Effective Generation Lifetime ($\tau_{g,eff}$) And Surface Generation Velocity (s_{eff}) Extractions Via Zerbst Plot Analysis

Sylvain Garaud

Abstract—**Capacitance vs. time (c-t) characteristics of a MOS structure show the capacitance change after a pulse bias is applied which drives the structure first into accumulation then into deep inversion. Since the time constant of minority carrier generation is relatively long, the MOS structure requires time to reach equilibrium after the pulse bias is applied. Immediately after the pulse bias is applied, the depletion layer extends more widely then the depletion layer becomes narrower - the MOS structure approaches equilibrium as more and more minority carriers are generated. Finally, the depletion layer reaches its equilibrium width. This proves charge neutrality. The C-t characteristics are obtained from this change in the depletion layer width.**

During this project, capacitance vs. time measurements were made using an external bias source. The system consists of a probe station located within a dark box, a Keithley KI82 system and a ICS metrics software. The measured capacitance-time (C-t) data were converted into a Zerbst plot using the Zerbst equation. The effective generation lifetime ($\tau_{g,eff}$) and the surface generation velocity (s_{eff}) were extracted from the slope and the intercept of the Zerbst plot. The main problem with this technique is that times of hundreds or even thousands of seconds per measurement are not uncommon. One method of optical excitation to reduce this measurement time was investigated. We have achieved our goal: setup the pulsed MOS capacitor recombination lifetime measurement technique in the RIT test area. Besides this project did not require the purchase of hardware or additional software. Finally we have shown that the total measurement time was significantly reduced by illumination and there was virtually no error compared to the curve recorded entirely in the dark.

Index terms—**pulsed MOS capacitor, recombination lifetime, surface generation velocity, capacitance vs. time, zerbst.**

I. Introduction

This project was done with the help of Dr. Sean Rommel. The test area at the Rochester Institute of Technology (RIT) provides a wide range of measurement solutions to characterize ICs.

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Unfortunately new electronic instruments are more and more complicated and end-users do not want to spend hours to understand how to perform measurements. Consequently, we have decided to setup the pulsed MOS capacitor recombination lifetime measurement technique in the RIT test area. This famous technique, associated with a Zerbst analysis, is commonly used to extract the effective generation lifetime ($\tau_{g,eff}$) and the surface generation velocity (s_{eff}) of a MOS.

We are going to do a user manual to perform this measurement technique. With the procedure, students and faculty members should be able to perform the measurement quickly, without spending a long time to study tool's documentations.

Moreover the technique will not require costly additional software or tools.

II. Theory

The principle of the pulsed MOS capacitor recombination lifetime technique is a measurement of the relaxation time of a MOS pulsed into deep depletion.[1]

Capacitance vs. time (C-t) characteristics of a MOS structure show the capacitance change after a pulse bias is applied which drives the structure first into accumulation then into deep inversion. Since the time constant of minority carrier generation is relatively long, the MOS structure requires time to reach equilibrium after the pulse bias is applied. Immediately after the pulse bias is applied, the depletion layer extends more widely. Then the depletion layer becomes narrower. The MOS structure approaches equilibrium as more and more minority carriers are generated. Finally, thermal generation returns the device to equilibrium and the depletion layer reaches its equilibrium width. This proves charge neutrality. The C-t characteristics are obtained from this change in the depletion layer width.

Appendix 2 displays the C-V_G and C-t behavior of a MOS pulsed into deep depletion.

The C-t data are generally analyzed using the Zerbst method which extracts an effective generation lifetime ($\tau_{g,eff}$) and an effective surface generation velocity (s_{eff}). This analysis is based on the Zerbst equation.

The Zerbst Equation for a p-substrate. [2]

$$-\frac{d}{dt}\left(\frac{C_{ox}}{C}\right)^2=\frac{2n_i}{\tau_g N_A}\frac{C_{ox}}{C_f}\left(\frac{C_f}{C}-1\right)+\frac{K_{ox}}{K_s}\frac{2n_i s_{eff}}{t_{ox}N_A}$$

Where τ'_g is the generation lifetime, s_{eff} is the surface generation velocity, C(t) is the measured capacitance, C_f is the capacitance at the equilibrium, C_{ox} is the oxide capacitance, n_i is the intrinsic concentration, K_{ox} and K_s are the oxide and silicon dielectric constants and N_A is the doping density.

Using the above equation, we can plot

$$-\frac{d}{dt}\left(\frac{C_{ox}}{C}\right)^2 \text{ vs. } \left(\frac{C_f}{C}-1\right) \text{ known as the Zerbst plot}$$

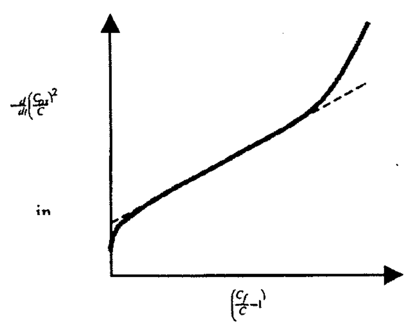

Fig.1 The Zerbst plot

We can extract τ'_g and s_{eff} from the slope and the intercept of this plot.

