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A-2-3

Experimental Evidence of Coexistence of Interface Traps Interacting with Majority and Minority Carriers in Ge MIS Structures

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1. Introduction

MOSFETs with Ge or strained Ge channels have recently attracted much attention because of the high carrier mobility. However, the Ge MOS or MIS interface properties have not been fully understood yet. Since the realization of good MIS interface properties is one of the most important issues on Ge MOSFETs, physical understanding of the electrical properties of Ge MIS interface traps is strongly needed. We have already proposed the accurate measurement techniques of interface trap density at Ge MIS interfaces [1]. In this study, it is found, for the first time, through the detailed analyses of the conductance-frequency curves of Ge MIS capacitors at various temperatures that Ge MIS interface states can be composed of two types of interface traps at a given surface potential.

2. Experimental

First, p-type Ge(001) wafers were cleaned with an alkaline solution and a dilute HF. The Ge wafers were exposed to N_2, H_2, NH_3 or O_2 in 720 Torr at 420°C for 30min in order to change the chemical structure of the Ge surfaces. Subsequently, a 10-nm-thick SiO_2 layer was deposited by low-pressure chemical vapor deposition. Aluminum was used as the gate electrodes of the Ge MIS capacitors. Each sample is denoted by the ambient gas species, to which the samples were exposed before depositing SiO_2. Ultrathin GeO_x, GeO_xN_y or GeO_2 layers were formed at the interfaces between SiO_2 and Ge in the samples N_2 or H_2, NH_3 and O_2, respectively [2]. Conductance vs Frequency (G_p/ω-F) measurement was carried out at various temperatures.

3. Results and Discussion

Figure 1 shows the C-V curve at 1MHz of the sample N_2 measured at -60°C and the ideal C-V curve. The large flatband voltage shift (ΔV_{FB}) of the magnitude of -0.85V is observed. In other samples, ΔV_{FB} are -0.58, -0.51 and -0.72V for the sample O_2, H_2 and NH_3, respectively. Assuming that ΔV_{FB} is caused by interface charges including interface traps and oxide fixed charges, the amount of ΔV_{FB} corresponds to charges of the order of 10^{12}cm^{-2} at the interfaces. These interface charges cause the surface potential fluctuation (SPF), whose amount is estimated to range from 2.4 to 3.2 in unit of kT/q at -60°C. The amount of SPF, which depends on the surface potential, the distance from the interface and temperature, is known to cause the broadening of G_p/ω-F curves in depletion region [3]. The G_p/ω-F curves of the sample N_2 in depletion region measured at -60°C and the calculated G_p/ω-F curve under the amount of SPF of 3.2 are shown in Fig. 2. The broadening of the measured G_p/ω-F curves is represented well by the calculated curve. It is found in Fig. 3 that the amount of SPF in the G_p/ω-F curves for all the samples is in good agreement with that evaluated from ΔV_{FB} based on Brew's model [4]. Also, the time constants estimated from these G_p/ω-F curves are well aligned with a gradient of 1/kT, as shown in Fig. 4. The energy distributions of the interface trap density (D_{it}) decrease with approaching the midgap like a U-shape distribution, as shown in Fig. 5. All these physical properties are consistent with those known for Si MOS interface traps.

On the other hand, another type of traps is observed in higher temperatures. Fig. 6 shows the G_p/ω-F curves of the sample N_2 measured at -15°C and the calculated G_p/ω-F curve under the amount of SPF of 2.6. It is found that the broadening of the peak of measured G_p/ω-F curves near midgap is much smaller than that of the calculated G_p/ω-F curve. It is also confirmed that the peak heights decrease with approaching the flatband condition. The activation energies (E_a) of the time constant at Fermi level of 0.0 (midgap) and -0.1eV (depletion region) were estimated from the temperature dependence, as shown in Fig. 7. E_a at midgap is almost a half of the bandgap. It is found that E_a increases with decreasing the surface Fermi level from 0.0 eV to -0.1 eV, though the energy difference between E_f and E_v decreases. This result suggests that this type of interface traps is interacting with minority carriers. The energy distributions of the time constant estimated from the G_p/ω-F peaks measure at -15°C are shown in Fig. 8. The small energy dependence of the time constants, observed for all the samples, is not in agreement with a gradient of 1/kT expected for conventional interface traps obtained in Si MOS interfaces. Figure 9 shows the amount of SPF measured from the main peak measured at -15°C for the capacitors with various interfaces and the calculated one from the ΔV_{FB} of the sample N_2. The amounts of SPF in all the samples are much smaller than the calculated one. The interaction of both carriers and interface traps, and the contribution of bulk traps could intricately influence these behaviors.

