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Electrical Properties of MOS Capacitors Irradiated with Co^{60}-γ Ray

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Co^{60}-γ선이 조사된 MOS Capacitors에서의 전기적 특성

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Abstract – When MOS(Metal-Oxide-Semiconductor) device is exposed to radiation, the resultant effects can create the positive space charge in the oxide and the interface state in the silicon-silicon dioxide interface. Irradiation effects on MOS capacitors were investigated by the measurements of capacitance and current at various radiation dose and oxide thickness. From the experimental results on capacitance-bias voltage characteristics, the flatband voltage and the interface state density was calculated. The I-V characteristics could be explained by positive space charges created by radiation in the oxide, and charges trapped at silicon-silicon dioxide interface.

요 약 – MOS(금속-산화막-반도체 접합) 소자가 방사선에 노출되면, 산화막내에 양의 공간전하가 생성되고 Si-SiO$_2$ 계면에 계면준위가 생성된다. MOS 커패시터의 방사선 조사효과를 방사선 피폭량과 산화막의 두께를 달리하는 시편에서 정전용량과 전류변화를 측정하여 고찰하였다. 정전용량-바이어스 전압 특성 실험 결과로부터 플렛밴드 전압 및 계면상태밀도를 계산하였다. 또한 전압-전류 특성은 방사선 조사로 산화막내에 생성된 양의 공간전하와 Si-SiO$_2$ 계면에 포획된 전하에 의해서 설명이 가능하였다.

1. Introduction

The insulator film has been used as an inert and passivating layer until the advent of Metal-Insulator-Semiconductor (MIS) device. In MIS device, however, such as MOSFET (Metal-Oxide-Semiconductor Field Effect Transistor), CMOS (complementary MOS), the film is an active and important part of the device. When MIS device is exposed to radiation, the resultant effects from this radiation can cause the modulation and/or degradation in device characteristics and in its operating life.

The effect of radiation on MOS device, first reported by Heghes and Giroux [1], was extensively studied thereafter by many authors [2-5]. The most commonly used techniques for determining the density of surface states and the charge behavior in MOS devices irradiated, are high frequency capacitance techniques [6]. Irradiation effects of conventional MOS structures which exposed to ionizing radiation are the introduction of a fixed positive space charge in the oxide, and on some occasions, the creation of new interface states at the silicon-silicon dioxide (Si-SiO_2) interface as known [7, 8]. But it is not still enough to explain all of the experimental results of the radiation effects on MOS structures.

In this study, we were electrically investigated the radiation effects on MOS capacitors which irradiated with Co^{60}-γ ray source .

2. Experimentals

The MOS capacitors used in this study were fabricated on ⟨100⟩ orientation p-type 10 Ω-cm Si wafers. The wafers were chemically cleaned and oxidized in a O_2+TCE ambient for 40~80 nm oxide. After metalization with aluminum, 0.2×0.2 mm^2 contact squares were defined by photolithographic techniques. The wafers were annealed then in dry nitrogen. Samples were mounted in 14-leads DIP headers and packaged with plastic material. The structure of capacitor is shown in Fig. 1. After the samples were made, the irradiations were performed by using Co^{60}-γ ray. The total dose range from 10 krad to 100 Mrad.

To investigate the electrical properties in irradiated MOS capacitors, C-V and I-V characteristics were measured by a computerized measuring apparatuses as shown in Fig. 2. The apparatus was consisted of an impedance/gain-phase analyzer, electrometer and computer.

3. Experimental Results and Discussion

Fig. 3 shows C-V characteristics of MOS capacitors with various thickness of oxide and irradiation dose, which was measured at frequency 1 MHz. The C-V traces shift to higher negative bias voltage with increasing the thickness of oxide and amount of dose.

The flatband voltage (V_{fb}) and the interface state density calculated from Fig. 3 is shown in Fig. 4~5. It is considered that usually observed negative shifts in C-V traces and flatband voltage shifts are due to the radiation-induced positive space charge in the oxide the radiation-induced interface states at the Si-SiO_2 interface.

