Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 182–183



# Intergrity of Gate Oxides Irradiated Under Electron-Beam Lithography Conditions

Pei Fen Chong, Byung Jin Cho+, Eng Fong Chor, Moon Sig Joo*, and In Seok Yeo*

Department of Electrical Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260.
+Phone: (65) 874-6470 Fax: (65) 779-1103 Email: elebjcho@nus.edu.sg
*Hyundai Electronics Industries Company Limited, Semiconductor Advanced Research Division,
Ichon-si, Kyungki-do, 467-701 Korea.

## 1. Introduction

As ULSI technology advances to the 0.10 μm level generation, new lithography tools with shorter wavelength such as E-beam and X-ray are expected to be used in mass production in the near future. However, these short wavelength beams can cause radiation damages to devices, especially to thin gate oxide in MOS devices. In this paper, the integrity of gate oxides irradiated under E-beam lithography conditions is discussed.

## 2. Experiments

MOS capacitors on p-type silicon wafers with gate oxide thickness of 35 ~ 70 Å were used. In the experiments, the E-beam scanned the entire gate area of each capacitor separately. In conventional E-beam lithography process, typically a 0.7μm resist is exposed with a dose of 20 $\mu C/cm^2$ at an accelerating voltage of 25 kV [1]. Consequently, the total dose used in this study was selected in the range from 5-700 $\mu C/cm^2$ at 25 keV. For comparison with the electrical stress, constant current stress (CCS) tests have also been carried out with a stress current density of -5 $mA/cm^2$.

## 3. Results and Discussion

Fig. 1 shows the I-V characteristics of fresh, E-beam irradiated (20 $\mu C/cm^2$ at 25 keV), and electrically stressed (0.1 $C/cm^2$) oxides. Both the irradiation and electrical stress exhibit a significant excess leakage current in the pre-tunneling regime. The Radiation-Induced Leakage Current (RILC) and the electrical Stress-Induced Leakage Current (SILC) look similar in the figure. To compare more precisely, the fractional excess leakage current, defined in terms of $(Ig-Ig_{fresh}) / Ig_{fresh}$, is plotted in Fig. 2 for the 45 Å oxide. Both curves exhibit similar trend, with the maximum leakage current increment occurring at about Vg = -4.5 V. Since the natures of both leakage currents are similar, it is meaningful to establish the relationship between the total radiation dose and charge fluence which induces the same amount of degradation. Fig. 3 plots the excess currents $(Ig-Ig_{fresh})$ as a function of fluence of both RILC and SILC for the 45 Å oxide. The currents were measured at Vg corresponding to the peak current in Fig. 2. It is observed that E-beam is much more effective in generating leakage current at the same fluence. This implies that E-beam is much more effective to generate oxide traps which contribute to low field tunneling current. The slope in Fig. 3 represents the rate of generating oxide traps, defined as change in oxide trap density per change in injected charge. Fig. 4 shows the relationship between E-beam dosage, D, and the equivalent charge fluence, F, at the same current degradation for different oxide thickness. F has been found to be proportional to $D^m$, where $m$ shows the relative rate of E-beam to CCS to generate oxide traps, and is 1.2 for a 45Å oxide. As the oxide thickness increases, it is observed that $m$ decreases, indicating that the oxide trap generation rate of E-beam is less in thick oxides compared to electrical stress, even though the absolute number of traps is larger. In Fig. 5, a linear relation is obtained for the thickness dependence of $m$. At around 50 Å, the trap generation rates of E-beam and electrical stress are the same.

Interface state generation by E-beam irradiation and CCS was monitored using quasi-static CV, as shown in Fig. 6 & 7. Fig. 7(a) shows that ΔDit increases with oxide thickness for a given E-beam dosage. However, the slope which represents the rate of generating interface states, defined as the change in interface state density per change in injected charge, is observed to be independent of the oxide thickness. In electrical CCS, the slope shows a strong dependence on the oxide thickness. This difference is explained by the difference of kinetic energies of injected electrons between E-beam irradiation and electrical stress (Fig. 8 & 9). It is worth noted that the magnitude of ΔDit at the same fluence of E-beam and CCS is in the same order of magnitude. However, as seen in Fig. 3, RILC is more than 2 orders higher than SILC at the same fluence. (See the data at $10^{-3}$ $C/cm^2$ for both figures.) From these results, we can conclude that E-beam is much more effective in oxide bulk trap generation but is similarly effective in interface state generation compared to the electrical CCS.

