Stress Induced Leakage Current and Bulk Oxide Trapping: Temperature Evolution

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A key issue for Flash cell scaling down is the reduction of tunnel oxide thickness[1]. This is mainly limited by the information loss induced by the higher gate leakage current after cycling[2], becoming critical below 10nm thickness. Multiple trap assisted tunneling has been proposed to model the conduction of degraded thick oxides[3], but it is not yet clear the nature of the associated defects.

Data here reported are obtained on flat area capacitors with a standard full CMOS process with STI (Shallow Trench Isolation) and dual-gate technology. Tunnel oxides of 8nm thickness have been grown with different oxidation technologies. The measurement procedure is based on three steps [4] to estimate the stable charge (Q_{stable}) and its position [5] and the stationary SILC measured at a fixed field and extrapolated by the tunneling front model [6,7].

The post oxidation treatment impacts SILC and trapped charge and a linear correlation between SILC and bulk negative trapped charge is found (fig. 1). SILC is generally associated with neutral bulk traps[3], allowing a trap assisted tunneling through the oxide. These neutral traps are created by a two-step process of anode injected hole trapping and subsequent recombination with electrons[8,9], as shown by the behavior of V(t) curve at the turn around during constant current stress. The observed correlation between negative trapped charge and SILC can be interpreted as due to the same trap, which is positively charged at low fields during SILC measurement, while it is negatively charged at the higher field used to determine the bulk trapped charge.

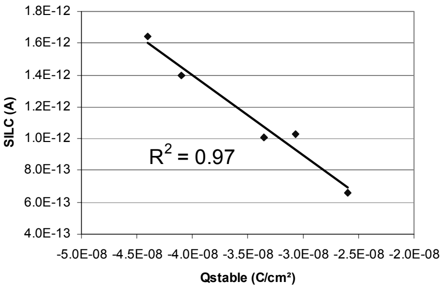

Figure 1: SILC measured at –5.3 MV/cm vs. Q_{stable} with different post-oxidation treatments (at fixed t_{ox} = 8 nm).

To verify if the same trap is involved, the kinetics of the defect annealing has been carried out at different temperatures between 50°C and 250°C. As reported in fig. 2, SILC is indeed observed to decrease with the annealing time. In order to have a significant SILC without reaching the F-N conduction, a standard measure at –5V has been chosen. In fig. 3 the value of SILC normalized for the SILC right after stress is reported versus the annealing time at different temperatures. Increasing the temperature over 150°C a much stronger annealing efficiency is found. The same effect is also observed for the fixed trapped charge (fig. 4). Both phenomena have activation energy of 1.1eV, similar to the Si-Si bond energy. A strong correlation between SILC and Q_{stable} is found (fig. 5): this fully confirms that the same defect is indeed responsible for the two phenomena.

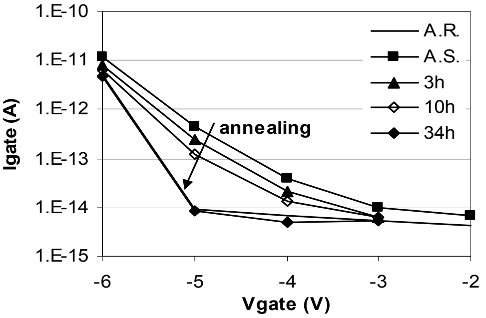

Figure 2: Stationary I(V) before and after stress and with subsequent annealing at 250°C: after 34h annealing the curve is superimposed to the as received one.

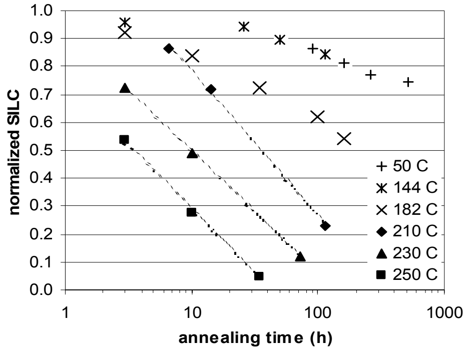

Figure 3: SILC at –5V annealing at different temperatures between 50°C and 250°C. Above 200°C activation energy can be extracted.

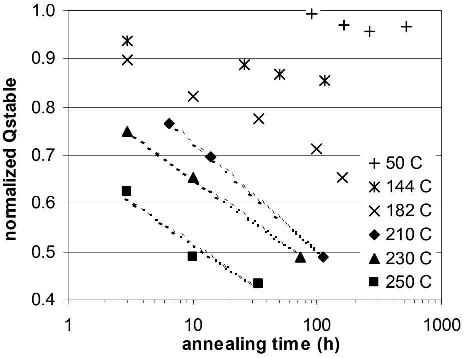

Figure 4: The annealing kinetics of Q_{stable} at different temperatures between 50°C

It should be pointed out that the complete SILC annealing does not correspond to a full recovery of Q_{stable}: there is hence a consistent portion of the trapped charge not directly associated with the

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conduction. To verify if a different annealing kinetics is associated with the residual charge after SILC recovery, a further annealing at 250°C has been performed. No change in the annealing behavior of the charge is detected (fig. 6): a single physical defect is then expected for bulk-trapped charge. For such thick oxides, the recovery of SILC could be obtained by repairing a critical trap in the multiple trap path, probably located in the middle of the oxide[10]. Indeed, preliminary measurements on 6 nm oxides indicate that SILC recovery is much slower.

