Extended Abstracts of the 16th (1984 International) Conference on Solid State Devices and Materials, Kobe, 1984, pp. 371-374

Transport Properties of n-Channel Inversion Layers on InP and InAs MISFET's

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Transport properties have been systematically studied on n-type inversion layers in InP- and InAs-MISFETs. Multi-subband structure and its effect on electronic transport have been investigated through Shubnikov-de Haas oscillation on these MISFETs. It has been found that the defect scattering mainly limits those mobilities, as well as revealed that the intersubband scattering gives rise to a remarkable effect on the mobilities in the InP- and InAs-MISFETs.

I. INTRODUCTION

Many efforts have recently been devoted to the fabrication of n-channel metal-insulator-semiconductor field-effect transistors (MISFETs) onto III-V compound semiconductors. These transport properties have also been studied extensively at room temperature within the context of device characterization. However, at present, the absence of experimental data concerning temperature (T)- and electron concencentration (N_s)-dependences of the mobilities prevents obtaining reliable knowledge about the transport mechanisms for these two-dimensional electron gas (2DEG) systems.

In the present report, results of experimental investigations for the transport properties have been presented as functions of N_s and T in InP- and InAs-MISFETs. Multi-subband structure and its effect on the mobilities have been studied through quantum oscillations in these systems[1]. Defect scattering effect on the mobilities has also been studied theoretically in the InP- and InAs-MISFETs[2].

II. SAMPLE PREPARATION

Substrates were Zn-doped InP and InAs with (100) orientation. The InP and InAs wafers were p-type with 1.7×10^{16} cm^{-3} and 1×10^{17} cm^{-3} carrier concentration, respectively. After the wafers were polished mechanochemically with a Br-methanol solution, the surfaces were freshly prepared by the following steps; a thorough rinsing in aceton and water, a 10 sec etch in the mixture of H_2SO_4, H_2O_2 and H_2O (2:1:1), a 30 sec etch in Br-methanol solution. Subsequently, an anodic oxide layer was grown onto the InAs surface as an inner gate insulator with a thickness of about 200 Å.

In the InAs, native inversion layers formed with contact to AuGeNi (8:1:1) was used as source and drain n-type regions. On the other hand, in the InP samples, source and drain regions were formed by Si^+ implantations with a 2×10^{14} cm^{-2} dose at 200keV, and subsequent annealing at 650 °C for 15 min with an SiO_2 encapsulation. After that, source and drain electrodes were formed by evaporating AuGeNi (8:1:1) in the InP. Here, for both semiconductor samples, these electrodes had a corbino-disk structure with inner diameter r_i of 100-210 μm and outer diameter r_o of 370 μm, respectively.

Film of SiO_2 was deposited pyrolytically at low temperatures[3] (>170 °C) as a gate insulator for the InP and an outer gate insulator for the InAs. The devices were completed by the deposition of a two layer metallization of Al and Au for a gate electrode. Fabricated InP/SiO_2 MISFETs and InAs/anodic-oxide/SiO_2 MISFETs were mounted and wire-bonded on DIP headers and set in a cryostat with a superconducting magnet.

III. EXPERIMENTAL RESULTS

A. Shubnikov-de Haas effects

Conductivity σ was measured as a function of gate voltage V_g under a strong magnetic field at 1.6 K for the fabricated InAs- and InP-MISFETs. Figure 1 shows the obtained results for InAs, where $d\sigma/dV_g$ is plotted versus V_g for various magnetic flux density B. It can be shown in this figure that the Shubnikov-de Haas oscillation clearly occurs when surface Fermi-level E_{Fs} meets Landau levels. From analyses of this quantum oscillation, two-quantized subbands has been found to be concerned with electronic conduction. Two threshold voltages $V_{th}^{(0)}$ and $V_{th}^{(1)}$, at which E_{Fs} meets E_0 and E_1, can be accurately determined to give -41V and -18V, respectively, for this sample (23.3B), by extraporating the peaks for the various Landau levels. Here, E_0 and E_1 are, respectively, bottoms of ground and first-excited subbands. The insulator capacitance C_i can also be determined to high accuracy from the relation $C_i=n_v e^2B/\pi\hbar\Delta V_g$, where n_v is valley degeneracy and ΔV_g is a oscillation period in one-subband conduction state. The value of C_i has been estimated 9.69 nF/cm^2 for this InAs-MISFET. Furthermore, we can determine the conduction electron concentration in the ν-th subband, N_ν, as a function of total electron concentration N_s from the analysis of the quantum oscillation data, where, N_s is deduced from V_g by using the relation $N_s=C_i(V_g-V_{th}^{(0)})/e$. Figure 2 shows the obtained results of N_ν versus N_s. It is shown in this figure that, above N_s of $(1.2\text{-}1.4)\times10^{12}$ cm^{-2}, two-subband conduction state is realized, and gives $dN_0/dN_s=0.73$, $dN_1/dN_s=0.27$. Therefore, it can be found that conduction electron concentration, $N_{inv}=N_0+N_1$, is exactly equal to N_s[4]. It is also indicated in Fig.2 that three-subband conduction state is realized above N_s of $(7\text{-}8)\times10^{12}$ cm^{-2}.

