

Effects of Alternating Bias Irradiation on Defects in MOS Devices

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A comprehensive model of MOS radiation response must apply to switched and alternating bias exposure as well as static bias irradiation [1]. Previous work has shown that defect buildup and annealing during alternating and switched bias irradiation is often qualitatively different than at steady-state bias [2-4]. For example, changing the bias from positive to zero or negative values and delivering an additional dose of radiation can lead a significant reduction in net oxide-trap charge due to radiation-induced charge neutralization [4,5]. Moreover, enhanced interface trap buildup has been observed under some alternating bias conditions [2-4]. These effects have been characterized at a phenomenological level, but the underlying defect buildup and annealing processes are not well understood.

To date, alternating and switched bias irradiations have been assessed via standard capacitance-voltage (C-V) and current-voltage (I-V) techniques that are sensitive only to the net oxide-trap charge and interface traps. In this summary, we use thermally stimulated current (TSC) for the first time to evaluate defect buildup during positive-to-negative and positive to 0 V alternating bias irradiation of MOS devices. This enables contributions of positive and negative charge to net oxide-trap charge to be separated. Surprisingly similar levels of trapped electrons are observed in the near-interfacial oxide for these two types of AC biases. However, there are different levels of trapped positive charge. More interface traps are found for positive to 0 V switching than positive to negative switching. Implications for charge trapping and recombination are discussed.

The devices used here were 0.004 cm^2 n-substrate capacitors with 45 nm radiation-hardened oxides. These devices were chosen because (1) they are easier to characterize via TSC than thinner oxides [6], (2) their response to static bias irradiation has been well characterized [7,8], and (3) the dominant defects in these devices are also the dominant defects in high-quality thermal oxides (thicknesses from 6 to 1000 nm) used in previous studies of MOS radiation response and high-field electrical stress [7,9]. Hence, defect generation and annealing processes in these devices are expected to occur quite generally in MOS oxides.

Figure 1 shows TSC measurements for (a) steady-state and (b) 1 kHz 5V/0V and 5V/-5V AC bias irradiations of capacitors to 2 Mrad(SiO_2) with 10-keV x rays at a dose rate of 900 rad(SiO_2)/s. The shapes of the TSC curves reflect the energy distributions of the trapped positive charge; the total trapped charge density ΔN_p can be estimated from the areas under the curves [7]. The main peak in the TSC curve is evidently associated with holes detrapping from E' centers, although a contribution of transporting H^+ cannot be ruled out.

Net oxide-trap charge densities ΔN_{ot} are estimated from midgap voltage shifts, and interface-trap charge densities ΔN_{it} are estimated from midgap-to-flatband stretchout of 1 MHz C-V curves.

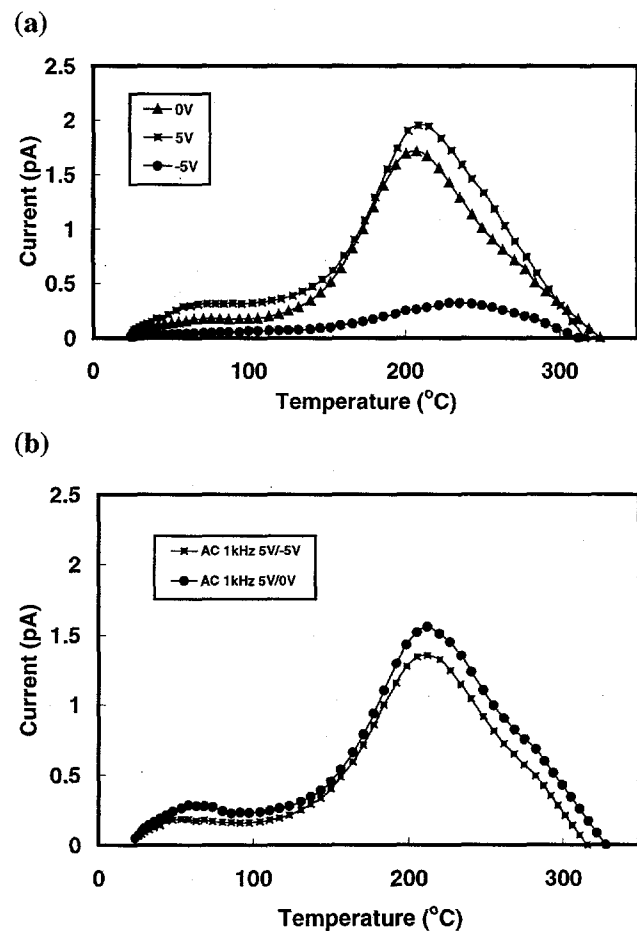


Fig. 1. TSC vs. temperature and bias during irradiation for 0.004 cm^2 n-substrate capacitors irradiated to 2 Mrad(SiO_2) with 10-keV x rays at $\sim 900 \text{ rad}(\text{SiO}_2)/\text{s}$. The TSC measurements were performed at a bias of -10 V , and a ramp rate of $\sim 0.11^\circ\text{C}/\text{s}$.

