0- π transition in S-N-S Josephson junction on a magnetic insulator

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Introduction

π-junction is a type of Josephson junction which has a superconducting phase difference of π between its banks in a ground state (at 0 current across the junction). They present scientific interest both on their own, for fundamental studies[1,2], and for applications in superconducting electronics, as composite part of more complex devices, for instance, RSFQ-logic[3] elements. The most widely used types of π-junctions are SFS or SIFS JJ or controllable junctions[4] (where the transition between states is triggered by some external parameter, usually a bias current), however we suggest an alternative.

In this work planar JJ with normal metal barrier on a substrate of a ferromagnetic insulator (S-N/F-S contact) has been researched. A.M. Bobkov and I.V. Bobkova, based on theory developed in [4], have derived critical current on temperature dependence function and calculated its phase diagram in respect to the temperature and contact length (Fig 1). Reverse proximity effect of magnetic insulator results in appearance of effective exchange field in N layer, which makes the transition to a π-state possible at some values of the parameters (see alternating areas on a diagram).

Thus, main goal were to fabricate S-N/F-S junction and to observe π-state transition by measuring critical current on temperature dependence.

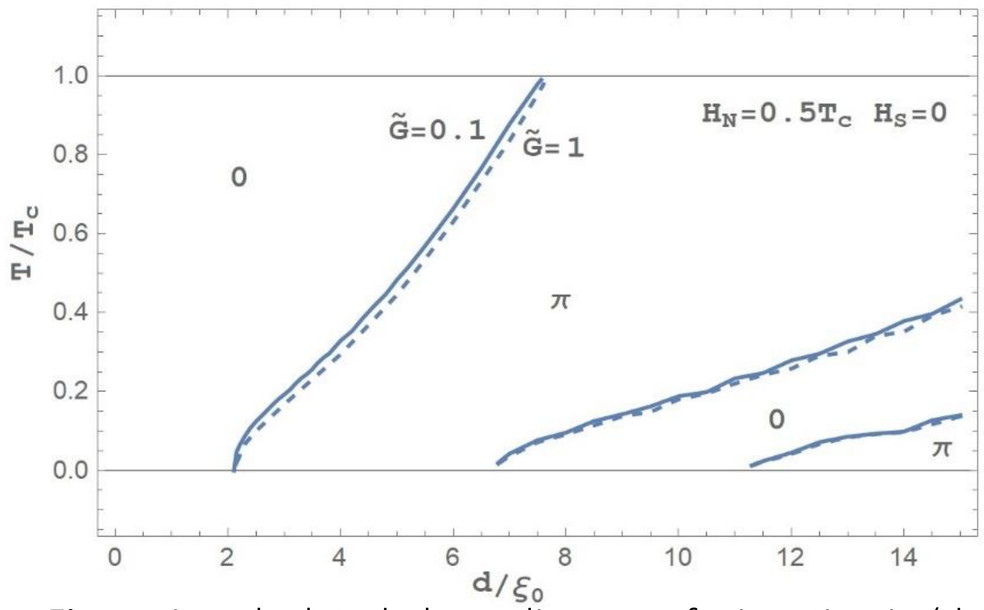

Figure 1 : calculated phase diagram of a junction in (d, T) coordinates.

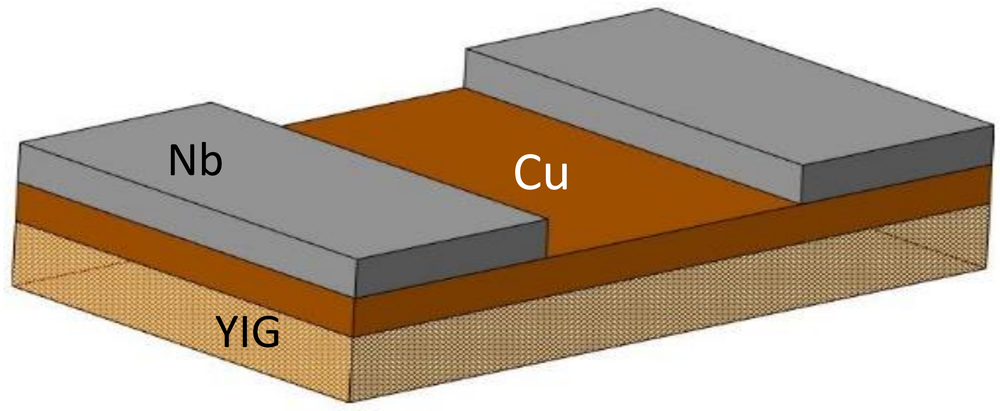

Figure 2 : structure layout.

