CHARACTERIZATION OF RIE INDUCED RADIATION DAMAGE IN SILICON USING NONDESTRUCTIVE TRANSVERSE ACOUSTOELECTRIC VOLTAGE MEASUREMENTS

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ABSTRACT

Reactive ion etching (RIE) is extensively used as a high resolution pattern transfer process for fabrication of silicon devices with increasing importance in VLSI technology. In this work, radiation damage in p-type boron doped, silicon wafers are investigated using nondestructive SAW technique. The transverse acoustoelectric voltage (TAV) is monitored across the silicon sample which is placed in proximity of a $LiNbO_3$ delay line. TAV is developed due to the nonlinear interaction between the electric field accompanying SAW and the free carriers near the silicon surface. TAV versus bias voltage (applied across the semiconductor) is obtained to measure the flat band voltage (V_{FB}) shift. The flat band voltage shift of the etched wafer is a measure of the amount of surface charge introduced into the semiconductor surface by ion bombardment. Wafers are etched in C_4F_8 and C_2H_2 with 2 watt/cm^2 input power. Ion energy is determined by the self biased dc voltage developed on the cathode. It is shown that magnetron RF discharge introduces an order of magnitude less damage than non-magnetron discharge.

INTRODUCTION

In modern silicon fabrication processes, precise pattern transfer techniques are playing a crucial role. Pattern transfer is the reproduction of features defined in photoresist to underlying films by chemical etching, and can be achieved with high fidelity using dry etching techniques. These etching methods typically involve the immersion of material to be etched in RF-excited plasma of various gases (plasma etching, reactive ion etching) or in ion or atom beams (ion beam milling, reactive ion beam etching). While the advantages of dry etching over wet etching in silicon device manufacturing are clear, it is important to determine whether there are any side effects accompanying the etching process. Particularly, it is important to study the amount of damage created at the silicon surface where it is crucial to the device operation.

In reactive ion etching, silicon substrates are subject to the bombardment of charged and neutral species with typical energies of a few hundred electron volts. Previously published papers report RIE induced radiation damage in silicon [1-6]. Dry etching alters oxide charge, interface state density and minority carrier lifetime. These effects have been measured by MOS devices using the capacitance-voltage (C-V) and photocurrent-voltage (I-V) techniques. Schottky barrier modification by RIE process was demonstrated and a model was proposed to explain the damage induced at the silicon surface.

In this paper, the Surface Acoustic Wave (SAW) technique is used as a nondestructive alternative to C-V and I-V measurements to determine radiation damage on silicon surfaces. SAW technique does not require MOS or Schottky diode fabrication and can be performed nondestructively on the silicon surface before and after removing the oxide by dry etching process.

EXPERIMENTAL PROCEDURE

MRC Magnetron Ion Etching (MIE)-710 System has been used for this work. Silicon p-type, 6-9 ohm-cm wafers have been cleaned and loaded onto the MRC Band Magnetron Cathode. The magnetic field is generated by permanent magnet rods within the cathode body and soft iron pole pieces (covered by aluminum sheets to prevent pole pieces sputtering.) A second symmetric set of magnets and pole pieces generates a quadrupole field which has a uniform magnetic field region parallel to the cathode surface. The effective cathode area is 880 cm^2 inside a chamber of 20 inches in diameter by 8 inches. Power input, cathode dc bias, and pressure were monitored during the etch process. Silicon wafers were exposed to reactive ion etching process of silicon dioxide for one minute. Operating pressure was 5 mTorr, gas mixture C_4F_8 with 12% of C_2H_2. The self dc bias across the sheath increases when the magnetic field intensity is reduced, hence ion energy is controlled by magnetic field to obtain constant power input. The wafers had been annealed after etching at 450°C in forming gas for 10 minutes. Table I summarizes the value of different parameters used in reactive ion etching of silicon wafers.