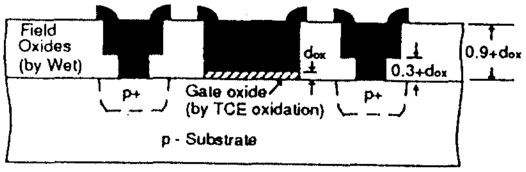
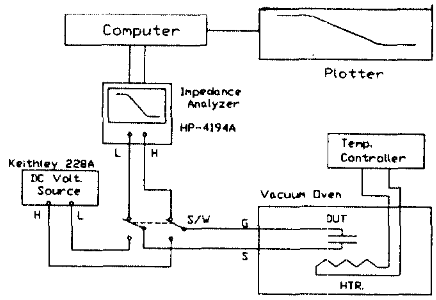
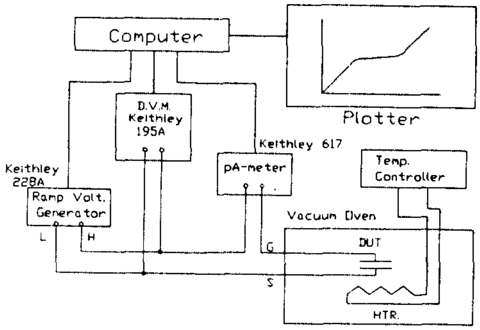


Fig. 1. Structure of MOS capacitor.



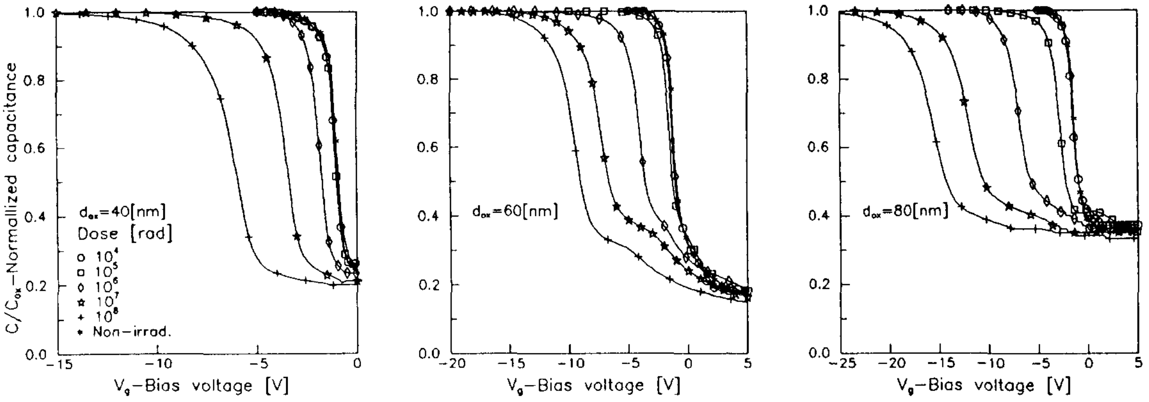
(a) C-V measuring apparatus.



(b) I-V measuring apparatus.

Fig. 2. Block diagram of measuring apparatus.

We assume qualitatively that the primary mechanism is the creation of electron-hole pairs. The mobility in the oxide is believed to be on the order of 30 cm^2/V·sec, whereas the hole mobility is thought to be on the order of 10^{-3} cm^2/V·sec [8], a factor of 3×10^{-3} smaller. Some of electrons undoubtedly recombine with holes, traps, but many are transported from the oxide into the elec-



(a) Oxide thickness 40[nm] (b) Oxide thickness 60[nm] (c) Oxide thickness 80[nm]

Fig. 3. C-V characteristics with different thickness of oxide.

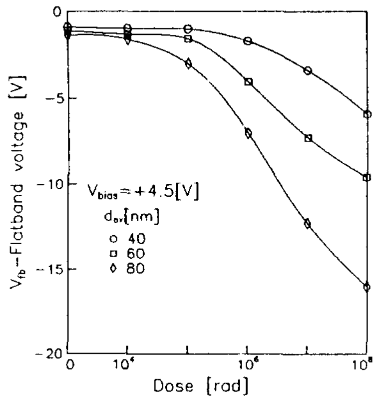


Fig. 4. Variation of V_{fb} with d_{ox} for each dose.