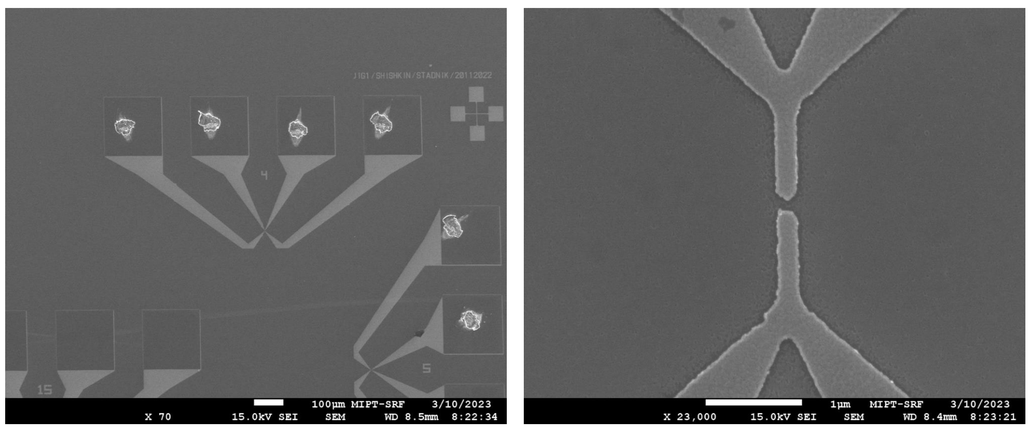

Figure 3 : sample №4, SEM image.

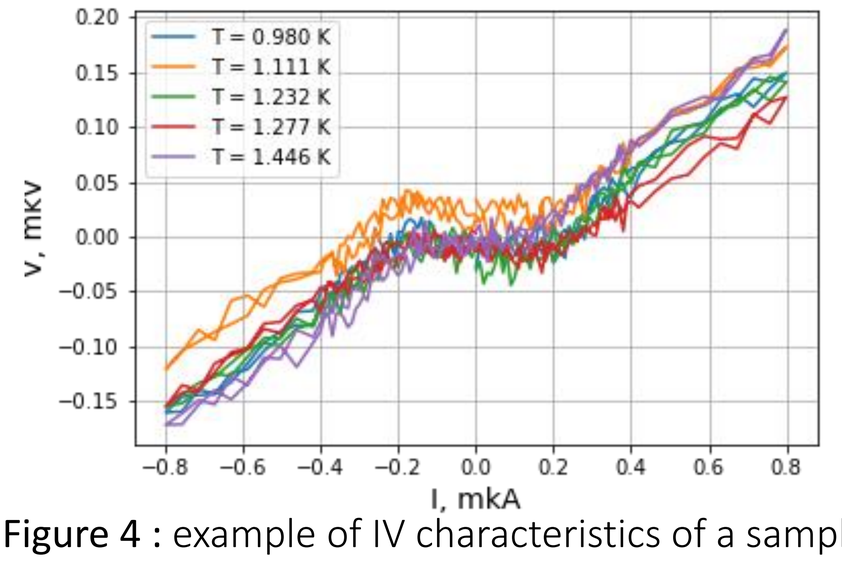

Figure 4 : example of IV characteristics of a sample

Fabrication

Structure has been fabricated using : Yttrium-Iron-Garnet ($Y_3Fe_5O_{12}$, YIG) – ferromagnetic insulator, ~4.5µm; Copper, 15nm; Niobium, 50nm (Fig. 2).

Fabricated chip with several samples with different contact length (distance between banks) d has been put inside a BlueForse dilution refrigerator, IV measurements have been conducted using 4-point method at various temperatures for samples №4 (d=125нм) and №7 (d=212нм) (Fig. 4).

