

# Electron Injection By Means of a Ballistic Source

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**Abstract--** The need for more robust micro-electro-mechanical systems (MEMS) devices is greatly increasing. But, along with new technologies come problems, which need to be addressed. One of the more important problems is stiction. Stiction is the strong interfacial adhesion present between contacting crystalline microstructure surfaces. This often causes many MEMS devices to fail. A new method of overcoming stiction has been disclosed. Electrons are stored at the interface between silicon dioxide and silicon nitride to create a force when an external applied electric field is applied to a MEMS component containing the stored charge. The purpose of this project was to devise a method of putting electrons into the oxide-nitride interface by ballistic injection of electrons through the use of a scanning electron microscope (SEM), a Manufacturing Electron Beam Exposure System (MEBES), and an electron flood gun. The amount of charge is measured by the degree of shift of the flatband voltage of the structure. Although initial data shows the order of magnitude of electrons stored at the oxide-nitride interface via ballistic injection is less than that using high field conditions the experimentation provides a proof of concept.

## 1. INTRODUCTION

Flatband voltage for a MIS structure is defined as the difference between the metal-substrate work function and the amount of stored charge divided by the capacitance of the oxide (see equation 1). However, when calculating the amount of stored charge in the capacitors following electron injection, the work function and the oxide capacitance terms drop out of the equation since they are the same before and after electron injection as seen in (1).

$$V_{FB} = \Phi_{MS} - \frac{Q_f}{C_{OX}} \quad (1)$$

Therefore, the theoretical value of flatband voltage is approximately -1V for low doped n-type silicon. If the flatband voltage shift is 30V, the amount of stored charge is approximately  $9.45 \times 10^{12} \text{ e/cm}^2$ .

The technique of ballistically injecting electrons into the dual layer interface has been examined. When a voltage

sufficient to inject electrons through most of the silicon nitride and reside at the nitride-oxide interface is applied to the dual-layer structure, the electrons will lose all of their excitation energy and will thus be "trapped" at the interface in energy levels below the conduction band of the silicon nitride. These energy levels are created at the interface of the two films due to irregularities in the bonds between silicon and either oxide or nitride. This is to say that not every silicon atom is paired with the corresponding oxygen or nitride atoms. These irregularities create energy traps for which the electrons can easily be stored. The trapped electrons do not have enough energy to leave these traps when they are stored via the ballistic injection. However, when the applied voltage is shut off, the stored electrons act as a voltage source and bend the energy bands of the films in the opposite direction as the electric field. This bending of the energy bands can be sufficient so that some of the trapped electrons have enough energy to tunnel out through the oxide and thus out of the system.

## 2. DEVICE FABRICATION

Before any devices were made at RIT, simulations of a film stack undergoing electron bombardment by a point source were performed. Dr. Philip Rack, from the University of Tennessee at Knoxville, donated the software used for the simulations. First a simulation was performed using thicknesses of materials that would eventually be used to fabricate the cantilever beam of the proposed microswitch. Once the materials are deposited on the wafer, a new simulation was performed to estimate the required voltage needed to inject electrons into the stack of films. The second simulation is required due to the amount of variation in deposition of the processes at RIT. The second simulation can be seen in Figure 1.

