Ultra-fast vortex dynamics in nanoengineered superconductors

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The dynamics of vortices at large transport currents is essential for modeling quasiparticle ensembles under far-from-equilibrium conditions and it sets practical limits for the use of superconductors in applications. Recently, two approaches were used to demonstrate ultra-fast vortex motion at velocities $v \gtrsim 5$ km/s: (i) A clean Pb bridge with a short electron-phonon relaxation time was studied [1], with a strongly nonuniform current distribution both across and along the bridge. (ii) An array of ferromagnetic Co nanostripes on top of a superconducting Nb film led to a dynamic ordering of flux quanta guided by the nanostripes and allowed to achieve a narrow distribution of their velocities v [2]. In both of these approaches, specially designed, locally nonuniform structures were used. At the same time, a close-to-ideal uniform system where the fast heat removal from electrons becomes the limiting factor for ultra-fast vortex dynamics was never investigated experimentally. Theoretically, however, it was predicted that dirty superconductors with weak volume pinning and strong edge barrier for vortex entry should also allow for ultra-fast vortex dynamics [3]. The presence of a strong edge barrier in such superconductors leads to a current gradient near the edge where vortices enter the superconductor and where the flux-flow instability (FFI) is actually nucleating.

In my talk, I will present our recent results [4] on the experimental observation of ultra-fast (5-15 km/s) vortex motion in a direct-write Nb-C superconductor (Fig. 1a). The spatial evolution of the FFI implies a chain of nucleation points along the sample edge and their development into self-organized Josephson-like junctions ("vortex rivers", Fig. 1b). The rarely achieved combination of properties – close-to-depairing critical current, weak volume pinning, and fast heat removal from electrons – make Nb-C a good candidate material for fast single-photon detectors.

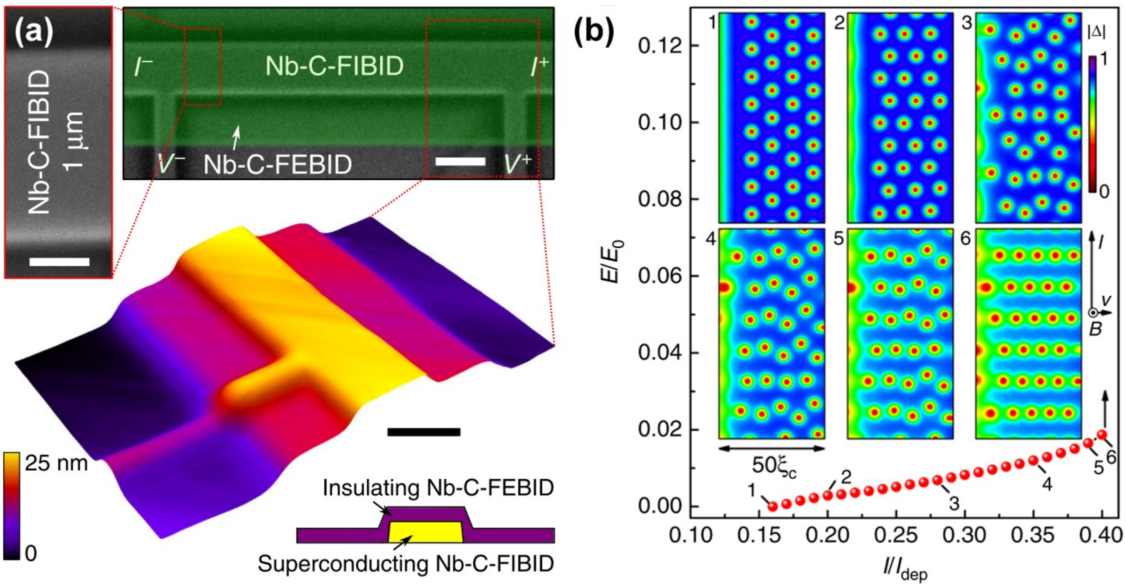

Fig. 1. (a) SEM and AFM images of a 15 nm-thick 1x6.6 μm^2 superconducting Nb-C-FIBID strip covered with an insulating Nb-C-FEBID layer. (b) *I-V* curve and the evolution of the superconducting order parameter in the microstrip, calculated relying upon the time-dependent Ginzburg-Landau equation.

[1] L. Embon, *et al.* Nat. Commun. **8** (2017) 85.
[2] O. V. Dobrovolskiy, *et al.* Phys. Rev. Appl. **11** (2019) 054064.
[3] D. Y. Vodolazov, Supercond. Sci. Technol. **32** (2019) 115013.
[4] O. V. Dobrovolskiy, D. Yu. Vodolazov, F. Porrati, R. Sachser, V. M. Bevz, M. Yu. Mikhailov, A. V. Chumak, and M. Huth. Nat. Commun. **11** (2020) 3291.