3 K depending on the structural phase state of the Al films. The issues on lattice distortion and superconducting performance were discussed.

Keywords: aluminum thin films, magnetron sputtering, superconductivity, residual stresses

Acknowledgments: This work was supported by the Ministry of Science and Higher Education of the Russian Federation «Priority-2030» implemented in the Moscow Institute of Physics and Technology.

References:

1. M.V. Ramallo, *Nanomaterials* **13**, 592 (2023).
2. T.-H. Do, C.-C. Wu, Y.-H. Wu, S.-D. Lin, *Vacuum* **226**, 113339 (2024).
3. Z. W. Zhong, J.H. Wang, *Surface Engineering* **21**, 119-124 (2005).
4. M. A. Tarasov, et al., *Physics of the Solid State* **64**, 1352-1355 (2022).

Wednesday, September 17

Moscow Sightseeing Tour, Visit to the Kremlin

Thursday, September 18

Section: Digital and Quantum Technology

25 EPR in the high-cooperativity regime: a playground for microwave quantum electronics

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Abstract

Quantum electronics operating in the microwave domain, e.g. quantum amplifiers/oscillators, are becoming essential building blocks of quantum computers, sensors and communication devices due to their ultralow (i.e. quantum-limited) noise performance. However, to maintain the delicate quantum coherence and non-equilibrium quantum states, microwave quantum electronics have long been imprisoned in refrigerators. The last decade has seen the dawn of solving the dilemma by the EPR-assisted discovery [1,2] of the optically pumped electron spins in solids that possess long spin relaxation times and high polarization at room temperature. By coupling the spins to microwave cavities with high cooperativity, several works [3,4,5] have demonstrated the feasibility of such hybrid quantum systems to be configured as room-temperature microwave quantum electronics while the functionalities and controllability are still lacking exploration. In this talk, we will report on a solid-state hybrid quantum system, constituted by the optically polarized pentacene triplet spins coupled to a high- Q sapphire cavity, that for the first time serve for quantum amplification and oscillation at X band (~ 9.4 GHz) via the masing process at room temperature. In particular, the performance of the device and the constituent parts can all be evaluated and optimized by the EPR techniques. Our work [6] demonstrates the powerfulness and full compatibility of EPR spectroscopy for facilitating the development of microwave quantum electronics at room temperature.

Keywords: masers, cavity quantum electrodynamics, quantum electronics

References:

1. H. Wu, W. Ng, S. Mirkhanov, A. Amirzhan, S. Nitnara, M. Oxborrow, *J. Phys. Chem. C*, 2019, **123**, 24275-24279.
2. M.W. Doherty, N. B. Manson, P. Delaney, F. Jelezko, J. Wrachtrup, L.C.L. Hollenberg, *Phys. Rep.*, 2013, **528**, 1-45.
3. M. Oxborrow, J.D. Breeze, N.M. Alford, *Nature*, 2012, **488**, 353-356.
4. J.D. Breeze, E. Salvadori, J. Sathian, N.M. Alford, C.W.M. Kay, *Nature*, 2018, **555**, 493-496.
5. W. Ng, X. Xu, M. Attwood, H. Wu, Z. Meng, X. Chen, M. Oxborrow, *Adv. Mater.*, 2023, **35**, 2300441.
6. K. Wang, H. Wu, B. Zhang, X. Yao, J. Zhang, M. Oxborrow, Q. Zhao, *Adv. Sci.*, 2024, **11**, 2401904.

26 Planar topological Josephson junctions and Majorana zero modes

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Abstract

Planar STIS Josephson junctions are actively studied experimentally [1] as a platform for the realization of Majorana zero modes (MZM) and topological quantum computations. It is important to analyze experimental manifestations of the MZM's. We study the Josephson current in a long junction and its suppression by magnetic field, where MZM's contribute to the modification of the Fraunhofer pattern due to their hybridization [2, 3]. These modifications, further, depend on their quantum state, opening possibilities for quantum readout.

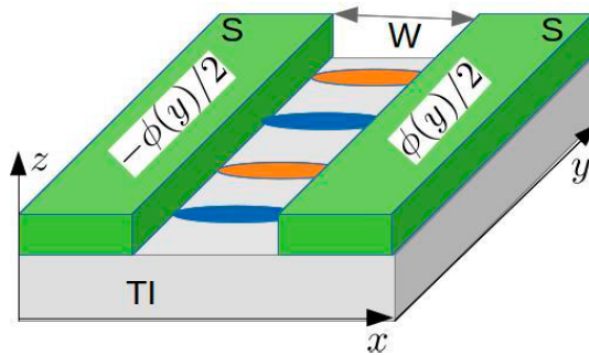


Figure 1: Majorana zero modes in a planar STIS junction

Keywords: Josephson, Majorana, topological

References:

1. A. C. Potter and L. Fu, Phys. Rev. B 88, 121109 (2013); S. S. Hegde et al., Ann. Phys. 423, 168326 (2020); G. Yue et al., Phys. Rev. B 109, 094511 (2024)
2. S. Backens et al., JETP Lett. 116, 891 (2022)
3. K. Piasotski et al., Phys. Rev. B 111, 174527 (2025)

27 Fabrication and application of optical synaptic devices based on two-dimensional materials

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Abstract

With the rapid advancement of artificial intelligence and neuromorphic computing, traditional silicon-based synaptic devices are increasingly constrained by issues such as high power consumption and limited integration density, making them insufficient to meet the demands of efficient parallel computation. In contrast, optoelectronic synaptic devices based on two-dimensional (2D) materials have demonstrated significant application potential due to their unique photoelectric synergistic regulation capabilities, low energy consumption, and excellent scalability, emerging as promising candidates for next-generation brain-inspired computing systems. In this work, an optoelectronic synaptic device based on 2D transition metal dichalcogenides (TMDs) was designed and fabricated. High-quality, large-area, and thickness-controlled TMD films were synthesized via chemical vapor deposition (CVD). The material was systematically characterized using optical microscopy and Raman spectroscopy to evaluate its structural quality. The synthesized 2D material was then transferred onto the target substrate, and microelectrode structures were defined using electron beam lithography and thermal evaporation coating techniques. The device architecture and electrode interfaces were optimized to enhance synaptic performance. Experimental results demonstrate that the device exhibits robust and tunable synaptic behaviors in response to variations in light intensity, wavelength, and pulse timing, effectively emulating key features of biological synaptic plasticity. This study provides a valuable reference for the further development of 2D-material-based optoelectronic synaptic devices and offers a promising pathway for constructing low-power, highly integrated neuromorphic vision systems.

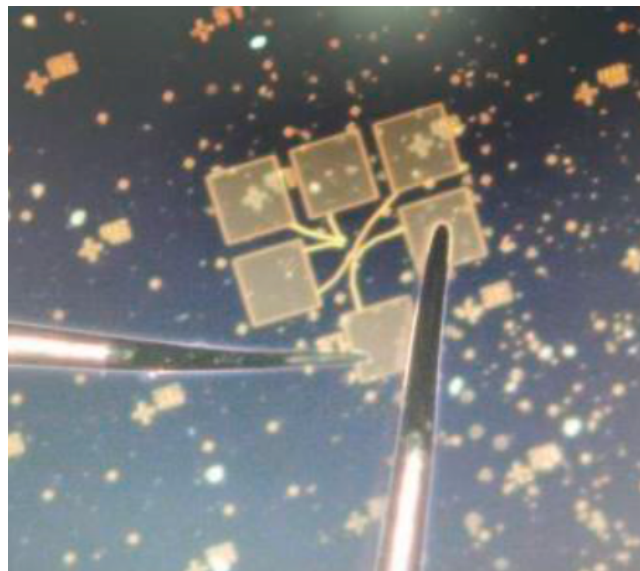


Figure 1: Optical micrograph of a optoelectronic synaptic device

Keywords: Two-dimensional electronic devices, neuromorphic synaptic devices, optoelectronic properties

References:

1. Huang X, Liu C, Zhou P. 2D semiconductors for specific electronic applications: from device to system[J]. *Npj 2D Materials and Applications*, 2022, **6**(1): 51.
2. Liu C, Chen H, Wang S, et al. Two-dimensional materials for next-generation computing technologies[J]. *Nature Nanotechnology*, 2020, **15**(7): 545-557.

28 All fractional Shapiro steps in the RSJ model with two Josephson harmonics

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Abstract

Synchronization between the internal dynamics of the superconducting phase in a Josephson junction (JJ) and an external ac signal is a fundamental physical phenomenon, manifesting as constant-voltage Shapiro steps in the current-voltage characteristic. Mathematically, this phase-locking effect is captured by the Resistively Shunted Junction (RSJ) model, an important example of a nonlinear dynamical system. The standard RSJ model considers an overdamped JJ with a sinusoidal (single-harmonic) current-phase relation (CPR) in the current-driven regime with a monochromatic ac component. While this model predicts only integer Shapiro steps, the inclusion of higher Josephson harmonics is known to generate fractional Shapiro steps. In this paper, we show that only two Josephson harmonics in the CPR are sufficient to produce all possible fractional Shapiro steps within the RSJ framework. Using perturbative methods, we analyze the amplitudes of these fractional steps. Furthermore, by introducing a phase shift between the two Josephson harmonics, we reveal an asymmetry between positive and negative fractional steps — a signature of the Josephson diode effect.

Keywords: Josephson effect, RSJ model, Shapiro steps

References:

1. Pavel N. Tsarev and Yakov V. Fominov, *arXiv:2505.20502*.

29 Ultra-Low-Damping Epitaxial YIG Films Grown by LPE with a Buffer Layer for Quantum Applications

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Abstract

The pursuit of quantum-coherent magnonic systems demands ultra-low-damping materials operable at mK temperatures—a domain where conventional YIG films fail due to interfacial paramagnetic relaxation. Overcoming the "GGG bottleneck" (Gd^{3+} diffusion below 100 K) remains critical for scaling quantum-hybrid architectures. While bulk YIG crystals achieve near-theoretical damping limits, thin-film counterparts suffer from inhomogeneous broadening that masks intrinsic properties [1]. Our approach targets this fundamental disparity by decoupling crystal perfection from substrate-induced spin decoherence.

In this work we continue to study cryogenic properties of LPE grown YIG [2,3]. We demonstrate record-low ferromagnetic resonance (FMR) linewidths in epitaxial yttrium iron garnet (YIG) films at cryogenic temperatures, achieved via a novel $\text{Y}_3(\text{GaScIn})_5\text{O}_{12}$ buffer layer grown by liquid phase epitaxy (LPE). The buffer eliminates gadolinium diffusion from the GGG substrate, suppressing paramagnetic damping below 100 K. Low intrinsic damping do not provide narrow FMR linewidth [4], but alongside with structural perfection of single crystal inhomogeneous broadening can be significantly lowered. FMR measurements reveal linewidths of 1.82 Oe at 4 K and 1.83 Oe at 14 mK – the lowest values reported for thin-film YIG. Lattice mismatch is minimized to 0.0025 Å through tailoring In^{3+} substitution, ensuring homogeneity. Optimized LPE synthesis with $\text{PbO-B}_2\text{O}_3$ solution-melts enables scalable production. The films show quantum-ready performance in dilution-refrigerator environments (14 mK), critical for hybrid quantum systems. This interfacial engineering approach overcomes intrinsic limitations of GGG substrates, reducing paramagnetic influence on intrinsic magnetic damping and provide low inhomogeneous broadening of FMR. Cross-sectional SEM and XRD confirm structural integrity and strain mitigation. The results establish YIG films as viable components for cryogenic spintronics and quantum magnonics.

Keywords: iron garnet films, liquid phase epitaxy, quantum magnonics

References:

1. Arsad A.Z., Zuhdi A.W.M., Ibrahim N.B., Hannan M.A., Appl. Sci., 13 (2023) 1218
2. Kuzmichev A.N. et al., Mater. Res. Bull. 149, 111691 (2022).
3. Kupchinskaya N.E. et al., J. Magn. Magn. Mater. 591, 171623 (2024).
4. Guo S. et al., J. Magn. Magn. Mater. 562, 169795 (2022).

30 Analysis of periodicity in arrays of triple steps on vicinal surfaces: Period-dependent suppression of Fourier peaks

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Abstract

We have investigated the peculiarities of atomic structures on vicinal surfaces Si(*h h m*), oriented at an angle close to 9.5° relative to the terraces (1 1 1). As a result, we have to consider the following surfaces: Si(8 8 11) (miscut angle of 8.93°, period of triple steps of $L_3=18b=5.99$ nm, where $b=0.335$ nm is the distance between atomic rows for the surface Si(1 1 1)1×1 in the [1 1 2] direction), Si(5 5 7) (9.44°, $L_3=17b=5.65$ nm) and Si(7 7 10) (10.0°, $L_3=16b=5.32$ nm). The expected difference in periods for these surfaces is rather small (about 6%) and can be easily masked by distortions in the scanning plane caused by thermal drift and/or creep of the piezo scanner. We propose a novel method for determining the periodicity of a system of triple steps.

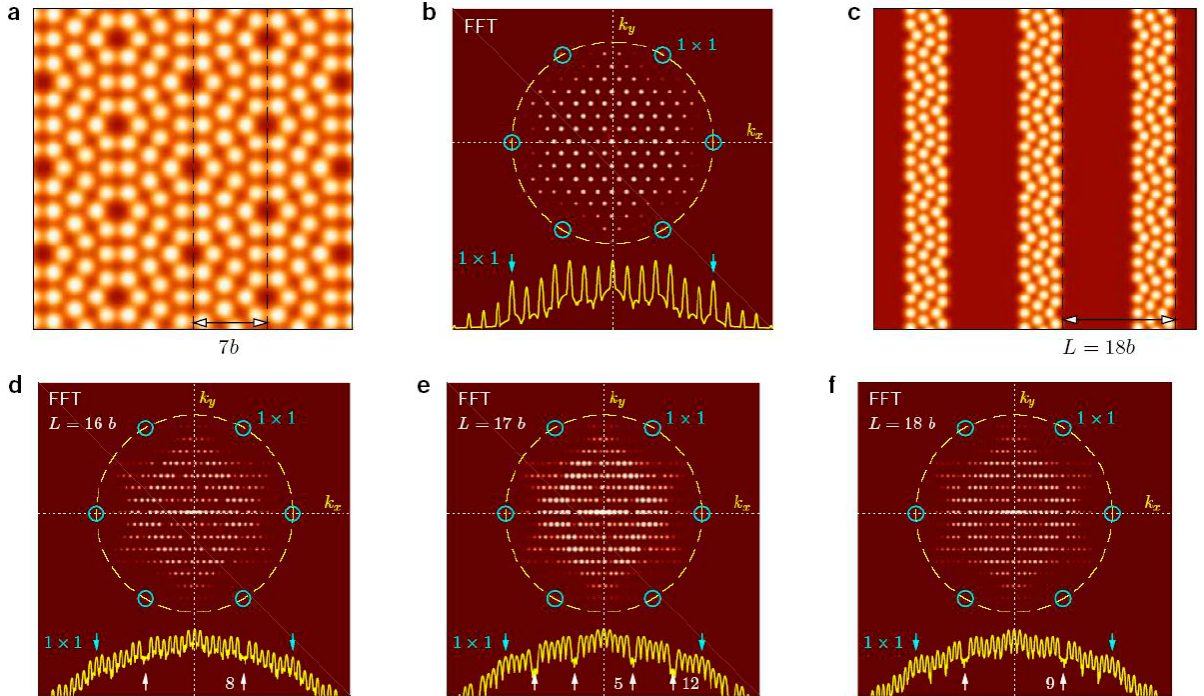


Figure 1: **a, b** – Model surface Si(1 1 1)7×7 and corresponding Fourier transform $z(k_x, k_y)$, yellow curve in the bottom part of panel b depicts the dependence $\ln|z(k_x, k_y=0)|$. **c** – A fragment of the model structure representing periodically repeating strips of the Si(1 1 1)7×7 reconstructions with period L . **d-f** – Fourier transform $z(k_x, k_y)$ for the periodical patterns with periods 16b (d), 17b (e) and 18b (f). The radius of the circle marking the expected positions of the first-order Fourier peaks for the Si(1 1 1) 7×7 lattice, is equal to 18.89 nm^{-1} .

We note that there are areas with 7×7 reconstruction on (1 1 1) terraces for vicinal surfaces Si(8 8 11), Si(5 5 7), and Si(7 7 10) (Fig. 1c). We have shown that the Fourier transforms of topography images for such structures could contain split Fourier peaks (Fig. 1, panels d-f). Depending on the period of the superstructure, one or two peaks on the dependence of $|z(k_x, k_y)|$, composed for $k_y=0$, become suppressed. This enables us to uniquely determine the structure period and establish Miller indices for the considered vicinal surfaces. For vicinal surface Si(*h h m*), studied experimentally, proper alignment can be done using the difference-of-Gaussian approach [1]. Fourier analysis of differential

topographic images obtained by scanning tunneling microscopy unequivocally indicates suppression of the ninth Fourier peak (at $k_x = 9.45 \text{ nm}^{-1}$ and $k_y = 0$, Fig. 1f). It apparently corresponds to the formation of Si(8 8 11) surface [2].

Keywords: High-index-Miller surfaces, 7×7 reconstruction, Fourier analysis, triple steps

Acknowledgements: The research was supported by the Russian Science Foundation project No. 23-72-30004

References:

1. A. Yu. Aladyshkin et al., *Ultramicroscopy*, **267**, 114053 (2024).
2. A. Yu. Aladyshkin et al., submitted (2025).

31 Studying photon statistics and noise with quantum sensors

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Abstract

We present the results of an investigation of quantum sensors for THz and microwave frequency range receivers for radioastronomy and dark matter search. The first considered type of sensors are cold-electron bolometers (CEBs) [1,2], which show record sensitivity due to direct electron cooling of an absorber thanks to the use of hybrid superconducting/ferromagnetic structures. The CEBs demonstrate both background limited operation and also record cosmic ray immunity due to the tiny volume of an absorber and the decoupling of electron and phonon subsystems. Another important advantage of these bolometers is due to their micron size, which allows the design and fabrication of multi-absorber receiving pixels [1,3]. We demonstrate the results of the design and investigation of different types of receivers with samples fabricated in Nizhny Novgorod [3,4]. The first one is a metamaterial based on ring antennas with CEBs, operating in a broadband frequency range from 150 to 550 GHz [3]. The second one is the two-bolometer system in a coplanar line, reaching a high sensitivity of 6×10^{-18} W/Hz^{1/2} at 300 mK [4]. We also perform an investigation of photon noise from a broadband Josephson junction source, using multi-absorber receivers with CEBs. Also, the current progress of microwave single photon detectors for dark matter search will be outlined [5,6]. As a source of microwave photons, classical sources are used. We will present the detection results of a strongly suppressed signal from the synthesizer, giving Poissonian photon statistics. Another source is the microwave cavity, heated from 20 to 80 mK, which shows super-Poissonian photon statistics, confirming the detection of thermal photons [6].

Keywords: photon noise, cold-electron bolometers, single photon detectors

Acknowledgments: The work was supported by RSF (Project 21-79-20227).

References:

1. L.S. Kuzmin, A.L. Pankratov, A.V. Gordeeva, V.O. Zbrozhek, V.A. Shamporov, L.S. Revin, A.V. Blagodatkin, S. Masi, P. de Bernardis, *Comm. Phys.*, **2**, 104 (2019).
2. A.V. Gordeeva, A.L. Pankratov, N.G. Pugach, A.S. Vasenko, V.O. Zbrozhek, A.V. Blagodatkin, D.A. Pimanov, L.S. Kuzmin, *Scientific Reports*, **10**, 21961 (2020).
3. L.S. Revin, et. al, *Phys. Rev. Appl.* **22**, 064040 (2024).
4. D.A. Pimanov, et. al, *Supercond. Sci. Technol.* **38**, 035026 (2025).
5. A.L. Pankratov, L. S. Revin, A. V. Gordeeva, A. A. Yablokov, L. S. Kuzmin, E. Il'ichev, *npj Quantum Inf.* **8**, 61 (2022).
6. A.L. Pankratov, A.V. Gordeeva, A.V. Chiginev, L.S. Revin, A.V. Blagodatkin, N. Crescini, L. S. Kuzmin, *Nature Communications* **16**, 3457 (2025),

32 Precise Control of the Electronic Structure in AB₂C₄-Type Topological Compounds

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Abstract

Magnetic topological insulators of the MnBi₂Te₄ family (AB₂C₄-type) have recently attracted significant attention due to the possibility of realizing exotic states such as the quantum anomalous Hall effect, axion electrodynamics, and Weyl semimetal phases. A key challenge for their practical implementation in quantum and spintronic technologies is the precise control of their electronic structure, including the smooth modification of the bulk gap and topological surface states [1]. An effective strategy to achieve this control is chemical substitution, which enables systematic tuning of band topology and electronic properties. In this work, we demonstrate that targeted substitution at different lattice sites (Mn → Pb, Bi → Sb, Te → Se) provides versatile means for engineering the electronic structure of AB₂C₄-type compounds. To reveal the underlying mechanisms, we investigated these systems using angle-resolved photoemission spectroscopy (ARPES), including photon-energy dependence, spin-resolved, and circular dichroism measurements. For (Mn_{1-x}Pb_x)Bi₂Te₄, ARPES revealed a gradual reduction of the bulk band gap with Pb substitution, its closure near $x \approx 40\%$, and reopening above $x \approx 80\%$, consistent with a topological phase transition. Topological surface states are present at low and high Pb concentrations but vanish near 50–60%, where the system becomes trivial or semimetallic [2]. The type of antiferromagnetic order remains unchanged, while the Néel temperature decreases with Mn dilution [3]. In the (Mn,Pb)Bi₂Te₄ system, additional Bi → Sb substitution leads to a controlled shift of the Fermi level, allowing tuning of carrier concentration. The amount of Sb required to reach a compensated semiconductor state depends on the Pb content. For GeBi₂Te₄ and SnBi₂Te₄, Te → Se substitution systematically modifies the bulk band gap, conduction band dispersion, and topological surface state group velocity. Differences between Ge- and Sn-based systems reflect cation site occupation and disorder, which affect scattering and transport. Overall, our results demonstrate that controlled substitution in AB₂C₄-type compounds is an effective route for precise tuning of their electronic, magnetic, and topological properties. This chemical flexibility enables the design of materials with tailored phases, opening new opportunities for spintronic and quantum applications.

