Vortex matter in advanced superconductor nanoarchitectures

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Advances in the high-tech fabrication methods have provided novel rolled-up architectures at nano- and microscale, for example, open nanostructured nanotubes and helical nanocoils including superconductor (SC) layers (e.g., InGaAs/GaAs/Nb), which opens up new avenues for tailoring the vortex matter properties in SCs [1]. Rolling up SC Nb nanomembranes into open tubes allows for a new, highly correlated vortex dynamics regime that shows a three-fold increase of a critical magnetic field for the beginning of vortex motion and a transition magnetic field between single- and many-vortex dynamic patterns [2]. In the helical SC nanocoils, the distribution and number of vortices in a quasi-stationary pattern can be controlled by the helical radius, pitch distance and stripe width [2]. A quasi-degeneracy of vortex patterns, which emerges under the condition that the total number of vortices is incommensurable with the number of half-turns, opens up new possibilities for bifurcations and the related control of the vortex transport in the helical SC nanocoils. These results demonstrate pathways of tailoring nonequilibrium properties of vortices in curved SC nanoarchitechtures leading to their application as tuneable superconducting flux generators for fluxon-based information technologies. An inhomogeneous transport current, which is introduced through multiple electrodes in an open SC Nb nanotube, is shown to lead to a controllable branching of the vortex nucleation period. Using an inhomogeneous transport current allows for a significant reduction of the average number of vortices in the nanotube. Open SC nanotubes produce less dissipation as compared to the planar structures under the same magnetic field and transport current, what is of importance for extending the spectrum of SC-based sensors to the low-frequency range. The voltage generated by moving vortices as a function of the applied magnetic field provides useful insight into spatial reorganization of the dynamical vortex patterns in rolled up open SC nanotubes. An increase of the number of vortex chains in a SC nanotube results in a 6-fold decrease of a slope of the induced voltage as a linear function of the magnetic field [3]. The magnetoresistance in an open SC nanotube as a function of the magnetic field reveals an expressed geometry-induced effect due to the occurrence of a phase slip in the area with small absolute values of the normal-to-the-surface magnetic field component. I acknowledge fruitful collaboration with R. R. Rezaev, E. A. Posenitskiy, E. I. Smirnova, E. A. Levchenko and O. G. Schmidt. I thank the Center for Information Services and High Performance Computing (ZIH) at TU Dresden for enabling computations on the HPC system. I gratefully acknowledge the support by the European Cooperation in Science and Technology COST Action "Nanoscale Coherent Hybrid Devices for Superconducting Quantum Technologies" CA16218 and the German Research Foundation (DFG) under grant #FO 956/5-1.

References

[1] V. M. Fomin, Topology and Geometry Controlled Properties of Nanoarchitectures, Phys. Stat. Sol. – Rapid Research Letters 13, 1800595 (2019).
[2] V. M. Fomin, Topology-Driven Effects in Advanced Nanoarchitectures, in: A. Sidorenko (Ed.), Functional Nanostructures and Metamaterials, 195-220 (Cham: Springer International Publishing, 2018).
[3] R. O. Rezaev, E. A. Posenitskiy, E. I. Smirnova, E. A. Levchenko, O. G. Schmidt, V. M. Fomin, Phys. Stat. Sol. – Rapid Research Letters 13, 1800251 (2019).

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