Novel microwave resonance around integer Landau level fillings in unidirectional lateral superlattices

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Abstract. We have investigated microwave conductivity of unidirectonal lateral superlattices (ULSLs). In the vicinity of the $\nu = 2$ quantum Hall state, striking microwave resonance is observed on the sample having the modulation along the rf electric field, while no resonance is discerned on the samples without modulation or with the modulation perpendicular to the rf electric field.

Keywords: Lateral superlattice; Microwave conductivity; Charge density wave; Pinning mode resonance
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INTRODUCTION

Microwave conductivity has recently proven to be a powerful probe to investigate electron-solid-like ground states, the Wigner crystal (WC) [1] and the charge-density-wave (CDW) [2,3] states, of a two-dimensional electron system (2DES) subjected to a quantizing magnetic field. Resonant peaks observed in the frequency dependence of the conductivity are interpreted as the pinning modes of WC or CDW. The study of these electron phases usually requires ultrahigh mobility 2DESs, since these fragile states are otherwise readily destroyed by disorder. Conversely, WC or CDW states are expected to be corroborated by artificially introduced periodic potential modulation having the period matching with the inherent period of WC (CDW). In fact, the present authors observed anisotropic dc resistivity suggesting the formation of the unidirectional CDW (stripe) phase in a short period (~100 nm) unidirectional lateral superlattice (ULSL) fabricated from a 2DES with a modest mobility [4]. In the present paper, we investigate diagonal microwave conductivity of ULSLs having the period 200 nm. We find novel resonances in the vicinity of integer quantum Hall states when modulation is along the rf electric field.

EXPERIMENTAL

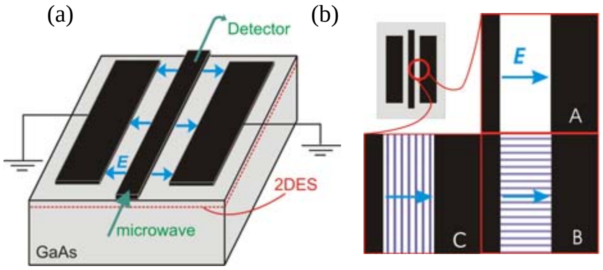

Fig.1. The schematic of the samples.
(a) Coplanar waveguide patterned onto the surface of the wafer. An rf electric field *E* is polarized perpendicular to the propagation direction. (b) Unidirectional modulations with the period 200 nm were introduced on the slots in two different orientations; B: along the rf electric field and C: perpendicular to the rf electric field. Sample A is a reference sample without modulation.

The schematic of the sample is shown in Fig. 1. A metal film coplanar waveguide (CPW) was patterned onto the surface of a GaAs/AlGaAs 2DES wafer (mobility $\mu = 102\ \mathrm{m^2V^{-1}s^{-1}}$). An rf electric field is polarized perpendicular to the transmission line, namely perpendicular to the propagation direction. The power transmission P through the CPW can be related to the real part of the diagonal conductivity $\mathrm{Re}(\sigma_{xx})$ of the 2DES underneath the slots between the metallic gates as $\mathrm{Re}(\sigma_{xx}) = -w/(2lZ_0)\ln(P/P_0)$, where $l = 1.6$ mm is the CPW length, $w = 28\ \mu$m is the slot width, $Z_0 = 50\ \Omega$ is the line impedance [1-3], and P_0 is the power transmission in the limit of vanishing conductivity of the 2DES. Periodic potential modulation with the period $a = 200$ nm was introduced via strain-induced piezoelectric effect by placing a grating of the negative electron-beam resist on the slots. Two samples differing in the direction of the modulation are examined: samples B and C have the modulation along and across the rf electric field, respectively. We also prepare a reference sample without modulation

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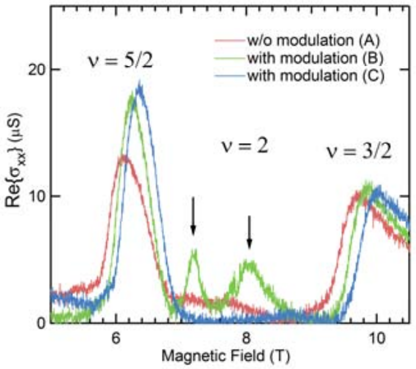

Fig.2. Real part of diagonal conductivity at the frequency $f = 0.5$ GHz in the vicinity of $\nu = 2$. In sample B, two extra peaks are discernible (indicated by arrows), which are absent in samples A and C.

