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Simulation of High-Field Magnetotransport in Non-Planar 2D Electron Systems

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Non-planar two-dimensional (NP2D) electron systems have started to attract theoretical attention [1,2], as they can presently be reliably fabricated on both III-V thin-film heterostructures [3-5] and strained Si nanomembranes [6]. Curvature becomes another degree of freedom available for manipulating electronic properties of these systems (Fig. 1), which leads to novel basic physics and suggests NP2D application in NEMS as ultra-sensitive scales and sensors.

In this paper, we report the high-field magnetotransport calculations in a ballistic curved resonant quantum cavity (RQC). The NP2D electron system is formed at the junction of a GaAs/InGaAs heterostructure by creating two symmetric constrictions (of 40 nm width) in a 200 nm wide quantum wire (Fig. 2). Upon selective underetching of the sacrificial layer, strain relaxation causes the wings of the cavity to roll into a partial cylinder, while the central spine (also 40 nm wide) remains tethered to the substrate. (This design loosely follows that of Ref. [7], although those experiments dealt with pronouncedly scattering-limited transport at non-cryogenic temperatures.) Planar RQCs of similar construction have been studied extensively and their transport properties are well-known [8]. Cylindrical structures, however, display interesting physics on a number of levels. Their curvature induces an attractive geometric potential [9], inversely proportional to the radius of curvature squared. Moreover, their surfaces do not remain normal to the direction of the magnetic field, creating non-uniformities in the flux. The interplay of these factors has interesting effects on the transport properties of cylindrical RQCs, as seen in Fig. 1, which depicts the dependence of the conductance on the curvature and magnetic field (low-field regime).

Computationally efficient modeling of quantum-scale transport under *strong* (>1 Tesla) magnetic fields has been a challenge. Recent enhancements to the well-known recursive Green's function method [10] have improved the feasibility of high-field magnetotransport simulations. This has been accomplished through the decomposition of complex geometries into multiple connected modules with symmetry-adapted gauges. Local gauge transformations are performed at the junctions between modules, and the final transmission matrix is transformed back to gauge-invariant form. We have expanded this method to incorporate non-planar (specifically cylindrical) geometries. Fig. 2 illustrates the evolution of the calculated electron density as the cavity rolls up in in a homogeneous magnetic field of 10 T, applied perpendicular to the flat cavity (topmost left panel). Starting from the well-defined edge states in the flat cavity, the electron distribution throughout the cavity is altered with increasing curvature.

In summary, we present a comprehensive magnetotransport calculation on NP2D cylindrical systems. This work elucidates a signature of NP2Ds and a source of their large potential in NEMS and sensing applications: the interplay between electronics and geometry.

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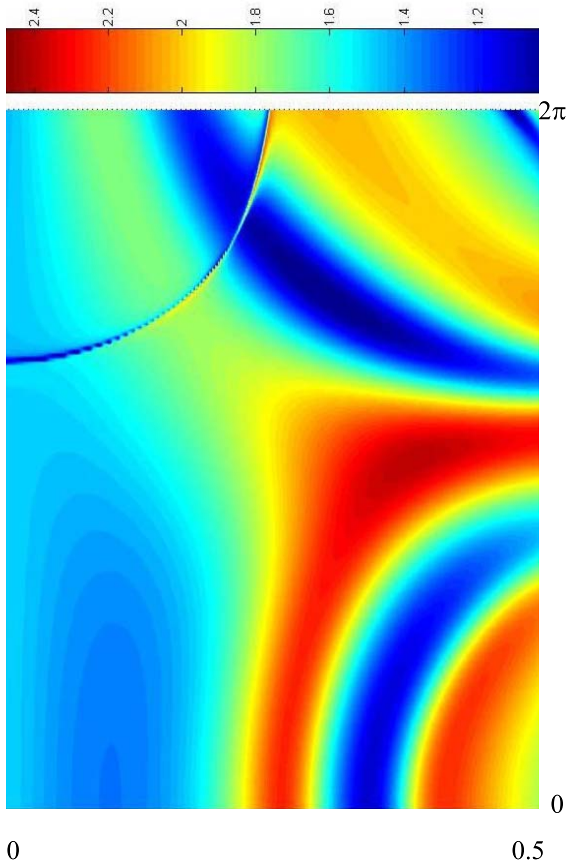

Fig. 1. Conductance, represented by color and given in the units of the conductance quantum $2e^2/h$ (see color bar, top) as a function of the magnetic field (horizontal axis, in Tesla) and curvature (vertical axis, in units of width / radius of curvature). Electron density is 4.5×10^{11} cm^{-2}.

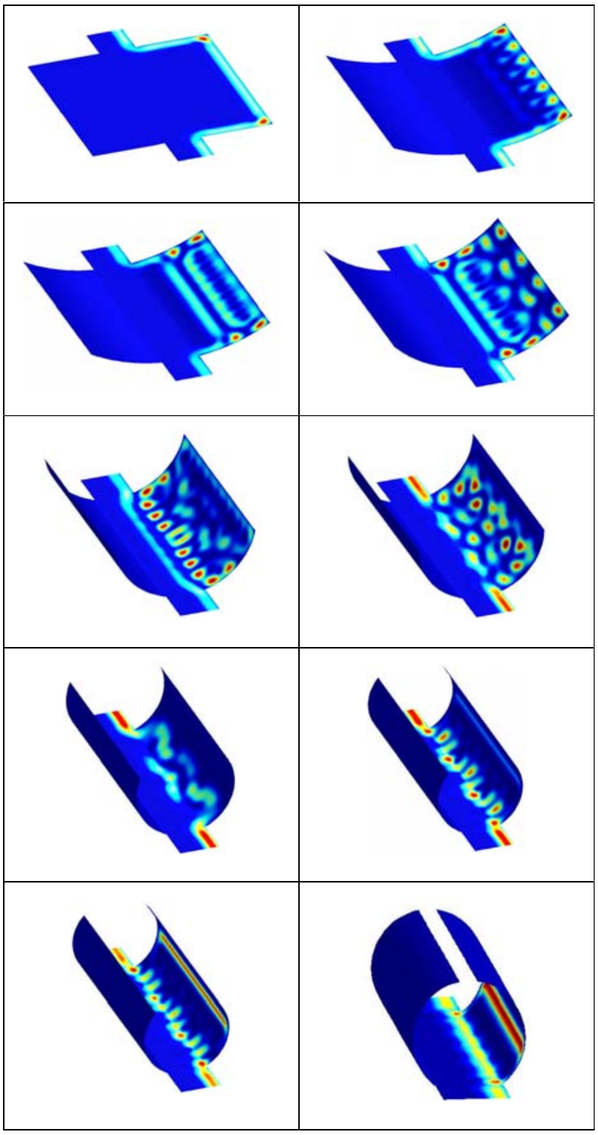

Fig. 2. Evolution of edge states under a 10 Tesla uniform magnetic field (perpendicular to the flat cavity), as the quantum cavity rolls up under strain.