EVALUATION OF PLASMA DAMAGE TO THIN GATE OXIDES

Patricia A. Ostling
5th Year Microelectronic Engineering Student
Rochester Institute of Technology

ABSTRACT

Capacitance-Voltage (C-V) and Conductance-Voltage (G-V) measurements were performed to characterize field induced charges in thin (300A) oxides subjected to a RF generated oxygen plasma used to remove photoresist. Results based on C-V curves indicate a -4.6V threshold voltage shift for capacitors exposed to the RF plasma as compared to capacitors without plasma processing. Results based on tunnel current measurements were inconclusive.

INTRODUCTION

Recent industry trends calling for the fabrication of high density MOS devices have concurrently resulted in the use of thinner gate oxides. These thinner oxides are more susceptible to damage due to the high electric field stressing that may occur in subsequent plasma processing steps.[1-4]

Oxide traps are present in the SiO2 bulk as well as the Si-SiO2 interface, and are generally associated with defects in the film such as impurities and broken bonds.[4,5] Though usually uncharged, they may become charged if exposed to a large electric field, as is the case with a plasma. These traps are thought to be generation-recombination sites, and positive charge generation at the site of these traps has been attributed to impact ionization that occurs during high field stressing. Charge trapping in SiO2 is one of the principal causes of device degradation and instability in MOSFET's.

The conduction mechanism in thermally grown SiO2 has been found to take place via a Fowler-Nordheim (F-N) tunnelling mechanism.[6,7] The energy difference between the Fermi level and the conduction band in the oxide presents a barrier for electrons that enter the oxide from the metal gate. When a sufficient bias is applied to the gate, electrons tunnel through this barrier, thus a current flow is evident. Figure 1 illustrates this phenomenon.

Trapped positive charges in the oxide are thought to reduce the tunneling barrier thereby increasing the F-N current flow.[7] The mechanism here is thought to be due to the enhancement of the electric field from the positive charges.[8] Figure 2 shows the effect that positively charged traps in the oxide have on the barrier described in Figure 1.

Figure 1: F-N tunnel mechanism through SiO2 insulator

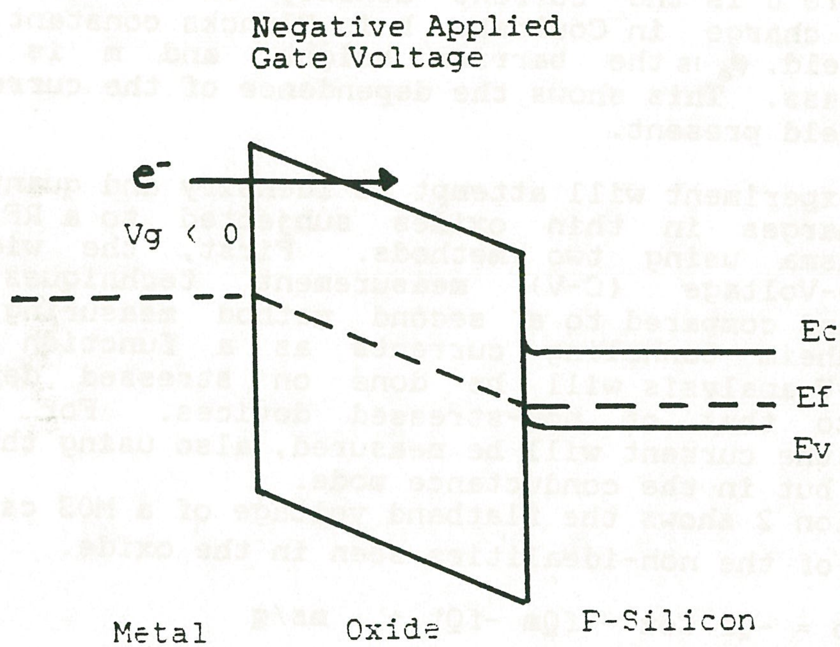
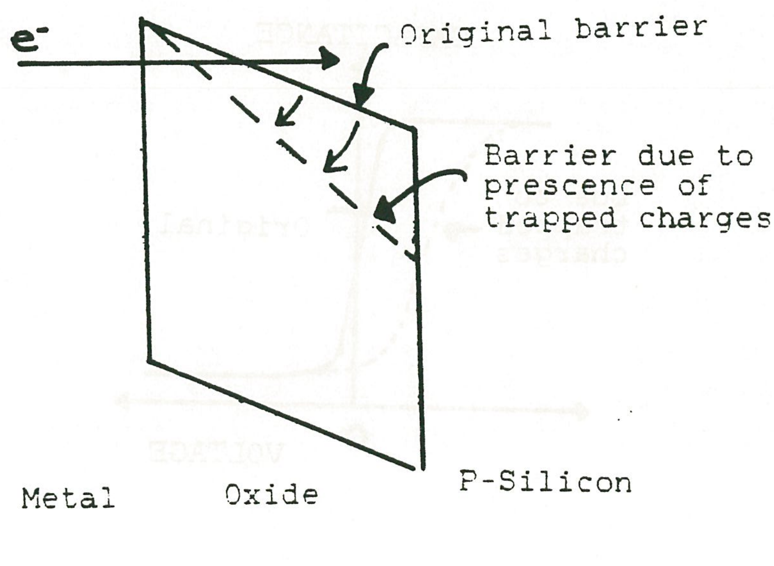