Quasi-breakdown[2] characteristic was also investigated, using a 35 Å oxide. Fig. 10 shows the charge-to-quasi-breakdown ($Q_{qbd}$) data of the fresh, 100 and 500 $\mu C/cm^2$ irradiated oxides. Wide range of stress current was used in the $Q_{qbd}$ measurement. The result shows that E-beam irradiation does not make any changes in $Q_{qbd}$. In other words, E-beam irradiation up to a dose of 500 $\mu C/cm^2$ does not accelerate quasi-breakdown of ultra-thin gate oxide. This result strongly supports the claim that quasi-breakdown is dominated by the interface damage rather than oxide bulk traps [2,3] because E-beam has been found to be not very effective in generating interface states in ultra-thin oxides.

## 4. Conclusions

It is found that E-beam lithography process can cause large increase in oxide leakage current but does not accelerate quasi-breakdown in ultra-thin oxide.

**References**

[1] J.M. Aitken, IEEE J. of Solid-State Circuits, Vol. 14(2), 294 (1979).

[2] S.H. Lee, B.J. Cho, J.C. Kim and S.H. Choi, IEEE International Electron Devices Meeting Technical Digest, 605 (1994).

[3] H. Guan, B.J. Cho, M.F. Li, Y.D. He, Z. Xu and Z. Dong, to be published in the Proceedings for the International Symposium on the Physical & Failure Analysis of Integrated Circuits 99.

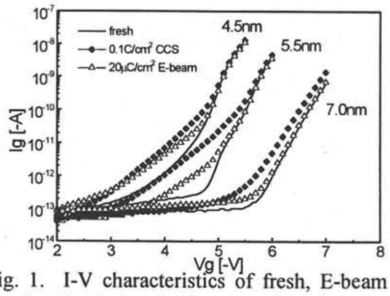


Fig. 1. I-V characteristics of fresh, E-beam irradiated and electrically stressed oxides.

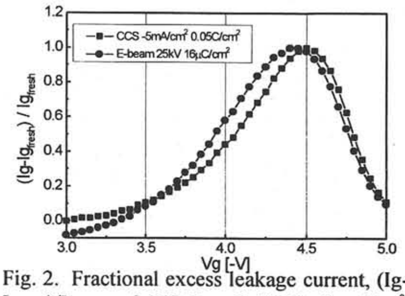


Fig. 2. Fractional excess leakage current, (Ig-Ig$_{fresh}$)/Ig$_{fresh}$ of RILC and SILC for 45 Å oxide. Both curves exhibit similar trend, peaking at about Vg = -4.5V.

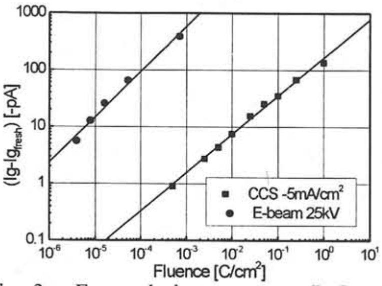


Fig. 3. Excess leakage current, (Ig-Ig$_{fresh}$) against fluence of 45Å oxide for both RILC and SILC.

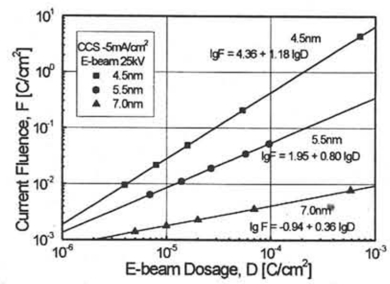


Fig. 4. Relationship between E-beam dosage, D, and equivalent charge fluence, F, which induces the same amount of excess leakage current.

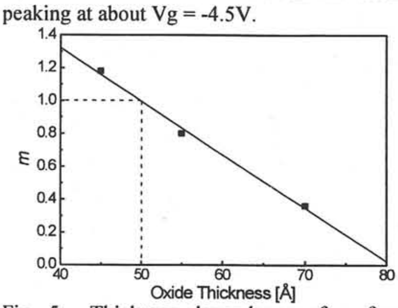


Fig. 5. Thickness dependence of *m* from figure 4.

