PREFORMING C-T MEASUREMENTS

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ABSTRACT

An IBM computer, a HP4145B parametric analyzer, a Micromanipulator 410 capacitance meter, and a Keithley 230 voltage source were networked together to form a test setup to measure the recombination and generation lifetimes of minority carriers. The Zerbst relationships were used to calculate lifetimes. Results indicate that the test setup has the ability to take accurate data, but when the capacitance-time data was analyzed, the calculated lifetimes were not believable. The problem seems to be the quality of the fabricated capacitors and not the setup.

INTRODUCTION

Electrical properties of diodes, transistors or more complicated devices are in a large part influenced by minority carrier lifetimes. Lifetimes can affect the rise and fall times of 'switches', and the refresh times of DRAMs. Lifetimes can be used to characterize the fabrication process, the insulator, and the semiconductor material. A typical application is in the study of internal gettering where different amounts of gettering will create different lifetimes. The location of the minority carrier traps, which is dependant on the amount of gettering or addition of impurities to the oxide, will affect lifetimes. If the traps are close to the surface, than lifetimes will be short. If the traps are deep in the layer, then the lifetimes will be longer.

Although there are other methods of finding lifetimes, the pulse gate method is the most practical to use due to the simple test setup and the ease of fabricating MOS capacitors. The pulsed gate voltage lifetime measurement technique is basically applying a instantaneous gate voltage to the capacitor, which is large enough to send the capacitor into deep depletion, and observing the amount of time it takes the capacitor to reach its equilibrium inversion state [1]. The depletion width must increase to provide the extra charge needed. The increase in depletion width causes the measured capacitance to decrease to a minimum (Cdep). As free carriers are generated, in the non-equilibrium state, the depletion width will decrease until the device reaches its equilibrium point at inversion (Cinv). The increasing amount of free carriers can be seen in the fact that the measured capacitance will increase. The time that it takes from the point where the capacitor was pulsed into deep depletion to where the capacitor has reached its equilibrium point is called its recovery time (Tf). Figure 1 shows what a typical C-t plot looks like.

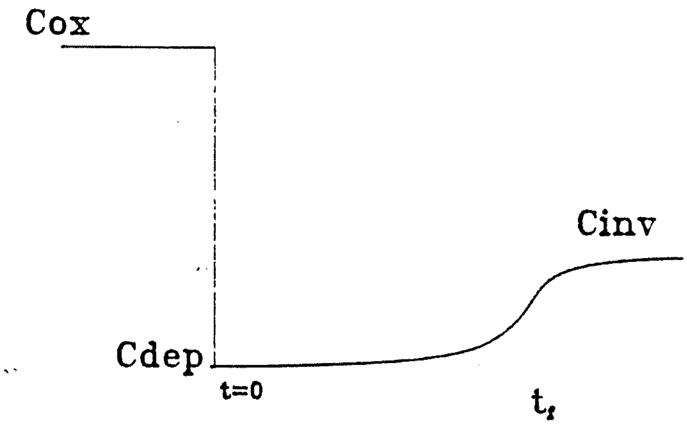


Figure 1: Capacitance vs Time

By analyzing the capacitance vs recovery time data, using the Zerbst relationships, the lifetimes of minority carriers can be determined. The following derivation of the relationships between the change in inversion carrier density, the change in depletion layer width, and lifetimes is summarized from Nicollian and Brews <u>MOS Physics and Technology</u> [2].

