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Superconductor-insulator transition in selected films of conventional and high temperature superconductors

One of the fundamental problems in nanoscience research is a question on the nature of the ground state in confined systems, particularly in the case of the superconducting materials. It is well established that upon the reduction of the thickness of superconducting film the film resistance increases and the superconductivity is suppressed. In addition, in a strongly-disordered thin films the external magnetic field induces superconductor-insulator transition.

In this work the superconductor-insulator transition is studied in two types of thin films, conventional superconductor, niobium (Nb) and in the thin films of high-temperature superconductor, $La_{2-x}Sr_xCuO_4$, with the strontium contents $x = 0.048$ and $x = 0.051$.

The Nb films are grown in a form of Si/Nb/Si trilayers using magnetron sputtering at room temperature. The thickness of Nb, d, is varied from 50 nm down to 1.1 nm with a fixed Si thickness of 10 nm. With decreasing d, the structure of the Nb layer changes from polycrystalline to amorphous at $d \leq 3.3$ nm, while the superconducting temperature monotonically decreases, reaching zero for $d < 1.2$ nm. The Hall coefficient, which is positive in thick films, starts decreasing for $d < 6$ nm. Eventually, it changes sign into negative in ultrathin films with $d < 1.6$ nm, indicating that two types of carriers contribute to the conduction, most likely due to the influence of boundary scattering on the relaxation rate of carriers.

The presence of perpendicular magnetic field, or reduction of the Nb film thickness, induces a transition from the superconducting phase to strongly disordered metal. In the films with $d \leq 11.3$ nm an isotherm crossing point is observed, possibly indicating a quantum critical transition. This hypothesis may be supported by the scaling relations for the resistance, which are found in the vicinity of the isotherm crossing, and the observation of negative magnetoresistance, which suggests the presence of superconducting fluctuations on both sides of the crossing point. Both the scaling exponents, and the field at which crossing point is observed, depend on the film thickness differently in case of amorphous and polycrystalline films. The different dependence is most likely caused by different disorder scale in both types of films.

In ultrathin films in the limit of low magnetic fields and very low temperatures the resistance saturates at a value which is several orders of magnitude smaller than the normal state resistance. The finite resistance is most likely caused by unpinned (liquid) vortex state, as confirmed by very low activation energy for vortex pining, and the absence of the vortex glass phase, inferred from the measurements of voltage-current characteristics.

The study of the transport properties of strained $La_{2-x}Sr_xCuO_4$ films ($x = 0.048$, $x = 0.051$), deposited by laser ablation from insulating targets, shows that strong compressive strain induces superconductivity. The superconductivity appears with the reduction of the film thickness, when the substrate-induced compressive strain is enhanced. This thickness-induced insulator-to-superconductor transition is in stark contrast to the thickness-induced destruction of superconductivity observed in niobium films; such behavior so far has not been described in the literature. The superconductivity in the strained films is accompanied by very small, but finite, residual resistance, which is present even in the absence of the magnetic field, and which increases with the enhancement of strain. The finite resistance is most likely caused by strong inhomogeneity of the strained films, which are likely to contain small nonsuperconducting areas within the sample volume.

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