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 $\mu_{FE}$ 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 $V_C$ 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 9T. 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, $\mu_{FE}$ turns to decrease for $N_s \geq 1.09 \times 10^{12}$ cm$^{-2}$. Yamaguchi observed similar $N_s$-dependence of $\mu_{FE}$ and claimed that this reduction of $\mu_{FE}$ is due to intersubband scattering [1]. In the present work, however, we confirmed that the reduction of $\mu_{FE}$ 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 $\mu_{FE}$ 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 $N_i$
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 ($B_\parallel < \sim 1$T). 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 $B_\parallel = 1$ T and 4 T as a function of $N_s$. While $\Delta \sigma$ monotonically decreases with increasing $N_s$ at $B_\parallel = 1$ T, it has a maximum around $N_s = N_c$ at $B_\parallel = 4$ T. The result suggests that the subband structure is related to the positive magneto-conductivity.

References