Superconducting insulators

Konstantin Yu Arutyunov[2,3], Janne S Lechtinen[4], Alexey A Radkevich[1], Andrew G Semenov[1,2], and Andrei D Zaikin[1,5]

[1]*P.N. Lebedev Physical Institute, 53 Leninsky avenue, Moscow 119991, Russian Federation*
[2]*National Research University Higher School of Economics, Moscow, Russia*
[3]*P.L. Kapitza Institute for Physical Problems RAS, Moscow, Russia*
[4]*VTT Technical Research Centre of Finland Ltd., Centre for Metrology MIKES, Espoo, Finland*
[5]*Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany*

Low-dimensional systems suffer from fluctuations which tend to destroy long-range order. In superconducting nanowires, this general statement manifests itself most prominently in the effect of so-called phase slips. In sufficiently thin wires phase slips completely disrupt long-range phase coherence and induce finite resistance which persists down to lowest temperatures T, thus, destroying superconductivity in the usual sense. Here, we address – both experimentally and theoretically – this state and show that in fact, it demonstrates a mixture of superconducting-like properties at shorter scales and non-superconducting behavior at long scales. Here, we introduce a physical concept of QPS-controlled localization of Cooper pairs that may occur even in uniform nanowires and identify a width-dependent critical length scale L_c which separates relatively long wires that remain resistive within the whole range of temperatures and relatively shorter ones with resistances sharply decreasing as the temperature is lowered. In contrast, the electron spectrum of all, even the most resistive, wires exhibits a well-defined superconducting gap while performing tunnel measurements on them yields superconducting-like $I - V$ curves. Furthermore, some of the samples demonstrate clear signs of Josephson current passing through the wire. Owing to the simultaneous presence of both superconducting-like and insulating-like properties, we name this state a superconducting insulator [1].

A.R. acknowledges financial support from RFBR grant No. 19-32-90229.

[1] K. Arutyunov, J. Lehtinen, A. Radkevich, A. Semenov, and A. Zaikin, Comm. Phys. 4 (2021) 146