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QUANTIFYING SRH RECOMBINATION IN GAAS PIN SOLAR CELLS

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ABSTRACT

Charge recombination is known to decrease a solar cell's efficiency. SRH recombination, which is always present in a solar cell, is, thus, a candidate about which knowledge must be extracted. SRH recombination affects the dark current, the photocurrent and, thus, the total current of a solar cell. To find the SRH recombination times, elaborate numerical simulations must be done and the experimental solar cell data must be curve fitted to the simulation results. This is a lengthy and detailed procedure. In this work, a simple and short method is proposed. A GaAs PIN solar cell is simulated and its photocurrent's slope (vs. voltage) is seen to show a peak which decreases with decreasing recombination times. A plot is given, from which the recombination time can be easily read by knowing the photocurrent's slope's peak value. This peak value can be easily found from the solar cell's experimentally measured data.

Keywords: SRH Recombination, Photocurrent, Gaas Solar Cells, PIN Solar Cells

1. INTRODUCTION

In the past few decades solar cells have been ubiquitous in research and society Wilson et al. (2020), Lee and Ebong (2017), Kirchartz and Rau (2018). As newer solar cells fight to take their place in the laboratories, reporting higher efficiencies than ever, more and more papers are being written, with time, on the various nuances of a solar cell. Solar cells have also transformed our lives through solar panels which nowadays easily find their way to our homes Nfaoui and El-Hami (2018), Durganjali et al. (2020).

The working of a solar cell is simple. A P-type semiconductor forms a PN junction with a N-type semiconductor and has a built-in electric field in the depletion region R. F. Pierret (1996). When the PN junction is illuminated new electron-hole pairs form, which then dissociate and get dragged to the P and N contacts. This gives rise to a current, called the short-circuit current of a solar cell A. N. Roy Choudhury (2025). At open circuit, upon illumination, the solar cell also has a voltage, called the open circuit voltage. Both the short-circuit current and the open circuit voltage are counted as figures of merit of a solar cell. The higher, in value, they are the better is the solar cell.

A PIN solar cell Carlson and Wronski (1976), Pawlikiewicz and Guha (1990) is formed by sandwiching an intrinsic semiconductor between two P and N layers. This intrinsic layer is often the optical absorber of the solar cell. The built-in electric field of the PN junction sweeps across the absorber layer dissociating and dragging electrons and holes to the N and P type layers respectively.

Charge recombination is often a problem in solar cells Zhou et al. (2013), Gogolin and Harder (2013), Zeiske et al. (2021), Ryu et al. (2021), Calado et al. (2019), Grover et al. (2013), Hubin and Shah (1995). Before the dissociated electrons and holes can be pulled out as a current the charge carriers often recombine and disappear. This reduces the efficiency of a solar cell. Recombination can be radiative which is band-to-band recombination of carriers in direct band gap semiconductors like GaAs. Or it can be trap-assisted like the Shockley-Read-Hall (SRH) recombination Gogolin and Harder (2013), Ryu et al. (2021) where, taking the help of material defects (traps) electrons and holes recombine and disappear. The SRH recombination time is a figure of merit denoting how long a free electron or hole can live before getting recombined. Usually, the lower the SRH time the higher the recombination.

The SRH recombination time depends heavily on traps. The traps can be characterized based on the SRH time and reduced in density (or effectively eliminated) during the solar cell materials manufacturing process. Thus, knowing the SRH time is of utmost importance.

The SRH time can be found by fitting the experimentally obtained solar cell current voltage curves to theoretical simulation results. But it is a long and detailed procedure as we will see in the next sections. A short method is often desired which is the goal of this paper.

In what follows, in this paper, a GaAs PIN solar cell is simulated. Both the dark current and photocurrent is simulated for different SRH recombination times and it is shown how elaborate the procedure of finding the SRH times from curve fitting is. Then the new method is demonstrated which is a quick and easy way to find the SRH times from the photocurrent's experimental data.

2. DARK CURRENT

A GaAs PIN solar cell is simulated in ADEPT 2.1 Gray et al. (2015), a software that solves the Poisson equations, the Continuity equations and the Drift-Diffusion equations simultaneously using a discrete mesh and a generalized Newton iteration method.

