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Tungsten based SQUID Nanofabrication by means of Focused Ion Beam Induced Deposition

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Direct write techniques such as Focused Electron/Ion Beam Induced Deposition (FEBID/FIBID) constitute versatile, resist-free techniques for the fabrication of nanostructures, offering an alternative to conventional methods such as Optical or Electron Beam Lithography.
The deposition of the comercially available precursor gas $W(CO)_6$ with Ga^+ ions results in a film of W-C with well-established superconducting properties [1]. Planar deposits exhibit a critical temperature of T_c = 4 K – 5 K, an upper critical magnetic field of $B_{c,2}$ = 7 T – 8.5 T and a critical current density of J_c = 0.001 MA/cm^2 – 0.01 MA/cm^2 [2]. The London penetration depth is reported to be λ_L = 850 nm and the superconducting coherence length as ξ = 6 nm – 9 nm [2]. With Ga^+ FIBID and the $W(CO)_6$ precursor, superconducting nanostructures with a linewidth of 50 nm are feasible to fabricate with high precision and reproducibility.

In this work we present the fabrication of nanoscale Superconducting Quantum Interference Devices (nanoSQUIDs) of W-C by means of Ga^+ FIBID. The SQUID loop is formed by a 50 nm thick and 200 nm wide film with a rectangular inner loop of 300 x 700 nm^2. The Josephson Junctions (JJs) are formed by 300 nm long constrictions with a cross-sectional area of down to 50 x 50 nm^2. The SQUIDs obtained show a critical temperature of up to T_c = 4.3 K and a critical current of up to I_c = 8.5 μA. The normal state resistance of the JJs is R_N = 496 Ω. Upon variation of the external magnetic field we observe periodic oscillations in the critical current, I_c, and upon injection of a constant bias current $I_b \sim I_c$ the voltage dropping across the structure displays a sinusoidal dependence on the external magnetic field. The transfer coefficient is remarkably high, with up to V_ϕ = 1301 $\mu A/\phi_0$ due to the high normal-state resistance of the JJs [3]. Recent efforts towards improving the nanoSQUIDs properties will be introduced.

[1] P. Orús, F. Sigloch, S. Sangiao and J. M. De Teresa. *Superconducting Materials and Devices Grown by Focused Ion and Electron Beam Induced Deposition*, Nanomaterials 12, (2022) 1367
[2] P. Orús, R. Córdoba, J. M. De Teresa. *Nanofabrication – Nanolithography techniques and their application,* IOP Publishing (2020), ch. 5.
[3] F. Sigloch, S. Sangiao, P. Orús, J. M. De Teresa. *Large output voltage to magnetic flux change in nanoSQUIDs based on direct-write Focused Ion Beam Induced Deposition technique*, arXiv [Prepint] (2022), [arXiv:2203.05278].

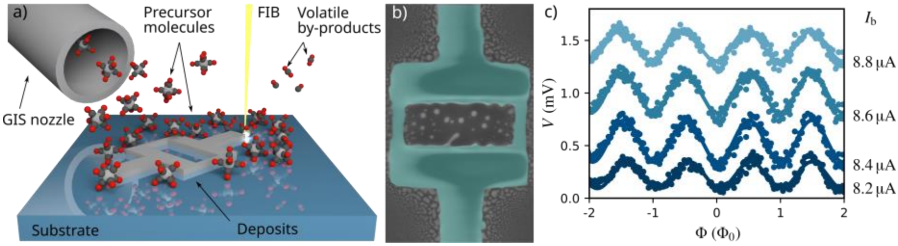

Fig. 1: a) Schematic representation of the FIB induced deposition of a nanostructure. b) A SEM image of a W-C (blue) nanoSQUID fabricated by Ga^+ FIBID. c) The corresponding periodic modulation of the voltage, V, in dependence of the magnetic flux threading the SQUID loop, ϕ. The different lines correspond to different bias currents $I_b \sim I_c$. Reproduced from [3].