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Topology- and Geometry-Induced Properties of Advanced Nanoarchitectures

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Study of topological matter is one of the fascinating main roads of modern physics. The present overview is aimed at topology- and geometry-driven effects, owing to special geometries of novel micro- and nanoarchitectures fabricated of both conventional and topologically nontrivial materials implemented by the high-tech techniques, in particular, self-organization [1, 2]. I will demonstrate how topology of the quantum fields determines electronic [3], excitonic [4], optical, superconducting [5], magnetic, thermal [6] properties of emerging nanostructured materials leading to their functionalization towards novel applications in advanced nanotechnologies. Self-assembled quantum volcanos, which are singly connected, surprisingly exhibit the Aharonov–Bohm behavior in experiment. This is explained by the fact that in a quantum volcano the electron wave functions are identical to the electron wave functions in a quantum ring from a topological point of view. Combination of a geometric potential and an inhomogeneous twist renders an observation of the topology-driven effects in the electron ground-state energy in Möbius rings at the microscale into the area of experimental verification. Advances in the high-tech roll-up fabrication methods have provided qualitatively novel curved superconductor micro- and nanoarchitectures, e.g., nanostructured microtubes and microhelices. Rolling up superconductor 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. These results demonstrate pathways of tailoring nonequilibrium properties of vortices and phase slips in curved superconductor nanoarchitectures leading to their application as tunable superconducting flux generators for fluxon-based information technologies. For various micro- and nanoarchitectures, we have found a possibility of efficiently engineering the Seebeck coefficient and electric conductivity in one-dimensional stacks of quantum dots, acoustic phonon energy dispersion in one-dimensional quantum-dot superlattices, cross-section-modulated nanowires, Si wires ranging from nanoscale to microscale, and, more recently, multishell tubular structures, which are promising candidates for an advancement in thermoelectric materials and devices. I gratefully acknowledge the support of the COST Action “Nanoscale Coherent Hybrid Devices for Superconducting Quantum Technologies” CA16218 and the German Research Foundation (DFG) under grants #FO 956/4-1 and FO 956/5-1.

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