TABLE I

SUMMARY OF RADIATION DAMAGE EXPERIMENTS

Run #	Magnetic Field Gauss	DC Bias V	Power W/cm^2	Pressure mTorr	Gas
62-164	100	265	2.0	5	C_4F_8/12% C_2H_2
62-165	200	157	2.0	5	C_4F_8/12%
63-165	0	1570	2.0	5	C_4F_8/12% C_2H_2

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RADIATION DAMAGE EVALUATION TECHNIQUE

The experimental arrangement is shown in Fig. 1. The delay line is a Y-cut Z-propagating $LiNbO_3$ with two aluminum interdigital transducers fabricated on the surface (Fig. 1(a)). The semiconductor is placed above the $LiNbO_3$ with the surface under study facing the $LiNbO_3$. The TAV is a dc voltage across the semiconductor, and to monitor this signal through the insulators such as the oxides at the semiconductor surface and the $LiNbO_3$, the RF signal and thus the probing electric field are pulsed [7]. As a result, the TAV can be detected as a transient through the capacitive coupling. The SAW technique is improved by evaporating a thin aluminum film (≃ 1000 A°) on the $LiNbO_3$ surface as shown in Fig. 1(a). This structure provides a ground path for the TAV signal which does not pass through the $LiNbO_3$ substrate [8]. At the center of the aluminum film a window is made to provide the interaction region. The mechanical surface wave produced by the interdigital transducers is accompanied by the probing electric field only in the region not covered by the aluminum. Under the aluminum covered area the electric field tends to zero while the mechanical wave continues to propogate. Once the mechanical wave reaches the interaction window the probing electric field is regenerated. The semiconductor under test is placed above the interaction region where the probing electric field penetrates inside the semiconductor and produces the TAV signal (Fig. 1(b)).

To change the surface potential, a dc voltage is applied across a contact to the semiconductor back surface and the ground path beneath the surface under study. The nature of these contacts are important in order to perform a nondestructive measurement. The back contact is provided by placing an Aℓ plate on the back surface without any evaporation. The contact to the surface under study (device side) is simply provided by placing the Si wafer on the Aℓ-coated $LiNbO_3$ as shown in Fig. 1(b), where there is no processing involved. If placing the wafer on the piezoelectric substrate is not desirable, an air gap can be maintained between the surface under study and the substrate by proper mechanical arrangement resulting in contactless measurement. The range of the external dc voltage needed to change the surface potential (to go from accumulation to inversion) is a few volts which is about the same as C-V measurements. In the following experiments, the interdigital transducer is excited by 110 MHz RF pulse with 4-15 msec period and the period of the TAV signal is the same as the rf pulse. The first harmonic of the TAV waveform is directly proportional to the TAV amplitude and is monitored by the lock in amplifier. The reference input is provided by the pulse generator which also generates the RF pulse through the mixer. To obtain the TAV-V curves, the amplitude of the TAV signal is recorded as a function of the applied dc voltage measured directly across the semiconductor, as the external voltage source is scanned over the desired range. The operation is simple, nondestructive, and there is no need to fabricate the MOS structure. The complete block diagram of the electronic setup is shown in Fig. 1(c).

RESULTS AND DISCUSSION

The TAV-V curve for p-type silicon wafers, which had been exposed to RIE process of SiO_2 etching, is shown in Figs. 2-4. The TAV-V curve for a controlled wafer is also shown. In order to obtain quantitative information from the TAV-V curve, the experimental curves are compared to the theoretical curve [8]. The TAV at flatband is determined from the theoretical ratio of TAV_{FB}/TAV_{min}, this determines the applied dc voltage at flatband condition. The shift in flatband voltage between the control and the damaged wafer determine the amount of surface charge introduced into the silicon wafer by ion bombardment. Table II summarizes the applied dc voltage shift at flatband condition. All wafers show negative shift in flatband voltage due to positive charge at the silicon surface.

TABLE II

Run #	Magnetic Field [Gauss]	DC Bias [V]	Applied DC Bias Shift at Flatband [V]
62-164	200	157	0.2
62-165	100	265	0.05
63-165	0	1570	0.65

This clearly shows that ion energy plays a major role in the amount of charge introduced into the substrate during the RIE process. The use of magnetron RF discharge, to reduce ion energy, results in very low damage. It is still to be determined why the damage for 200 gauss is reduced by a factor of three, whereas for 100 gauss it is reduced by a factor of ten as compared to non-magnetron discharge process.

CONCLUSION

Surface damage to silicon surface, after the oxide etching by magnetron RIE process, was measured using surface acoustic waves. The extent of damage is measured by the shift in the applied dc bias corresponding to flatband condition in TAV curves for damaged and controlled wafer. It is shown that magnetron RF discharge causes an order of magnitude less positive charge at the silicon surface as compared to non-magnetron discharge. This is due to the high flux low energy ion bombardment of the silicon wafer in a magnetron RF discharge.