Keywords: magnetic topological insulators, electronic structure, ARPES

References:

1. P. Wang, et al., *The Innovation* **2**, 100098 (2021).
2. D. A. Estyunin et al., *Physical Review Research* **7** (2), 023168 (2025).
3. D. A. Estyunin et al., *Magnetochemistry* **9** (9), 210 (2023).

33 Research on Multimodal Sensors Based on Two-Dimensional MXene Materials

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Abstract

The rapid advancement of flexible electronics has created an urgent demand for high-performance, low-cost, and scalable sensors. Two-dimensional transition metal carbides and nitrides (MXenes) have emerged as a star material for constructing next-generation flexible sensors, owing to their exceptional metal-like electrical conductivity, hydrophilicity, tunable surface functional groups, and outstanding mechanical flexibility. This research focuses on systematically investigating the application of MXene materials in temperature, pressure, and strain sensing. High-quality few-layer MXene nanosheets will be synthesized from MAX phases such as $\text{Ti}_3\text{C}_2\text{T}_x$, Nb_2CT_x , and $\text{Mo}_2\text{TiC}_2\text{T}_x$ through etching and exfoliation processes. The MXene will be formulated into a stable material with suitable viscosity and deposited onto various flexible substrates using advanced patterning techniques to achieve efficient, controllable, and scalable sensor fabrication. The expected outcomes of this study will provide important experimental and theoretical foundations for developing multifunctional integrated sensing platforms based on a single active material, MXene. The proposed strategies are anticipated to promote the practical application of flexible sensors in artificial intelligence, health monitoring, human-machine interfaces, and beyond.

Keywords: MXene, flexible electronics, multimodal sensors, two-dimensional materials

34 Enhancing the visibility of Majorana Zero Modes via non-magnetic impurity

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Abstract

We present a novel strategy to enhance the detectability of Majorana zero modes (MZMs) in topological superconductors. Contrary to the prevailing focus on ultra-clean systems, we demonstrate through numerical solutions of the Bogoliubov-de Gennes equations that a strategically placed non-magnetic impurity, which acts as a vortex pinning site, can selectively shift the energy of trivial bound states away from zero. Crucially, the topologically protected MZM remains robustly pinned at zero energy. This effect creates a significantly larger energy gap between the MZM and its nearest excitations, resulting in a more pronounced and isolated zero-bias peak in the local density of states measurements. Our findings suggest that engineered impurity structures offer a practical pathway to facilitate the unambiguous observation of MZMs, relaxing the extreme material purity requirements for their detection.

Keywords: Majorana, superconductivity, vortex, impurity

References:

1. G. Volovick, *JETP Letters* **70**, 609 (1999).
2. E. J. H. Lee, X. Jiang, M. Houzet, R. Aguado, C. M. Lieber, and S. De Franceschi, *Nature Nanotechnology* **9**, 79 (2014).

35 Observation of the Superconductivity and Vortex in In-doped SnBi_2Te_4 by Scanning Tunneling Spectroscopy

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Abstract

SnBi_2Te_4 is a topological insulator, which is proved by previous angle-resolved photoemission spectroscopy (ARPES) measurement [1]. But doping indium into it can induce superconductivity[2]. By means of scanning tunneling microscopy/spectroscopy (STM/S), we confirm the superconductivity in In-doped SnBi_2Te_4 ($\text{Sn}_{0.56}\text{In}_{0.44}\text{Bi}_2\text{Te}_4$) with a critical temperature T_c up to 0.95 K and an upper critical field up to 1.24 T. Moreover, the superconducting vortex with an Abrikosov lattice is observed as well. The coexistence of topological surface states and superconductivity in In-doped SnBi_2Te_4 makes it one of the candidate materials for exploring topological superconductivity.

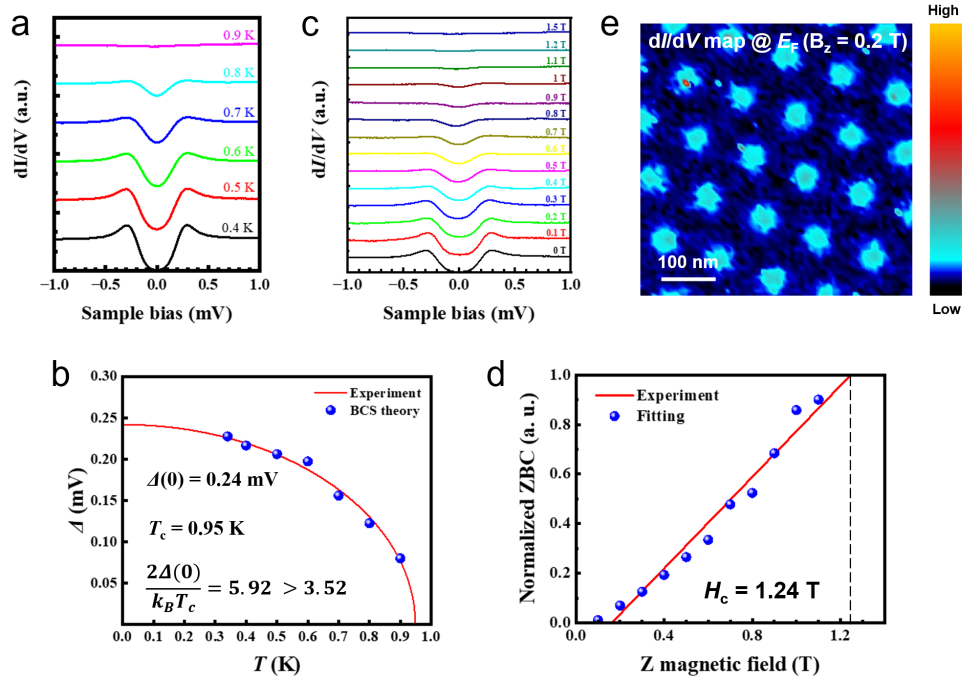


Figure 1: Superconductivity and vortex lattice in $\text{Sn}_{0.56}\text{In}_{0.44}\text{Bi}_2\text{Te}_4$ probed by STM/S.

References:

1. Wentao Zhang, Dong Qian et al., Chinese Phys. B 30, 127901 (2021).
2. Michael A. McGuire et al., Phys. Rev. Materials 7, 034802 (2023).

36 Nonreciprocal phenomena in the asymmetric superconducting interferometer with external microwave irradiation

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Abstract

The superconducting diode effect has recently gained attention due to its relevance in fundamental research and potential in superconducting electronics [1]. Superconducting interferometers (SQUIDs) are often used to study this effect, as they allow for easy geometric asymmetry and time-reversal symmetry breaking via an external magnetic field. Our study focuses on a SQUID intentionally fabricated from two qualitatively different types of Josephson junctions with sinusoidal and linear current-phase relation [2]. The main manifestation of the diode effect is the asymmetry of critical currents, which in our system amounted to 3%. However, in this work we go beyond conventional measurements of this phenomenon and highlight additional features of the current-voltage (I-V) characteristics – specifically, Shapiro steps that emerge under external microwave irradiation [3]. We find that in our system, the Shapiro steps display a significantly stronger asymmetry than the critical currents. Notably, this asymmetry oscillates with the SQUID's magnetic periodicity. Our experimental data enabled the development of a theoretical model that qualitatively reproduces these effects, offering deeper insight into nonreciprocal behavior in superconducting systems and potential applications across various devices and materials.

Keywords: superconducting diode effect, Shapiro steps, SQUID

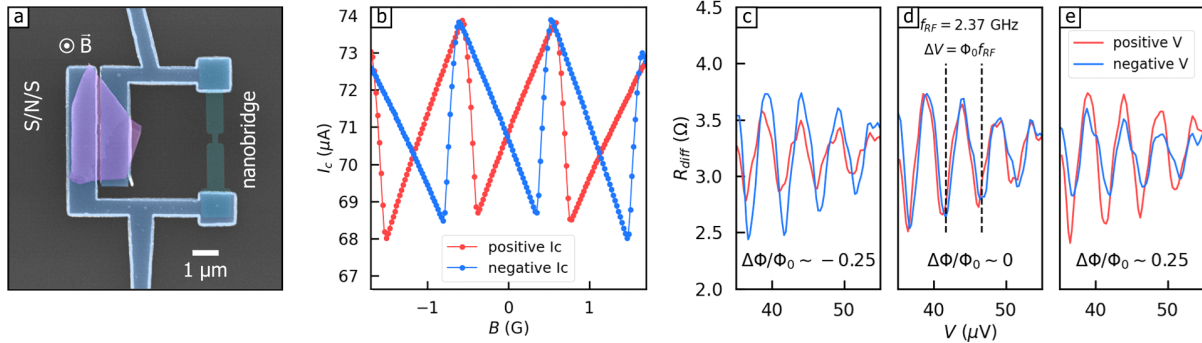


Figure 1: a) An image of the investigated SQUID; b) the diode effect in critical currents; c–e) diode effect in Shapiro steps at different magnetic fluxes through the SQUID.

Acknowledgements: The research was supported by the Russian Science Foundation project No. 25-42-00058

References:

1. M. Nadeem, M.S. Fuhrer, and X. Wang. Nature Reviews Physics 5, 55 (2023).
2. I. Babich, A. Kudriashov, et al. Nano Letters 23, 14 (2023).
3. Y.V. Fominov, D.S. Mikhailov. Physical Review B 106, 13 (2022).

37 Quantum Transport in Graphene-Based van der Waals Heterostructures

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Abstract

Two-dimensional (2D) materials and their van der Waals heterostructures have emerged as a major frontier in condensed matter physics, driven by their unique quantum properties and broad prospects for applications in next-generation technologies. These systems offer atomically sharp and highly tunable interfaces that enable the exploration of phenomena inaccessible in conventional bulk materials. Among them, graphene stands out as a model platform due to its exceptional electronic properties, such as massless Dirac fermions, high carrier mobility, and long coherence lengths. When coupled with layered magnetic systems, graphene-based heterostructures provide unprecedented opportunities to study proximity-induced effects, spin-dependent transport, and correlation-driven electronic states in reduced dimensions. Such hybrid systems not only deepen our understanding of interfacial quantum physics but also hold promise for the realization of novel device functionalities in the realms of spintronics and quantum information science. My research is primarily devoted to the experimental investigation of these heterostructures. High-quality and precisely aligned devices are fabricated using advanced nanofabrication techniques, ensuring clean interfaces and reliable structures. Low-temperature quantum transport measurements are employed to probe spin, valley, and correlation effects, while complementary spectroscopic and microscopic characterizations are used to verify material quality and device integrity. The overarching aim is to understand and explore inter-layer interactions and proximity effects in a controllable manner. From a broader perspective, this research seeks to advance the fundamental understanding of quantum phenomena in low-dimensional systems and to assess their potential applications in quantum technologies. The expected outcomes of this study are expected to contribute to the development of low-power spintronic devices, quantum sensors, and related applications based on atomically thin materials.

Keywords: van der Waals heterostructures, graphene, quantum transport, spintronics

Friday, September 19

Section: New Materials & Spintronics

38 Heterostructures and Spins Clusters

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Abstract

The study of the interplay between the Kondo effect and magnetic correlations in new platforms, such as heterostructures [1] and systems with spin clusters [2], may be a new path to developing materials with tailored properties. Here, we propose a heterostructure that consists of three coupled lattice layers. The Kondo-Heisenberg lattice model describes the first layer, called here the Kondo layer, with strengths of the Kondo and Heisenberg terms given by J_K and J_H , respectively. The other two layers are composed of non-interacting itinerant conduction electrons, with their coupling to the first layer determined by a perpendicular hopping parameter. Using the mean-field approximation within the Green's function formalism, we demonstrated that variations in interlayer coupling significantly influence the behavior of mean-field order parameters of the Kondo layer that characterize the Kondo singlet formation and short-range magnetic correlations. The resulting temperature versus interlayer hopping parameter phase diagram reveals a rich interplay of discontinuous and continuous transitions. In particular, for the regimes $|J_K| < |J_H|$ and $|J_K| > |J_H|$, we identify diverse phase diagrams that encompass Kondo, ferromagnetic, and antiferromagnetic correlations. Furthermore, we provide a detailed investigation of electronic properties, including the band structure, offering new insights into the interplay of coupling mechanisms in this class of heterostructures. Next, we discuss the interplay between Kondo interaction and magnetic frustration in a system with a cluster of spins [2]. We consider J1-J2 the model for magnetic couplings. The system is divided into identical finite clusters, with the magnetic intercluster interaction treated using a cluster mean-field approach [2]. The resulting effective intracluster problem is solved exactly, considering the Kondo coupling for different electron densities within each cluster. The results indicate that frustration weakens magnetic ordering by lowering the temperature of the order-disorder phase transitions. The Kondo interaction strongly affects these transitions, altering their critical behavior by inducing only continuous phase transitions and driving the system toward quantum critical points. This process takes place in the highly frustrated regime and becomes more pronounced as the electron density increases. Our findings suggest that even a weak Kondo coupling can affect magnetic ordering in a competitive magnetic scenario.

Keywords: Heterostructure, Spin Clusters, Kondo Effect, Magnetism, Frustration

References:

1. M. Naritsuka, T. Terashima, and Y. Matsuda, *J. Phys.: Condens. Matter* **33**, 273001 (2021).
2. F. M. Zimmer, W. C. Silva, M. Schmidt, S. G. Magalhaes, *Journal of Magnetism and Magnetic Materials* **554**, 169273 (2022).

39 Advanced Spintronic True Random Number Generators and Their Applications

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Abstract

Such artificial intelligence as generative neuron networks are booming, which allows spintronics as a spring of randomness to have immense chances to apply for. Based on the studies on the field-free spin-orbit torque (SOT) effect [1] and successful development of high-performance SOT-magnetic tunnel junctions (MTJ), we have been investigating the applicability of SOT-MTJ as stochastic samplers in stochastic neuron networks [2, 3, 4] and stochastic computing such as the restricted Boltzmann machines (RBM) prevalent in unsupervised learning and combinational problem solvers. Their works show SOT-MTJs well match the needs of RBM nodes, enabling the SOT-MTJ-sampled RBM to achieve handwritten and spoken digits recognition, generation, and crossmodal learnings [5]. Their works clearly demonstrate spintronic devices ready for developing hardware tailored for stochastic networks and also open a promising outlet for spintronics, especially SOT devices.

Keywords: True Random Number Generators, Probabilistic Computing, Stochastic Computing, Restricted Boltzmann Machines

References:

1. W. Q. He, CHW, S. Alexander, X.F.Han, et al. Nano Lett. 22 (2022) 6857-6865.
2. X. H. Li, CHW, X.F.Han, et al. APL 123, 142403 (2023).
3. R. Zhang, CHW, X.F.Han, et al. Adv. Sci. (2024) 2402182.
4. R. Zhang, CHW, T. K ampfe , X.F.Han, et al. arXiv:2501.04447.
5. X. H. Li, CHW, X.F.Han, et al. Nano Lett. 24 (2024) 5420-5428.

40 Theory of hybrid collective excitations in topological superconductor/ferromagnetic insulator heterostructures

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Abstract

In this talk we address a still unexplored type of dynamical proximity effects in S/F heterostructures. As a basic system sustaining the strongest spin-orbit coupling (SOC), we consider a topological superconductor/ferromagnetic insulator (TS/FI) heterostructure. It is predicted that the magnons in the TS and the Nambu-Goldstone (NG) phase mode in the TS are coupled forming composite magnon-NG excitations. The coupling occurs via the interface exchange coupling between the conductive electrons of the 2D TS superconducting surface state and the FI magnetization. The key ingredient providing the coupling is the spin-momentum locking of electrons in the helical surface state of the TS, which always maintains the same magnitude of singlet and triplet correlations, thus giving the superconducting OP the ability to respond to a magnon. Conversely, excitation of the NG mode in the TS leads to the appearance of an ac current, which is always accompanied by electron spin polarization (direct magnetoelectric effect). The current-induced spin polarization creates a torque, generating magnons in the FI. The strength of magnon-NG coupling is anisotropic. It is maximal for excitations propagating along the equilibrium magnetization of the FI and vanishes for the perpendicular propagating direction. The reconstructed spectra and specific features in the decay rate of these composite excitations can be used for experimental study of the NG mode and its interaction with the magnon. At the same time, the amplitude Higgs mode is not coupled to the magnon for the 2D helical state of the TS.

Keywords: proximity effect, collective modes

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41 Unusual magnetic phenomena at the surfaces of lanthanide materials: Insights from ARPES and XAS experiments

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Abstract

For a long time, lanthanide (Ln) materials have attracted considerable interest due to their rich and exotic properties. These include complex magnetic phases, unconventional superconductivity, valence fluctuations, heavy-fermion and Kondo behavior, and non-Fermi-liquid properties. A key aspect of the involved physics is the interplay between itinerant electrons and the lattice of localized 4f moments. It is important to note that the surfaces of such materials often receive less attention than their bulk. However, it is reasonable to anticipate that the 4f-driven physics at the surface can be even richer and more compelling than in the bulk. The lack of inversion symmetry, spin-orbit coupling (SOC), the appearance of surface states and resonances, relaxation and reconstruction, as well as strong changes in the crystal-electric field near and at the surface, are driving forces for novel 4f-driven phenomena, phases, and temperature scales that differ significantly from those in the bulk. We will focus on a class of LnT_2Si_2 materials, where T represents transition metal atoms. In addition to their unique bulk properties, these materials exhibit rather unusual phenomena at the surface and can be considered as models for studying the peculiarities of 4f physics within the non-centrosymmetric Si-T-Si-Ln surface-silicide blocks. In these systems, the strength of spin-orbit coupling (SOC) can be tuned by choosing appropriate transition metal (T) atoms. The SOC gradually increases by substituting Co (3d) with Rh (4d), and further with Ir (5d). As a competing effect, exchange magnetic interactions can be introduced by incorporating elementary 4f magnets like Gd as the Ln component. Since the orbital moment of the Gd 4f shell vanishes ($L = 0$), the pure and large spin moment of Gd provides a strong and robust source of magnetic phenomena. A rotation of the 4f moments relative to the surface normal can be achieved by coupling with the crystal electric field (CEF). To exploit notable CEF effects, a non-vanishing orbital moment is required, as in the case of Ho or Tb. This allows for the implementation of an exchange magnetic field with varying strength and orientation at the surface, competing with the Rashba SOC field and offering additional opportunities to manipulate the properties of the 2D electrons in the Si-T-Si-Ln system. Another element to consider is the Kondo effect, which can be introduced by inserting elements with an unstable 4f shell, such as Yb or Ce. This presents the opportunity to explore the interplay between 2D electrons and 4f moments within a 2D Kondo lattice in the presence of spin-orbit coupling and a non-centrosymmetric environment. By performing systematic ARPES and XAS experiments based on the aforementioned chain of thought, we have realized most of these scenarios and demonstrated that the Si-T-Si-Ln surfaces of the LnT_2Si_2 materials serve as a versatile platform for studying the fundamental properties linked to f - d interactions at reduced dimensionality. These surfaces act as a "construction kit" comprising Rashba SOC, Kondo interactions, crystal-electric fields, and magnetic exchange with varying strengths. Their mutual combination allows for the design of systems for different scenarios and the study of 2D electron states in the presence of these competing interactions. In this talk, I will present the most interesting results that reveal novel 4f-driven properties and related temperature scales at the surfaces of the discussed LnT_2Si_2 , as well as CeIrIn_5 and LnCo_2P_2 materials. We will also demonstrate how an essential property of 4f moments, such as their orientation in the individual Ln layers, can be reliably derived from the line shapes of classical momentum-resolved 4f photoemission spectra. This opens up significant opportunities to control the 4f-derived magnetic properties in Ln-based heterostructures. The results carry strong implications for how novel functional and quantum materials can be developed by using thin layers of 4f materials as building blocks. In these systems, different combinations of fundamental interactions can be realized, and their combination offers the potential to predict and create novel materials with new functionalities.

Keywords: lanthanide materials, surface magnetism, ARPES, XAS, 4f electrons

References:

1. D. Yu. Usachov et al., *Surface effects in x-ray absorption spectra of lanthanides: Focus on strongly correlated cerium materials*, Physical Review B **112** 035137 (2025).
2. D. Yu. Usachov et al., *Probing surface and bulk ground states of lanthanides: 4f moment orientation through 4d x-ray absorption spectroscopy*, Physical Review B **110** 075157 (2024).
3. G. Poelchen et al., *Interlayer Coupling of a Two-Dimensional Kondo Lattice with a Ferromagnetic Surface in the Antiferromagnet CeCo_2P_2* , ACS Nano **16** 3573 (2022).
4. D. Usachov et al., *Estimating the Orientation of 4f Magnetic Moments by Classical Photoemission*, J. Phys. Chem. Lett. **13** 7861 (2022).
5. M. Mende, et al., *Strong Rashba Effect and Different f-d Hybridization Phenomena at the Surface of the Heavy-Fermion Superconductor CeIrIn_5* , Advanced Electronic Materials **8** 2100768 (2022).
6. S. Schulz, et al., *Classical and cubic Rashba effect in the presence of in-plane 4f magnetism at the iridium silicide surface of the antiferromagnet GdIr_2Si_2* , Physical Review B **103** 035123 (2021).
7. D. Yu. Usachov et al., *Cubic Rashba Effect in the Surface Spin Structure of Rare-Earth Ternary Materials*, Physical Review Letters **124** 237202 (2020).
8. G. Poelchen, et al., *Unexpected differences between surface and bulk spectroscopic and implied Kondo properties of heavy fermion CeRh_2Si_2* , npj Quantum Materials **5** 70 (2020).
9. S. Schulz et al., *Emerging 2D-ferromagnetism and strong spin-orbit coupling at the surface of valence-fluctuating EuIr_2Si_2* , npj Quantum Materials **4** 26 (2019).
10. A. Generalov et al., *Strong spin-orbit coupling in the noncentrosymmetric Kondo lattice*, Physical Review B **98** 115157 (2018) (Editors' Suggestion).
11. A. Generalov et al., *Spin orientation of two-dimensional electrons driven by temperature-tunable competition of spin-orbit and exchange magnetic interactions*, Nano Letters **17** 811 (2017).
12. S. Patil et al., *ARPES view on surface and bulk hybridization phenomena in the antiferromagnetic Kondo lattice CeRh_2Si_2* , Nature Communications **7** 11029 (2016).
13. A. Chikina et. al., *Strong ferromagnetism at the surface of an antiferromagnet caused by buried magnetic moments*, Nature Communications **5** 3171 (2014).

