Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 126–127

Time Evolution of Mean and Dispersion in Si/SiO_2 Interface States Generation Statistics

Yuichiro Mitani, Hideki Satake and Akira Toriumi
Advanced Semiconductor Devices Research Laboratories, Toshiba Corp.
8, Shinsugita-cho, Isogo-ku, Yokohama 235-8522, Japan
Phone: +81-45-770-3689 Facsimile: +81-45-770-3578 E-mail: mitani@amc.toshiba.co.jp

Introduction

To achieve the high reliability of thin gate oxides required with shrinking ULSI devices, the microscopic degradation model of SiO_2 or surface analysis on Si has been extensively investigated in recent years. On the other hand, we think that almost all of the reliability issues should be considered statistically, because electron energy, bonding configuration, or passivated states are all in a thermodynamically equilibrium state. Only the SiO_2 dielectric breakdown has been studied in a statistical sense [1]. Our final target is to understand the physical correlation between the microscopic defect nature and macroscopic degradation results. In this study, we have focused on the interface state generation at Si/SiO_2 by injecting the current into SiO_2, from the statistical distribution viewpoint. As a result, we have demonstrated, for the first time, that both mean and dispersion of the generated interface states distribution increase with electron injection, and also have proposed a new type of interface states generation mechanism.

Experiment

The devices used in this work were W/L= 50 μm×2 μm n-channel MOSFETs fabricated on Si (100) wafers by the conventional submicron CMOS process. The gate oxide was grown in a dry O_2 atmosphere at 850 °C. The oxide thickness was 9 nm. For the statistical discussion, the interface states density of 120 MOSFETs on a wafer was evaluated by the charge-pumping method [2] at room temperature. The distribution of initial interface states density is in average 3×10^{10} $cm^{-2}eV^{-1}$ as shown in Fig.1, which indicates that initial interface is well controlled. The interface states were generated by F-N electron injection in both gate polarities under a constant current condition.

Results and Discussion

Figure 1 shows the statistical distribution of the interface state densities, Dit. It is found that the mean value and the dispersion of Dit are increased with the total electron fluence, Qinj, under a constant current injection for the negative gate bias. Another interesting point is that both upper half and lower half of the initial Dit distribution are rapidly mixed each other by electron injection. This result indicates that not all the interface defects become electrically active in a simple way (for instance, transition **f** in Fig.2(a)), but some devices suffer a big change (transition **g** in Fig.2(a)). From the experimental results in Fig.1, it is inferred that two kinds of interface states are generated by the electrical stress as schematically shown in Fig.2(b). Most of interface defects become active independently, but a small amount of defects are correlated one another, and may bring about **g** transition in Fig.2(a). The area which is evaluated in the present devices is 100 μm^2, which means that macroscopically a large amount of interface states are included in each device. Therefore, our view is that two kinds of interface states do not come from the thermodynamic distribution, but from a small process fluctuation within a wafer. However, the oxide thickness variation was very small (±0.1 nm), and the present result strongly indicate that the statistical approach is a very sensitive method to evaluate the process and quality control.

Figure 3 shows the time evolution of the generated interface state densities, ΔDit, which is calculated by subtracting the initial Dit value from that after electron injection. It should be noted that the upper half and lower half of the ΔDit distribution after Qinj=0.01 C/cm^2 are not mixed each other very much and these behave almost independently. Moreover, ΔDit distribution seems separated gradually into two peaks. This indicates that there are statistically two groups of the interface states, which are divided by the just slight F-N injection such as Qinj=0.01 C/cm^2. We think that the separation into these two ΔDit distribution peaks are due to two different interface states generation mechanisms, as mentioned in Fig.2(b). It is inferred that, (1) the upper half of ΔDit distribution (unfilled area in Fig.3) is composed of the *correlated* defects, which become active in the small F-N injection. On the contrary, (2) the lower half of ΔDit distribution is composed of the *independent* defects.

Fig.4 shows the ΔDit distribution in the case of electron injection from the inversion layer. It is seen that the mean and dispersion of ΔDit increase with the electron injection, but the degradation is severer in the case of electron injection from the gate electrode (at 0.3 C/cm^2, $\bar{x}=1.8\times10^{11}$ $cm^{-2}eV^{-1}$ for substrate injection and $\bar{x}=2.4\times10^{11}$ $cm^{-2}eV^{-1}$ for gate injection). However, it can be concluded that the interface degradation mechanism is similar for both gate polarities, because the trend of the mean ΔDit increase as a function of Qinj is almost the same as shown in Fig.5. This gate polarity effect is similar to other SiO_2 reliability issues such as the charge-to-breakdown. Although the relationship between the interface state and the other SiO_2 degradation has not been clarified yet, we expect that the statistical approach becomes a clue for the comprehensive understanding of SiO_2 degradation mechanism.

Conclusion

The interface degradation has been investigated from the viewpoint of the statistical distribution of the interface states generated under a constant current injection. As a result, we found that, (1) ΔDit distribution becomes wide and that, (2) this distribution is divided statistically into two groups of the interface defect generation under the F-N electron injection. To our knowledge, this is the first approach to understand the interface states generation statistically. This method will be a very powerful method to evaluate the oxide reliability and may provide an essential clue to understand the SiO_2 reliability physics.

References

[1] R.Degraeve et al., IEEE Trans. Electron Devices, ED-45,472 (1998).

[2] J. S. Burgler and P. G. A. Jespers, IEEE Trans. Electron Devices, ED-16, 297 (1969).

[3] D. J. DiMaria et al., J. Appl. Phys., 73, 3367 (1993).

