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Measurement of Charge-up Voltage in Glow Discharge Using MNOS Capacitor

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Gate breakdown of MOS devices occurs due to plasma exposure in dry etching apparatus. The voltage applied to the gate electrode during dry etching is measured from the flat band voltage shift of MNOS capacitors exposed to plasma. For microwave plasma etching apparatus used in this experiment, the maximum applied voltage is about 15 V. This corresponds to the floating potential of the plasma. It is also determined that gate breakdown is caused by applied voltage, which is due to positive ion charge build-up on the gate electrode.

1. Introduction

Dry etching has been widely used for fine pattern delineation in VLSI manufacturing. In the etching process, devices fabricated on Si wafers are usually exposed to plasma directly. As a result, MOS device gate insulator breakdown due to plasma exposure during dry etching becomes a serious problem. This is because thinner SiO_2 film is used as a gate insulator for higher packing density VLSIs.[1),2)]

The breakdown is thought to be caused by charge build-up at MOS device gate electrodes. Upto the present, dry etching insulator breakdown has been observed only from the difference between breakdown frequency of plasma exposed MOS capacitors and that of unexposed capacitors. However, neither the gate electrode voltage nor the polarity of the stored charge on the gate electrode has been exactly measured.

This report presents a new method for investigating the gate insulator breakdown due to dry etching. Both the applied voltage to the gate insulator and the charge polarity have been measured from the flat band voltage shift of an MNOS capacitor fabricated on a Si wafer. Moreover, a model of gate breakdown for microwave plasma etching is proposed. It is clarified that breakdown is not caused by ion and electron bombardment damage, but is done by electrostatic stress induced by charge-up.

2. Experimentation

A microwave plasma etching apparatus was used to expose plasma to MOS or MNOS capacitors.[3),4)] The schematic diagram of the apparatus is shown in Fig. 1. The plasma was generated by 2.45 GHz microwave power introduced from the magnetron into the discharge volume through the waveguide. This

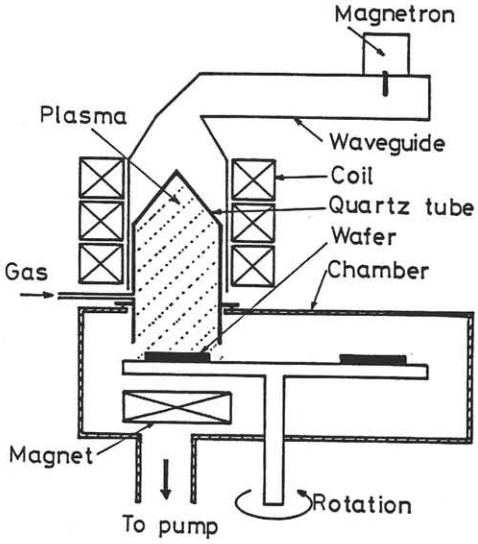

Fig. 1 Schematic diagram of microwave plasma etching equipment.

plasma was confined in and under the quartz tube by a mirror type magnetic field, as shown in the figure.

Etching is usually carried out using wafer table rotation. Consequently, the wafer goes in and out of the discharge volume. In this experiment, plasma exposure to the wafer was carried out without table rotation. Moreover, O_2 gas was used to generate plasma instead of CF_4 or SF_6 gas used for Si etching. This was done in order to prevent Si and its compounds from being etched off.

MOS capacitors exposed to plasma were fabricated on a p-type (100) Si wafer. The gate insulator was composed of thermally grown SiO_2 of 20 nm thickness. The gate electrode was phosphorous doped poly-Si of about 300nm thickness with an area of 1.0 mm^2 . In addition, a wet chemical process was used to avoid dry etching damage for poly-Si etching. Breakdown voltage measurements were performed by applying a ramp voltage to the poly-Si gate electrode. The breakdown voltage was defined as the voltage at a 10 nA leakage current.

