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Influence of Organic Contamination on Reliability and Trap Generation in MOS Devices

T. Yoshino, S. Yokoyama, T. Fujii[1], K. Shibahara, A. Nakajima, T. Kikkawa, H. Sunami and Q. D. M. Khosru
Research Center for Nanodevices and Systems, Hiroshima University, 1-4-2 Kagamiyama, Higashi-Hiroshima 739-8527, Japan
Phone: +81-824-24-6265, Fax: +81-824-22-7185, e-mail: Takenobu Yoshino <yoshino@sxsys.hiroshima-u.ac.jp>
[1]EBARA Research Co., Ltd., 4-2-1 Honfujisawa, Fujisawa 251-8502, Japan

1 Introduction

We have shown that the UV/photoelectron and photocatalyst wafer box as drawn in Fig. 1 is suitable for the semiconductor manufacturing processes using 300-mm Si wafers because of less organic contamination [1–3]. In this report, to evaluate the influence of organic contaminant at the interface, we fabricated metal-oxide-semiconductor (MOS) capacitors and MOS field-effect transistors (MOSFETs) which were intentionally stored in various wafer boxes before or after gate oxidation, and measured the time-dependent dielectric-breakdown (TDDB) and the transistor characteristics. We applied, for the first time, the hot-electron injection technique to evaluate the interface contamination and revealed that it is useful for detecting the organic contaminant in the oxide.

2 Experimental

2.1 Sample preparation

The MOS capacitors and n-channel MOSFETs with n^+poly-Si gate were fabricated on p-Si (100) wafers. Before gate oxidation of capacitors, we stored samples for 12 h in (i) polyether sulfone (PES) box, (ii) PES box cleaned by the UV/photoelectron method (PES/UV) and (iii) nitrogen gas purged polycarbonate (PC/N_2) box, where PES is a newly developed plastic for less gas emission and PC/N_2 box is a reference for the practical wafer box. In all boxes, twenty five 300-mm glass wafers were stored to emulate the practical use. The gate oxide was formed with dry oxidation, resulting in approximately 2.8 nm thickness. For MOSFETs, the storage process was also added before or after gate oxidation for 6 h in commercial front opening unified pod (FOUP) made of PC.

2.2 Measurement procedures

The TDDB characteristics under the constant current was measured for 100 μm × 100 μm gates of MOS capacitors. The hot-electron injection for MOS capacitors was carried out by the avalanche injection [4] with a 1 MHz square wave and ±1 V in amplitude with +10 V offset. The band structure during the injection is illustrated in Fig. 2, at which the Si surface is in deep depletion and the hot-carriers can jump over the barrier between Si-SiO_2 interface. After the stressing, the capacitance-voltage (C-V) and conductance-voltage (G-V) characteristics were measured simultaneously at 1 kHz.

For MOSFETs, the hot-electrons were injected from emitters arranged near transistors as drawn in Fig. 3. Before and after injection, the threshold voltage and induced oxide trap were evaluated.

3 Results and Discussions

3.1 TDDB examination of MOS capacitors

The results of TDDB characteristics are compared each other in Fig. 4 for various samples. For samples stored in the PES/UV box as well as that stored in the PC/N_2 boxes, the reliability is higher than that stored in the conventional PES box.

For the practical use, although the performance is comparable with each other, the PES/UV box is estimated to be superior to PC/N_2 box because the PC/N_2 box costs for nitrogen gas, the nitrogen gas causes a suffocation, the gas flow causes electrostatic charge and particle adhesion. Thus, plastic box using the UV unit is favorable for the practical wafer box for semiconductor fabrication processes.

3.2 Effect of hot-electron injection on MOS capacitors

Figures 5 and 6 show measured C-V and G-V curves, respectively, after the hot-electron injection. For samples stored in the PES box, with increasing the stress time, pronounced peaks grow in both C and G at -0.5 V< V_G < 1.5 V. Especially, three different peaks are observed in G. On the other hand, for samples stored in the PES/UV box and non-stored control samples, a single peak is exhibited in G at around $V_G = 0.5$ V, but that in C is extremely weak compared to samples stored in the PES box. These phenomena are reproducible for each storage conditions as shown in Fig. 7, i.e., the magnitude of peak in G for PES-stored samples is more than three times larger than others. It should be noted that these peaks rapidly decrease after the injection and almost vanished within 30 min, indicating that the induced interface trap is instable.

