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Estimation of border trap distribution in electron irradiated SiC MOS capacitor using high temperature 1M Hz C-V method

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Abstract

The effect of high energy electron irradiation on the border trap distribution in SiC MOS is studied with high temperature 1M Hz C-V method. It is found that after electron irradiation, the border trap density experiences a great increase. This work presents an effective method for border trap distribution evaluation.

1. Introduction

Silicon carbide (4H-SiC) is regarded as a promising material for the next generation of power electronic devices. 4H-SiC MOSFETs can be excellent candidates to replace silicon insulated gate bipolar transistors (IGBTs) in power modules. However, the full potential of 4H-SiC MOSFETs has not been realized because of the low channel mobility resulting from a high density of interface traps (D_{it}) [1]. Besides, border traps in the oxide near the SiC/SiO_2 interface will lead to threshold voltage instability, which is also a main problem [2]. Many efforts have been made on D_{it} in the last decades. Recently, border trap has drawn significant attention [3-4]. Electron irradiation has been proved to be useful in D_{it} reduction. Its effect on border traps still remain unknown. In this paper, the effect of high energy electron irradiation on border trap distribution in SiC MOS capacitor is investigated using high temperature 1M Hz C-V method.

2. Experimental

SiC MOS capacitors were fabricated on an n-type 4H-SiC (0001) wafer covered by a 12 μm epilayer. Before dry oxidation, the SiC wafers were cleaned by the RCA cleaning procedure. Thermal oxides were grown by dry oxidation at 1300 ºC for 20 min in pure oxygen atmosphere. The samples were finally pulled out from the furnace in 100% N_2 ambient in 30min. The final thickness of SiO_2 was 30 nm. Circular gate electrode and backside ohmic contact were formed by aluminum evaporation and the diameters of the electrode were 200 μm. The electron irradiation experiment was carried out at Shanghai SN Irradiation Technology Co., Ltd. China at 10 MeV energy at 100 kGy (Si). During the irradiation, no bias was applied to each electrode of the MOS capacitors. Another control sample without irradiation is also prepared as reference. C-V measurement was performed with Agilent B1500A LCR meter at temperatures ranging from room temperature (RT) to 180 ºC under dark condition.

3. High temperature 1MHz C-V Method

The distribution of border traps in the oxide is estimated based on high temperature 1M Hz C-V method [4]. It was found that frequency dispersion exists between the 1M Hz C-V curves measured at high temperatures and RT, like the frequency dispersion among C-V curves at RT. Comparing this two different dispersion, it was revealed that the dispersion among 1M Hz C-V curves with various temperatures was dominated by two different types of traps. At high temperature region, the dispersion is dominated by border traps, just as shown in Fig. 1, while at low temperature region, interface traps dominate. In addition, the dependence of time constant on temperature can also be determined through comparing these two dispersion. Fig. 2 shows the schematic of border trap distribution in the oxide and the extraction of border trap density from the measured 1M Hz C-V curves at temperature region where border traps dominate.

4. Results and discussion

Based on the method described above, high temperature 1M Hz C-V measurements were carried out at various temperatures. For comparison, the C-V data at various frequencies at RT was also measured. Note that short and open calibration of the LCR meter was done before C-V measurements. Figs. 3 and 4 show the RT frequency dispersion between 1k Hz and 1M Hz and the measured high temperature C-V characteristics for the reference and irradiated samples, respectively. The dispersion degree is defined as the maximum capacitance difference between two C-V curves. The reference sample shows a frequency dispersion of ~0.31 C_{OX}, while the irradiated sample has a much smaller frequency dispersion of ~0.086 C_{OX}, indicating that electron irradiation helps to reduce the D_{it}. The 1M Hz C-V curves at high temperatures become steeper than that at RT although a right shift is in company. The right shift of C-V curve is possibly due to the unreleased electrons which are captured by the border traps during C-V sweep despite the increase in their time constants. On the other hand, it is believed that the dispersion change mainly results from response of border traps to the ac probe signal in C-V measurement. And it is reasonable that the 1M Hz frequency at high temperature corresponds to a low frequency at RT. The relationship between temperature and frequency can be extracted through the dispersion between high temperatures 1M Hz C-V curves in contrast with the frequency dispersion at RT. Finally, it is calculated that 1k Hz at RT corresponds to 120 ºC and 100 °C 1M Hz C-V for the reference and irradiated samples, respectively. Assume the time constant of border traps follows Shockley-Read-Hall statistic model [4], therefore, the time constant can be expressed as

$$\tau(T) \propto \exp(E_a / k_B T) \quad (1)$$

And the calculated E_a are 1.43 and 1.08 eV for the reference and irradiated sample respectively. The depth of the traps is determined by taking both time constant and electron thermal velocity into consideration. The electron thermal velocity is

$$\upsilon_{th}(T) = \sqrt{2k_B T / m^*},$$

where k_B is the Boltzmann constant. Assume $m^* = 0.3m_0$, m_0 is the mass of a free electron.