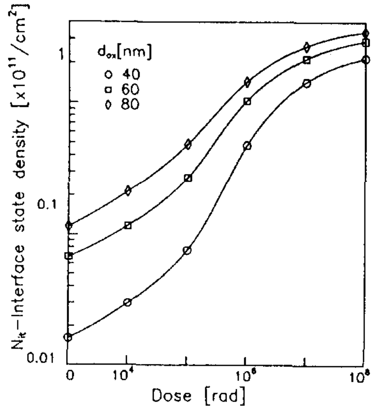
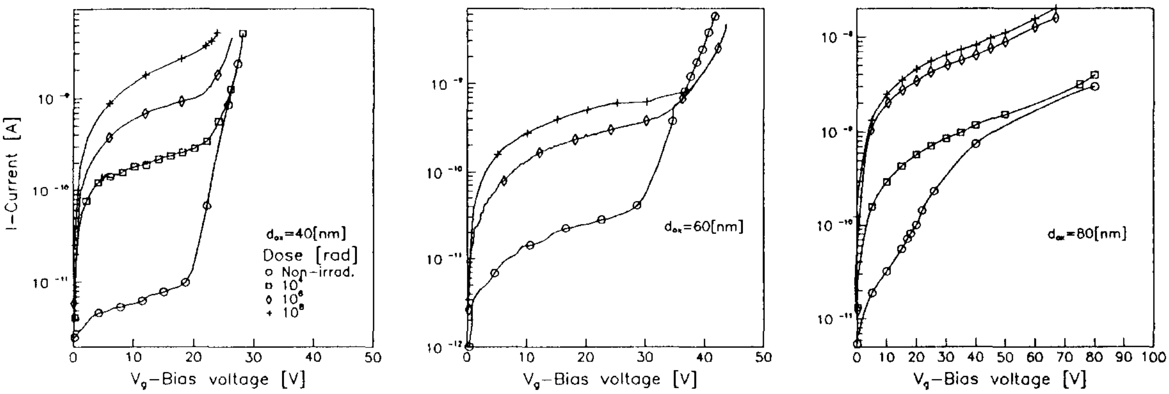
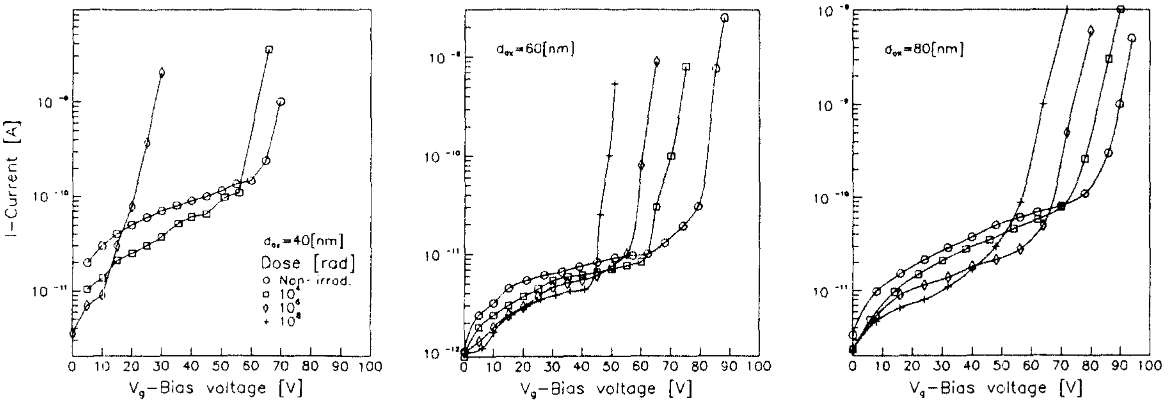


Fig. 5. Variation N_{it} with d_{ox} for each dose.



(a) Oxide thickness 40[nm] (b) Oxide thickness 60[nm] (c) Oxide thickness 80[nm]

Fig. 6. I-V characteristics in case of negative bias voltage.



(a) Oxide thickness 40[nm] (b) Oxide thickness 60[nm] (c) Oxide thickness 80[nm]

Fig. 7. I-V characteristics in case of positive bias voltage.

