DETERMINATION OF MINORITY CARRIER LIFETIMES USING THE CAPACITANCE-TIME TECHNIQUE

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ABSTRACT

Capacitance-Time (C-T) plots were generated using a Micromanipulator model 410 CV system with a Yokogawa 3022 A4 X-Y recorder (with time base activated). MOS capacitors were pulsed instantaneously from accumulation into deep-depletion. The capacitance was then recorded as the samples relaxed back to their equilibrium state (Cmin). The method used to analyze the C-T data was known as a ZERBST analysis. A FORTRAN program was created to handle the differentiating required for the ZERBST plot. Preliminary results indicate that this set-up will accurately determine minority carrier lifetimes.

INTRODUCTION

Capacitance-Time (C-T) methods can be an extremely useful tool in the monitoring of process flows in any modern microelectronics facility. Thru the analysis of C-T plots, one can determine the minority carrier lifetimes of given MOS structures. The monitoring of lifetimes will indicate if a given process is going astray.

C-T measurements can be obtained using a simple MOS capacitor. The depletion region of a capacitor can be forced into a non-equilibrium condition by pulsing the capacitor from accumulation to inversion by using a square wave as a toggle voltage. This rapid change in bias causes a non-equilibrium to occur in the depletion region of the capacitor. It is this very fact that allows one to record the C-T response of a structure. One is not allowing the minority carriers to be generated fast enough to offset the rapidly changing bias on the gate. In time, the capacitor will relax to its equilibrium value (Cmin). The recording of this event is a C-T plot, as shown below (1).

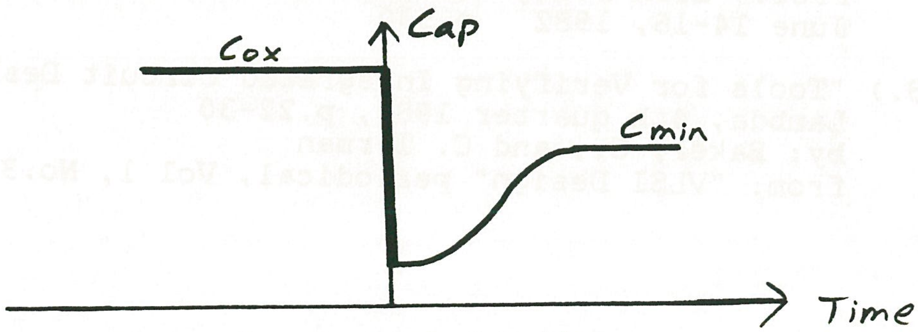

Figure 1: Typical C-T Plot

The minority carrier lifetime (Tg) of a device can be defined as "the average time an excess minority carrier will live in a sea of majority carriers." (2). Zerbst proposed a method of evaluating the C-T response so as to determine Tg. It is worth noting that Zerbst's analysis is the most widely accepted C-T analyzation technique used today. Zerbst's derivation is given below, as outlined in Nicollian and Brews' MOS PHYSICS and TECHNOLOGY (3).

The following equation takes into account the total voltage drop of a capacitor in the deep-depletion mode of operation. By Gauss's law:

$$Cox(Vg - \psi(T)) = q(Ni(T) + \int_0^{W(T)} Nb(x)dx) \qquad (1)$$

where:
- Cox = Oxide Capacitance
- Vg = Gate Voltage
- $\psi(T)$ = Instantaneous band bending
- Ni(T) = Instantaneous inversion layer carrier density
- Nb(x) = Dopant density at position x
- W(T) = Instantaneous value of depletion layer width

Differentiating Equation 1 with respect to time yields:

$$dNi/dT = -Cox(d\psi/dT) - Nb(W(T))dW/dT \qquad (2)$$

The depletion width at a given capacitance C(T) is given by:

$$W(T) = \epsilon si(1/C(T) - 1/Cox) \qquad (3)$$

Zerbst related the surface generation velocity (S) to W by neglecting the voltage drop across the inversion layer:

$$\psi(T) = \frac{q}{\epsilon_{si}} \int_0^{W(T)} xNb(x)dx \qquad (4)$$

Differentiating Equation 4 yields:

$$d\psi(T)/dT = \frac{qW(T)}{\epsilon_{si}} Nb(W(T))dW/dT \qquad (5)$$

Combining Equations 2,3, and 5 yields:

$$dNi/dT = -\frac{Nb(W)\epsilon si}{2Cox} d/dT(Cox/C(T))^2 \qquad (6)$$

Equation 6 is Zerbst's relation between the rate of change on the inversion layer carrier density and the rate of change of depletion layer width. Zerbst then related the generation in the bulk and surface to the inversion layer charge density as:

$$dNi/dT = \frac{Ni}{Tg} (W(T) - W(T=\infty)) + NiS \qquad (7)$$

where: Tg = minority carrier lifetime

Substitute Equations 3 and 6 into 7 yields:

ZERBST Equation:

$$-d/dT\,(Cox/C(T))^2 = \frac{2Ni}{N_b}\left(\frac{Cox}{C_{min}}\right)\left(\frac{Cmin/C(T) - 1}{T_g}\right) + \frac{\epsilon_{ox}}{\epsilon_{si}}\frac{S}{T_{ox}}$$

A Zerbst plot can now be generated by plotting:

$$-d/dT\,(Cox/C(T))^2 \quad VS \quad Cmin/C(T) - 1$$

This plot will have a slope = (2*Ni*Cox)/(Nb*Cmin*Tg)

Thus, once a C-T measurement is performed, th minority carrier lifetime can be determined.

EXPERIMENTAL

The C-T response of MOS capacitors were measured using a Micromanipulator model 410 CV plotter in conjunction with a Yogowawa A4 X-Y recorder. Samples were pulsed from accumulation into deep-depletion by manually altering (instantaneously) the voltage across the gate. The X-Y recorder was then activated (time base mode), thus measuring the capacitance of the system as the capacitor relaxed back to Cmin. The experimental set-up is shown in Figure 2:

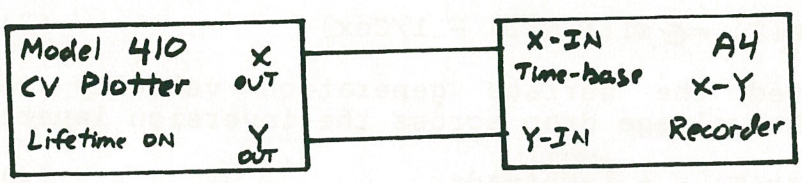

Figure 2: C-T measurement set-up.

RESULTS

A typical C-T response that resulted from the measurement of MOS capacitors is shown in Figure 3.

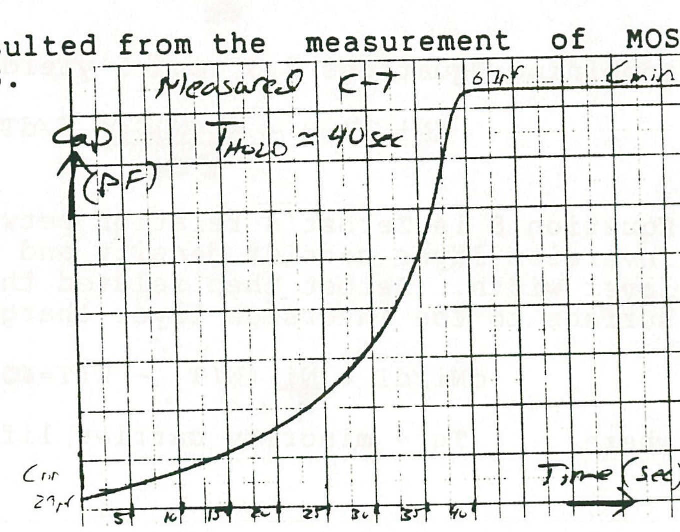

Figure 3:

Measured C-T Response.

