Investigation of Localized Breakdown Spots in Thin SiO_2 using Scanning Capacitance Microscopy

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ABSTRACT

Scanning capacitance microscopy (SCM) was employed to observe the oxide breakdown sites. The localized breakdown spots obviously exhibit low differential capacitance signals. The observed area of the breakdown spots approximately ranges from 6 nm to 13 nm in lateral direction. According to contact-mode atomic force microscopy (AFM) image, the surface morphology has little effect on the SCM signal. [*Keywords:* Scanning capacitance microscopy (SCM), oxide breakdown, breakdown spots, atomic force microscopy (AFM).]

INTRODUCTION

With the continued scaling down of metal-oxide-semiconductor (MOS) devices, the quality of thin gate oxide is more and more important for maintaining the device performance [1]-[3]. Oxide breakdown (OBD) is one of the most important problems for the reliability of future ICs. Although many efforts have been done in understanding the exact OBD mechanisms, there is still a lack of a consistent theory so far. It is only accepted that OBD is a local phenomena, which is a nano-scale region, not created in total device area [4]. Using Conventional MOS capacitors through electrical measurements, just average information of the whole oxide region under the capacitor area is acquired. For investigating the detail OBD mechanism, scanning capacitance microscopy (SCM) analysis was used to study the OBD sites of thin SiO_2 layer, based on contact-mode atomic force microscopy (AFM).

EXPERIMENTAL

Figure 1 shows the schematics of the process flow for this study. First, the MOS capacitors were fabricated on (100) oriented p-type wafer. A 500-nm-thick thermal oxide layer was grown on silicon wafer by wet oxidation. The active areas were defined by photolithography and wet-chemical-etched. After a standard cleaning, a 40Å-thick oxide layer was grown at 900°C in diluted O_2 ambient. Then, a poly-Si film was deposited to serve as gate electrode. Subsequently, phosphorous ion implantation was preformed at the dosage and energy of 5×10^{15} cm^{-2} and 40 KeV, respectively. The dopant was activated by RTA at 1000°C for 30s. The OBD was performed, followed by the removal of the poly-Si gate. The OBD spots were investigated by a scanning probe microscope (Digital Instruments D5000) equipped with an SCM scanner, which is employed to obtain SCM images and the corresponding atomic force microscopy (AFM) images. All the SCM images were acquired using the constant voltage mode using dc bias of 0V and ac bias of 200 mV at 89 kHz.

RESULTS AND DISCUSSION

Figure 2 shows the high frequency (1MHz) capacitance versus gate voltage (C-V) characteristic swept from inversion to accumulation. The effective oxide thickness (EOT) of 4.06 nm was estimated from the capacitance of strong accumulation regime. Figure 3 plots the negative J-E characteristic of the thin oxide layer. Ten samples on different positions of the wafer were compared. The results from different samples are almost the same and present a high breakdown field (~14MV/cm) as well as low leakage current (~10^{-6} A/cm^2 at -1 V). This means that high quality and good uniformity oxide film has been obtained for the investigation in this study.

Figures 4 (a) and (c) illustrate the AFM images of the oxide layer before and after OBD, respectively. Figures 4 (b) and (d) show the corresponding SCM images of Figs. 4 (a) and (c), respectively. It can be found that the surface morphology of the oxide layer is still uniform after OBD. The root mean square (rms) roughness of sample surface is about 3.36 Å and 2.29Å for the oxide film before and after OBD, respectively. It can be clarified that the OBD does not cause the change of surface morphology. However, there are some spots, which show a low *dC/dV* signal, as shown in Fig. 3 (d). Obviously, these low *dC/dV* signals are not related to the corresponding surface morphology. We attribute this spots to the damaged sites of the oxide layer. One possible reason is that many defects were generated during OBD; then the percolation paths were built in localized regions and carriers might leak through the oxide layer by these paths.

