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# Effects of Si Ion Implantation on the Total-Dose Radiation Properties of SIMOX SOI Materials

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**Abstract**: To improve the total-dose radiation hardness, silicon-on-insulator (SOI) wafers fabricated by the separation-by-implanted-oxygen (SIMOX) method are modified by Si ion implantation into the buried oxide with a post anneal. The $I_D$-$V_G$ characteristics can be tested with the pseudo-MOSFET method before and after radiation. The results show that a proper Si-ion-implantation method can enhance the total-dose radiation tolerance of the materials.

**Key words**: SIMOX; SOI; Si ion implantation; total-dose radiation effect; pseudo-MOS
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## 1 Introduction

Silicon-on-insulator (SOI) technologies have been developed on radiation-hardened applications for many years for their unique advantages compared to bulk-silicon in some radiation environments. However, the buried oxide (BOX) limits the radiation hardness of SOI materials. To improve the total-dose radiation tolerance for SIMOX SOI wafers, many modified technologies have been explored[1~4]. But the modified materials usually have to be fabricated into MOSFETs to test the characteristics, a process which requires many steps and a very long time. With this understanding, Cristoloveanu *et al*. developed the pseudo-MOSFET (Ψ-MOSFET) technique to characterize the quality of SOI wafers before any device processing[5~9]. As shown in Fig. 1, the Ψ-MOSFET has an upside-down MOS configuration. The Si-film and BOX properties can be evaluated by monitoring electrical parameters such as mobility, Si film doping, and oxide and interface defects. Since the Ψ-MOSFET can provide rapid evaluation of charge trapping in buried oxides, it is also useful for radiation-effects analysis.

In this paper, SIMOX SOI wafers are modified by Si ions implanted into the BOX layer with post annealing. The Ψ-MOSFET method is used to test the $I_D$-$V_G$ characteristics before and after irradiation to investigate the influence of the modification process on the total-dose radiation effects of the wafers.

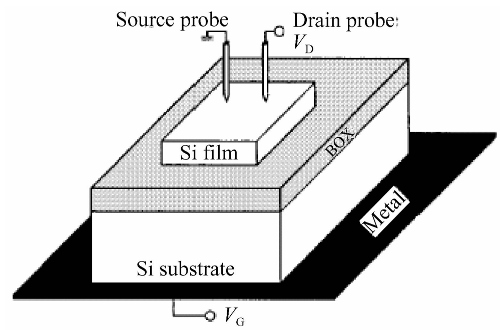


Fig. 1 Schematic configuration of the Ψ-MOSFET

## 2 Experiment

The initial materials are the commercial standard SIMOX SOI wafers with a top Si layer of 200nm and a BOX layer of 380nm, which is ⟨100⟩ p-type with a resistivity of 15～25Ω·cm. Silicon ions are implanted into these wafers with a dose of $1\times10^{15}cm^{-2}$ and energy of 190keV, followed by an anneal in Ar for 180min at 900℃. The unimplanted wafer is annealed along with the implanted wafer. Then the Si films are etched into square islands with the areas of 5mm×5mm.

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Irradiations are performed using an ARACOR 4100 10keV X-ray irradiator. The dose rate is $5\times10^4$ rad (Si)/min and the total doses are up to $1\times10^6$ rad (Si). During the irradiation, the substrate is biased with 15V and the top Si is biased with 0V. All the measurements are performed at room temperature with an HP4155B semiconductor parameter analyzer under the same conditions before and after irradiation. Two point contacts are made on each Si-island for the source and drain using tungsten probes, with an inter-probe distance of 1mm, where the pressure is maintained at 70g and the voltage is 0.1V.

## 3 Results and discussion

Figures 2(a) and (b) show the drain current versus gate voltage ($I_D$-$V_G$) characteristics of the Ψ-MOSFET for SIMOX SOI materials before and after radiation. As the total radiation dose is enhanced, all the $I_D$-$V_G$ curves shift negatively along the voltage axis. Furthermore, the curves of wafer A (unimplanted sample) shift much more than those of wafer B (implanted sample). After irradiation to 600krad (Si), the $I_D$-$V_G$ curves of wafer A already lose the MOS characteristics, while wafer B also works normally when the total radiation dose is as high as 1Mrad (Si). This illustrates that Si ion implantation can improve the total-dose radiation tolerance of SIMOX SOI materials.

As show in Fig. 2, the pre-irradiation midgap voltages for wafer A and wafer B are $-2$ and $-13.2$V, respectively. This suggests that implanting Si ions into the buried oxide of SIMOX SOI wafers increases the initial fixed positive charge in the BOX, which leads to the negative drift of the pre-irradiation midgap voltage for wafer B. After irradiation, however, the midgap voltage shifts for wafer B are much less than those for wafer A. Since interface traps are approximately neutral when the Fermi level is at midgap, it is clear that the oxide-trap charge contributes to the midgap voltage shifts.

