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Demonstration of High Channel Mobility and Low Trapped Electron Density of SiO_2/SiC $(0\bar{3}3\bar{8})$ Interfaces

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Abstract

We demonstrated that more than 80% of the induced electrons at SiO_2/4H-SiC $(0\bar{3}3\bar{8})$ interface contributes to current conduction by the combination methods by the split CV and Hall-Effect measurements.

1. Introduction

A SiC MOSFET is a promising candidate for a high power device with high speed switching and low conduction loss compared to the conventional Si IGBTs. The trench SiC MOSFETs can be a main stream because the high channel mobility of the SiO_2/SiC interfaces on the sidewalls are utilized. In particular, V-groove MOSFETs using SiO_2/SiC $(0\bar{3}3\bar{8})$ interfaces have the unique and excellent characterizations which maintain the high channel mobility of 80 cm^2 V^{-1} s^{-1} even under the high channel doping concentration of $1.0x10^{18}$ cm^{-3} [1, 2]. This mean that the short channel effect is suppressed and the threshold voltage is kept high, even if shrinking the channel length. On the other hand, it has been recently reported that many electron traps around the MOS interface cause low channel mobility of the conventional 4H-SiC (0001) MOSFET by T. Hatakeyama, et al [3]. In this paper, we first report a quantitative analysis of the trapped carrier density at the SiO_2/SiC $(0\bar{3}3\bar{8})$ interfaces by the split *CV* method and Hall-Effect measurements.

2. Experimental

The evaluated samples are lateral n-type MOSFETs and MOS diodes for the van der Pauw Hall-Effect measurement formed in the same 4H-SiC $(0\bar{3}3\bar{8})$ substrate inclined at 54.7 degrees from the $(000\bar{1})$ face. The channel regions were formed by the p-type epitaxial growth or by an aluminum ion-implantation into the n-type epitaxial layer. The doping concentration of p-type layers are valuable in the range of $4.7x10^{15}$~$1.0x10^{18}$ cm^{-3} in Table 1. The thickness of thermally grown gate oxidation is about 50 nm. Post oxidation annealing in nitric oxide (NO-POA) is performed in 60 minutes at 1250 ºC. This oxidation and post oxidation sequence fits to the previous report [3].

Figure 1 shows the field-effect mobility of the lateral n-type MOSFETs. As well as the previous report, the field effect mobility of a 100 cm^2 V^{-1} s^{-1} at the low doping concentration of $4.5x10^{15}$ cm^{-3} was measured, which was high enough compared to the conventional (0001) MOSFETs [3]. In addition, even in the high doping concentration of $1.0x10^{18}$ cm^{-3}, the high field-effect mobility of 60 cm^2 V^{-1} s^{-1} was maintained. It also shows that the field effect mobility depends on the doping concentration, not in the way of channel formation by the epitaxial growth or the ion-implantation.

Table I Channel doping method and concentration of six samples on 4H-SiC $(0\bar{3}3\bar{8})$ substrates.

Name	Doping method	Doping concentration N_a-N_d (cm^{-3})
E1	P-type epitaxial growth	$4.7x10^{15}$
E2	P-type epitaxial growth	$1.9x10^{16}$
E3	P-type epitaxial growth	$3.0x10^{16}$
E4	P-type epitaxial growth	$4.1x10^{17}$
I1	Al^+ ion implantation	$1.3x10^{17}$
I2	Al^+ ion implantation	$1.0x10^{18}$

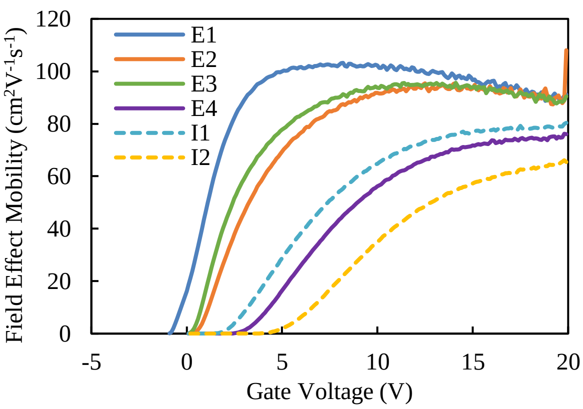

Fig. 1 Field effect mobilities of the six samples on the 4H-SiC $(0\bar{3}3\bar{8})$ substrates.

Figures 2 (a) and (b) show the relationship between free carrier and total carrier densities which was obtained from Hall-effect and the split *CV* measurements, respectively. The trapped carrier density which was calculated by subtracting free carrier density from the total carrier density, rises up at the threshold voltage. The free carrier density simply increases by the rising gate voltage, and the free carrier density occupies more than 80% of the total induced carrier density at the gate voltage of 15V. Further, the trapped carrier density is saturated at 1.0~$2.0x10^{12}$ cm^{-2} and a small part of the induced total carrier density because of the low density of the traps at the SiO_2/SiC $(0\bar{3}3\bar{8})$ interface near the conduction band edge. This tendency is the difference from that of other crystal orientations of 4H-SiC increasing the trap density by the gate voltage.