Figure 5 clearly demonstrates three OBD spots with small *dC/dV* signals. It is found that these spots vary in size. We believe that thermal-damage-induced OBD propagation caused this difference. Figure 6 shows the section view for one of the OBD spots. The diameter of the OBD spot is approximately 12.6 nm, which is consistent with the order of the magnitude of previous reports by other authors [4]. It is worth noting that because the applied voltage is generally low in SCM measurements, the OBD spots would not be further destroyed or no new OBD spot would be triggered during SCM scanning. Therefore, the SCM images of OBD spots would be more stable and reliable compared with conduction-AFM images [4].

CONCLUSION

We have employed SCM with nanometer-scale resolution to investigate OBD of thin oxide films. The results reveal that OBD is localized. After OBD, the property of the oxide film changes from insulation to conduction, resulting in lower *dC/dV* signals. Experimental results indicate that SCM can be widely used in observing and studying the OBD sites. SCM is also very potential in further investigating the detail OBD mechanism. For instance, SCM with scanning capacitance spectroscopy provide fruitful information on the breakdown behavior and on the reliability issue of the future ICs.

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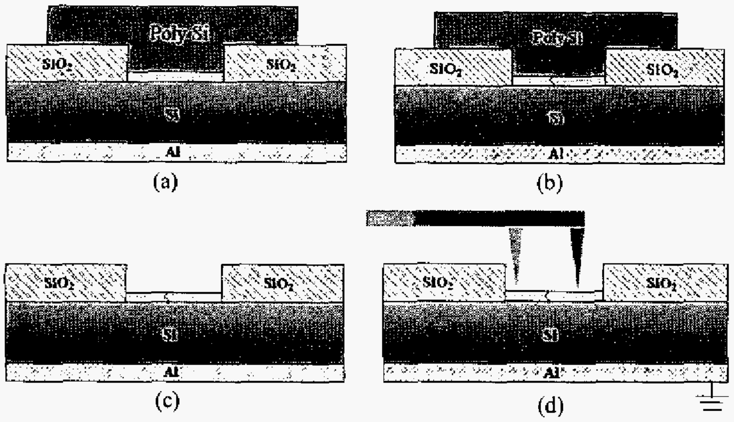

Fig. 1. (a) Schematic structure of the MOS capacitor fabricated in this study. (b) C-V measurement followed by OBD achieved by semiconductor parameter analyzer. (c) Poly-Si gate removal. (d) SCM measurements.

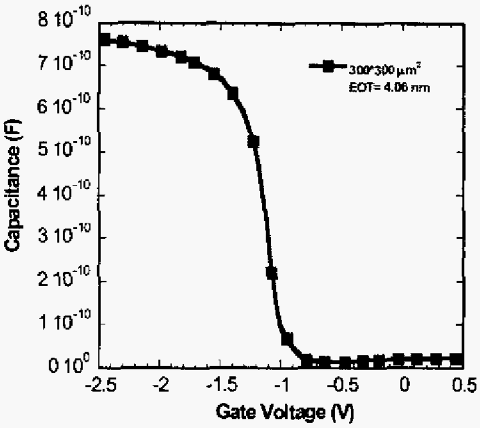

Fig. 2. High frequency (1MHz) capacitance versus gate voltage (C-V) characteristic swept from inversion to accumulation.

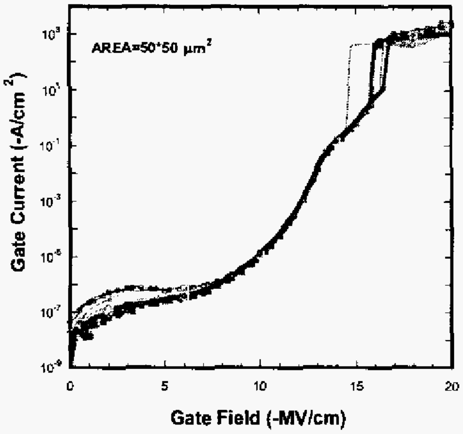

Fig. 3. Negative J-E characteristic of the thin oxide under $-V_g$ injection.

