PHOTOCONDUCTIVITY AND RELATED MEASUREMENTS OF THE CONDUCTION BAND TAIL IN a-Si:H

R. Street

To cite this version:

R. Street. PHOTOCONDUCTIVITY AND RELATED MEASUREMENTS OF THE CONDUCTION BAND TAIL IN a-Si:H. Journal de Physique Colloques, 1981, 42 (C4), pp.C4-575-C4-578. <10.1051/jphyscol:19814125>. <jpa-00220743>

HAL Id: jpa-00220743
https://hal.archives-ouvertes.fr/jpa-00220743
Submitted on 1 Jan 1981

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
PHOTOCONDUCTIVITY AND RELATED MEASUREMENTS OF THE CONDUCTION BAND TAIL
IN a-Si:H

R.A. Street
Xerox Palo Alto Research Centers, Palo Alto, California 94304, U.S.A.

Abstract. - Different measurements based on transient photoconductivity and luminescence are identified which give information about the band tail width in an amorphous semiconductor. We report measurements using these techniques on a-Si:H films which were deposited under the same deposition conditions and compare the results.

Introduction. - Studies of drift mobility by the time-of-flight technique often find a dispersive response in amorphous semiconductors. The effective drift mobility \( \mu_D \) is time dependent and given by

\[ \mu_D = \mu_0 t^{(1-\alpha)} \] (1)

Recent experiments interpret the dispersive mobility in a-Si:H based on a multiple trapping process in an exponential band tail (1). Within this model the dispersion parameter \( \alpha \) is given by \( T/T_0 \) where \( T \) is the temperature and \( T_0 \) is a parameter related to the exponential energy distribution of tail states \( \exp(-W/W_0) \) by

\[ W_0 = kT_0 \] (2)

For electrons, Tiedje et al. (2) have reported a value of \( T_0 \) of 312K, and that \( \alpha \) is approximately proportional to \( T \).

Luminescence measurements have been suggested as an alternative way of obtaining the same band tail parameter in chalcogenide glasses. The temperature dependence of the luminescence intensity \( I_L \) is given by (3)

\[ I_L = I_0 \exp(-T/T_L) \] (3)

There have been several attempts to explain this relation. One of the most recent suggestions by Higashi and Kastner (4) uses essentially the same idea of carrier release from an exponential band tail as used in the drift mobility. The optical excitation is assumed to populate tail states with equal probability. An occupied tail state at depth \( E_D \) has a radiative rate \( \tau_R^{-1} \) and a non-radiative rate of \( \nu_0 \exp(-E_D/kT) \). Therefore, the shallow carriers will be thermally released while the deeper carriers will recombine giving luminescence. Higashi and Kastner (4) show that the luminescence intensity is then given by Eq. 3 with

\[ T_L = \frac{W_0}{k \ln(\nu_0 \tau_R)} = \frac{T_0}{\ln(\nu_0 \tau_R)} \] (4)

This paper presents measurement of the drift mobility by transient photoconductivity and of the temperature dependence of luminescence in a-Si:H samples made under the same deposition conditions. We also show that the temperature dependence of the luminescence peak energy
provides another measurement related to the band tail width. The different measurements are compared.

**Transient Photoconductivity.** - The photoconductivity measurements were made in a gap cell geometry under conditions of uniform illumination. The samples are made by glow discharge decomposition of SiH₄ as described elsewhere (5). By a suitable choice of deposition conditions, the defect density can be made to vary from ~3x10¹⁵ cm⁻³ to above 10¹⁷ cm⁻³. Assuming an effective mobility as given by Eq. 1, the rise, decay and steady state photoconductivity is given by

\[
\sigma_{ph}(t)=G\mu_0 t^\alpha / \alpha
\]

(4)

\[
\sigma_{ph}^D(t)=GT_p\mu_0 t^{(1-\alpha)}
\]

(5)

and

\[
\sigma_{ph}^{SS}=G\tau\mu_0(\tau)/ \alpha
\]

(6)

where T_p is the pulse length, \(\tau\) is the recombination time and G is the excitation density. For the rise and decay, it is assumed that \(t<<\tau\) and \(T_p<<\tau\).

![Fig. 1](image1.png)

**Fig. 1** The onset of photoconductivity in a-Si:H over two different time scales. The upper curve shows that a steady state can be observed by increasing the illumination intensity.