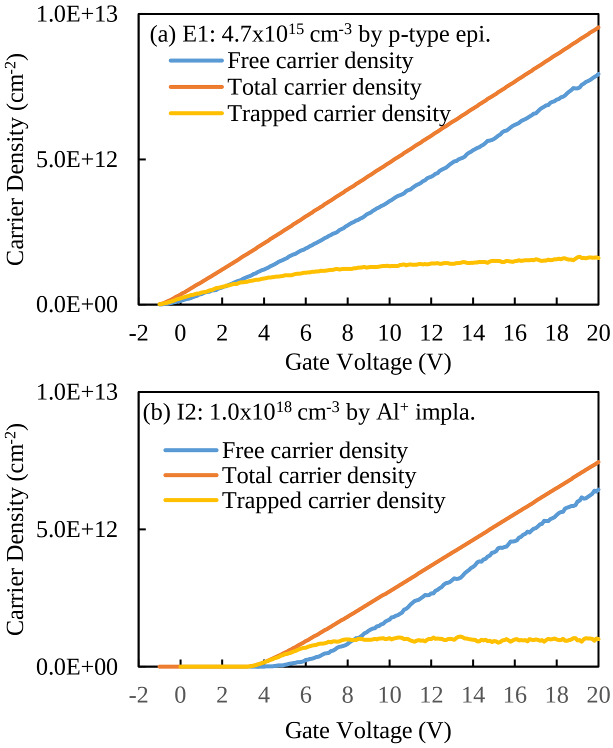

Fig. 2 Trapped electron densities for two samples with different doping method and concentration.

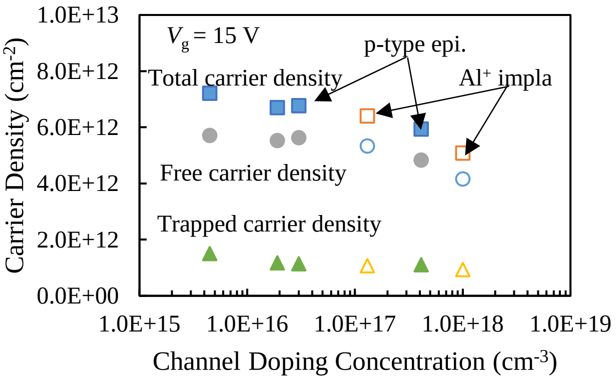

Fig. 3 The channel doping concentration dependence of the trapped carrier density at the gate voltage of 15 V.

Figure 3 shows the channel doping concentration dependence of trapped carrier density. The doping concentration dependence of the total and free carrier density indicates similar trend and decreases by rising up the concentration because the effective gate voltage which subtracts the threshold voltage from the gate sampling voltage of 15 V reduce by increasing the threshold voltage. The 80% of the total induced carrier in the doping concentration of 1.0x10^{18} cm^{-3} On the other hand, the trapped carrier density is an almost constant value of 1.0x10^{12} cm^{-2} in the high doping concentration without depending on the doping methods (epitaxial growth or aluminum ion-implantation).

Figure 4 shows the Hall-effect mobility versus free carrier density of the six samples. The Hall-effect mobility increases with the increasing of the free carrier density and it is degraded by the increasing of doping concentration. Hence, it is supposed that the main scattering mechanism at the SiO_2/SiC $(0\bar{3}3\bar{8})$ interface is a Coulomb scattering.

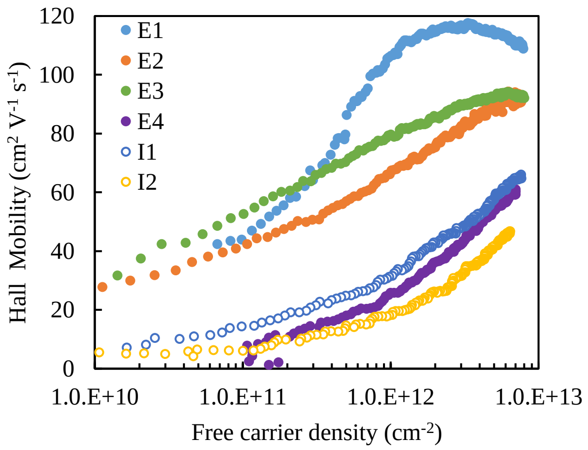

Fig. 4 Hall mobility versus free carrier density of the six samples.

3. Conclusions

We fabricated the lateral MOSFETs on 4H-SiC $(0\bar{3}3\bar{8})$ substrates evaluated the trapped carrier density. We first demonstrated that more than 80% of the induced electrons contribute the current conduction and that the trapped electron density is saturated at 1.0x10^{12} cm^{-2} regardless of the channel doping method and concentration. We supposed that the SiO_2/SiC $(0\bar{3}3\bar{8})$ interface having such superior characteristics should be used as the channel of SiC-MOSFETs.

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