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High Channel Mobility in Inversion Layer of SiC MOSFETs for Power Switching Transistors

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1. Introduction

SiC MOSFETs are promising devices for high-power applications. Though some prototype SiC power MOSFETs which overcome Si-limit have been reported, they still show a large on-resistance compared to a theoretically expected value. Most of these devices were fabricated on the (0001) face of 4H or 6H polytype because of large-area wafer availability. At the moment, however, there are big problems in SiC MOSFETs as follows; a low inversion channel mobility in 4H-SiC regardless of a high bulk mobility, and a low bulk mobility along the c-axis in 6H-SiC due to large anisotropy.

15R-SiC is another choice for power MOSFETs[1] because of a higher electron mobility and less anisotropy than 6H-SiC. In this paper, we report the difference in MOSFET performances of 4H-, 6H-, and 15R-SiC on the (0001) Si-face. To avoid the low inversion mobility in 4H-SiC and the small bulk mobility along the c-axis in 6H-SiC, we describe the success in improving MOSFET performance (drastically in 4H-SiC) by utilizing the $(11\bar{2}0)$ substrate.

2. Experiments

N-channel planar MOSFETs were fabricated on B-doped p-type epilayers grown on 4H-, 6H-, and 15R-SiC (0001) Si-face substrates and 4H- and 6H-SiC $(11\bar{2}0)$ a-face substrates. The thickness and the acceptor concentration of epilayers were 4μm and $5\sim10\times10^{15}$ cm^{-3}, respectively. The source and drain regions were formed by multiple N^+ ion implantations at room temperature and post-implantation annealing at 1550°C for 30min in Ar. Before gate oxidation, the samples were clearned by RCA cleaning followed by additional H_2 annealing at 1000°C for 30min[2]. The gate oxidation was performed by wet oxidation at 1150°C for 2h ((0001) substrate) or 1100°C for 1h ($(11\bar{2}0)$ substrate) followed by post-oxidation annealing at the oxidation temperature for 30min in Ar, resulting in an oxide thickness of about 40nm. The ohmic contacts for source and drain were Al/Ti, and the gate electrode was Al. The channel length (L) and width (W) were 30 and 200μm, respectively.

Two types of MOSFETs, whose current directions were perpendicular each other as illustrated in Fig.1, were fabricated on the same substrates. There was little difference in MOSFET performance on the (0001) face. All measurements were done at room temperature.

3. Results and Discussion

The transfer characteristics of 4H-, 6H-, and 15R-SiC MOSFETs on the (0001) Si-face at low drain voltage of V_D=0.1V are shown in Fig.2. 4H-SiC MOSFET shows a quite poor characteristics of low channel mobility and high threshold voltage. A large number of negative charges at the 4H-SiC MOS interface (both negatively-charged interface states and border traps in SiO_2)[3] may work as scattering centers. Drain current of 15R-SiC MOSFET is higher than that of 6H-SiC, meaning a higher channel mobility in 15R-SiC, maybe due to a higher bulk mobility and almost the same interface state density. Low-field mobility (μ_0) and threshold voltage (V_T) of MOSFETs on the (0001) face are listed in Table I.

Figures 3 and 4 show the transfer caracteristics at V_D=0.1V of 4H- and 6H-SiC MOSFETs fabricated on the $(11\bar{2}0)$ face and the (0001) face with the same current direction of $\langle 1\bar{1}00\rangle$. Even along the same current direction, the drain current on the $(11\bar{2}0)$ face was much larger than that on the (0001) face. μ_0 and V_T of MOSFETs on the $(11\bar{2}0)$ face are summarized in Table II for both $\langle 0001\rangle$ and $\langle 1\bar{1}00\rangle$ current directions. Big improvement of channel mobility (drastically in 4H-SiC, 17 times higher) has been achieved by using the $(11\bar{2}0)$ face. The channel mobility in the saturation region was also improved. The improvement of channel mobility indicates that the MOS interface on $(11\bar{2}0)$ has superior properties than that on the (0001) face. Especially in 4H-SiC, a lower V_T(~4V) on the $(11\bar{2}0)$ face than V_T(~8V) on the (0001) face suggests that there are fewer negative charges in the MOS interface on the $(11\bar{2}0)$ face, and hence a higher channel mobility can be realized. The small anisotropy of μ_0 in 4H-SiC ($\mu_{0\langle 1\bar{1}00\rangle}/\mu_{0\langle 0001\rangle}$=0.85) and the large anisotropy in 6H-SiC (3.17) reflect the small and the large anisotropy in bulk electron mobility, respectively.

4. Conclusions

The channel mobility of MOSFETs on the $(11\bar{2}0)$ face was drastically improved especially in 4H-SiC. These results suggest that the problem in the present power MOSFETs of low channel mobility of 4H-SiC and low bulk mobility along the c-axis in 6H-SiC could be solved using $(11\bar{2}0)$ substrates.

In the case of the (0001) face, a higher channel mobility was obtained using 15R-SiC compared to 6H- and 4H-SiC. This indicates that 15R-SiC is a promising polytype for power MOSFETs because of high bulk and channel mobility and small anisotropy.