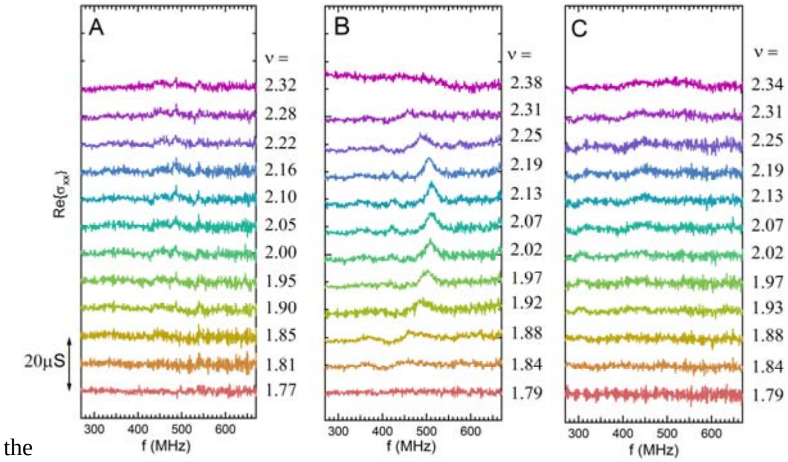

Fig.3. Conductivity spectra at fixed ν (noted in the figure) in the vicinity of $\nu = 2$ for samples A, B, and C. Adjacent traces are offset by 10 μS for clarity. The small spikes in the trace of A, which are not shifting with magnetic field, are likely to be brought about by experimental artifact.

(sample A). Measurements are performed at ~ 50mK. At low magnetic fields, we observe commensurability oscillation (CO) [5] on sample B, which represents the first direct observation of the CO in the conductivity. (Note that CO has thus far been observed in the resistivity.)

RESULT

Our central finding is presented in Figs. 2 and 3. In Fig. 2, we show Re(σ_{xx}) at the frequency $f = 0.5$ GHz in the vicinity of the $\nu = 2$ quantum Hall state. In sample B, two extra peaks (marked by arrows) are observed to emerge, which are absent in the reference sample A without modulation and therefore can unambiguously be ascribed to the effect of the modulation. The extra peaks are also absent in sample C, indicating the anisotropic nature of the origin of the peaks. In Fig. 3 we display conductivity spectra Re(σ_{xx}) vs. f at fixed ν in the vicinity of $\nu = 2$. We choose a spectrum at a filling within the quantum Hall plateau (Re(σ_{xx}) ~ 0) as the reference power transmission P_0: the spectrum at $\nu = 1.75$ for sample A, $\nu = 1.77$ for sample B, and $\nu = 1.76$ for sample C. The choice of the reference does not make significant difference, so long as it is located within the quantum Hall plateau. The spectra shown in Fig. 3B reveal that the resonant peak appears in the filling factor range $1.84 < \nu < 2.31$, and that the peak frequency f_{pk} slightly varies with ν. Similar but weaker resonances are also observed around $\nu = 3$ and 4 on sample B. Such peaks are absent in samples A and C. The origin of the novel resonant peak is not known at present, but its resemblance to the pinning mode of WC [1], as well as the high Q-factor $Q = f_{\mathrm{pk}}/\Delta f \sim 20$ (with Δf the full width at half maximum), suggests that the peak represents the pinning mode of a certain electron-solid-like state induced by the periodic modulation. The filling factor range where the present resonance is observed overlaps with the range the pinning mode resonance of WC is reported in [1]. However it is rather unlikely that WC is corroborated by the unidirectional periodic modulation. Anisotropic behavior of the present resonance is reminiscent of the pinning mode resonance of the stripe phase [3], although the filling factor range where the present resonance is observed deviates from the range the stripe phase is expected to form. If we assume that the stripe is formed along the modulation, the presence (absence) of the resonant peaks in sample B (C) suggests that the pinning mode oscillations take place along the stripe. Apparently, further studies are required to clarify the origin of the resonance peaks.

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