Subband Structure and Magneto-Conductivity of InAs-MIS Inversion Layers

Yukihide Tsuji and Tohru Okamoto

Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

InAs-MISFET

It is well known that natural *n*-channel inversion layers can be formed on surface of *p*-type InAs crystals. This property is so remarkable and applied to a lot of devices. But it makes difficult to confine the surface *n*-channel within specified areas, such as Hall-bar patterns. In this work, we have succeeded in the fabrication of Hall-bar-type InAs-MISFET (metal-insulator-semiconductor field-effect-transistor) samples on *p*-type, (111)-oriented substrates using a hydrogen passivation technique and systematically investigated the 2D transport properties at low temperatures.

Subband Structure

The 2D density of states in the InAs inversion layers is low due to a small effective mass at the lowest conduction-band minimum. The multi-subband electronic state is expected to be formed by applying a gate electric field of a rather small strength.

Fig. 1 shows the field effect mobility m_{FE} at $T = 0.34$ K as a function of electron concentration N_s. N_s was determined from the Hall coefficient in the single subband regime and the obtained relationship between N_s and V_G was applied to the multi-subband regime where we cannot deduce N_s from the Hall coefficient exactly. The electron concentration N_1 in the first subband and N_2 in the second subband were determined from Shubnikov-de Haas oscillations in various perpendicular magnetic fields up to 9 T. We found that the double subband state is realized for $N_s \geq N_c = 1.66 \times 10^{12}$ cm^{-2} and the in-plane effective mass in the first subband is larger than that in the second subband by a factor of ~3. The latter may come from the conduction band nonparabolicity of InAs. In the single subband regime, m_{FE} turns to decrease for $N_s \geq 1.09 \times 10^{12}$ cm^{-2}. Yamaguchi observed similar N_s-dependence of m_{FE} and claimed that this reduction of m_{FE} is due to intersubband scattering [1]. In the present work, however, we confirmed that the reduction of m_{FE} occurs in the single subband regime. We consider that it is caused by the increase in the surface roughness scattering rate and/or by the increase in the effective mass with a rise of the Fermi energy. The increase in m_{FE} for $N_s > N_c$ can be associated with the conduction of electrons in the second subband with a smaller effective mass.

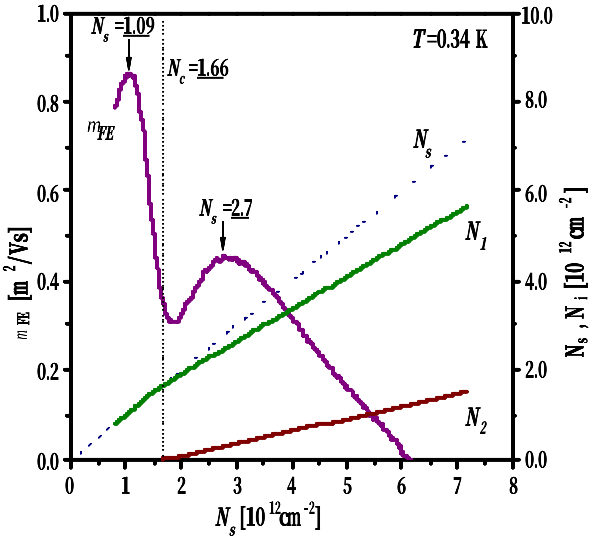

Fig. 1 *Field-effect mobility and electron concentration of each subband as a function of the total electron concentration N_s*

Magneto-Conductivity

As shown in Fig. 2, we observed a negative magneto-conductivity at low magnetic fields perpendicular to the 2D plane (|**B** | = $B_\perp$) while a positive magneto-conductivity due to the destruction of the quantum interference was observed at high magnetic fields. The low-$B_\perp$ negative magneto-conductivity associated with the spin-orbit scattering was suppressed by a strong parallel magnetic field (|**B** | = 9 T) which causes the Zeeman energy splitting.

We also investigated the effect of the Zeeman energy splitting on conductivity for $B_\perp = 0$. We observed a negative magneto-conductivity at low magnetic fields ($B_{//} <$ ~1T). The result at low magnetic fields can be reproduced using the theory by Maekawa and Fukuyama [2]. On the other hand, the conductivity turned to increase at high magnetic fields. At the present stage, we cannot explain the reason for the positive magneto-conductivity in parallel magnetic fields. In Fig. 3, we show the magneto-conductivity at $B_{//}$ = 1 T and 4 T as a function of N_s. While Δs monotonically decreases with increasing N_s at $B_{//}$ = 1 T, it has a maximum around $N_s = N_c$ at $B_{//}$ = 4 T. The result suggests that the subband structure is related to the positive magneto-conductivity.

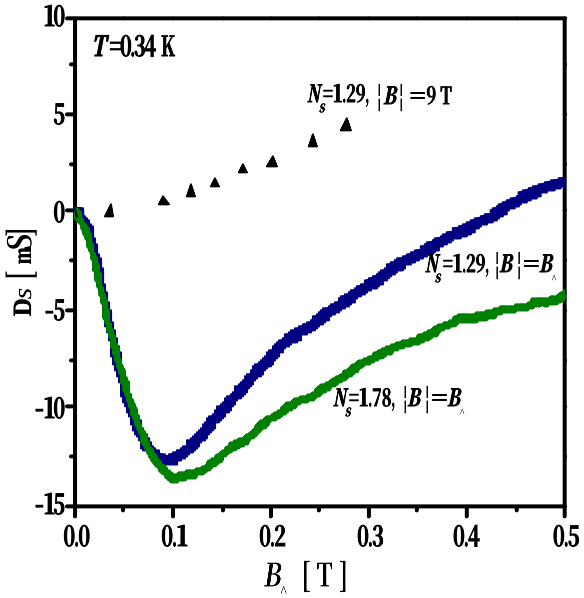

Fig. 2 Magneto-conductivity vs perpendicular component of magnetic fields. The electron concentrations are indicated in units of 10^{12} cm^{-2}. The data for |B | = 9 T were obtained by rotating the sample in the magnetic field.

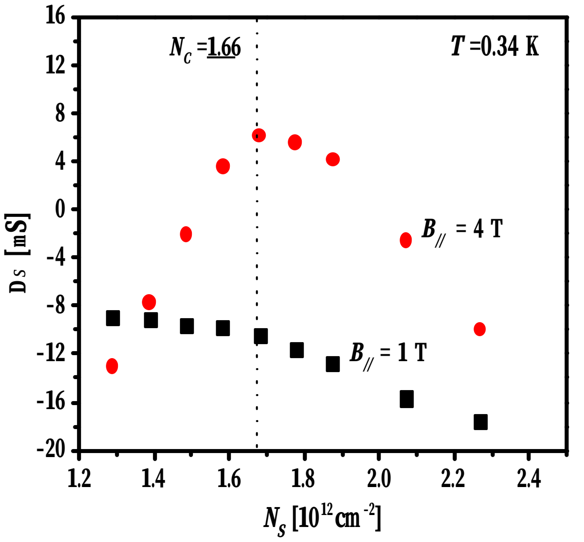

Fig. 3 Magneto-conductivity in parallel magnetic fields as a function of N_s

References

[1] E. Yamaguchi, Phys. Rev. B **32** (1985)5280.

[2] S. Maekawa and H. Fukuyama, J. Phys. Soc. Jpn. **50** (1981) 2516.