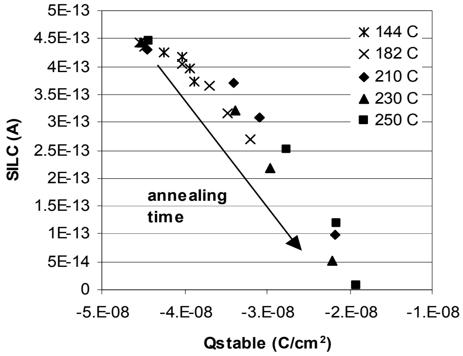

Figure 5: Correlation of SILC and Q_{stable}: during annealing at all temperatures a linear correlation between the two parameters is observed, hence suggesting a common physical origin.

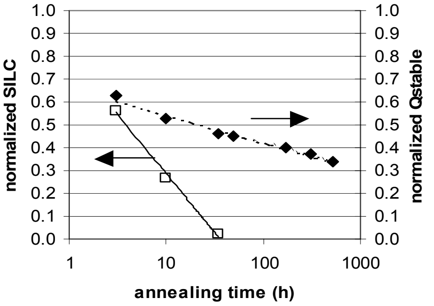

Figure 6: Before and after the complete annealing of SILC the kinetics of Q_{stable} is the same: hence a single defect is present.

As the oxide nitridation has been proved to introduce stronger bonds into the dielectric pattern at the Si-SiO2 interface [11], the N_2O annealing of the tunnel oxide has been investigated. Increasing the N content a lower SILC is indeed found together with a significant reduction of trapped charge [12]. The annealing behavior of SILC and Q_{stable} for the nitrided oxide has been investigated at different temperatures: no difference in the evolution during annealing with respect to the standard oxide is found (figs. 7). Moreover, the same correlation between SILC and Q_{stable} is also verified (fig. 8). This indicates that the same defect is responsible for both phenomena and the impact of nitridation is only a reduction of defect precursors activated during stress.

In order to understand if the oxide was actually fully recovered, a further stress has been applied after a complete annealing of SILC. The SILC obtained is comparable to the one measured after the first stress procedure, while Q_{stable} monotonously increases (fig. 9). The traps associated with SILC conduction and Q_{stable} are then completely annealed, but only a portion of the negative bulk trapped charge is correlated with the leakage current. All the charge is annealed in temperature with the same kinetics and hence the impact on conduction probably depends on the trap location and not on the type of traps, whose activation energy is 1.1eV. The similar behavior of nitrided oxide, whose interface quality is improved, further points out that the nitridation reduces the anode hole injection, responsible for neutral trap formation, but the defect type remains the same.

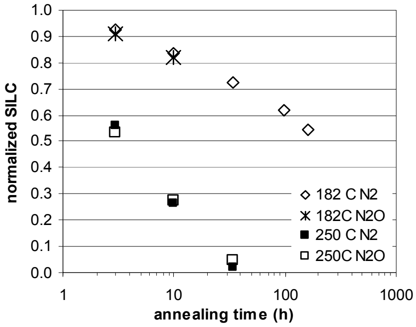

Figure 7: Normalized SILC annealing kinetics below and above 200°C for steam oxides with N_2 and N_2O treatment: the same behavior is found.

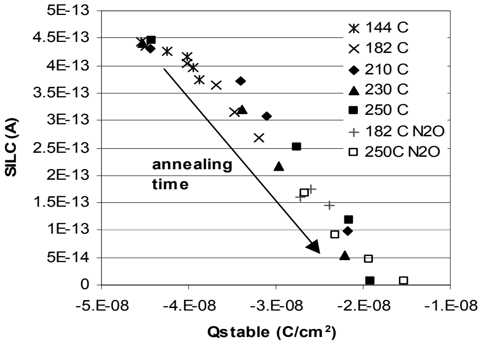

Figure 8: Correlation of SILC and Q_{stable}: during annealing at all temperatures for nitrided and non-nitrided tunnel oxide a linear correlation between the two parameters is still observed.

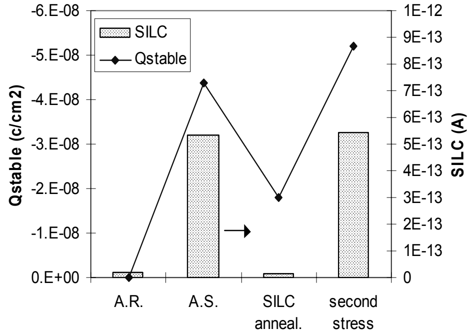

Figure 9: Q_{stable} and SILC before (AR) and after (AS) stress and after high temperature annealing and a second stress: SILC is fully reproduced after the second stress, while Q_{stable} increases.

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