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Steady state photo carrier grating technique for measurement of charge carrier diffusion length

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Abstract . Steady State Photo carrier Grating technique (SSPG) is fabricated to measure the charge carrier diffusion length in semi conducting thin films The experiment is carried out in some hydrogenated amorphous silicon and silicon germanium alloys, the values of diffusion length are found to be in good agreement with literature

Keywords · Amorphous silicon, silicon germanium alloys, diffusion length, solar cell and photoconductivity

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1. Introduction

The prior knowledge of carrier diffusion length (L_d) in a semiconductor is very necessary in the fabrication and optimization of devices like Solar Cell, Thin Film Transistor etc. Especially for hydrogenated amorphous silicon (a-Si:H) and alloys like amorphous silicon germanium (a-SiGe:H), the value of diffusion length is a very good indicator of the material quality for solar cell application. Hence a number of techniques have been developed for the measurement of L_d, Haynes-Shockley method, Surface Photo Voltage method (SPV) being some of them. Another important method, which is gaining importance, is Steady State Photo carrier Grating (SSPG) method originally developed by Ritter, Zeldov and Weiser [1]. This is a self consistent and self sufficient [2] and at the same time very simple and versatile method for routine characterization of L_d. In this paper we report the instrumentation of SSPG that we have done in our laboratory and results of some L_d measurements carried out for some a-Si:H and a-SiGe:H alloys.

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2. Theory

When the two coherent light beams superpose on thin photoconductive film, the resulting light intensity on the sample will be modified due to the formation of photo grating according to the equation,

$$I(x) = (I_1 + I_2)\ 1 + \gamma_0 \frac{\quad}{I_1 + I_2} \cos \left. \frac{2\pi x}{\Lambda} \right) \tag{1}$$

where, I_1 and I_2 are the intensities of interfering beams $\Lambda = \lambda/(2\sin\delta/2)$ is the grating period, λ is the wavelength of light, δ is the angle between the two beams, γ_0 is fringe visibility factor

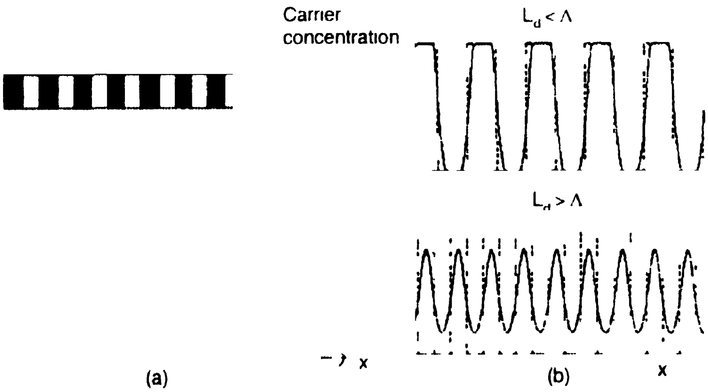

Figure 1. (a) Light Grating (above) and photo carrier grating (below) and (b) Blurring of Carriers for $L_d < \Lambda$ and $L_d > \Lambda$

Due to the formation of photo grating on the sample there will be subsequent formation of photo carrier grating (periodic variation of carriers). Because of the formation of low and high resistance regions photocurrent perpendicular to the grating fringes will be less than the case when there is uniform illumination. After the formation of carrier grating, the carriers will diffuse from high concentration region to low concentration region. If the diffusion length (L_d) is less than the grating period (Λ), carrier grating will persist in the sample and in the other case carrier grating will blur resulting uniform concentration

If $I_2 < I_1$, one can solve the diffusion eqs. [1, 3] to get the photoconductivity as,

$$\sigma(x) = \sigma(I_1 + I_2)\left[1 + A\cos\left(\frac{2\pi x}{\Lambda}\right)\right] \tag{2}$$

where, $A = 2\alpha\gamma_0\gamma \dfrac{\sqrt{I_1 I_2}}{(I_1 + I_2)}$ and $\gamma = \dfrac{1}{1 + \left(2\pi\, L_d/\Lambda\right)^2}$

α - Exponent of power law dependency of σ_{ph} with light intensity, γ_0 = grating quality factor.