The slope is $\frac{2n_i}{\tau_g N_A}\frac{C_{ox}}{C_f}$

and the intercept is $\frac{K_{ox}}{K_s}\frac{2n_i s_{eff}}{t_{ox}N_A}$

What is the physical meaning of such a plot ?

To be able to understand the meaning of this plot, we have to look at the following equation where $\frac{dQ_N}{dt}$

$$\frac{dQ_N}{dt}=-\frac{qK_s\varepsilon_0 C_{OX}N_A}{C^3}\frac{dC}{dt}$$

represents the thermal generation components.

The thermal generation components of a deep depleted MOS-C are depicted in Fig.2

(1) Bulk space-charge region (scr) generation
(2) Lateral surface scr generation
(3) Surface scr generation under the gate
(4) Quasi-neutral bulk generation
(5) Back surface generation

The thermal generation components of a deep-depleted MOS is illustrated above.

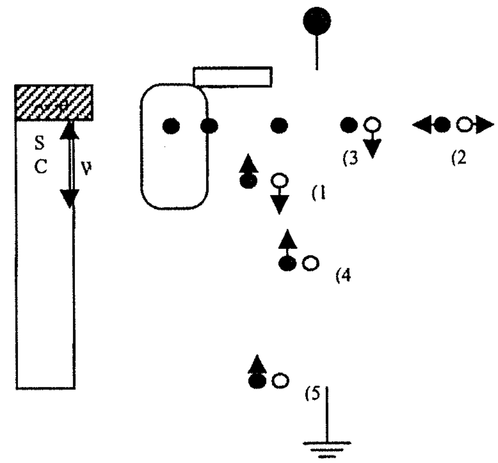

Fig.2 Various generation components in a MOS capacitor.

Now if we use the identity

$$\frac{2}{C^3}\frac{dC}{dt}=-\frac{d}{dt}\left(\frac{1}{C^2}\right)$$

and the Zerbst equation, we can show that

$$-\frac{d}{dt}\left(\frac{C_{ox}}{C}\right)^2\approx\frac{dQ_N}{dt}$$

The Y axis of the Zerbst plot is proportional to the total electron-hole pair (ehp) carrier generation rate or in others words the generation current.

The X axis is proportional to the scr generation width.

$$\left(\frac{C_f}{C}-1\right)\approx W-W_f$$

To sum up the complicated Zerbst plot is nothing more than a plot of generation current versus scr generation width.

The recovery time t_f is related to τ'_g by a time magnification factor [5].

$$t_f\approx 10\frac{N_A}{n_i}\tau_g$$

The advantage is that we determine a lifetime in the order of the microseconds by measuring a recovery time in the order of seconds. But unfortunately, it is also the main disadvantage of this measurement technique; for example if τ_g = 1 ms and (N_A/n_i) = 10^5 , we have approximately t_f = 1000 s. This is a perfect illustration of the major limitation of this technique: the data acquisition time (C-t).

In order to reduce the measurement time two techniques have been proposed. The first one is an increase of the temperature. It is well known that n_i, the intrinsic concentration, is strongly dependent of the

temperature. So we can easy understand by looking at the time magnification factor that as the temperature increases, n_i increases too. Consequently t_f decreases. We have not studied this method because τ'_{geff} is temperature dependent. Moreover above a certain temperature the quasi-neutral bulk generation dominates. So the Zerbst Equation becomes false and the C-t data analysis more complicated. [3]

The second method, to reduce the measurement time, is to illuminate the device. This optical excitation creates ehp carrier. We illuminated the device only during the beginning of the C-t measurement. So the recovery time is considerably reduced. The Zerbst plot is shifted horizontally retaining the slope in the remaining dark portion [4].

III. Experimental Procedure

The reader, who wants to have the complete procedure of the KI82 system [6] setup, can find it in Appendix 1.

We measured a n-substrate MOS, which was done during winter quarter 2002 at RIT (silicon process lab – course number 0305 632) at room temperature. The wafer was lightly doped N_d = 3E14 cm^{-3}. Consequently the relaxation time expected was short (approximately ten seconds). The thickness of the oxide was 420 Å. The measurement was performed using the Keithley KI82 system [6] in the dark and in two optical excitation states: Intensity 1 (I1) and Intensity 2 (I2). When we directly illuminated the MOS with a lamp, the MOS reached instantly the equilibrium and the lifetime extraction was impossible. So we needed to a very smooth luminosity. For I1 we have just opened the box with a light turned on at the back of the test area. For I2 we have done exactly the same thing, but we have slightly increased the luminosity of the room. We applied a voltage of 5V during 5s and we swept to –5V during 50s. The oxide capacitance was C_{ox} = 0.3834 nF. We used a frequency of 100 KHz. We acquired 250 points at a reading rate of 24 rdg.

