EFFECT OF TOTAL IRRADIATION DOSE ON MOSFETs/SOI

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ABSTRACT

The MOSFETs are built on SIMOX material, the oxide positive charge, interface state, threshold voltage and leakage current of MOSFETs/SOI after ^{60}Co-γ irradiation are measured with *I-V* technique. The results indicate that the accumulation rate of oxide charge density is more than that of interface state density in dose range of 0–3×10^{4}Gy (Si), and the "on" radiation bias is worst case for NMOSFET and PMOSFET.

Keywords Oxide charge, Interface state, Threshold voltage, Leakage current, MOSFET, Physical radiation effect

1 INTRODUCTION

Recent years, SOI (silicon on insulator) technology has been developed rapidly and is very satisfying three dimensional VLSI (very large scale integration) applications, CMOS (couple metal oxide semiconductor) devices fabricated on SOI substrate exhibit significantly increased tolerance to transient irradiation and single event upsets[1]. In addition, several alternative constructions have been proposed and investigated for producing SOI materials. But thus for only Seperation by IMplantation of OXygen (SIMOX), Bond and Etchback Silicon On Insulator (BESOI) have shown the potential for being manufacturable technologies compatible with fabrication of generic wafer for both CMOS and bipolor large area IC production. SIMOX has currently demonstrated the potential to produce very thin superficial layers needed for advanced performance CMOS device applications[2], and BESOI has been used to produce the thicker, dislocation free layers needed for bipolor device applications[3]. The total dose effects in CMOS/SOI devices are similar to those in bulk CMOS devices, but the buried oxide layer is sensitive to total dose irradiation.

The difference of fabrication between CMOS/SOI and bulk CMOS is that there is a buried oxide layer in CMOS/SOI; the only difference in the SOI case is that the total dose effects are sometimes very difficult to control. According to lots of studies[4], the

Manuscript received date: 1994-05-02

buried oxide layer characteristics of multiple implanting SIMOX material is considerably better than that of single implanting SIMOX material for total dose radiation hardening.

In this discussion, we will describe the accumulation of trapping charge (ΔN_{ot}, ΔN_{it}), the leakage curent (I_D), threshold voltage shift (ΔV_T) of MOSFETs/SOI in total dose (D_{ose}) radiation environment.

2 EXPERIMENTAL

Single-crystal silicon wafers are implanted with 200 keV oxygen ions to dose as high as 1.8×20^{18} ions/cm^2, SIMOX materials are obtained after three multiple (low-dose: 0.6×10^{18} ions/cm^2) implanting/annealing cycles, the buried oxide thickness is about 430 nm, and the overlaid silicon film is about 160 nm. Then enclosed gate NMOSFET and PMOSFET are fabricated on SIMOX material using standard MOSFETs process. Gate oxide thickness is 58nm grown at 950°C and channel length is 2.0μm.

The packaged devices are irradiated in ^{60}Co gamma cell at dose rate of 0.8–7.0 Gy(Si)/s, dose range is 0–3×10^4 Gy(Si), and all measurements are finished within 20 min after each irradiation. For N-channel MOSFET irradiation, in the "on" state, gate voltage (V_G), source voltage(V_S) and drain voltage (V_D) are respectively V_G=3V, $V_D=V_S$=0V; in the "off" state, $V_G = V_S$=0V and V_D=3V. For P-channel MOSFET, in the "on" state, the bias is V_G=0V and $V_S=V_D$=3V; in the "off" state, the bias is $V_G = V_S$=3V, V_D=0V.

3 RESULTS AND DISCUSSION

The silicon film on buried oxide layer is only 160nm, so the MOSFETs/SOI is fully depleted, after irradiation, the electric characteristics of MOSFETs/SOI measured are as follows.

