Electrochemical preparation of metallic nanowires for superconducting microelectronics

Sotnichuk S.V.[1,2,*], Skryabina O.V.[2,3,4], Shishkin A.G.[2,3], Bakurskiy S.V.[2,5], Stolyarov V.S.[2,3], Napolskii K.S.[1,2,3]

[1] Lomonosov Moscow State University, Faculty of Materials Science, Moscow 119991, Russia
[2] National University of Science and Technology MISIS, Moscow 119049, Russia
[3] Moscow Institute of Physics and Technology, Dolgoprudny 141701, Russia
[4] Osipyan Institute of Solid State Physics RAS, Chernogolovka 142432, Russia
[5] Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Moscow 119991, Russia
*e-mail: sotnichuksv@my.msu.ru

This work is dedicated to the development of a new approach for creating superconducting microelectronics based on metallic nanowires. This innovative geometry, compared to traditional fabrication methods, allows for significantly reducing the lateral dimensions of the devices, as well as enhancing the performance parameters of future systems with high element density.

Using a template-assisted electrodeposition technique, we have successfully synthesized various types of nanowires using porous templates of anodic aluminium oxide (AAO). The nanowires have a diameter of 30−65 nm and include monometallic Au, ferromagnetic Co, and segmented Au/Ni/Au structures, where a thin layer of ferromagnetic material separates the segments of normal metal. We have paid close attention to studying the influence of the electrodeposition process on the composition, structure, and properties of the nanowires.

To create hybrid systems based on individual nanowires, current-carrying Nb contacts were fabricated using electron lithography and magnetron sputtering techniques. Measurements of the low-temperature transport properties of the SNS systems (Nb/Au/Nb) showed high values for the critical current density, up to $1.6\cdot10^6$ A/cm^2. Gold nanowires with a diameter of 60 nm have a coarse crystalline structure, whereas those with a diameter smaller than 30 nm are characterized by a polycrystalline structure. The lack of the proximity effect for small-diameter nanowires with weak link lengths larger than 300 nm indicates the important role of grain boundaries in electronic transport. The experimentally observed monotonic decrease in the critical current with increasing temperature and the strength of the external magnetic field was quantitatively described using the Usadel approach for long SN-N-SN junctions with diffuse normal metal regions.

For Nb/Co/Nb hybrid structures with cobalt nanowires ranging in length from 280 to 365 nm, no transition to the superconducting state was observed. The fabricated structures exhibit $\rho_{Co}(5\ K) = 4.94 \pm 0.83\ \mu\Omega\cdot cm$, a residual resistivity ratio of 4.5 and low contact resistance values.

For the first time, SNFNS junctions based on individual segmented Au/Ni/Au nanowires were fabricated, and the occurrence of the proximity effect in these structures was demonstrated for Ni layer thicknesses of less than 12 nm at temperatures below 3.5 K. The critical current increases to 50 μA when the temperature drops to 13 mK. The results obtained, combined with additional research in an external magnetic field, offer new possibilities for the development of miniature digital components and superconducting devices for quantum and spin-based technologies.

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