Figure 2: The effect of trapped charges on oxide barrier height.



Fowler-Nordheim current may be represented by Equation 1 for the ideal case.

$$J = (q^3E^2/\ 8\pi h\phi_B)\ \exp[\ -4(2m)^{1/2}\ \phi_B^{3/2}/3hqE] \qquad (1)$$

where J is the current density in A/cm2, q is the electronic charge in Coulombs, h is Plancks constant, E is the electric field, ϕ_B is the barrier height, and m is the free electrom mass. This shows the dependence of the current on the electric field present.

This experiment will attempt to identify and quantify field induced charges in thin oxides subjected to a RF generated oxygen plasma using two methods. First, the widely used Capacitance-Voltage (C-V) measurement techniques will be employed, and compared to a second method measuring enhanced Fowler-Nordheim tunneling currents as a function of plasma damage. C-V analysis will be done on stressed devices and compared to that of non-stressed devices. For these same conditions,the current will be measured, also using the C-V test apparatus, but in the conductance mode.

Equation 2 shows the flatband voltage of a MOS capacitor is a function of the non-idealities seen in the oxide.

$$Vfb = -Qf/Cox - fQm - fQt + \ ms/q \qquad (2)$$

where Qf, Qm, Qt are positive charges in the oxide as a function of fixed, mobile, and trapped charges. If trapped charges are present, a negative shift in the flatband voltage would be experienced. Figure 3 shows representative curves which illustrate the flatband voltage shifts that might be expected due to the trapped charges in the oxide for a p-type device.

Figure 3: Representative C-V curves illustrating flatband shifts due to trapped oxide charges.

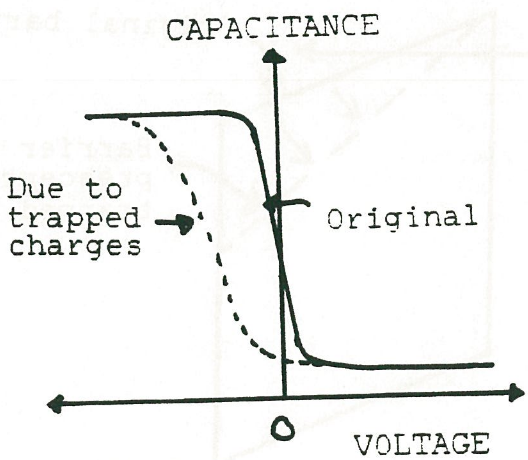
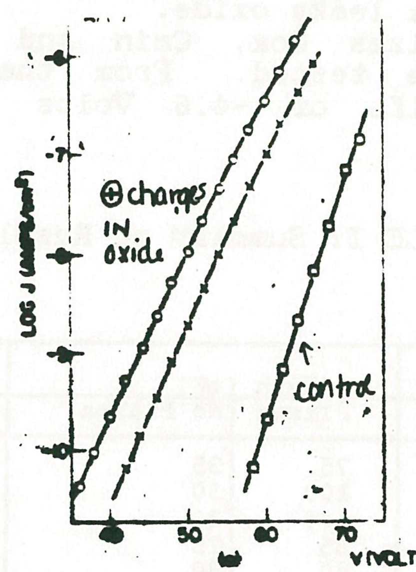


