

Implementation of a J-ramp Test Process to Examine the Reliability of Dielectric Films

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Abstract— As film thicknesses get smaller and smaller it is important to maintain high quality dielectric films. A J-ramp test is a method for extracting the characteristics of dielectric films breakdown. Two important parameters that can be extracted using a J-ramp test are the maximum electric field and the charge to breakdown (QBD) of the dielectric. The charge to breakdown the dielectric is a very important parameter because it will be significantly affected by moderate changes within a dielectric. Historically, this parameter would be obtained through stress tests, using a single current level measurement that may take hours or even days. A J-ramp measures the same parameter in only a fraction of the time.

The J-ramp test was successfully implemented into the RIT device characterization laboratory. The test worked well for characterizing changes in the film after certain processes. The absolute values for the charge to breakdown appeared to be lower than literature values.

Index Terms—J-ramp, Charge-to-breakdown

I. INTRODUCTION

Testing the breakdown voltage and charge to breakdown of thin films is very important when characterizing reliability. Low breakdown voltages or low charge needed to induce breakdown could lead to catastrophic failure of devices. For this reason it is essential to characterize the breakdown of the thin films that are used in devices.

The J-ramp designed for this experiment has a dual function. The first function is to accurately measure the breakdown voltage for dielectric films. The J-ramp can do this by performing a fast logarithmic current sweep. Since charge induced breakdown takes long amounts of time to occur, a fast current sweep will force the film to breakdown due to the electric field across it. The breakdown voltage could then be measured as the maximum voltage across the capacitor during the test.

The second function of this test is to accurately determine the charge to breakdown. This can be done by performing a very slow current ramp. The slow current ramp will allow

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charge to build up in the film much like in a stress test. The difference between this and a stress test is that the current levels in the J-ramp test will be rising logarithmically while in a stress test they are held constant. This allows for faster testing and also a more robust process.

II. J-RAMP METHODOLOGY

In contrast to a V-Ramp test, which uses voltage as the initiator, the J-Ramp test uses current [1]. More specifically, the J-Ramp test uses a current ramp that follows equation 1.

$$I_{\text{FORCED}} = I_0 * 10^n \quad (1)$$

Where n is can be chosen for this method

When a capacitor is subjected to this current ramp, charge within the capacitor will build up until breakdown occurs. Breakdown can be realized through the measurement of the voltage across the capacitor. A working capacitor will display a significant amount of voltage drop, while a capacitor that has undergone breakdown will appear to be a short circuit and display little to no voltage. This can be seen in Fig. 1, where oxide failed around 60 sec.

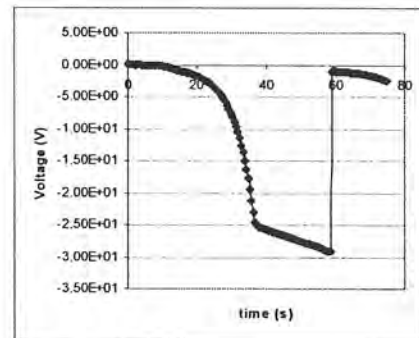


Fig. 1: Example Response

Fig. 1 shows an example of the measurement of the voltage as a function of time. The sudden change near 60 sec. shows the point of breakdown within the capacitor. This drop occurs at a specific point which is the breakdown voltage. Correspondingly Fig. 2 shows the current ramp applied to cause the output from Fig. 1. The area underneath the curve in Fig. 2 is the charge required to breakdown the capacitor. This is quantified in Eq. 2.

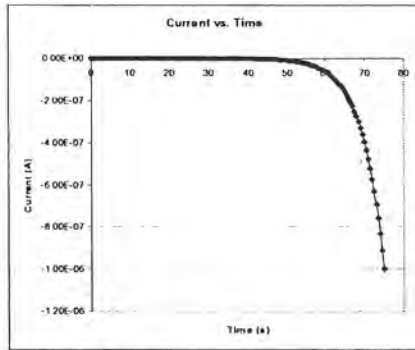


Fig. 2: Current Ramp

$$Q_{BD} = \frac{\sum_{k=1}^N i_k \Delta t}{\text{area}}; t_{BD} = N \Delta t \quad (2)$$

Where Q_{BD} is the charge required to breakdown the capacitor and t_{BD} is the time that corresponds to the breakdown.

III. EXPERIMENTAL SETUP

The J-ramp test was performed using an HP4145A and a shielded test probe station. Both of these pieces of equipment already reside in the RIT device characterization lab and can be easily optimized for J-ramp testing.

The main piece of equipment used for this experiment was an HP4145A electrical characterization machine. This was connected to a shielded box. The actual testing was done inside this box in order to reduce the amount of external influences in the experiment (light, local electric fields, etc.). The HP4145A was connected to this box by 2 triaxial cables. One of these cables was designated to be a common ground and was connected to the wafer chuck. The other cable was connected to a resistor and the probe. This setup is depicted in Fig. 3.