The behaviors of Ge MIS interface traps, experimentally obtained in this study, is summarized in Fig. 10. It can be concluded that there exist two types of interface traps at a given surface potential. One type of traps with a shorter time constant, observed in lower temperature, interacts with majority carriers and provides a broader conductance peak. This type of traps is quite similar to the conventional one seen in Si MOS interfaces. The other type of traps with a longer time constant, observed in higher temperature, can interact with minority carriers and provides a narrower peak. Although the physical origin of these traps has not been clear yet, the longer time constant can be explained by lower capture-emission probability due to the interaction with minority carriers. Note here that interface traps observed at room temperature are in the category of this latter type.

4. Conclusions

The conductance method in depletion region for the Ge MIS near room temperature has revealed that Ge MIS interface states are composed of two types of interface traps; one to interact with majority carriers and the other to interact with minority carriers because of the narrow bandgap of Ge than Si.

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References [1] N. Taoka *et al.*, SSDM 2006 p.396, [2] N. Taoka *et al.*, Semicond. Sci. Technol., **22**, S114(2007). [3] E. H. Nicollian *et al.*: MOS physics and Technology (Wiley-interscience 2003) chapter 6, [4] J. R. Brews, J. Appl. Phys., **43** 2306(1972).

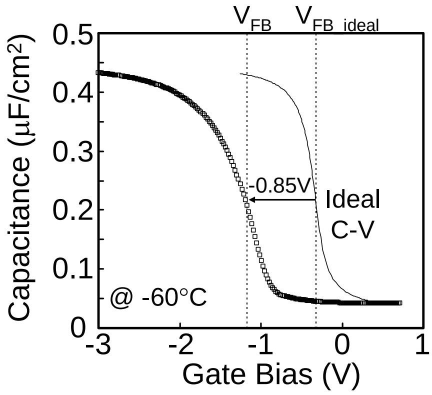

Fig. 1: C-V curve at 1MHz of the sample N_2 measured at -60°C and the ideal C-V curve.

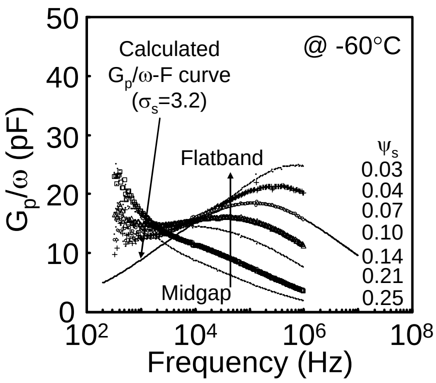

Fig. 2: G_p/ω-F curves of the sample N_2 at the various surface potentials measured at -60°C.

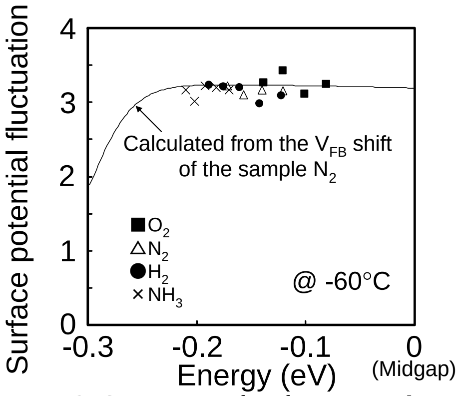

Fig.3: Comparison of surface potential fluctuation between the measured SPF at -60°C and the calculated SPF.

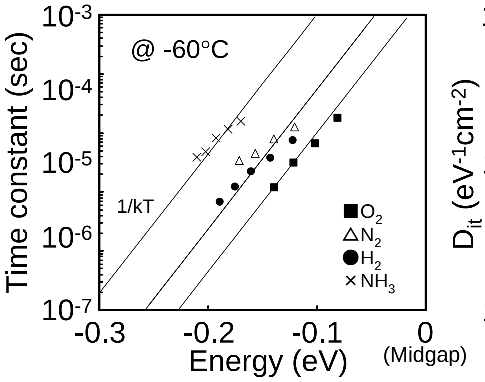

Fig. 4: Energy distribution of the time constants for each sample measured at -60°C.

