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Energy relaxation of two-dimensional electrons in Si-MOSFETs : determination of deformational potential constant of conduction band of Si

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1. Introduction

Transport properties of two dimensional (2D) electrons in Si-MOSFETs at high temperature regions are dominated by acoustic phonon scattering. The deformation potential constant, *D*, of the conduction band of Si is an important parameter which governs the strength of acoustic phonon scattering. *D* has been determined experimentally by various techniques. However, the reported values of *D* scatter very much. For instance, the values of *D* obtained by high pressure measurements at various temperatures ranges from 8 eV to 12 eV [1-4]. On the other hand, *D* derived from mobility data at room temperature region are much larger, ranging from 12 eV to 23 eV [5-7]. Accurate determination of *D* is of great importance for clarifying the ultimate performance of Si-MOSFETs at room temperatures.

In this work, we have investigated the energy relaxation process due to acoustic phonon scattering of 2D electrons in the conventional Si-MOSFETs by measuring Shubnikov-de Haas (SdH) amplitudes at low temperatures. We performed the calculation of energy-loss rate due to acoustic phonon scattering via the deformation potential coupling. From comparison between the experimental results and the theoretical calculations, we determine the deformation potential constant of the conduction band of Si. The determined value of *D* is much larger (16 ± 2 eV) than the commonly accepted value 9 eV.

2. Determination of electron temperatures

The sample used in the present work was n-type Si-MOSFETs with Hall bar geometry. The thickness of the gate oxide, t_{ox}, was 25 nm. The channel length, *W*, was 200 μm and the distance between the potential probes, *L*, was 125 μm. The experiments were performed in liquid He ambient, *T* = 4.2 K. High magnetic fields up to 10 T were applied for SdH measurements, which were performed under various DC excitation current for the electron heating process.

Figure 1 shows the longitudinal voltages, V_x, as a function of magnetic field measured for various excitation densities, J_x, when the carrier density, $N_s = 4.8 \times 10^{12}$ cm^{-2}. As seen in the figure, the SdH oscillations were clearly observed above 2 T. However, the oscillation becomes vanishingly small with increasing current densities. Similar SdH measurements were carried out at N_s = 3.9, 2.6 $\times 10^{12}$ cm^{-2}.

Electron temperatures, T_e, are determined as a function of input power per electron, P_e ($\equiv J_xE_x/N_s$), which is equal to the energy-loss rate, $-\langle dE/dt \rangle$, in a steady state, by monitoring the amplitudes of SdH oscillations. Figure 2 shows the dependence of T_e on P_e. The determined T_e increases rapidly with P_e, reaching ~ 7 K when $P_e > 10^{-16}$ W. Since the 2D electrons in the channel are heated by the applied electric fields, the power balance between electron and phonon systems makes T_e higher than T_L.

3. Energy relaxation via emission of acoustic phonons and deformation potential constant

To quantify the energy relaxation process, we have performed theoretical calculations of the energy-loss rate due to acoustic phonon scattering via deformation potential coupling by taking the T_e- and *q*-dependence of screening

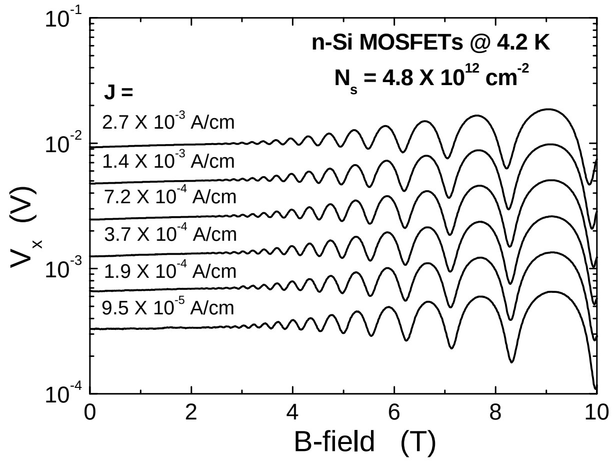

Fig. 1. Shubnikov-de Haas oscillations measured at 4.2 K for various current densities

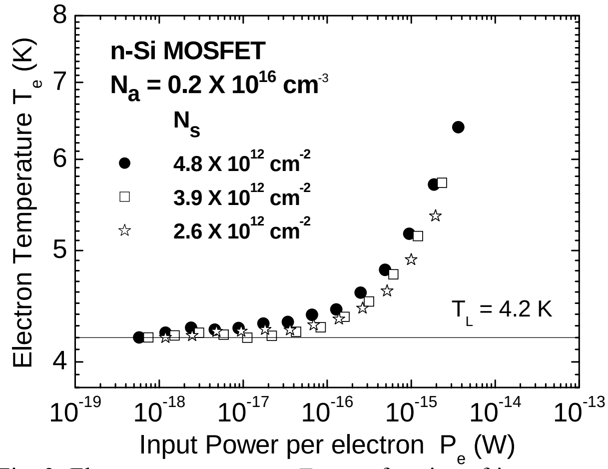

Fig. 2. Electron temperatures, T_e, as a function of input power per electron, P_e.

