FEBID and FIB meet Mr. Feynman and other curious fellows…
…not a joke!

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The combined capabilities of FEBID nanolithography and FIB nanofabrication available in Dual Beam instruments have been exploited to prepare fundamental quantum physics experiments with electrons that were proposed as thought experiments in the 50s and 60s.

The first experiment is the interference and diffraction of electrons through nanoslits as suggested by Feynman in his famous lectures [1]. We have realized the originally proposed scheme by opening two nanoslits on a silicon nitride membrane by FIB milling, to obtain interference of 200 keV electrons in a TEM (Fig. 1(a)), and then closing one by FEBID of Pt precursor to obtain single-slit diffraction (Fig. 1(b)) [2]. We also realized the third part of the Feynman proposal, the which-way experiment about the cancellation of the interference effect when a localization of the electron path is attempted. By depositing an increasing thickness of a TEOS layer over one slit, and analyzing the elastic portion of the transmitted beam, we were able to follow the vanishing of interference due to the increasing contribution of a localized inelastic interaction [3].

The second experiment is the detection of the Ehrenberg-Siday effect (also known as Aharonov-Bohm), whereby the phase of electrons is modified by travelling in a region of zero magnetic field (B=0) where the magnetic flux is non-zero ($\Phi \neq 0$) [4]. The originally proposed setup to realize such a condition was a double slit with a magnetic rod placed in between, on the opposite side from the impinging electrons. We have realized such a setup starting from a double-nanoslit sample, and depositing a Co nanowire by FEBID in between the slits (Fig. 2(a)) [5]. The interference fringes are observed in a TEM as a function of the sample tilt, in order to vary the magnetization along the nanowire with the immersion lens field (Fig. 2(b)). The abrupt shift of the fringes, occurring at ± 5° when magnetization is reversed, are a clear indication of the effect.

Finally, recent applications of FEBID and FIB nanofabrication to the realization of electron vortex beams employed as magnetic probes will be presented. Our group, in collaboration with colleagues at the University of Ottawa, has recently shown that electron beams with unique physical attributes, such as a high orbital angular momentum L (vortex beams) [6] can be obtained from transmission through holographic phase plates in a TEM. These holograms are designed by computer simulation and patterned on silicon-nitride membranes by FIB milling. Since they carry an angular momentum, vortex beams interact with magnetic fields and become an ideal tool to analyse magnetic nanostructures that we produce by FEBID.

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[6] V. Grillo, G. C. Gazzadi, E. Mafakheri, S. Frabboni, E. Karimi, and R.W. Boyd; *Holographic Generation of Highly Twisted Electron Beams*; Phys. Rev. Lett. 114 (**2015**), 034801.

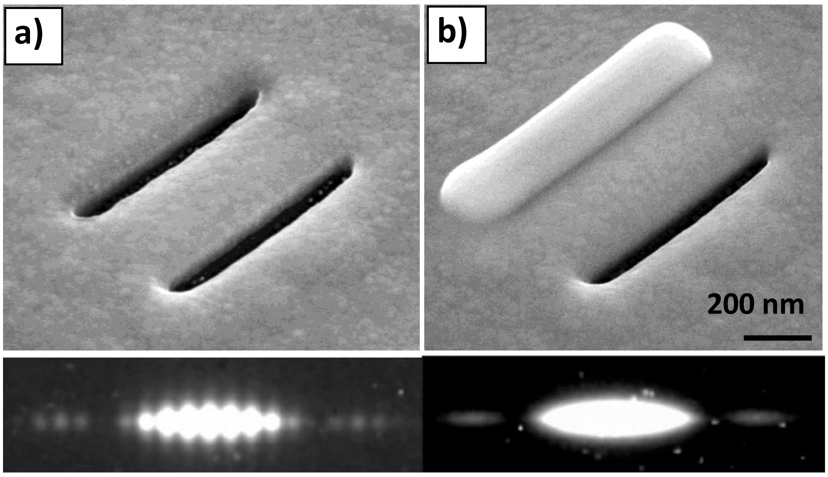

Fig. 1: Feynman double-slit experiment. (a) Two nanoslits opened by FIB milling and, below, the interference pattern of 200 keV electrons measured with TEM; (b) single-slit sample obtained by covering the left slit with a FEBID Pt layer and, below, the corresponding diffraction pattern.

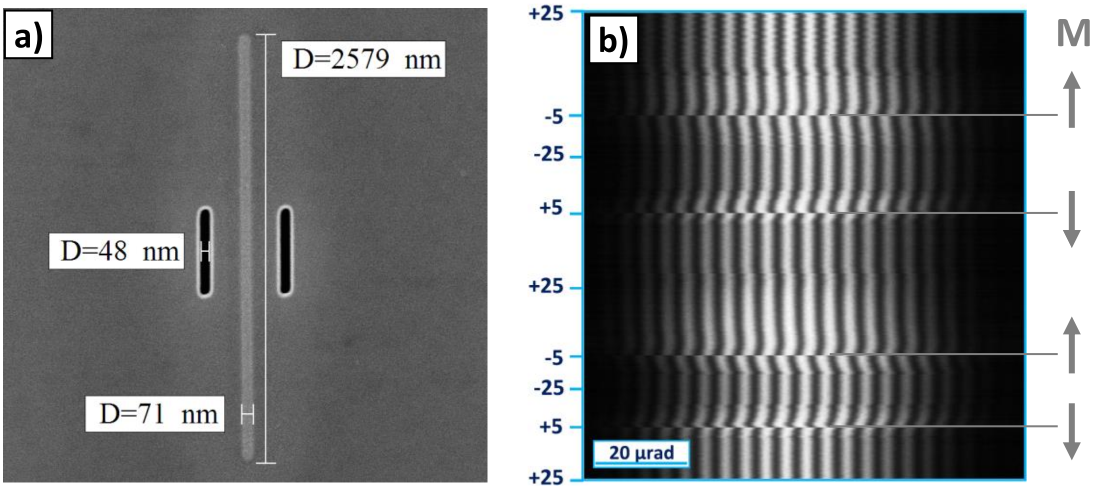

Fig. 2: Ehrenberg-Siday experiment. (a) Double-nanoslit with a Co nanowire deposited in between by FEBID; (b) interference fringes of 300 keV electrons measured with TEM as a function of the tilt angle in order to change the magnetization direction along the Co nanowire. At ± 5° magnetization reverses as shown aside by the arrows and the fringes shift abruptly.