Tuning Superconducting Silicon with Nanosecond Laser Doping

Francesca Chiodi
L. Desvignes[1], D. Débarre[1], G. Hallais[1], L. Largeau[1], M. Amato[4], A. Debernardi[2], B. Sermage[3]

1 C2N, Université Paris-Saclay, CNRS, 10 bd Thomas Gobert, 91120 Palaiseau, France.
2 Sede Agrate Brianza, CNR-IMM, via Olivetti 2, Agrate Brianza, I-20864, Italy.
3 Probion Analysis, Bat Alpha, 3 avenue du Canada, Les Ulis, 91490, France.
4 LPS, Université Paris-Saclay, CNRS, 1 rue Nicolas Appert, 91405 Orsay, France

francesca.chiodi@universite-paris-saclay

Since the discovery of BCS superconductivity in silicon by nanosecond laser ultra-doping with boron, theoretical and experimental works have endeavoured to understand what triggers and controls the superconducting phase. Indeed, superconducting Si has great potential to develop a cryogenic electronics with the advantages of large scale integration and high reproducibility. Through the optimization of the nanosecond laser temporal profile, we achieved an excellent control of both the electrical and structural properties of ultra-doped Si thin layers, with a maximum carrier concentration of 8 at.%, 5 times higher than the state of the art, in monocrystalline epilayers with no defects, 100% dopant activation up to the solubility limit, and homogeneous doping profile [1-3]. We demonstrated that the carrier concentration has now hit an intrinsic maximum: at such large doping concentrations, the concentration of substitutional, active, single B atoms is 'geometrically' limited by the non-negligible probability of having a substitutional B neighbour, thus creating inactive dimers [2]. The control and improvement of the active doping is directly reflected in the control of the superconducting critical temperature T_c, increased by 30% in this optimized setup, in agreement with theory and opposite to previous results (Fig.1) [2].

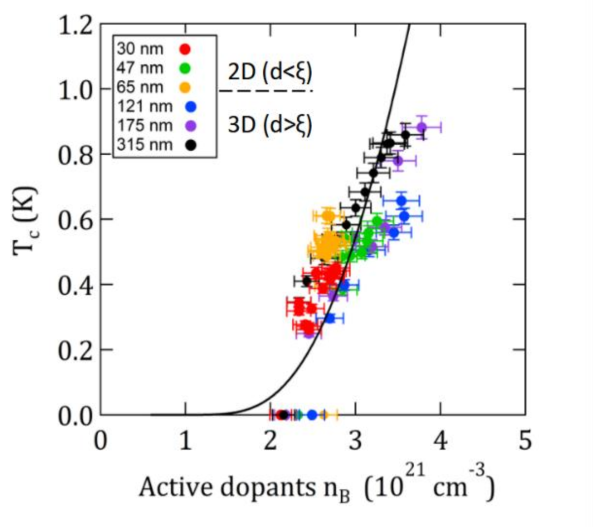

Figure 1: Superconducting critical temperature vs active B concentration of thin SiB layers 30 to 175 nm thick, superposed to the theoretical expectations (theory adapted from Boeri, PRL 2004)

Furthermore, we demonstrated that superconductivity is not only controlled by doping, but also by the lattice deformation, and the superconductivity threshold corresponds to the relaxation of the doping-induced strain. As a consequence, it is possible to tune up to 50% T_c by modifying by 1% the lattice parameter, as shown through nanosecond laser incorporation of Ge up to 20 at.% [4].
Mastering and understanding the materials properties has brought to the development of all-silicon devices, such as Josephson junctions and superconducting microwave resonators [3].

References

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