effect into account within the frame work of random phase approximation [8-10]. The T_e dependence of the energy-loss rate calculated for various electron densities, N_s, is plotted in Fig. 3, together with the experimental data shown in Fig. 2. In the calculation, the deformation potential constant D is set to be 16 eV. The calculated results are in good agreement with the experimental data. The results of energy-loss rate increase rapidly with the rise in T_e and are approximately proportional to $T_e^{7\sim5}$, which results from the phonon distribution at low temperatures (Bloch-Gruneisen range).

Figure 4 shows the N_s-dependence of the energy-loss rate when T_e = 4.6 K and T_L = 4.2 K. The calculated energy-loss rates are also plotted as functions of N_s with the deformation potential constant D as a parameter and exhibit an increase with decreasing N_s due to reduced screening

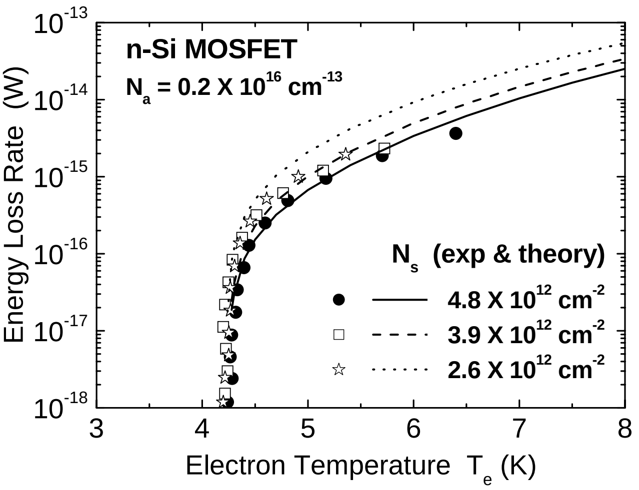

Fig. 3. The energy-loss rates (= P_e) measured at T_L = 4.2 K as a function of electron temperature T_e under various electron densities, N_s (symbols) and the calculated results of T_e-dependence of energy-loss rate due to acoustic phonon scattering via deformation potential coupling (lines).

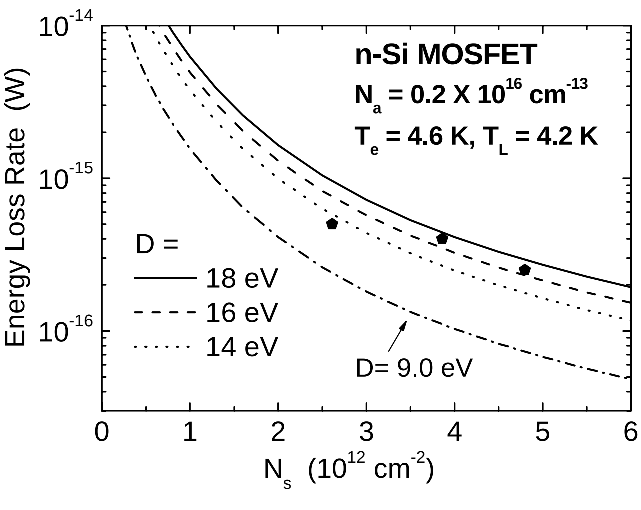

Fig. 4. The energy-loss rates measured when T_e = 4.6 K and T_L = 4.2 K as a function of electron density, N_s (symbols) and the calculated results of N_s-dependence of energy-loss rate with the deformation potential constant D as a parameter (lines).

effect for low-N_s.

From a careful comparison between the experimental data and the theoretical results, we found that reasonable agreement is obtained when the deformation potential constant D is set to be 16 ± 2 eV, which is significantly larger than the commonly accepted value 9 eV. Furthermore, it is also found that the mobility calculated with the present value of D is in good agreement with experiment at high temperature regions, the detail of which will be presented at the conference.

4. Summary

We have investigated the energy relaxation process of 2D electrons in the conventional Si-MOSFETs by the Shubnikov-de Haas measurements at low temperatures. From comparison between the observed increase in T_e and the calculated energy loss rate due to acoustic phonon scattering via deformation potential coupling, we determined the deformation potential constant for the conduction band of Si to be D = 16 ± 2 eV.

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