Anomalous Aharonov-Bohm-Type Effects in Square Array of Antidots

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Abstract. We have studied the Aharonov-Bohm(AB)-type oscillations in square arrays of antidots fabricated from GaAs/AlGaAs two-dimensional electron systems. The oscillation period was found to evolve smoothly from the low magnetic field range to the quantum Hall regime. The AB-type oscillation phenomenon exhibited a few unexpected features in the vicinity of filling ν=2, including an anomalous oscillation period and a new phase-shifted oscillation period. The latter phenomenon is attributed to spin-resolved edge states around the antidots.

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Antidot array fabricated from two-dimensional electron system provides an interesting system to explore the electron transport in artificial periodic potential. The magnetoresistance in the system exhibits the so-called Aharonov-Bohm(AB)-type oscillations both in low and high magnetic field regimes [1-3]. The *B*-periodic oscillations reflect the modulation of the electronic density of states originating from the Bohr-Sommerfeld quantization of electron orbits pinned around individual antidots.

In this work, we investigated the AB-type oscillation in the square array of antidots. We found the period of AB-type oscillations to evolve smoothly as the nature of the relevant quantized orbits changes from pinned orbits in the low field regime to edge states in the quantum Hall (QH) regime. In some filling ranges, we found AB-type oscillations with different period.

Samples were fabricated from a GaAs/AlGaAs single heterostructure, which contained a two-dimensional electrons gas (2DEG) of density n= 4.0×10^{15} m^{-2} and mobility μ= 98 m^2/Vs residing at 60 nm below the surface. The electron mean free path at 4.2 K was about 10.2 μm. Using electron beam lithography and shallow wet chemical etching, a square array of antidots was fabricated on the active area of a Hall bar. Precise alignment of the antidot pattern with the edges of the Hall bar was ensured by a single step lithography and etching. We prepared several antidot array samples with different numbers of antidots (5×25 and 5×5). The lattice period and antidot radius were a=1 μm and r=350 nm in all arrays.

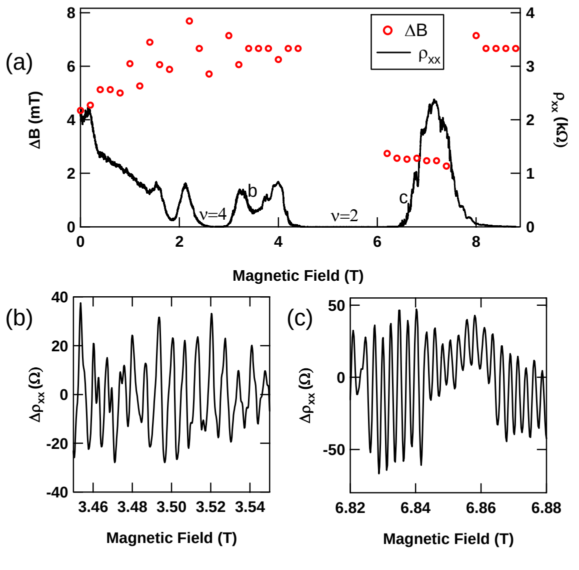

FIGURE 1. (a) Magnetoresistivity (right axis) of a 5×25 antidot array sample at a front gate bias V_G=0V. Circles (left axis) represent the period of AB-type oscillations in the respective field ranges. The periods of the oscillations are obtained from the Fourier spectra of the oscillatory component of $\Delta\rho_{xx}$ of the magnetoreistance. The spectra are taken from the field ranges at the indicated fileds spanning 0.2 T (0–0.2T, 0.2–0.4T, 0.4–0.6T...), which contains more than 25 periods of the oscillations. (b),(c) $\Delta\rho_{xx}$ at around 3.5 T and 6.85 T respectively. The period ΔB is 6.7 mT in (b) and 2.5 mT in (c).

A Au-Ti Schottky front gate enabled us to tune the Fermi energy of the system. The samples were cooled in a mixing chamber of a dilution refrigerator whose base temperature was 30 mK. The magneto- and Hall resistance components were measured by a standard low frequency ac lock-in technique in perpendicular magnetic fields up to 15 T.

