Thesis

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Physics and Materials Laboratory
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Vortex-based Digital Superconducting Diode

Last several decades the importance of creating effective superconducting electronics arises again for two main reasons. The first one is the energy consumption of modern computers based on semiconductors because of its large resistance, a dissipated heat in large-scale circuits becomes a significant problem. This resistance also limits the possible operation speed. Superconductors have zero resistance and can work in THz range, that is two order of magnitude faster than current semiconductor processors. The second reason is the progress in quantum computing [1]. Qubits are very sensitive and can work only at very low temperature, and the question of having some preliminary operating circuit, that can de-couple qubits from room-temperature computers, while making some classical computation efficiently, arises naturally.

Recent improvements in cryogenic and nanofabrication allow us not only show concepts of superconducting electronics but open a path to a real competition against semiconducting one. One of a basic element of any circuits is the diode — the element, that can provide signal flow only in one direction [2, 3]. It is used in rectifiers, AC–DC converters, and antennas for detecting electromagnetic signals. One of possible realizations of the superconducting diode is based on the operation of Abrikosov vortices — magnetic flux quantum [4]. The main advantages of this type is a relative fabrication simplicity. But there are still a lot of optimization in terms of design and operating protocols. Coupling vortices with external periodic drive can lead to effect of their synchronous motion [5]. Using that effect, it is possible to make a digital version of the superconducting diode: vortices move synchronously "1" or asynchronously "0". In the Fig.1 these two states and transition from one to another are presented. Realization of this basic device with high-efficiency leads to more complex superconducting integrated circuits.

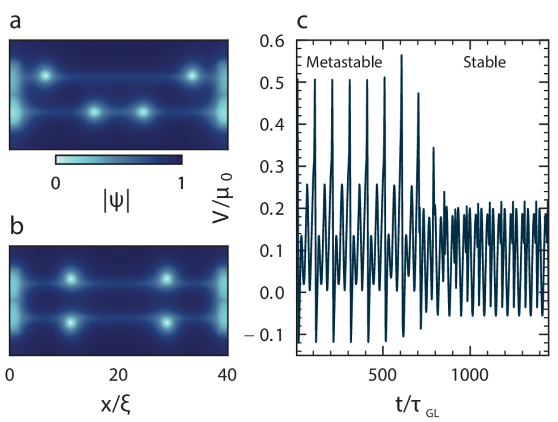

Figure 1: Vortex dynamics in the case of two identical linear defects. (a) and (b) are snapshots of the order parameter amplitude $|\psi|$ in the stable (a) and synchronous (b) states. (c) Evolution of the instantaneous voltage $V(t)$ at the transition from the synchronous to the stable state.

In this internship we propose to study properties of a vortex-based superconducting diode and optimizing its parameters for the best efficiency. It consists of three main parts: fabrication of different diode designs, transport measurements at cryogenic temperatures and numerical modelling based on time-dependent Ginzburg-Landau formalism for an optimal performance. The intern will acquire skills in nanofabrication, cryogenics, low-noise measurements and numerical modelling, as well as knowledge in the field of superconductivity and condensed matter physics in general.

Prerequisite: A strong background in superconductivity and a taste for simulations and Python coding are recommended. If you are interested: please contact **cheryl.feuilletpalma@espci.fr** and **sergei.kozlov@espci.fr**.

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