THE AHARONOV-BOHM EFFECT IN SELF-ASSEMBLED InGaAs/GaAs QUANTUM RINGS

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Abstract. Based on the structural information obtained from X-STM measurements, we calculate the electron energy spectra in quantum rings (QR)s and the electron orbital magnetization as a function of the applied magnetic field. Shape anisotropy of QRs results in a mixing of electron states with different magnetic quantum numbers and tends to suppress oscillations of the electron magnetization versus magnetic field. We show that the oscillatory behavior of the average magnetization survives for ensembles of QRs with radial dispersion as large as 10-20%.

Key words: self-assembled quantum rings, magnetization, Aharonov-Bohm effect.

In view of our observation that buried InGaAs/GaAs quantum rings (QRs) are characterized by an asymmetric rim and a depression rather than an opening at the center (see Fig. 1), it is questionable whether these asymmetric crater-like structures can effectively manifest the electronic properties (like the Aharonov-Bohm oscillations) peculiar to doubly connected geometry. When modeling an in-plane shape anisotropy of the quantum ring, the rim height and width are described by the expressions $h_M(1+\xi\cos 2\varphi)$ and $\gamma(1+\eta\cos 2\varphi)$, where φ is the azimuthal angle. With $h_M = 3.6$ nm, $\xi = 0.2$, $\gamma = 3$ nm, $\eta = -0.25$, the thickness of the crater at its center $h_0 = 1.6$ nm, and the rim radius $R \approx 11$ nm we find that for an indium concentration of about 60% a calculated surface relaxation matches the measured relaxation of the [110] and $[1\bar{1}0]$ cleaved surfaces.

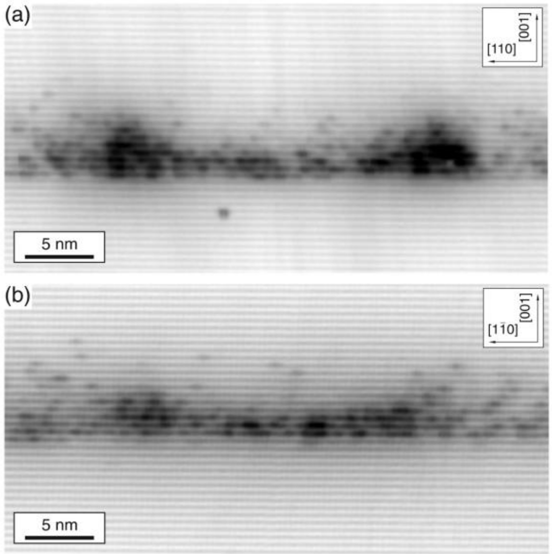

Fig. 1. Topography X-STM images of a cleaved quantum-ring in the $[110]$ **direction (a) and** $[1\bar{1}0]$ **direction (b);** V_{sample}**= –3 V. The height scale is 0 nm (white) to 0.25 nm (black).**

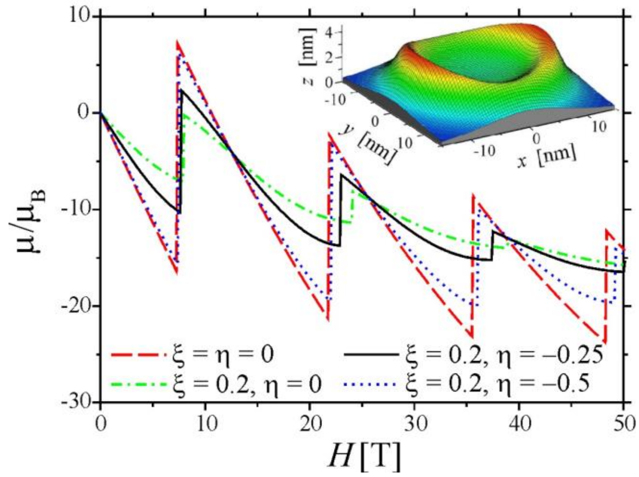

Fig. 2. Magnetic moment induced by the ground-state persistent current as a function of the applied magnetic field for $In_{0.6}Ga_{0.4}As$ **QRs with** R **=10.75 nm,** h_0 **= 1.6 nm,** h_M **= 3.6 nm,** γ **= 3 nm, at different values of the anisotropy parameters** ξ **and** η**.** μ_B **is the Bohr magneton. Inset: the used model for the shape of a QR for** ξ**=0.2,** η **= –0.25.**

Figure 2 shows the effect of the ring-shape anisotropy on the oscillations of the calculated magnetic moment μ, induced by the electron persistent current, as a function of the applied magnetic field H. In a ring with a constant rim width, transition magnetic fields, which correspond to sharp jumps of μ due to interchange between the ground and first excited electron energy levels, increase with increasing ξ. More importantly, variations of the height of the rim with φ suppress oscillations of μ versus H. However, for the experimentally revealed ring geometry, where a decrease of the rim height as a function of φ is accompanied by a simultaneous increase of rim width, the aforementioned suppression effect is significantly weakened, implying that the oscillatory behavior of $\mu(H)$ should be observable for these asymmetric rings.

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