Electron Spin Resonance Characterization of Trapping Centers in Unibond® Buried Oxides

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Abstract

Electron spin resonance and capacitance vs. voltage measurements are used to evaluate the radiation response of Unibond buried oxides. When damaged by hole injection, it is found that Unibond® buried oxides exhibit a rough correspondence between E' centers and positive charge as well as generation of P_b centers at the Unibond® buried oxide/Si interface. In these respects, Unibond® buried oxides qualitatively resemble thermal SiO_2. However, a hydrogen complexed E' center known as the 74 G doublet is also detected in the Unibond® buried oxides. This defect is not detectable in thermal SiO_2 under similar circumstances. Since the presence of 74 G doublet center is generally indicative of very high hydrogen content and since hydrogen is clearly a significant participant in radiation damage, this result suggests a qualitative difference between the radiation response of Unibond® and thermal SiO_2. Unibond® results are also compared and contrasted with similar investigations on separation-by-implanted-oxygen (SIMOX) buried oxides. Although the charge trapping response of Unibond® buried oxides may be inferior to that of radiation hardened thermal SiO_2, it appears to be more simple and superior to that of SIMOX buried oxides.

I. INTRODUCTION

Silicon-on-insulator (SOI) technologies offer potential advantages in speed, power consumption, and transient radiation hardness [1]. An important reliability issue is the radiation response of the buried oxide. Radiation induced charge trapping within the buried oxide can cause threshold voltage shifts and back channel leakage in SOI transistors.

The two leading forms of SOI technology are separation-by-implanted-oxygen (SIMOX) and bond-and-etchback SOI (BESOI) [1]. A new SOI technology, Unibond®, seemingly combines the best of both SIMOX and BESOI [2]. The process involves four major steps [3]: 1) hydrogen implantation ($2x10^{16}$-$1x10^{17}/cm^2$) into a thermally grown SiO_2 capped Si wafer A, 2) cleaning and bonding with a second Si wafer B, 3) two-step annealing: a) a 400-600° C anneal to split at the boundary defined by the H implant and b) an 1100° C anneal to strengthen the bond interface, and 4) fine polishing to remove surface micro-roughness. An important advantage is that Wafer A is reused.

The Unibond process avoids problems associated with other SOI technologies: 1) elimination of the need for the high current implant step and thus the expensive specialty implanter required for SIMOX and 2) elimination of the complicated etchback and inherent waste characteristic of BESOI. Since Unibond starts with a thermally grown oxide and avoids the very high temperature (1320° C) post-implant anneal, one might expect that the electronic properties of the resulting Unibond material would closely resemble those of a thermal oxide. One might also expect that the hydrogen implant step could impact the electronic defect structure of the buried SiO_2 film.

Although recent studies of the electrical properties of Unibond films have reported promising electrical characteristics [4,5], an electron spin resonance (ESR) identification of the physical nature of the defect structures responsible for the charge trapping properties of these films has not yet been reported. Because ESR can provide structural information and allows testing of minimally processed structures it is an ideal tool for studying charge trapping in SiO_2 films [6]. When combined with electrical measurements such as capacitance vs. voltage (CV), ESR studies can provide detailed information about the atomic scale defect structures that dominate the radiation response of thin insulating films. An atomic scale understanding of the electronic properties can be an important guide for future development. In this abstract, we compare the CV and ESR response of Unibond wafers to hole injection and VUV irradiation. We find that H-related defects play an greater role in Unibond buried oxides than in thermal oxides.

II. EXPERIMENTAL DETAILS

The four inch, p-type, (100) orientation, 14-22 Ω-cm Si substrate Unibond wafer (t_{Si}=2032 Å, t_{BOX}=4019 Å) used in this study was provided by SOITEC.

ESR samples were cut into 2 cm x 4 mm rectangular bars and, before any measurements were taken, the Si overlayer was removed with a ~30 min etch in KOH at room temperature.

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ESR measurements were performed at room temperature on a Bruker Instruments X-band spectrometer. Spin densities were determined using a TE_{104} cavity with a calibrated "weak pitch" spin standard and are accurate to a factor of two in absolute number and to +/-15% in relative number. High frequency 1MHz CV measurements were performed at room temperature with a mercury probe.

E' centers are generated by a VUV hole injection scheme in which oxide surfaces are positively biased with corona ions [7] and then exposed to 10.2 eV VUV photons in an evacuated chamber. The use of corona ions avoids the use of a metal gate which can seriously degrade ESR measurements. Since the ions have essentially thermal kinetic energy, they do not damage the surface of the oxide. The 10.2 eV photons are strongly absorbed within the top 10 nm of the oxide where they create electron-hole pairs. Holes are driven across the oxide while electrons are swept out to remove positive corona charge. The number of injected holes, Q, is determined from $[C(\Delta V)]/e = Q$, where C is the geometric capacitance of the oxide, ΔV is the difference between pre-and post-VUV Kelvin probe measurements of the surface voltage, and e is the electronic charge. E' centers and P_b centers were generated by exposure to unfiltered VUV light ($hc/\lambda \leq 10.2$ eV) with oxide surface unbiased.