42 Photoelectron diffraction for probing structural, electronic and magnetic properties of 4f materials

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Abstract

Photoelectron diffraction (PED) is well established as an efficient method for structural analysis of crystalline surfaces, defects and impurities, thin films, adsorbates, 2D materials, and other systems [1]. It is based on the fact that photoelectrons emitted from the atomic sites, called emitters, experience multiple scattering on the surrounding atoms when they propagate to the sample surface. As a result, the angular distribution of the measured photocurrent represents a diffraction pattern, which contains information about the local environment of the emitters. In a common PED experiment, electrons are emitted from the closed core shell, leaving the atom with a core hole. Interactions of the core hole with valence electrons may give rise to several spectral components, known as the atomic multiplet. The photoemission intensities of the multiplet components are sensitive to the local magnetic order in the system even in the absence of net magnetization, enabling PED-based insight into magnetic phase transitions in the near-surface region. Nonradiative decay of the core hole produces Auger electrons, giving rise to a so-called Auger electron diffraction. Both direct photoemission and Auger processes can be combined to selectively increase the signal from the atoms of interest by an order of magnitude or even more. This is realized in resonant PED experiments, when the photon energy is selected close to the absorption edge of a core shell, being particularly useful for studies of impurities and defects at low concentrations. Here, we will consider the applications of PED in the structural studies of graphene-based systems and magnetic topological insulators. While PED became a routine technique when based on photoemission from a closed shell, it may also be of interest to consider emission from an open shell. This is of particular importance for studies of materials containing lanthanides. Here, we demonstrate a methodology of PED experiments with the aim to study the properties of 4f materials. Some of these materials exhibit strongly correlated electronic behavior and unusual magnetic properties. Our results demonstrate that the capabilities of photoelectron diffraction extend far beyond the crystal structure analysis, allowing us to study the changes in the valency of 4f elements, the directions of magnetic moments, the differences in the magnetic properties of the surface layers relative to the bulk ones, and the ground state of the 4f shell split in the crystal electric field [2-4].

Keywords: photoelectron diffraction, 4f materials, surface structure, magnetic properties

Acknowledgments: The work was supported by the Ministry of Science and Higher Education of the Russian Federation (No. 075-15-2025-010) and by the St Petersburg State University (Grant No. 125022702939-2).

References:

1. M.V. Kuznetsov et al. *J. Phys. Soc. Japan* **87**, 061005 (2018)
2. D.Yu. Usachov et al. *Phys. Rev. B* **102**, 205102 (2020)
3. D.Yu. Usachov et al. *J. Phys. Chem. Lett.* **14**, 5537 (2023)
4. D.Yu. Usachov et al. *Phys. Rev. B* **109**, L241118 (2024)

43 Electric field induced spin polarized tunneling current

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Abstract

Usually magnetic contrast in STM is obtained using magnetic probes. These are either probes formed from a magnetic material, such as MnNi [1], or non-magnetic probes, such as a conventional tungsten tip, coated with a thin magnetic film [2]. In both cases, the influence of the magnetic or exchange field of the probe on the magnetic structure under investigation cannot be ruled out.

In the present work, the STM probe was fabricated of a whisker of the topological insulator Bi₈₈Sb₁₂. The Bi₈₈Sb₁₂ is an insulator and the conductivity of the tip is provided by the topological surface states of the (111) surface. TEM experiments with atomic resolution justifies high quality of the crystal lattice of the whisker. In order to detect the spin polarization of STM tunneling current the STM experiment on the 0.02 monolayers of Fe deposited on the surface of the Sb(111) surface were performed. Three types of islands with heights of 1.52 Å, 2.46 Å and 4.77 Å were observed on the surface. Density functional theory (DFT) simulations revealed the intercalation of Fe atoms into Sb(111) surface. DFT calculations showed that the islands with height of 1.52 Å are non-magnetic. For the islands with heights of 2.46 Å and 4.77 Å calculations demonstrated a significant difference in the density of states for electrons with different spins. The STS spectra reveal spin polarization in a tunneling current that is justified by DFT calculation. The results are discussed in terms of the spin polarization of the surface states of the Sb(111) of the tip in a strong electric field.

Keywords: scanning tunneling microscopy/spectroscopy, spin polarization, topological insulator, DFT simulations

Acknowledgements: Financial support of the state assignment of the Institute of Solid State Physics of the Russian Academy of Sciences is gratefully acknowledged. We acknowledge support of the Research Facility Center at the ISSP of RAS in the preparation of the sample for TEM using the VERSA dual beam facility. The support in part through computational resources of HPC facilities at NRU HSE is gratefully acknowledged.

References:

1. S. Murphy, K. Radican, I. V. Shvets, A. N. Chaika, V. N. Semenov, S. S. Nazin, and S. I. Bozhko, Asymmetry effects in atomically resolved STM images of Cu(014)-O and W(100)-O surfaces measured with MnNi tips, Phys. Rev B 76, 245423 (2007), DOI:10.1103/PhysRevB.76.245423
2. Roland Wiesendanger, Spin mapping at the nanoscale and atomic scale, Rev. Mod. Phys. 81, 1495 (2009), DOI:10.1103/RevModPhys.81.1495

44 GOLUBOV Alexander: tba

45 High-Resolution Visualization of Single Melanin Molecules Using Atomic Force Microscopy

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Abstract

High-resolution atomic force microscopy (AFM) has been employed to study single melanin molecules. While melanin samples typically contain large aggregates, the use of ultra- sharp probes (with a tip radius of curvature of 1 nm) enabled the clear identification and imaging of individual melanin molecules deposited on a highly oriented pyrolytic graphite (HOPG) substrate.

We prepared monolayer melanin films and investigated their conductive properties using conductive atomic force microscopy (C-AFM). Given our previous work on proximity-induced superconductivity in DNA molecules, we propose that studying composite films of melanin and DNA could be of significant interest. Preliminary AFM data suggest a weak interaction between the two biomolecules.

Keywords: Melanin Molecules, AFM, C-AFM

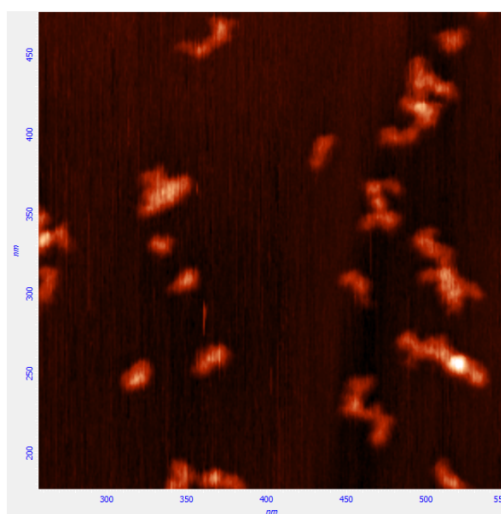


Figure 1: AFM image of single molecules obtained by ultra-sharp tip.

Acknowledgements: This work was supported by the Russian Science Foundation (Grant No. 25-12-00134).

References:

1. A. Yu. Kasumov, M. Kociak, S. Guéron, B. Reulet, V. T. Volkov, D. V. Klinov, and H. Bouchiat, Proximity-Induced Superconductivity in DNA, *Science*, 2001: 280-282.
2. D. Klinov and S. Magonov, True molecular resolution in tapping-mode atomic force microscopy with high-resolution probes. *Applied physics letters*, 2004, 84 (14), 2697-2699
3. E. A. Obraztsova, D. V. Basmanov, N. A. Barinov, D. V. Klinov, Carbon Nanospikes: Synthesis, Characterization and Application for High Resolution AFM. *Ultramicroscopy*, 2019, V. 197, P. 11-15.

46 Facet-Controlled Film Growth and Magnetism in YBaCo₂O₆ Epitaxial Thin Films

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Abstract

We report on the epitaxial growth and comprehensive characterization of YBaCo₂O₆ thin films deposited on SrTiO₃ (001) and (110) substrates. The films were grown by pulsed laser deposition followed by ozone annealing, enabling full oxidation into the O=6 phase with preserved crystallinity. Structural characterization confirmed high-quality epitaxy, while XPS measurements verified the mixed Co³⁺/Co⁴⁺ valence state required for double-exchange ferromagnetism. Magnetic measurements (M–H and M–T) revealed clear ferromagnetic ordering with $T \sim 130$ K, consistent with bulk reports, and demonstrated a distinct dependence on substrate facet: (001)-oriented films exhibited enhanced magnetic anisotropy. Transport studies (R–T, Hall effect, and magnetoresistance) confirmed metallic conduction with carrier densities on the order of 10^{21} cm^{−3} and revealed pronounced magnetoresistance near T . These results highlight the crucial role of facet-controlled epitaxy in tuning the strain state, octahedral connectivity, and ultimately the magnetic and transport properties of YBaCo₂O₆. Our findings establish facet engineering as a promising approach for designing correlated oxide thin films with programmable anisotropy and spin-dependent transport.

Keywords: antiferromagnetic magnons, magnon-photon coupling

References:

1. Hu W., Yang K., Wen X. Ferromagnetic half-metallicity in YBaCo₂O₆ and spin-state driven metal-insulator transition[J/OL]. Journal of Materials Chemistry C, 2021, 9(31): 10112-10118.
2. Goto M., Saito T., Shimakawa Y. Unusual Ferromagnetic Metal: A-Site-Layer-Ordered Double Perovskite YBaCo₂O₆ with Unusually High Valence Co^{3.5+}[J/OL]. Chemistry of Materials, 2018[2025-08-22].
3. Chikamatsu A., Katayama T., Maruyama T. Electronic states of A-site ordered double perovskite YBaCo₂O_x ($x = 5.3$ and 6) thin films investigated by X-ray spectroscopy[J]. Photon Factory Activity Report 2020 38 (2021)
4. Katayama T., Chikamatsu A., Hirose Y. Ferromagnetism with strong magnetocrystalline anisotropy in A-site ordered perovskite YBaCo₂O₆ epitaxial thin films prepared via wet-chemical topotactic oxidation[J/OL]. Journal of Materials Chemistry C, 2018, 6(13): 3445-3450.
5. He J., Borisevich A., Kalinin S. V. Control of Octahedral Tilts and Magnetic Properties of Perovskite Oxide Heterostructures by Substrate Symmetry[J/OL]. Physical Review Letters, 2010, 105(22): 227203.
6. Fungerlings A., Wohlgemuth M., Antipin D. Crystal-facet-dependent surface transformation dictates the oxygen evolution reaction activity in lanthanum nickelate[J/OL]. Nature Communications, 2023, 14(1): 1-13.
7. Chikamatsu A., Katayama T., Maruyama T. Investigation of the electronic states of A-site layer-ordered double perovskite YBaCo₂O_x ($x = 5.3$ and 6) thin films by x-ray spectroscopy[J/OL]. Applied Physics Letters, 2021, 118(1)[2025-08-22].

47 Composite excitations in S/AF/S systems

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Abstract

Superconducting nanostructures with magnetic interlayers are objects of interest to observe hybrid magnon-polariton modes resulting from ultra-strong coupling between magnon and Swihart photon modes, which makes such structures promising for magnonics applications. Such coupling appears due to the interaction between magnon and photon modes, carried by the Meissner currents in the superconductor. While there are experimental observations [1] and theoretical predictions [2-3] of ultra-strong magnon-photon coupling in S/F/S systems, in this work we transfer those studies to a perspective field of antiferromagnetic spintronics [4,5] and suggest a theoretical description of composite excitations in S/AF/S structures.

We demonstrate the formation of magnon-polariton modes in the considered system by both quantum and classical approaches. Strong dependence of the composite excitations spectra on the value of external magnetic field is obtained and explained by analyzing the magnetization configuration on the eigenmodes.

Keywords: antiferromagnetic magnons, magnon-photon coupling

Acknowledgements: Science and Higher Education of the Russian Federation (No. FSMG2023-0014)

References:

1. I. A. Golovchanskiy et al., Phys. Rev. Appl. 16, 034029 (2021).
2. Mikhail Silaev, Phys. Rev. B 107, L180503 (2023).
3. Zhuolun Qiu et al., Phys. Rev. B 110, 184403 (2024).
4. T. Jungwirth et al., Nat. Nanotechnol. 11, 231 (2016).
5. V. Baltz et al., Rev. Mod. Phys. 90, 015005 (2018).

48 Dual-Cation Co-Intercalation Strategy for Enhanced Electrochemical Performance of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene Membranes

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Abstract

This work proposes a dual-cation co-intercalation strategy to enhance the electrochemical performance of $\text{Ti}_3\text{C}_2\text{T}_x$ MXene membranes. By applying a potentiostatic bias in aqueous electrolytes, both lithium (Li^+) and magnesium (Mg^{2+}) ions are simultaneously driven into the MXene interlayers. Li^+ ions contribute fast and reversible intercalation kinetics, while Mg^{2+} ions act as structural stabilizers that expand and support the interlayer spacing. This cooperative effect facilitates deeper ion penetration into thick MXene films and mitigates structural collapse during cycling. Structural and electrochemical characterizations confirm enlarged interlayer spacing, reduced ion diffusion resistance, and improved charge storage kinetics. As a result, the co-intercalated MXene electrodes exhibit enhanced capacitance, superior rate capability, and excellent cycling stability compared with single-ion intercalation. This study demonstrates the feasibility of dual-cation cooperative intercalation as an effective structural engineering approach, offering new opportunities for the design of high-performance MXene-based supercapacitors.

Keywords: MXene, dual-cation intercalation, supercapacitors, electrochemical performance

49 Disorder-enhanced superconductivity in altermagnet-superconductor hybrids

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Abstract

We demonstrate that in hybrid structures composed of a superconductor and altermagnet – a recently discovered class of magnetic materials – introduction of disorder leads to restoration of superconductivity. We explore the influence of disorder by studying a bilayer model consisting of a s-wave superconductor and a planar altermagnet with out-of-plane Néel vector. Due to the proximity effect, electrons in the superconducting layer experience an effective momentum-dependent, Zeeman-like spin-splitting. This leads to the suppression of superconducting critical temperature. Starting from the Gor'kov equations we show that the introduction of potential impurities mixes electron trajectories, averaging the exchange field over the electron trajectory, thus leading to an effective suppression of spin-splitting, a restoration of superconducting order and a rise in critical temperature (see Pic.1). Moreover, using quasiclassical approach, we show that in the dirty limit the influence of altermagnetic order on the superconducting layer can be well approximated by the introduction of effective magnetic impurities with easy axis along the altermagnetic Néel vector and the inverse spin-flip time $1/\tau_s$ proportional to $h_0^2\tau$, where h_0 is the amplitude of altermagnetic exchange field and τ is a mean free time from potential scattering. Our results can be useful for both the design of spintronic devices and the experimental detection of altermagnetism.

Keywords: superconductivity, altermagnetism, impurities

Acknowledgements: This work was supported by the Russian Science Foundation (Grant No. 24-12-00152), and by the Ministry of science and higher education of the Russian Federation (Grant No. 075-15-2025-010).

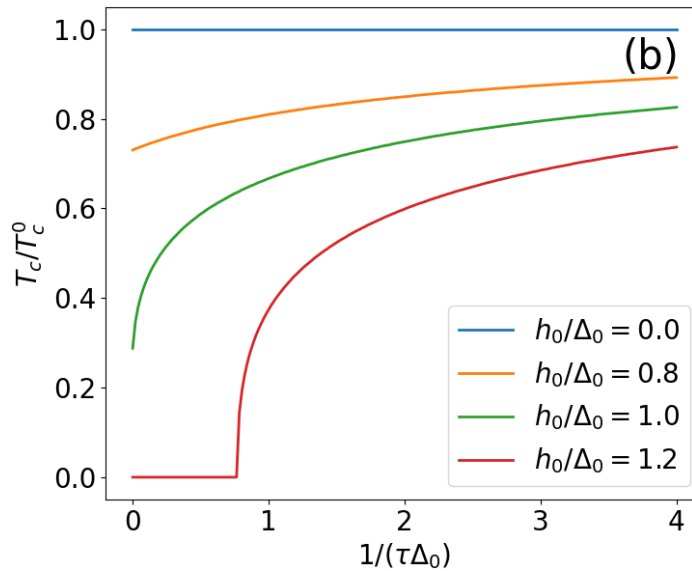


Figure 1: Critical temperature T_c of altermagnet-superconductor bilayer as a function of scattering rate at nonmagnetic impurities $1/\tau$ plotted for different altermagnetic exchange field amplitude h_0 , where T_c^0 and Δ_0 are the critical temperature and the superconducting gap without the exchange field, respectively.

50 Strain-Induced One-Dimensional Magnetic Stripe in Metallic Monolayer H-NbSe₂

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Abstract

Lattice distortion of materials has a profound impact on their electronic and magnetic properties, which can generate local magnetic states in intrinsically non-magnetic systems. Here we report on the realization of a one-dimensional (1D) magnetic stripe in monolayer H-NbSe₂ sustained by strain along the terraces of the graphene/SiC substrates. The strength of this tensile strain is widely tunable by the height-to-width ratio of the terraces. Increasing the tensile strength leads to the shifts and splitting of the Nb 4d bands crossing the Fermi energy, generating spin polarization in a 1D magnetic stripe along the terrace. Simultaneously, the charge-density wave signature of strained H-NbSe₂ is significantly suppressed. Such a magnetic stripe can be locally quenched by an individual Se-atom defect via the defect-induced Jahn–Teller distortion and charge density redistribution. These findings provide a different route to achieving and manipulating 1D magnetism in otherwise non-magnetic systems, offering a new way for spintronic devices.

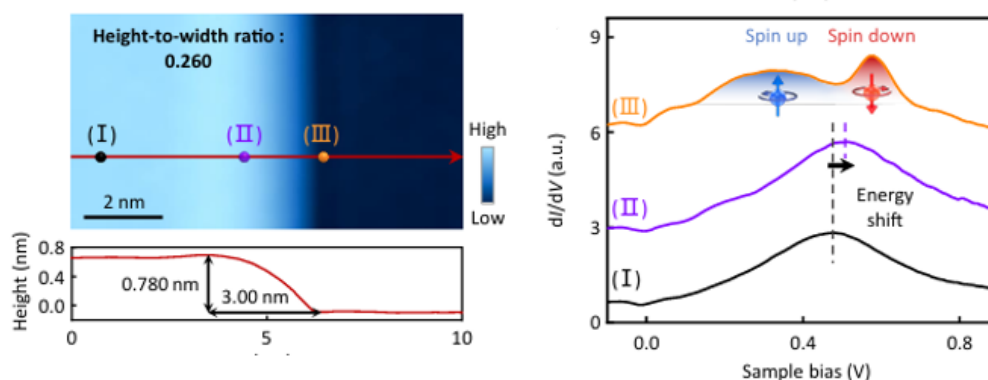


Figure 1: Lattice strain induces magnetism in nonmagnetic H-NbSe₂.

References:

1. Zhou Y.; Wang Z.; Gao F. et al. ACS Nano. 2012; 6: 9727.
2. Jia, L.; Chen, Y.; Zhang, Y. et al. Nano lett. 2024, 24: 8843.
3. Jia, L.; Zhang, C.; Zhang, Y. et al. Chin. Phys. Lett. 2025, 42: 080712.

Friday, September 19

Poster section

51 Research of Superconducting Properties of S/NFN/S-Structures Based on Segmented Nanowires

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Abstract

The present work is devoted to the fabrication and study of the electronic properties of superconducting hybrid S/NFN/S-structures based on segmented nanowires which are made of a normal metal (Au) and a ferromagnet (Ni). Niobium was used as superconducting electrodes, while AuNi-NW served as a weak link. Nanowire-based structures ensure the miniaturization of Josephson junctions, which is important for spintronics and superconducting nanoelectronics. Previously, superconducting state formation has been found in S/N/S structures with various normal metals (Cu [1, 2], Au [3]). In the case of S/NFN/S systems with a ferromagnetic interlayer (Ni), a critical current has been detected [4]. This makes it possible to enhance the Josephson current through a ferromagnetic layer. We have presented the technology developed for fabricating superconducting structures and conducted their transport measurements. Nanowires have been obtained from an AAO matrix which had been stored for 4 years. Samples with ferromagnetic inserts with a thickness from 7 nm to 44 nm and lengths of weak link from 300 nm to 550 nm have been fabricated. For such multi-parameter structures measurements was performed in a dilution refrigerator, i.e. the temperature dependence of resistance has been studied, magnetoresistance has been measured, and current-voltage characteristics have been recorded. The obtained results have been compared with the characteristics of samples fabricated from a freshly prepared AAO matrix, as described in [4]. During storage, Ni and Au in the AAO matrix underwent partial dissolution, which has been detected by the absence of a critical current or its significant reduction in case of Nb/Au/Nb.

