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Cumulative Effects of Gamma Irradiation on Oxide Traps and Interface States in SiC MOS Capacitor

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Abstract

In this study, the cumulative effects of gamma irradiation on oxide traps and interface states in SiC MOS capacitor (MOSC) were separately characterized by C-V measurements. The samples were irradiated by ^{60}Co gamma-ray source with a variety of doses. Before 15 kGy, the gamma-induced ionizing charges are predominately captured by oxide traps instead of interface states. When the dose reached 37.8 kGy, the oxide trapped charges seemed saturated and the interface states started to increase slightly.

1. Introduction

In recent years, an increasing demand for applications in high-radiation environment such as aerospace promotes the development of radiation-hardened electronics. Relying on the intrinsic property of large bandgap, SiC possesses excellent radiation tolerance which can effectively suppress radiation damage caused by energetic particle interactions. However, common SiC-based devices still have to incorporate the gate-controlled metal-oxide-semiconductor (MOS) structure or oxide passivation therein. Due to the fact that oxide is highly susceptible to ionizing radiation, the buildup of ionizing charges trapped within MOS structure or oxide layer could change the electrical properties of devices and thus increase the risk of system failure [1]. Generally, the impact of radiation damage on electronics can be categorized as cumulative effects and single event effects. Over the past years, the cumulative effects induced by displacement damage or total ionizing dose have been thoroughly investigated on Si-based devices [2-4]. However, there has been still lack of comprehensive understanding on SiC-based devices. Furthermore, the stability of the SiO_2/SiC interface in SiC MOS structure against radiation is also a great issue of concern. Therefore, the purpose of this study is to investigate the total ionizing effects on SiC MOS capacitor (MOSC), especially focusing on separately identifying the trapped charges arising from oxide traps and interface states. In addition, the results of SiC MOSC are also compared to those of Si MOSC.

2. Experimental Procedures

In this study, the Si and SiC MOSCs were fabricated with standard semiconductor process in clean room. The Si MOSCs were built on an n-type phosphorous doped Si wafer, while the SiC ones were fabricated on a lightly doped n-type SiC epilayer grown on an n^+ 4H-SiC substrate. The thickness of the gate oxide in both MOSCs is about 60 nm. In particular, for the SiC oxidation process, a post oxidation annealing was performed in N_2O ambient at a high temperature of 1250 ℃. The test MOSCs were irradiated by gamma rays emitted from a ^{60}Co source. The gamma irradiation experiments were conducted to reach a variety of accumulated doses ranging from 0.5 to 37.8 kGy under a fixed dose rate about 0.877 kGy/hr. After irradiation, the MOSCs were characterized by high frequency capacitance-voltage (C-V) curves using an HP-4980 LCR analyzer. The photoluminescence (PL) spectra of the SiC crystals which were irradiated simultaneously were also measured using a Hitachi F-7000 spectrometer with an excitation wavelength of 325 nm.

3. Results and Discussion

Fig. 1 shows the high frequency C-V curves of the Si and SiC MOSCs as a function of gamma dose. As can be seen, the Si MOSC showed a monotonic negative shift of C-V curves with gamma dose. When compared to the Si samples, the SiC MOSC revealed the same negative shift initially but exhibited a reverse shift when the cumulative dose is up to 37.8 kGy. In order to identify the origin of the shift of C-V curves, the voltage variations resulting from oxide trapped charges and interface states ΔV_{ox} and ΔV_{it} were separately extracted from those curves based on the relationships given below,

$$\Delta V_{ox} = \left|\left(V_{mg}\right)_{post} - \left(V_{mg}\right)_{pre}\right| \quad (1)$$

$$\Delta V_{ox} = \left|\left(V_{mg} - V_{fb}\right)_{post} - \left(V_{mg} - V_{fb}\right)_{pre}\right| \quad (2)$$

where the V_{fb} and V_{mg} represent the flatband and midgap voltages, respectively. The values of ΔV_{ox} and ΔV_{it} under various gamma doses are plotted in Fig. 2. Clearly, the curve shift is dominated by the ΔV_{ox} which originates from oxide trapped charges for both cases. In both Si and SiC MOSCs, the ΔV_{ox} gradually decreased while the ΔV_{it} almost kept unchanged before the dose of 15 kGy. When the dose was raised to 37.8 kGy, ΔV_{it} exhibited a slight increase and even an inversion point of ΔV_{ox} was found in SiC MOSC. This implies that such a gamma dose could create a lot of interface states such that comparable charge trapping sites can be provided. To verify this statement, the irradiations with higher gamma doses are currently under progress. Further derivation on the net areal number density of the oxide trapped charges and interface states was also done as shown in Fig. 3. The charge trapping rates of oxide before 15 kGy were estimated to be about 4.0×10^{15} and 4.2×10^{15} (#/cm^3)/kGy for Si and SiC MOSCs, respectively.

The C-V profiling method based on $1/C^2$ versus V relationship was used to assess the influence of gamma irradiation on carrier concentration. As shown in Fig. 4, the carrier concentration in Si and SiC did not change with gamma dose. Fig. 5 also presents the PL spectra of the gamma-irradiated 4H-SiC crystals. A PL peak due to the point defects bonded to carbon or nitrogen atoms created during crystal growth can be found around 2.4 eV. As revealed, the intensity of this peak did not increase after gamma irradiation, but it decreased due to the self-heating effect during gamma irradiation [5].

Thus, it can be concluded that no point defects were introduced into SiC by gamma irradiation at the dose used in this study.

