Photoconductivity in a-Si:H – a point of view

1. Introduction

In this work some experimental results concerning the photoconductivity of n-type a-Si:H layer samples obtained by glow discharge technics are presented. The lux-ampere characteristics are considered and plotted in a double-logarithmic scale. Their shapes may be approximated by some straight lines with variable slopes depending both on the temperature and the electric field in which the photo-carriers are generated. These experimental data are explained in the frame of a model including electron trapping and the recombination kinetics based on the energy band diagram with continuous distribution of gap states in semiconductors proposed initially by Rose [10] and extended by Wronski and Daniel [3] to the case of a-Si:H samples.

2. Fundamental notions

Briefly, the main theoretical models/notions used in this work, are:

- ✓ The conductivity in the presence of external photoexcitation is $\sigma = \sigma_0 + \delta\sigma_{ph}$, where $\sigma_0 = e\mu n_0$ is the dark conductivity and $\delta\sigma_{ph} = e\mu\,\delta n$ is the photoconductivity. (e is the electron charge, n_0 the dark free electron concentration, δn the photoelectron concentration due to the light excitation, and μ the electron mobility in the conduction band (extended states for electrons);
- ✓ The concentration of photogenerated electrons δn may be obtained by the well-known photoconduction law $\delta n = G\ \tau_n\ (\delta n)$ with G = the volume photogeneration rate of free carriers and $\tau_n(\delta n)$ = the electron lifetime (a function on the photoelectron concentration;
- ✓ the lifetime τ_n is given by $\tau_n = (v_T S_n p_r)^{-1}$ where v_T is the electron thermal velocity, S_n, the electron capture cross section, and p_r the density of electron recombination centres. The location of the recombination centres is defined by demarcation levels which are closely coupled to the quasi-Fermi levels.

After calculations showed in https://doi.org/10.1002/pssb.2221790224 the photoconduction law becomes:

$$\delta n = \frac{\alpha G x}{T^{3/2}} \cdot \left(\frac{N_C}{n_0}\right)^x \cdot \left[\left(\frac{n}{n_0}\right)^x - 1\right]^{-1}$$

where $x=T/T_C$, $\alpha = (m/3k_B^3)^{1/2} \cdot (1/AS_n)$, $n=n_0+\delta n$, with all notations described in the published paper. This is a transcendental equation in δn which may be numerically solved.

The alternatives are to consider limit cases:

i) Low light intensity => $\delta n \sim G$

ii) High light intensity => $\delta n \sim G^{(1/(1+x))}$

iii) High light intensity and the concentration of the photogenerated carriers exceeds the density of recombination centers, p_r , $\delta n \sim G^{0.5}$.

3. Experimental

3.1 Sample preparation and measurements details

The n-type a-Si:H film samples have been deposited by rf discharge decomposition of SiH_4 (diluted 5% in argon) and PH_3; the sample substrates were optical glass. The sample deposition: 600nm.

The electrical measurements have been made on ring-type configuration with the gap of the coplanar Al electrodes of about 70 μm. All the measurements have been carried out in the temperature range 290 to 360 K, in a vacuum cryostat (≈10^{-2}Pa) having a thermocouple in good contact with the sample. Electrical fields corresponding to voltage in the range 0.5 V to 18 V have been applied between the two electrodes to drive the photo-generated carriers. The dark current-voltage characteristic exhibited ohmic behavior.

The photoconductivity has been measured on known and reproducible states of electrical conductivity for various values of the light intensity ranging from 10^{12} to 10^{15} photons cm^{-2} s^{-1}. The measured photocurrent values have been significantly greater than the dark current values and the photocarrier generation may be considered as uniform [11].

3.2 Results

The lux-ampere characteristics are plotted in double logarithmic scale, $\lg I_{ph} = f(\lg \phi)$, where I_{ph} is the photocurrent and Φ is the light flux (ranged between 10^{13} and 10^{15} cm^{-2} s^{-1}). In Fig. 1 these characteristics are plotted for various driving electric fields between the electrodes at a temperature T = 290 K and in Fig. 2 the same dependence is plotted for various ambient temperatures at a driving electric field E = 1.43 x 104 V/m.

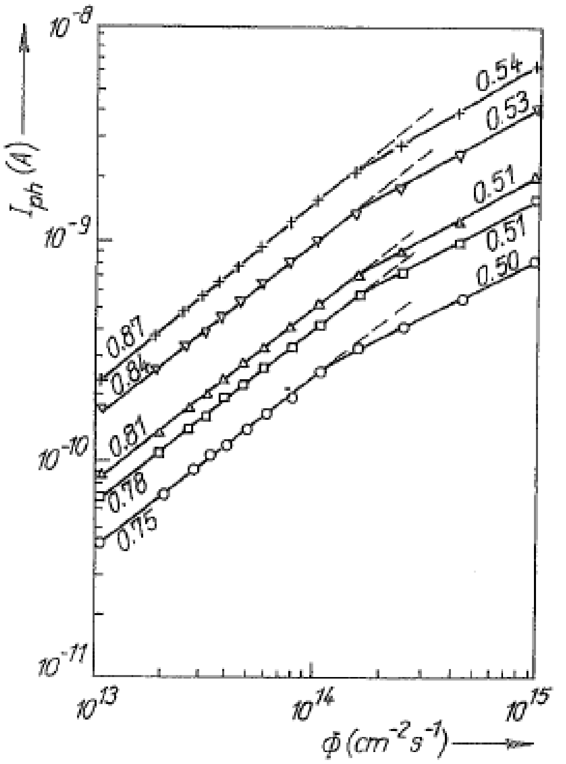

Figure 2. Photocurrent vs. light flux at ambient temperature T=290 K for several driving electric fields: o 7.4x10^3, □ 1.14x10^4, Δ 1.43x10^4, v 2.26x10^4, + 3.68 x10^4 V/m