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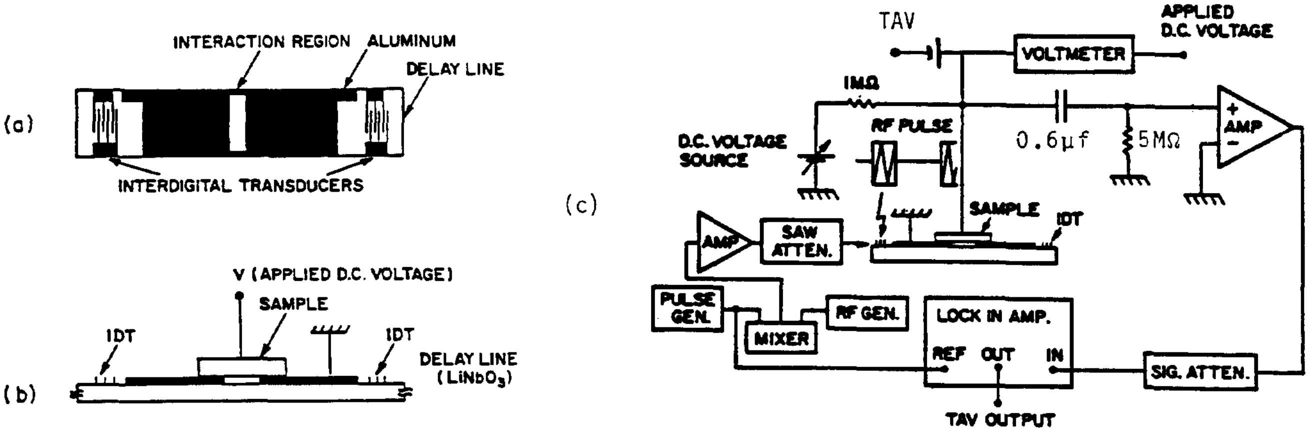

Fig. 1. TAV vs. applied dc bias experimental apparatus

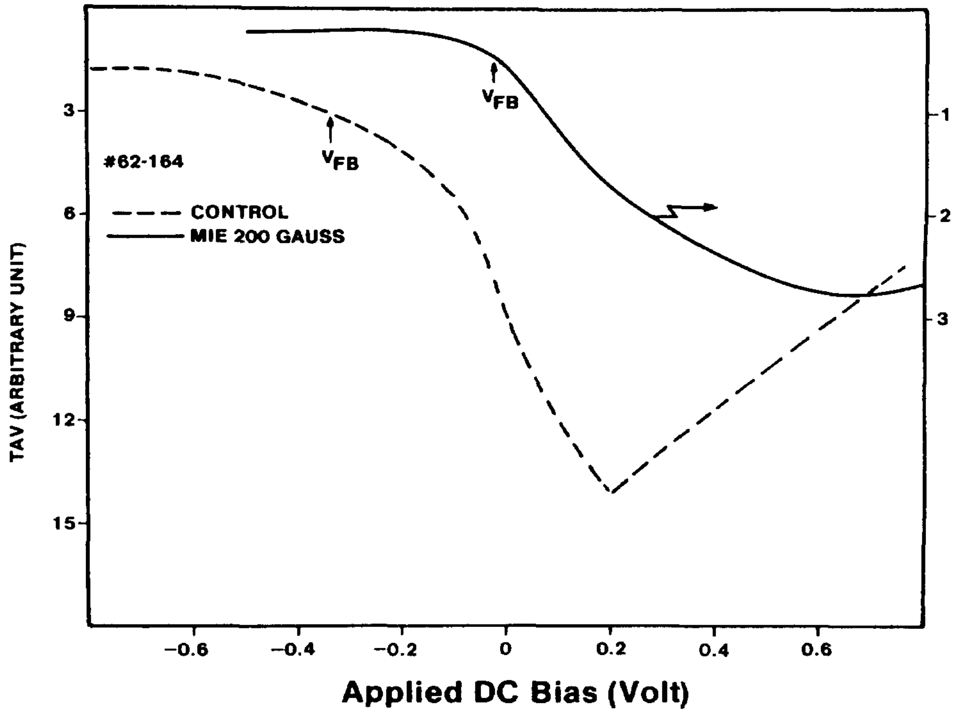

Fig. 2. TAV-V curve for control and damaged p-type silicon. Magnetic field 200 gauss.

