DEFECT TRANSFORMATION PROCESS AT SiO₂/Si INTERFACES


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ABSTRACT

The interface traps created by ionizing radiation or hot-electron injection in MOS capacitors have been found to undergo significant changes with time over an extended period (several months). Immediately after radiation or hot-electron damage, a interface trap peak above midgap (\( \sim E_v + 0.75\text{eV} \)) invariably appears. This peak, along with its background, would continuously change with time after damage, and one salient feature of this change is the gradual conversion of this peak to a second peak located below midgap (\( \sim E_v + 0.35\text{eV} \)). The rate of this interfacial defect transformation process is a function of the device structure, its processing parameters, the details of the radiation or hot-electron treatment, the gate bias polarity, and the process is thermally activated. These and other pertinent results will be discussed.

1. INTRODUCTION

In recent publications, we reported on the long-term time dependent evolution of the interface traps in MOS capacitors after ionizing radiation or hot electron damage [1,2]. There we noted the observation that, in many cases, the post-radiation characteristic interface trap peak located above midgap would continuously decrease with time after irradiation or hot-electron damage, and accompanying that was the growth of a second peak located below midgap. We also noted that the formation and growth of the second peak appeared to be at the expense of the first peak, suggesting that some kind of defect transformation process might be taking place at the interface. Since then much more extensive work has been done, and we are convinced that not only does it indeed occur, but that the interfacial defect transformation process appears to be a fundamental process occurring generally in all the samples that we studied. Some of our recent results are presented and discussed here.

2. EXPERIMENTAL

The MOS capacitor samples used in this study covered a wide range of gate electrode materials (e.g., Al, Poly-Si, Mo, TiSi₂), various oxidation conditions (e.g., dry \( O_2 \), steam, with/without Cl, various oxidation temperatures), and processed at several different laboratories. Although due to the space limitation, the results to be presented here are for some specific sets of samples, qualitatively similar results have been observed in all the samples investigated.
The irradiation source used was an X-ray beam generated from a W target bombarded by 40 KeV electrons with a typical dose rate of 30 Krad(Si)/min. A total dose of up to 6 Mrads(Si) was used for some of the samples.

For the study of hot electron effects, a HP4145 parameter analyzer was used to inject Fowler-Nordheim tunneling current at a constant current level of $6 \times 10^{-6}$ to $5 \times 10^{-5}$ A/cm$^2$ for 200 seconds. Electrons were injected from the silicon substrate toward the gate (with a positive gate voltage).

The interface trap distributions were analyzed by measuring the high frequency and quasi-static C-V curves, with a ramp rate of 0.01 V/sec.

After X-ray irradiation or hot electron injection, the samples were stored at either room temperature, 50 °C, or 75 °C, and C-V measurements were made at several time intervals to monitor the time dependent evolution of the generated interface traps.

3. RESULTS

As shown in Figs. 1(a) and 1(b), a characteristic interface trap peak above midgap (dotted curves in both figures) appears right after irradiation or hot electron injection for two samples with different gate electrodes. This has been generally observed in all of the samples that we studied.

When measured some time later after irradiation (or injection), in some samples we observed an increase with time of this peak (designated peak-1 hereafter) for some extended period, followed by a decreasing trend; in some other samples peak-1 would continuously decrease with time right from the beginning. The detailed time dependence is a function of the processing history and damaging conditions, and is not the focus of this paper. What should be noted here is that, regardless whether peak-1 is rising or decreasing during the initial phase of this time dependent evolution, whenever peak-1 starts to decrease we observe the emergence and subsequent growth of a new peak below midgap (designated peak-2 hereafter), and the growth of this new peak is correlated with the reduction of peak-1.