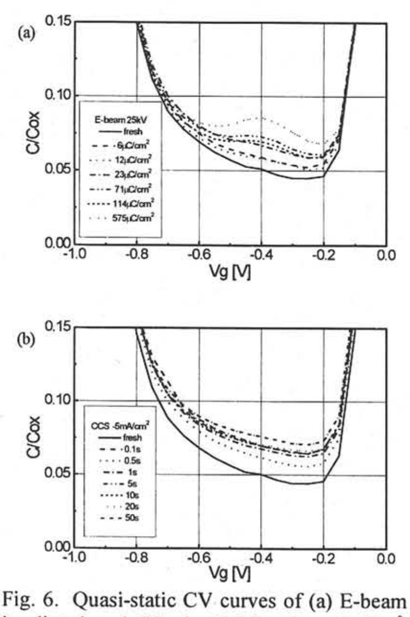


Fig. 6. Quasi-static CV curves of (a) E-beam irradiated and (b) electrically-stressed 45 Å oxides.

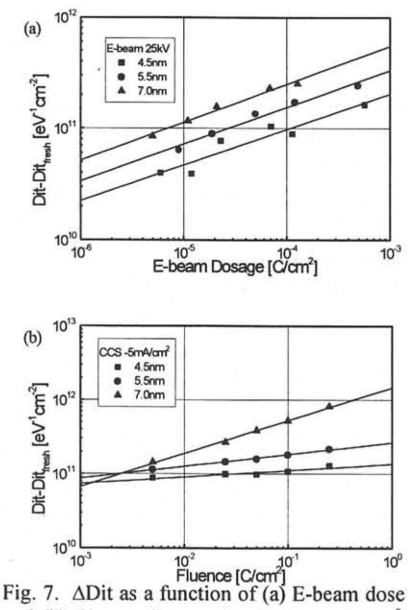


Fig. 7. ΔDit as a function of (a) E-beam dose and (b) Current fluence for 45, 55, and 70 Å oxides.

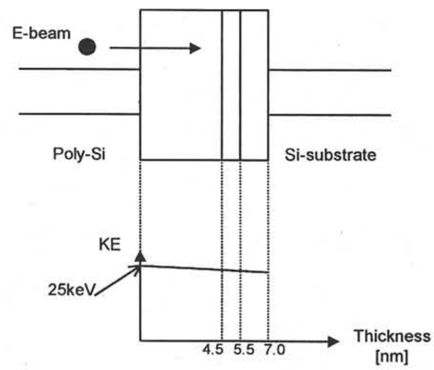


Fig. 8. Conduction process of electrons in oxides during E-beam irradiation. Due to the high electron energy of 25keV during E-beam irradiation, the kinetic energy (KE) of electrons at the $SiO_2$/Si interface is similar regardless of the oxide thickness.

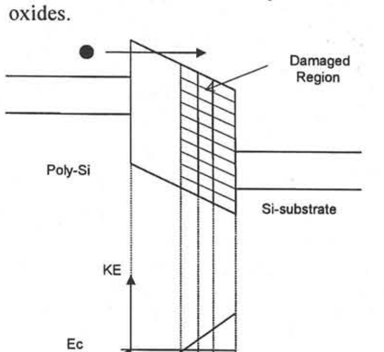


Fig. 9. Conduction process of electrons in oxides during CCS. During CCS, electrons are accelerated towards the anode. KE of electrons at the anode will be higher in thicker oxide for the same oxide field. Thus, more interface states are generated and wider area is involved in trap generation in thicker oxide.

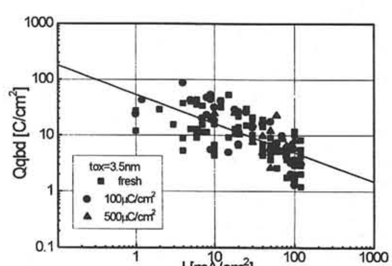


Fig. 10. Stress current density and E-beam dosage dependence of charge-to-quasi-breakdown. No difference between non-irradiated and irradiated oxides was found, implying that E-beam irradiation does not accelerate Quasi-Breakdown .