MEASUREMENT OF MINORITY-ARRIER LIFETIME IN SILICON SOLAR CELLS BY THE PHOTOCONDUCTIVE DECAY METHOD*

BY

C.E. OKEKE
DEPARTMENT OF PHYSICS
UNIVERSITY OF NIGERIA,NSUKKA,
NIGERIA.

ABSTRACT

One of the critical parameters for the overall efficiency of solar cells is the lifetime of minority carriers. This manuscript describes the measurement of minority - carrier lifetime of silicon solar cells, at room temperature, by photoconductive decay method. The Holobeam, Model 655 Double-Pulsed Holographic system, is used as the light source. This consists of a Q-switched, pulsed ruby laser oscillator with two ruby laser amplifiers. Silicon samples with projected lifetimes of less than 0.25μ secs to about 8μ secs are used for the investigation, and the results obtained using this technique, compare favourably with the results furnished by the manufacturers.

INTRODUCTION

An important parameter for the overall efficiency of solar cells is the lifetime of minority carriers. Lifetime (volume) is defined [1] as: "the average time interval between the generation and recombination of minority carriers in a homogeneous semi-conductor". Numerous techniques exist for measuring carrier lifetime, but we have used a method which has gained most widespread use [2], [3].

We have measured at room temperature, the minority carrier lifetime in silicon by the photoconductive decay method using as the light source the Holobeam Model 655 Double-Pulsed Holographic system, which consists of a Q-switched, pulsed ruby laser oscillator with two ruby laser amplifiers. Several solar cells of different resistivities and varying projected lifetimes were used in the investigation. The method of photoconductive decay is prefered over other methods because the measurements of carrier lifetime can be made with a higher degree of precision.

2. THEORY OF PHOTOCONDUCTIVE - DECAY METHOD

In thermal equilibrium, the voltage drop along the section of the specimen to be illumated is V_o for a given constant current. When illumination starts, the voltage decreases, since additional carriers are being provided to support the current. The excess carrier lifetime can be determined from observations of the change in voltage, $\Delta V = (V_o - V)$ during the period of conductance build-up. However, it is most useful to study the decay of ΔV when the light is suddenly turned off. During the later period excess holes and electrons excess holes and electrons are progressively made unavailable for conduction through recombining and trapping processes. The two excess populations are equal in density only when recombination is the dominant factor.

During the decay, the excess conductivity$\Delta\sigma$ is:

$\Delta\sigma \ \alpha \ \Delta p$ or Δn

and

$$\Delta\sigma \quad \alpha \ \exp[\,[-\frac{t}{\tau}]\,] \qquad (1)$$

Where Δp and Δn are respectively, the concentrations of excess holes and excess electrons and τ is a characteristic time

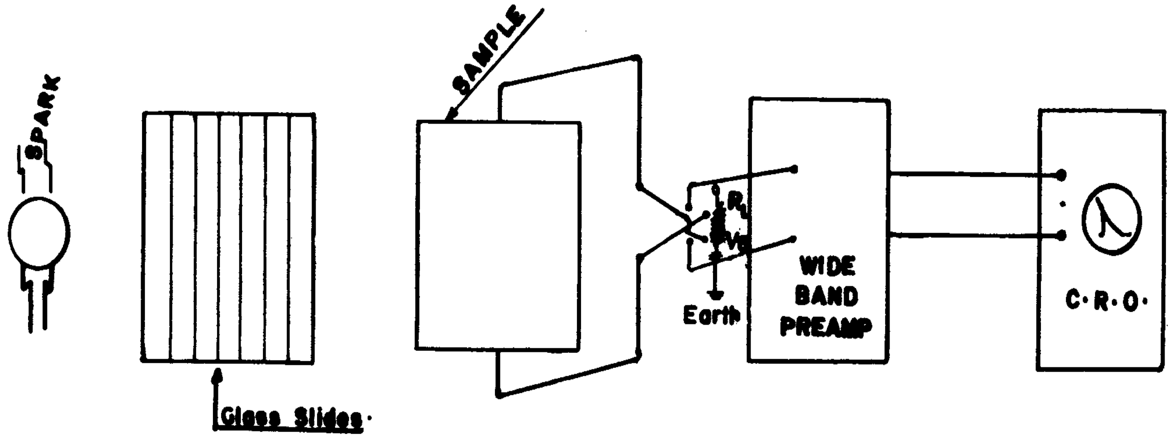


FIG.1. SCHEMATIC CIRCUIT ARRANGEMENT

constant. For specimens operated under constant-current conditions, voltage is inversely proportional to conductance. Hence, for small deviations from thermal equilibrium conditions, ΔV is directly proportional to excess conductance but is of opposite sign. Accordingly the effective measured lifetime at any instant is given by:

