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Radiation Response of MOS Structures Containing Oxides Grown in a NF_3/O_2 Oxidizing Ambient

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The effects of incorporating small amounts of fluorine in the oxide by the presence of NF_3 in the oxidizing ambient has resulted in a dramatic change of the radiation response of MOS structures. The radiation sensitivity is significantly reduced, The Al-gate size dependence disappears, and the long-term post-irradiation buildup of the interface traps is either suppressed (at room temperature) or greatly reduced. While the results themselves are of significant technological importance, we believe the scientific implications are no less significant.

1. INTRODUCTION

We have recently reported [1] that the pre-oxidation surface treatment of silicon in HF prior to thermal oxidation changes drastically the radiation response of MOS devices. Those effects were attributed to the presence of fluorine in SiO_2 and at the interface.

In this paper we show qualitatively very similar effects observed in samples into which the fluorine is introduced by a different method. Besides providing additional evidence to support the fluorine model, this method allows the control of the amount of fluorine incorporated in the oxide, and gives added flexibility for both research and technology development.

2. EXPERIMENTAL

The samples were made on p-type Si(100) wafers of 1Ω-cm resistivity. The oxides, range in thickness 200-500A, were grown in dry O_2 (for the Control samples) or in dry O_2+NF_3 (for the Fluorinated samples) at temperatures of 900, 1000, or 1040^{o}C, followed by dry N_2 annealing at the growth temperature. The amount of F incorporated into the oxide was controlled by varying the NF_3/O_2 flow ratio and the time that the NF_3 gas was turned on. Al films approximately 2000Å thick were thermally evaporated from a Ta boat on to the oxide surface, and photolithographically defined to form circular gates of 10-50 mil in diameter. After backside metallization, the wafers were annealed in forming gas at 420 ^{o}C for 30 minutes. The radiation source was an X-ray beam generated from a W target bombarded by 35 KeV electrons. Both the Control Samples and the Fluorinated Samples were characterized by the high frequency and quasi-static C-V measurements.

3. RESULTS AND DISCUSSION

Figure 1 shows a comparison of the radiation response between the Control and a Fluorinate sample. It is evident that both the midgap shift and the interface trap density for this Fluorinated sample were much lower than the Control after the same radiation exposure. While only the zero bombardment bias case is shown here for simplicity, our results are qualitatively similar for positive and negative biases as well.

Figure 2 shows the density of radiation induced interface traps as a function of the NF_3 purge time. One can see that considerable improvement of the radiation response may be obtained with small amounts of F. Excessive amounts of NF_3 during oxidation will cause the degradation of the radiation hardness, suggesting the possibility of finding a process window within which the radiation hardness can be greatly improved. Obviously, it is desirable to produce a wide process window for pratical implementation, and work is underway in this direction.

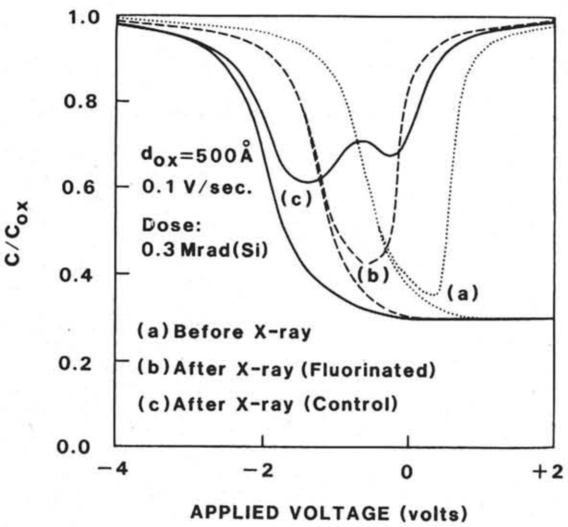

Fig.1. High frequency and Quasi-static C-V curves for the Control and Fluorinated samples right after 0.3 Mrad(Si) exposure to 40KeV x-ray. Aluminum gate thichness is 2000 Å.

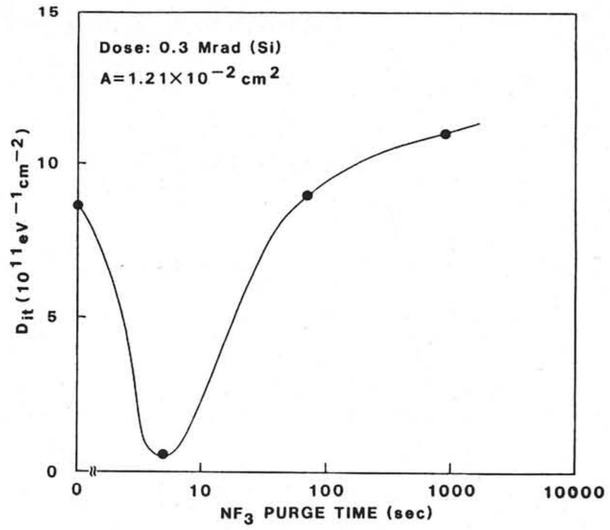

Fig.2. Radiation-induced interface trap density as a function of NF_3 purge time during oxidation. Oxide thickness is 500 Å.