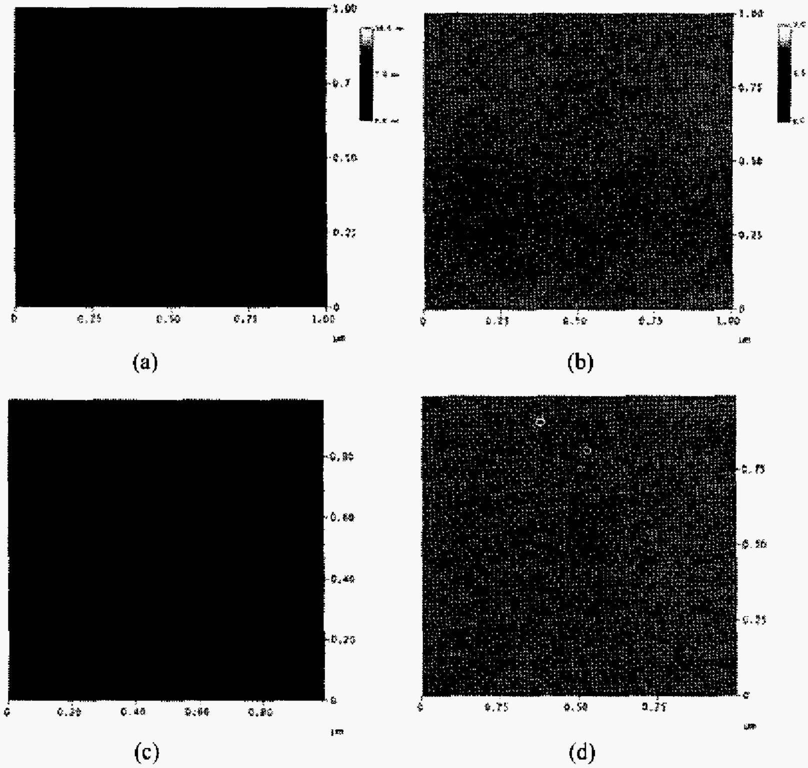

Fig. 4. (a) AFM image and (b) the corresponding SCM image of the oxide layer before OBD, (c) AFM image and (d) the corresponding SCM image of the oxide layer after OBD. The surface morphology of oxide is still uniform after OBD.

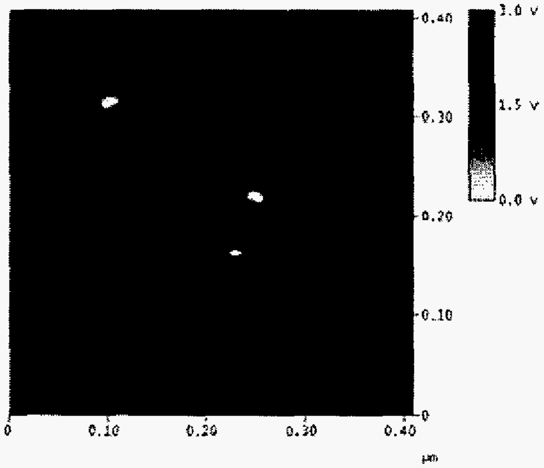

Fig. 5. Enlarged SCM image of the OBD spots in fig.4 (d).

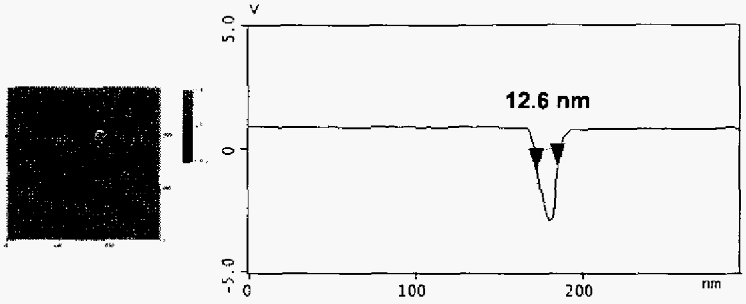

Fig. 6 Cross-section view of the SCM signal of an OBD spot.