After the measurements the chip has been observed in SEM to establish the actual dimensions of the samples (Fig. 3).

Experiment

Critical currents have been determined using measured IV curves. Resulting critical current on temperature dependence is plotted in Fig. 5.

The data has been compared to a regular SNS junction based on Nb/Cu on a silicon substrate, fabricated using the same technological process and featuring similar dimensions[5] (Fig. 6).

The figure shows comparison of normalized dependencies, because absolute values of crit. current densities differ 40 times.

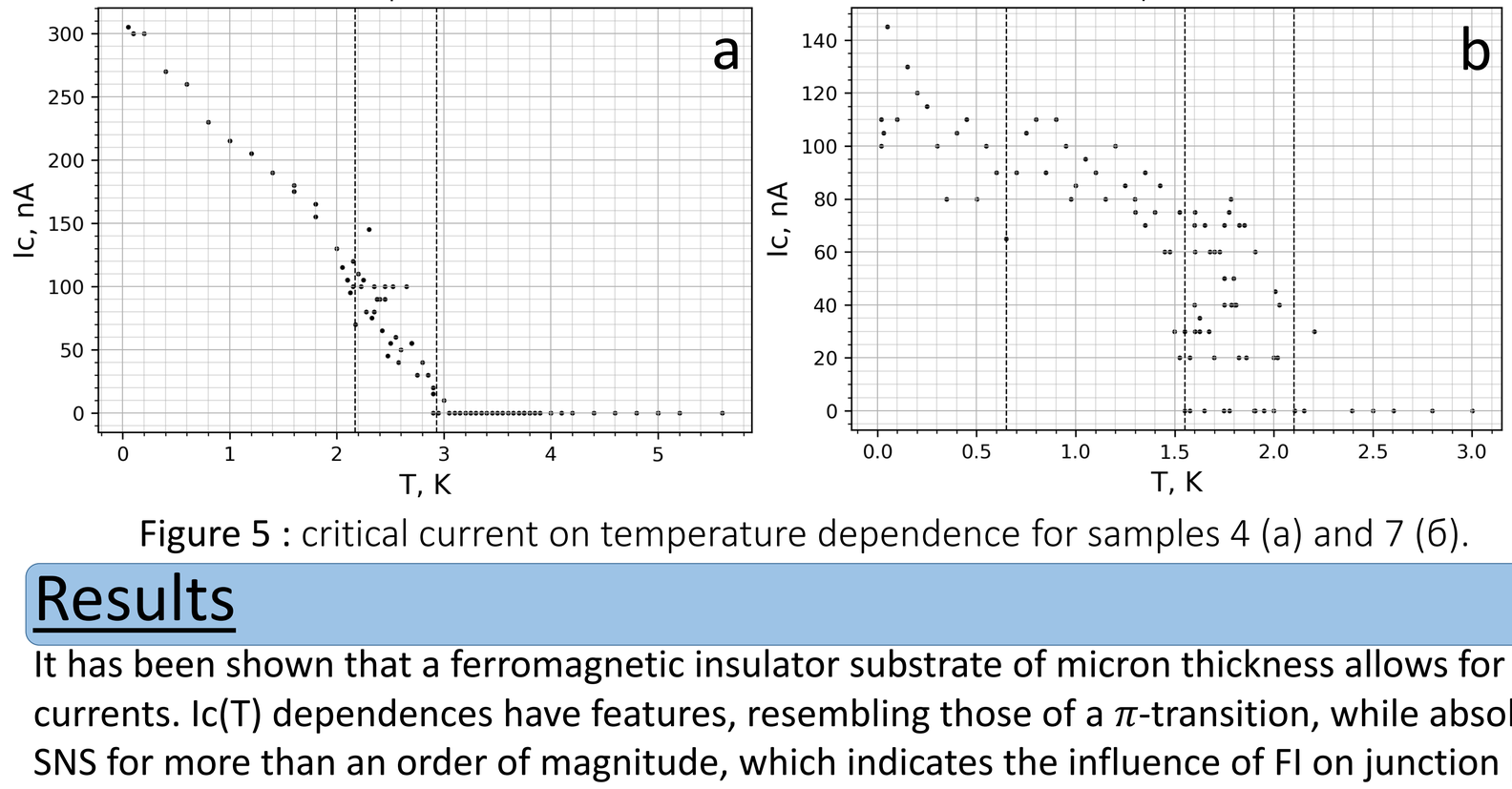

Figure 5 : critical current on temperature dependence for samples 4 (a) and 7 (б).