Figure 3 shows the dependence of the radiation-induced interface trap density on the size of the Al gate. A strong size effect is observed in the Control samples, which is consistent with the results reported earlier [3], but hardly any size dependence is present for the Fluorinated samples. This lack of size dependence may prove very valuable in our understanding of the effect of fluorine, as to be discussed later.

Figure 4 shows the interface trap density as a function of time after the termination of the irradiation. Different doses were used on the two samples to yield similar amounts of interface traps for ease of comparison. It is obvious that the post-radiation time dependent behavior is very different for the two samples. While the Control shows a decreasing of the interface trap density up to many hours, the Fluorinated sample shows a decreasing trend.

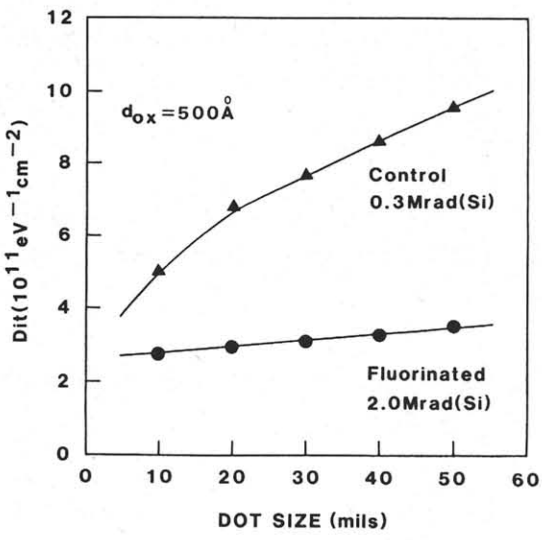

Fig.3. Effect of gate size on the radiation-induced interface trap density, after 0.3Mrad (Si)(Control) and 2.0Mrad (Si)(Fluorinated) respectively x-ray exposure. Aluminum gate thickness is 2000 Å.

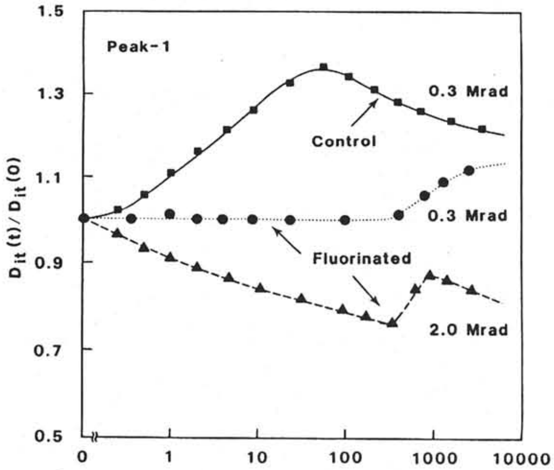

Fig.4. Time dependence of the Control and Fluorinated samples. Aluminum gate thickness is 2000 Å.

The lack of size dependence in the Fluorinated samples suggests that somehow the effects due to the interfacial stress [3] are suppressed in these samples. It is possible that the incorporation of fluorine in the oxide may substantially reduce the as-grown bond strain gradient of the oxide near the SiO_2/Si interface to a point that it is overcome by the Al-gate induced strain gradient (which is in the direction opposite to the as-grown gradient). According to the Bond Strain Gradient model [4], this would mean that the nonbridging oxygen defect, which when migrates to the SiO_2/Si interface could form interface traps, would tend to move in the direction away from the SiO_2/Si interface. Therefore, one would not expect to see any dependence on the gate size as long as the gate induced stress is sufficiently large. This model would also be consistent with the results that no latent generation of the interface traps is observed after irradiation, because if the bond strain gradient were to be present in it's ordinary direction, one would expect to see a slow increase of the interface trap density for a period of time after irradiation is terminated, due to the continuous arrival of the nonbridging oxygen defects at the interface.

Additionaly, the results may also be due to the chemistry of the fluorine species as follows. Some of the fluorine species, which were bonded to the SiO_2 lattice, could be set free by the radiation and become highly chemically active. For example, it may form Strong Si-F bonding with the dangling bond of a trivalent Si center at the interface, thus removing an interface trap. This could account for the reduction of radiation sensitivity in the Fluorinated samples. It may also react with dangling bonds related to the nonbridging oxygen defect complex in the oxide transition region, preventing posterior migration of these defects towards the interface, and therefore suppressing the evolution of interface traps as a function of time.

4. SUMMARY

As a summary, the incorporation of small amounts of fluorine in the oxide by the presence of NF_3 in the oxidizing ambient has resulted in a dramatic change in the MOS capacitor's radiation response: the radiation sensitivity is significantly reduced (for samples with the right amounts of NF_3), the Al-gate size dependence disappears, and the long-term post-irradiation buildup of the interface traps is either completely stopped (at room temperature) or greatly suppressed. While the results themselves are of significant technological importance, we believe the scientific implications are no less significant. Either of the two possibilities discussed above would be consistent with our experimental observations. At the conference these will be discussed in more detail. Further investigation is being planned to bring out more clearly the possible mechanisms.

5. ACKNOWLEDGMENTS

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