The Zerbst relationships are derived from Gauss's law which states that the oxide field is proportional to the net charge per unit area. Equation 1 states Gausses law in mathematical terms.

$$Cox[Vg - \Psi s(t)] = qNi(t) + \int_0^{w(t)} Nb(x)\, dx \qquad (1)$$

where $\Psi s(t)$ is the instantaneous band bending, Ni(t) is the instantaneous inversion layer carrier density, Nb(x) is the doping density at a certain position, and w(t) is the depletion layer width at a certain position. By differentiating Equation 1 with respect to time, it can be shown that,

$$dNi/dt = -\frac{Cox}{q}\, d/dt(\Psi s) - Nb[w(t)]dw/dt \qquad (2)$$

The relationship between the depletion width at a particular capacitance, is given by Equation 3.

$$w(t) = Esi\left(\frac{1}{C(t)} - \frac{1}{Cox}\right) \qquad (3)$$

If the change in voltage drop across the inversion layer is neglected, the depletion approximation gives,

$$\Psi s(t) = \frac{q}{Es} \int_0^{w(t)} x\, Nb(x)\, dx \qquad (4)$$

Substituting Equation 3 and the derivative of Equation 4 into

Equation 2, Equation 5 is derived as,

$$dNi/dt = -\frac{Cox}{C(t)} Nb(w)Es \frac{d}{dt}\left(\frac{1}{C(t)} - \frac{1}{Cox}\right) \tag{5}$$

or

$$dNi/dt = -\frac{Nb(w)Es}{2Cox} \frac{d}{dt}\left(\frac{Cox}{C(t)}\right)^2 \tag{6}$$

which is the Zerbst relationship between the rate of change in depletion layer width and the rate of change in inversion layer carrier density. Equation 7a relates the change in inversion layer carrier density to lifetimes. It is

$$dNi/dt = \frac{ni}{t} (w - w(\infty)) \tag{7a}$$

or substituting Equation 3 into Equation 7a gives

$$dNi/dt = \frac{ni}{t} Es \left(\frac{1}{C(t)} - \frac{1}{Cmin}\right) \tag{7b}$$

where t is the lifetime given as

$$t = tn\ e^{(-vt)} + tp\ e^{(vt)} \tag{8}$$

and vt is the energy in units of kt/q of the bulk trap level with respect to the midgap. Substituting Equation 7b into Equation 6 gives the Zerbst equation which assumes uniform doping, given by

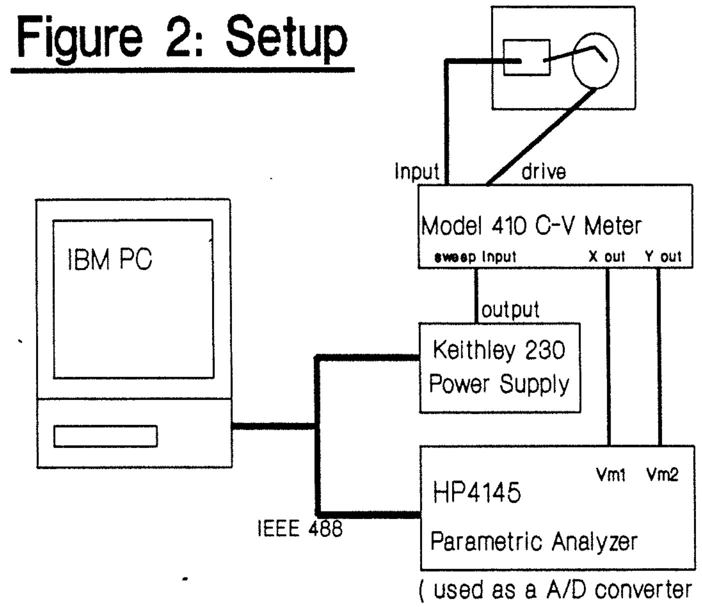
$$-\frac{d}{dt}\frac{(Cox)^2}{(C(t))} = \frac{2\ Cox\ Ni}{Nb\ t\ Cmin} (Cmin/C(t) - 1) \tag{9}$$

from which lifetimes can be found by plotting $-d(Cox)^2/dt(C(t))$ vs $(Cmin/C(t) - 1)$, which is linear with a slope of $(2Cox \cdot Ni)/(Nb \cdot Cmin \cdot t)$. The slope of the curve should be taken where the curve is most linear. Typically this occurs between the ranges of .25 and 1.5 [3].

