Thesis
ESPCI - PSL - PARIS
Physics and Materials Laboratory
(LPEM)

Quantum Geometry for a Superconductor-Insulator Transition in superconducting materials

Superconducting quantum technologies are at the heart of major advances, enabling applications ranging from single-photon detectors to qubits for quantum computing, which exploit the coherence and sensitivity of the superconducting macroscopic quantum state to enable high precision and efficiency.

However, a fundamental challenge remains: dissipation. This phenomenon limits the coherence time and sensitivity of these devices, and thus their full potential. One way to reduce dissipation lies in the very nature of superconducting materials, which have a polycrystalline structure.

Most applications are based on granular superconducting materials such as Nb, NbN[1] or grAl[2] (granular aluminium). The grains are surrounded by an oxide layer, the site of dissipation. They are coupled together by the Josephson effect, forming a network of Josephson junctions. In these disordered superconductors, disorder, superconductivity and electron localisation coexist. Superconductivity in such a disordered system remains one of the key questions of modern quantum physics.

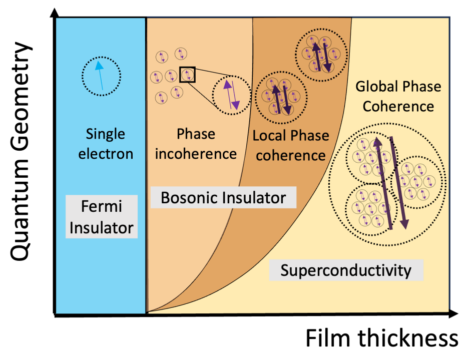

Figure 1: Superconductor-insulator transition with film thickness, Quantum Geometry or Gate Voltage

Depending on various parameters including thickness, disorder or magnetic field, a superconducting thin film can undergo a superconducting to insulating transition (SIT), which allows to extract the most relevant characteristic scales of the system.

Recently, we have shown that a SIT can be tuned by electric field effect in NbN thin films through space charge doping [3].

During this internship, we will investigate the effect of strength of inter-grain coupling affects dissipation mechanisms. We will characterize samples of varying thicknesses through electrical transport measurements at zero and finite frequencies, in a resonant microwave circuit, under magnetic fields, and in cryogenic conditions. We will study the effect of disorder on the intrinsic characteristic scales of superconducting fluids and extract the effect of inter coupling on the dissipation mechanism. Moreover, we will study the effect of controlled disorder geometry, namely quantum geometry, on the SIT. For this purpose, we will introduce high-energy ion magnetic defects into the Nb thin films to selectively weaken superconductivity following the Abrikosov Gorkov law [4]. This strategy will allow us to demonstrate the pair localisation effect in a disordered geometry configuration on the order of the superconducting scales leading to the superconducting to insulating transition in Nb.

Prerequisite: A strong background in quantum mechanics and a taste for simulations and Python coding are recommended. If you are interested: please contact :
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[1] E. Zadeh and al., "Superconducting nanowire single-photon detectors: A perspective on evolution, state-of-the-art, future developments, and applications," *APL*, vol. 118, p. 190502, May 2021.

[2] Grünhaupt and al., "Granular aluminium as a superconducting material for high-impedance quantum circuits," *Nat Mater*, vol. 18, pp. 816–819, Aug. 2019.

[3] S. et al., "Comprehensive phase diagram of two-dimensional space charge doped Bi2Sr2CaCu2O8+x," *Nat Comm*, vol. 8, p. 2060, Dec. 2017.

[4] A. A. Abrikosov and L. P. Gor'kov, "CONTRIBUTION TO THE THEORY OF SUPERCONDUCTING ALLOYS WITH PARAMAGNETIC IMPURITIES," *Zhur. Eksptl'. i Teoret. Fiz.*, vol. Vol: 39, Dec. 1960.