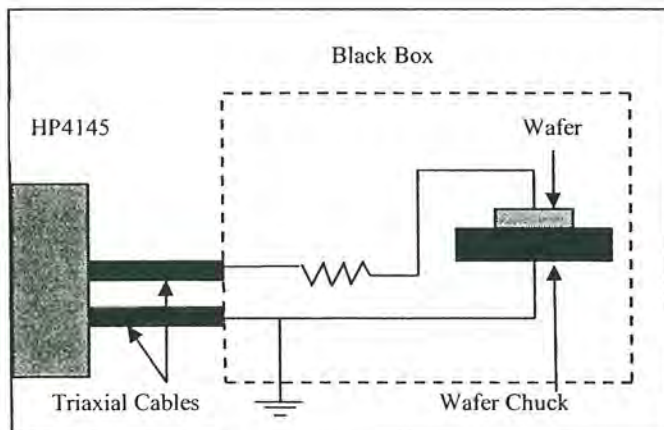


Fig. 3: Experimental Setup

The data for the experiment can be extracted by using an

excel spreadsheet that was prepared for this test. The spreadsheet will calculate the breakdown voltage and also the charge to breakdown. The spreadsheet will also plot the voltage in the system versus time, shown in Fig. 1. The data is entered into the spreadsheet from a simple "copy" command directly from the Metrics ICS (Interactive Characterization Software).

IV. FILM CHARACTERIZATION

There are two different methods for testing the capacitors based on the desired output. To obtain an accurate measurement of the breakdown voltage a "short" test should be used. This test involves a very fast current ramp. A fast current ramp will cause the electric field within the dielectric to rise while minimally changing the charge within the capacitor. This type of test should not be used for charge to breakdown measurements.

The second method for testing capacitors using the J-ramp test is the "long" method. This method involves a very slow current ramp. This slow current ramp will cause a buildup of charge within the film, while keeping the electric field below the maximum. This test cannot accurately measure the breakdown voltage or maximum electric field.

V. PROCESS FLOW

Upon completion of the implementation J-ramp method a 2 factor, full factorial experiment was performed. The purpose of this experiment was to improve the fabrication process to obtain improved data about the reliability of the thin films. The two factors that were varied for this experiment were the aluminum deposition method and the method for cleaning the wafers. The deposition method was varied from evaporation to sputtering. The theory for this was that the plasma used during the sputtering process would cause the oxide to be damaged and lower the charge to breakdown. The clean method was varied by adding an extra hydrofluoric acid dip to the end of the process. The theory behind this is that the hydrofluoric acid would remove any chemical oxides grown during the clean.

The following process flow was used to fabricate the wafers for testing:

1. Clean <100> B-doped (14-22 Ω -cm) Si wafers
2. Deposit/grow a dielectric
3. Evaporate/Sputter Aluminum
4. g-line photolithography to define aluminum contacts
5. Etch aluminum
6. Spin on another layer of photoresist to block the surface of the wafer
7. Dip the wafers into HF to remove backside oxide
8. Strip photoresist (solvent Strip)
9. Evaporate aluminum onto the backside.

VI. RESULTS/DISCUSSION

The J-ramp test was calibrated using a 350A dry oxide dielectric on a p-type wafer. The voltage required to breakdown the capacitor was near -30 Volts for all of the measurements. This corresponds to previously documented values. The charge to breakdown the film was lower than previously documented values, but the value was consistent from test to test. Until further improvement of the testing techniques this test will not provide absolute values for the charge to breakdown. The process can be used for comparative studies of oxide reliability. This type of test was used to run the aforementioned experiment.

Table 1: Average charge to breakdown as a function of deposition and cleaning methods.

Deposition Method	Cleaning Method	Average Q_{BD}
Evaporation	Without HF dip	-0.23 C/cm ²
Sputtering	Without HF dip	-0.00018 C/cm ²
Evaporation	With HF dip	-1.80 C/cm ²
Sputtering	With HF dip	-0.00011 C/cm ²

Table 1 shows the results from the processing experiment. The wafers that received sputtered aluminum had significantly lower Q_{BD} values, signifying that the dielectric was damaged by the plasma. The wafer with the evaporation and an extra HF dip appeared to have a higher charge to breakdown indicating that the film was improved by the removal of native and chemical oxides before deposition.

VII. CONCLUSIONS

The J-ramp test was useful for obtaining precise data in reasonable amounts of time. The measurements for the voltage and maximum electric fields were very accurate while the measurements for the charge to breakdown were too low. For this reason the charge to breakdown measurements should only be used for comparative characterization of films.

The processing experiment showed that an extra HF dip and using evaporated aluminum is the best method for obtaining accurate data.

VIII. ACKNOWLEDGEMENTS

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