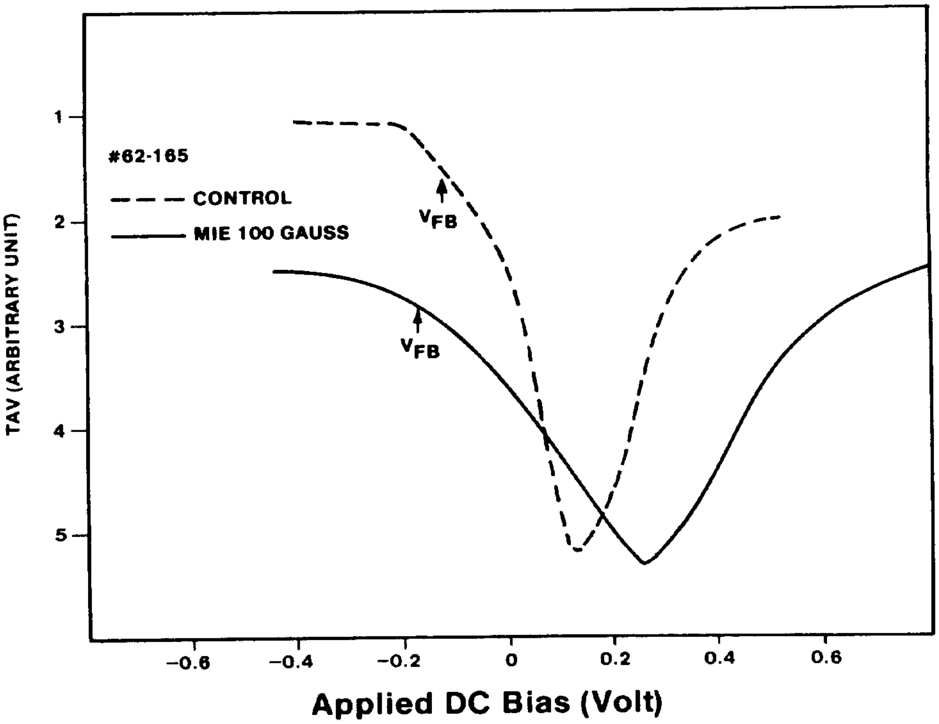

Fig. 3. TAV-V curve for control and damaged p-type silicon. Magnetic field 100 gauss.

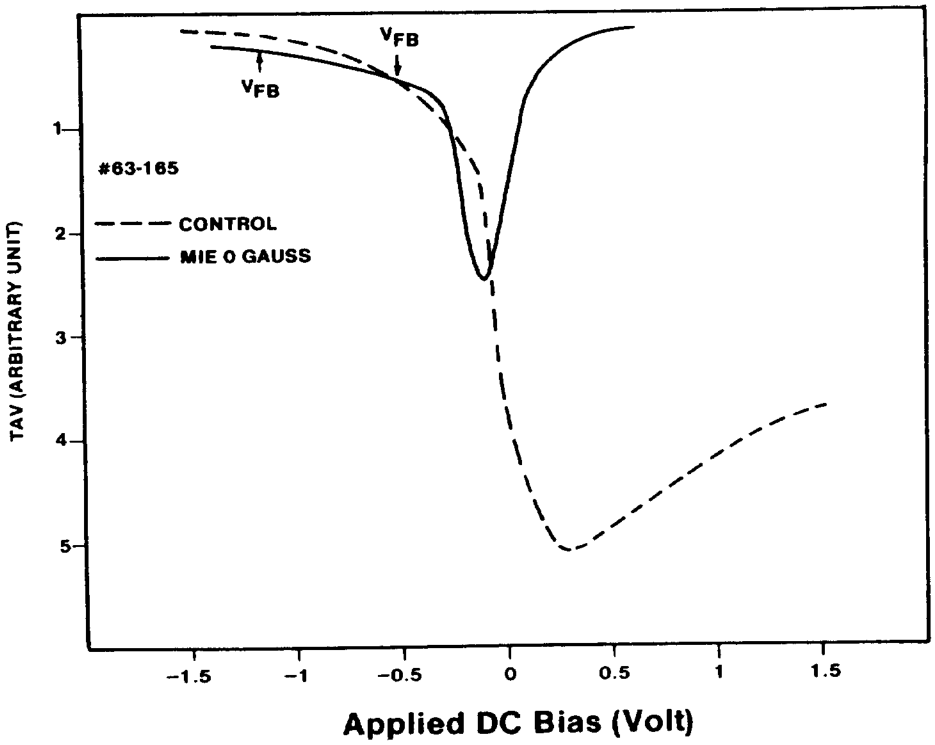

Fig. 4. TAV-V curve for control and damage p-type silicon. No magnetic field.