4. Conclusions

In summary, the impact of gamma irradiation on the preference of charge trapping sites in Si and SiC MOSCs was investigated in this study. The results indicated that oxide trapping charges dominate at low dose, while the interface states become significant with the increase of gamma dose. The charge trapping rates of oxide in Si and SiC MOSCs are close about 4.2×10^{15} (#/cm^3)/kGy. In addition, the results of carrier concentration and PL spectra also suggested that no point defects were introduced into SiC during gamma irradiation.

Acknowledgements

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References

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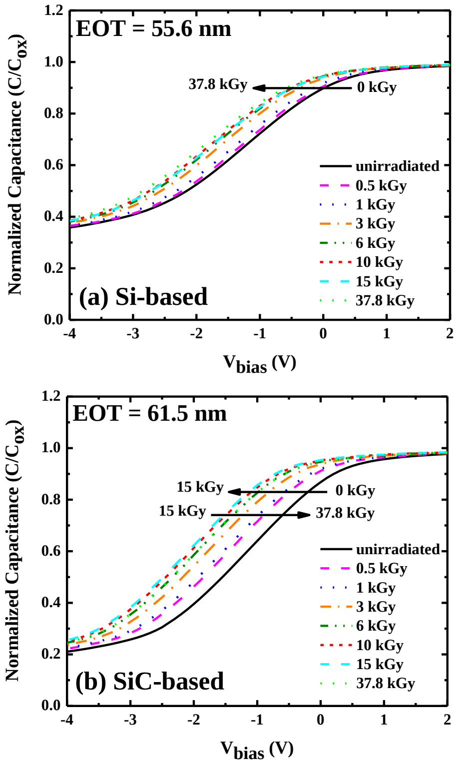

Fig. 1 Normalized C-V curves of (a) Si and (b) SiC MOSCs before and after gamma irradiation.

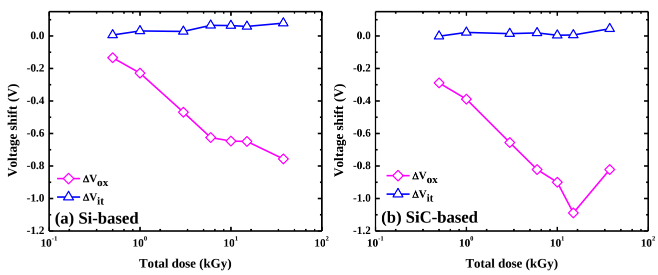

Fig. 2 Values of ΔV_{ox} and ΔV_{it} for (a) Si and (b) SiC MOSCs as a function of gamma dose.

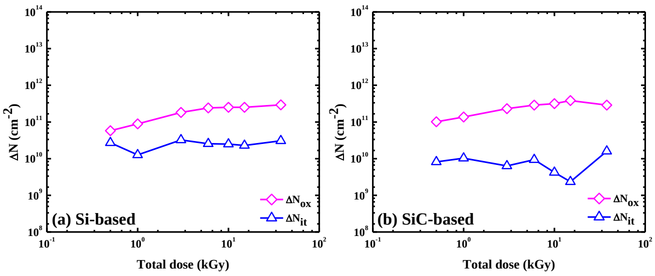

Fig. 3 Net areal number density of oxide trapped charges and interface traps for (a) Si and (b) SiC MOSCs as a function of gamma dose.

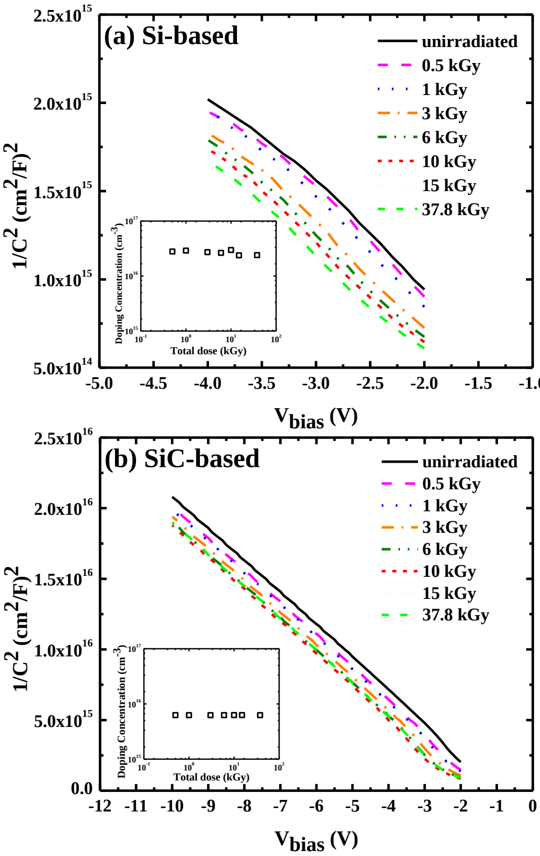

Fig. 4 $1/C^2$-V curves of (a) Si and (b) SiC MOSCs as a function of gamma dose. The inlet presents the derived carrier concentration before and after gamma irradiation.

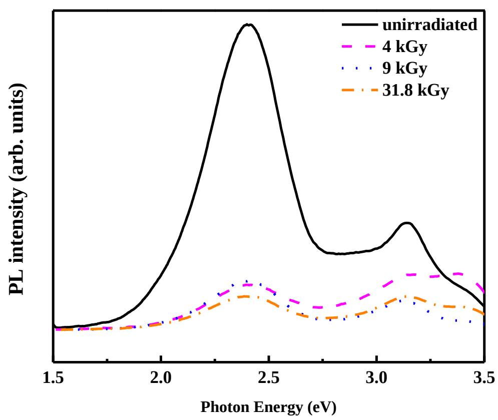

Fig. 5 PL spectra of 4H-SiC crystals before and after gamma irradiation.