Projekt 4.11. Anomalous metal phase at the superconductor-insulator transition

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Background:
Metals, insulators, and superconductors are three different phases of condensed matter systems, in which electrical conductivity behaves very differently in the limit of very low temperatures: it becomes constant and finite in metals, drops to zero in insulators, and becomes infinite in superconductors. These differences are related to the nature of electrical transport. In metals the current carriers are quasiparticles (electrons or holes). In the presence of strong disorder or strong electron-electron interactions quasiparticles become localized, and the metal is transformed into insulator. In superconductors, on the other hand, the quasiparticles interact to form Cooper pairs, which can carry transport current without resistance. The studies of materials in thin film form, which may be considered 2 dimensional (2D) systems, show that the transport properties may be drastically altered by tuning of various parameters (film thickness, carrier density, or external magnetic field), inducing a superconductor to insulator transition (SIT). The nature of the SIT has been a subject of intensive studies for decades. One of the most outstanding questions has been the nature of the metallic phase, which is observed in some of the systems at the SIT, so that the transition is not direct, but proceeds through a metallic phase. This intervening metal displays conductivity significantly higher that the conductivity in the normal metallic phase, so it has been named anomalous metal (AM). Recent experiments suggest that the fluctuating Cooper pairs, in addition to quasiparticles, or instead of them, contribute to the transport in the AM, possibly as a result of microscopic inhomogeneity developing near the transition, in the form of intertwined superconducting and non-superconducting islands.

Aim:
Here we propose to study experimentally the magnetotransport properties of the AM in thin amorphous films of conventional superconductor, niobium (Nb). Recently, we have observed the AM phase in this system, along with the evidence that in high magnetic fields superconductivity is destroyed by large spin susceptibility of quasiparticles. This would be compatible with the existence of superconducting islands, immersed in the metallic background with nonzero spin susceptibility, and we propose further studies to verify this idea. The studies will involve the preparation of thin Nb films of various thickness on glass and sapphire substrates, detailed characteristic of the films using the X-ray diffraction and transmission electron microscopy, and measurements of the current-voltage characteristics and magnetoresistance in magnetic fields parallel and perpendicular to the film surface. For comparison, additional experiments involving thin films of high temperature superconductors will be performed in the second stage of the project. The magnetotransport experiments will require measurements in milikelwin temperature range, which will be performed in Laboratory of Ultra Low Temperatures, University of Science and Technology (AGH), Kraków (magnetic fields up to 14 T), or in the European Magnetic Field Laboratory (EMFL) in Toulouse, France (pulsed magnetic fields up to 50 T).

Requirements:
M.Sc. in physics (preferably solid state experiment); the ability of basic programming; the manual and technical skills for experimental work; fluency in English.