Figure 4 is a plot of current density vs.applied gate voltage, and shows the shift that may occur if positive charges are increased in the oxide.[9] It is expected that I-V curves for devices processed with and without plasma would resemble these curves.

Figure 4: Current density vs.applied gate voltage [9]



EXPERIMENT

P-type, 14 -cm, 3" wafers were cleaned using standard RCA techniques. A thermal oxide was grown in a dry oxygen ambient at 1000C, with a resultant thickness of 320 Angstroms. This was followed by a nitrogen anneal at the same temperature for 20 minutes. The anneal step was done to minimize the amount of fixed surface states in the oxide. The wafers were split; one half was coated with photoresist and ashed for 20 minutes in a Plasmaline RF generated (250W) oxygen plasma. The control group did not see a plasma at any time. All the wafers were brought together; wafers were again cleaned, and aluminum was evaporated on the front side and the capacitor contacts were patterned. Following the patterning, aluminum was evaporated on the backside to form an ohmic contact. A 450C sinter in forming gas (H2N2) was done to anneal the aluminum.

Testing was done on a Micromanipulator Model 410 high frequency C-V apparatus to determine flatband voltage shifts due to plasma processing. Using the same C-V test equipment, conductance was measured as a function of applied gate voltage.

RESULTS/DISCUSSION

Figure 5 is a representative C-V plot for a device that was exposed to a plasma (curve A) and compared to one that did not see a plasma (curve B). As expected, significant flatband voltage shifts have occurred in the devices that saw a plasma. The more gradual slope of curve A indicates the prescence of interface states as well. Curve B shows a region in Cox which may be indicative of a leaky oxide.

Table I summarizes Cox, Cmin and Vt data for seven capacitors that were tested. From these values, an average flatband voltage shift of -4.6 Volts due to plasma was calculated.

TABLE I: Summary of Results

Cox (pF)		Cmin (pF)		Vt (Volts)		
Plasma	No Plasma	Plasma	No Plasma	Plasma	No Plasma	
485	475	75	35	-4.5	0.2	
555	494	100	30	-4.1	0.4	
640	425	100	30	-4.0	0.2	
585	505	85	25	-3.7	0.3	
610	450	80	30	-4.6	0.4	
510	450	80	30	-5.2	0.3	
515	475	45	37	-3.8	0.3	
557	468	81	31	-4.3	0.3	Mean
57.2	28	18.7	3.9	0.53	0.08	Std. Deviation

The theoretical threshold voltage as generated on the RIT CVPLOT program is approximately -0.3 Volts for a metal-semiconductor work function difference of -0.9 Volts, and Qf = 7.0E10. It should be noted that the threshold voltage for the control devices that did not see a plasma was much closer to the theoretical value than those that did see a plasma. This has been unprecedented at RIT for p-type MOS capacitors.

Cox and Cmin were both higher in the plasma group than the no plasma group. Different oxide thicknesses might cause this phenomenon but the difference in the two wafers was only 10 Angstoms and would not account for the large difference.

The variation across the wafer was also worse for the plasma group for Cox, Cmin and Vt.

Figures 6 is a plot of current versus applied gate voltage. The magnitude of the current is much larger than was expected, and the curve is linear as well. This supports the hypothesis that the oxide is leaky, thus we are simply measuring a resistance.