$$t = -\Delta V\left[\frac{a(\Delta V)^{-1}}{dt}\right] \quad \text{when } \Delta V << v_o \qquad (2)$$

If the conductivity decay at the half point is observed, we have from the fundamental decay law;

$$\sigma\frac{1}{2}\ \alpha \exp\left(\frac{-t}{\tau}\right)$$

$$\log\frac{1}{2} = \frac{-t}{\tau\frac{1}{2}}$$

$$\tau\frac{1}{2} = \frac{t}{\mathrm{In}2} \qquad (3)$$

Therefore, We only need to read the t value (abscissa) at the $\sigma\frac{1}{2}$ value and divide by 1n2 to obtain 2the actual lifetime. At times it is easier to plot the decay curve directly on semi-logarithmic paper. In this case the $\exp\left(\frac{-t}{\tau}\right)$ curve is liberalized. :

$$y = \mathrm{In}\sigma = \frac{-t}{\tau} \qquad (4)$$

Figure 2 shows how we can use the exponential signal decay curve to estimate the lifetime.

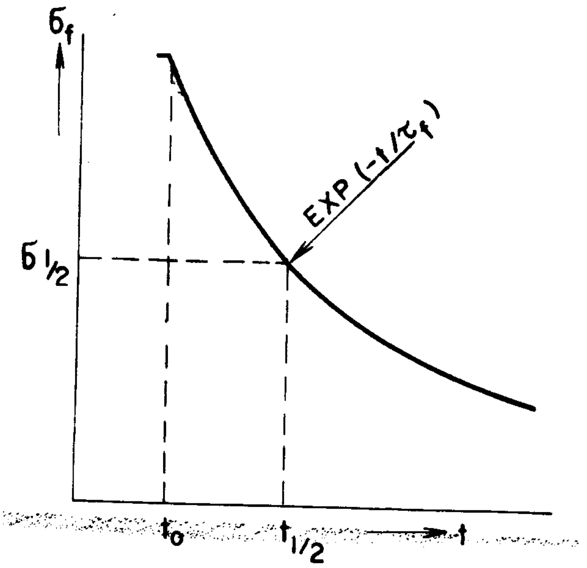


Fig.2. exponential signal decay curve and lifetime, τ_f

3. EXPERIMENTAL APPROACH

In the photoconductive-decay method, a constant current is passed through a semiconducting sample equipped with ohmic contacts and the voltage drop along the specimen is monitored continuously. For a short period, excess carriers are deliberately created in the body of the specimen, upon exposing the sample to high laser beam. Figure 1 show the experimental set up used in the investigation. To cut down the high intensity from the laser beam, bunch of glass slides were used in place of beam splitters. These slides were placed between the source and the sample. First, we establish very nice ohmic contacts at the ends of the sample with the aid of Viking metal and pure indium solder. These contacts should be non- rectifying. This condition is tested with transistors cope, by observing the voltage across the sample corresponding to each polarity. If these two voltage readings are within 2 per cent of each other the contacts can be regarded as satisfactory for life time measurement

An ohmic contact is defined as a contact which will not add significant parasitic impedance to the structure on which it is used [4] and it will not sufficiently change the equilibrium carrier densities within the semi- conductor to affect the device characteristics. In other words, an ohmic contact should have a linear and symmetrical current-voltage relationship; it is characterized by having no potential barrier (hence no symmetry) and an infinite surface recombination velocity (hence linearity). At an ohmic contact the electrons and holes are at their thermal equilibrium values. Also the resistivity profile can be checked and the highest and the lowest resistivity should not differ by more than 10 per cent. The current source is a 9 volt transistor battery. In series with this is a non-reactive low-noise resistor R_L whose resistance must be at least 20 times greater than the sample resistance. The rest of the circuit consists of a wide band preamplifier and a fast scope.

