

## Comparison of Field Effect Mobility Enhancement by Different Oxidation Processes at 4H-SiC a-face MOS Interface

M. Sometani<sup>1</sup>, H. Hirai<sup>1</sup>, M. Okamoto<sup>1</sup>, T. Hatakeyama<sup>1,2</sup>,  
S. Harada<sup>1</sup>, H. Okumura<sup>1</sup>, and H. Yamaguchi<sup>1</sup>

<sup>1</sup> National Institute of Advanced Industrial Science and Technology (AIST)

16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan

Phone: +81-29-861-8741 E-mail: m.sometani@aist.go.jp

<sup>2</sup> Toyama Prefectural University

5180 Kurokawa, Imizu, Toyama 939-0398, Japan

Phone: +81-766-56-7500

### Abstract

Free electron mobility in the inversion channels of 4H-SiC (11 $\bar{2}$ 0) a-face MOSFET subjected to different oxidation processes were evaluated by using Hall effect measurement. The free electron mobility of the wet oxidation sample is higher than that for the NO post oxidation annealing sample for the same doping concentration epilayers. This result indicates that the degradation of the free electron mobility by scattering origins depends on the oxidation processes.

### 1. Introduction

Field-effect mobility ( $\mu_{FE}$ ) is a key characteristic of 4H-SiC metal-oxide-semiconductor (MOS) devices. The  $\mu_{FE}$  of a MOS field-effect transistor (FET) depends on the free electron density and free electron mobility in the inversion channel [1]. With a 4H-SiC(0001) Si-face, the free electron ratio is approximately 30% even after NO post-oxidation annealing (POA) [1]. Thus, with a Si-face, there is room for increase of the  $\mu_{FE}$  by reducing the density of the interface trap ( $D_{it}$ ) and/or near interface trap (NIT). By contrast, with a (11 $\bar{2}$ 0) a-face, a (1 $\bar{1}$ 00) m-face, and (0 $\bar{3}$ 38), a free electron ratio of over 70% can be achieved by employing NO POA [2]. The free electron mobility must be increased if we are to further improve the  $\mu_{FE}$  at these crystal faces. Recently, our group has demonstrated a high inversion channel mobility which is comparable to bulk mobility by adopting ultralow net doping concentrations [3]. This high free electron mobility results from the broad inversion channel caused by an ultra-low doped p-well, which makes the electrons recede from the interface. This result indicates that there are unidentified scattering origins at a SiO<sub>2</sub>/SiC interface which significantly deteriorates the free electron mobility [3,4]. Therefore, these scattering origins must be eliminated to improve  $\mu_{FE}$ . It has been reported that a wet oxidation process on an a-face provides an extremely high  $\mu_{FE}$  [5,6]. The  $\mu_{FE}$  is higher than the free electron mobility of a MOS inversion channel formed by NO POA [2,4]. This means that the higher  $\mu_{FE}$  of a MOSFET on an a-face with a wet oxidation process cannot be explained solely by the decrease in  $D_{it}$  and/or NIT. In this work, the free electron ratio and mobility in the inversion channel on a-face MOSFETs formed by NO POA and a wet oxidation process were compared by using Hall-effect measurement.

### 2. Experiments

The n-channel MOSFETs were fabricated on 4H-SiC a-face Al-doped p-type epitaxial layers on an n-type substrate. The doping concentration of the epitaxial layer was approximately  $3 \times 10^{16} \text{ cm}^{-3}$ . Gate oxide films of 60 nm thick were formed by either dry O<sub>2</sub> oxidation at 1200 °C followed by NO POA at 1250 °C (NO sample), or pyrogenic oxidation at 1100 °C followed by H<sub>2</sub> POA at 1000 °C (Wet sample). The total electron density ( $n_{\text{total}}$ ) was estimated by performing a split capacitance-voltage ( $C$ - $V$ ) measurement at 10 Hz. In addition, the free electron density ( $n_{\text{free}}$ ) and mobility ( $\mu_{\text{Hall}}$ ) were determined by undertaking a Hall-effect measurement using the van der Pauw method. The strength of the applied magnetic field was approximately 0.5 T. The Hall factor was assumed to be unity.

### 3. Results and Discussion

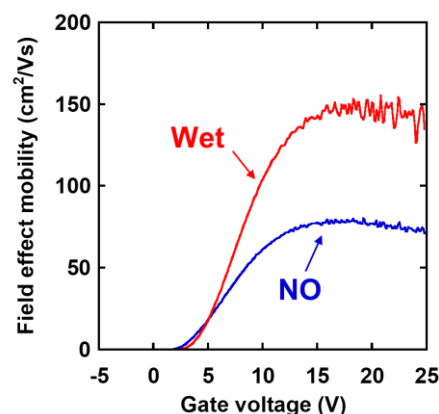


Fig. 1.  $\mu_{FE}$  of NO and Wet samples at 300 K.

Figure 1 shows the  $\mu_{FE}$  of NO and Wet samples at 300 K. An extremely high  $\mu_{FE}$  was obtained for the Wet sample compared with that for the NO sample. This result is consistent with the reported trend [5,6]. Figure 2 shows the  $n_{\text{total}}$ ,  $n_{\text{free}}$ , and  $n_{\text{trap}} (= n_{\text{total}} - n_{\text{free}})$  values for the (a) NO and (b) Wet samples at 300K. Additionally, the free electron ratio ( $= n_{\text{free}} / n_{\text{total}}$ ) is shown in Fig. 2 (c). The free electron ratios of both samples are almost the same. It has been reported that wet oxidation reduces the  $D_{it}$  value at  $E_c - E > 0.2 \text{ eV}$  as calculated by the High-Low  $C$ - $V$  method [6]. However, a comparison of the free electron ratios of the NO and Wet samples indicates that

the  $D_{it}$  and/or NIT values near the conduction band edge for both processes, which affect the free electron ratio, are the same. Therefore, the fact that  $\mu_{FE}$  of the Wet sample is higher than that of the NO sample cannot be explained by a difference between the free electron ratios.