Keywords: superconductivity, nanowires, Josephson junction

Acknowledgements: The research was supported by the Russian Science Foundation project No. 25-72-10127

References:

1. P. Dubos, *Phys. Rev. B* **63**, 064502 (2001).
2. O. V. Skryabina, *Appl. Phys. Lett.* **110**(22), 222605 (2017).
3. O. V. Skryabina, *Supercond. Sci. Technol.* **37**(12), 125018 (2024).
4. S. V. Sotnichuk, *J. Mater. Chem. C* **13**, 4236 (2025).

52 Proximity effect in SSH-superconductor junction

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Abstract

The study of the properties of topological insulators remains an important task. The most interesting aspect is the existence of so-called edge states, which are localized on the surface of a topological insulator and decay into the interior of the sample. These states allow the sample to conduct electricity, despite the fact that the bulk spectrum of the material contains a forbidden band characteristic of an insulator. Of great interest are various contacts of topological insulators and, for example, superconductors. As a consequence, it is important to understand what happens to the topological properties of the insulator in such a situation. In particular, we are curious about whether the edge state continues to exist and how its energy changes. The simplest model of a topological insulator is a one-dimensional Su-Schrieffer-Heeger (SSH) chain [1]. It is a model of strong connection with jumps between the nearest neighbors, and the jumps alternate. Such a model exhibits the main properties of a topological insulator, namely: the presence of a forbidden zone in the bulk spectrum; the existence of an edge state with zero energy under a certain limitation on the magnitude of jumps. In particular, such a model describes the electronic subsystem of polyacetylene molecules. In this paper, we consider a model in which the SSH chain lies on a bulk superconductor with s-wave pairing. In such a model, tunnel interactions of two subsystems appear. The aim of the work was to study the influence of this interaction on the topological properties of the SSH chain. Using the functional integral method, we managed to obtain an effective theory that describes the dynamics of the chain. With its help, corrections to the bulk spectrum of quasiparticle excitations of the chain were calculated. As part of the study of the fate of the edge state, a shift in the energy of the edge state was obtained, caused by induced superconducting correlations from the superconductor.

References:

1. A. J. Heeger, S. Kivelson, J. R. Schrieffer and W. P. Su, Solitons in conducting polymers. Rev. Mod. Phys., 781-850, 1988. doi:10.1103/RevModPhys.60.781.

53 $0-\pi$ transition in planar Josephson S-N-S junction on a ferromagnetic insulator substrate

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Abstract

The work is devoted to experimental investigation of a planar Josephson junction with normal metal barrier on a ferromagnetic insulator substrate. According to theoretical predictions, such a system should, under certain conditions, undergo a transition from a 0 -state to a π -state. Several samples have been manufactured using Nb/Cu bilayer and YIG as a substrate (along with some reference samples on Si substrate) and measured at low temperatures, using BlueForce dilution refrigerator. IV measurements were conducted with varying temperature as well as with varying magnetic field and fixed temperature. Some of the $I_c(T)$ and $I_c(H)$ dependences are shown at Fig. 1. $I_c(T)$ dependences of some samples show features, that are characteristic for a π -transition, while absolute values of I_c differ from those of a conventional SNS for more than an order of magnitude, which indicates the influence of FI on the electronic transport properties of the junction.

Keywords: Josephson junction, π -transition, ferromagnetic insulator

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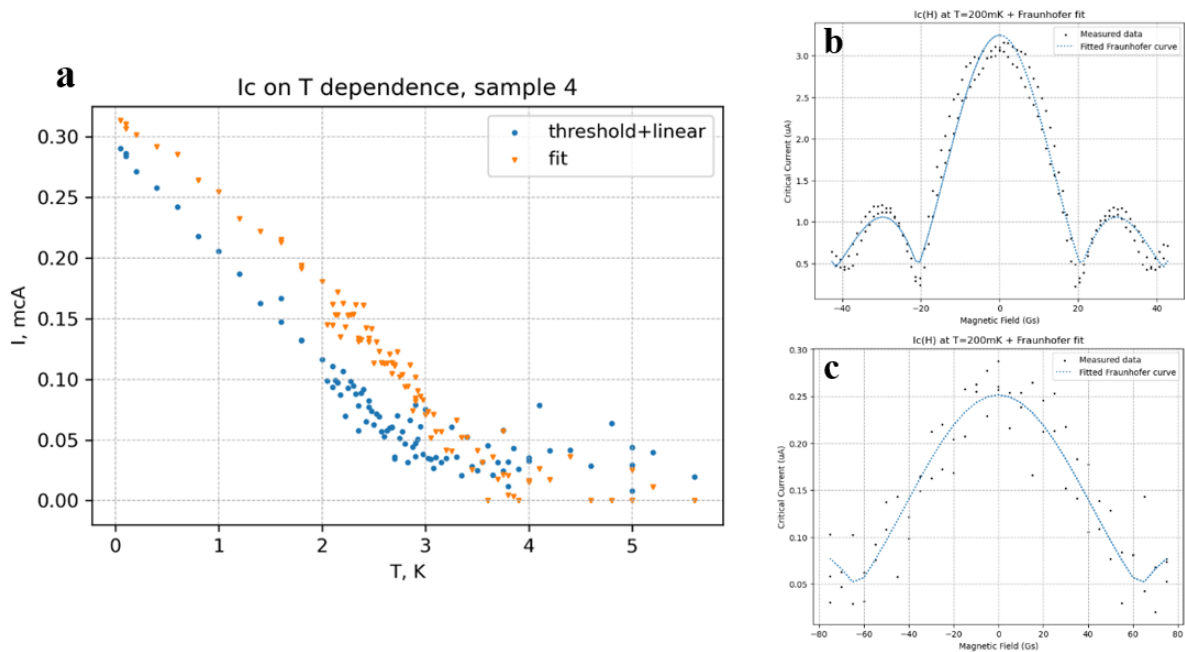


Figure 1: Measured $I_c(T)$ dependence (a) and $I_c(H)$ dependences for SNS junctions on Si (b) and YIG (c) substrates.

References:

1. V. V. Ryazanov, V. A. Oboznov, Phys. Rev. Lett. 86, 2427 (2001).
2. A. V. Ustinov, V. K. Kaplunenko, Journal of Applied Physics 94, 5405 (2003).

54 Spin-valve effect in ferromagnet/superconductor/ferromagnet van der Waals heterostructures

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Abstract

Quasi-2D and van der Waals ferromagnet/superconductor/ferromagnet metal F/S/F heterostructures are a promising platform for the realization of phenomena related to proximity effects, since in their case the interface area extends to the entire material. A number of studies have demonstrated that due to the small number of atomic layers in van der Waals S/F structures, the physics of the proximity effects is determined by the effects of hybridization of electronic bands of both materials [1,2]. It results in strong modification of proximity effects, including the superconductivity suppression, the singlet-triplet conversion and the zeeman splitting of the electronic density of states, and provides high controllability of these effects by gating.

The current work demonstrates that in a van der Waals F/S/F spin-valve structure consisting of a few atomic layers, it is possible to control the amplitude and the sign of the spin-valve effect by applying gate voltage. It is also shown that hybridization effects can serve as a mechanism for implementing a gate-controlled non-collinear spin-valve effect in the van der Waals F/S/F heterostructure.

Keywords: spin-valve effect, van der Waals materials, magnetic proximity effects

Acknowledgements: The work was supported by Grant from the ministry of science and higher education of the Russian Federation No. 075-15-2025-010 28.02.2025

References:

1. G. A. Bobkov et al., Phys. Rev. Materials 8, 104801 (2024).
2. A. S. Ianovskaia et al., Phys. Rev. B 110, 214503 (2024).

55 High Frequency Dynamic Response of Abrikosov Vortices: Time-Dependent Ginzburg-Landau Approach

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Abstract

We employ the time-dependent Ginzburg-Landau theory (TDGL) to describe the motion of an Abrikosov vortex in thin superconducting films driven by weak alternating current. Despite the known limitations of this model's validity range, it provides valuable insight into various dynamical phenomena in superconductors. Solving the TDGL equations within the perturbative scheme described in Ref. [1], we derive the equation for vortex line motion:

$$\left(\eta_{\text{Rel}} + \frac{2\ell_E^2}{R_V^2} \cdot \frac{1}{1 - i\omega\ell_E^2/D} \right) \mathbf{v}(\omega) = \frac{8eTD}{\sigma\pi\Delta_\infty^2} [\mathbf{j}_s(\omega), \mathbf{e}_z], \quad (1)$$

where $\eta_{\text{Rel}} \simeq 0.279$ is the relaxation contribution to the vortex viscosity, $R_V \sim \xi$ is the characteristic vortex radius and temperature-dependent coherence length, ℓ_E is the electric field penetration depth, D is the diffusion coefficient, $\mathbf{j}_s$ is the transport supercurrent, $\mathbf{v}$ is the vortex velocity, σ is the normal state conductivity, and Δ_∞ is the gap value far from the vortex core.

Analysis of this equation reveals several important conclusions:

1. Linear expansion of the kernel $(1 - i\omega\ell_E^2/D)^{-1}$ in powers of frequency leads to the appearance of an “effective negative mass” for the vortex, indicating that proper description of vortex dynamics requires consideration of the full kernel.
2. The kernel form demonstrates that vortex motion exhibits a retardation effect characterized by a relaxation time ℓ_E^2/D .
3. At high frequencies, the kernel contribution becomes inversely proportional to frequency. In the time domain, this term corresponds to an effective elastic force resulting from the back-action of the charge imbalance potential.

The presented approach provides an analytical description of relaxation processes in the viscous dynamics of a single vortex under weak alternating current and reveals important features of high-frequency impedance in superconducting systems.

Keywords: Time-dependent Ginzburg-Landau, non-stationary vortex motion, vortex dynamics, high-frequency response

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References:

1. N. B. Kopnin, *Theory of Nonequilibrium Superconductivity* (Oxford University Press, Oxford, 2001).

56 Photoinduced magnetic moment of the superconducting disk

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Abstract

In this work we calculate dc current and magnetic moment induced by the circularly polarized wave in a thin superconducting (SC) disk. Our calculations are based on the time-dependent Ginzburg-Landau equation with a complex relaxation constant which reflects the electron-hole asymmetry of the quasiparticle spectrum. The photoinduced dc current is known to be the second-order non-linear response of the superconducting condensate due to the presence of the electron-hole asymmetry and the generation of the charge imbalance potential (see [1], [2]). The key difference between this work and the previous study [1] of the dc photocurrent in a thin SC disk is the correct consideration of the charge imbalance potential. Circulating component of such a dc photocurrent creates the dc magnetic moment which is the manifestation of the inverse Faraday effect (see Pic.1). Radial component of the dc current which is calculated in this work is compensated by the inhomogeneous distribution of the zero-frequency superconducting phase which leads to the appearance of the phase difference between the center and the edge of the disk and gives rise for using such a SC system as the phase battery.

Keywords: inverse Faraday effect, time-dependent Ginzburg-Landau theory, phase battery

Acknowledgements: This work was supported by the Russian Science Foundation (Grant No. 25-12-00042) and by the Grant of the Ministry of science and higher education of the Russian Federation No. 075-15-2025-010.

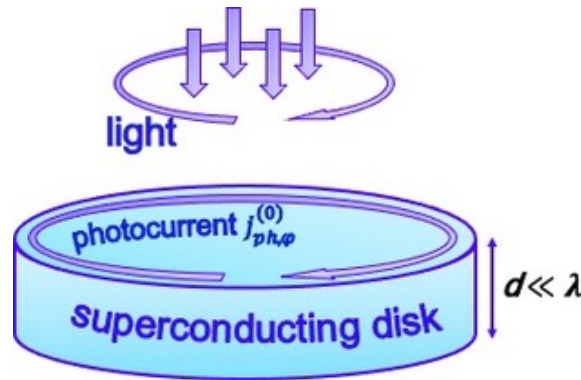


Figure 1: Illustration of the inverse Faraday effect in a thin superconducting disk. Circularly polarized wave induces circulating dc current inside the superconductor which creates the magnetic moment of the disk. Creation of such a dc magnetic moment by the circularly polarized wave is actually the manifestation of the inverse Faraday effect.

References:

1. Mironov S. V., Mel'nikov A. S., Tokman I. D. [et al.] Inverse Faraday effect for superconducting condensates. Phys. Rev. Lett. 2021. V. 126: 137002.
2. Mironov S. V., Mel'nikov A. S., Buzdin A.I ac Hall effect and photon drag of superconducting condensates. Phys. Rev. Lett. 2024. V. 132(9): 096001.

57 Peculiarities of the vortex dynamics in a narrow granular niobium bridge

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Abstract

We discovered that $V - I$ characteristics of a submicron-width granular Nb bridge exhibit sections with negative differential resistance (NDR). Investigation by atomic force and magnetic force microscopy (AFM/MFM) revealed the presence of large grains in the bridge, and the areas near them can be considered as weak spots for vortex penetration. Simulations using the time-dependent Ginzburg-Landau equation showed that even with one or two vortices present in the resistive state, specific vortex dynamics can occur, leading to the emergence of NDR and "plateaus" on $V - I$ characteristics.

Keywords: superconductivity, scanning probe microscopy, granular superconductor

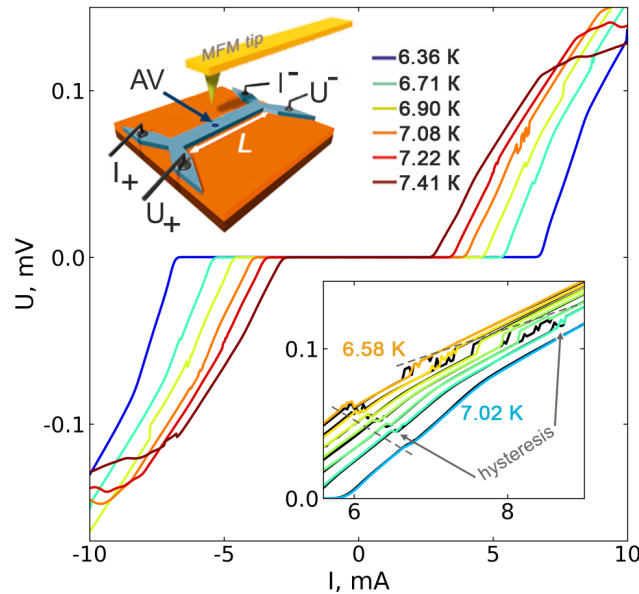


Figure 1: Experimental scheme and electronic transport measurements.

Acknowledgements: The research was supported by the Russian Science Foundation project No. 23-72-30004

References:

1. C. Reichhardt, C. J. Olson, and F. Nori, Phys. Rev. Lett. 78, 2648 (1997).
2. V. R. Misko, S. Savel'ev, A. L. Rakhmanov, and F. Nori, Phys. Rev. Lett. 96, 127004 (2006).
3. V. R. Misko, S. Savel'ev, A. L. Rakhmanov, and F. Nori, Phys. Rev. B 75, 024509 (2007).
4. J. Gutierrez, A. V. Silhanek, J. Van de Vondel, W. Gillijns, and V. V. Moshchalkov, Phys. Rev. B 80, 140514 (2009).
5. S. S. Ustavshikov et al., JETP Lett. 115, 626 (2022).
6. S. Kozlov, J. Lesueur, D. Roditchev, and C. Feillet-Palma, Commun. Phys. 7, 1 (2024).
7. S. Y. Grebenchuk, R. Cattaneo, and V. M. Krasnov, Phys. Rev. Appl. 17, 064032 (2022).
8. R. A. Hovhannisyan et al., Commun. Mater. (2025).

58 Optical and structural properties of niobium oxide nanostructures fabricated by femtosecond laser irradiation

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Abstract

Niobium oxides represent a class of promising functional materials, where the specific phase dictates its unique applications. Niobium pentoxide (Nb_2O_5) is particularly valued for its gasochromic properties — the ability to change its optical characteristics upon reduction in a hydrogen atmosphere ($\text{Nb}_2\text{O}_5 \rightarrow \text{Nb}_2\text{O}_{5-x}$). This makes it an excellent candidate for highly sensitive optical and electrical hydrogen sensors [1, 2]. A key factor in enhancing sensor performance is increasing the effective surface area of the gasochromic material. On the other hand, niobium dioxide (NbO_2) is critically important for electronic applications due to its metal-insulator transition and negative differential resistance [3, 4]. Unlike thermal oxidation or vacuum-deposited films, which typically yield planar oxide films, laser-induced oxidation allows for the single-step creation of complex, developed surface nanostructures, suitable for various applications. This work investigates the laser oxidation of thin niobium films (100 nm thick) deposited by magnetron sputtering. Oxidation was performed by a femtosecond laser (wavelength 525 nm, repetition rate 80 MHz, pulse duration 200 fs) irradiation focused into a 5 μm spot. The structural, optical, and electrical properties of the resulting layers were characterized by atomic force microscopy, scanning electron microscopy (SEM) and Raman spectroscopy. The experiments revealed a strong dependence of the modified layer height on the laser parameters. At a constant scan speed of 200 $\mu\text{m/s}$, increasing the pulse energy from 3.2 to 7 nJ resulted in growth of the laser-modified region height from 3 nm to 170 nm. A sharp, non-linear increase in height (up to 170 nm) was observed at a threshold energy of 4.6 nJ. Reducing the scan speed at a fixed power similarly led to a significant increase in the oxide thickness. Raman spectroscopy confirmed the formation of the NbO_2 phase, and SEM imaging revealed the formation of periodic surface nanostructures with a period of 410 nm. Local electrical measurements showed that the conductivity of the laser-oxidized regions is an order of magnitude lower than that of the pure metallic film. The results showed that laser oxidation is a powerful single-step technique for creating developed niobium oxide nanostructures with a high surface-to-volume ratio. The defined optimal laser parameters allow for significant oxide growth (>100 nm) without any substrate damage. These nanostructures are highly promising for developing sensitive elements of optical hydrogen sensors. The precise control over the oxide's electrical and topographic properties makes these structures attractive for applications in quantum photonic devices. Additionally, performing the laser oxidation in a controlled atmosphere (e.g., using a gas cell) could offer a way to precisely control the oxide phase, allowing to customize the material for different purposes.

Keywords: niobium oxides, laser oxidation, gasochromic materials

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References:

1. R. Ab Kadir et al., ACS Appl. Mater. Interfaces 7, 4751 (2015).
2. H.A. Komurcu et al., J. Mater. Sci.: Mater. Electron. 34, 922 (2023).
3. D. Music et al., Crystals 11, 217 (2021).
4. S. Kumar et al., Nat. Commun. 8, 658 (2017).

59 Magnetic Resonance Spectroscopy of Topological Insulator MnSb_2Te_4

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Abstract

Magnetic topological insulators (MTIs) are extensively studied nowadays [1, 2]. The topologically protected surface states in them hold promise for both fundamental science and practical applications. In this work magnetic resonance spectroscopy (Pic. 1) technique was used to investigate magnetic properties of four samples $\text{Mn}_{1+\delta}\text{Sb}_{2-\delta}\text{Te}_4$ (MST) with $|\delta| < 0.2$.

Magnetic properties of MST are strongly depended on the manganese concentration [3]. The type of magnetic order changes over a small variation of δ . In this work temperature dependences of magnetocrystalline anisotropy constant and gyromagnetic ratio were found.

Keywords: ferromagnetic resonance, magnetic topological insulator, magnetocrystalline anisotropy, gyromagnetic ratio

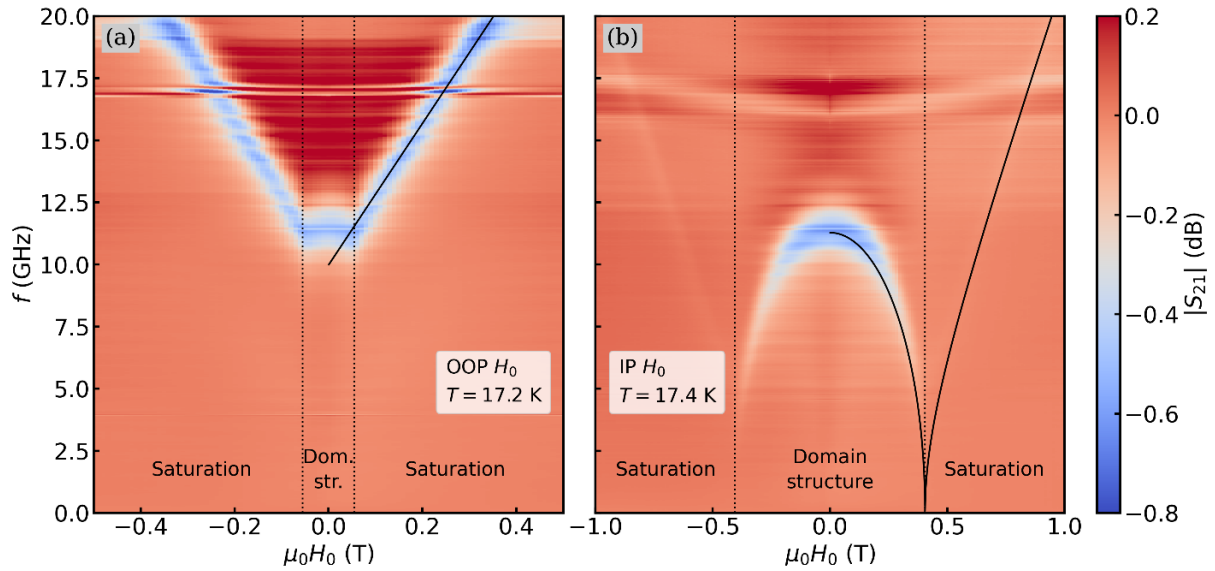


Figure 1: Absorption maps in frequency – field coordinates for MnSb_2Te_4 sample at temperature $T \simeq 17$ K and approximation of resonance by theoretical curves in out-of-plane (a) and in-plane (b) magnetic fields.

