Defect Centers in Chemical-Mechanical Polished MOS Oxides

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Defect centers generated in vacuum-ultraviolet irradiated chemical-mechanical polished oxides have been characterized using electron paramagnetic resonance and C-V analysis. Both oxide trap E'_γ and interface trap P_{b0} centers were detected in unpolished and polished oxides. In addition, another interface defect center known as the P_{b1} center was only identified in the polished oxides, suggesting that the polishing process altered the SiO_2/Si interface.

1. INTRODUCTION

Chemical-mechanical polishing (CMP) has become the surface planarization method of choice for technologies with feature sizes ≤ 0.35 μm [1,2]. Films deposited on wafers are planarized by rotating the wafer under pressure against a polishing pad in the presence of a silica-based alkaline slurry. CMP is used to eliminate depth of focus problems for submicron lithography and defects associated with metal thinning that can occur over steep topography. While there has been a great deal of work done on developing CMP processes, little is known (or published) about how CMP processing affects the electrical characteristics and reliability of devices.

In this paper, we used electron paramagnetic resonance (EPR) to investigate the effects of CMP on fundamental material issues. The data show that CMP processing introduces defect centers in polished SiO_2/Si structures that are not present in unpolished SiO_2/Si structures. These defect centers may lead to unexpected device degradation and reliability problems.

2. EXPERIMENTAL DETAILS

Samples were prepared by first growing a 1.5-μm wet oxide on p-type silicon wafers. The oxide on some of the wafers was polished back to 0.8 μm using a Cybeq System 3900 Polisher. The polishing pad consisted of an IC1000/Suba IV stacked pad manufactured by Rodel. The slurry utilized was Cabot SC-1 which contains a colloidal silica (30% by weight) abrasive and KOH (<1% by weight). The slurry was diluted (1:2 ratio) with de-ionized water. The wafers were polished using a downward pressure of 7.5 psi on the carrier. The platen, head, and carousel rotation speeds were 20, 15, and 5 rpm respectively. Defect centers were activated in both polished and unpolished oxides by exposing unbiased samples to an unfiltered vacuum-ultraviolet light (VUV) source. High-frequency (1 MHz) C-V

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measurements were performed using a Hg probe before and after VUV exposure to estimate the voltage shift due to oxide- and interface-trap charge. In addition, to determine the spatial location of the charge centers sensed by C-V measurements, etchback experiments were performed on the oxides. The etchant was a buffered HF solution. The EPR measurements were performed at 300 K using a Bruker ESP-300E X-band spectrometer.

3. RESULTS

Figure 1 shows EPR spectra for both unpolished and polished oxides. The traces were taken with the magnetic field perpendicular to the (100) plane. The trace for the unpolished oxide clearly shows that the VUV exposure activated E'_γ centers at g = 2.0005 and P_{b0} centers at g=2.0060. The E'_γ center is a hole trapped at a oxygen vacancy in the oxide ($O_3{\equiv}Si^+$ $\bullet Si{\equiv}O_3$) [3] and the P_{b0} center is an interface trap believed to be identical to the P_b center on (111), namely ($\bullet Si{\equiv}Si_3$) [3]. However, it has recently been suggested theoretically [4] and experimentally [5] that this identification of the P_{b0} is suspect. These same two defect centers were also activated in the VUV illuminated polished oxides. A third defect center, known as the P_{b1} center, was also activated in the polished oxides. The chemical nature of the P_{b1} center is not known with any certainty at this time; however, like the P_{b0} center, it is likely an interfacial Si dangling bond defect [6]. The identities of the P_{b0} and P_{b1} centers were confirmed by rotating the samples in the EPR cavity. That we observed P_{b1} centers in the polished oxide and not in the unpolished oxide indicates that the polishing process affects the SiO_2/Si interface. (P_{b1} and P_{b0} centers are located at or near the SiO_2/Si interface.) The P_{b1} centers may be a result of polished-induced stress changes at the SiO_2/Si interface. It has been reported that radiation induced interface-trap buildup can be affected strongly by with interfacial stress [7,8]. In addition, we eliminated the possibility that the P_{b1} centers are a function of the oxide thickness of the sample by wet etching unpolished oxide samples to 0.8 μm, the same oxide thick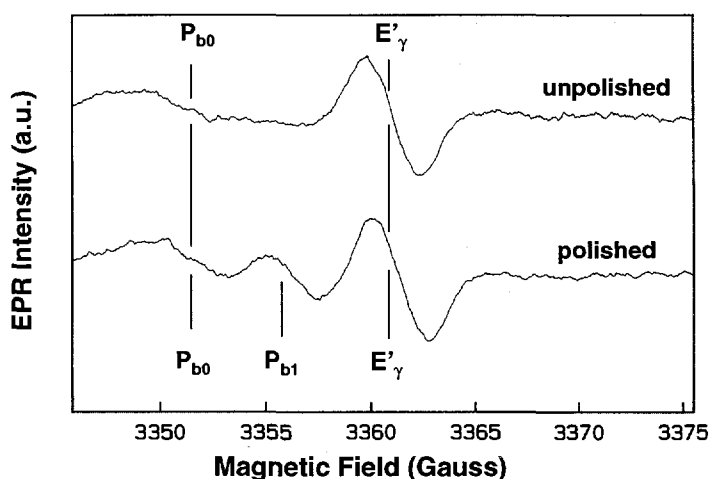ness as the polished sample. The EPR traces on these samples exposed to VUV were consistent with the unpolished trace shown in Figure 1. It is interesting to note that only P_{b0} centers are typically observed following hot electron injection [9], channel hot carrier stress [10], or gamma irradiation [11] in thermal oxides grown on (100) Si. It is quite evident that these polished samples behave somewhat differently.