3.1 Irradiation induced trapping charge in MOSFETs/SOI

After measurement, the irradiation induced oxide charge (ΔN_{ot}) and interface state (ΔN_{it}) are obtained and shown in Fig.1. Fig.1a shows that ΔN_{ot} is increasing gradually with increment of total dose (D_{ose}), and the accumulation rate of ΔN_{ot} of NMOSFET is higher than that of PMOSFET. In addition, accumulation rate of ΔN_{ot} under "on" bias is higher than that under "off" bias for NMOSFET or PMOSFET, especially for NMOSFET under "on" bias, the ΔN_{ot} accumulates rapidly with increment of D_{ose}, it's due to positive gate voltage which is from gate electrode point to Si/SiO_2 interface, during irradiation, a large amount of electron-hole pairs are produced and seperated by electric field, the electrons move towards gate, the holes move towards Si/SiO_2 interface and are trapped in gate oxide layer and formed oxide charge and accumulated, so the total oxide charge density is increased. Under "off" bias, the recombination rate of electron-hole pairs is higher and lead to lower ΔN_{ot}[5]. So it can be concluded that the ΔN_{ot} in gate oxide layer of NMOSFET strongly depends on the NMOSFET gate electric field. The results of PMOSFET are similar to NMOSFET.

In Fig.1b, with increment of D_{ose}, little of ΔN_{it} which irradiation induces interface state increases for PMOSFET under "on" and "off" bias, and for NMOSFET under "off" bias. There are some increase for ΔN_{it} of NMOSFET only under "on" bias. For fully depleted NMOSFET/SOI, the measured ΔN_{it} consists of gate SiO_2/Si film interface state and buried SiO_2/Si film interface state. Comparason between Fig.1a and Fig.1b shows that the accumulation rate of ΔN_{ot} is far more than that of ΔN_{it}, it means that during fabrication process of device, positive central traps which could form oxide charge during irradiation are very much.

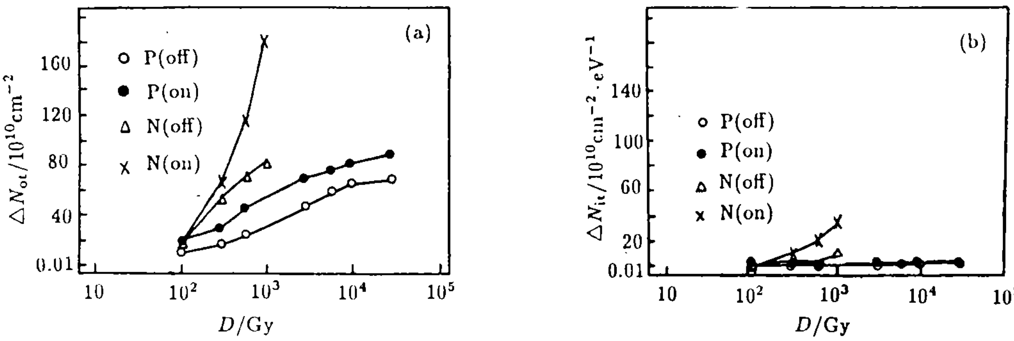

Fig.1 The irradiation-induced trapping charge effects as a function of total dose for MOSFETs/SOI

3.2 Threshold voltage of MOSFETs/SOI

Fig.2 shows threshold voltage shifts ΔV_T of MOSFETs/SOI as a function of dose. With increment of D_{ose}, all ΔV_T shift to negative under "on" and "off" biases, and the ΔV_T of NMOSFET is more than that of PMOSFET. The ΔV_T of NMOSFET with "on" bias is more than with "off" bias at each dose point, so is PMOSFET. It is because a large amount of electron-hole pairs are produced in gate oxide during irradiation.

For the NMOSFET under "on" bias, V_{GS}=3V, electrons move to gate electrode in gate electric field, and are absorbed finally by gate electrode, so the recombination rate of electron-hole is reduced, holes are trapped by oxide traps and fixed positive charges are formed. So a large quantity of electrons are induced at interface of gate SiO_2/Si by fixed charge, and the top surface inversion of P-type silicon film is increased, but the interface state is acceptor for P-type silicon, the increment of ΔN_{it} during irradiation would delay the surface inversion of silicon film. From analysis of Fig.1, the ΔN_{it} somewhat increase in dose range of 3×10^3Gy (Si), so the surface inversion of silicon film is increased due to effects of fixed charge and interface state, and the negative shift of ΔV_T is increased[6].

Under "off" bias, V_{GS}=0V, the recombination rate of electron-hole pairs produced in gate oxide layer during irradiation is higher than that under "on" bias (V_{GS}=3V), and result in decrease of fixed charges which formed by oxide traps trap holes, so a few quantity of electrons on surface of P-type silicon film are induced by fixed charges, in addition, the interface state of gate SiO_2/Si is acceptor, so the negative ΔV_T "off" bias is less than "on" bias as effect of fixed charge and interface state[7].

