Threshold Voltage Instability in 4H-SiC MOSFETs with Nitrided Gate Oxide Revealed by Non-relaxation Method

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Abstract

Threshold voltage (V_{th}) shift of 4H-SiC metal-oxide-semiconductor field effect transistors with N₂O post-oxidation annealing (POA) was measured by sweep and non-relaxation methods. Although the V_{th} shift values for both the samples were almost identical when measured by the sweep method, those for the Ar POA samples were larger than those for the N₂O POA samples when measured by the non-relaxation method. Thus, it is difficult to investigate the exact V_{th} shifts by using only the conventional sweep method. Temperature-dependent analysis of V_{th} shift revealed that the N₂O POA decreases charge trapping in the near-interface region of the SiO₂.

1. Introduction

Threshold voltage ($V_{\rm th}$) instability, as characterized by bias temperature instability (BTI) measurement, is a serious concern in SiC metal-oxide-semiconductor (MOS) devices. $V_{\rm th}$ shifts occur because of the injection of channel charges into the gate oxide and/or the generation of interface states through gate stress. The injected charges in the bulk SiO₂ and near-interface region are transiently released after the gate stress is removed. In typical BTI measurement, $V_{\rm th}$ is independently measured after the gate stress is removed. Therefore, $V_{\rm th}$ is partially recovered during the gate voltage sweep in the $V_{\rm th}$ measurement because some of the trapped charges are immediately released. Such stress relaxation phenomenon results in underestimation of true $V_{\rm th}$ shift which is observable for only a short moment after the gate stress removal.

We have reported that the V_{th} shift without the stress relaxation was evaluated using the non-relaxation method, and the detrapping time constants of the trapped charges were distinguished by comparing with the V_{th} shift measured by the conventional sweep method [1]. The post-oxidation annealing (POA) is known to have large influence on the interface characteristic of the SiC MOS devices [2]. In this work, we investigated the effects of N₂O POA on the detrapping time constants of the trapped charges induced by the gate stress.

2. Experiments

N-channel MOSFETs (MOS field-effect transistors) were fabricated on 4H-SiC (0001) p-type epitaxial layers. 50-nm-thick gate-oxide films were formed by thermal oxidation at 1200°C in dry O_2 followed by POA in Ar or N_2O ambient. The n-type polycrystalline silicon electrodes were deposited by chemical vapor deposition and patterned by photolithography to form the MOSFET structure.

 $V_{\rm th}$ shifts were measured at various temperatures using the conventional sweep and non-relaxation methods. In the sweep method, drain current ($I_{\rm d}$)-gate-source voltage ($V_{\rm gs}$) measurement to determine the $V_{\rm th}$ and application of constant $V_{\rm gs}$ as the gate stress were iterated. The $I_{\rm d}$ - $V_{\rm gs}$ measurements were taken from $V_{\rm gs} = 0$ V to over $V_{\rm th}$ within a time period of roughly 10 s. Figure 1 shows the schema of the non-relaxation method. In this method, constant $V_{\rm gs}$ is continuously applied as gate stress, while the drain voltage ($V_{\rm ds}$) shift needed to maintain a constant $I_{\rm d}$ is measured. Then, the $V_{\rm ds}$ shift is converted to $V_{\rm th}$ shift using the following equation:

$$I_{\rm d} = \frac{Z}{L} \mu C_{\rm ox} \left(V_{\rm gs} - V_{\rm th} \right) V_{\rm ds} \,, \tag{1}$$

where Z is the gate width, L is the gate length, μ is the channel mobility, and C_{ox} is the oxide capacitance [3]. The product of Z/L, μ , and C_{ox} can be estimated from the slope of I_{d} - V_{gs} characteristics.



Fig. 1. Schema of the non-relaxation method.

3. Results and Discussion

Figure 2 shows the V_{th} shifts of Ar and N₂O POA samples, measured by the sweep and non-relaxation methods at room temperature. The V_{th} shift values for both the samples are almost identical when measured by the sweep method.

On the other hand, the $V_{\rm th}$ shifts for the Ar POA samples are larger than those for the N₂O POA samples when measured by the non-relaxation method. The difference of the $V_{\rm th}$ shift values between two methods indicates the amount of the trapped charges with a fast (<10 s) detrapping time constant. Thus, it is found that amount of these charges are decreased by the N₂O POA.



Fig. 2. Comparison of $V_{\rm th}$ shift values measured by the sweep and non-relaxation methods for Ar and N₂O POA samples.

Figure 3 shows the V_{th} shift values for the N₂O POA samples measured by the sweep and the non-relaxation methods at various temperatures during stress and measurement. Figure 4 shows the temperature dependence of the amount of trapped charges with fast and slow detrapping time constants. The amount of trapped charges with a slow detrapping time constant increases with temperature, while the amount of trapped charges with a fast detrapping time constant decreases with increasing temperature.



Fig. 3. Temperature dependence of $V_{\rm th}$ shift values for N₂O POA samples measured by the sweep and non-relaxation methods.

Figure 5 shows the estimated location of the charge trap sites causing the V_{th} shift. The increase in the amount of charges with a slow detrapping time (>10 s) constant at high temperature is considered to be caused by charge trapping in the deep region of the SiO₂, located away from the interface, which is enhanced by the increase in leakage current at high temperature. The decrease in the amount of charges with a fast detrapping time constant is considered



Fig. 4. Temperature dependence of $V_{\rm th}$ shifts for N₂O POA samples by trapped charges with fast and slow detrapping time constants.

to be caused by charge trapping in the shallow energy level near the conduction band edge of the 4H-SiC located in the near-interface region of the SiO₂ because the charges were easily detrapped during gate stress at high temperatures. The trap sites near the interface were effectively removed by N₂O POA, resulting in reduced fast $V_{\rm th}$ shift values in comparison with those for the Ar POA samples.



Fig. 5. Estimated location of the charge trap sites causing $V_{\rm th}$ shift.

4. Conclusions

The amount of trapped charges with slow (>10 s) and fast (<10 s) detrapping time constants in Ar and N₂O POA samples were investigated by comparing the V_{th} shift measured by sweep and non-relaxation methods. It was found that the amount of charges with fast detrapping time constant was decreased by N₂O POA.

The locations of charge trap sites causing the $V_{\rm th}$ shift were estimated from the temperature dependence of $V_{\rm th}$ shift. The charge trapping with slow and fast detrapping time constants are considered to be located in deep region of the SiO₂ and in the near-interface region of the SiO₂, respectively.

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