Figure 1: EPR traces for unpolished and polished samples after VUV illumination. The E'_γ signal is overmodulated to better observe the P_{b0} and P_{b1} signals.

The EPR density of P_{b0} centers in the unpolished and P_{b0} and P_{b1} centers in the polished samples shown in Figure 1 are 4.5 x 10^{11}/cm^2 and 7 x 10^{11}/cm^2, respectively. For the polished oxide the density of
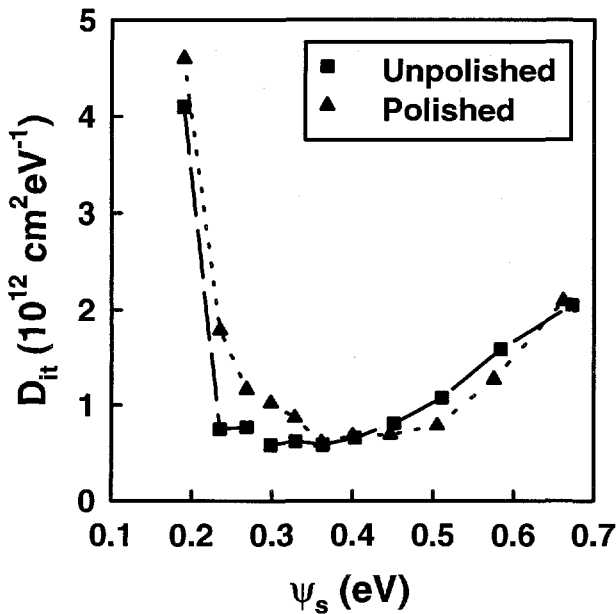
Figure 2: Interface-trap density in 0.8 μm unpolished and polished oxides.