Furthermore, MNOS capacitors were also fabricated on a p-type (100) Si wafer. The gate insulator consisted of 2 nm thick thermally grown SiO_2 and 50 nm thick CVD Si_3N_4. The gate electrode was Al having a 1.0 µm thickness with an area of 1.0 mm^2

High frequency (1.0 MHz) C-V characteristics of MNOS capacitors were measured to obtain the flat band voltage. This voltage was always initially set at nearly zero V , in order to measure the flat band voltage shift. This voltage shift was due to applying bias voltage at the gate electrode or to plasma exposure.

3 Results and Discussion

The breakdown frequency of MOS capacitors after plasma exposure is shown in Fig. 2. The plasma exposed area on the wafer surface is also shown in the figure. It should be noted that gate breakdown does not occur in the plasma exposed area, but it dose in the unexposed one. This result suggests that breakdown does not occur due to ion and electron bombardment to the gate electrode. In addition, another mechanism exsists to break down the gate insulator .

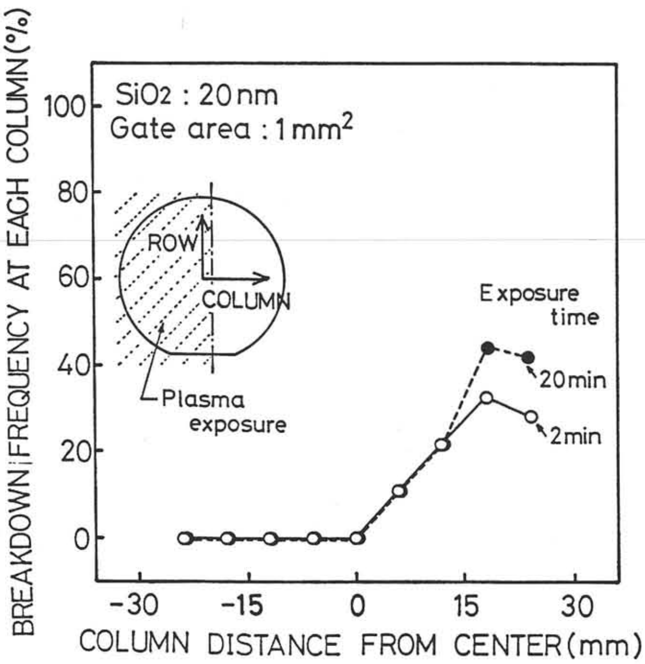

Fig. 2 Breakdown frequency of MOS capacitors fabricated on a wafer.

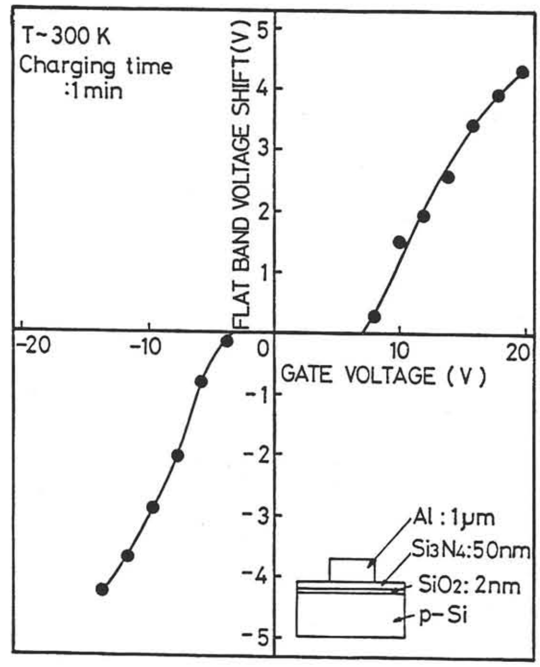

Fig. 3 Flat band voltage shift of MNOS capacitors as a function of gate voltage.

MNOS capacitors fabricated on a wafer were also exposed to plasma in this way in order to clarify the breakdown mechanism. The relationship between the voltage applied to the gate electrode for one minute and the MNOS capacitor flat band voltage shift used in the experiment is shown in Fig. 3. The value of the applied voltage and the polarity are determined from measuring the flat band voltage shift after plasma exposure. The flat band voltage shift as a function of charging period for several applied voltages is shown in Fig. 4. The flat band voltage shift for a constant applied voltage increases slightly with the charging period. Therefore, the dependence of flat band voltage shift on the plasma exposure period can be clarified. This clarification determines whether the voltage is applied to the gate electrode transiently or steadily.