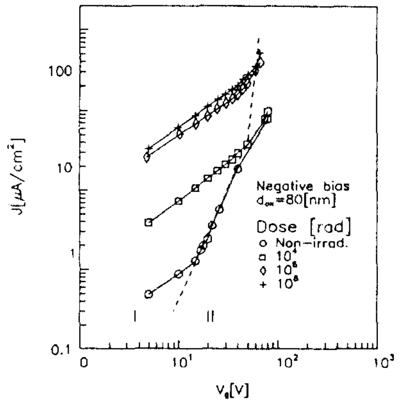


Fig. 8. J-V characteristics derived from Fig. 6.

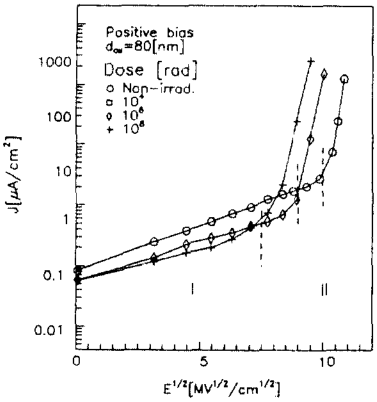


Fig. 9. Schottky plot derived from Fig. 7.

trode. The remaining holes, which by comparison have essentially zero mobility, are probably to trapped by special bonding states (holes trap) in the oxide, such as the nonbridging oxygen bonds associated with sodium impurities. The result is that a space sparge is buildup, causing a negative shift in C-V curve and in flatband voltage. The magnitude of the shift depends on the density of the space charge, its distribution, and oxide thickness. It is also considered that total interface states density increases with increasing the amount of dose as shown in Fig. 5.

Fig. 6, 7 show I-V characteristics of MOS capacitors with various thickness and irradiation dose, which was measured at 5℃. When the gate electrode is negatively biased, I-V characteristics show to be a linear relation at a lower field, thereafter, all curves are very steep as shown in Fig. 8. The dose dependence of the ohmic current in these samples can be explained by the space charge effect. That is, this tendency is due to the cathode and median field highering affected by the positive space charges and thus the conduction current the oxide layer becomes large. In Fig. 8, the gradient in the region of rapid increase in current is about 2. Thus, such rapid increase in current is assumed to be due to space charge limiting current, The voltage, V_{tr}, at which the transition from the linear from to the quadratic dependence of voltage occurred, is found to be increased which increasing the irradiation doses. This effect is assumed to be due to traps created by irradiation in the oxide layer. When the gate electrode is positively biased, I-V characteristics also show to be a linear relation at a lower field, thereafter, all curves are very steep as shown in Fig. 9.

The dose dependence of the ohmic current can be also explained by the space charge effect. On the contrary to the case of negative bias, the oxide and cathode field become to be lowering by the positive space charge in the oxide layer is decreased with increasing the irradiation dose. In Fig. 9, the characteristics in the high field region are fit well to the Schottky plot. Thus, the increase in current is assumed to be due to the Schottky effect. The voltage, V_{tr}, at which the transition from the ohmic current to the Schottky current occurred, is found to be decreased with increasing the irradiation doses. This tendency can be explained in terms of the effective potential barrier at Si-SiO$_2$ interface. The effective potential barrier become to be lowering due to the interface traps charges.

4. Conclusion

To investigate the electrical properties in MOS capacitors irradiated, C-V and I-V characteristics were measured and discussed.

From the experimental results, the C-V traces shift to higher negative bias voltage with increasing the thickness of the oxide and amount of dose. It is considered that the usually observed negative shifts in C-V traces and flatband voltage shifts are due to the radiation-induced interface state at the Si-SiO$_2$interface. When the gate is negatively biased, the current through oxide is found to be ohmic current at a lower field and space charge limiting current at a higher field. The dose dependence of the ohmic current can be explained by the effect of positive space charge in the oxide layer, which induced by irradiation. The transition voltage, V_{tr}, is increased with increaing the irradiation dose. This effect is assumed to be due to traps created by irradiation in oxide layer. When the gate voltage is positively biased, the current is found to be ohmic current at a lower field and Schottky current at a higher field. The transition voltage, at which from the ohmic current to Schottky current occurred, is found to be decreased with increasing the irradiation doses. This tendency can be explained in terms of the effective potential barrier lowering due to the trap charges at the interface of Si-SiO$_2$.

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