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Impact of Optical Phonon Scattering on Inversion Channel Mobility in 4*H*-SiC Trenched MOSFETs

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Abstract

Temperature characteristics of the channel mobility were investigated for 4*H*-SiC trenched MOSFETs in the range from 30 to 200 ˚C by calculation and experiment. The conventional model of the mobility based on Si-MOSFETs shows a large difference from the experimental value of the mobility, especially at the high temperature. On the other hand, the improved mobility model including the optical phonon scattering was in an excellent agreement with the experimental results. Moreover, the major factors limiting the channel mobility were found to be Coulomb scattering in low effective field (E_{eff}) and the optical phonon scattering in high E_{eff}.

1. Introduction

One of the greatest challenges in 4*H*-SiC MOSFETs technology is reduction of the channel resistance by increasing channel mobility. Even though high values of mobility were achieved [1], the reported channel mobility is much lower than that anticipated from SiC bulk mobility (800-1000 cm^2 V^{-1} s^{-1}), which suggests a need for deeper understanding what controls the carrier scattering limiting the inversion channel mobility in 4*H*-SiC MOSFETs.

Recently, the several scattering models in SiC MOSFETs based on the silicon model have been proposed [2-4]. Naik *et al.* reported that the surface acoustic phonons have very small impact on the carrier scattering, and that Coulomb scattering in the low E_{eff} and surface roughness scattering in the high E_{eff} are dominant [2]. On the other hand, Frazzetto *et al.* concluded that the inversion channel mobility is not limited by the surface roughness but limited by Coulomb scattering based on experimental results using AFM [3]. Clearly, understanding inversion carrier scattering mechanism on SiC MOSFETs remains still an open issue. Since the property of bulk mobility has great impact on channel mobility in conventional Si-based MOSFETs [5,6], the key is considered to be characteristics of bulk mobility in SiC. Given the difference between the electron negativity of Si and C in SiC, the optical phonon scattering must be taken into account as scattering factor derived from the lattice vibration in addition to the acoustic phonon scattering included in the conventional scattering models [7].

In this letter, the impact of optical phonon scattering on the channel mobility is discussed, based on the temperature dependence of channel mobility in the trenched 4*H*-SiC MOSFETs.

2. Experimental

The starting material was n-type 4*H*-SiC epitaxial layer grown on heavily doped n+-type SiC(0001) substrate. The isolated one-cell trenched MOSFET with n-channel was fabricated in order to extract the channel resistance component and determine the effective channel mobility (μ_{eff}). Nitridation was performed following deposition of a 75-nm-thick gate oxide in order to reduce the interface state. The drain current-gate voltage (I_D-V_G) characteristics of fabricated MOSFETs were measured at the temperature in the range from 30 to 200 ˚C.

3. Results and Discussion

The value of μ_{eff} was directly evaluated from I_D-V_G characteristics measured at each temperature by two-step process [8]. Figure 1 shows the temperature dependence of μ_{eff} characteristics. The results suggest that μ_{eff} has strong dependence not only on the effective field but also on the temperature, which indicates Coulomb scattering and phonon scattering.

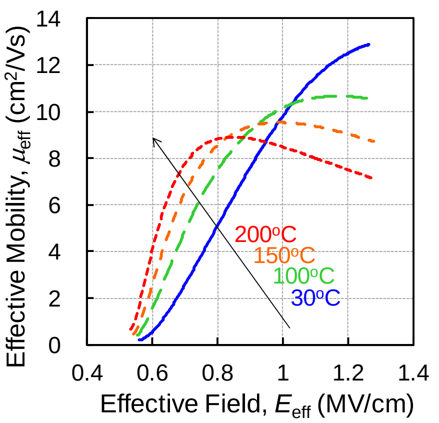

Fig. 1 Temperature dependence of the effective channel mobility extracted from I_D-V_G characteristics as a function of effective field.

Next, the carrier scattering model in 4*H*-SiC MOSFETs was investigated based on the μ_{eff} characteristics. In this paper, we described the total inversion layer mobility which consists of five terms,

$$\mu_{eff} = \left(\frac{1}{\mu_B} + \frac{1}{\mu_{AC}} + \frac{1}{\mu_{SR}} + \frac{1}{\mu_C} + \frac{1}{\mu_{OP}} \right)^{-1} \qquad (1)$$

taking into account the optical phonon scattering term μ_{OP} expressed as:

$$\mu_{OP} = \frac{Z}{E_{eff}} \cdot \exp\left(\frac{\hbar\omega_{OP}}{kT} - 1 \right) \qquad (2)$$

where $\hbar\omega_{OP}$ is the optical phonon energy, k is the Boltzmann constant, T is the absolute temperature and Z is an empirical parameter, in addition to the other conventional terms consisting of the bulk mobility (μ_B), the acoustic phonon scattering (μ_{AC}), the surface roughness scattering (μ_{SR}), and the Coulomb scattering (μ_C) [2-6]. μ_{OP} is based on the phonon occupation factor of the polar optical phonons of energy $\hbar\omega_{OP}$ as mentioned in Ref. 7.

