

Aharonov-Bohm-type Oscillations of Small Array of Antidots in Quantum Hall Regime

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Abstract. We have studied the B -periodic resistance oscillation in the quantum Hall transition region in a small array of antidots. These Aharonov-Bohm-type oscillations at high magnetic field originate from periodic crossing through the Fermi level, of the single particle states circumnavigating each antidot. In addition to the normal AB-type oscillation in the range of filling factor between $\nu=2$ and 3 and other higher fillings, a new oscillation with a singular period which is about one third of what one expects from the antidot size has been observed between $\nu=1$ and 2.

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Antidot array in two-dimensional electron system (2DES) exhibits the B -periodic Aharonov-Bohm-type (AB-type) oscillation in the low magnetic field [1]. We have recently observed another AB-type oscillation in the quantum Hall plateau transition region in triangular and square arrays of antidots [2,3], whose periods were determined by the size of antidot. We suggest that the density of states, which originate from single particle states circumnavigating each antidot, causes these oscillations.

In this work, we investigated oscillatory magneto-resistance in the field range between $\nu=1$ and 2 at very low carrier density in the small array of antidots, and found an unexpected oscillation period which was about one third of what one expects from the antidot size. To our knowledge, such anomalous oscillation has not been observed in macroscopic[1-3] or mesoscopic[4] antidot lattices or in single antidots [5,6].

Samples were fabricated from a GaAs/AlGaAs wafer which contained a 2DES of density $n=3.8 \times 10^{15} \text{ m}^{-2}$ and mobility $\mu=60 \text{ m}^2/\text{Vs}$ at 60 nm beneath the surface. Using electron beam lithography and 30 nm wet etching, a square array of finite antidots as shown in the inset of Fig.1-(b) was fabricated on the active area ($5.4 \times 10 \text{ } \mu\text{m}^2$) of a Hall bar with AuGe/Ni Ohmic contact pads. The lattice period was $a=1 \text{ } \mu\text{m}$ and the antidot diameter was $d=600 \text{ nm}$. A Au-Ti Schottky front gate enabled us to control the carrier density. The sample was cooled down to 30 mK in a mixing chamber of a dilution refrigerator. Four-terminal measurements were made under a perpendicular

magnetic field up to 15 T by a standard ac lock-in technique at 13 Hz.

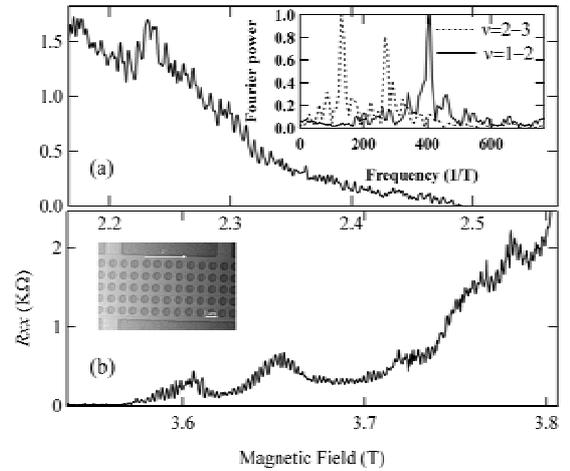


FIGURE 1. Magnetoresistance at $T=30 \text{ mK}$ at electron density $n=1.49 \times 10^{15} \text{ m}^{-2}$ in the filling factor range between (a) $\nu=2$ and 3, and (b) $\nu=1$ and 2. The upper inset shows Fourier power spectra obtained from the oscillatory part in the range $3.57 < B < 3.72 \text{ T}$ (between $\nu=1$ and 2) and in the range $2.2 < B < 2.34 \text{ T}$ (between $\nu=2$ and 3). The lower inset shows an atomic force micrograph of a square array (5×10) sample.

Figure 1 presents the magnetoresistance in the field range between (a) $2 < \nu < 3$ and (b) $1 < \nu < 2$ at $V_g = -190 \text{ mV}$. The AB-type oscillation periodic in B is observed

in the quantum Hall plateau transition region over a wide range of filling from $\nu=2$ to 10 in this sample[3]. The oscillation period corresponds to a single flux per antidot area $\Delta B=h/eS$, $S=\pi(d/2)^2$ (with an appropriate correction for the depletion region). The AB-type oscillation seen at $V_g=-190$ mV in the field range between $\nu=2$ and 3 shown in Fig.1-(a) is of this “normal” type. The period 7.5 mT corresponds to diameter of electron trajectory 840 nm, which agrees with the lithographical diameter of the antidot with the estimated width of the depletion region.