Figure 2 also shows the radiation-induced interface-trap contribution, which can be estimated from the change in the slopes of the sub-threshold curves. The pre-irradiation slopes are 1.6 for both wafers. When the total radiation up to 400krad (Si), the slope for wafer A is 6.4 and that for wafer B is 2.4. The slopes for wafer B only have a little change before and after irradiation, indicating that the radiation-induced interface-trapped charge also decreases with the implantation.

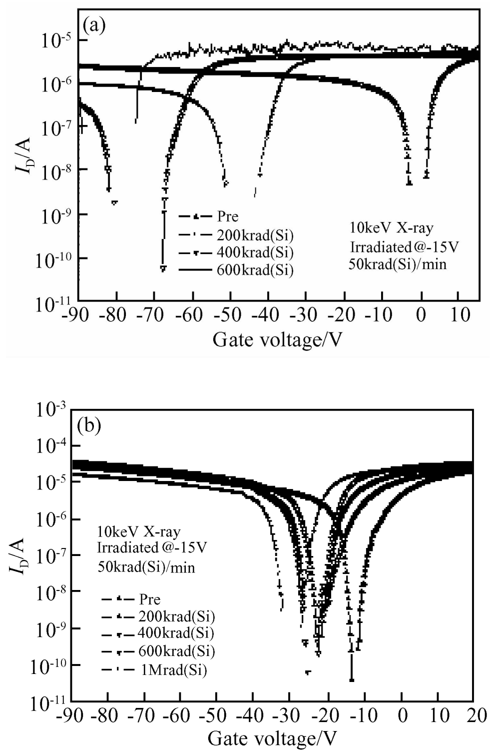


Fig. 2 Drain current versus gate voltage ($I_D$-$V_G$) characteristics of the Ψ-MOSFET for SIMOX SOI materials before and after radiation (a) Unimplanted sample A; (b) Implanted sample B

As is the case with irradiation, the total threshold-voltage shift for the transistor is the sum of the threshold-voltage shifts due to the radiation-induced oxide-trapped charge and the interface-trapped charge. Figure 3 shows the threshold voltage shifts for the n-channel transistor $\Delta V_{thn}$ extracted from the curves of Fig. 2. The threshold voltage has a negative shift along the voltage axis after irradiation. It can be seen from Fig. 3 that the $\Delta V_{thn}$ for wafer B is obviously less than that for wafer A under the same conditions. This phenomenon appears more evidently for high total radiation dose. The implantation leads to smaller threshold voltage shifts, making it clear that implanting Si ions into the buried oxide largely reduces the amount of the trap charge introduced during the irradiation.

The above results can be explained in the fol-

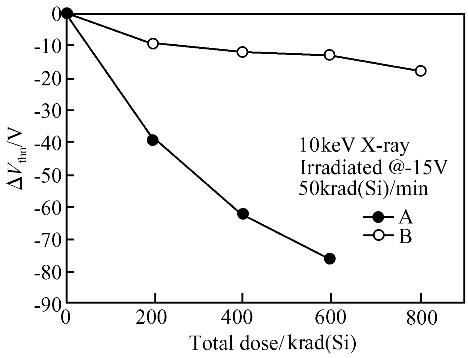


Fig. 3　Threshold voltage shifts in n-channel transistors for implanted sample B and unimplanted sample A

lowing way. When the MOS structures are exposed to X-ray radiation, in which both holes and electrons are generated in the oxide, the oxide becomes positively charged by the trapping of holes. This leads to the shift of the $I_D$-$V_G$ curves, and can adversely affect device operation. The Si implantation creates electron traps throughout the buried oxide. When filled, the additional electron traps compensate the trapped positive charge by providing recombination centers for radiation-induced holes[10,11], decreasing the net positive charge in the oxide. According to the research work of Nicklaw, Si implantation does not result in a significant change in the density of hole traps in the oxide[12,13]. Thus the implantation has no effect on the breakdown field strength of the oxide. However, the implantation may have some influence on the top Si, which is a possibility that needs to be studied further.

## 4　Conclusions

The Ψ-MOSFET radiation results show that Si ion implantation can improve the total-dose radiation tolerance of SIMOX SOI materials remarkably. The implantation significantly decreases the radiation-induced trap charge. But some work still needs to be performed to reduce the initial fixed positive charge in the BOX.

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# Si 离子注入对 SIMOX SOI 材料抗总剂量辐照性能的影响

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**摘要：** 为了提高 SIMOX SOI 材料抗总剂量辐照的能力，采用硅注入绝缘埋层后退火得到改性的 SIMOX SOI 材料．辐照前后，用 pseudo-MOSFET 方法测试样品的 $I_D$-$V_G$ 特性曲线．结果表明，合适的硅离子注入工艺能有效提高材料抗总剂量辐照的能力．

**关键词：** SIMOX；SOI；Si 离子注入；总剂量辐照效应；pseudo-MOS

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