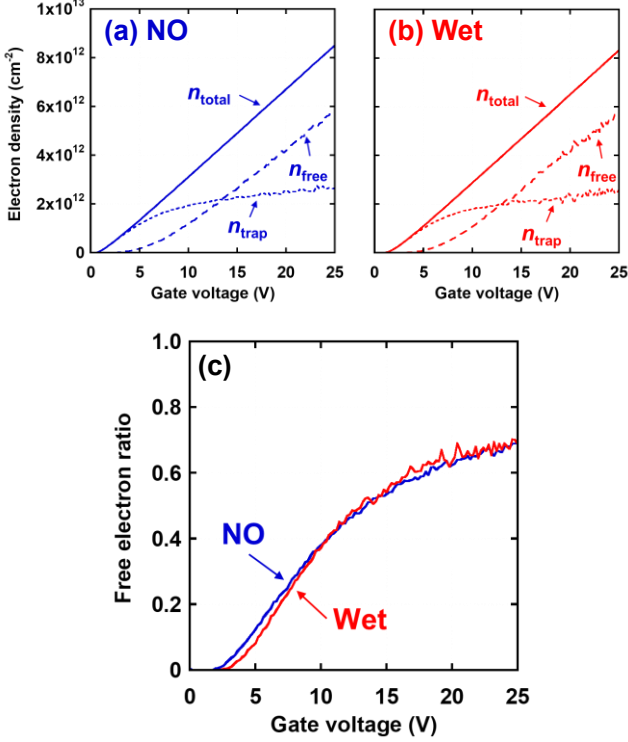


Fig. 2.  $n_{total}$ ,  $n_{free}$ , and  $n_{trap}$  for (a) NO and (b) Wet samples, and (c) free electron ratio at 300 K.

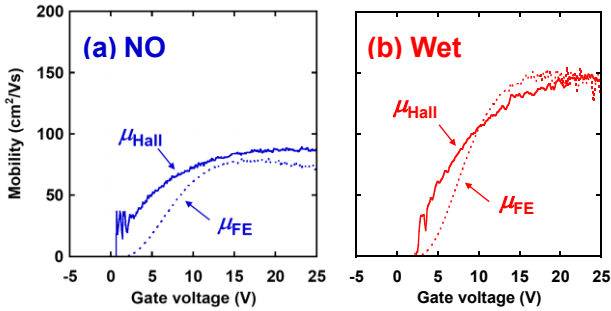


Fig. 3. Comparison between  $\mu_{Hall}$  and  $\mu_{FE}$  for (a) NO and (b) Wet samples at 300 K.

Figure 3 compares the  $\mu_{Hall}$  and  $\mu_{FE}$  values of (a) NO and (b) Wet samples at 300 K. The  $\mu_{Hall}$  of the Wet sample is almost twice that of the NO sample, although it does not reach the bulk mobility value. Given that the doping concentrations of the samples are almost the same, this result indicates that the Wet oxidation process is superior to the NO post oxidation process in terms of eliminating scattering origins at the SiO<sub>2</sub>/SiC interface. Figure 4 shows the  $\mu_{Hall}$  temperature dependence for NO and Wet samples from 150 to 350 K at  $n_{free} = 5 \times 10^{12} \text{ cm}^{-2}$ . The temperature dependence of the Wet sample is stronger than that of the NO sample, probably because

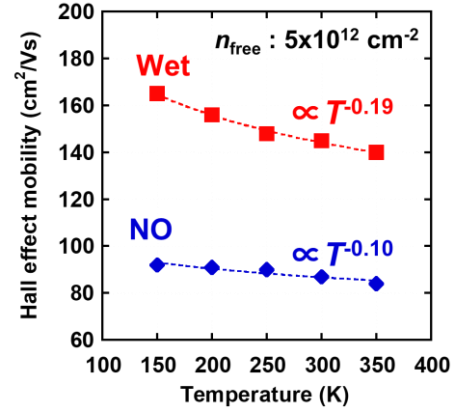


Fig. 4. Temperature dependence of  $\mu_{Hall}$  for NO and Wet samples from 150 to 300 K at  $n_{free}$  of  $5 \times 10^{12} \text{ cm}^{-2}$ .

the phonon scattering becomes relatively apparent by eliminating the scattering origins; however, the dependence is still weaker than that of phonon scattering ( $\propto T^{-1.5}$ ) [3]. It is known that a large quantity of nitrogen atoms is present at the SiO<sub>2</sub>/SiC interface on the a-face when the NO POA process is employed [7]. This nitrogen atom may be one component for a scattering origin which decreases the free electron mobility. Therefore, a more effective oxidation process that can eliminate the scattering origin achieve higher free electron mobility as expected from the bulk mobility of 4H-SiC.

### 3. Conclusions

The origins of field effect mobility enhancement on 4H-SiC a-face MOSFET by wet oxidation were investigated. It was found that the increase of field effect mobility of the wet oxidation sample compared with NO sample was not due to the increase of the free electron density, but rather due to the increase of free electron mobility. This result indicates that the wet oxidation process generates less scattering origins at SiO<sub>2</sub>/SiC interface. This idea is also suggested by the increased temperature dependence of free electron mobility, which would originate from that the phonon scattering becomes relatively apparent. A more effective oxidation process will achieve higher free electron mobility as expected from the bulk mobility of 4H-SiC.

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### References

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