

Fig. 2. Schematic representation of possible deuterium diffusion in silicon.

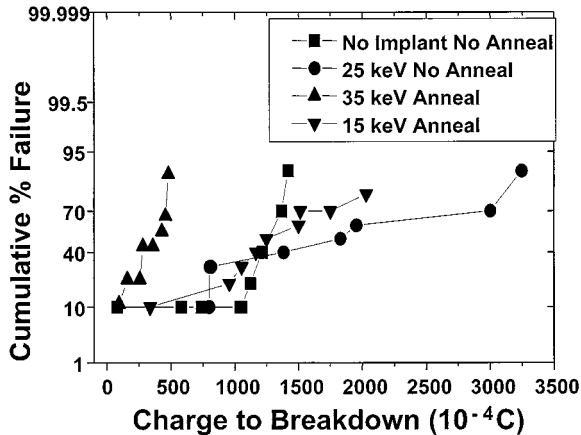


Fig. 3. Charge-to-breakdown characteristics for various devices measured by gate injection mode at a constant current of  $400 \text{ mA/cm}^2$ .

planted devices at different implantation energies is shown in Fig. 3. The 25 keV-implanted devices have the largest charge to breakdown characteristics. The 15 keV-implanted devices have a similar distribution of that of control devices. The 35 keV implanted devices have the worst charge to breakdown performance suggesting absence of deuterium at the interface. One possible explanation is that during oxidation (thermal budget), deuterium might have diffused into vacancies rather than diffusing toward the interface as the implantation depth ( $\sim 0.75 \mu\text{m}$ ) was rather deep for the 35 keV-implanted devices (Fig. 2). In addition, irreparable crystal damage is possible as the implantation energy is higher.

During electron injection, electron trapping establishes a high internal field in the oxide, which leads to increased hole current due to enhanced impact ionization [11]. The hole fluency leads to generation of new traps which also increases the electron trapping. Presence of deuterium at the interface suppresses the hole induced increase in the density of electron traps at the near interface region thereby increasing the charge to breakdown for the 25 keV-implanted devices. For all the devices, charge to breakdown behavior correlates well with that of interface state density. This result also confirms the dependency of charge to breakdown on interface states. It is known that the silicon-dangling bonds at the interface are the major contributors to the interface state density. The number of dangling bonds does not scale significantly with reduction in oxide thickness. Even though an oxide thickness of  $40 \text{ \AA}$  is used in our work, deuterium incorporation using ion implantation can be achieved for thinner oxides.

#### IV. CONCLUSIONS

In summary, we have demonstrated that incorporation of deuterium at the silicon-silicon dioxide interface using ion implantation before the growth of gate oxide is an effective way of improving the oxide quality and reliability. This process may be a viable alternative to extended annealing through a "backend" process. Deuterium implantation brings about a clear enhancement in gate oxide quality by improving the charge to breakdown characteristics through reduction of

interface states. Finally, the selection of appropriate implantation energy, implantation doses and annealing conditions can further optimize thin oxide quality.

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