RADIATION-INDUCED CHARGE TRAPPING IN BIPOLAR BASE OXIDES

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35-wd Abstract

Capacitance-voltage and thermally-stimulated-current methods are used to investigate radiation induced charge trapping in bipolar base oxides. Results are compared with models of oxide and interface trap charge buildup at low electric fields.

DISCLAIMER

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Introduction

Many types of bipolar devices show significantly greater gain degradation in low-dose-rate radiation environments than in high-rate environments. Several physical mechanisms have been proposed to account for this behavior. These include (**A**) space charge effects in the base oxide associated with metastably trapped holes [1], (**B**) reduced recovery rates due to retarded hole transport in thick oxides at low electric fields [2,3], (**C**) enhanced electron-hole recombination due to electrons in shallow traps in the base oxide [4], and (**D**) delayed buildup of near-midgap interface traps at the surface of the base [5,6]. Mechanisms (**A**) and (**C**) have been discussed primarily in the context of NPN transistor results, while (**B**) and (**D**) have been discussed primarily for PNP transistors. There are compelling reasons to believe that NPN and PNP structures would show qualitatively different radiation responses even if the trapped charge densities in the base oxides were identical [6-9]. However, to date there has not been a comparison of the charge trapping properties of the base oxides used in different bipolar processes.

In this summary we compare the radiation response of two types of capacitors processed to simulate base oxides in development versions of Analog Devices' RF25 and XFCB processes [10,11]. Enhanced low-rate gain degradation in the RF25 (formerly called ADRF) process is observed primarily in lateral and substrate PNP's; in the XFCB process, it is observed in vertical NPN's. The base oxides differ significantly in the two processes. For the development RF25 devices we have evaluated, a 600-nm wet thermal oxide is employed. For the XFCB oxide, a 540 nm deposited oxide is stacked on a 60 nm thermal oxide over the base. Both oxides see base implantation and high-temperature annealing steps, making them quite susceptible to radiation-induced charge trapping [1]. High-frequency capacitance-voltage (C-V) and thermally-stimulated-current (TSC) test methods [12] were used to evaluate radiation-induced charge trapping in these two types of base oxides. Results are compared with mechanisms A-D above.

Experimental Results

Figure 1 shows radiation induced net-oxide (ΔN_{ot}) and interface-trap (ΔN_{it}) charge densities inferred from C-V measurements on capacitors simulating RF25 and XFCB base oxides. ΔN_{ot} was estimated from midgap C-V shifts, and ΔN_{it} was estimated from midgap to flatband stretchout [13]. ΔN_{ot} is slightly higher in the XFCB base oxide ($\sim 3.0 \times 10^{11}$ cm^{-2} at 200 krad) than the RF25 base oxide ($\sim 2.3 \times 10^{11}$ cm^{-2}). However, ΔN_{it} is much larger in the RF25 oxides ($\sim 2.9 \times 10^{11}$ cm^{-2} at 200 krad) than the XFCB oxides ($\sim 0.25 \times 10^{11}$ cm^{-2}). These results are consistent with device studies showing that oxide charge is the dominant factor that determines the radiation response of XFCB devices (e. g., Mechanisms A-C) [7-9], with interface traps (Mechanism D) being more important in RF25 devices [6].

That the RF25 base oxides show such large densities of net oxide-trap charge and interface traps suggests they are quite useful to study in detail to examine the potential effects of both types of charge on bipolar base oxide radiation response. Figure 2 shows inferred flatband voltage shifts (ΔV_{fb}) and components due to oxide traps and interface traps (ΔV_{ot} and ΔV_{it}) from C-V measurements on RF25 base oxides as a function of radiation dose rate. ΔV_{ot} and ΔV_{it} show similar dose-rate dependencies, so they contribute equally to the dose-rate dependence of ΔV_{fb}. It is interesting that the transition between trap densities characteristic of "high rate" response and those reflecting "low rate" response in Fig. 2 occurs between ~ 10 and 100 rad(SiO_2)/s for these 600 nm oxides. This is the same region of dose rates in which this transition occurs for the much thinner (~ 60 nm thermal) RBCMOS base oxides studied in Ref. [1], strongly suggesting that a simple difference in recovery rates due to differences in oxide thickness (Mechanism B) [2,3] cannot account for the dose rate effects in these oxides. If Mechanism B dominated the device response, the transition region should occur at much lower dose rates for the 600-nm RF25 base oxides than the 60-nm RBCMOS oxides.