Acknowledgments: The work was supported by the RSF (No. 23-74-30004)

References:

1. A. Yu. Vyazovskaya et al., Comm. Mat. 6.1, 88 (2025).
2. J.-X. Qiu et al., Nature 1-8 (2025).
3. Y. Liu et al., Phys. Rev. X 11.2, 021033 (2021).

60 A modified Bridgman method for growing single crystals of magnetic topological insulators based on MnBi_2Te_4

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Abstract

Magnetic topological insulators (MTI) represent a new family of materials that combine topologically protected surface states and magnetic order in the crystal volume. Due to this unique combination, they are considered as a promising platform for the implementation of the quantum anomalous Hall effect, topological magnon excitations and new directions in spintronics [1,2]. Among MTI, special attention is paid to layered compounds based on MnBi_2Te_4 , in which the antiferromagnetic ordering is combined with the topological properties of the electronic spectrum. However, their practical use is significantly limited by the difficulties of synthesizing single crystals of sufficient size and high quality. Traditional methods, such as crystallization from a melt (solution in a melt) or chemical transport in the gas phase, lead to a product with limited dimensions not exceeding several mm, a high concentration of defects, as well as the presence of secondary phases (Bi_2Te_3 , MnTe , etc.), which reduces reproducibility and complicates the interpretation of physical properties [3,4]. The Bridgman directed crystallization method has proven to be one of the most effective approaches for obtaining single crystals of layered chalcogenides. Unlike other methods, it allows you to control the speed of the crystallization front and the temperature gradient, which significantly reduces the formation of structural defects and cracks. In addition, its classic version involves the use of sealed containers, which is important in the synthesis of volatile and highly reactive compounds. The main problem in the synthesis of crystals of the $\text{MnTe-Bi}_2\text{Te}_3$ system and related phases is their peritectic melting pattern and extremely narrow primary crystallization region. The application of the modified Bridgman method to the Mn-Bi-Te system ensures the growth of MnBi_2Te_4 single crystals with large lateral dimensions (up to several millimeters in thickness and centimeters in length) and a high degree of crystallinity, which is especially important for studies of transport properties and topological surface states [5]. In addition, the Bridgman method provides the possibility of purposefully obtaining solid solutions based on MnBi_2Te_4 by varying the composition of the initial source. This opens the way to systematic studies of substitutive compounds such as $(\text{Mn}_{1-x}\text{Ge}_x)(\text{Bi}_{1-y}\text{Sb}_y)_2\text{Te}_4$, which are of interest for tuning both the magnetic and topological properties of the material. The report will cover the physical and chemical bases of crystallization of compounds based on MnTe and Bi_2Te_3 . The possibilities of targeted synthesis of crystals of a given composition with the general formula $(\text{Mn}_{1-x}\text{Ge}_x)(\text{Bi}_{1-y}\text{Sb}_y)_2\text{Te}_4$ will be discussed. The results of a study of the physical properties of grown crystals will be presented.

Acknowledgments: The work was supported by the RSF (No. 22-72-10074-P)

References:

1. Tokura Y., Yasuda K., Tsukazaki A. Nat. Rev. Phys. 1, 126–143 (2019).
2. Otrokov M. M. et al. Nature 576, 416–422 (2019).
3. Lee D. S. et al. CrystEngComm 15, 5532–5538 (2013).
4. Zeugner A. et al. Chem. Mater. 31, 2795–2806 (2019).
5. Anton I. Sergeev et al. Materials Chemistry and Physics. 344, 131160 (2025).

61 Reconstruction of the spatial and temperature dependence of the superconducting gap from scanning tunneling spectroscopy data

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Abstract

The work considers an algorithm for reconstructing the spatial and temperature dependence of the energy gap in a superconducting sample based on scanning tunneling spectroscopy data. The experiment was carried out using a superconducting tip with unknown characteristics. To address the problem of separating the superconducting contributions of the tip and the sample in the observed spectra, various theoretical models were examined, the model that best describes the experiment was identified, and a numerical analysis of the experimental data was performed. The proposed method will be applied to the study of spatially inhomogeneous superconducting states in a granular niobium film.

Keywords: scanning tunneling spectroscopy, superconductivity, superconducting energy gap, spatially inhomogeneous superconducting states

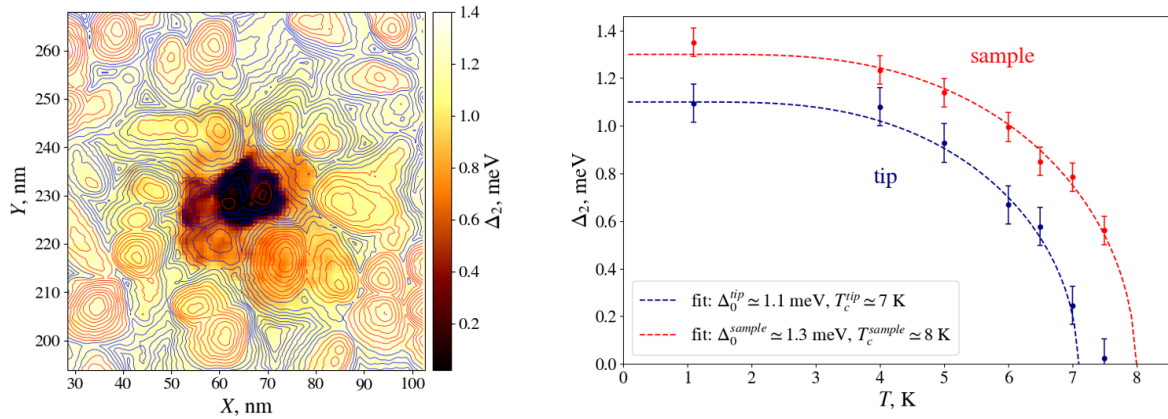


Figure 1: Spatial dependence of the reconstructed gap values at $T = 1.1$ K, $H = 0.25$ T (left, showing a 75 nm × 75 nm region), and temperature dependence of the reconstructed gap values together with the optimal curves corresponding to the BCS model temperature dependence of the gap (right). The method used is minimization of the residual over a given class of functions.

References:

1. A. A. Abrikosov, Fundamentals of the Theory of Metals (Fizmatlit, Moscow, 2009).
2. R. C. Dynes, V. Narayanamurti, J. P. Garno, Phys. Rev. Lett. 41, 1509 (1978).
3. Ya. V. Fominov, M. Houzet, L. I. Glazman, Phys. Rev. B 84, 224517 (2011).

62 Study of multilayer SRRs as Magnetic-memory inductance in superconducting circuits

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Abstract

One of the main limitations of classical passive superconducting elements (for example, resonators and filters) is their fixed operating frequency and quality factor after manufacture. Tunable linear elements are critically needed for modern applications to dynamically control resonant characteristics.

In this work, a theoretical and experimental study of multilayer split-ring resonators (SRRs) with a hybrid (superconductor/ferromagnetic) structure is carried out to create broadband and low-loss tunable elements controlled by an external magnetic field. Unlike traditional multilayer S/F/S/F/S structures, in this work, samples with an additional normal metal layer of aluminum (Al) integrated into the heterostructure are studied. It is assumed that this layer, due to the strong superconducting proximity effect from neighboring layers, can significantly increase the difference of SRR inductance between open and closed states, which is due to high conductance of Al [1].

As a result of this work, it was experimentally demonstrated that the resonant frequency of the SRR varies depending on the open or closed state of the spin valve. Due to the observed hysteresis behavior, both states can be obtained in a zero magnetic field, which opens up the possibility of using this structure as a memory element. From the study of structures with and without a layer of normal metal, it was found that the addition of normal metal leads to enhancement of the desired effect. In addition, a theoretical model has been proposed that successfully describes experimental data.

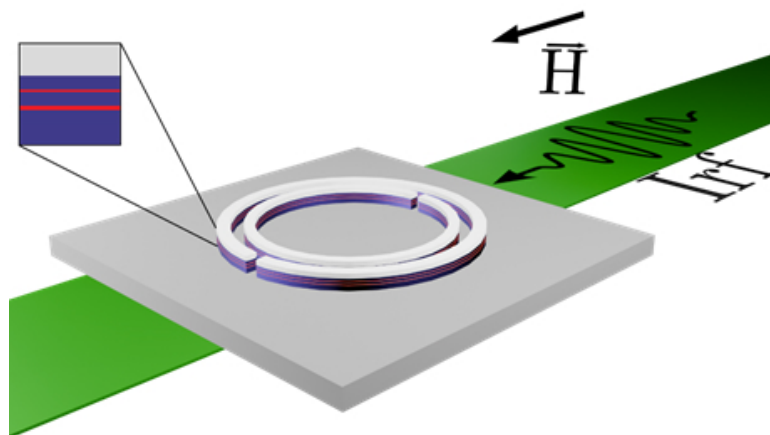


Figure 1: The scheme of the SRR research experiment. The layers that make up the SRR are shown on the top left. Blue is Nb (20, 8, 8 nm), red is a thin ferromagnetic layer of Co (2.5 and 1.5 nm), gray is a layer of normal metal Al (20 nm).

Keywords: split-ring resonators, superconducting circuits, magnetic memory, proximity effect, tunable elements

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References:

1. Schegolev A. E., Klenov N. V., Bakurskiy S. V., Soloviev I. I., Kupriyanov M. Y., Tereshonok M., Sidorenko A. S. Tunable superconducting neurons for networks based on radial basis functions. *Beilstein Journal of Nanotechnology* 2022, 13, 444–454. DOI:10.3762/bjnano.13.37.

63 Quantum enhanced magnetometry on a transmon qutrit based on phase estimation algorithm

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Abstract

Phase estimation algorithms are among the most important protocols in quantum information science, offering precise and efficient methods for extracting phase information from quantum states. These protocols are essential for the advancement of quantum sensing technologies, enabling measurement precision that surpasses classical shot-noise limit and approaches the fundamental Heisenberg limit. In this study, we present a thorough comparative analysis of a transmon-based magnetic field quantum sensor utilizing phase estimation algorithms and operated in both qubit and qutrit regimes. Theoretical analysis under ideal, noise-free conditions indicates that both regimes can, in principle, reach the Heisenberg limit; however, operation in the qutrit regime affords a twofold improvement in the measurement precision prefactor compared to the qubit regime. In realistic experimental scenarios, however, external noise sources degrade the achievable precision and can significantly diminish the advantage offered by higher-dimensional regimes. In this work, we experimentally compare the performance of phase estimation algorithms – Kitaev algorithm, the semiclassical Fourier transform, and LAMA—operating in both qubit and qutrit regimes. Our results demonstrate that three-level (qutrit) sensors outperform two-level (qubit) sensors in magnetic field sensing, even under noise conditions. Moreover, we show that LAMA outperforms both Kitaev’s algorithm and the semiclassical Fourier transform in phase estimation efficiency. This superior performance arises from LAMA’s use of linearly scaled Ramsey delay intervals, enabling operation at shorter delays while exploiting higher-contrast regions of the interference pattern to enhance phase sensitivity. Additionally, LAMA allows for a greater number of measurement steps within a fixed total measurement time, further improving the overall precision. Collectively, these findings underscore the significant potential of qutrit-based sensors and advanced phase estimation protocols for practical quantum metrology applications.

Keywords: transmon, qutrit, magnetometry, Heisenberg limit

References:

1. Danilin, Sergey; Lebedev, Andrey; Vepsalainen, Antti; Lesovik, Gordey; Blatter, G.; Paraoanu, G. (2018). npj Quantum Information. 4. 10.1038/s41534-018-0078-y.
2. Perelshtein, M. R., Kirsanov, N. S., Zemlyanov, V. V., Lebedev, A. V., Blatter, G., Vinokur, V. M., Lesovik, G. B. (2021). Linear ascending metrological algorithm. Physical Review Research, 3(1), 013257.

64 Non-stationary theory of charge transport based on many-body wavefunction theory and its application to SIS-junctions

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Abstract

SIS junctions are of great practical interest in a wide variety of fields: superconducting quantum computing, magnetic flux detectors, and light detectors. In the latter field, the practical use of such structures is already commonplace. SIS junctions are used to create a heterodyne receiver: when light, even of very low intensity, falls on a contact biased into the so-called “first step” regime, and an AC voltage generator is present in the circuit, the junction produces a nonlinear response in the form of a current at the difference frequency between the light and the generator. This method of radiation analysis in radio astronomy still remains one of the most accurate and sensitive to this day [1].

In fact, to create a heterodyne receiver, a superconducting tunnel junction is not strictly necessary: any circuit element with a nonlinear response to incident radiation will suffice. The theory describing the “pumping” of SIS junctions by radiation was proposed back in 1979 [2] and is still considered fundamental in the field (it is referred to as “Tucker’s Theory” or the “Linear Response Theory”). Despite its extreme practical effectiveness, it does have certain issues. In [2] and earlier works, the author employs perturbation theory with the Bardeen tunneling Hamiltonian to first order in order to derive expressions for the components of the “pumped current” (in the interaction representation):

$$i\hbar \frac{dU_I}{dt} = H_T U_I \quad (2)$$

$$U_I = 1 - \frac{i}{\hbar} \int_{-\infty}^t e^{\delta t} H_T(t') dt' \quad (3)$$

Where, in the last expression, the limit $\delta \rightarrow 0$ is taken. In quantum field theory and the theory of nonequilibrium processes in quantum systems, this is referred to as the “adiabatic limit,” which in fact reflects the assumption that the system is in equilibrium at infinity. This is not a particularly natural way to introduce irreversibility into the equations, and moreover, it is not always valid for nonequilibrium systems. In addition, such an approach may not be suitable for the analysis of cases where the tunneling amplitudes in Bardeen’s Hamiltonian themselves depend on time. Furthermore, since in [2] the author works only with current operators, the analysis of quantum noise is also somewhat limited.

We propose an alternative, non-perturbative theory of SIS-junction pumping, based on the method of the many-body quasiparticle wavefunction of the SIS junction, which traces back to the ideas of Gurvitz [3]. We generalize the derivation of master equations to cases where the potential on the contact depends periodically on time—something that has not been done previously within this formalism (earlier work only considered time-dependent energy levels in quantum dots [4]). In fact, this method can be applied to any many-body fermionic system. As a result, in the Markovian approximation, we obtain:

$$\frac{d\sigma^n}{dt} = \left(\sum_{N=-\infty}^{\infty} \text{Re}(\Gamma_{N\hbar\omega}) \cos(N\omega t) + \text{Im}(\Gamma_{N\hbar\omega}) \sin(N\omega t) \right) (\sigma^{n-1} - \sigma^n), \quad (4)$$

where

$$\Gamma_{N\hbar\omega} = \sum_{M=-\infty}^{\infty} J_M (-1)^M J_{N-M} (\Gamma(V_0 + M\hbar\omega) + i\Gamma_{KK}(V_0 + M\hbar\omega)) \quad (5)$$

$\Gamma(V)$ is the level width in the contact at constant bias, proportional to the current, $\Gamma_{KK}(V)$ the Kramers–Kronig transform of the widths, corresponding to the reactive part of the contact’s response to the voltage, ω the frequency of the incident light, $\sigma^n(t)$ the probability that n particles have tunneled to the right lead by time t , and V_0 the initial bias on the contact. The obtained expressions for the current are in complete agreement with the results of Tucker’s Theory. Within this formalism,

one can formally derive various current statistics, for example by using MacDonald's formula [5] for the power spectrum of a stationary process (our process is quasi-stationary due to periodicity, which can be accounted for by a renormalizing exponential):

$$\frac{S(\omega)}{2e^2} = \omega \int_0^{+\infty} \sum_{n=0}^{+\infty} n^2 \frac{d\sigma^n}{dt} \sin(\omega t) dt, \quad (6)$$

Moreover, this approach makes it possible to non-perturbatively analyze the case where the Bardeen coefficients themselves depend periodically on time, enabling a non-phenomenological treatment of the interaction between radiation and an SIS junction, in contrast to the traditionally used perturbation theory, e.g., in [6]. The master equation formalism also allows us to consider initially nonequilibrium distributions in the contact by adding inhomogeneous terms to the chain of equations (3).

Keywords: many-body wavefunction formalism, quantum charge transport, SIS heterodyne receiver, master equation, perturbation theory

References:

1. Wengler, Michael. Submillimeter-Wave Detection with Superconducting Tunnel Diodes. *Proceedings of the IEEE* 80, 1810–1826 (1992). DOI:10.1109/5.175257.
2. Tucker, John R. and Marc J. Feldman. Quantum detection at millimeter wavelengths. *Reviews of Modern Physics* 57, 1055–1113 (1985).
3. Gurvitz, S. Rate equations for quantum transport in multidot systems. *Physical Review B* 57, 6602–6611 (1997).
4. Gurvitz, Shmuel. Single-electron approach for time-dependent electron transport. *Physica Scripta* T165, 014013 (2015). DOI:10.1088/0031-8949/2015/T165/014013.
5. MacDonald, D. K. C. *Noise and Fluctuations: An Introduction*. (John Wiley and Sons, New York, 1962).
6. Davids, Paul and Shank, Joshua. Density matrix approach to photon-assisted tunneling in the transfer Hamiltonian formalism. *Physical Review B* 97, 075411 (2017). DOI:10.1103/PhysRevB.97.075411.

65 High-Precision State Discrimination of a Transmon Qutrit Using a Feedforward Neural Network

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Abstract

Reducing qubit state readout errors is one of the key challenges on the path to realizing quantum computers. As the number of qubits grows, classical readout methods become inefficient and, moreover, are inapplicable to higher-dimensional systems such as qutrits or qudits. In particular, accurate qutrit state readout is critical for quantum magnetometry tasks, where the sensor's precision directly depends on measurement accuracy.

In this work, we propose the use of a feedforward neural network (FNN) for classification of the transmon qutrit state. This approach offers several advantages over other methods, such as support vector machines (SVM) and their nonlinear variants (NSVM). Unlike SVMs, which require full retraining each time the system is recalibrated, FNNs support transfer learning, significantly accelerating the network adaptation process upon system parameter changes. Furthermore, FNNs demonstrate superior performance in classifying multilevel systems like qutrits and exhibit high scalability.

The neural network was implemented and trained using the PyTorch library. The developed FNN takes as input the in-phase and quadrature components (I and Q) of the two-tone signal obtained during qutrit state measurement (I1[n], Q1[n], I2[n], Q2[n]). The network architecture consists of two hidden layers with 16 and 8 nodes respectively, employing the SELU (Scaled Exponential Linear Unit) activation function. The output layer contains three nodes with a softmax activation function, representing the probabilities of the qutrit being in states $|0\rangle$, $|1\rangle$, and $|2\rangle$. Training was performed using the Adam optimizer with a learning rate of 0.0005 and the cross-entropy loss function. The dataset comprised 8000 training and 2000 validation samples. Training lasted for 300 epochs with a batch size of 64.

The training results show that the achieved accuracy of qutrit state discrimination is 90.2%. Additionally, the use of the FNN demonstrates greater robustness to fluctuations in qutrit parameters compared to classical methods. This feature is especially important for quantum magnetometry, where the qutrit is detuned from its "sweet spot" to enhance sensitivity to magnetic flux, which also causes frequency jitter.

Thus, the proposed approach shows potential for significantly improving measurement accuracy in quantum magnetometry tasks and can be adapted for other applications involving multilevel quantum systems.

Keywords: transmon, qutrit, fnn, readout

References:

1. Lienhard, Benjamin, et al. Deep-neural-network discrimination of multiplexed superconducting-qubit states. *Physical Review Applied* 17.1 (2022): 014024.
2. Shlyakhov, A. R., et al. Quantum metrology with a transmon qutrit. *Physical Review A* 97.2 (2018): 022115.
3. Chen, Liangyu, et al. Transmon qubit readout fidelity at the threshold for quantum error correction without a quantum-limited amplifier. *npj Quantum Information* 9.1 (2023): 26.

66 Superconducting photocurrents induced by structured electromagnetic radiation

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Abstract

We develop a phenomenological description of how a Bessel (twisted-light) beam drives dissipationless photocurrents and magnetic fields in a superconductor. Within the time-dependent Ginzburg – Landau framework with a complex relaxation constant, we compute the spatial patterns of the rectified (dc) response together with the second-harmonic signal. The photocurrent is controlled jointly by its orbital angular momentum and by the light's helicity, which enables symmetry-selective current patterns in both half-space and thin-film geometries. Rectification stems from a charge-imbalance potential induced by the ac field; its coupling to the condensate dynamics generates the second-order response that can persist after the pulse. We provide closed-form expressions and numerical profiles for the currents and the corresponding magnetic fields.

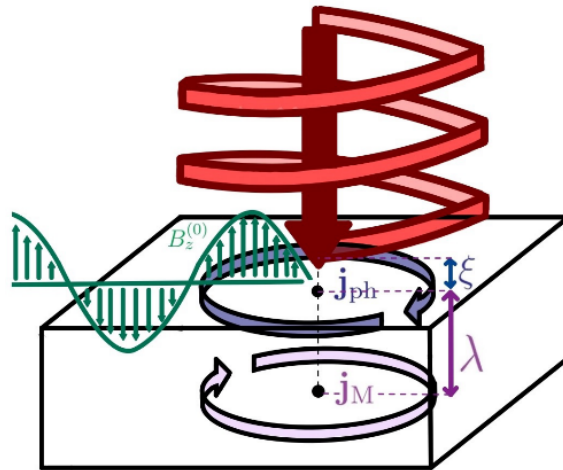


Figure 1: A Bessel (twisted-light) beam drives a rectified photocurrent in a shallow surface layer, while a compensating Meissner current flows deeper, keeping the interior free of magnetic field. The field pattern at the surface is tunable by the beam's orbital momentum and polarization.

