Superconducting Silicon quantum devices

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Even though silicon is one of the most studied materials, the superconductivity at ambient pressure of boron doped silicon was long ignored due to the extreme doping concentration required to trigger superconductivity, more than three times the boron solubility limit in silicon. This concentration, impossible to reach using conventional micro-electronic techniques, was obtained by the EPLA group using Gas Immersion Laser Doping (GILD), an out-of-equilibrium technique combining chemisorption of a precursor gas and nanosecond laser annealing. The Si:B thin layers epitaxied over a Si substrate could thus achieve active boron concentrations well above the solubility limit and as high as 11 at.% ($6x10^{21}$ cm^{-3}) [Bustarret2006].

Silicon is a low temperature, BCS, superconductor, with a critical temperature tunable with doping from 0 to 0.8 K [Grockowiak2013]. Despite being a ‘classic’ superconductor, the low density of charge carriers (holes bound into Cooper pairs), and the tunability of the electrical, optical, structural and superconducting characteristics with the boron doping, make such superconducting semiconductor a unique system. Modulating the B doping allows for example to combine, in the same material, semiconducting, metallic, and superconducting regions, without the constraint of Schottky barriers at their interfaces. Quantum devices, such as SQUIDs (Superconducting Quantum Interference Devices), Josephson junctions, or superconducting silicon resonators, were demonstrated in the last years [Duvauchelle2015, Chiodi2017, Bonnet2021]

In the frame of quantum engineering, the realization of an all-silicon superconducting electronics would be a major advance. Indeed, silicon micro/nano fabrication clean room processes are mature, allowing the realization of scalable devices. Moreover, spin qubits made of isotopically purified silicon have recently emerged as a most promising technology. Silicon thus appears as a choice material to realize coherent quantum circuits, even more so when coupled to the robustness and absence of dissipation of superconductivity.

This post-doc centers on the realization and full characterization of an all-silicon superconducting transistor, the Josephson FET, basic brick of a superconducting silicon electronics. Such transistor consists in a Si Josephson junction, where two superconducting Si electrodes contact a gated semiconducting channel. If the phase coherence is preserved, a non-dissipative supercurrent can cross the Si channel thanks to the proximity effect, and be modulated by a gate.

Thanks to the epitaxial sharp laser doping profile, associated with the doped Si/Si highly transparent, ohmic interface (an order of magnitude less resistive than that of metallic superconductor/Si interfaces), we were able to demonstrate all-silicon Josephson junctions [Chiodi2017]. Our aim is now to demonstrate that this supercurrent can be modulated by an electrostatic gate in a lower-doped silicon channel, realizing a Josephson transistor (JoFET).

In parallel, we seek, in collaboration with the LETI and the CEA/Grenoble, to reproduce a full proximity effect in transistors from the CMOS technology, in the aim of obtaining a scalable silicon JoFET. To do so, multiple challenges need to be overcame: we need to induce superconductivity on the extremely thin silicon layer forming the source and the drain on FD-SOI standards; to do so not by laser doping but by laser annealing of pre-implanted dopants, to maintain the compatibility with the actual fabrication; to be able to use laser annealing on the pre-formed gate stack…During the PhD thesis of A. Francheteau [Francheteau2017], we have already demonstrated superconductivity on 23 and 33-nm thick SOI layers, both by laser doping and laser annealing of pre-implanted boron. Tests at LETI have moreover shown the possibility of laser treatment on a transistor without damaging the gate stack, that we now wish to reproduce on the ultra-doped devices.

Finally, if successful, we plan to make a step further, coupling the realized JoFET to superconducting resonators, thus realizing the configuration of a gatemon qubit.

During her / his post-doctoral work, the graduate student will grow B-doped Si by the Gas Immersion Laser Doping technique in the EPLA group of C2N. She / he will benefit from the clean-room nano-fabrication techniques available at C2N to conceive superconducting silicon-based micro and nanodevices. The designs will be realised using electronic and laser lithography, reactive ion / chemical etching. The superconducting layers and the devices will be characterised using electron microscopy, optical and structural characterisations (FTIR, XRD, TEM..). Electric transport measurements will be carried out at low temperature either in an ADM (Adiabatic Demagnetisation) setup or through the collaborations established with the Lateqs team at CEA/Grenoble, the Quantronics group at CEA / SPEC and the Detector Physics group at IJCLab.
Candidate profile: experience in superconductivity / quantum devices / mesoscopic physics /semiconductor physics / transport measurements

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