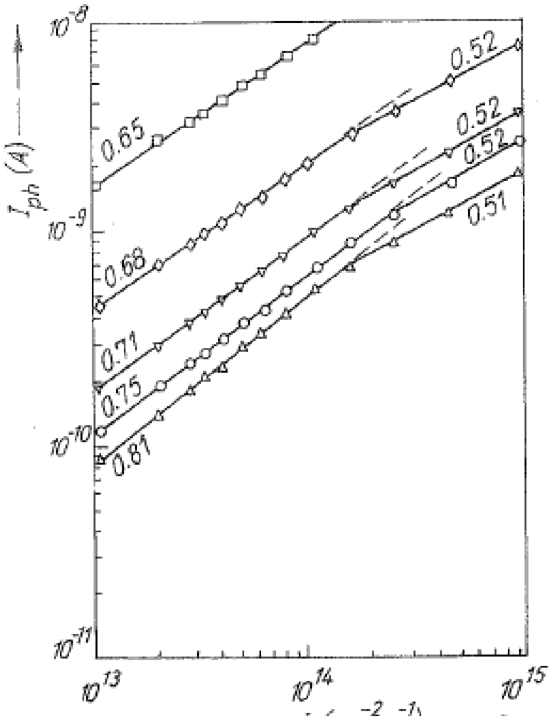

Figure 1*. Photocurrent vs. light flux for a driving electrical field E=1.43x10^4 V/m at several temperatures: Δ T=290 K, o 305K, v 320K, ◊ 340K, □ 360K*

The experimental data may be approximated by two straight lines with distinct slopes. This behavior agrees with that mentioned in [3, 4].

The first group of straight lines has slope values (the parameter γ) between 0.75 and 0.87, while the second group of straight lines reveals γ in the range 0.50 to 0.54.

Therefore, the behavior of the dependence lg $I_{\text{ph}} = \gamma$ lg Φ agrees with that described in cases (ii) and (iii) for high light intensity. The second group of straight lines may be taken with enough accuracy as case (iii) considering approximatively γ = 0.5. Both interpretations, based on the bimolecular recombination model [1], explain satisfactorily the dependence $I_{\text{ph}} \sim \Phi^{0.5}$.

Because of this in the following we shall analyze the first group of straight lines characterized by a variable parameter γ in the range 0.5 to 1 presenting a significant departure from the case described commonly by bimolecular recombination. One may observe that the variable $x = T/T_0$. satisfies the transcendental equation

$$Lg\, x = x \cdot Lg\left(\frac{\delta n}{N_C}\right) + Lg\left(\frac{\delta n \cdot T^{3/2}}{\alpha \cdot G}\right)$$

which has been solved graphically.

A special attention was paid to the dependency of the γ parameter versus the electrical field and the measurement temperature. This is suggestively presented in *Figure 3* and *Figure 4*.

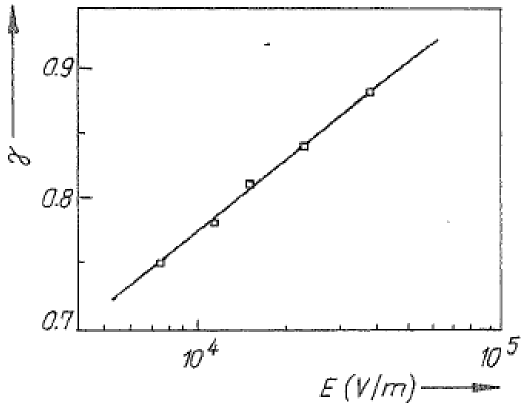

Figure 4. The γ parameter versus the electric field for T=290K

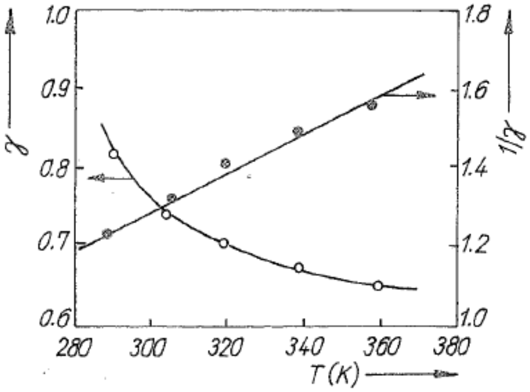

Figure 3. The dependence of the γ parameter on temperature for electrical field of 1.43 10^4 V/m