As mentioned previously, a PIN solar cell has an intrinsic light absorber sandwiched between a P-type and an N-type semiconductor and is drawn in Figure 1.

Figure 1

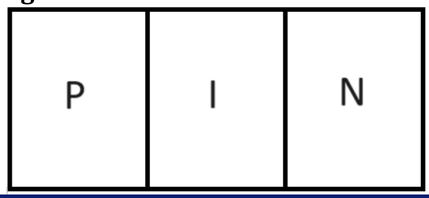

Figure 1 Schematic of the PIN Solar Cell based on which Simulations are Done

The material parameter values for GaAs is taken from the Ioffe website [Semiconductor Website] and are given in Table 1.

Table 1

Table 1 Parameter Values of GaAs Chosen for Simulations

Parameter	Value
Band Gap	1.424 eV
Electron Affinity	4.07 eV
Dielectric Constant	12.9
Effective Conduction Band DOS*	4.7 x 10^{17} /cc
Effective Valence Band DOS*	9 x 10^{18} /cc
Electron Mobility	8000 cm^2 /Vs
Hole Mobility	400 cm^2 /Vs
SRH Electron Recombination Time	5 ns
SRH Hole Recombination Time	3 µs

DOS means Density of States

The doping density of the P and N layers is 1015 /cc. The SRH recombination time for electrons and holes in the P and N layers are as per Table 1. In the I layer the SRH time is varied. The thickness of the P, N and I layers are kept at 10 µm. Temperature is 300 K. The absorber of the PIN cell is illuminated with 1 Sun intensity of light, the standard AM 1.5 G radiation.

The dark current of the solar cell is simulated without any light. The electron and hole SRH recombination time in the absorber is varied from 100 ns to 1 ns. Dark current is also simulated for a SRH time of 1 s which represents no recombination. For all practical purposes, the electron and the hole SRH times are considered equal. The dark currents are given in Figure 2.

Figure 2

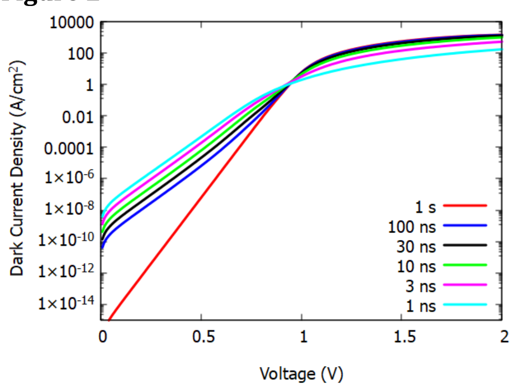

Figure 2 Simulated Dark Current Characteristics of the GaAs PIN Solar Cell for Various Absorber SRH Times

We see that the dark current increases when SRH recombination is accounted for in the absorber layer. Lower the recombination time more is the current. This increasing dark current reduces the open circuit voltage of the solar cell and makes the solar cell inferior. The SRH recombination occurs due to the presence of traps in the absorber layer. The elimination of these trap states is the only way in which the solar cell can be made better. Thus, knowing how much recombination is present (in other words, knowing the SRH time) becomes crucial for device engineers and material scientists. Apparently, the only way to know the SRH time is to fit the experimentally obtained dark current curve to the numerically simulated data.

We take a peek at what all needs to be done usually to know the SRH time.

The Continuity equations for electrons and holes Pierret (1996), in absence of light, and in presence of SRH recombination are given below.

$$D_n \frac{d^2 n}{dx^2} - \frac{\mu_n V}{d_i}\frac{dn}{dx} + \frac{np - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)} = 0 \qquad (1)$$

$$D_p \frac{d^2 p}{dx^2} + \frac{\mu_p V}{d_i}\frac{dp}{dx} + \frac{np - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)} = 0 \qquad (2)$$

Here, Dn is the electron diffusion coefficient, Dp is the hole diffusion coefficient, μn is the electron mobility, μp is the hole mobility, ni is the intrinsic carrier concentration, τn is the electron SRH time, τp is the hole SRH time, n1 is the trapped concentration of electrons, and p1 is the trapped concentration of holes. n and p are the electronic concentration and the hole concentration respectively, and di is the intrinsic layer thickness. V is the voltage, assuming the electric field in the absorber is flat with space which is often the case for a PIN solar cell. The spatial variable is x.