The flat band voltage shift caused by plasma exposure is shown in Fig. 5. This shift is nearly zero in the plasma exposed area, whereas it is about 3 V in the unexposed area. From Fig. 3, the applied voltage to the MNOS capacitor gate electrode in the plasma exposed area is less than 7.0 V, and that in the unexposed area is about 15 V. Therefore, the MOS capacitor gate breakdown with thin gate oxide will occur in the unexposed wafer area when the plasma is exposed to a part of the wafer in the microwave plasma etching apparatus. This result is in good agreement with the breakdown frequency shown in Fig. 2. Moreover, the value of the applied voltage corresponds to the floating potential voltage of the microwave plasma generated under experimental conditions.

The flat band voltage shift was also measured for various exposure periods to clarify when the voltage due to plasma exposure was applied to the gate electrode. The flat band voltage shift dependence on exposure period is shown in Fig. 6. The flat band voltage of the MNOS capacitor located outside of the plasma increased with exposure time. Therefore, the bias voltage at the gate electrode was applied steadily during plasma exposure.

From these results, the gate insulator breakdown mechanism due to microwave plasma exposure in the apparatus is now described. A model of the charge-up mechanism is schematically shown in Fig. 7. When the capacitor is in the plasma exposed area, both gate electrode and substrate potentials are almost the same floating

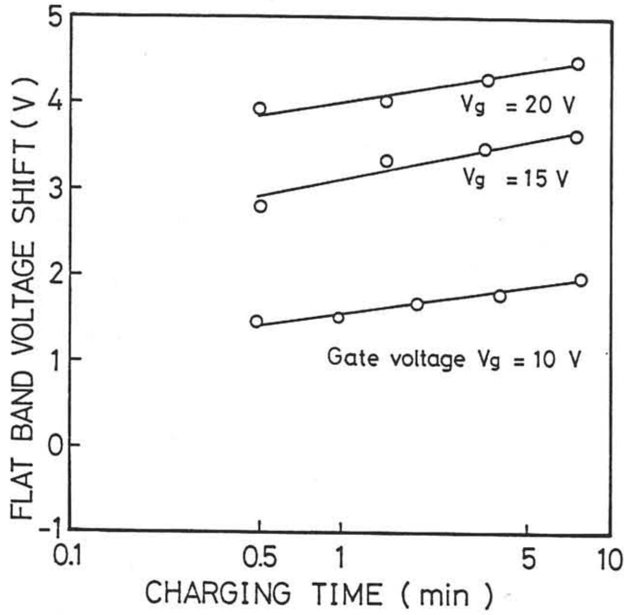

Fig. 4 Flat band voltage shift of MNOS capacitors as a function of charging time.

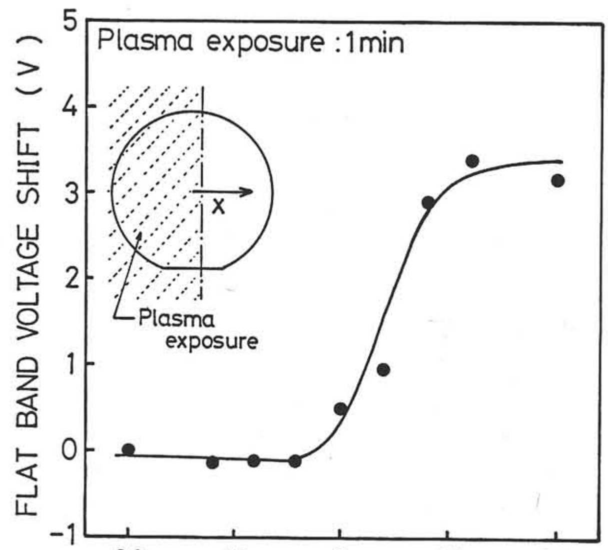

Fig. 5 Flat band voltage shift of MNOS capacitors exposed to microwave plasma.

potential. This floating potential is negative with respect to the plasma potential. Therefore, the applied voltage across the gate insulator is zero.

