Evaluation of SiO$_2$/GeO$_2$/Ge MIS Interface Properties by Low Temperature Conductance Method

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1. Introduction

Ge-channel MOSFETs have been proposed as one of the candidates of device structures over the scaling limit of Si technology because of the high carrier mobility than Si (2x for electrons and 4x for holes). On the other hand, the realization of the superior MIS interfaces is one of the most critical issues on Ge MOSFETs. However, their interface properties have not been investigated in detail. Particularly, it has recently been reported that interface states densities of Ge near the conduction band are high [1], which can be an essential reason for low mobility in Ge n-channel MOSFETs and, thus, a fatal problem for Ge CMOS. They have evaluated $D_{it}$ near the band edge by using low temperature conductance method. It is still necessary, however, to examine the accuracy and the validity of the results, because they used only n-type Ge substrate MIS capacitors for measuring the interface states near both conduction and valence bands and the measurement temperature only at 80 K. In this study, thus, we systematically evaluate the energy distribution of $D_{it}$ and the dynamic properties of the interface states up to near the band edge by applying the low temperature conductance method to n- and p-type Ge MIS capacitors in a wide range of measurement temperatures.

In this paper, SiO$_2$/GeO$_2$/Ge MIS interfaces are evaluated. This is because SiO$_2$/SiGe MIS structures formed by the Ge-condensation method have been reported to have superior interfaces so as to provide the hole mobility of 10 times as high as the universal one [2] and also we have already presented the good interface characteristics by forming GeO$_2$ between SiO$_2$ and Ge substrates [3].

2. Samples Fabrication

The fabrication flow is shown in Fig. 1 [3]. SiO$_2$/GeO$_2$/Ge MIS capacitors were fabricated on (100) oriented n- and p-type Ge substrates. Cyclic HF (buffered HF) dip with DI water was used to remove Ge native oxides. Si films of as thin as 1.2-1.5 nm were grown at 100 °C by MBE. Subsequently, the samples were oxidized at 200 °C in O$_2$ plasma for 120 min. The oxidation time, when Si was fully oxidized and GeO$_2$ between SiO$_2$ and Ge substrate was formed, was determined by XPS analyses. Finally, Al films were deposited to form gate electrodes.

3. Results and Discussions

In order to evaluate the energy distributions of $D_{it}$, the surface potential corresponding to each conductance peak needs to be accurately determined. For this purpose, one-to-one relationship between the capacitance under high frequency limit and the surface potential is utilized. Fig.2 shows the frequency dependence of the conductance at various temperatures. It is found that the frequency dispersion over 100 kHz is hardly observed at less than 221 K, meaning that we can regard the C-V curves at less than 221 K as the high-frequency C-V curves.

Here, the upper or lower limit of the surface potential where $D_{it}$ can be measured, in other words, the minimum value of the surface potential as a function of the measurement frequency is known to be described by

$$
\tau = (1/\sigma_{he}N_{A}) \exp(q\phi/k_BT) \quad (1)
$$

as seen in Fig.6, however, the slope of the time constants of both p- and n-type samples is not represented by $q/k_BT$, predicted on a basis of (1). This fact suggests the energy and/or temperature dependence of the capture cross sections or the relevance of any other processes than the simple capture/emission process of the majority carriers.

In order to modify $D_{it}$, annealing after metal gate formation (PMA) using N$_2$, H$_2$ and atomic hydrogen are carried out. The annealing temperature and time are 300°C and 30 min, respectively. The energy distribution of $D_{it}$ is
shown in Fig.7. It is found that the H₂ and atomic hydrogen annealing cause the increase in Dᵦ, while the N₂ annealing lead to almost no change in Dᵦ. This fact indicates that hydrogen deteriorates the Ge MIS interfaces at least under the present condition.

4. Conclusion

The systematic evaluation of Ge MIS interface properties was carried out by using the SiO₂/GeO₂/Ge MIS structures. The low temperature conductance method was found to be effective in measuring Dᵦ near the band edges. The higher Dᵦ near the conduction band edge was observed, which could be an essential problem for realizing Ge n-MOSFETs. Also, hydrogen annealing does not work for the present MIS interfaces, though the further optimizations of the annealing process are still needed.

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References