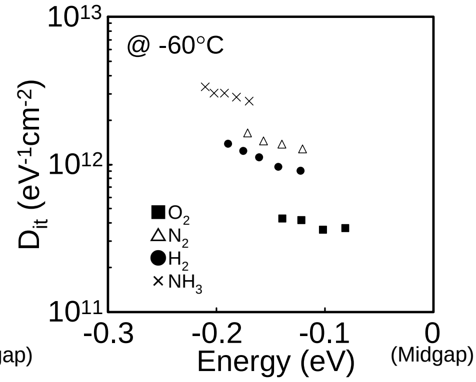

Fig. 5: Energy distribution of the interface trap densities for each sample measured at -60°C.

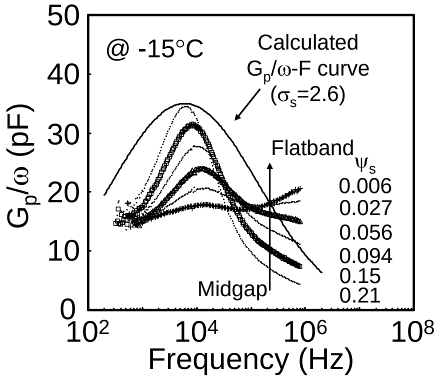

Fig. 6: G_p/ω-F curves of the sample N_2 at the various surface potentials measured at -15°C.

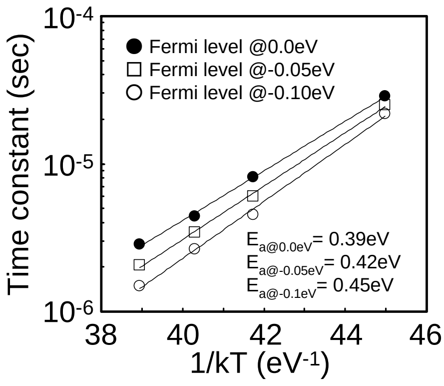

Fig. 7: Arrhenius plots of the time constants for the narrow G_p/ω-F peaks vs. 1/kT.

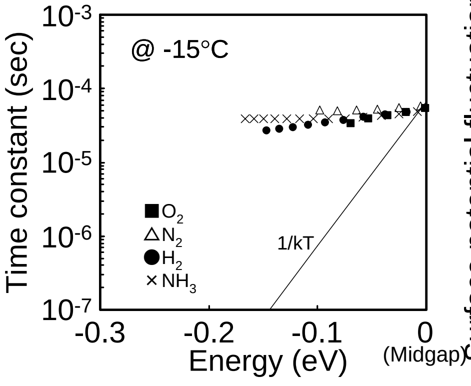

Fig. 8: Energy distribution of the time constants for each sample measured at -15°C.

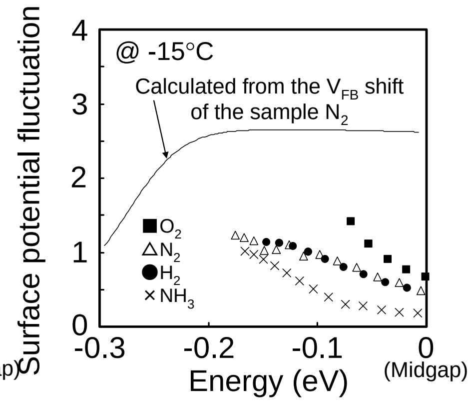

Fig. 9: Comparison of surface potential fluctuation between the measured SPF at -15°C and the calculated SPF.

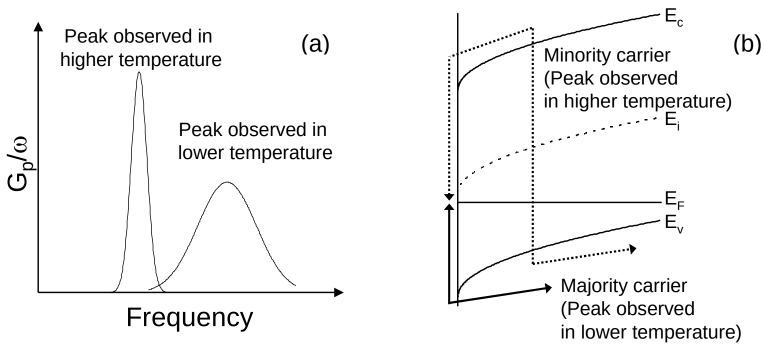

Fig. 10: Schematic diagrams of (a) the relationship of peak frequencies of the peak observed in higher and lower temperatures, and (b) the path of the carriers for ac voltages for the both peaks at Ge MIS interfaces.

Such unique feature arises from the narrower bandgap of Ge than Si.