The estimated interface trap density $D_{\rm it}$ as a function of the gate voltage is drawn in Fig. 8 for PES and PES/UV-box-stored capacitors. For the PES/UV-box stored capacitors, the interface contamination was dramatically removed by using the UV unit.

3.3 Influence of hot-electron injection on MOSFETs

Figures 9 shows an example of the change of the transistor characteristics. Some examples of the threshold voltage ($V_{\rm th}$) shift are plotted in Fig. 10 as a function of the number of injected hot-electrons. The value of $V_{\rm th}$ was determined as the gate voltage when the drain current normalized by the ratio of the width to the length of gate W/L reaches to 10^{-7} A. The density and the capture cross section of electron traps are obtained by fitting of the experimental data to the following equation [5]:

$$V_{\rm th}(\infty) - V_{\rm th}(N_{\rm inj}) = \frac{q}{2C_{\rm ox}} \sum_i D_i^{\rm t} \exp(-N_{\rm inj}\sigma_i).$$

Here, $N_{\rm inj}$ is the number of injected electrons, q is the electron charge, $C_{\rm ox}$ is the oxide capacitance, $D_i^{\rm t}$ and σ_i are the density and the capture cross section of the i-th trap, respectively. The multiplication factor, 2, in the denominator of the right hand term is appeared because the trap levels are assumed to be uniformly distributed through the oxide. The resulting capture cross section and the trap densities are plotted in Fig. 11. The traps are assigned to the neutral traps judged from the magnitude of the capture cross section [6]. Figure 12 summarizes the total trap densities for the samples made after different stock methods. Although the data is scattered, it seems that the trap densities tend to increase for pre-oxidation stock. Namely, the influence of the organic contamination before oxidation is more enhanced than that for after-oxidation, which is consistent with the TDDB results for MOS capacitors [2, 3].

4 Conclusions

From the avalanche injection method as well as the TDDB examination for MOS capacitors, it was found that the PES/UV wafer box results in less organic gas contamination, and the induced trap density is small compared with the box without the cleaning unit. It was indicated from the hot-electron injection experiment for MOSFETs that the organic contaminant adsorbed before gate oxidation induces the higher density of neutral traps in the oxide than those adsorbed after oxidation. It is noted that the hot-electron injection technique reflects the contamination effect more obviously than TDDB examination.

Acknowledgment

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References

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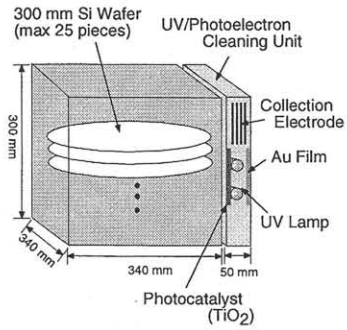

Fig. 1: Illustration of a 300-mm wafer box with the UV/photoelectron cleaning unit.

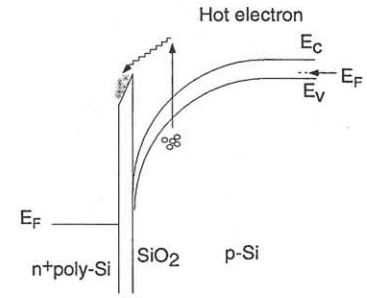

Fig. 2: Energy band diagram for the hot-electron injection.

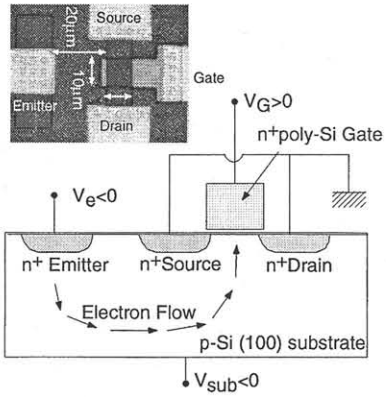

Fig. 3: Overview and cross sectional structure of MOSFET. During the hot-electron injection, the values of V_G, V_e and V_{sub} were kept at 1.0 V, −3.3 V and −2.5 V, respectively.

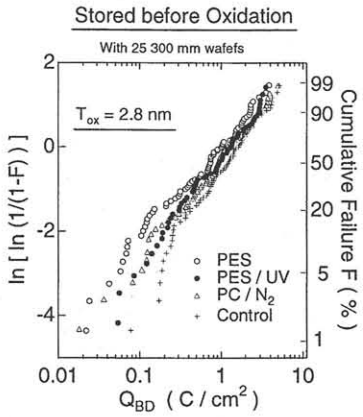

Fig. 4: Weibull plot for MOS capacitors fabricated using various boxes.