Figure 5: Capacitance Voltage Curves with and without Plasma

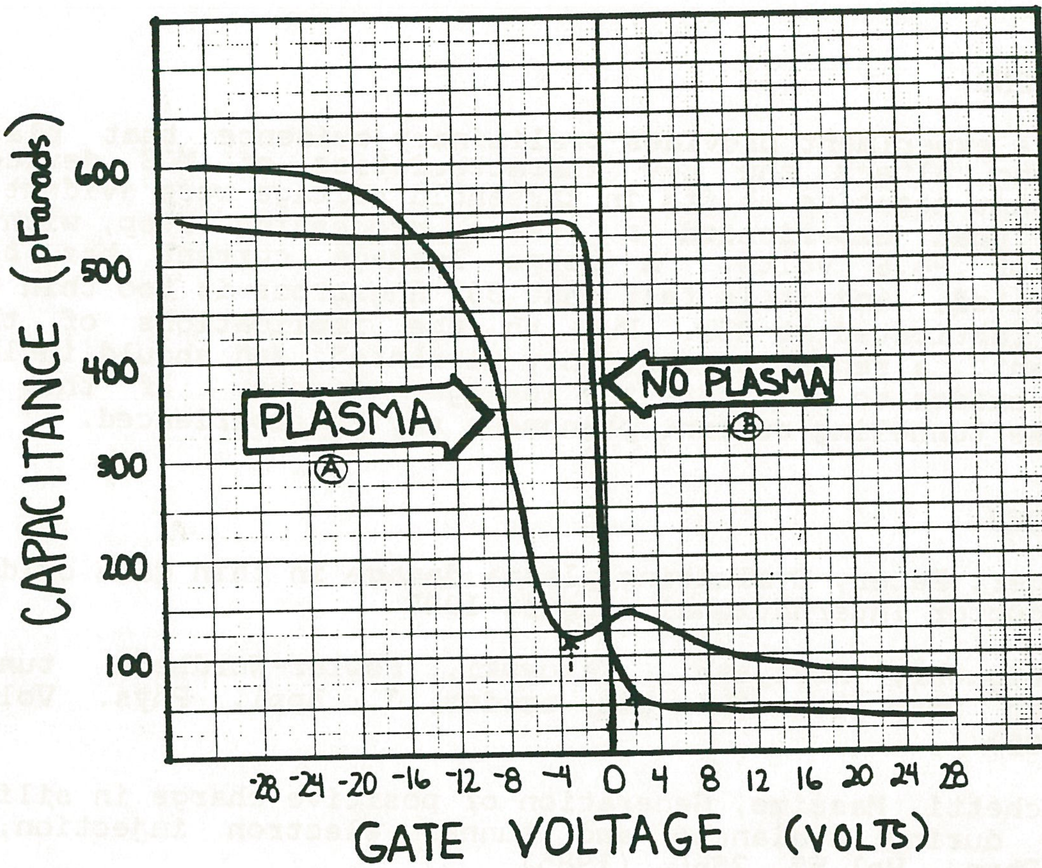
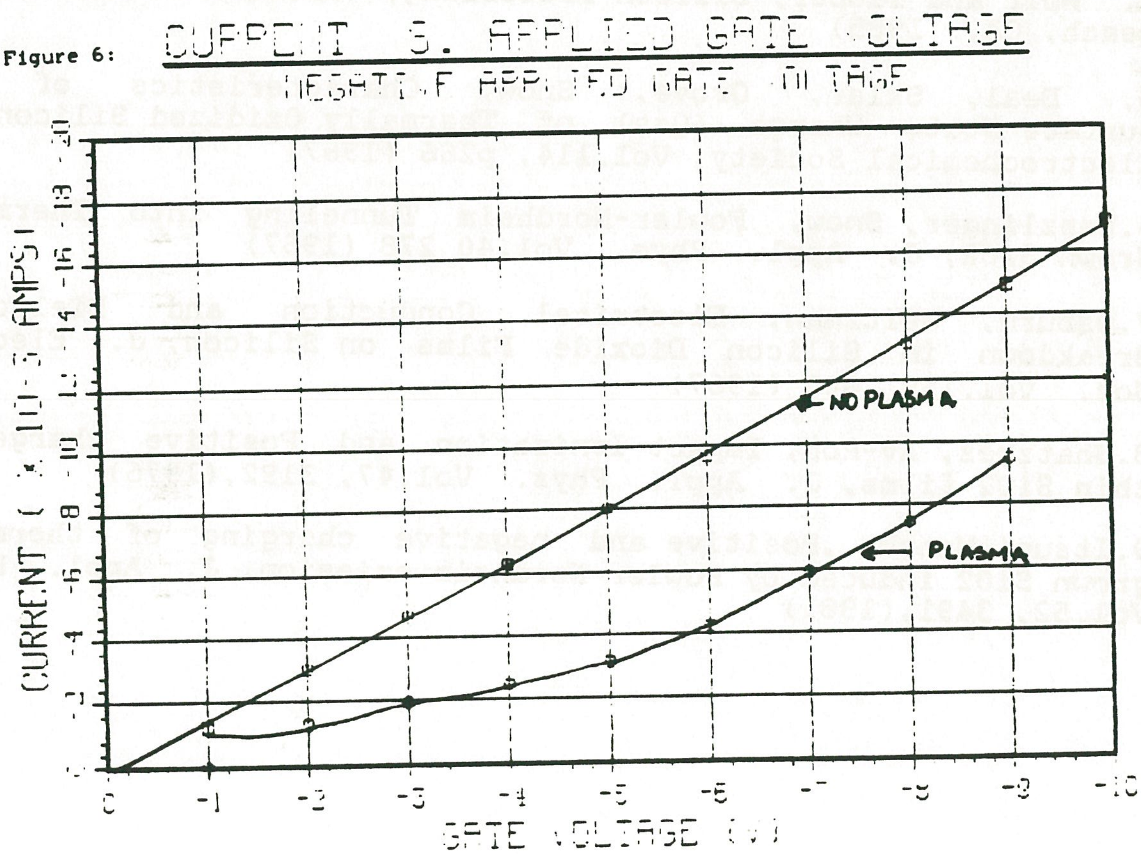