Equations (1) and (2) need to be simultaneously solved to know n(x) and p(x). Then the drfit and diffusion currents for the electrons and holes must be found and added to know the total current of the solar cell. (1) and (2) cannot be solved analytically; a numerical path must be sought.

After numerically solving (1) and (2) the solved current must be fitted to the experimentally obtained dark current to know the SRH times. This procedure is long and cumbersome.

3. PHOTOCURRENT AND ITS SLOPE

Solving for the photocurrent is similar. Equations (3) and (4) must be numerically solved and the solved photocurrent must be fitted to the experimental data which is again lengthy and a detailed procedure. Here G is the generation rate.

$$D_n \frac{d^2 n}{dx^2} + \frac{\mu_n V}{d_i}\frac{dn}{dx} + G - \frac{np - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)} = 0 \qquad (3)$$

$$D_p \frac{d^2 p}{dx^2} - \frac{\mu_p V}{d_i}\frac{dp}{dx} + G - \frac{np - n_i^2}{\tau_p(n + n_1) + \tau_n(p + p_1)} = 0 \qquad (4)$$

The photocurrent simulated in ADEPT 2.1 for our GaAs solar cell is shown in Figure 3.

Figure 3

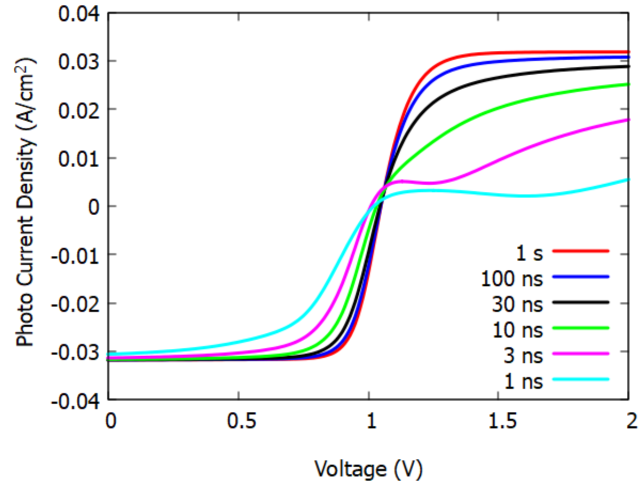

Figure 3 Simulated Photocurrent for Different SRH Recombination Times in the Absorber

We see that the SRH recombination time in the absorber decreases the photocurrent at low voltages, and the photocurrent near the zero-current-point becomes flatter and flatter with decreasing recombination time. In other words, the slope of the photocurrent decreases. Using this information, we decide to plot the first derivative of the photocurrent vs voltage.

The photocurrent of the solar cell, when added to the dark current, yields the total current of the solar cell. With decreasing SRH time of the electrons and holes in the absorber the photocurrent becomes flatter near the zero-current-point which degrades the photocurrent of the solar cell. This also decreases the open circuit voltage of the solar cell. We show the simulated open circuit voltage in Figure 4.

Figure 4

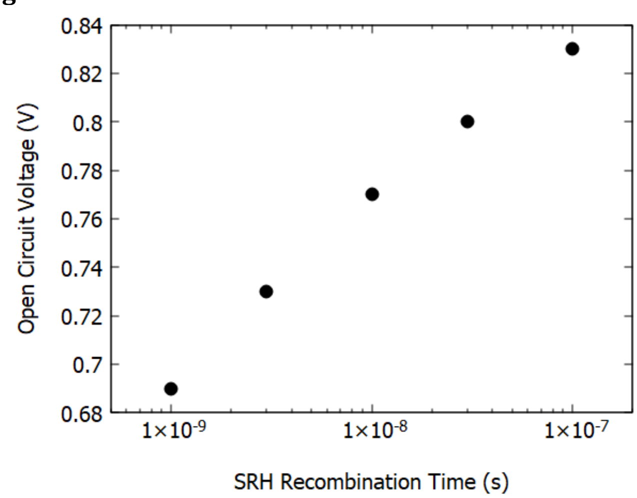

Figure 4 Simulated Open Circuit voltage for the GaAs PIN Solar Cell

The photocurrent of a solar cell can be independently experimentally measured during solar cell characterization. Many literature sources have measured this current using various experimental techniques Sandberg et al. (2020), Limpinsel et al. (2010), Ooi et al. (2008). Some work has also been done on the effect of recombination on photocurrent Wehenkel et al. (2012), Dibb et al. (2011), Liu and Li (2011).

