TIME DEPENDENCE OF HOT ELECTRON INDUCED SURFACE STATES

Joseph P. Magliocco
5th Year Microelectronic Engineering Student
Rochester Institute of Technology

ABSTRACT

Hot electron injection was investigated using the HP 4145B SPA to induce Fowler- Nordheim tunneling. High frequency and quasi-static capacitance-voltage (C-V) measurements were taken on p-substrate MOS capacitors in order to generate the distribution of surface states throughout the band gap. The results proved inconclusive with no deformation of the low frequency C-V technique being observed.

INTRODUCTION

The density of interfacial traps (also called surface states or interface states) throughout the the band gap of a metal/SiO2/Si (MOS) capacitor can be modulated by hot electron injection through the thin gate oxide. It has been shown [1] that the distribution of surface states, created in the above manner, will vary as a function of the time elapsed since the injection.

Ideally in metal/oxide/semiconductor (MOS) structures the conductance of the Silicon Dioxide (SiO2) is considered to be negligible until the voltage across the oxide is greater than its dielectric strength. In this circumstance the conductance dramatically increases and the oxide loses its insulating property. In real MOS structure, however,current flow is possible before breakdown under conditions of heightened electric field or temperature. This is possible due to quantum theory which allows for a finite probability of finding a particle outside of the classically forbidden potential well. This probability increases monotonically with increased energy. When the probability is high, ie when a particle has enough energy, it is possible for it to travel between potential wells in the lattice, as is shown in Figure 1. This process is called tunneling. [3]

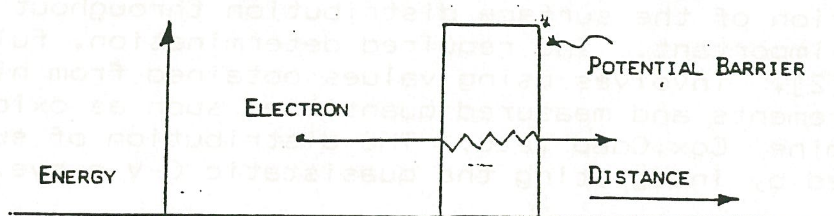

Figure 1 Electron Tunneling

In a metal gate MOS capacitor the induced tunneling involves electrons moving through the potential barrier between the metal fermi energy and the insulator conducting band. This process, as stated above, requires the electrons to be at energies quite larger than thermal equilibrium hence the term "Hot" electrons. The high energy electrons passing through the oxide have been shown [4],[5],[6] to effect the density of surface states at the oxide-semiconductor interface. Surface states are defined as allowed energy states in which electrons are localized (trapped) in the vicinity of a materials surface. These states introduce energy levels throughout the forbidden band gap, as shown in Figure 2. The interaction of a state with an electron results in the state becoming charged and so affecting the charge distribution in the device and, thereby, device performance. The effect upon the charge distribution is a function of the gate bias.

Surface states are, to a first approximation, filled when located below the fermi energy and the empty when above it. The gate bias serves to modulate the position of the fermi energy throughout the band gap and hence also the status of the surface states. This is illustrated in Figure 3. A further complication is that the interfacial states have different charge properties depending upon their location in the band gap. Traps with energies above mid gap are acceptor like - negatively charge when filled, neutral when empty. Traps with energies below midgap are donor like - neutral when filled, positively charge when empty.

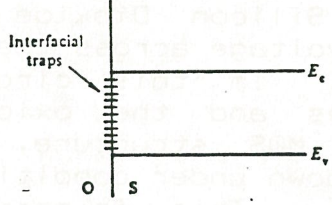

Figure 2 Interfacial Traps in the Band Gap. From Ref.[3]

The dependence of device performance on the internal charge distribution and its dependence, in turn, on the density and location in the band gap of surface states, makes an accurate determination of the surface distribution throughout the band gap extremely important. The required determination, fully described in ref [2], involves using values obtained from high frequency C-V measurements and measured quantities such as oxide thickness to determine Cox, Cdep, etc. The distribution of surface states is obtained by integrating the quasistatic C-V curve.

Figure 4 shows expected low frequency C-V curves prior to, immediately after, and 32 hours after hot electron injection. The change in surface state distribution after injection manifests itself as a deformation of the quasi-static C-V curve.

As shown, the distribution of surface states changes as a function of time after injection.

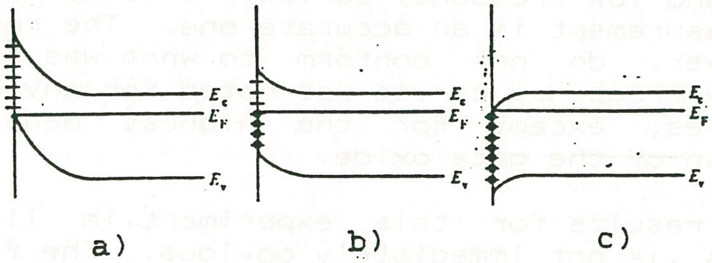

Figure 3 Trap Filling As a Function of Bias
a) Inversion b) Depletion c) Accumulation
From Ref. [3]

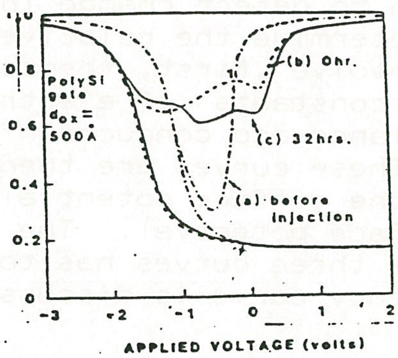

Figure 4 Expected Results. From Ref. [1]

This project was an initial attempt to observe the effects of Hot Electron injection to the surface state distribution of P-substrate MOS capacitors. The Hot carriers will be forced using a constant current source and the effects determined via the high and low frequency capacitance-voltage technique.