On the other hand, only the substrate is equal to the floating potential, whereas the gate electrode is nearly equal to the plasma potential. This situation occurs when the capacitors are outside of the plasma exposed area. Positive charge ions are stored at gate electrodes in order to shield the potential of the substrate. Negative charge electrons cannot reach gate electrodes outside of the plasma, because the electrons are confined in the plasma by a magnetic field. In addition, the positive ions are stored until the electrodes' potential nearly equals the plasma potential. Therefore, the applied voltage across the gate insulator of capacitors outside of the plasma becomes nearly equal to the floating potential.

4. Conclusion

The MNOS capacitor was successfully used to measure the applied voltage to the gate insulator during plasma exposure. The value of the applied voltage was precisely obtained for the first time. It was clarified that the gate breakdown was caused by the voltage applied to the gate insulator.

For microwave plasma etching apparatus, a model of the charge-up mechanism was proposed, which successfully explained the experimental results. The model showed that the value of the applied voltage does not exceed the floating potential of the plasma. This method of voltage measurement utilizing MNOS capacitors can also be used to examine gate breakdown due to plasma ashing, reactive ion etching, and other plasma processes.

Acknowledgments

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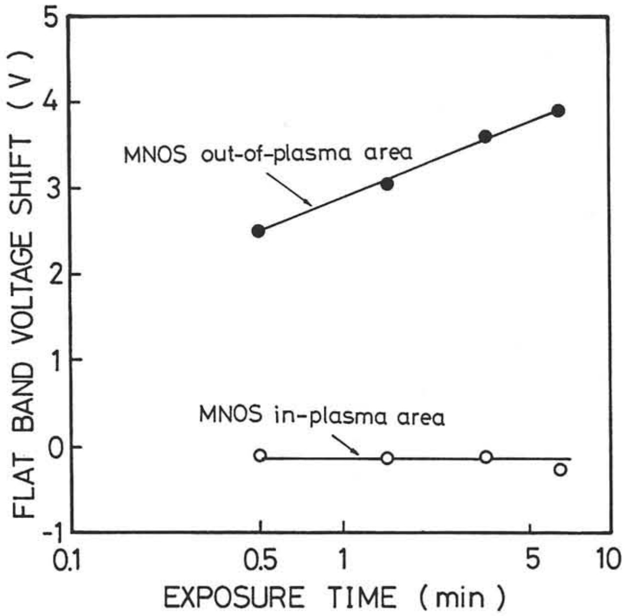

Fig. 6 Flat band voltage shift of MNOS capacitors exposed to microwave plasma as a function of exposure time.

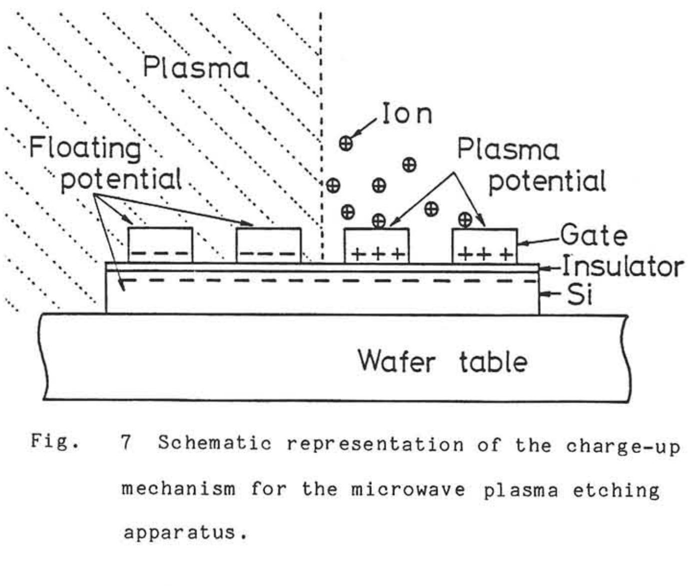

Fig. 7 Schematic representation of the charge-up mechanism for the microwave plasma etching apparatus.