Figure 3 shows TSC results for RF25 base oxides irradiated at 320 and 0.83 rad(SiO_2)/s. The TSC is a measure of the total density of radiation-induced trapped positive charge (assumed primarily to be holes) that is emitted and transported across the oxide [12]. Despite their very different levels of net oxide-trap charge (Fig. 2), the TSC is nearly identical in the two cases in Fig. 3! This means that the reduction in net oxide-trap charge at high dose rates in these devices is not due to a difference in the total number of trapped holes in the base oxide. Instead, it is caused by a different number of compensating electrons at high rates than at low rates. Integrating the TSC curves in Fig. 3, we find ~ 2.5 x 10^{12} cm^{-2} holes trapped after either 320 or 0.83 rad(SiO_2)/s irradiation. The net oxide-trap charge density is ~ 1.7 x 10^{11} cm^{-2} for the high rate case, and ~ 4.6 x 10^{11} cm^{-2} in the low-rate case (see Fig. 2). This implies that ~ 93 % of the radiation-induced trapped positive charge is compensated by trapped electrons in the high rate case, and ~ 82 % is compensated in the low-rate case. Thus, it is evidently not a difference in trapped-hole density due to enhanced electron-hole recombination (Mechanism C) that causes the dose-rate response in these base oxides. It is the relatively small difference between the number of compensating electrons in the two cases that leads to the large difference in ΔN_{ot}. This is consistent with Mechanism A and the results of Ref. [1], and reinforces the crucial role that electron trapping plays in determining the radiation response of bipolar base oxides [1,4]. Finally, it is certainly quite interesting that ΔN_{it} would scale similarly to the *net* oxide-trap charge density in Fig. 2, for example, as opposed to the *total* oxide-trap charge density. Reasons for this connection will be explored in the full paper.

Similar trends for ΔN_{ot} and ΔN_{it} were observed with increasing temperature during 10-keV x-ray irradiation (22 to 125°C) as with decreasing dose rate, as shown in Fig. 4. That is, both the net oxide-trap charge and interface-trap density increase with increasing radiation temperature (at least to ~ 125°C) for a fixed high dose rate, and increase with decreasing dose rate for room temperature irradiations. Similar trends have been observed with Co-60 irradiations as a function of temperature. TSC measurements (which will be shown in the full paper) again show that, at higher temperatures, the total number of trapped holes is not significantly increased, but the number of holes compensated by trapped electrons decreases, just as for the dose-rate data of Figs. 2 and 3. This supports hardness assurance techniques that rely on elevated temperature irradiations to simulate low-rate response for these types of devices [1,14]. Moreover, it is encouraging that both the oxide-trap charge and interface-trap charge components are enhanced similarly by increasing temperature, suggesting that using elevated-temperature irradiations to simulate low-rate response does not depend critically on whether oxide traps [1,7-9] or interface traps [5,6,13,14] lead to the enhanced low-rate response, at least for these devices.

Summary and Conclusions

We have found that interface traps play a much more significant role in determining the radiation response of capacitors simulating base oxides for Analog Devices' RF25 development process than their XFCB process. This is consistent with device studies suggesting interface traps dominate the dose-rate response of the RF25 process [6], but oxide traps dominate the response of the XFCB process [7-9]. The enhancement of the net oxide-trap charge for the RF25 process at low dose rates and/or high temperatures is primarily due to differences in the number of compensating trapped electrons in the base oxides in the two cases. Results are consistent with a model that depends on space charge effects to modify the distribution of trapped holes in the base oxides, which in turn leads to differences in the number of compensating trapped electrons [1]. Results for these oxides do not appear to be consistent with models that depend on differences in recovery rates in thick and thin oxides at low electric fields [3], or on a reduction in the number of trapped holes due to enhanced recombination of radiation-induced holes with electrons in shallow traps [4]. However, these mechanisms may be more significant in other bipolar base oxides. Additional TSC and C-V results on these and other thick oxides will be presented in the full paper, along with their implications for models of enhanced bipolar gain degradation at low dose rates.

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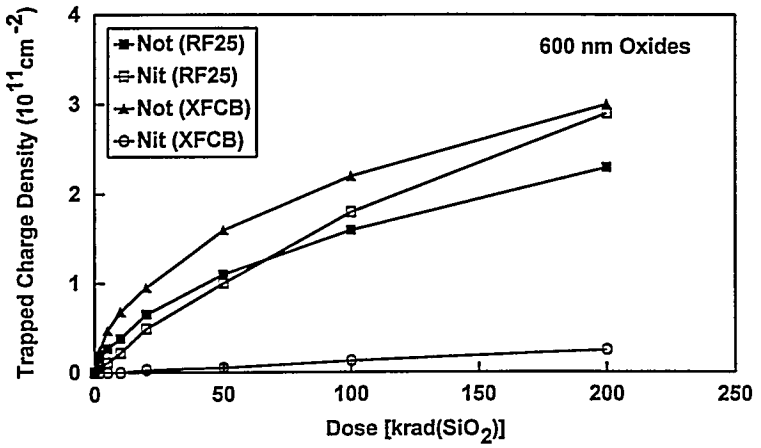

Figure 1. Radiation-induced trapped charge density vs. dose for XFCB and RF25 base oxide capacitors. Devices were irradiated at room temperature with 10-keV x rays at 320 rad(SiO_2)/s and 0 V bias.