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References:

1. Zhou Y.; Wang Z.; Gao F. et al. ACS Nano. 2012; 6: 9727.
2. Jia, L.; Chen, Y.; Zhang, Y. et al. Nano lett. 2024, 24: 8843.
3. Jia, L.; Zhang, C.; Zhang, Y. et al. Chin. Phys. Lett. 2025, 42: 080712.

67 Spin Waves in Easy-Plane Canted Antiferromagnets

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Abstract

The study of spin waves (SWs) is of great interest from the point of view of creating next-generation information transmission and storage devices [1]. In particular, the propagation of spin waves in antiferromagnets (AFMs) is of significant attention. The advantages of antiferromagnets over ferromagnets include, for example, terahertz frequencies and wide possibilities for tuning frequencies [2]. To improve the functionality of next-generation devices, it is also important to provide directional control of signal processing. Here we study the types of spin waves, traveling through the canted antiferromagnets in magneto-static approximation, following the work [4], where the spin waves in antiferromagnets without Dzyaloshinskii–Moriya interaction (DMI) and external permanent magnetic field were studied. We consider antiferromagnets, schematically shown in Fig. 1. The Fig. 1 shows two possible modes of SW propagating in the AFM, which differ in the motion of the ferromagnetic order (net magnetization) $\mathbf{m} = (\mathbf{M}_1 + \mathbf{M}_2)/(2M_s)$, where M_s is a saturation magnetization. The net magnetizations in different x positions for quasi-ferromagnetic and quasi-antiferromagnetic modes are shown with blue and red arrows, respectively.

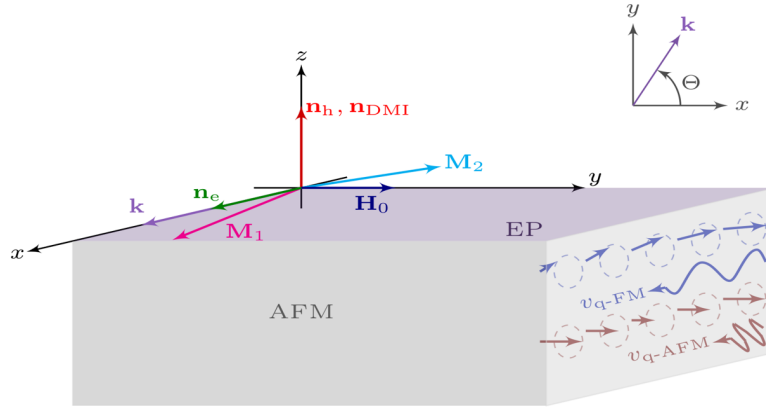


Figure 1: The scheme of the studied antiferromagnetic structure with directions of magnetization vectors $\mathbf{M}_1$ and $\mathbf{M}_2$; hard and easy axes and DMI vectors $\mathbf{n}_{h,e,DMI}$; external magnetic field $\mathbf{H}_0$ and wave vector $\mathbf{k}$. Easy plane (EP) is in the plane of the sample. There are two possible modes of spin waves (quasi-ferromagnetic q-FM and quasi-antiferromagnetic q-AFM) propagating through the canted easy-plane antiferromagnet (AFM).

We start our analysis with the σ -model [3] for the antiferromagnet moment $\mathbf{l} = (\mathbf{M}_1 - \mathbf{M}_2)/(2M_s)$,

$$\mathbf{l} \times \left[\frac{d^2 \mathbf{l}}{dt^2} + \alpha_G \omega_{ex} \frac{d\mathbf{l}}{dt} - 2\gamma \left[\frac{d\mathbf{l}}{dt}, \mathbf{H}_{eff} \right] - \gamma \left[1, \frac{d\mathbf{H}_{eff}}{dt} \right] - \omega_{ex} c^2 \Delta \mathbf{l} + \frac{\partial W_0}{\partial \mathbf{l}} \right] = 0,$$

The linearization process results in the following system

$$\mathbf{H}_{eff} = \mathbf{H}_0 + \mathbf{H}_4 + [\mathbf{H}_{DMI}, \mathbf{l}],$$

$$W_0 = -\frac{\omega_e \omega_{ex}}{6} (\mathbf{l} \cdot \mathbf{n}_e)^6 + \frac{\omega_h \omega_{ex}}{2} (\mathbf{l} \cdot \mathbf{n}_h)^2 + \frac{\gamma^2}{2} ((\mathbf{H}_0 + \mathbf{H}_4) \cdot \mathbf{l})^2 + \frac{\gamma^2}{2} (\mathbf{H}_{DMI} \cdot \mathbf{l})^2 + \gamma^2 \mathbf{l} \cdot [\mathbf{H}_{DMI} \times (\mathbf{H}_0 + \mathbf{H}_4)].$$

$$\begin{cases} \delta l_z (\omega^2 - \omega_{q-AFM}^2 - i\alpha_G \omega \omega_{ex} - \omega_{ex} \omega_s (\bar{k}_x^2 + \bar{k}_y^2 + \tilde{q}^2)) - \psi \omega_s \tilde{k}_y &= 0, \\ \delta l_y (\omega^2 - \omega_{q-FM}^2 - i\alpha_G \omega \omega_{ex} - \omega_{ex} \omega_s (\bar{k}_x^2 + \bar{k}_y^2 + \tilde{q}^2)) + \psi \omega_s (\bar{q} \omega + i\tilde{k}_x (\omega_0 + \omega_{DMI})) &= 0, \\ \delta l_y \varepsilon (\bar{q} \omega - i\tilde{k}_x (\omega_0 + \omega_{DMI})) - \delta l_z \varepsilon \tilde{k}_y \omega + \psi \omega_s (\bar{k}_x^2 + (1 + \varepsilon) (\bar{k}_y^2 + \tilde{q}^2)) &= 0. \end{cases}$$

Solving this system for q and analyzing its real and imaginary parts, we obtain the results shown in Fig. 2.

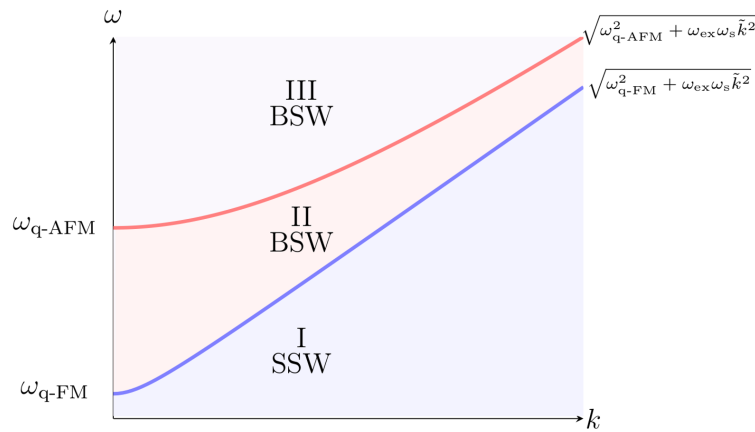


Figure 2: Obtained results of the spin waves types (bulk spin waves BSW and surface spin waves SSW) for hematite.

Keywords: spin waves, antiferromagnets, easy-plane, canted AFM, Dzyaloshinskii–Moriya interaction

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References:

1. El Kanj A. et al. Sci. Adv. **9**, eadh1601 (2023).
2. Kimel, A. V. et al. Nature **429**, 850–853 (2004).
3. Khymyn R. et al. Sci. Rep. **7**, 43705 (2017).
4. Ivanov B.A. et al. Physics of Solid State **27**, 173-180 (1985) (In Russian)

68 Influence of unidirectional and uniaxial anisotropy in Pt/Co/FeMn/Pt heterostructures on the antiferromagnetic layer thickness

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Abstract

The control of magnetization and exchange bias in antiferromagnet (AFM)/ferromagnet (FM) heterostructures has been identified as a promising approach for enhancing the performance of various spintronic devices, such as magnetic tunnel junctions and magnetoresistance sensors. The in-plane exchange field at the AFM/FM interface enables field-free switching of perpendicular magnetization that the potential for faster switching speeds, leading to quicker data writing [1]. Exchange bias, also known as unidirectional anisotropy, occurs when an antiferromagnetic layer is present at the interface with a ferromagnetic layer, resulting in a shift of the ferromagnetic film's magnetization curve. This effect is typically characterized by the displacement of the center of the macroscopic magnetic hysteresis loop, $M(H)$ (which represents the magnetization of the sample as a function of the applied magnetic field), away from the origin along the magnetic field axis [2]. The exploration of layered AFM/FM heterostructures has unveiled promising opportunities for their application in amplifying spin currents through the inverse spin Hall effect (ISHE) [3, 4]. This advancement highlights the significant potential of AFM/FM systems in the rapidly growing field of spintronics. This study combines theoretical and experimental approaches to investigate the angular characteristics of Pt/Co/FeMn/Pt heterostructures (Fig1(a)) with varying antiferromagnetic layer thicknesses, aiming to understand the mechanisms of exchange bias and its influence on spin current generation and manipulation.

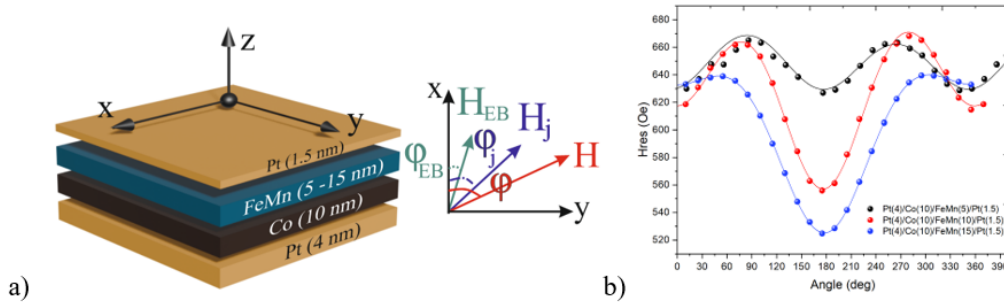


Figure 1: a) Geometry of the structure with axes and angles φ , φ_j , φ_u from the x-axis to the corresponding field; b) Angular dependences of the resonance field of Pt/Co/FeMn/Pt heterostructures at different angles of the external magnetic field with different thicknesses of the antiferromagnetic layer.

To study the unidirectional anisotropy in FM/AFM structures, a series of Pt/Co/FeMn/Pt structures were grown by magnetron sputtering. The structures were annealed in a magnetic field, producing uniaxial anisotropy in ferromagnets and antiferromagnets. The exchange coupling between the layers created an exchange bias. The method for determining the parameters of the magnetic anisotropy consists in processing the angular dependencies of the resonant fields of the FMR spectra. The solution of the Landau-Lifshitz equation for the evolution of the magnetization $\mathbf{M}$ under the action of the magnetic component of the radio-frequency field is used [5], which gives an analytic relation for the resonance field $\mathbf{H}$ and the frequency ω :

$$\left(\frac{\omega_{res}}{\gamma}\right)^2 = (H \cos(\varphi) + H_j \cos(\varphi_j) + 4\pi M_f + H_u \cos^2(\varphi_u)) \cdot (H \cos(\varphi) + H_j \cos(\varphi_j) + H_u \cos(2\varphi_u)),$$

where M_f is the saturation magnetization of the ferromagnetic layer, H_u is the magnitude of the field of uniaxial in-plane anisotropy, H_j is the magnitude of the unidirectional magnetic anisotropy field, φ_j the

azimuthal angle between the x-axis and the unidirectional anisotropy vector, φ_u is the angle between the x-axis and the uniaxial in-plane anisotropy axis. Equation (1) is a quadratic equation with respect to the magnitude of the resonant field $\mathbf{H}$. While this type of equation yields two solutions, we focused only on the one where $\mathbf{H}$ is non-negative.

Table 1: Magnetic parameters of the heterostructures Pt/Co/FeMn/Pt, obtained from angle dependency of resonance field (1) with the frequency.

The AFM/FM heterostructures (nm)	M_f , Oe	H_u , Oe	H_j , Oe	φ_u , deg	φ_j , deg
Pt(4)/Co(10)/FeMn(5)/Pt(1.5)	1374.1±2.6	17.8±0.3	0	4.3±0.8	0
Pt(4)/Co(10)/FeMn(10)/Pt(1.5)	1425±1.5	38.1±0.2	30.3±0.8	2.5±0.6	8.6±1.1
Pt(4)/Co(10)/FeMn(15)/Pt(1.5)	1485.3±2.5	22.7±0.2	53.1±0.8	2.4±0.6	3.2±1.1

The results obtained by processing the data presented in Figure 1 using the resonance coupling formula are presented in Table 1. Table 1 shows the parameters of the uniaxial and unidirectional anisotropy of the Co film in the Pt/Co/FeMn/Pt heterostructure from the thickness of the FeMn antiferromagnetic layer. It is evident that upon reaching a certain thickness of the antiferromagnetic layer, the value of the unidirectional anisotropy begins to increase, which generally agrees with the literature data indicating that in AFM/FM heterostructures there is an optimal thickness of the antiferromagnetic layer at which the maximum of unidirectional anisotropy is observed (Table 1) [6]. However, in addition to this effect, we observe suppression of uniaxial anisotropy in Co with an increase in unidirectional anisotropy. The reasons for the occurrence of this effect may be the strengthening of the exchange interaction between the ferromagnetic layer and the antiferromagnetic layer, which in turn should affect the generation of spin current in this heterostructure (Table 1).

Keywords: exchange bias, unidirectional anisotropy, uniaxial anisotropy, AFM/FM heterostructures, spin currents

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References:

1. B. Dieny, V. S. Speriosu, S. S. P. Parkin, B. A. Gurney, D. R. Wilhoit, and D. Mauri, Giant magnetoresistive in soft ferromagnetic multilayers, *Phys. Rev. B* **43**, 1297 (1991).
2. J. Nogues and I. K. Shuller, Exchange bias, *J. Magn. Magn. Mater.* **192**, 203-232 (1999).
3. C. Hahn, G. de Loubens, V. V. Naletov, J. B. Youssef, O. Klein, and M. Viret, Conduction of spin currents through insulating antiferromagnetic oxides, *Europhys. Lett.* **108**, 57005 (2014).
4. A. L. Khoroshilov, A. V. Bogach, S. V. Demishev, K. M. Kraskov, S. E. Polovets, N. Yu. Shiisevalova, V. B. Filipov, and N. E. Sluchanko, Hall Effect in the Antiferromagnetic State of $\text{Ho}_{0.8}\text{Lu}_{0.2}\text{B}_{12}$, *JETP Lett.* **115**, 130-135 (2022).
5. V. V. Demidov, G. A. Ovsyannikov, A. M. Petrzhik, I. V. Borisenko, A. V. Shadrin and R. Gunnarsson *J. Appl. Phys.* **113** 163909 (2013).
6. R. Jungblut, R. Coehoorn, M.T. Johnson, Ch. Sauer, P.J. van der Zaag, A.R. Ball, Th.G.S.M. Rijks, J. aan de Stegge, A. Reinders, Exchange biasing in MBE-grown $\text{Ni}_{80}\text{Fe}_{20}/\text{Fe}_{50}\text{Mn}_{50}$ bilayers, *JMMM*, **148**, 300-306 (1995).

69 Experimental implementation of elements of superconducting bio-like neurons based on Nb/Au/Nb Josephson junctions

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Abstract

The development of neural networks based on biosimilar spiking neurons represents a leading frontier in artificial intelligence research. These networks are expected to offer superior capabilities for parallel information processing and enhanced adaptability to dynamic environments. However, a key challenge remains: the fundamental components required for the fastest and most energy-efficient Josephson-based implementations currently possess excessively large planar dimensions, limiting the scalability of such systems. In this study, we explore the practical feasibility of implementing Josephson junctions with a weak normal (SNS) region—an approach that may overcome the existing barriers to miniaturizing Josephson biosimilar neurons [1, 2]. Josephson SNS contacts Nb/Au/Nb and a two-contact SQUID were manufactured. Experimental measurements were conducted using a dilution refrigerator capable of reaching temperatures as low as 0.2 K. The samples were connected via a four-terminal DC circuit (see Fig. 1a). We investigated the current-voltage characteristics of the samples across a range of temperatures up to the critical temperature $T_c = 9.2$ K, and in magnetic fields of up to 3.57. The SQUID parameters were also investigated by applying a bias current (see Fig. 1b).

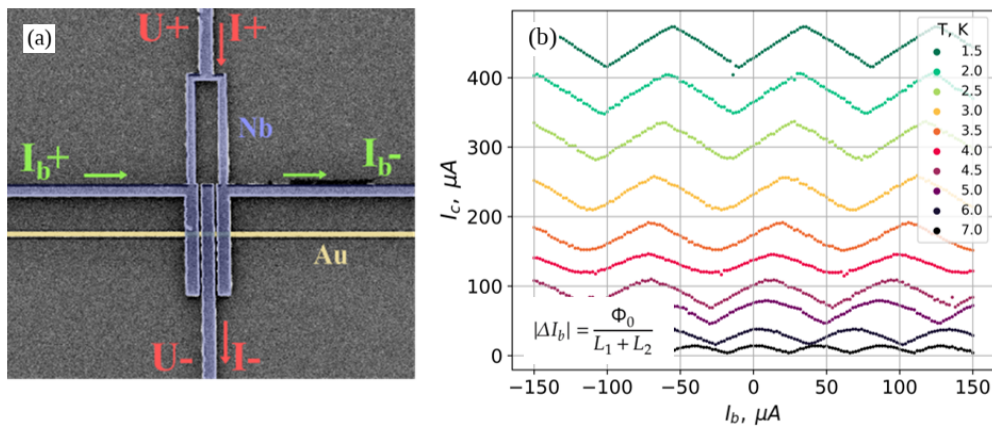


Figure 1: Two-contact SQUID: (a) – photo taken with SEM; (b) – the dependence of the critical current on the flux induced by the bias current $I_c(I_b)$.

Keywords: SNS-junctions, RSFQ, neuromorphic computing

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References:

1. Schegolev, A., Klenov, N., Gubochkin, G., Kupriyanov, M., Soloviev, I.I., Nanomaterials, **13**(14) 2101 (2023).
2. Gubochkin G.I., Elistratova A.A., Shishkin A.G., Sidelnikov M.S., Klenov N.V., Stolyarov V.S., Radiotekhnika i elektronika, Vol 70, No 2 (2025)

70 Surface spin-flop in antiferromagnetic topological insulator $\text{Ge}_{0.4}\text{Mn}_{0.6}\text{Bi}_2\text{Te}_4$

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Abstract

Topological insulators (TI) represent a promising class of materials that attract attention due to their unique properties and prospective applications. In this work, we studied a sample of an antiferromagnetic topological insulator $\text{Ge}_{0.4}\text{Mn}_{0.6}\text{Bi}_2\text{Te}_4$ with layered alternation of magnetic moments (A-type magnetic order) [1]. The surface electronic structure of such materials is crucially dependent on the surface magnetic ordering as it was shown in [2, 3]. On the other hand, the layered antiferromagnets with small anisotropy parameters exhibit surface spin flop transitions in the magnetic fields applied along the easy axis [4]. The research is motivated by an interest in the magnetic properties of the TI surface, which determine its surface electronic structure, such as the magnetic gap in the Dirac point, spin texture of the surface states, and so on [5].

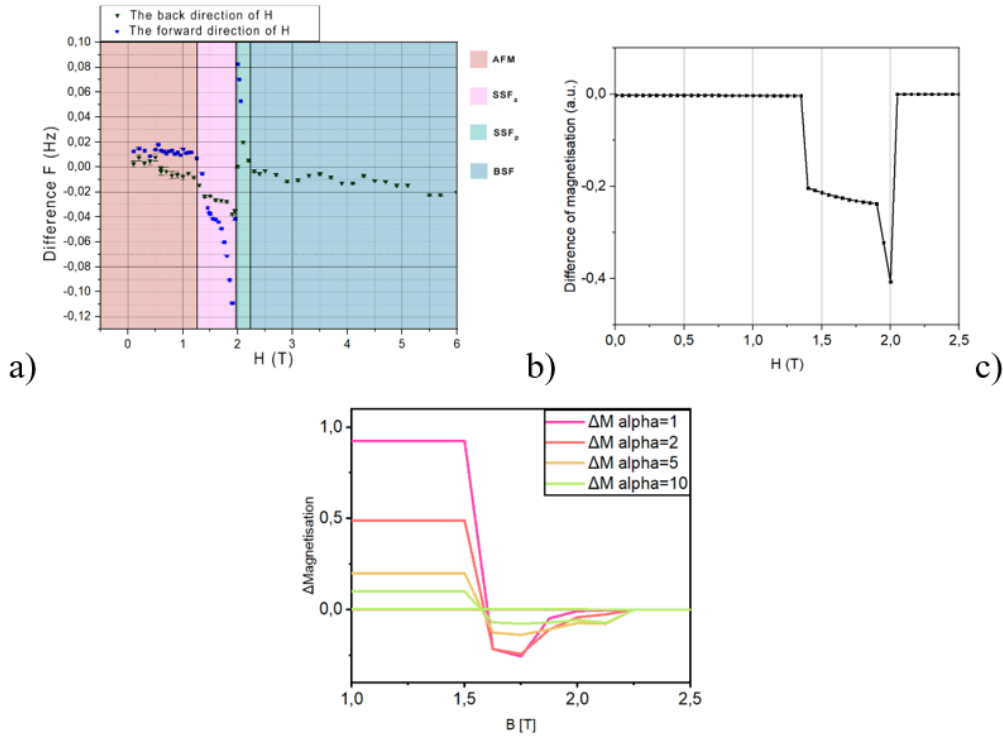


Figure 1: a) The dependence of the domain contrast on the magnetic field, measured using MFM. b) Reproduced within Heisenberg model. c) Domain contrast for big system of spins.