Figure 3 shows results of Shubnikov-de Haas oscillation for the InP-MISFET. It is seen from this figure that hybrid-oscillatory conductivity, due to concerning the two quantized subbands, have been observed also in InP MISFETs. From the analyses of this data, $V_{th}^{(0)}$, $V_{th}^{(1)}$ and C_i has been estimated 1.2V, 25V and 25.6 nF/cm^2 for this sample (8.2B). In Fig.4, obtained results of N_ν is plotted as a function of N_s. It is found in this figure that dN_0/dN_s and dN_1/dN_s are, respectively, 0.79 and 0.21 in two-subband conduction states, which is realized above N_s of $(3.7\text{-}3.9)\times10^{12}$ cm^{-2}.

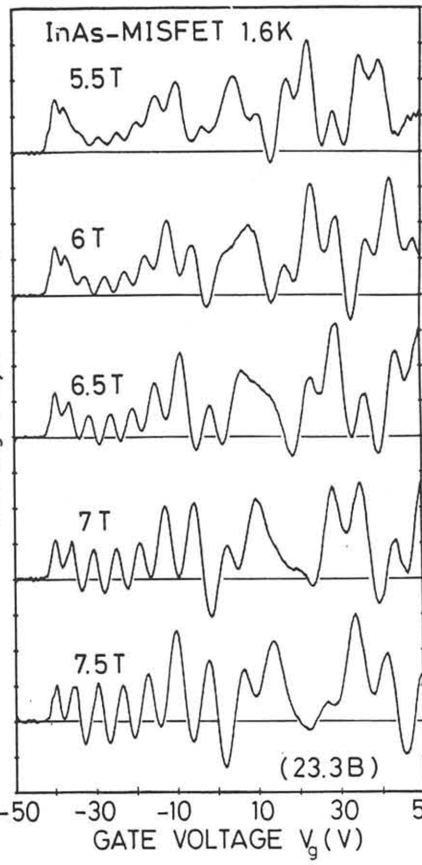

Fig.1 Shubnikov-de Haas oscillations at 1.6K for an InAs-MISFET (23.3B).

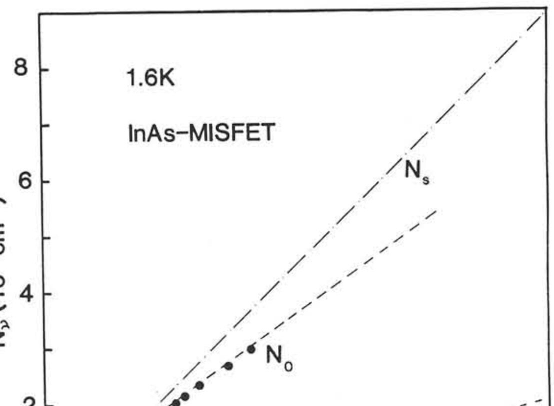

Fig.2 Electron concentration of ground subband (N_0) and first-excited subband (N_1) as a function of total electron concentration (N_s) for InAs MISFETs.

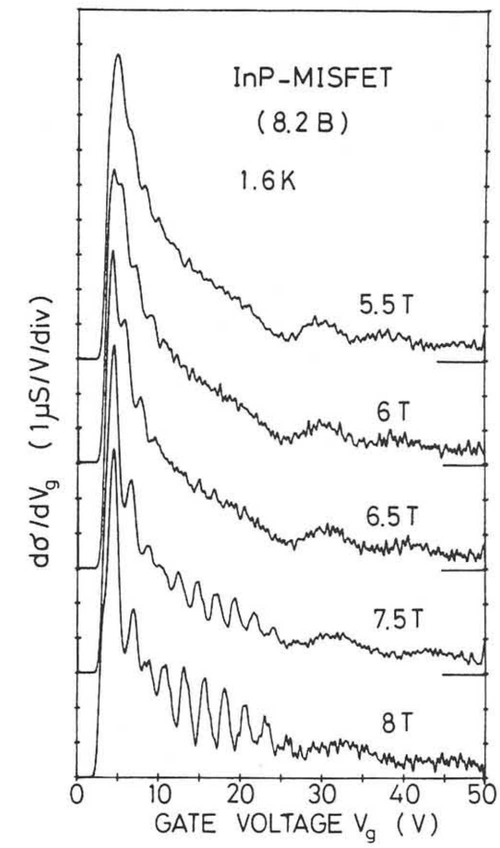

Fig.3 Shubnilov-de Haas oscillations at 1.6K for an InP-MISFET (8.2B).

