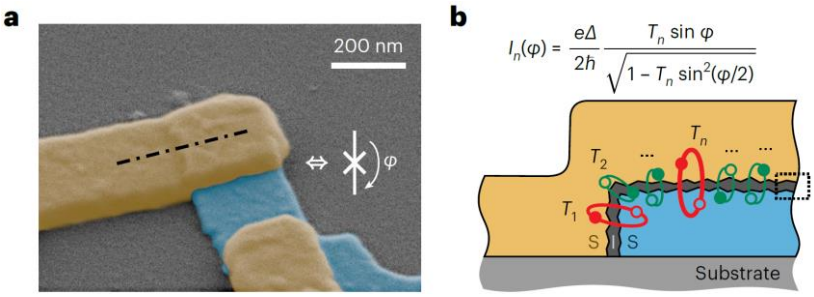
INSTITUT NÉEL Grenoble

Topic for Master 1 internship – Academic year 2024-2025

Measurement of the tunneling probability of Cooper pairs in superconducting quantum circuits.

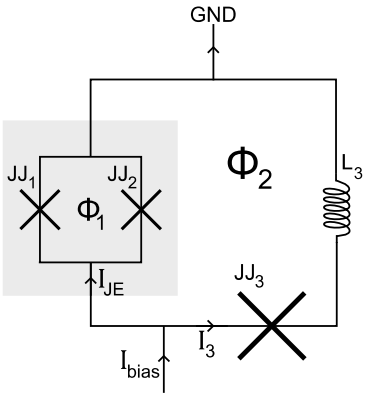
General Scope:



Superconducting circuits have emerged as a powerful and versatile platform for quantum computing technologies. The central element of these circuits, the Josephson junction based on aluminum, rely on the tunneling of Cooper pair through a thin layer of aluminum oxide responsible for a phase φ across the junction. For more than 50 years, they have been used in various devices assuming the canonical current-phase relation (CPR) $I=I_c\sin(\varphi)$. In recent years, however, progress in characterization techniques and extensive use of these components in quantum computing experiments have suggested that this picture is not sufficient to describe very accurately tunnel Josephson junctions [1]. In particular, a non-vanishing transmission probability of Cooper pairs at the tunnel oxide barrier could result in the CPR to include higher order sin(2φ) harmonics resulting from 2-Cooper pairs tunneling events, sin(3ϕ) resulting from 3-Cooper pairs events etc. The observation of these higher order harmonics could this way provide valuable insights of microscopic tunneling events.

Research topic and facilities available:

We recently demonstrated a circuit architecture able to simultaneously control and measure the CPR of superconducting devices, that we used to show dominant sin(2ϕ) harmonics in graphene Josephson junctions [2]. We propose to use this architecture with canonical aluminum/aluminum oxide Josephson junctions to measure higher order harmonics in these junctions. You will first learn the cleanroom fabrication procedure of superconducting quantum circuits based on aluminum/aluminum oxide Josephson junctions, involving e-beam evaporation, oxidation and lithography techniques. Some fabrication parameters could be explored and you will then realize room-temperature DC transport characterization on these samples. When promising samples will have been identified, a few experimental runs in the dilution refrigerator could be performed to measure the CPR of such devices using low temperature DC transport measurement.



References:

-[1] Willsch, Dennis, et al. "Observation of Josephson harmonics in tunnel junctions." *Nature Physics* (2024) 1-7.

-[2] Messelot, Simon, et al. "Direct measurement of a sin(2φ) current phase relation in a graphene superconducting quantum interference device." *Phys. Rev. Lett.* (2024)

Possible collaboration and networking:

This work will be carried out in the Quan2m team at Institut Neel in collaboration with other teams specialized in the fabrication of aluminum based superconducting circuits.

Required skills: Master 1 or equivalent.

A basics level in the field of superconductor, condensed matter physics or quantum physics would be useful, as well as prior experience in applied physics experimental works. The candidate should be interested in learning the cleanroom fabrication technique of aluminum superconducting circuits.

Starting date: 2nd semester 2024-2025

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More information : http://neel.cnrs.fr