In addition, in Fig.2, the negative ΔV_T of NMOSFET is more serious than ΔV_T of PMOSFET during irradiation under "on" bias. It is due to ΔN_{ot} in NMOSFET gate oxided layer is nearer the gate SiO_2/Si than in PMOSFET, so the effect to channel is more serious in NMOSFET.

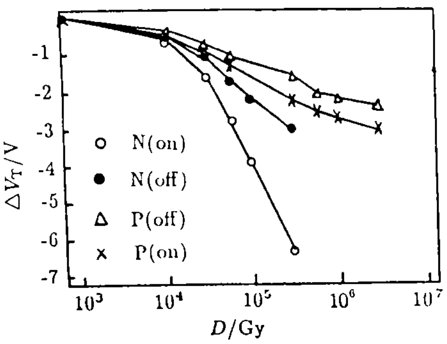

Fig.2 V_T shifts vs total dose for MOSFETs/SOI

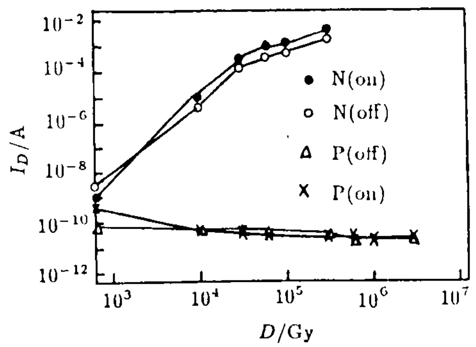

Fig.3 Static leakage current vs total dose for MOSFETs/SOI

3.3 Static leakage current of MOSFETs/SOI

Drain to source leakage current (I_D) of MOSFETs/SOI as a function of D_{ose} is shown in Fig.3, there are two interfaces for each MOSFET/SOI, one is gate SiO_2/Si interface and could form top channel, the other is buried SiO_2/Si film interface and could form back channel, the I_D of MOSFET/SOI consists of top and back leakage current because of enclosed gate. According to Fig.1, the accumulation of ΔN_{ot} is far more than ΔN_{it} during irradiation, so only effect of ΔN_{ot} on I_D is needed to discuss.

In Fig.3, with increment of D_{ose}, the I_D of NMOSFET is increasing rapidly, and the I_D is increasing more rapidly under "on" bias than "off" bias. It can be explained that as increment of dose, the electron-hole pairs in gate oxide layer and buried oxide layer are increasing yet, and lead to increment of positive charges trapped by oxide traps, that is oxide charge. With the increment of oxide charge in gate oxide layer, the top channel is forming gradually, so the leakage current in top channel is increasing gradually yet; with the increment of oxide charge in buried oxide layer, the back channel is forming gradually, so the leakage current in back channel is increasing gradually yet[8]. So the I_D is increasing gradually with the increment of D_{ose}. Especially under "on" bias, the quantity of ΔN_{ot} is more than "off" bias, lead to the top channel is forming more rapidly, and the leakage current of top channel is increasing more rapidly under "on" bias, so at each dose point, the I_D is more under "on" bias than "off" bias[8].

In addition, in Fig.3, with increment of D_{ose}, the I_D of PMOSFET reduces a little, it is because the ΔN_{ot} in gate and buried oxide layer is increasing gradually with increment of D_{ose}, electrons at silicon top surface are induced more and more by ΔN_{ot} in gate oxide layer, so the top channel is strongly accumulated, and the forming of top channel is retarded. Similarly, electrons at silicon film back surface are induced more and more by oxide charges in buried oxide layer, so the back channel is strongly accumulated[9], and the forming of back channel is retarded. In general, with increment of D_{ose}, the I_D of PMOSFET/SOI is decreasing gradually.

4 CONCLUSIONS

4.1 The influence of irradiation dose on the oxide charge is more remarkable than on the interface state in MOSFETs/SOI.

4.2 Threshold voltage shifts of NMOSFET/SOI and PMOSFET/SOI are all more serious under "on" bias than "off" bias during irradiation.

4.3 The leakage current of NMOSFET/SOI is increasing with increment of total dose, and the leakage current is more under "on" bias than "off" bias; the leakage current of PMOSFET/SOI is reducing a little under "on" or "off" bias with increment of total dose.

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