This project was designed to acquire C-t data from n and p type MOS capacitors. Existing programs were used to calculate lifetimes from the data acquired from the experimental setup.

EXPERIMENT

The test setup involves networking a IBM PC as the "driver", a Keithley 230 voltage source as the pulse generator, a HP4145B parametric analyzer as an A/D converter, and a model 410 Micromanipulator capacitance meter together by using IEEE488 interfaces. A lifetime switch on the back of the capacitance meter has to switched "ON" so that external synchronous control of the step voltage can be done by the computer. The conversion of the analog measurements to digital measurements allows the C-t data to be transferred to the IBM PC and then to the VAX mainframe computer, via the KERMIT transfer program, where existing analysis programs can be used to study the data and calculate lifetimes. Figure 2 shows what the setup looks like and how the particular outputs and inputs to the test equipment are connected.

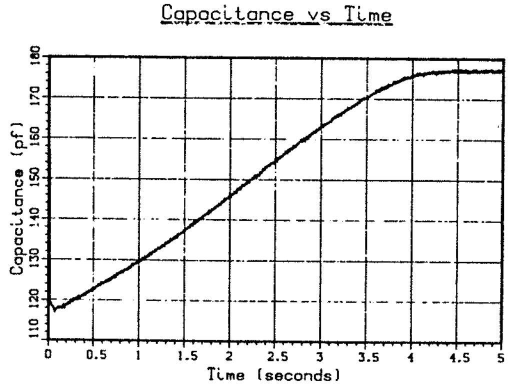


Kevin Gratzer had written programs for the IBM which automatically signals the voltage source to send a pulse to the capacitance, completes the measurements, stores the data on the HP4145B, thereby converting it to digital information [4]. The program also allows the IBM to retrieve data from the HP4145B and save it on the IBM PC's hard drive for further analysis. Once the system was verified to be accurate, in its measurements, the HP4145B was replaced with a Tektronix 2430A digital oscilloscope, which was tested as a possible A/D converter. The Tektronix oscilloscope was looked at as an A/D converter since it should provide more accurate measurements than the HP4145B. Once the test setup was functioning properly, a manual was written so that any student can preform C-t measurements on a MOS capacitor at R.I.T.

RESULTS/DISCUSSION

The experimental setup did acquire capacitance vs time data which was analyzed on previously written programs. Figure 3 shows a experimental plot of measured capacitance vs time.

Capacitance vs Time



Visual analysis of Figure 3 shows that the measured capacitance didn't vary with time in the same manner that the theoretical C-t curve did. This indicates that the system has the capability to take measurements but the quality of the fabricated capacitors needs to be looked into. Even though the capacitor can be initially be biased in accumulation, depletion, or inversion to run the experiment, for all the tests done, the capacitor had to be biased in accumulation to be able to send the capacitor into deep depletion. If the capacitor was biased in inversion, which should give the best results in theory, no change in measured capacitance was seen. This may be due to surface generation of minority carriers. The Tektronix 2340A digital oscilloscope did give more accurate results. It was actually to accurate. Noise was picked up on the signal from the capacitance meter by the Tektronix oscilloscope. The HP4145B gave the same results as the Tektronix oscilloscope but without the noise. Also modifications were made to Kevin Gratzer's program which allowed n-type wafers to be tested on the setup, allowed the user to enter in the initial bias voltage, made the program more user friendly and streamlined the actual program to make it easier to make future modifications in the future.

CONCLUSIONS

The pulse gate lifetime measurement system is ideal to use here at R.I.T. since the test setup is easy to understand, and the MOS capacitors are simple to fabricate. The test setup has the capabilities to take data, if the capacitor is biased in accumulation, but a quality capacitor had to be fabricated or acquired to completely test the setup from beginning to end.

ACKNOWLEDGMENTS

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