In the filling range between $\nu=1$ and 2, another kind of B-periodic oscillation is observed with period $\Delta B=2.5$ mT (shown in Fig.1-(b)). The amplitude of oscillation tends to be larger at more negative V_g , and it disappears for $V_g>-50$ mV. The period of the oscillation was about one third of what is expected from the antidot area. The difference between the “normal” AB-type oscillation between $\nu=2$ and 3 and “anomalous” oscillation between $\nu=1$ and 2 is highlighted in the Fourier power spectra of the oscillatory part shown in the inset of Fig. 1-(a).

There are a few cases in which AB-type oscillation with non-standard period is observed. Ford *et al.*[5] report frequency doubling (*i.e.* $h/2e$ oscillation) in their single antidot sample, which they interpret as a phenomenon occurring in a regime where crossover of dominant edge channel takes place. Schuster *et al.*[4] also report observation of frequency doubling around $\nu=2$ at very low carrier density in one of their finite antidot lattice samples. They attribute the phenomenon to resonant process between spin-resolved edge states.

These are, however, $h/2e$ period, and there is no report, to our knowledge, of $h/3e$ period. It is obvious that the presently observed singular period close to $h/3e$ does not fit to any of the existing picture.

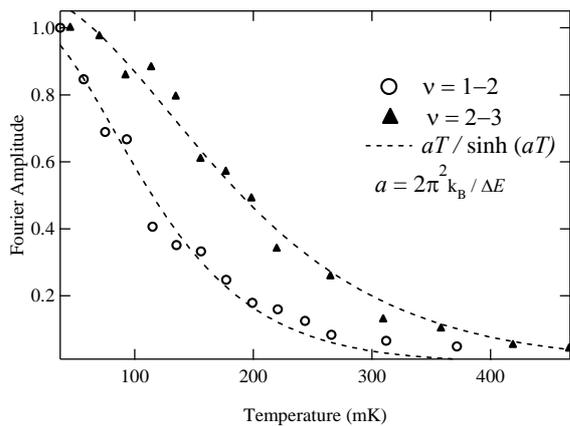


FIGURE 2. Temperature dependence of the amplitude of the AB-type oscillation seen between $\nu=1$ and 2 at $V_g=-190$ mV and between $\nu=2$ and 3 at $V_g=-191.5$ mV. The dashed curve represent the fit to $aT/\sinh(aT)$.

In order to shed light on the origin of the singular oscillation between $\nu=1$ and 2, we studied the temperature dependence of the oscillation amplitude. As shown in Fig. 2, the temperature dependence can be fitted to $aT/\sinh(aT)$, which is similar to the temperature dependence of Shubnikov-de Hass effect and reflects the thermal smearing of the Fermi function. This suggests that the oscillation between $\nu=1$ and 2 reflect the fine structure in the density of states at Fermi energy like at other fillings. As the energy spacing calculated from the fit was $\Delta E=0.087 \pm 0.003$ meV, which was smaller than the value $\Delta E=0.137 \pm 0.006$ meV obtained for the one between $\nu=2$ and 3.

We also investigated the period of the oscillation as a function of the gate voltage V_g . The value $\Delta V_g=0.22$ mV obtained from the oscillation in the field between $\nu=1$ and 2 was much smaller than the value $\Delta V_g=1.3$ mV between $\nu=2$ and 3 near $V_g=-190$ mV. As the oscillation with gate voltage was caused by the periodic crossing of energy states through Fermi energy the oscillation in this experiment reflects narrower energy separation than that in $\nu=2$ and 3. This result was consistent with the temperature dependence.

In summary, we have studied the AB-type oscillation in the quantum Hall plateau transition region in the small array (5 by 10) of antidots. In the field range between $\nu=1$ and 2, we have found a singular oscillation with period about 1/3 of the normal period. From the temperature dependence and the period with gate voltage of the oscillation, it appears to originate from the fine structure in the density of states and the energy separation is smaller than the normal AB-type oscillations at other fillings. The origin of the singular period close to $h/3e$, however, is yet to be elucidated.

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