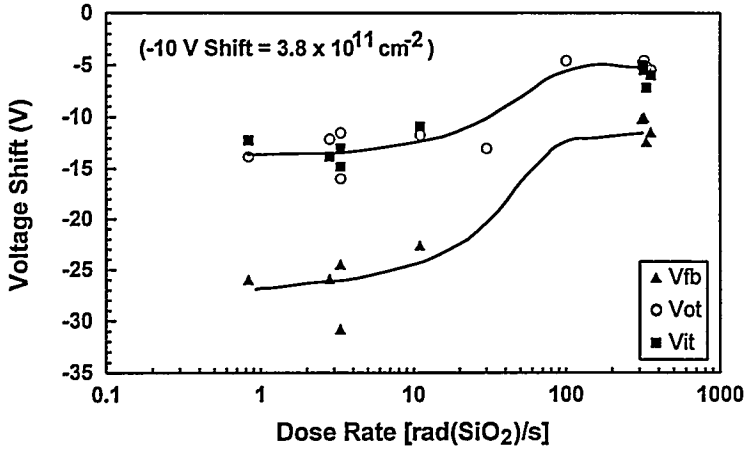

Figure 2. Flatband voltage shifts and components due to net-oxide and interface-trap charge vs. dose rate for RF25 base oxide capacitors. Devices were irradiated at room temperature with 10-keV x rays at 0 V bias to 200 krad(SiO_2). A conversion factor from voltage shift to trap density is provided for the net oxide-trap charge density and the interface-trap density.

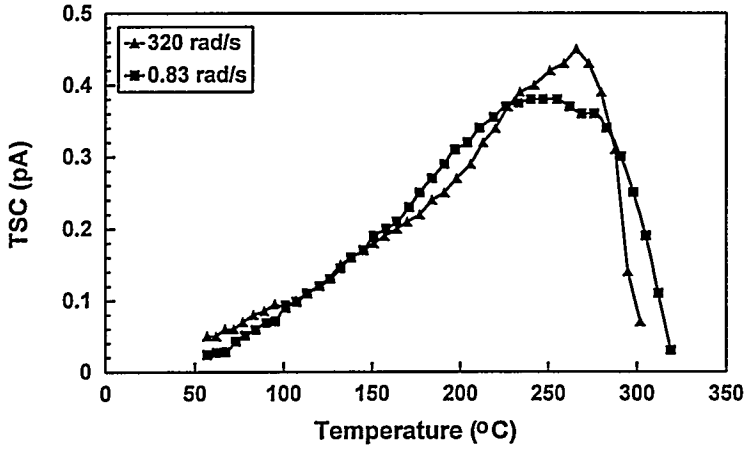

Figure 3. TSC corrected for background leakage for RF25 base oxides irradiated to 200 krad(SiO_2) with 10-keV x rays at 0 V at room temperature. The TSC ramp rate was ~ 7°C/min (Ref. [12]), and the TSC bias was -60 V.

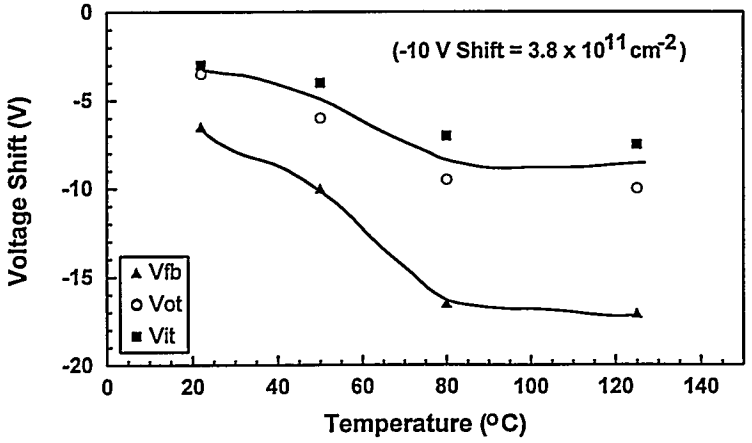

Figure 4. Flatband voltage shifts and components due to net-oxide and interface-trap charge vs. radiation temperature for RF25 base oxide capacitors. Devices were irradiated at 315 rad(SiO_2)/s with 10-keV x rays at 0 V bias to 50 krad(SiO_2). A conversion factor from voltage shift to trap density is provided for the net oxide-trap charge density and the interface-trap density.