To directly probe the magnetization along the cleavage plane of the crystal with high surface resolution (50 nm) we used Magnetic Force Microscopy (MFM) at temperatures down to 5 K, which is much lower than Neel temperature of the crystal ($T_N = 16.1$ K). The magnetic signal was collected in frequency modulation regime. MFM signal maps were acquired over magnetic fields from -6.100 T to -2.025 T, covering both bulk surface and bulk spin-flop transitions. The obtained data demonstrated that domains with opposing orientations of the first layer's magnetic moment exhibit different responses, as it is shown in Figure 1a. The data obtained show that the bulk spin flop (BSF) effect occurred at 2.3 T. We see that the surface spin flop occurs at different fields for two types of domains: at 1.3 T for domains whose upper layer is directed against the field (SSF_α), and at 1.9 T for those in which the upper layer is aligned with the external field (SSF_β). It should be noted that the general case described in [4] does not predict the SSF_β transition. Moreover, in the applied fields near the SSF_β

transition, the magnetic structure of the surface demonstrated critical behavior, where the magnetic contrast inside the domain became more pronounced than the contrast between former domains. The magnetic properties were modeled using quantum simulation within the Heisenberg model. The field of the bulk spin-flop effect and saturation fields along various crystallographic axes and the Neel temperature were reproduced. It was also possible to qualitatively reproduce the surface SSFa spin-flop transition. The difference in the magnetization of the first layers depending on the field is shown in picture 1.b. Then, we modeled a system of $64 \times 64 \times 16$ spins in the Spirit package [6]. The movement of the spins was calculated using the Landau-Lifshitz-Hilbert equation. Solution methods: Velocity Projection [7] and Depondt [8]. Thus, the dependence of the domain contrast on the external field for a three-dimensional system was obtained. It was possible to see the SSFa transition in it, as well as to see horizontal defects. The picture 1.c shows curves depending on the depth of the interaction: exponential accounting of the magnetization from the depth of the layers.

Keywords: topological insulators, antiferromagnetism, surface spin-flop, magnetic force microscopy, Heisenberg model

Acknowledgments: The work was supported by the Russian Science Foundation (grant No. 22-72-10074-P).

References:

1. A. S. Frolov et al., Magnetic Dirac semimetal state of $(\text{Mn,Ge})\text{Bi}_2\text{Te}_4$, Commun. Phys. **7**, 180 (2024).
2. H. Li et al., Dirac Surface States in Intrinsic Magnetic Topological Insulators EuSn_2As_2 and $\text{MnBi}_{2n}\text{Te}_{3n+1}$, Phys Rev X **9**, 041039 (2019).
3. Y.-J. Hao et al., Gapless Surface Dirac Cone in Antiferromagnetic Topological Insulator MnBi_2Te_4 , Phys Rev X **9**, 041038 (2019).
4. D. L. Mills, Surface Spin-Flop State in a Simple Antiferromagnet, Phys. Rev. Lett. **20**, 18 (1968).
5. Y. Yuan et al., Electronic States and Magnetic Response of MnBi_2Te_4 by Scanning Tunneling Microscopy and Spectroscopy, Nano Lett. **20**, 3271 (2020).
6. G. P. Muller, M. Hoffmann, C. Dibelkamp, D. Schurhoff, S. Mavros, M. Sallermann, N. S. Kiselev, H. Jonsson, and S. Blugel, Spirit: Multifunctional framework for atomistic spin simulations, Phys. Rev. B **99**, 224414 (2019).
7. P. F. Bessarab, V. M. Uzdin, and H. Jonsson, Method for finding mechanism and activation energy of magnetic transitions, applied to skyrmion and antivortex annihilation, Comput. Phys. Commun. **196**, 335 (2015).
8. P. Depondt and F. G. Mertens, Spin dynamics simulations of two-dimensional clusters with Heisenberg and dipole-dipole interactions, J. Phys.: Condens. Matter **21**, 336005 (2009).

71 Investigation of superconductivity in In doped PbBi_2Te_4 using a scanning tunneling microscope

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Abstract

The search for materials where superconductivity coexists with non-trivial topology is of significant interest due to the potential to realize Majorana zero modes and their prospective applications in topological quantum computing [1]. Compounds of the AM_2X_4 family, which combine a layered structure with topological properties, serve as a promising platform for realizing such a state. One member of this family is PbBi_2Te_4 , which is a well-established three-dimensional topological insulator. Since it is known that superconductivity in this material and its analogs can be induced by both pressure and chemical doping [2], in this work, we investigate the $\text{Pb}_{1-x}\text{In}_x\text{Bi}_2\text{Te}_4$ system with an indium content of $x = 0.7$. Using scanning tunneling microscopy on this material, we have observed a temperature-dependent gap at the Fermi energy below the critical temperature, indicating the presence of superconductivity in this topological insulator. Furthermore, it was shown that an external perpendicular magnetic field induces Abrikosov vortices, and by studying their field-dependent behavior, the values of the critical field and coherence length were obtained.

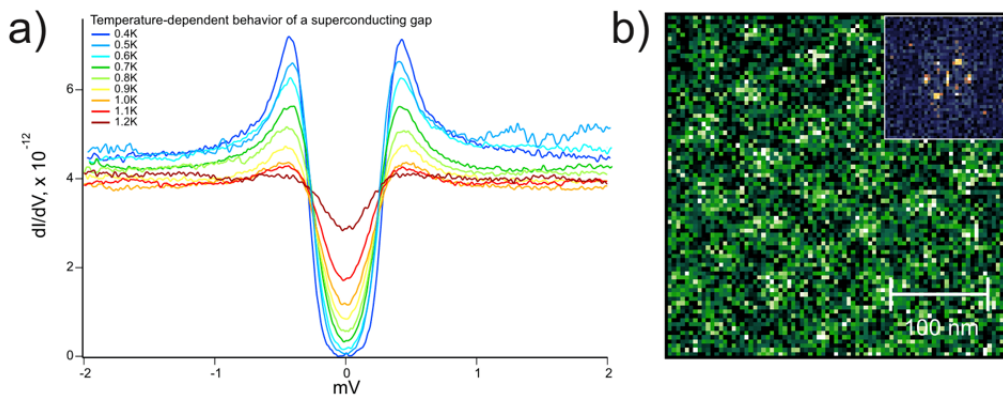


Figure 1: a) Dependence of the superconducting gap on temperature; b) Abrikosov vortices with perpendicular magnetic field $B = 0.6\text{T}$

Keywords: STM, superconductivity, topological insulators, Majorana fermions

Acknowledgments: This work was supported by RSF 22-72-10074-P

References:

1. M. Leijnse and K. Flensberg, Introduction to topological superconductivity and Majorana fermions, *Semicond. Sci. Technol.* **27**, 124003 (2012).
2. Xu, Xianghan, et al. "Superconductivity in electron-doped PbBi_2Te_4 ." *Physical Review B* **108.5** (2023): 054525.

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Special section: Advanced Microelectronics

72 Operando synchrotron studies of prototype non-volatile memory devices for nanoelectronics and spintronics

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Abstract

The report will consider the methodology developed over the past 10 years and a review of the results of in operando studies using spectroscopic methods (HAXPES, MCDAD, XMCD, Mössbauer spectroscopy) at various synchrotron sources on the relationship between the physical and functional properties of multilayer structures in prototypes of microelectronic and spintronic devices, including resistive [1] and ferroelectric (FE) [2-4,8] non-volatile memory devices based on $\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$ (HZO), as well as composite multiferroics based on bilayer ferromagnet (FM)/FE structures (FM=Ni, ^{57}Fe , EuS, FE= $\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$) [5-7].

Key words: ferroelectrics, HfO_2 , non-volatile memory devices, XPS, XMCD, synchrotron source, composite multiferroics, magnetoelectric coupling

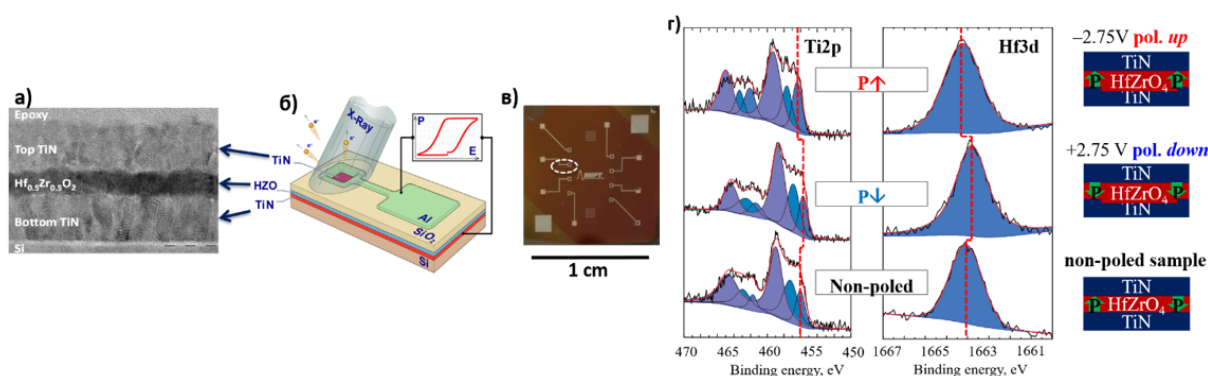


Figure 1: a) Cross-section of the memory cell prototype based on the TiN/FE-HZO/TiN structure; b) general scheme of the experiment using the HAXPES technique; c) Chip with FE memory devices prepared for operando experiments; d) Hf3d and Ti2p spectra taken after in situ switching of the FE polarization up/down in the capacitor [2].

References:

1. Matveyev Yu. et al. Effect of biasing at elevated temperature on the electronic structure of Pt/HfO₂/Si stacks // Microelectronic Engineering. 88 1353 (2011).
2. Matveyev Yu. et al. Effect of Polarization Reversal in Ferroelectric TiN/Hf 0.5 Zr 0.5 O 2 /TiN Devices on Electronic Conditions at Interfaces Studied in Operando by Hard X-ray Photoemission Spectroscopy // ACS Appl. Mater. Interfaces. 9 43370 (2017).
3. Mikheev V. et al. Ferroelectric Second-Order Memristor // ACS Appl. Mater. Interfaces. 11 32108 (2019).
4. Matveyev Yu. et al. Polarization-dependent electric potential distribution across nanoscale ferroelectric Hf_{0.5}Zr_{0.5}O₂ in functional memory capacitors // Nanoscale. 11 19814 (2019).
5. Khanas A. et al. EuS/Hf_{0.5}Zr_{0.5}O₂ Bilayers as a Prospective Multiferroic System // Adv. Materials Inter. 7 2000411 (2020).

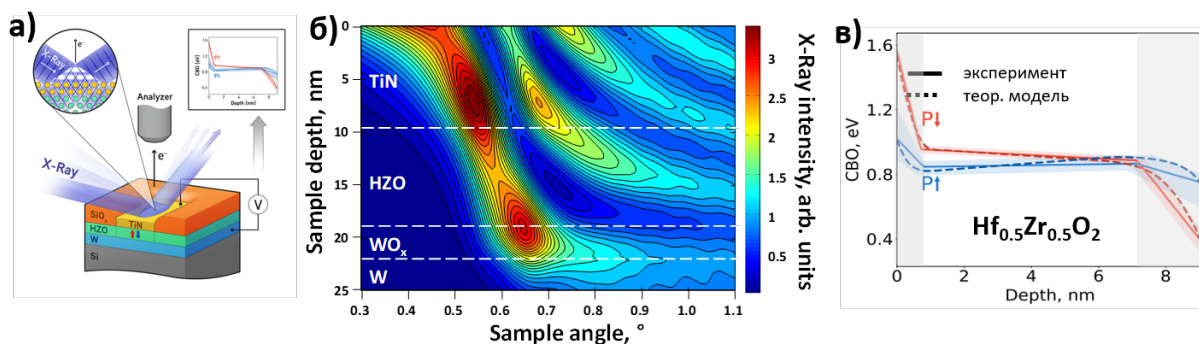


Figure 2: a) General scheme of the operando experiment on reconstructing the potential distribution in the FE-HZO layer of the prototype non-volatile memory device based on TiN/HZO/TiN for different polarization directions using the HAXPES technique in the “standing X-ray wave” mode; b) modeling the distribution of X-ray radiation intensity over the depth of the TiN/HZO/TiN structure as a function of the incidence angle; c) reconstructed potential distribution over the depth of the FE-HZO layer for two opposite FE polarization directions [4].

6. Dmitriyeva A. et al. Magnetoelectric Coupling at the Ni/Hf_{0.5}Zr_{0.5}O₂ Interface // ACS Nano. 15 14891 (2021).
7. Mikheev V. et al. Search for Magnetoelectric Coupling at the ⁵⁷Fe/Hf_{0.5}Zr_{0.5}O₂ Interface Using Operando Synchrotron Mössbauer Spectroscopy // Adv. Materials Inter. 9 2201341 (2022).
8. Chouprik, A. et al. Effect of Domain Structure and Dielectric Interlayer on Switching Speed of Ferroelectric Hf_{0.5}Zr_{0.5}O₂ Film // Nanomaterials. 13 3063 (2023).

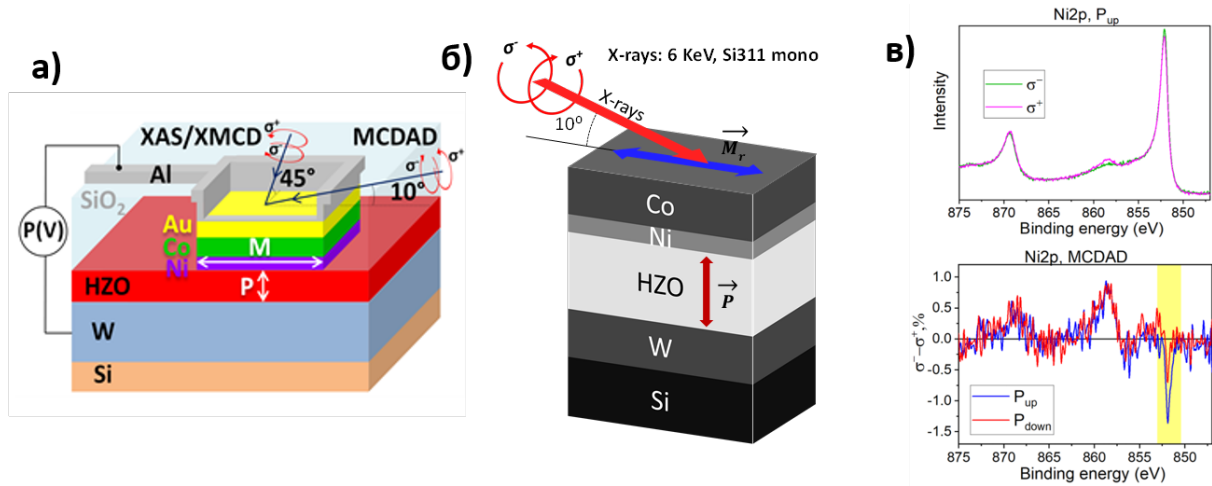


Figure 3: a) Schematics of the operando experiment to search for magnetoelectric interaction at the FM/FE interface in a bilayer composite multiferroic based on Co/Ni/HZO using the XMCD and MCDAD (magnetic circular dichroism in angular distribution) techniques; b) scheme of measurements using the MCDAD method in operando; c) Ni2p spectra for different directions of X-ray circular polarization and differential spectra for opposite directions of FE-HZO polarization [6].

73 Ferroelectric field-effect memory transistor with $\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$ and 2D MoS_2

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Abstract

This study examines the technological aspects of fabricating a ferroelectric field-effect transistor (FeFET) based on a thin $\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$ ferroelectric film grown by atomic layer deposition, and a two-dimensional MoS_2 serving as the semiconducting channel material. Modern processors perform a vast number of complex operations that require constant data movement between memory and computing units. This leads to decreased performance and increased energy consumption. Several studies have shown that data transfer can account for up to one-third of the total energy consumption associated with performing computational tasks [1]. As a result, there is a growing demand for approaches aimed at improving data processing efficiency. One such approach is in-memory computing, which involves storing and processing data within the same device. Clearly, this approach requires combining the key functional properties of logic transistors (such as high speed) and memory cells (non-volatility, long-term data retention) into a single element. A prominent concept in the field of in-memory computing is ferroelectric memory, with the most promising implementation being the ferroelectric field-effect transistor (FeFET). FeFETs offer numerous advantages, including high speed, non-volatility, non-destructive readout, and strong scalability potential—unlike the more traditional 1T-1C (1 transistor–1 capacitor) FeRAM cell. Nevertheless, despite its high potential, the practical realization of FeFETs had long been challenging due to integration issues of the conventional perovskite ferroelectrics with silicon channel. The discovery of ferroelectricity in HfO_2 and $\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$ fundamentally changed the outlook on FeFET fabrication. HfO_2 , widely used in high-k metal gate (HKMG) technology for silicon transistors since 2007, is compatible with existing CMOS processes and lacks the drawbacks of perovskite ferroelectrics. This is evidenced by the rapid development of FeFET technology based on $\text{HfO}_2/\text{Hf}_{0.5}\text{Zr}_{0.5}\text{O}_2$ —from initial demonstrations of feasibility [2] to integration into 28-nm HKMG processes and the creation of vertical, ultra-dense FeFET arrays [3,4]. On the other hand, to overcome the limits of current miniaturization and to extend Moore's Law, the development of devices with ultra-thin semiconductor channels has become increasingly important. However, silicon—the main material in the microelectronics industry—exhibits a critical drop in carrier mobility when the channel thickness is reduced to just a few nanometers. Under these conditions, two-dimensional (2D) semiconductors, such as MoS_2 , WS_2 , WSe_2 , and others, are

gaining attention as promising alternatives to silicon for next-generation nanoelectronics. In recent years, significant progress has been made in growing monolayer MoS₂ films of electronic quality on substrates with commercially relevant areas, achieving carrier mobilities of ~ 40 cm²/Vs, which is significantly higher than that of silicon at comparable thicknesses [5]. In the present study, we investigated the feasibility of fabricating an FeFET based on Hf_{0.5}Zr_{0.5}O₂, where a two-dimensional MoS₂ layer is used as the semiconductor channel. Special attention was paid to the architecture of the ferroelectric gate stack and the possibility of depositing a high-quality gate dielectric directly onto MoS₂ using atomic layer deposition (ALD). Device measurements under both active gate bias and pulsed operation confirmed the formation of a stable memory window and the presence of multiple stable channel conductivity states. The results may contribute to the further development of in-memory computing devices that are fully compatible with CMOS technology and possess high scalability potential.

Keywords: MoS₂, ferroelectrics, hafnium oxide, Hf_{0.5}Zr_{0.5}O₂, atomic layer deposition, FeFET

Acknowledgements: The work was supported by Russian Science Foundation (project No. 23-19-00227, <https://rscf.ru/project/23-19-00227/>).

References:

1. Marega, G. M.; Wang, Z.; Paliy, M.; et al. Low-Power Artificial Neural Network Perceptron Based on Monolayer MoS₂. *ACS Nano* 2022, 16 (3), 3684–3694.
2. Böske, T. S.; Müller, J.; Bräuhäus, D.; et al. Ferroelectricity in hafnium oxide: CMOS compatible ferroelectric field effect transistors. *IEEE Int. Electron Devices Meeting* 2021, 24.5.
3. Möller, J.; Yurchuk, E.; Schlösser, T.; et al. Ferroelectricity in HfO₂ en ables nonvolatile data storage in 28 nm HKMG. *IEEE Symp. on VLSI Technology (VLSIT)* 2012, 25–26.
4. Florent, K.; Pesic, M.; Subirats, A.; et al. Vertical ferroelectric HfO₂ FET based on 3D NAND architecture: towards dense low-power memory. *IEEE Int. Electron Devices Meeting (IEDM)* 2018, 2.5.
5. Sebastian, A.; Pendurthi, R.; Choudhury, T. H.; et al. Benchmarking monolayer MoS₂ and WS₂ field-effect transistors. *Nature Communications* 2021, 12, 693.

74 Memory transistors for neuromorphic computing: a perspective

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Abstract

Neural network algorithms applications are a huge technological success of recent years, however, the well-known issue of enormous energy consumption causes the search for novel computing architectures and electronic components for their realization, which would enable their implementation in autonomous edge devices for a variety of important tasks. One of the most promising routes is the development of neuromorphic architectures, in which the computation and memory units are combined (in contrast to traditional von Neumann machines, requiring constant data transfer between separate CPU and memory), quite closely reproducing the principles of the biological brain organization. Thus, in order to fully realize the potential of neuromorphic systems, there is a need for novel electronic components, which would emulate the behavior of biological neural elements – neurons (responsible for active signal generation) and synapses (responsible for long-term memory).

Memory transistors, such as the ones used in floating gate/charge trap Flash memory, are the most relevant electronic components in this regard, since they combine the possibility of the organization of the required neuromorphic behavior with the production technology maturity. Thus, in this talk, the review of the possibilities for implementation of memory transistors for neuromorphic computing will be given. In particular, we will present the comparison of the traditional memory transistors, used in Flash memory, with the emerging ferroelectric field effect transistors (FeFET) in terms of energy efficiency and spatial scalability. Finally, we will review the plan of FeFET study for memory and neuromorphic applications in the framework of the world-level science center at the Moscow Institute of Physics and Technology.

Key words: neuromorphic computing, memory transistors, ferroelectric field-effect transistors.