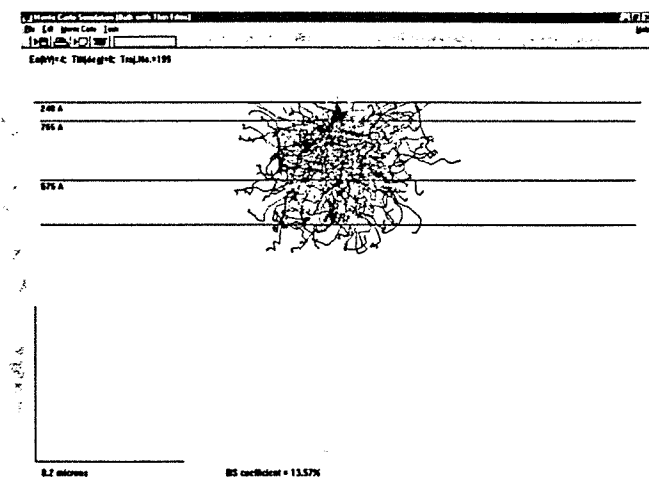


Figure 1: Monte Carlo Simulation of Film Stack

After the first simulation, the thicknesses of the materials needed for the The device fabricated at RIT was done on lightly doped n-type wafers. A 57.5nm layer of thermal oxide was grown on three wafers. Next a silicon nitride layer ( $\text{Si}_3\text{N}_4$ ) was deposited on top of the silicon dioxide via Low Pressure Chemical Vapor Deposition (LPCVD) at a temperature of 809°C for 6 minutes to give a thickness of 76.5nm. A Low Temperature Oxide (LTO) was then deposited on the nitride oxide stack at a thickness of 24.0nm at a temperature of 425°C for 5 minutes. Once the three materials had been deposited and the thicknesses of each material had been measured by ellipsometry a second simulation was performed to estimate the correct beam voltage needed to store electrons at the oxide nitride interface. The backside of the wafer was stripped down to bare silicon using a DryTek Reactive Ion Etch (RIE) tool with  $\text{SF}_6$  as the etchant chemistry.

Before electron injection, a box measuring  $1\text{cm}^2$  was written on the front side of the wafer using a blue Sharpie marker. The reason for this was to be able to see the marking easily with the Scanning Electron Microscope (SEM) as well as to be able to test the same location after electron injection. A voltage of 4keV was simulated to be the optimum voltage needed to store the electrons within the nitride. The wafers were then exposed under a SEM at a beam voltage of 4keV for varying times (10 minutes to 60 minutes).

In order to test the film quickly (as seen in past wafers the charge degradation is highest during the first 100 minutes following charge injection) no photolithography step was performed after injection as it would take approximately 4 hours to both deposit an aluminum contact as well as perform the subsequent contact photolithography and metal etch steps. Instead, a dot of GaIn was used as the top electrode. The wafers were tested on a Keithley CV plotter and capacitance vs. voltage

plots were generated both before injection as well as after injection. These plots can easily be seen in Figure 2.

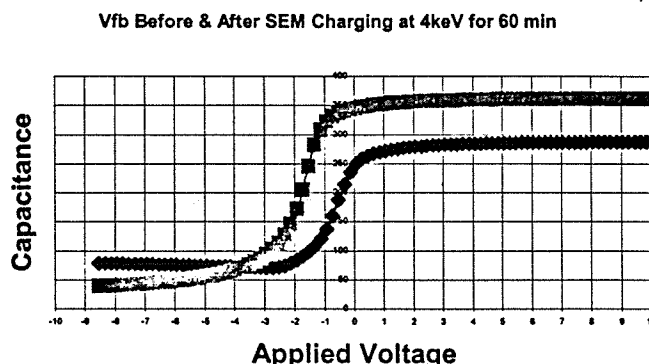


Figure 2: CV Plot Before and After Electron Injection

### 3. RESULTS

A flatband voltage shift of approximately 1V was seen in the wafer charged by the SEM for 60 minutes. All other injection times produced no shift. The electron flood gun and the MEBES III both produced no flatband voltage shift. A reason why the flood gun did not work is because the energies used were too low to penetrate the nitride. The MEBES III did not work because the films used were too conductive and lost all of the stored charge within 100 minutes after injection.

### 4. CONCLUSION

A method other than high field injection has been introduced to storing electrons at a nitride-oxide interface for use in a microswitch design. Although the process has obtained only a 1V shift in the flatband voltage, future work will be done to alleviate this problem at RIT.

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**Erik M. Wheeler**, originally from Crittenden, NY, received B.S in Microelectronic Engineering from Rochester Institute of Technology in 2002. He attained co-op work experience at RIT working under Michael Potter. He is currently seeking employment.