Transport measurement of two-dimensional electron system under ultra-high magnetic fields

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We report on the transport property of a two-dimensional electron system (2DES) in ultra-high magnetic fields. There is a prediction that the 2DES will go into Wigner crystal state in extremely strong magnetic field regime. On the other hand, according to another prediction based upon the global phase diagram, the 2DES is expected to go into Hall insulator in strong magnetic fields. These pictures are incompatible with each other from the viewpoint of disorder and electron-electron interaction. As mentioned above, various phenomena in strong magnetic fields would be expected. However, such a strong magnetic field can be obtained only as a short pulse, so that there are much difficulties in the experimental approach because of huge induced voltage, noise, and self-heating of samples. Therefore, experimental observation, especially concerning transport properties, has not been performed.

In this study, we have tried to develop transport measurement technique of 2DES up to 100 T in order to investigate the electronic state directly in ultra-high magnetic fields. Ultra-high magnetic fields were generated using the single-turn coil method in the megagauss laboratory, ISSP (Fig.1). Using this method, magnetic fields were generated beyond 100 T within 10 μs by discharging huge current to a single-turn coil (Fig. 2). The magnetotransport measurement was carried out by RF reflection method: the RF bias was used mainly aiming to reject induced voltage incidental to pulsed magnetic fields. The reflectivity r is written as the next formula: $r = Z\text{-}Z_0/Z+Z_0$, where Z is impedance of a sample; Z_0 is characteristic impedance of a system. The RF system consists of filters, amplifiers, and a phase sensitive detector (center frequency of 350 MHz, signal bandwidth of 50 MHz) with low noise specification (Fig. 3). Present sample was prepared from AlGaAs/GaAs heteojunction with density of 4×10^{11} cm^{-2} and mobility of 2.4×10^{6} cm^2/V s at 4.2 K. To measure the diagonal conductance s_{xx} with two-terminal method, samples were patterned into Corbino geometry with Au/Ge/Ni alloy contacts. These samples are modified from normal Corbino geometry in order to lower $1/G_{xx}$ compared to the characteristic impedance (50 Ω) of the measurement system: these samples have closed 2DES channel, but folded into a square shape (Fig. 4). Using these samples, we succeeded in reducing impedance of a sample compared to characteristic impedance of the measurement system and obtaining sufficient change of reflectivity even in short-pulsed magnetic fields.

Figure 5 shows reflectivity (V_{ref}) as a function of the magnetic field for f = 350 MHz, and initial temperature ($T_{initial}$) of 4.2 K. In the low magnetic field regime (B < 10 T), structures of V_{ref} were observed corresponding to the integer quantum Hall effect. In higher magnetic fields, two structures of V_{ref} were observed at ν = 1, 1/3. We speculate that these structures would indicate the existence of fractional quantum Hall state in ultra-high magnetic fields even under high temperature circumstance (temperature of a sample during magnetic field generation will be higher than $T_{initial}$ due to induced voltage proportional to dB/dt).

To summarize, we have succeeded in developing transport measurement technique of 2DES with considerable sensitivity, though detailed study is task for the future.

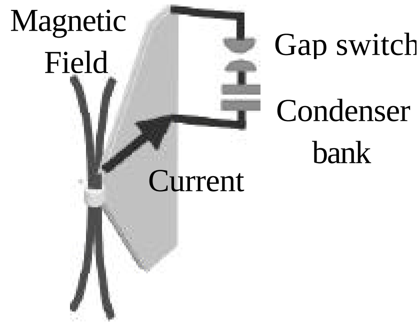

Fig. 1. Single-turn coil technique of ultra-high magnetic field generation. Ultra-high magnetic fields are generated by directly discharging current from a fast condenser bank to a single-turn coil.