The difference between the total trapped positive charge (from TSC) and net oxide-trap charge (from C-V) allows one to estimate the density of trapped electrons ΔN_e in the near-interfacial SiO₂ [7]. Charge densities for the irradiations of Fig. 1, as well as 100 Hz AC bias irradiations, are shown in Table 1. As expected, more radiation-induced trapped positive charge is observed for 5 V bias than for 0 V bias, due to the higher charge yield under positive bias [10]. Negative bias irradiations lead to still less trapped positive charge because holes are transported away from the critical Si/SiO₂ interface. Alternating bias irradiations in Fig. 1(b) show similarly shaped TSC curves, but the values of ΔN_p differ widely among the various bias conditions. In Table 1 it is seen that the values of ΔN_p for the 5V/0V AC bias cases lie between the corresponding values for the 5 V and 0 V static bias cases, and the 5V/-5V AC bias cases lie between the 0 V and -5 V static bias cases. Results at other frequencies confirm these trends, as we will discuss at the SISC.

Table 1. Summary of trapped-charge densities after 2 Mrad(SiO₂) steady state or square-wave AC bias x-ray irradiation, for the measurements of Fig. 1, and for 100 Hz AC bias. All charge densities are quoted in multiples of 10¹² cm⁻².

Bias	ΔN_p	ΔN_{ot}	ΔN_{it}	ΔN_e
5 V static	2.95	1.43	1.13	1.52
5/0: 1 kHz	2.77	1.02	0.92	1.75
5/0: 100 Hz	2.96	1.09	0.94	1.87
0 V static	2.56	0.71	0.91	1.84
5/-5: 1 kHz	2.19	0.38	0.63	1.82
5/-5: 100 Hz	2.16	0.51	0.53	1.64
-5 V static	0.53	0.18	0.23	0.36

Table 1 also shows that significantly less interface trap buildup occurs for 1 kHz 5V/-5V AC bias irradiations than for 1 kHz 5V/0V AC exposures. At a given frequency, values of ΔN_p and ΔN_{ot} follow the same trend. During the steady-state 5 V and the positive-bias portions of the AC bias irradiations, radiation-induced holes and other positively charge species (e.g., H⁺) transport toward the Si/SiO₂ interface. That this transport is more efficiently reversed during the 5V/-5V AC bias irradiations than the 5V/0V irradiations accounts for most of the observed results for ΔN_p , ΔN_{ot} , and ΔN_{it} . However, the values of ΔN_e are nearly constant for all switched bias irradiations. We find this result to be surprising,

because one might intuitively expect that electrons would be swept out of the oxide more efficiently during the low phase of 5V/-5V AC bias irradiation than 5V/0V irradiation, due to the more negative electric field near the interface in the 5V/-5V case. Indeed, preliminary results appear to show a reduction in trapped electron density at 5V/-5V bias when the frequency is very low (i.e., below 1 Hz). Hence, these types of measurements may allow one to measure a characteristic detrapping rate for at least some compensating electrons in the SiO₂.

That AC bias and 0 V irradiations show such similar levels of electron trapping strongly suggests that most trapped electrons in these devices do not tunnel in from the Si, as commonly assumed in models of trapped positive charge compensation [7,11]. In contrast, these results seem much more consistent with the idea that most of these compensating electrons originate within the bulk or near-interfacial SiO₂. This in turn implies that deep electron trapping likely has been mistaken for recombination events in prior work. This conclusion is especially significant because hole and electron trapping are known to depend significantly on device processing [7], while recombination events are considered to be process independent [10,12]. In contrast, trapping properties of oxides are typically independent of radiation energy (at least above ~ 1 keV), while recombination rates are strongly energy dependent [10,12]. At the SISC, we will show how these results may help explain some discrepancies in recombination data in the literature.

Acknowledgments

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