III. EXPERIMENTAL DATA

Shown in Fig. 1 is a plot of oxide trapped charge in Unibond material vs. hole injection fluence. In the absence of prior specific information about the distribution of trapped holes in the Unibond BOX, we assume that the holes are captured primarily near the Si/SiO_2 interface and thus conclude that Unibond material captures about 1/3 of the injected holes. In comparison, a typical radiation hard thermal SiO_2 film captures less than 10% of incident holes [8] and a typical SIMOX film captures >>50% of incident holes [9-12]; hole capture in BESOI films is strongly dependent on processing conditions including the location of the bonded interface and post bonding anneals [13,14].

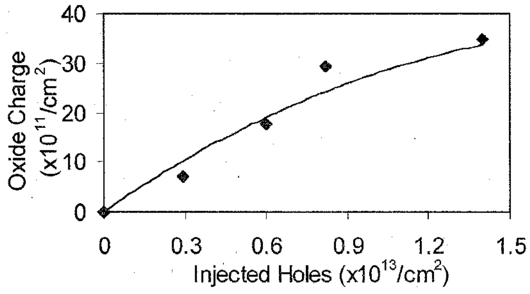

Fig. 1: Plot of oxide trapped charge vs. hole injection fluence. The line serves only to guide the eye

Fig. 2 displays a post $5x10^{13}/cm^2$ hole injection ESR spectrum of Unibond material. This trace reveals the presence of E'_γ and EP centers; no signals were detected prior to hole injection. E'_γ centers, shown in Fig. 3(a), are unpaired electrons localized on a single Si backbonded to three O atoms: $O_3{\equiv}Si\bullet$ [15]. Although a detailed structure of the EP centers is unknown, it is very likely that they are Si dangling bond defects related to oxygen vacancies [16].

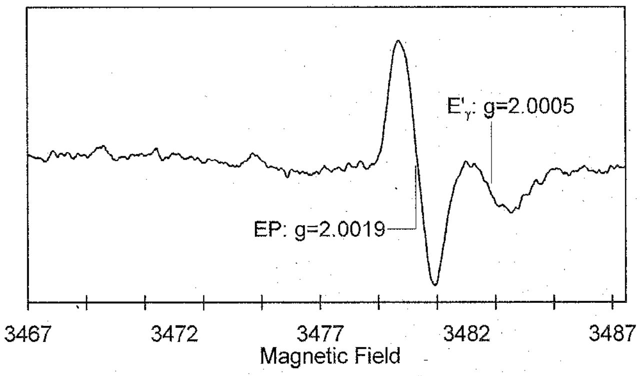

Fig. 2: Post hole injection ESR trace of Unibond material.

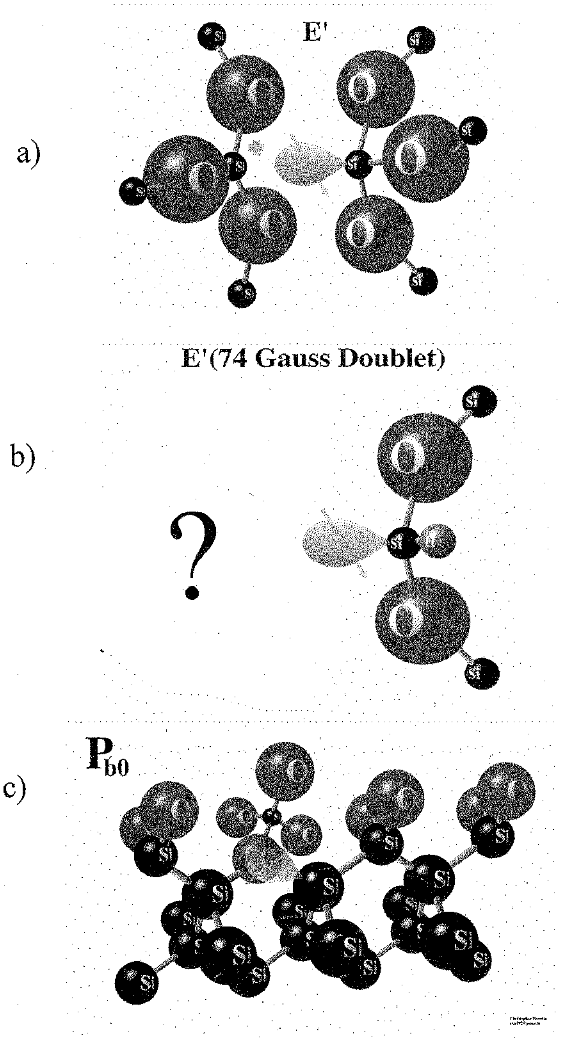

Fig. 3: Defect structure sketches for (a) the E'γ center, (b) the 74 G doublet, and (c) the P_{b0} center.