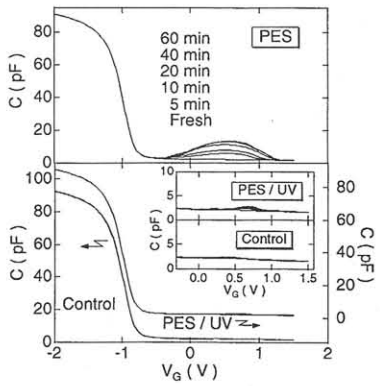

Fig. 5: Measured capacitance C as a function of gate voltage V_G after hot-electron injection. The insets show C in an expanded scale.

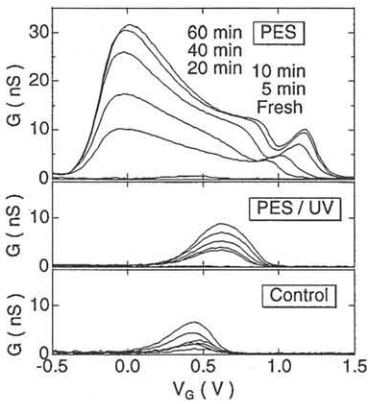

Fig. 6: Measured conductance G as a function of gate voltage V_G after hot-electron injection.

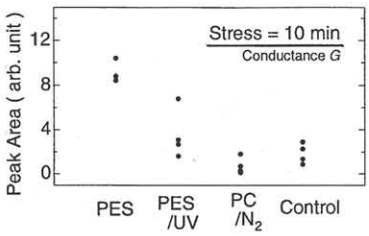

Fig. 7: Peak area in G versus wafer stock method.

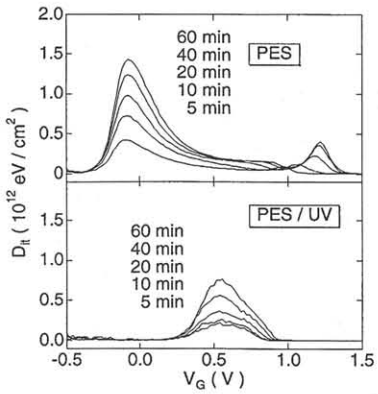

Fig. 8: Calculated interface trap D_{it} as a function of gate voltage V_G.

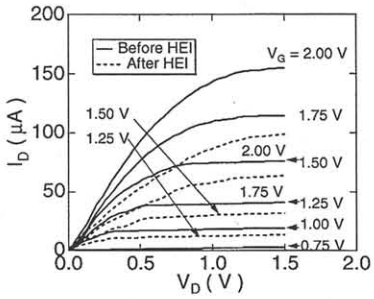

Fig. 9: Example of drain current I_D versus drain voltage V_D characteristics for the fabricated transistor before and after hot-electron injection (HEI).

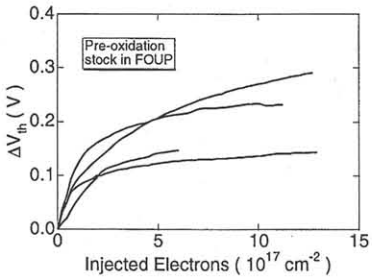

Fig. 10: Threshold voltage shift ΔV_{th} for MOSFETs versus number of injected hot-electrons.

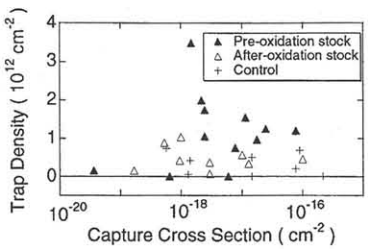

Fig. 11: Trap density versus capture cross section for three kinds of transistor samples.

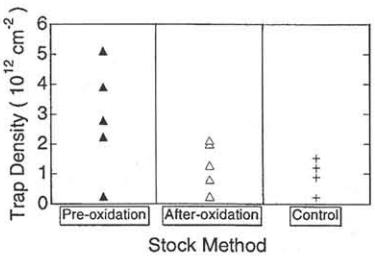

Fig. 12: Total trap density versus wafer stock method for MOSFETs.