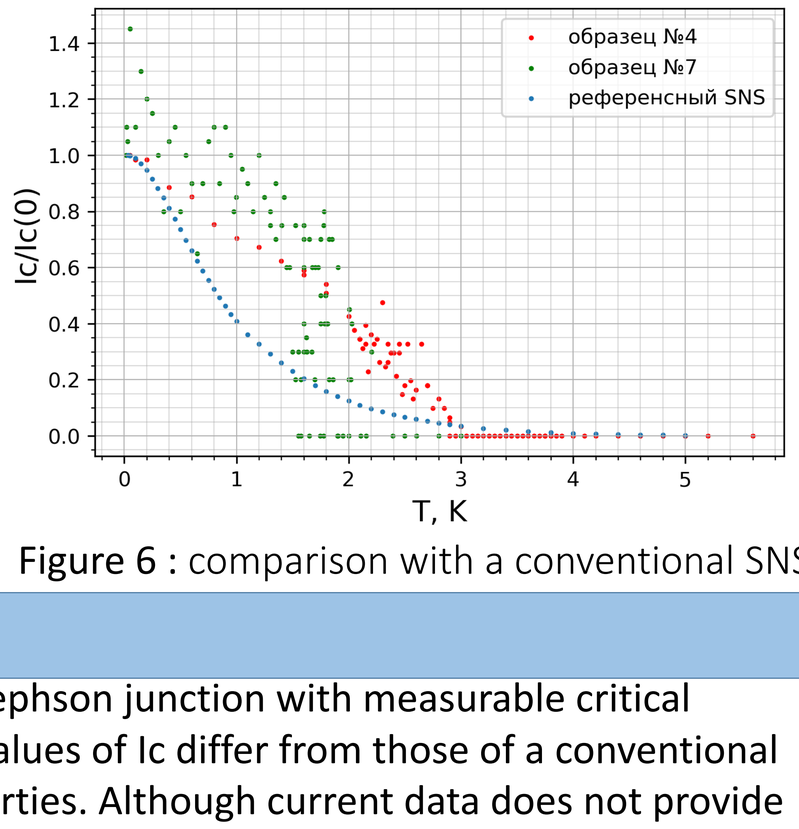

Figure 6 : comparison with a conventional SNS

Results

It has been shown that a ferromagnetic insulator substrate of micron thickness allows for a Josephson junction with measurable critical currents. Ic(T) dependences have features, resembling those of a π-transition, while absolute values of Ic differ from those of a conventional SNS for more than an order of magnitude, which indicates the influence of FI on junction properties. Although current data does not provide unambiguous proof for a π-transition, further improvement will allow to observe the transition more reliably.

1) *Coupling of Two Superconductors through a Ferromagnet: Evidence for a πJunction,* Ryazanov, V. V., Oboznov, V. A., Rusanov, A. Y., Veretennikov, A. V., Golubov, A. A., & Aarts, J., Phys. Rev. Lett. 86, 2427 (2001);
2) Proximity effects in superconductor-ferromagnet heterostructures / A. I. Buzdin // Rev. Mod. Phys. — 2005. — Sep. — Vol. 77. — Pp. 935–976
3) Rapid single-flux quantum logic using π –shifters, A. V. Ustinov and V. K. Kaplunenko, Journal of Applied Physics **94**, 5405 (2003);
4) Controllable supercurrent in mesoscopic superconductor-normal metal-ferromagnet crosslike Josephson structures, T. E. Golikova *et al* 2021 *Supercond. Sci. Technol.* **34** 095001
5) Резонансная спектроскопия динамики вихрей сверхпроводящих токов в джозефсоновских планарных контактах, магистерская диссертация / Д.С. Калашников. — 2022.