$P_{b0} = 5 \times 10^{11}/cm^2$ and $P_{b1} = 2 \times 10^{11}/cm^2$. The density of P_b centers is in good agreement with the corresponding density of interface traps, D_{it}, as determined from C-V analysis. D_{it} at midgap (integrated over half the bandgap) is $1.1 \times 10^{12}/cm^2eV$ $(4.4 \times 10^{11}/cm^2)$ for the unpolished oxide and $2.1 \times 10^{12}/cm^2eV$ $(8.6 \times 10^{11}/cm^2)$ for the polished oxide. Part of the factor of two difference in the total density of Pb (P_{b0} + P_{b1}) centers and D_{it} in the unpolished and polished oxides could be attributed to oxides thickness differences (1.5 μm versus 0.8 μm). We confirm the thickness dependence by etching the unpolished oxide down to 0.8 μm using a dilute HF solution and irradiating the samples as discussed above. The resulting D_{it} measured by C-V analysis is plotted in Fig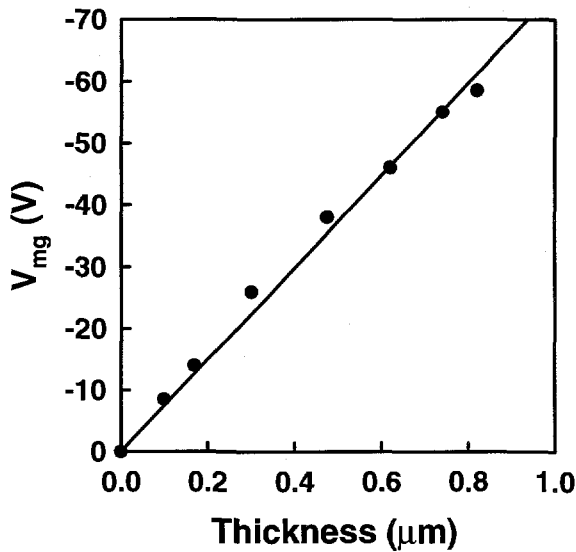ure 2 as a function of the semiconductor surface potential (ψ_s) for both the etched back unpolished oxide and the polished oxides. The D_{it} for both oxides is similar. However, the EPR trace (not shown) for the 0.8 μm unpolished samples still shows no evidence of P_{b1} centers. So, although the distribution of interface traps in energy is qualitatively similar in the unpolished and polished oxides, there is a difference in the type of defect center found in each oxide.

The locations of the trapped charge and the paramagnetic defect centers were determined by performing etchback experiments. The results for the polished oxides are illustrated in Figures 3 and 4. The results for the unpolished oxides were similar. Figure 3 is a plot of the midgap-voltage (V_{mg}) determined by C-V analysis versus depth in the oxide. The negative values of V_{mg} indicate positive charge in the oxide. The linear relationship of V_{mg} with oxide thickness, as shown in Figure 3, indicates that the majority of positive charge sensed by C-V is located at the Si/SiO_2 interface (i.e., at 0.0 μm). The E'$_\gamma$ centers shown in Figure 4 appear to be located at both the bottom and top oxide interfaces. It is likely that the E'$_\gamma$ centers located near the bottom SiO_2/Si interface are at least partly responsible for the positive charge. The E'$_\gamma$ centers located at the top SiO_2 interface are also likely positively charged, but are not sensed by C-V (moment arm considerations).

4.   SUMMARY AND CONCLUSIONS

Three defect centers have been observed in CMP oxides. These defect centers include the E'$_\gamma$ center, the P_{b0} center, and the P_{b1} center. The P_{b1} centers were observed in polished oxides but not observed in unpolished oxides. However, for equivalent thicknesses the total density of P_{b0} and P_{b1} centers in the polished oxide is equivalent to density of P_{b0} centers in the

Figure 3: Etchback experiments show that the net positive charge sensed by CV is located at the bottom SiO_2/Si interface.
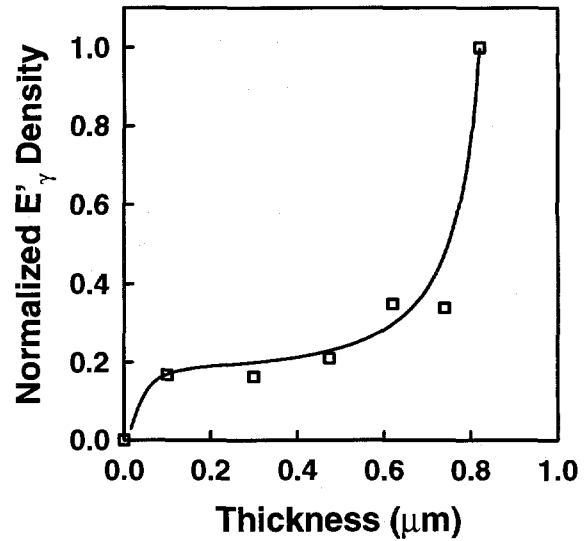
Figure 4: Etchback experiments show that E'_γ centers are located at both the top and bottom SiO_2 interfaces.

unpolished oxides. Although the mechanism responsible for the generation of the P_{b1} centers in the polished oxide is not known, changes in the stress of the oxide during the CMP process is a possible cause. That we observed P_{b1} centers in the polished oxide and not in the unpolished oxide suggests that the polishing process affects the SiO_2/Si interface.

5. ACKNOWLEDGMENTS

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