The average conductivity perpendicular to the grating fringes σ_g will be,

$$\sigma_g = \Lambda \Big/ \int_0 \frac{dx}{\sigma(x)} = \sigma(I_1 + I_2)\sqrt{1 - A^2} \tag{3}$$

The parameter β, which is the ratio between the photocurrent in the presence and absence of grating, is related to Λ and L_d as,

$$\beta = \frac{J_{\parallel}}{J_{\perp}} = 1 - \left[2\phi \Big/ \left(1 + 4\pi^2 L_d^2 / \Lambda^2\right)^2\right] \tag{4}$$

where, $\phi = \alpha\gamma_0^2$

A little bit of modification of the eq (4) shows that a plot between $1/\Lambda^2$ *vs* $\sqrt{2/1-\beta}$ gives, intercept $= -1/(2\pi L_d)^2$ and slope $= \gamma_0 \alpha^{0.5}/(2\pi L_d)^2$, from where L_d and γ can be found out

3. Instrumentation and Experimental

Figure 2 shows the schematic diagram of SSPG set up for the measurement of carrier diffusion length. The randomly polarized monochromatic light from a laser source (633 nm) is split into two coherent beams with the help of a beam splitter, which are then reflected by two mirrors in Mczhender geometry and then allowed to superpose on the sample The photograting is created by using two polarizers in the path of the beams which are in same state of polarization (P_1 and P_2), whereas for uniform illumination instead of P_2, another polarizer P_3 (cross polarized) is used. In order to measure the

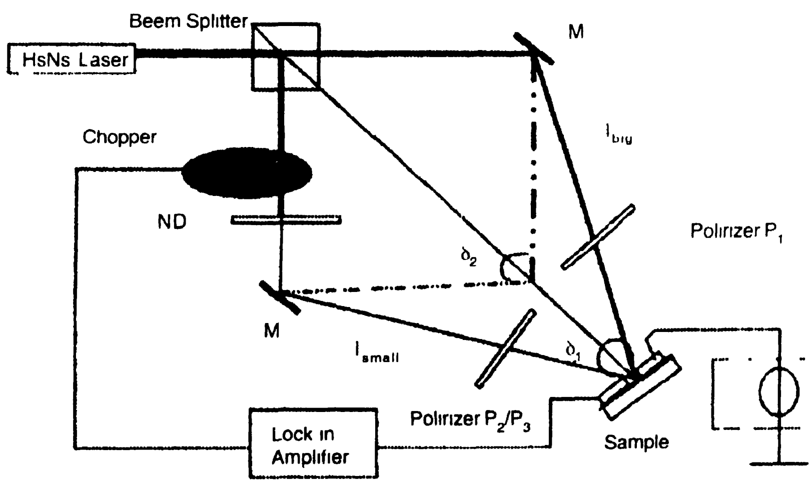

Figure 2. Schematic diagram for diffusion length measurement by SSPG

carrier diffusion length, we modulate the optical grating on a uniformly illuminated background and measure the change in photoconductivity due to diffusion of carriers using an optical chopper and lock-in amplifier. We use one ND filter to reduce the intensity of the chopped beam to 10% of the other beam. The signal is fed to the lock in amplifier (LA) across a load resistance (R_L). Hence the signal monitored by the LA will be proportional to $\sigma_g \quad \sigma(I_1)$ when there is grating formation and $\sigma(I_1 + I_2) - \sigma(I_1)$ when there is no grating. So,

$$\beta = \frac{\sigma_g \quad \sigma(I_1)}{\sigma(I_1 + I_2) - \sigma(I_1)} \tag{5}$$

This experimental parameter β is measured as a function of Λ by varying the angle between the beams This is done by rotating the mirrors. For easy and precise movement of the mirrors they are mounted on gymble mounts.