75 Multistep atomic layer deposition process for ultrathin superconducting NbN films with high critical current density on different substrate

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Abstract

The advancement of superconducting electronics requires high-quality epitaxial films with controlled structural properties. Understanding and controlling the growth mechanisms is crucial for developing next-generation superconducting devices. Here we present comprehensive structural and superconducting characterization of ultrathin epitaxial niobium nitride (NbN_x) films grown on C-plane sapphire substrates. Using plasma-enhanced atomic layer deposition (PEALD) at 350°C, we demonstrate the growth of high-quality crystalline films with (111) orientation. Our investigation reveals that the NbN layers consist of twins with [1 $\bar{1}$ 0] axes parallel to the substrate [1 $\bar{1}$ 00] axes in the basal plane. The cubic lattice undergoes rhombohedral deformation with angle distortion up to 89° due to the coincidence of four NbN_x lattice periods with three sapphire periods, resulting in a remarkably low misfit of 0.31%. We determine the superconducting transition temperature and critical current density as 12 K and 6.2 MA/cm², respectively. Additionally, we extract the quasiparticle diffusion constant and coherence length, providing fundamental parameters for device optimization. These findings enable the development of optimized epitaxial structures for high-performance superconducting circuits and support the integration of NbN-based devices into scalable quantum computing architectures.

Keywords: Atomic layer deposition, niobium nitride, epitaxy, twins, critical current density, coherence length

Acknowledgments: The work was supported by the Russian Science Foundation (project no. 25-19-00057; <https://rscf.ru/project/25-19-00057/>).

References:

1. M.V. Shibalov, et al. A study of ultrathin superconducting films of niobium nitride obtained by atomic layer deposition. *Tech. Phys.*, 66(5):658-663, 2021.
2. M.V. Shibalov, et al. Multistep atomic layer deposition process for ultrathin superconducting NbN films with high critical current density on amorphous substrate. *Supercond. Sci. Technol.*, 34(8):085016, 2021.

76 High performance microheater-based catalytic hydrogen sensors fabricated on porous anodic alumina substrates

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Abstract

Nowadays, hydrogen plays an important role in the global energetics. Environmentally friendly H₂ fuel already makes up a significant share in the energy sector. In the near future hydrogen will become the basis of a green economy and will help overcome a number of local and global energy, environment, and economy related challenges and provide a sustainable future of our planet. Several important characteristics, such as high energy density, low mass, affordability, carbon-free nature, and a wide variety of production methods, drive the rapidly growing use of hydrogen. On the other hand, hydrogen is dangerous due to its high flammability and explosibility. According to the NFPA 704 standard, hydrogen possesses the highest rating of 4 on the flammability scale. Hydrogen-air mixtures ignite in the range of 4 to 74 vol% of hydrogen. Therefore, rapid and accurate measurement of hydrogen concentration in air (especially in the range lower than the Lower Explosive Limit (LEL)) is extremely important to prevent the risk of fire and explosion.

Here we developed microheater-type catalytic hydrogen sensors based on porous anodic aluminium oxide served simultaneously as a substrate for platinum microheater and as a carrier for a catalyst. The fabricated sensors have a high sensitivity of 76 mV/vol% hydrogen. The deviation of the sensor response during continuous operation for 14 days is less than 4%. The relative humidity of the ambient atmosphere does not affect the sensor response. The fast sensor response time (0.4 s) makes it possible to use the pulsed power supply mode to reduce the power consumption to 3.2 mW without sacrificing the measurement accuracy. The performance of the developed catalytic hydrogen sensors promotes the high competitiveness in the market and the prospects for industrial applications.

It has been shown that when the sensor operates in air, palladium oxidation blocks its activity in the hydrogen combustion reaction. Only after the reduction of PdO to metallic Pd in presence of hydrogen at a temperature of 38 °C, the hydrogen catalytic oxidation manifests itself as a sharp increase in sensor response. The observed feature is important for detecting low hydrogen concentration with no response lag, decreasing the operating temperature of the sensor, and measuring in pulsed mode.

Acknowledgements: This work was performed under financial support of the Russian Science Foundation (grant No. 25-13-00417) and the Ministry of Science and Higher Education of the Russian Federation (grant No. 075-15-2025-608).

77 Electrically tunable sub-terahertz resonance in antiferromagnet-normal-metal heterostructure

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Abstract

Antiferromagnetic (AFM) materials have natural resonance frequencies in the sub-THz or THz ranges. Thus, it is tempting to use antiferromagnets (AFM) as active layers in THz-frequency oscillators [1] and detectors [2]. It has been shown theoretically [2,3] that both uniaxial and biaxial AFMs can be used for the resonance quadratic rectification of a linearly polarized AC spin current of THz frequency and could have a sensitivity in the range of 100 – 1000 V/W. Recent experiments [4] indicate the possibility of the electrical manipulation (for the current densities $(2 - 6 \cdot 10^7 \text{ A/cm}^2)$) of the high-frequency antiferromagnetic mode for the biaxial easy plane antiferromagnet NiO from 1.1 THz down to 0.9 THz. One promising candidate for microwave and sub-THz experiments is the easy plane antiferromagnet with small ferromagnetism caused by strong Dzyaloshinskii-Moriya interaction hematite $\alpha\text{-Fe}_2\text{O}_3$ [5,6]. In most experiments with hematite, the easy antiferromagnetic plane is located in the plane of the sample, which significantly limits the ability to manipulate both the upper and lower resonant frequencies. This work aims to find the influence of the direction of the easy plane on the tuning of the subterahertz resonant frequency of hematite by constant electric current via the spin-Hall effect. Let us consider the antiferromagnet-normal-metal heterostructure (see the inset in Fig.1) with the antiferromagnetic easy plane (EP) oriented in the angle θ_p to the surface plane, and hard axis $\mathbf{n}_h$ is perpendicular to the EP. An additional bias DC current in the normal metal layer (here Pt) is used for tuning the AFM high-frequency mode (near 0.17 THz for $j_{dc}=0$) and for a partial regeneration of the system losses. Based on our previous theoretical analysis [2,3,6] applied to the hematite crystal, we analyzed the so-called “ σ -model” equation describing the dynamics of Neel vector $\mathbf{l}(t)$; we have found the analytical expressions for both low and high frequencies of hematite as functions of current density for an arbitrary angle of inclination of the easy plane relative to the sample plane. Our theoretical analysis showed that decreasing the angle between the sample plane and the easy antiferromagnetic plane leads to an increase in the value of threshold current density. Thus, our analysis shows that minimizing the critical tuning current would be desirable for the easy plane to be oriented perpendicular to the sample plane, which can be achieved by choosing a unique substrate.

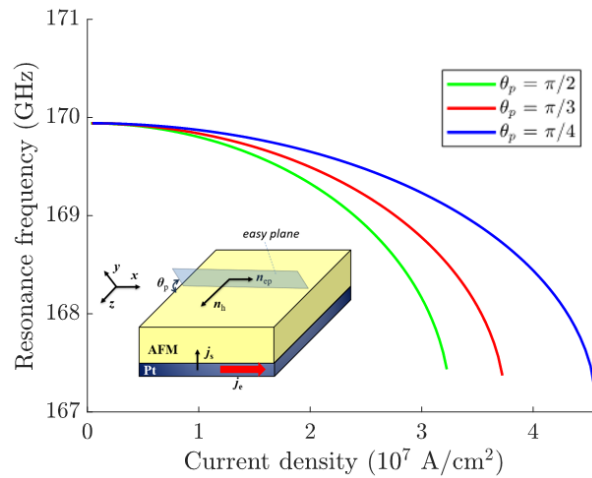


Figure 1: Dependence of the AFMR oscillation frequency on the input bias electrical current density flowing in the Pt layer for different orientations of easy plane relative to the sample plane ($\theta_p = \pi/2, \pi/3, \pi/4$). The inset is an image of the proposed AFM-Pt heterostructure.

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References:

1. R. Khymyn et al. Sci. Rep. 7, 43705 (2017).
2. A. R. Safin et al. Appl. Phys. Lett. 117, 222411 (2020).
3. A. R. Safin et al. Magnetochemistry 8, 26 (2022).
4. O. R. Sulymenko et al. Phys. Rev. Appl. 8, 064007 (2017).
5. A. Yu. Mitrifanova et al. Chaos 33, 113135 (2023).
6. Q. Liu et al. Adv. Func. Mat. 33, 2305173 (2023).
7. H. Qiu et al. Adv. Sci. 10, 2300512 (2023).

78 Voltage controlled magnetic anisotropy of antiferromagnetic modes of bulk $\alpha\text{-Fe}_2\text{O}_3$

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Abstract

Mechanical deformations arising in nanolayers of heterostructures under the influence of external fields of different nature are one of the promising ways to control the magnetic subsystem [1]. This control, including local and electrical, without the need for tunable magnetic field sources, is an important element for the integration of magnon spintronics devices and conventional CMOS-electronics [2]. The aim of this work is to investigate the possibility of applying the voltage-controlled magnetic anisotropy (VCMA) to tune the magnetic dynamic properties of an antiferromagnet with weak ferromagnetism $\alpha\text{-Fe}_2\text{O}_3$ in a synthetic antiferromagnetic/ferroelectric multiferroic structure (see Fig. 1a). PMN-PT material (composition 68% $\text{Pb}(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3$ - 32% PbTiO_3 and two different orientations (001) and (011)) was chosen as the ferroelectric layer. The polarization of the ferroelectric was carried out by applying an electric voltage V to the Pt contacts. The in-plane deformations of PMN-PT due to the rigid bonding with the $\alpha\text{-Fe}_2\text{O}_3$ layer induce mechanical strain in the antiferromagnetic layer. The structure has been experimentally investigated by BLS spectroscopy. The spectra of quasi-ferromagnetic and antiferromagnetic modes have been measured. For the quasi-ferromagnetic mode, the control of angular dependencies taken at rotation of the constant magnetic field H in the easy plane of the antiferromagnet (xy) has been measured. By comparing the isotropic (001) and anisotropic (011) orientation, the appearance of preferred directions in the (xy) plane caused by $\pm z$ polarization of the ferroelectric is demonstrated. For the antiferromagnetic mode, the hysteresis behaviour of the frequency shift at polarization of the ferroelectric in the bipolar regime is shown (see Fig. 1b). This is a consequence of the standard 'butterfly-like' strain-voltage characteristics in the polarization of ferroelectrics. A theoretical model is also constructed, which takes into account the mechanical deformations $u_{ij} = d_{ijk}E_k + Q_{ijkl}P_kP_l$ arising at the appearance of the electric field $\mathbf{E}$ in the inverse piezoelectric effect and polarization $\mathbf{P}$ in the electrostriction effect, respectively. Taking into account the strain transfer from the PMN-PT layer to $\alpha\text{-Fe}_2\text{O}_3$, the magnetoelastic energy functional of the antiferromagnet $\text{FME} = B_{ijkl}u_{ij}l_kl_l$ for a fixed value of the voltage V will have the form of effective induced magnetic anisotropy $F = K^{eff}_{ij}(V)l_i l_j$. Thus it is possible to change the ground states of the antiferromagnetism vector $\mathbf{l}$ in the (xy) plane and to tune the resonance frequencies, which can be useful for the design and construction of memory devices, receivers and transmitters of sub-THz range signals.

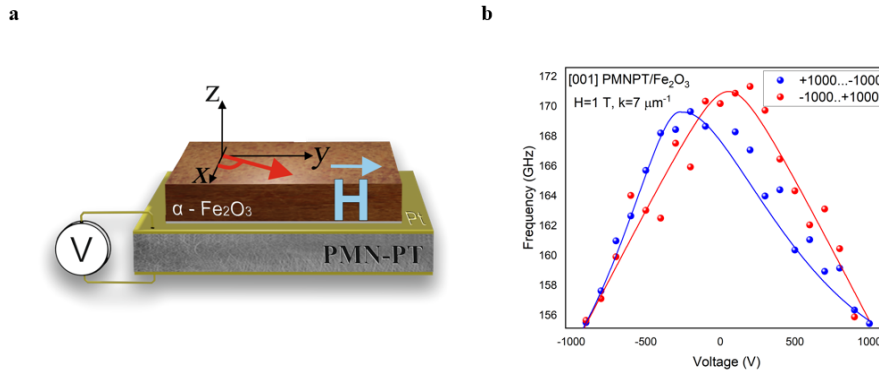


Figure 1: a) Experimental setup for BLS spectra measurements. External magnetic field H is rotated in (xy) plane of $\alpha\text{-Fe}_2\text{O}_3$ /PMN-PT heterostructure; electric field E is induced along $\pm z$ axis. b) Hysteresis shift of antiferromagnetic mode frequency under mechanical strain induced by PMN-PT polarization in bipolar regime.

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References:

1. A. A. Bukharaev, A. K. Zvezdin, A. P. Pyatakov, and Y. K. Fetisov, “Straintronics: a new trend in micro- and nanoelectronics and materials science,” *Physics-Uspekhi* 61, 1175–1212 (2018).
2. A. V. Chumak, V. I. Vasyuchka, A. A. Serga, and B. Hillebrands, “Magnon spintronics”, *Nature Physics* 11, 453–461 (2015).
3. P. Popov, A. Safin, A. Kirilyuk, S. Nikitov, I. Lisenkov, V. Tyberkevich, and A. Slavin, “Voltage-controlled anisotropy and current-induced magnetization dynamics in antiferromagnetic-piezoelectric layered heterostructures,” *Physical Review Applied* 13 (2020).

79 Electronic Structure and Topological Properties of Natural Superlattices Based on Tetradymite-like Structural Blocks

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Abstract

Systems with non-trivial topology of their band structure are a major focus of modern condensed matter physics. One example of such systems are topological insulators (TIs) — materials that possess a bandgap in the bulk and metallic states on the surface. Due to the unique topology of the bulk bands, the surface electronic states of TIs exhibit a number of characteristic features, such as near-linear dispersion and spin-momentum locking.

The functional characteristics of topological insulators can change significantly in the presence of magnetic or superconducting order. These materials belong to the subclasses of magnetic and superconducting topological insulators, making their study relevant in the context of potential applications in spintronics, quantum computing, and neuromorphic systems. The family of magnetic topological insulators (MTIs) derived from the MnBi_2Te_4 structure [1] is particularly promising. This precursor has a layered structure composed of septuple-layer blocks [Te-Bi-Te-Mn-Te-Bi-Te], held together by van der Waals interactions. An A-type antiferromagnetic order is formed by the magnetic moments of the manganese atoms, allowing for the application of Z_2 classification to this compound [2,3]. The emergence of magnetic order leads to the opening of a bandgap at the Dirac point of the surface states [4]. It is assumed that the emergence of superconducting correlations in topological insulators leads to the formation of Majorana fermions on the surface, which can be localized in the vortex core [5,6]. Research on such objects is conducted both in systems with the proximity effect [5] and in intrinsic superconducting topological insulators [7].

Experimental studies of the properties of topologically protected electronic subsystems primarily rely on scanning tunneling microscopy/spectroscopy (STM/STS) and photoemission spectroscopy (ARPES). Combining these techniques provides additional information about the object under study. The report will present a review of existing methods and approaches for studying the electronic properties of TIs, superconducting TIs (STIs), and MTIs. The main focus will be on the synergy between methods offering high spatial resolution, such as scanning probe microscopy (SPM), and integral methods, such as angle-resolved photoemission spectroscopy (ARPES).

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References:

1. Tokura Y., Yasuda K. and Tsukazaki A. // Nat. Rev. Phys. 2019, V. 1. P. 126–143.
2. Otrokov M.M. et al. // Nature. 2019. V. 576. P. 416–422.
3. Frolov A.S. et al. // Commun. Phys. 2024. V. 7. P. 180.
4. Estyunin D.A. et al. // Apl. Mater. 2020. V. 8. P. 021105.
5. Fu L., Kane C.L. // Phys. Rev. Lett. 2008. V. 100. P. 096407.
6. Hosur P. et al. // Phys. Rev. Lett. 2010. V. 107. P. 097001.
7. Hor Y.S. et al. // Phys. Rev. Lett. 2010. V. 104. P. 057001.

80 Schottky Defects Suppress Nonradiative Recombination in $\text{CH}_3\text{NH}_3\text{PbI}_3$ through Charge Localization

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Abstract

Hybrid organic-inorganic perovskites (HOIPs) are of great interest in recent years because their excellent optoelectronic properties enable high power conversion efficiencies in solar cells with the latest record of 26.7% [1]. Further improving the performance of HOIP solar cells requires a better understanding of the energy loss mechanisms. Structural defects usually serve as carrier recombination centers to accelerate the energy dissipation in HOIPs. In this report, we demonstrate some stoichiometric Schottky defects [2], specifically, PbI_2 and $\text{CH}_3\text{NH}_3\text{I}$ vacancies, can actually suppress the nonradiative electron-hole recombination in $\text{CH}_3\text{NH}_3\text{PbI}_3$ [3]. We employed density functional theory and nonadiabatic molecular dynamics to simulate the material properties and carrier recombination dynamics. These Schottky defects rarely affect the bandgap of $\text{CH}_3\text{NH}_3\text{PbI}_3$, and no mid-gap states are introduced. However, the spatial distribution of holes is dramatically modified, reducing their overlap with electrons and reducing the corresponding nonadiabatic couplings. Especially, the holes are localized around the vacancies with enhanced structural distortions. Our simulations indicate the carrier lifetime is efficiently extended from 1 ns to 2.1 and 2.6 ns by PbI_2 and $\text{CH}_3\text{NH}_3\text{I}$ vacancies, respectively, see Fig. 1 [3]. This work suggests the counterintuitive potential of Schottky defects in enhancing the performance of HOIP solar cells.

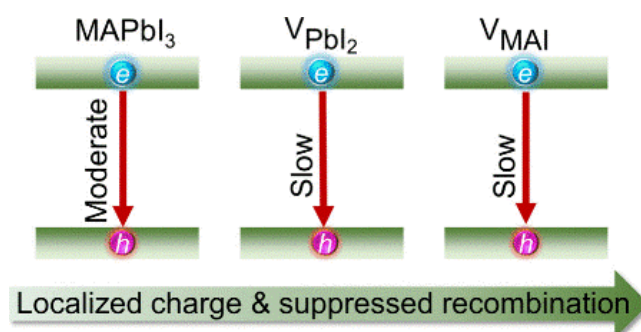


Figure 1: Scheme of Schottky defects extending the carrier lifetime in $\text{CH}_3\text{NH}_3\text{PbI}_3$. Here MA is CH_3NH_3^+ .

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References:

1. M. A. Green, E. D. Dunlop, M. Yoshita, N. Kopidakis, K. Bothe, G. Siefer, D. Hinken, M. Rauer, J. Hohl-Ebinger, X. Hao, Solar Cell Efficiency Tables 32, 425-441 (2024).
2. C. Ran, J. Xu, W. Gao, C. Huang, S. Dou, Chem. Soc. Rev. 47, 4581-4610 (2018).
3. L. Qiao, A.S. Vasenko, E.V. Chulkov, R. Long, J. Phys. Chem. Lett. 16, 1, 215-221 (2025).

Submission guide for «Mesoscience and Nanotechnology» journal

In terms of information and publication support of the **I International Scientific Conference “Advanced Functional Materials for Digital and Quantum Electronics 2025”**, a special issue of the journal “*Mesoscience and Nanotechnology*” (<https://jmsn.press>) will be organized, in which articles will be published based on the reports presented at the Symposium.

To submit an article, you must complete the following steps:

1. Go to the website of the journal “*Mesoscience and Nanotechnology*” using this link: <https://jmsn.press>.
2. Click on the “**Submit your article**” button (see Fig. 2).

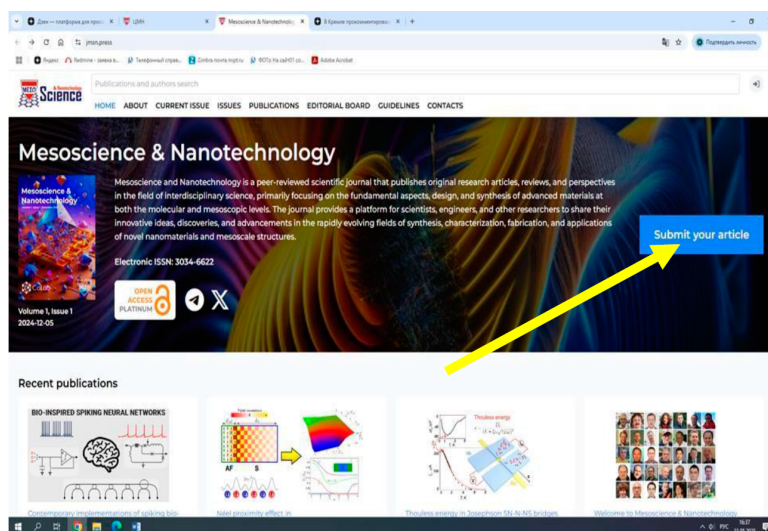


Figure 2: Homepage of the “Mesoscience and Nanotechnology” journal with the submission button

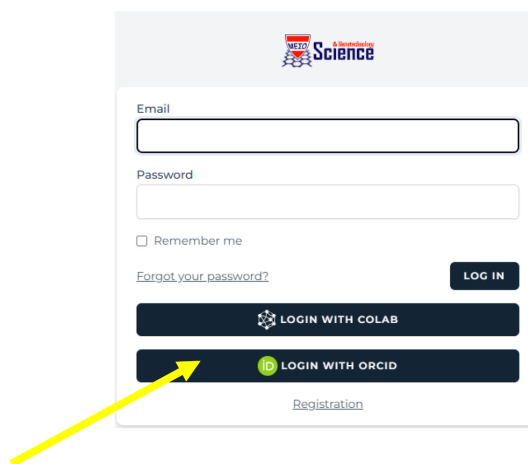


Figure 3: Login page with ORCID authentication option

In the appearing window (Fig. 3), you must select “Login with ORCID” and then follow the standard “ORCID” instructions for uploading articles in any format.

Articles are formed according to the template established by the journal (go to **Guidelines - LaTeX Template**, PDF Template, Word Template).

We recommend registering on the website: **COLAB.WS**, which unites more than 25,000 leading Russian and foreign scientists.