Figure 6:



CONCLUSIONS

This experiment provides preliminary evidence that plasma processing alters the C-V characteristics of MOS devices. Significant negative shifts in threshold voltage were evident in devices that experienced a plasma processing step, with an average of -4.6 Volts. A large leakage current has been demonstrated, and it is felt that 300 Angstroms is too thin for devices fabricated at RIT. Due to the implications of this experiment, a repeat is certainly warranted, and should include thicker oxides to eliminate the leakage effects. If this is done, the tunneling current phenomena may be experienced.

REFERENCES:

1. Singer, Peter, Evaluating plasma damage in thin gate oxides, Semiconductor International, August 1987

2. Horiguchi, Koyayashi, Kazuyuki, Fowler-Nordheim tunnel injection into ultra-thin gate oxides, J. Appl. Phys. Vol.58 387 (1985)

3. Fischetti, Massimo, Generation of positive charge in silicon dioxide during avalanche and tunnel electron injection, J. Appl. Phys. Vol.57, 2860, (1985)

4. Wolf and Tauber, Silicon Processing, (Lattice Press, Sunset Beach, CA. 1985)

5. Deal, Sklar, Grove, Snow, Characteristics of the Surface-State Charge (Qss) of Thermally Oxidized Silicon, J. Electrochemical Society, Vol.114, p266 (1967)

6. Lenzlinger, Snow, Fowler-Nordheim Tunneling into Thermally Grown SiO2, J. Appl. Phys. Vol.40 278 (1967)

7. Osburn, Weitzman, Electrical Conduction and Dielectric Breakdown in Silicon Dioxide Films on Silicon, J. Elechem. Soc. Vol.119 ,603 (1967)

8. Shatzkes, Av-Ron, Impact Ionization and Positive charge in thin SiO2 films, J. Appl. Phys. Vol.47, 3192,(1976)

9. Itsumi, Manabu ,Positive and negative charging of thermally grown SiO2 induced by Fowler-Nordheim emission, J. Appl. Phys. Vol.52, 3491,(1981)