The crystal sample is subjected to a light pulse from a ruby laser and the conductivity decay over time is observed on the scope which is triggered directly from the light source. The specimen is mounted in a small metal box which provides adequate electrical shielding. All connections between parts of the system are made with shielded cables which are kept as short as possible. This is to reduce the random noise.

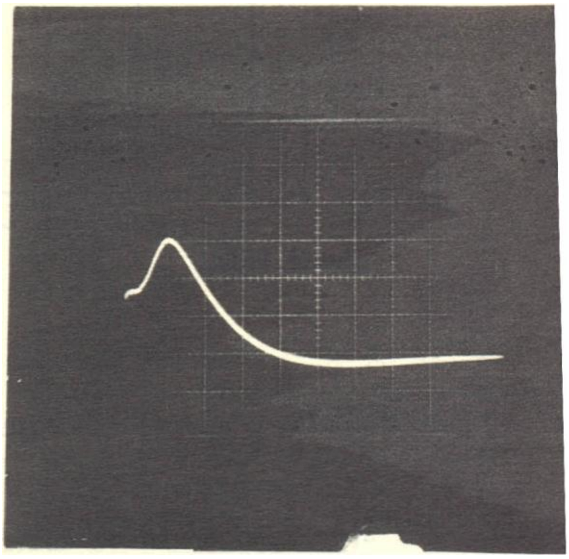


Fig. 3: Exponential signal decay curve for Boron doped silicon, 0.5Ω-cm, 2cm x 2cm. The time scale is 1μ s/div.

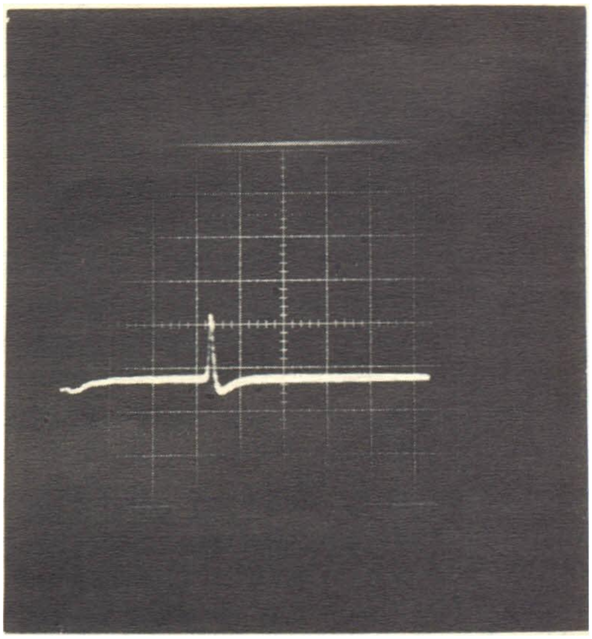


Fig.4: Exponential signal decay curve for Boron doped silicon doped with titanium. ρ 0.5Ω - cm, 2cm x 2cm. The time scale is 1μs/div.

4. RESULTS

Fig.	Sample Curve Descrption and History	Observed minority carrier Lifetime	Manufacturers' specification	% deviation from the manufactures' specification
3.	Exponetial signal decay curve for boron doped silicon. Dimension is 2cm X 2cm with a resistivety of 0.5Ω-cm	3µs (approx.)	2-5µs	14.30 (apporx.)
4.	Exponential signal decay curve for boron doped silicon doped with titanium. Dimension is 2cmx2cm, with a resistivity of 0.5Ω-cm	0.2 µs	0.25µs	20.00
5.	Exponential signal decay curve for borom doped silicon. The sample has dimesion (1cm x2cm) and resistivity 1-3Ω-cm	7 µs	7.5-8 µs	9.68
6.	Exponential signal decay curve of sample ‡ ‡ tyco with epy –layer.	8 µs	None	-