The trace in Figure 1(a) is $\rho_{xx}(B)$ of a 5×25 antidot array sample. The trace contains an oscillatory component over a wide range from zero magnetic field to the QH transition region. Near 0 T the period is ΔB=4.2 mT, which corresponds to a single flux quantum per unit cell area of the square lattice $\Delta B = h/eS$ ($S= a^2 = 1\ \mu\mathrm{m}^2$). Figure 1(b) shows the oscillatory components of $\rho_{xx}(B)$ in the vicinity of ν=3. The oscillation amplitude as converted to $\Delta\sigma_{xx}(B)$ is typically ~0.04 e^2/h. As shown by the red circles in Figure 1(a), the period ΔB shows a tendency of gradually increasing with B in the low magnetic field range (0<B<2T) and settles at a value about 6.7 mT in the QH regime, which corresponds to a single flux quantum per effective antidot area $S=\pi r_{\mathrm{eff}}^2$ which includes the depletion region of width ~100 nm around the antidots.

In addition to the “normal” AB-type oscillations described above, we observed unexpected features at specific filling ranges. Figure 1(c) shows the oscillatory component $\Delta\rho_{xx}(B)$ observed on the higher field slope of the $\nu = 2$ QH valley. These oscillations are clearly seen in the range 6.5T<B<7.3T. However, the period ΔB~ 2.5 mT bears no simple relation with the antidot area or its multiples, so that the origin of this effect is presently unidentified.

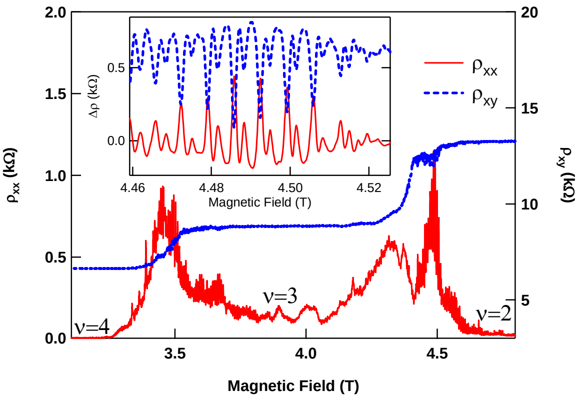

FIGURE 2. Traces of ρ_{xx} and ρ_{xy} of a 5×5 array sample in the field range between ν=2 and 4 (the respective vertical scale is given on each side). The inset shows the oscillatory components $\Delta\rho_{xx}$ and $\Delta\rho_{xy}$ (offset by 0.6 kΩ) around 4.5 T, which show a remarkable correlation. The oscillatory behavior shows up as two series with the same period ~6.6 mT but phase shifted by ~0.7π and different amplitudes.

The main panel of Figure 2 shows the traces of ρ_{xx} and ρ_{xy} of a 5×5 array sample in the field range between ν=2 and 4. The inset shows expanded traces of $\Delta\rho_{xx}$ and $\Delta\rho_{xy}$ around B~4.5 T, *i.e.* the lower field side of the ν=2 QH state, which exhibit two noteworthy features. As is clear from the traces, the oscillation comes in two series with different amplitudes which have the same period ΔB=6.6 mT but mutually phase shifted by ~0.7π. Similar phenomena were reported for single antidots[4] and mesoscopic antidot arrays[5], although in these cases the phase shift of the additional series was π so that they were in some cases referred to as frequency doubling (*i.e.* emergence of $h/2e$ oscillation). The additional period was interpreted as arising from spin-resolved edge states. It also constitutes a plausible interpretation for the present case, because the effect occurs in the vicinity of ν=2, even though it is difficult to rule out the possibility that the two series originate from different parts of the antidot array.

Another noteworthy feature of the data shown in the inset of Figure 2 is the strong correlation between the oscillatory components of ρ_{xx} and ρ_{xy}. In fact, the relation $\Delta\rho_{xx}= -\Delta\rho_{xy}$ appear to hold very well in this range. A similar correlation between mesoscopic fluctuations in ρ_{xx} and ρ_{xy} has been reported for a mesoscopic Hall bar sample, and discussed in terms of edge channel transport even though the exact mechanism for the correlation is still unsolved[6]. The present result shows that such correlation can occur for the case of periodic AB oscillation. Since the regular array of antidots in the QH regime can be regarded as an experimental realization of the network model, the present system should shed light on this issue.

In summary, we have studied the AB-type oscillation in antidot arrays of different overall sizes. The period of the oscillation evolves smoothly from the low magnetic field regime to the QH regime. A few additional features observed in the vicinity of ν=2 pose interesting subjects for further studies.

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