Assuming, as above, that oxide trapped charge is distributed mainly near the Si/SiO_2 interface, the combined density of the two defects, $5x10^{12}/cm^2$, is approximately equal to the density of trapped positive charge, $3.5x10^{12}/cm^2$. (Even if we assume that the positive charge is distributed throughout the BOX, which would result in a factor of two increase in trapped positive charge density, the positive charge density and E' density would still match to within a factor of two, our stated experimental error.) In comparison, it is known that E' density is closely correlated with oxide charge density in thermal SiO_2, where a rough one to one correspondence between E' and positive charge has been reported [15]. In SIMOX [6,12,17] and in BESOI [18] the relationship between E' and trapped charge is more complex. Shown in Fig. 4 is a wide field ESR trace of Unibond material after exposure to two hours of 10.2 eV VUV illumination, an ionizing radiation dose roughly equivalent to about 500 Mrad (SiO_2). In addition to E'_γ and EP centers, this trace reveals the presence of hydrogen complexed defect centers known as 74 G doublets. The structure of the 74 G doublet defect [19], shown in Fig. 3(b), is that of an E'_γ center with one of the backbonded O atoms replaced by a H atom: $HO_2{\equiv}Si\bullet$. 74 G doublet defects are not normally observable in thermal SiO_2 subjected to similar stress but can be observed in SIMOX. To the best of our knowledge, it has not been established whether or not 74 G doublet defects can be generated in BESOI oxides. The detection of 74 G doublets indicates a high concentration of H in the Unibond BOX [19]. Also revealed in the ESR spectrum in Fig. 4 are the dominant interface trap defects known as P_{b0} centers ($\sim 10^{12}/cm^2$). The P_{b0} center, shown in Fig. 3, consists of an unpaired electron in an sp^3 hybridized wavefunction localized at the Si/SiO_2 interface on a single Si atom backbonded to three other Si atoms: $Si_3{\equiv}Si\bullet$. The presence of P_{b0} defects reveals another similarity between Unibond buried oxides and thermally grown oxides: P_{b0} centers are generated in thermal oxides subjected to similar doses of VUV irradiation but are *not* detected in SIMOX oxides exposed to even higher doses of VUV irradiation. To the best of our knowledge, it has not been established whether or not P_b defects can be generated in BESOI oxides.

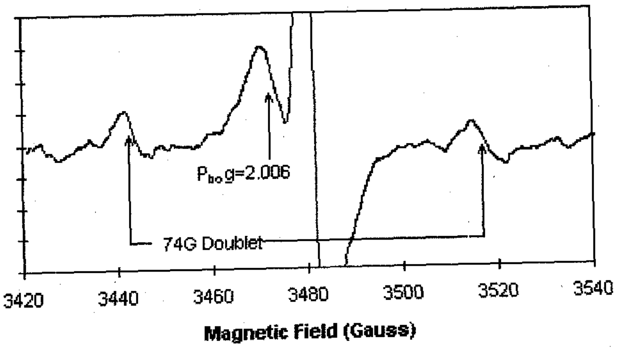

Fig. 4: Post VUV wide field ESR trace of Unibond material.

IV. SUMMARY/CONCLUSION

In summary, we find that E' centers dominate Unibond hole trapping. The close correspondence in Unibond oxides between E' density and oxide trapped hole density, observed in many thermally grown oxides, but not generally observed in SIMOX or BESOI buried oxides, and the detection of P_{b0} centers suggests that the Unibond BOX retains thermal SiO_2 characteristics. However, we find that Unibond oxides capture a greater percentage of holes than do radiation hard thermal oxides, although a smaller percentage than typical SIMOX or BESOI oxides. More significantly, detection of the hydrogen complexed 74 G doublet defects suggests that these oxides contain more hydrogen than thermally grown oxides and clearly demonstrates an increased role for hydrogen complexed defects in Unibond.

The additional hydrogen in Unibond over that of thermal SiO_2 may be a result of the H implant step. Another possibility is that it is the result of the hydrophilic bonding process [20]. One way to determine whether or not hydrophilic bonding is the culprit would be to look for 74G doublet defects in hydrophilic bonded BESOI. At the present, it is not known whether or not the 74 G doublet defects are generated in BESOI buried oxides.

An increased role for hydrogen complexed defects could be harmful. For example, it has been shown that in irradiated oxides, reactions involving hydrogen and positive charge [21], more specifically, *positively charged E' centers* [22,23], can lead to increased interface trap generation. The combined presence of a high density of E' centers and abundant hydrogen could lead to increased generation of radiation induced interface traps in Unibond [22,23]. Increased P_b center interface trap generation is not necessarily bad. In the presence of trapped positive charge, P_b centers could actually help suppress back channel leakage at the Unibond BOX/Si interface in non fully depleted devices.

In conclusion, our results indicate that Unibond wafers exhibit promising radiation response characteristics, probably superior to that of SIMOX. Although the ultimate effect of the high hydrogen density in the buried oxide is not clear, the Unibond radiation response is probably inferior to rad hard thermal SiO_2. At the very least, our results strongly suggest that Unibond buried oxides will exhibit a radiation response unlike rad hard thermally grown oxides and unlike SIMOX buried oxides.

V. ACKNOWLEDGMENTS

The authors are grateful to Dr. A. Wittkower of SOITEC for supplying the Unibond wafer used in this study, C.J. Frye for experimental assistance, and Dr. P. Roitman, and Dr. A.J. Auberton-Herve for useful discussions.

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