We used Microsoft Excel to analyze the C-t data (experimental C-t curves fig. 1). Two methods are possible to plot the derivative of the Zerbst analysis.

The first one is to fit the C-t curve with a polynomial approximation. The second one is to plot $(C_{ox}/C)^2$ vs. time. We fund the $d((C_{ox}/C)^2)/dt$ values by using the function SLOPE of Excel and the mathematical definition of the derivative

$$f'(x_0) = \lim_{x \to x_0} \frac{f(x) - f(x_0)}{x - x_0}.$$

This method needs to have C-t with a very small noise or to treat the data with some mathematical tools to reduce the noise. In our case the two methods gave the same result.

IV. Results and Discussion

Fig. 3 displays the Capacitance vs. time characteristics for the n-substrate MOS taken with and without optical excitation. The effect of the illumination appears clearly. During the illumination the MOS, the thermal generation is faster. So the capacitance increases faster too. When we turn off the light, the C-t characteristic slope becomes as in the dark. The correct lifetime will be obtained only if it will be extracted from the "dark portion" of the C-t characteristic. Besides by increasing the light intensity, we can observe that the reduction of t_f is greater.

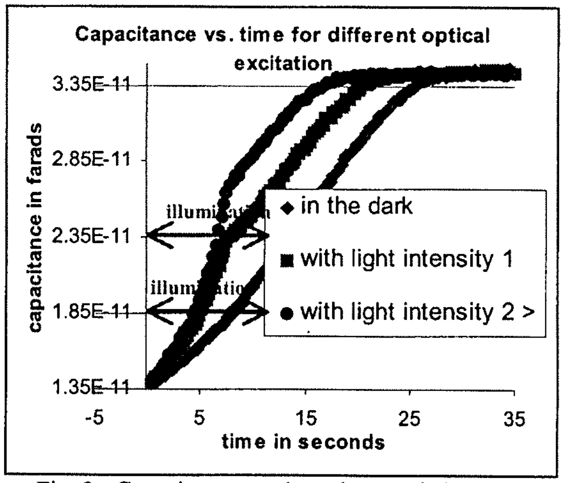

Fig. 3 - Capacitance vs. time characteristics for the n- substrate MOS taken with and without optical excitation at room temperature.

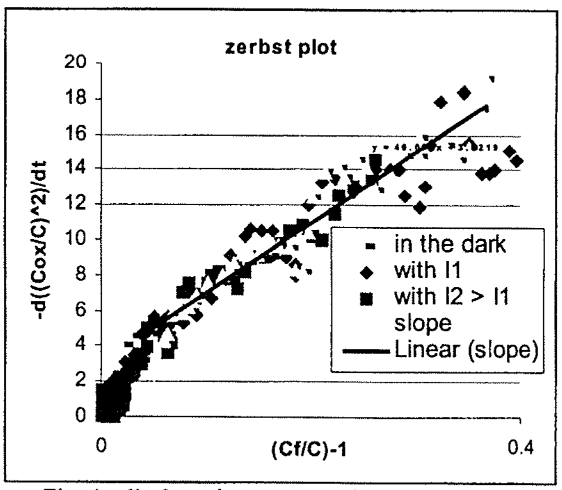

Fig. 4 - displays the corresponding Zerbst plots.

We may reduce the measurement time to less than 10s.

The effective generation lifetime ($\tau_{g,eff}$) and the surface generation velocity (s_{eff}) ,extracted from the slope and the intercept respectively of the Zerbst plot (Fig 4), are: $\tau_{g,eff}$= 2.53E-5 s and s_{eff}= 0.42 cm.s^{-1}
These values are in the range expected. Textbooks give values for $\tau_{g,eff}$ between 10^{-6}s to 10^{-3}s for quality devices [1].

V. Conclusion

We have achieved our goal: setup the pulsed MOS capacitor recombination lifetime measurement technique in the RIT test area without the purchase of hardware or additional software.

During this project, capacitance vs. time measurements were made using an external bias source. The system consists of a probe station located within a dark box, a Keithley KI82 system and a ICS metrics software. The measured capacitance-time (C-t) data were converted into a Zerbst plot using the Zerbst equation. The effective generation lifetime ($\tau_{g,eff}$) and the surface generation velocity (s_{eff}) were extracted from the slope and the intercept of the Zerbst plot. The main problem with this technique is that times of hundreds or even thousands of seconds per measurement are not uncommon. One method of optical excitation to reduce this measurement time was investigated. Finally we have shown that the total measurement time was significantly reduced by illumination and there was virtually no error compared to the curve recorded entirely in the dark.

Appendix

1. The pulsed MOS capacitor recombination lifetime measurement - Complete procedure of the KI82 system setup

2. the C-V_G and C-t behavior of a MOS pulsed into deep depletion.

Acknowledgment

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