As a central result of this paper, we propose to measure the slope of the photocurrent which can be experimentally measured. The slope of the simulated photocurrent is shown in Figure 5 We see that the slope shows a peak with voltage and this peak of the slope decreases with decreasing SRH recombination time in the absorber. The peak also shifts to lower voltages with decreasing recombination time.

Figure 5

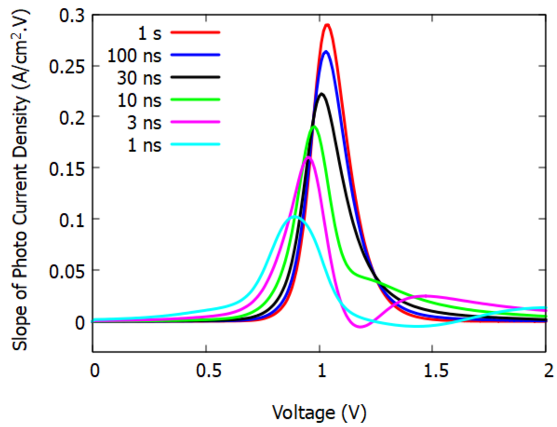

Figure 5 Slope, i.e. the First Derivative, of the Simulated Photocurrents for Various Absorber SRH Times

In this paper, we propose a short way in which the absorber SRH recombination times can be found from the experimental data. The photocurrent must be measured. Then the slope of the photocurrent must be found. The slope will show a peak. This peak value is directly related to the SRH recombination time. Thus, by studying this peak value the SRH time can be directly read from Figure 6 This is the central result of this paper.

Figure 6

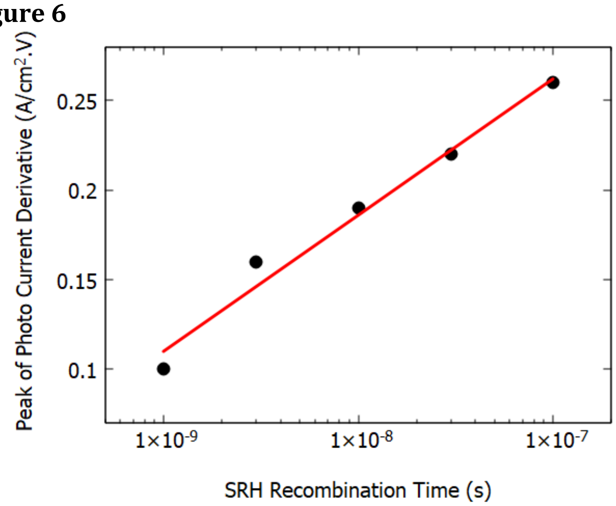

Figure 6 The Peak Values of Figure 5 are Plotted Against the Absorber SRH Recombination Times

We see that the peak value of the photocurrent's slope decreases linearly when plotted in a semilogarithmic scale with decreasing absorber SRH recombination time.

Thus, we propose, from Figure 6 the SRH time can be found easily and quickly by knowing the slope's peak value.

It is to be noted that in Figure 4 the open circuit voltage also follows a linear relationship, in a semilogarithmic scale, with the SRH recombination time. So, then, why not find the SRH time from the open circuit voltage? The answer is simple. The open circuit voltage depends on the SRH recombination time through both the dark current and the photocurrent. Such a dual dependence complicates the dependence of the open circuit voltage on the SRH recombination time. In contrast, the photocurrent depends on the SRH time in an explicit way and by finding its slope we probe that dependence directly.

4. CONCLUSION

In summary, this paper forwards a quick and easy way following which the SRH recombination time in the absorber can be found from experimental data of a solar cell. The proposed method is that the photocurrent of the solar cell should be measured experimentally. Then the slope of the photocurrent will show a peak against voltage. The SRH time depends semi logarithmically on this peak value and by reading the peak value (and using the map which is Figure 6) the SRH time can be found.

CONFLICT OF INTERESTS

None.

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