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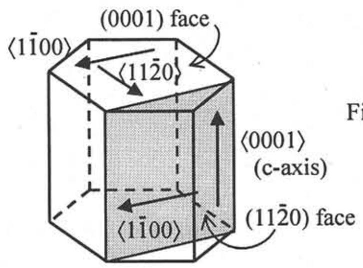

Fig.1: Current directions of MOSFETs on (0001) and (11$\bar{2}$0) faces.

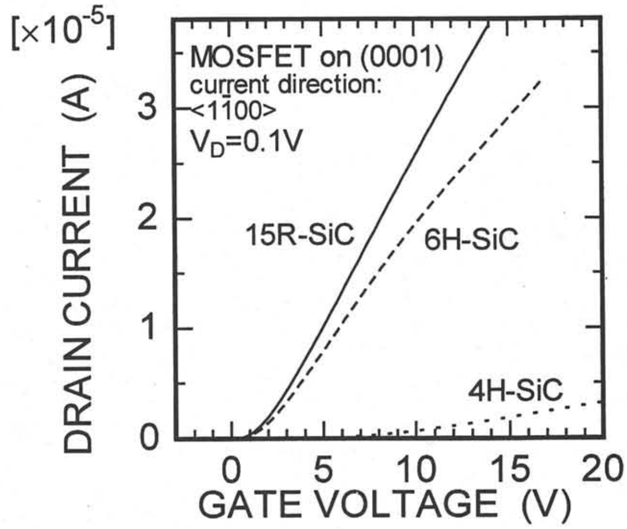

Fig.2: Linear-region transfer characteristics of 4H-, 6H-, and 15R-SiC MOSFETs on (0001) face.

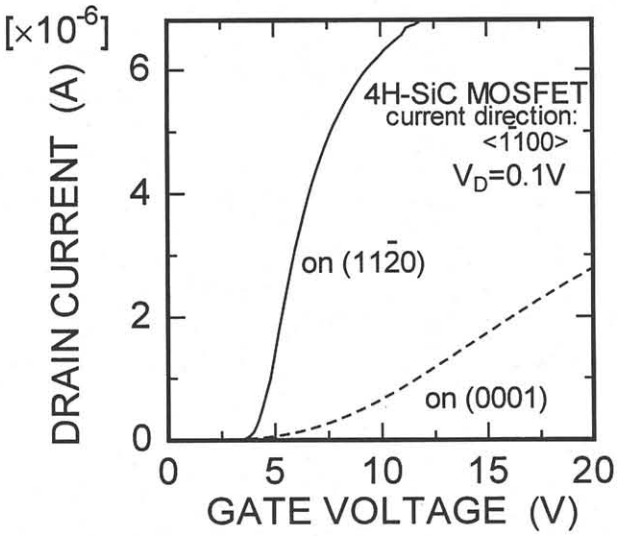

Fig.3: Linear-region transfer characteristics of 4H-SiC MOSFETs on (11$\bar{2}$0) and (0001) faces. Both MOSFETs have the same current direction of ⟨1$\bar{1}$00⟩.

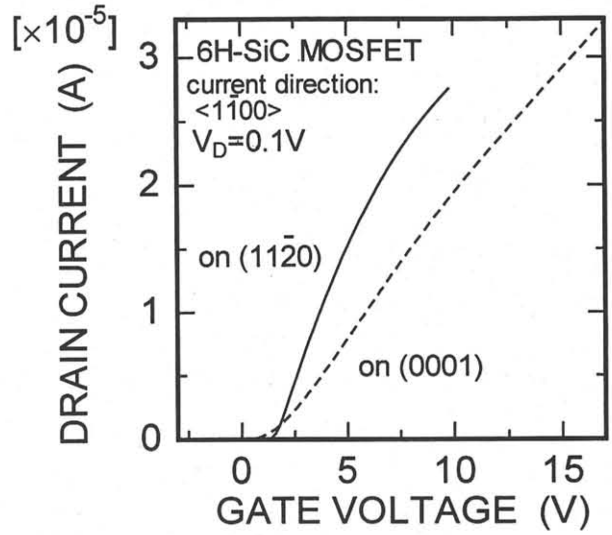

Fig.4: Linear-region transfer characteristics of 6H-SiC MOSFETs on (11$\bar{2}$0) and (0001) faces. Both MOSFETs have the same current direction of ⟨1$\bar{1}$00⟩.

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Table I: Channel mobility and threshold voltage of MOSFETs on (0001) Si-face substrates.

polytype	4H-SiC	6H-SiC	15R-SiC
μ_0 (cm^2/Vs)	5.6	44.8	59.2
V_T (V)	7.8	1.5	1.6

Table II: Channel mobility and threshold voltage of MOSFETs on (11$\bar{2}$0) a-face substrates for different current directions.

polytype	4H-SiC		6H-SiC	
current direction	⟨0001⟩	⟨1$\bar{1}$00⟩	⟨0001⟩	⟨1$\bar{1}$00⟩
μ_0 (cm^2/Vs)	95.6	81.7	36.5	115.7
V_T (V)	3.9	4.0	1.5	1.5