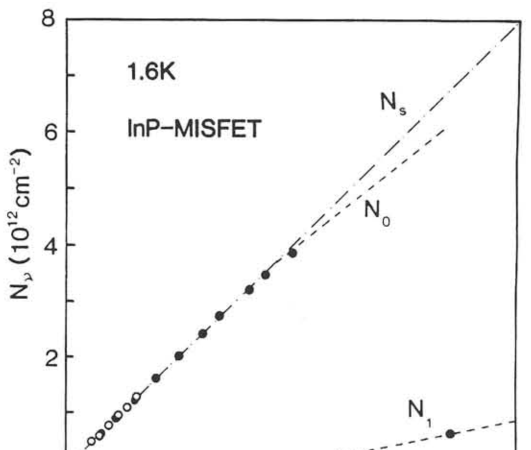

Fig.4 N_0 and N_1 versus N_s for InP-MISFETs.

B. Mobilities

Figures 5 and 6 show experimental results of effective mobility μ_{eff}, field effect mobility μ_{FE} and magnetoresistance mobility μ_H as a function of N_s in the InAs- and InP-MISFETs, respectively. In these figures, magnetoresistance electron concentrations N_H deduced from the relation $\sigma = e\mu_H N_H$ are also plotted as a function of N_s.

The following results have been obtained from these figures:

(a) μ_{FE} abruptly decrease at the onset of two-subband conduction (N_s=1.4x10^{12} cm^{-2} for InAs, N_s=3.8x10^{12} cm^{-2} for InP). This is a remarkable effect of multi-subband structures.

(b) μ_H is almost independent of temperatures. Thus, it can be considered that scattering relaxation time is almost independent of 2D wave-vector **k**.

(c) In the two-subband conduction region for InAs, μ_H becomes larger than μ_{eff}. This implies that value of mobility for first-excited subband, is different from that for ground subband.

Furthermore, it has been found that, in strong inversion, μ_H and μ_{eff} are proportional to $N_s^{-\gamma}$ ($0.2 < \gamma < 1$), and that its proportional coefficient and γ-value strongly depend on thermal processes.

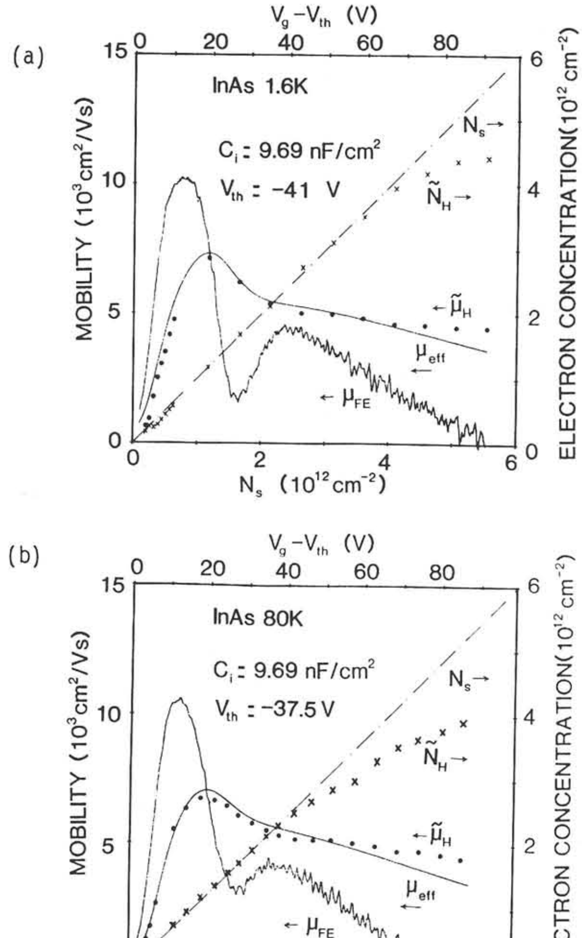

Fig.5 Mobilities and N_H as a function of N_s for an InAs-MISFET (23.3B) at (a)1.6K and (b)80K.

