Master 2 Internship 2023-2024 + PhD thesis 2024-2027

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Topological superconductivity : towards quantum computation with complex oxide two-dimensional electron gases

Electric-field effect control of two-dimensional electron gases (2DEG) has enabled the exploration of nanoscale electron quantum transport in semiconductors. Beyond these materials, transition metal-oxide-based structures have d-electronic states favoring the emergence of novel quantum orders absent in conventional semiconductors. In this context, the 2DEG formed at oxide interfaces, which combines gate-tunable superconductivity and Rashba spin-orbit coupling is a promising platform to develop novel electronic devices[1]. This unique combination of properties can promote topological superconductivity, an exotic electronic state with remarkable chiral properties. In particular, topological superconductors are predicted to be suitable hosts for Majorana zero energy modes (MZM), which could be used to encode and manipulate non-local quantum information, opening new perspectives for the realization of "fault tolerant" quantum computation technology[2].

The recent discovery of new oxide 2DEGs based on $KTaO_3$ [3] (e.g. $LaAlO_3/KTaO_3$ or $AlO_x/KTaO_3$ interfaces) pave the way towards the observation of MZMs in quantum oxide matter. The project aims at fabricating and studying field-effect mesoscopic nanodevices in $KTaO_3$ oxide interfaces, in which superconductivity and spin-orbit coupling could be tuned at the relevant scales using a set of nano-gates[4]. We will start by investigating the superconducting phase of the 2DEGs by combining various experimental techniques. This includes low temperature electronic transport, microwave conductivity[5], and tunnelling spectroscopy. Our primary objectives are to ascertain the nature of the superconducting state—distinguishing between single-gap and multigap scenarios—and to elucidate the symmetry of the order parameter(s). This foundational knowledge will serve as the basis to understand the origin of superconductivity in KTO 2DEGs, and the interplay between Rashba spin-orbit coupling and superconductivity in the context of topological superconducting phases.

Simultaneously, we will embark on the creation and analysis of Josephson junctions and SQUID devices, in which we will look for signatures of topological superconductivity. Our ultimate objective involves the fabrication of topological 1D nanowires, wherein we will search for robust signatures of Majorana zero modes (MZMs). This quest will be pursued through tunneling spectroscopy of edge states and microwave experiments.

The work will be perform within the SURIKAT ANR project involving several groups in France and Europe. In particular, the project will be done in close collaboration with the group of M. Bibes at the UMphy CNRS-Thales.

Experimental tools : Low and very low temperature cryogenics, dc and microwave transport measurements (20 mK), participation to microfabrication in clean room.

Prerequisite: Student with a strong background in physics and motivated by experimental science.

Contract : The 3 years PhD thesis will be funded either by the ANR project.

[1] *A.D. Caviglia, et al. Electric field control of the $LaAlO_3$ /$SrTiO_3$ interface ground state. Nature* ***56****, 624–627 (2008).*
[2] *A. Stern and N. H. Lindner, Topological quantum computation—from basic concepts to first experiments. Science* ***339****, 1179–1184 (2013).*
[3] *C. Liu et al, Two-dimensional superconductivity and anisotropic transport at $KTaO_3$(111) interfaces, Science* ***371****, 716 (2021)*
[4] *A. Jouan et al. Quantized conductance in a one-dimensional ballistic oxide nanodevice. Nature Elec. 3, 201–206 (2020).*
[5] *S. Mallik et al.* Superfluid stiffness of a $KTaO_3$-based two-dimensional electron gas. *Nature Commun.* ***13****, 4625 (2022).*