![Fig. 2](image2.png)

**Fig. 2** Values of the time-dependent mobility obtained from the photoconductivity. Samples a, b and c have spin density ~3x10¹⁵, 10¹⁷ and 2.2x10¹⁷ cm⁻³ respectively. The squares are obtained from Eq. 6, and the other data from Eq. 4. The dashed line shows decay data (Eq. 5) for sample a. Inset is the intensity dependence of \(\sigma_{ph}^{SS}\) for sample a.
Experimental data that confirm Eqs. 4-6 are shown in Figs. 1 and 2. Fig 1 shows that the rise is proportional to $T^\alpha$ with $\alpha \approx -0.4$, provided the excitation density is sufficiently low. The recombination is bimolecular so that as the excitation density is increased, $\tau$ decreases and a steady state photoconductivity is reached. An example of this is shown in Fig. 1. Fig 2 shows that the transient decay follows Eq 3, again with approximately the same value of $\alpha$. The magnitude of the effective mobility is obtained independently from Eq. 1 and Eq. 3 since $G$ is known and $\tau$ can be measured. Fig. 2 shows that these data agree well, giving extra confidence in the measurements. The drift mobility in samples with spin density $\sim 3 \times 10^{15} \text{cm}^{-3}$ is $\sim 1 \text{cm}^2/\text{Vsec}$ at the shortest times, decreasing to $10^{-4}$ at 1 sec. As the spin density $N_s$ is increased by changing the sample deposition conditions, the mobility decreases approximately inversely with $N_s$.

The high values of mobility at short times agree with the electron mobility data measured by time-of-flight in similar samples (Rosenblum, private communication), and is in accordance with the widespread assumption that photoconductivity is carried by electrons. There are two possible explanations for the dependence on the dangling bond density. One is that the mobility is trap limited by these states, although this result is contrary to other measurements which have concluded that the mobility is intrinsic to the band tails (1, 2, 7). The second possibility is that the deposition condition which result in a large defect density, also change the density of tail states. We have no further evidence for either of these models except to note that the value of $\alpha$ decreases slightly in samples of high spin density, indicating that $W_0$ may increase (see Fig. 3).

Luminescence - Collins et al. (8) have pointed out that the temperature quenching of luminescence in many different samples of a-Si:H obeys Eq. 3. For low defect density samples made under identical deposition condition as for the transient photoconductivity, the value of $T_L$ is 20K. The average radiative lifetime in the same sample is approximately $10^{-4}$ sec (9) and assuming $\nu_0 \sim 10^{12} \text{sec}^{-1}$ in eq. 4 gives $\ln(\nu_0 T_R) \approx 21$ and $T_0 \approx 420$K.

The luminescence model (4) implies that the average binding energy of the electrons participating in the radiative transition increases with temperature as $kT \ln(\nu_0 T_R)$, because electrons with smaller binding energy will be thermally released in the non-radiative process. Since the dominant luminescence is believed to be a transition from the conduction band tail (9), there should be a corresponding decrease in the luminescence energy. Fig. 4 shows that indeed the peak energy decreases with temperature much faster than the band gap energy, the coefficients being $1.8 \times 10^{-3}$ eV/K and $4.3 \times 10^{-4}$ eV/K respectively (9). The difference between these values is 16k and agrees fairly well with the predicted value of $k \ln(\nu_0 T_R)$ which is 21k. Note that any similar contribution from the hole states is neglected. If holes are trapped deeper than the electrons, as indicated by their lower mobility, then the distribution should not change substantially with temperature over the measured range.

![Fig. 3](image-url) Fig. 3 Temperature dependence of the luminescence peak energy compared to that of the band gap energy (from ref. 9).
Discussion. - The band tail width $W_0$ estimated from the temperature dependence of the luminescence intensity is $kT_0 = 35$ meV. If the value of $\ln(\rho_0\tau_R)$ from the temperature dependence of the peak energy is used, then $W_0$ is reduced to 28 meV. From the transient photoconductivity $\alpha$ is 0.4 at room temperature which gives a value of $W_0$ of 65 meV, approximately twice that obtained from luminescence. However, the drift mobility reported by Tiedje et al. (2) by time-of-flight gives $W_0 = 27$ meV which is in excellent agreement with the luminescence data. It is not clear why the transient photoconductivity data gives a different result. However, both the high temperature luminescence and time-of-flight data occur on a time scale generally less than 10 $\mu$sec, whilst the data of Fig. 2 extends to 1 sec, and therefore different processes may be important. Despite this difference, the overall consistency of the interpretation provides good support for the models based on trapping in band tails for both the drift mobility and the luminescence data.

Acknowledgment. - This work is supported by the Solar Energy Research Institute under contract XJ-0-9097-0.

References.