EXPERIMENTAL

The MOS capacitors used in this experiment were p-type with an acceptor doping of 6.2E14 cm3, and oxide thickness of 900A, and an area of 10.3E-3 cm2. Fowler-Nordheim tunnel injection was produced using an HP4145B Semiconductor parameter analyzer in constant current mode. The current densities forced ranged from 6.0 E-6 A/cm2 to 1.7E-4 A/cm2. A positive gate bias was used. Since the injection mechanism occurs from the substrate to oxide, the device was illuminated to insure a sufficient supply of the minority electrons. Both high frequency and quasi-static C-V measurements were made immediately prior to and after injection,as well as, at appropriate intervals thereafter.

RESULTS/DISCUSSION

The high frequency and quasistatic CV measurements taken just prior to injection are presented in Figure 5 and 6 respectively. Note the similarity between Cmin and Cmax values for the high and low frequency curves. This would suggest the low frequency measurement is an accurate one. The results after injection, however, do not conform to what was expected. No change in the low frequency curves was noted for any of the input current densities, except for the highest densities which produced breakdown of the gate oxide.

The lack of results for this experiment,in light of the published results ,is not immediately obvious. The first step in attempting to evaluate this problem would be to investigate the low frequency C-V technique used. According to reference 2,in order to obtain the true low frequency curve,it is necessary that during the measurement the structure, remain in thermal equilibrium. When this is the case,the measured capacitance contains the total response of the interface states, ie the system is sensitive enough to detect change in surface density. The method proposed to determine the relative sensitivity of the low frequency technique involve ,first, theoretically determining and plotting the time constants of electron exchange between surface states and the valance and conduction bands as a function of surface potential. These curves are then compared to a plot of the rate of change of the surface potential with respect to time as a function of surface potential. The criterion which the relationship between these three curves has to satisfy to result in a "true" low frequency curve is discussed in detail in the reference.

CONCLUSION

Hot electron injection of P type MOS capacitors produced no measurable change in surface state distribution. This was not as expected or predicted by references [1],[4],[5], and [6]. It is recommended that the low frequency C-V technique used to determine the surface state distribution be investigated to determine its relative sensitivity to changes in surface state density.

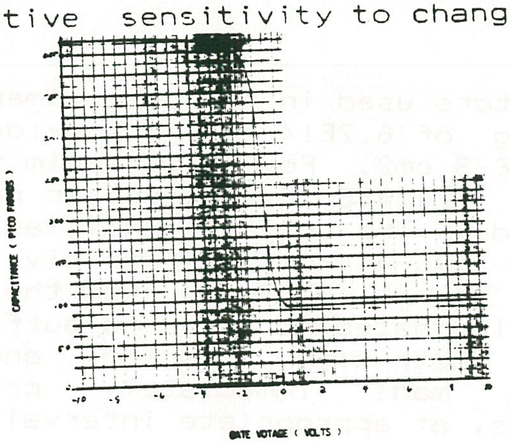

Figure 5 High Frequency Capacitance vs. Voltage
Prior to Injection
Ramp Rate = 100 mV/sec; Cmax = 415 pF; Cmin = 92 pF

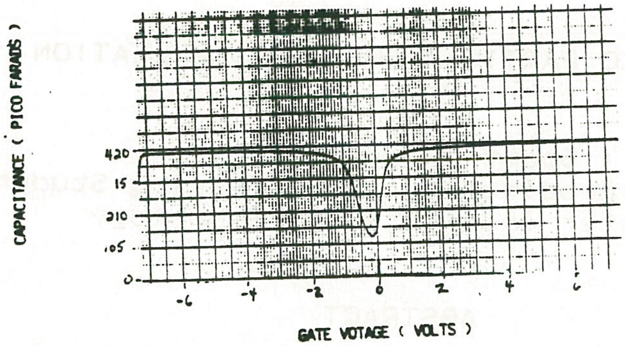

Figure 6 Low Frequency Capacitance vs. Voltage
Prior to Injection
Ramp Rate = 200 mV/sec; Cmax = 420 pF; Cmin = 126 pF

ACKNOWLEDGEMENTS

My thanks to Rob Pearson for assisting me with the low frequency C-V measurements and to Mike Jackson for his help and guidance.

REFERENCES

1. Hishioka, Da Silva, and MA. "Time Dependent Evolution of Interface Traps in Hot Electron Damaged Metal/SiO2/Si Capacitors". IEEE Electron Device Letters. Vol.8 No.12 Dec.1987 pp. 566-568

2. R. Castagne and A. Vapaille. "Description of the SiO2-Si Interface Properties by Mean of Very Low Frequency MOS Capacitance Measurements". Surface Science. Vol.28 1971 pp. 157-193

3. Pierret R.F.."Modular Series On Solid State Devices- Vol. 4- Field Effect Devices. Addison-Wesley Co., Reading,1983,pp. 71-74

4. Fischetti and Ricco. "Hot Electron Induced Defects At The Si-SiO2 Interface at High Fields At 295 and 77K" J.Appl.Phys.Vol.57 No.8 April 1985 pp.2854-2859

5. Hook and Ma."Hot Electron Induced Interface Traps In Metal/Sio2/Si Capacitors:The Effect Of Gate Induced Strain". Appl.Phys.Lett. Vol.48 NO.18 May 1986 pp. 1208-1210

6. Wang,Yasushiro,Nishioka,ma and Barker."Radiation and Hot Electron Effects on SiO2/Si interfaces With Oxides grown in O2 containing small amounts of trichloroethane".Apply.Phys.Lett.Vol.52 No.7 Feb. 1988 pp.573-575