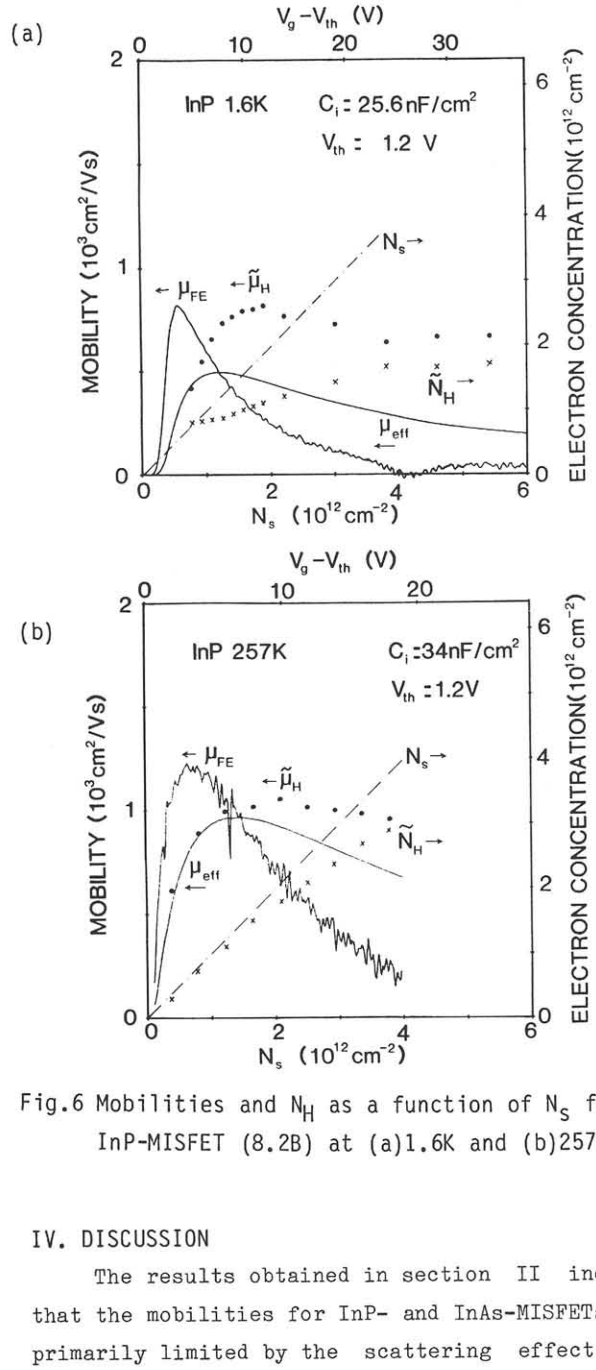

Fig.6 Mobilities and N_H as a function of N_S for an InP-MISFET (8.2B) at (a)1.6K and (b)257K.

IV. DISCUSSION

The results obtained in section II indicate that the mobilities for InP- and InAs-MISFETs are primarily limited by the scattering effect with some short-range scatterers, such as surface roughness. However, mobility limited by surface roughness scattering is proportional to N_S^{-2}, and cannot be so sensitive to thermal processes. Thus, taking notice of another short-range scatterer, "defect", induced by out-diffusion of the group-V atoms in III-V compound semiconductors, a simple theory of defect scattering in 2D multi-subband systems has been developed on the basis of Mori and Ando's formula[5].

Figure 7 shows a comparison between the experiment and the theory for the mobility of an InAs MISFET at 4.2 K. Here, μ_{def} is a calculated result of mobilities on the present defect model, and μ_{sc} and μ_{sr} are calculated mobilities limited by screened Coulomb scattering of charged interface states and impurities[6] and by surface roughness scattering[7]. As shown in this figure, the agreement is fairly good. Therefore, it can be concluded that mobilities in InP and InAs MISFETs are mainly limited by the defect scattering. The abrupt decrease in mobilities at the onset of two-subband conduction state has also been found to be due to the intersubband defect scattering effect on ground subband electrons.

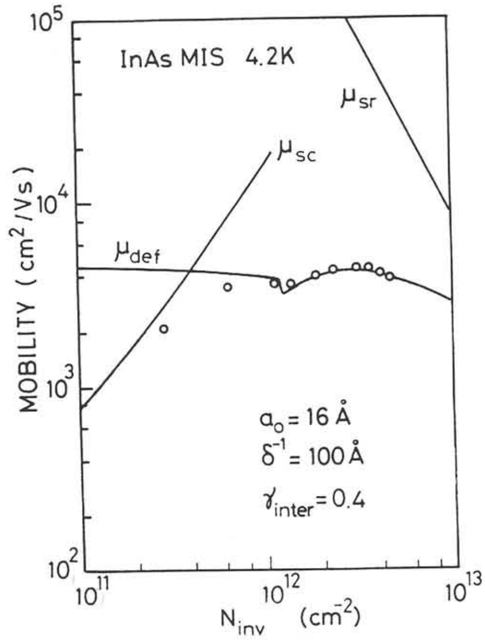

Fig.7 Calculated mobilities at 4.2K.

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3)M.Okamura and M.Minakata, J.Appl.Phys. (to be published)

4)This implies that effective mobility given by σ/eN_S is exactly equal to drift mobility given by σ/eN_{inv} at low temperatures.

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