After determination of v_{th}, the border trap density against its depth in the oxide is shown in Fig. 5. It is apparent that electron irradiation results in relatively large density of border traps near the interface. However, it still needs further investigation. A possible reason for this phenomenon is that traps at the interface undergo structure reconstruction after electron irradiation, leading to reduction in D_{it} while increase in border trap density.

5. Conclusions

The border trap distribution of SiC MOS after irradiation is investigated through a high temperature 1M Hz C-V method. Results reveal that electron irradiation will result in large density of border traps near the SiC/SiO_2 interface. Further investigation is needed to explore its mechanism.

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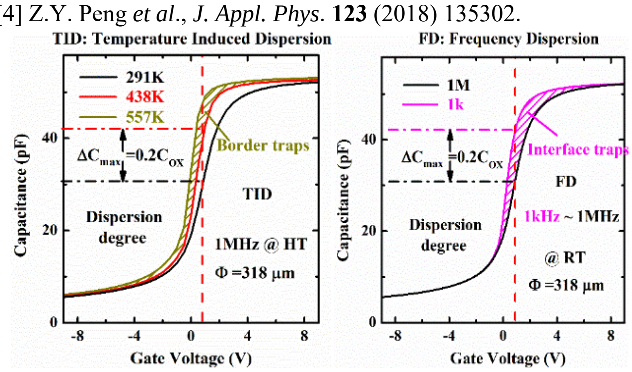

Fig. 1 Comparison of dispersion among high temperature 1MHz C-V curves with frequency dispersion at RT.

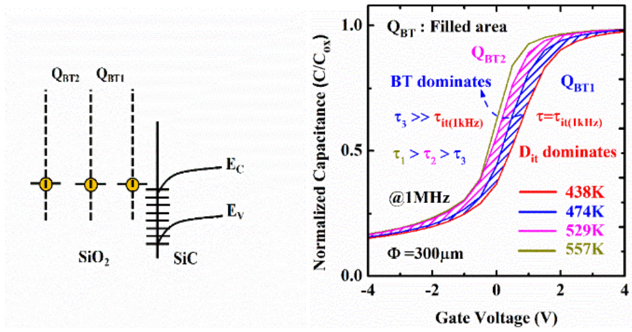

Fig. 2 Schematic of border trap distribution in the oxide the border trap charge extracted from high temperature 1M Hz C-V data.

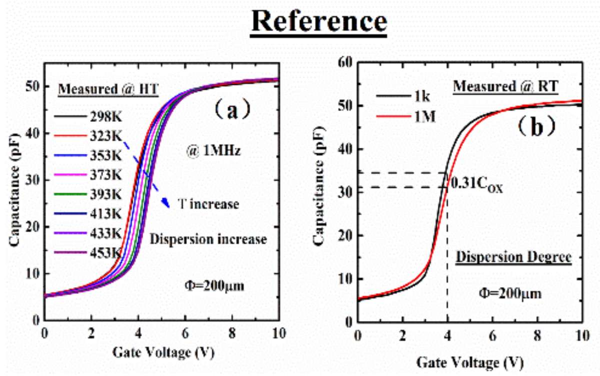

Fig. 3 Measured high temperature 1M Hz C-V data and the frequency dispersion between 1k Hz and 1M Hz at RT for the reference sample.

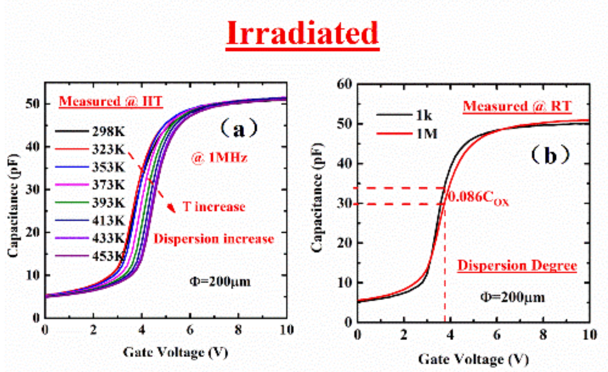

Fig. 4 Measured high temperature 1M Hz C-V data and the frequency dispersion between 1k Hz and 1M Hz at RT for the irradiated sample.

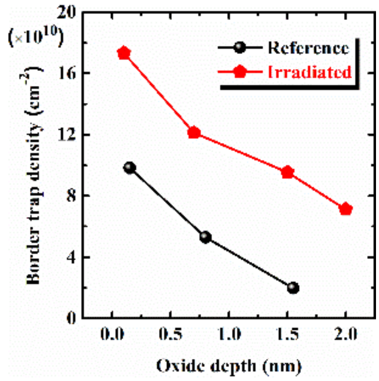

Fig. 5 Extracted border trap density distribution against the depth in the oxide from the SiC/SiO_2 interface.