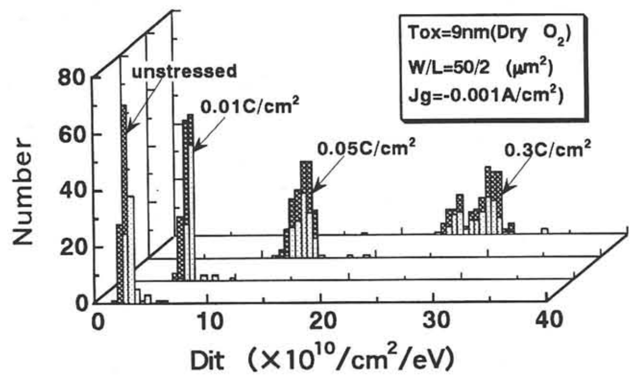

Fig.1 Time evolution of interface states distribution, Dit. Shaded area and unfilled area correspond to lower half and upper half MOSFETs of initial Dit distribution, respectively.

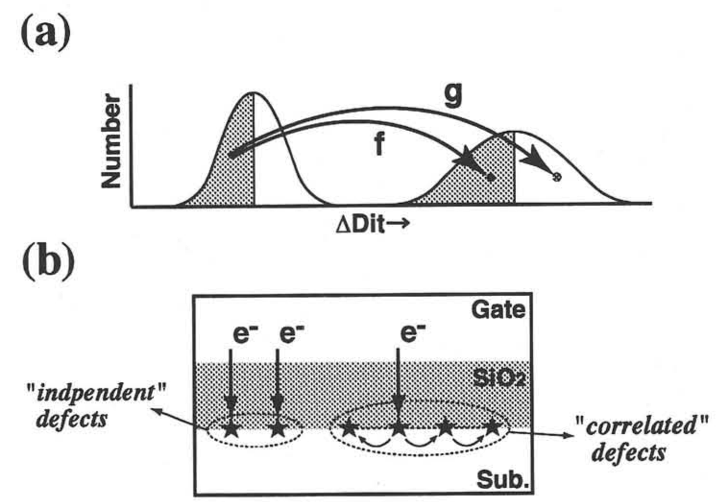

Fig.2 Schematic diagram of (a) time evolution of ΔDit under F-N electron injection, and (b) two different interface states generation mechanisms.

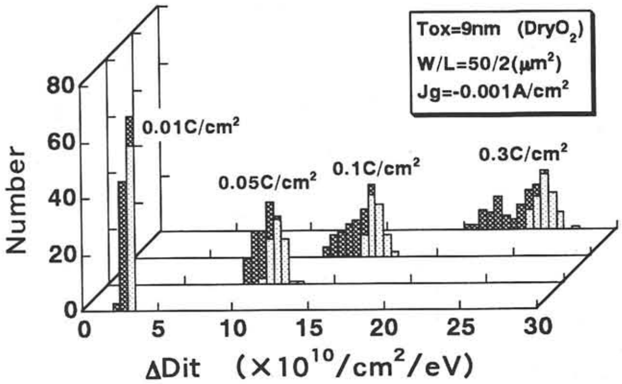

Fig.3 Time evolution of the generated interface states distribution. Shaded area and unfilled area correspond to the lower half and upper half MOSFETs of ΔDit distribution at Qinj=$0.01C/cm^2$, respectively.

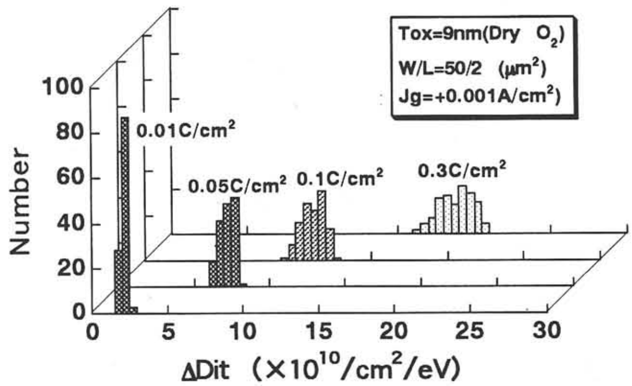

Fig.4 Dit distribution in the case of electron injection from an inversion layer as function of electron fluence.

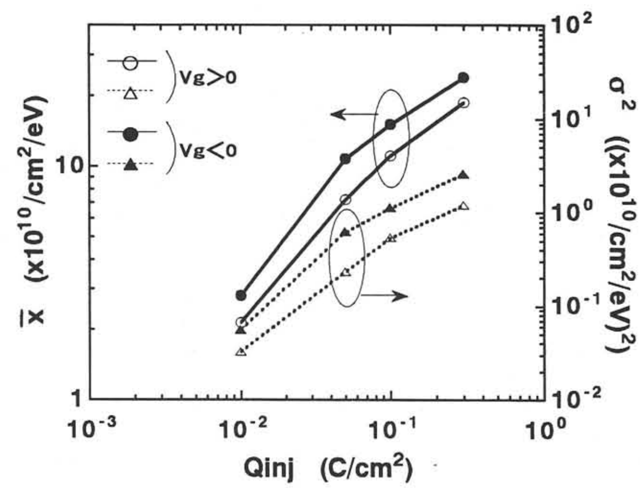

Fig.5 Mean value of ΔDit as function of Qinj for both positive and negative gate conditions. Both unfilled circle and unfilled triangle correspond to the lower-half devices and both filled circle and filled triangle correspond to the upper half devices.