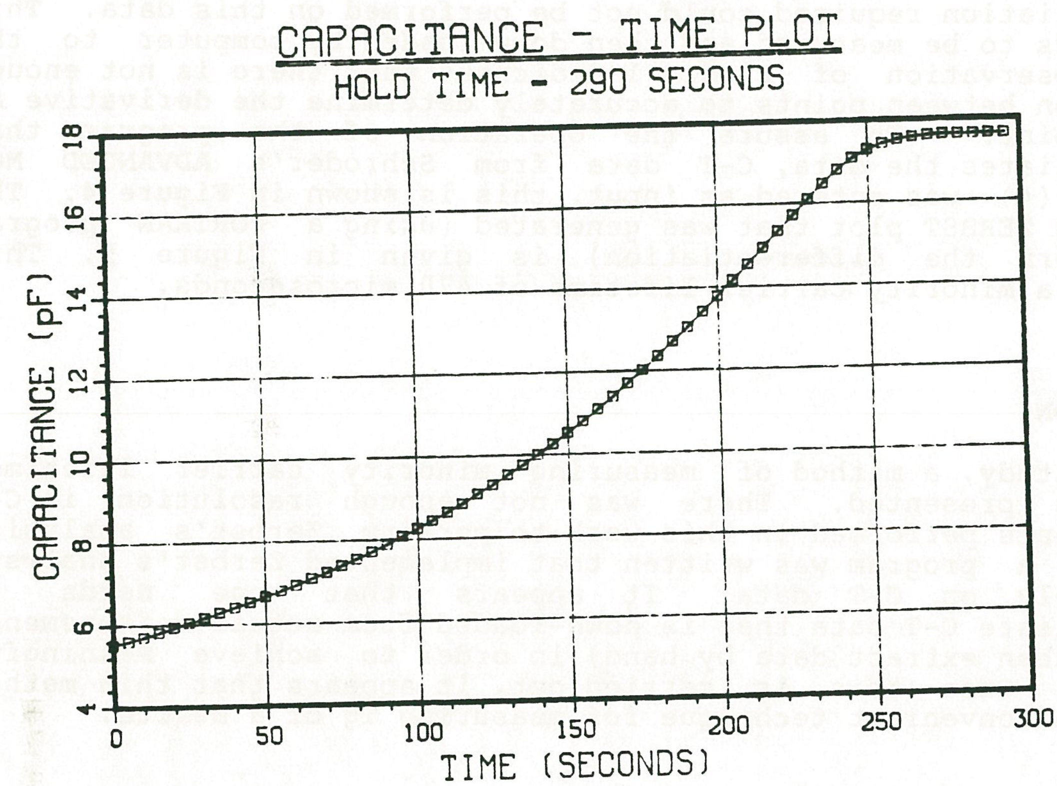

Figure 4: C-T Plot

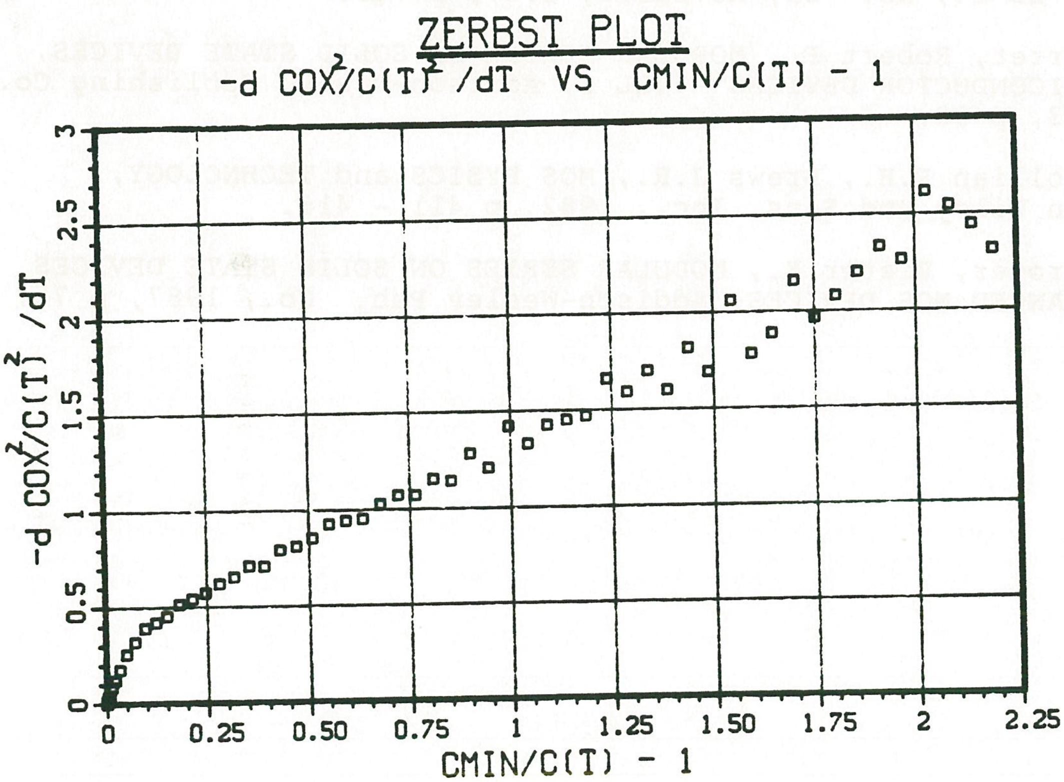

Figure 5: ZERBST Plot of C-T from Figure 4.

A Zerbst analysis was attempted on this C-T data. However, the differentiation required could not be performed on this data. This data needs to be measured and then down-loaded by computer to the VAX. Observation of Figure 1 indicates that there is not enough resolution between points to accurately determine the derivative at each point. To assure the operation of the program that differentiates the data, C-T data from Schroder's ADVANCED MOS DEVICES (4) was entered as input, this is shown in Figure 4. The resulting ZERBST plot that was generated (using a FORTRAN program to perform the differentiation) is given in Figure 5. This produced a minority carrier lifetime of 470 microseconds.

CONCLUSION

In this study, a method of measuring minority carrier lifetimes (Tg) was presented. There was not enough resolution in C-T measurements performed in this work to perform Zerbst's analysis. However, a program was written that implemented Zerbst's analysis effectively on C-T data. It appears that one needs to differentiate C-T data that is down-loaded from actual measurements (rather than extract data by hand) in order to achieve meaningful results. Once this is carried out, it appears that this method will be a convenient technique for measuring Tg of a device.

REFERENCES

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