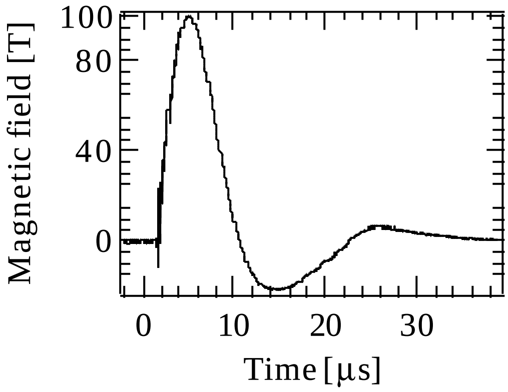

Fig. 2. Waveform of the magnetic field generated by single-turn coil technique. The magnetic field is generated within 10 μs.

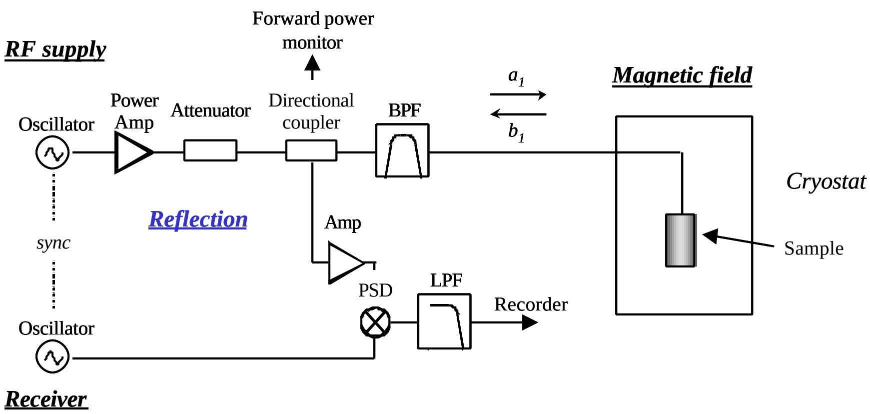

Fig. 3. Schematic diagram of RF reflection measurement system. Noise and induced voltage component in reflected signals were first eliminated by the band-pass filter. The signal is amplified using the signal amplifier and detected by a phase sensitive detector (PSD). The PSD output signal is recorded on recorders.

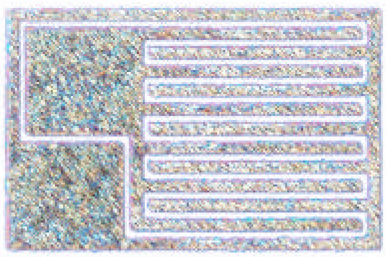

Fig. 4. (ω) Top view of the sample. 2DES exists between inner contact and outer contact.

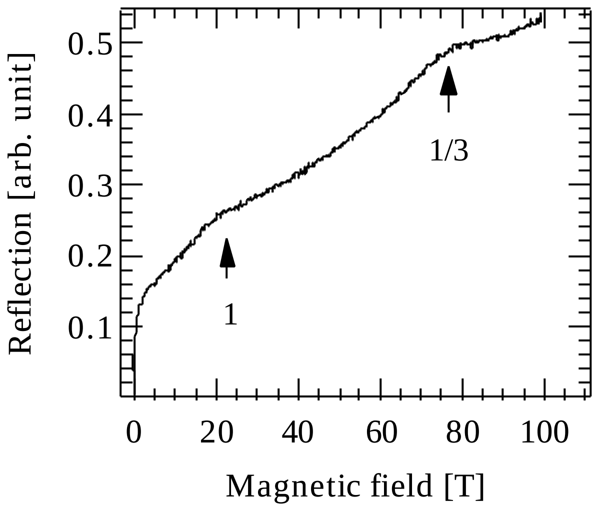

Fig. 5. (ζ) Real part of reflectivity as a function of the magnetic field (for bias frequency of 350 MHz and initial temperature of 4.2 K). In the low magnetic field (B < 10 T), structures of V_{ref} were observed corresponding to the integer quantum Hall effect. In higher magnetic fields, reflectivity shows monotone increase and two structures of V_{ref} at ν = 1, 1/3