Figure 2 and 3 show the experimental data measured at 30, 100 and 200 ˚C, and the calculated values without and with the optical phonon scattering term, respectively. In the case of conventional model as shown in Fig. 2, while a good agreement in low E_{eff} region can be seen between the calculated and experimental data, a large gap was demonstrated in high E_{eff} region, especially at high temperature. On the other hand, when the optical phonon scattering term is included, an excellent agreement can be seen not only at low E_{eff} but also at high E_{eff} in the temperature range from 30 to 200 ˚C, as shown in Fig. 3. These results suggest that the proposed mobility model enables to identify the factor limiting mobility. The correlation with physical analyses, e.g. atomic force microscopy (AFM) and transmission electron microscopy (TEM), is under investigation.

4. Conclusions

Given the difference between the electron negativity of Si and C in 4*H*-SiC, we proposed mobility model including the optical phonon scattering. The calculated mobility based on this model was in an excellent agreement with the experimental results. The major factors limiting the channel mobility were revealed to be Coulomb scattering in the low E_{eff} and the optical phonon scattering in the high E_{eff}.

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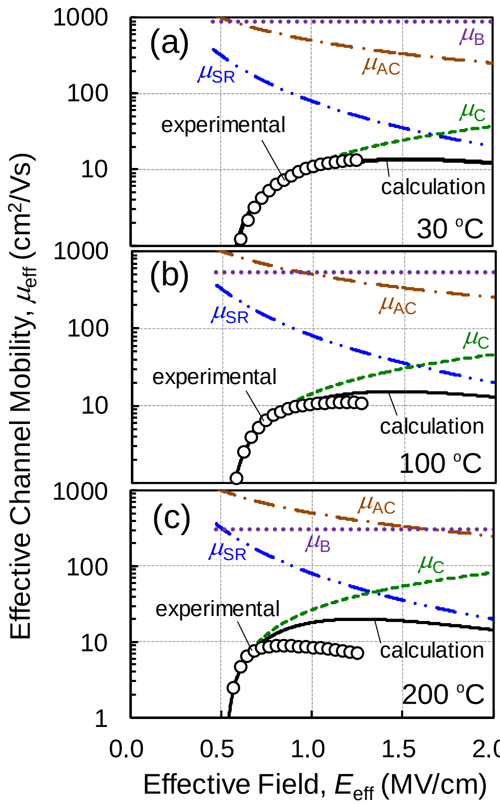

Fig. 2 Calculated and experimental channel mobility based on the conventional Si-based model at (a) 30, (b) 100, and (c) 200 ˚C.

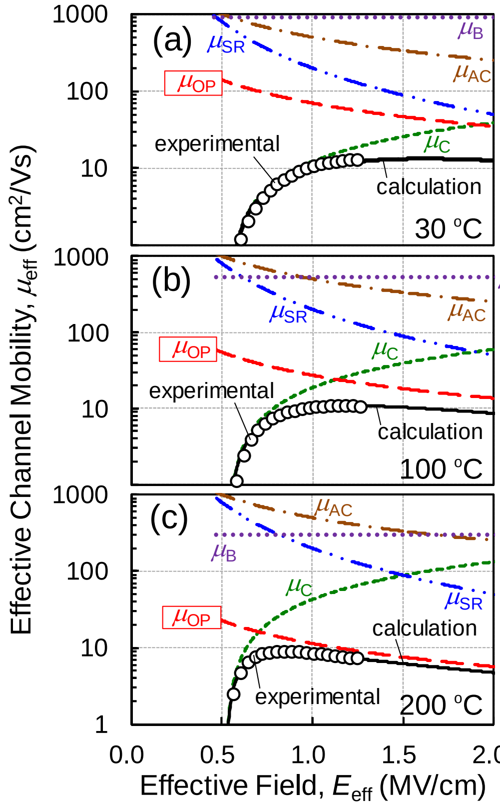

Fig. 3 Calculated and experimental channel mobility based on the proposed model including μ_{OP} .