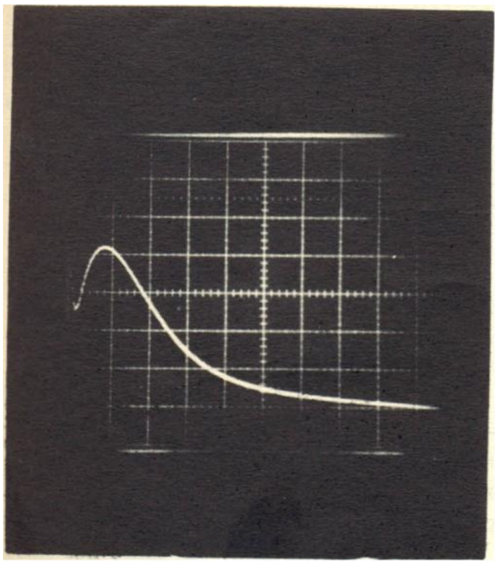
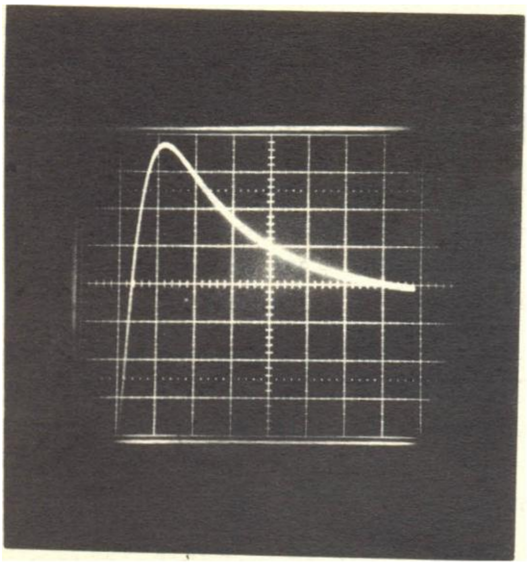


Fig.5: Exponential signal decay curve for Boron doped silicon, 1-3Ω-cm, 1cm x 2cm. The time scale is 5µs/div.

5. CONCLUSIONS AND COMMENTS

We have demonstrated the suitability of photoconductive decay method with pulse ruby laser as source, for determining minority carrier lifetime in silicon. Most of the results obtained compare favourably with those predicted by the supplier. The photoconductive decay method is superior to other methods, for it yields more accurate results and it is an easier approach.



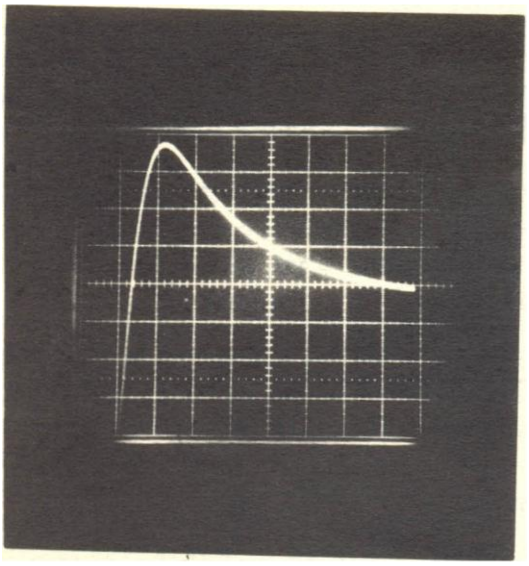


Fig.6: Exponential signal decay curve of sample ‡ Tyco with Epy-layer. The time scale is 5μs/div. and the observed lifetime is 8μs.

REFERENCES

1 IRE Standard on Solid-State Devices Definitions of Semiconductor Terms, (1960): 60 IRE 28 SI, Proc. IRE, 1772, October (1960).

2 "Recombination in semiconductors" Proc. IRE, 46 990-1004, June (1958).

3 IRE Standards on Solid-State Devices: Measurement of Minority Carrier Lifetime in Germanium and silicon by the method of Photoconductive Decay. Proc. IRE. 61 IRE 28, S2 1292-1999 , August- (1961) .

4 Physics of Semiconductor Devices by S.M. SZE, Wiley-Interscience pp. 416.