4. Results and discussions

We have performed the SSPG experiment on some hydrogenated amorphous silicon (prepared by PECVD technique from precursor gas SiH_4) and silicon germanium alloys (prepared by PECVD, precursor gases Si_2H_6 and GeH_4). The values of diffusion length we have got are in agreement with literature. Table 1 gives the deposition condition and

Table 1. Deposition conditions and L_d values for a-SiGe H films

Sample	$R \; \frac{[GeH_4]}{[Si_2H_6]}$	Thickness (μm)	Band gap (eV)	H Conc (%)	α	γ_0	L_d(nm)
GD 357	0 72	0 7	1 48	9 8	0 57	0 99	105
GD 359	0 36	0 7	1 65	14 2	0 76	1 0	126
GD361	0 00	07	1 84	16 4	0 82	0 96	140

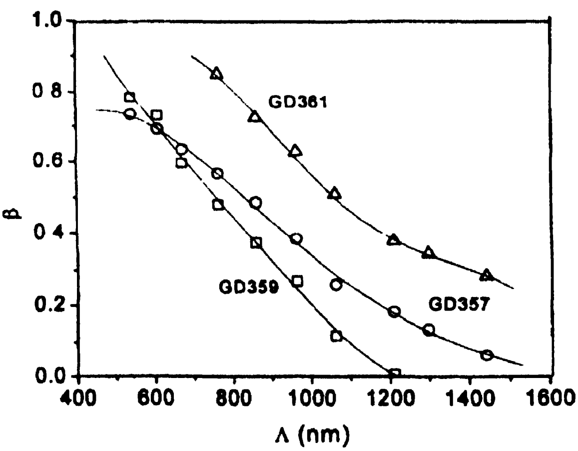

Figure 3. $\beta - \Lambda$ curve for a-SiGe H films

diffusion length of some of the a-SiGe:H films. Figure 3 shows the β *vs* Λ curve while Figure 4 shows the $1/\Lambda^2$ *vs* *sqrt* $\{2/(1-\beta)\}$ curve for the films. Though we have reported here only the results of a-SiGe:H films in details, other series of films (a-Si:H) also show diffusion length around 100 nm.

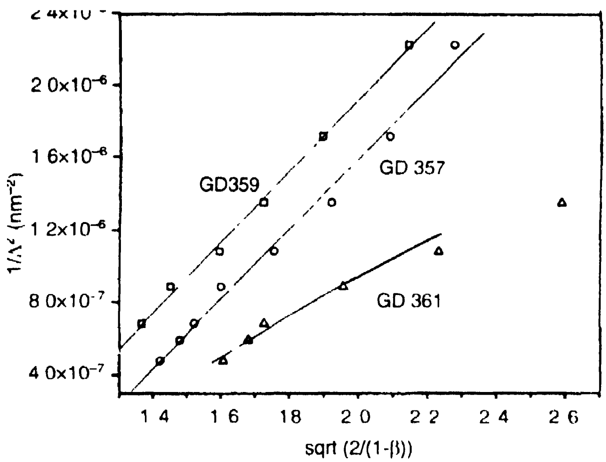

Figure 4. $1/\Lambda^2 - \sqrt{2/(1-\beta)}$ curve for a-SiGe H films

While performing the SSPG measurements there are a few points to be taken care of. In the first place, because of the difference in the transmittance of the polarizers', intensity of weak beam may be different depending on whether it is crossed polarized or same polarized. So it is very important to ensure that the intensity of the weak beam is the same in both the cases. This ensures that the difference in photocurrent is coming from the actual formation of grating and it is not an artifact. Secondly, one beam should be much weak compared to the other; the theory is valid for that approximation only. Otherwise large modulation of carrier concentration will cause band bending, which makes the transport drift limited. Another important point is that the bias voltage should be sufficiently small so that conductivity comes from diffusion of carriers only and not from drift. We put the polarizers after the mirrors to avoid the mirror-induced polarization. The load resistance (R_L) has also to be optimized so as to get good signal and at the same time it should not modify the current in the circuit. The theory presented here is valid for insulating films (dark conductivity negligible compared to photoconductivity). For films having good dark conductivity, the theory has to be modified and the effect of dark conductivity has to be taken into account [4].

5. Conclusion

In this paper we have presented a simple and versatile technique for the charge carrier diffusion length measurement. This technique further can be used for the density of state determination in semiconductors [5].

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