RELAXATION OF PHOTOINDUCED SUB-BANDGAP ABSORPTION IN a-Si:H

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ABSTRACT

The decay of photoinduced sub-bandgap absorption (PA) following pulsed excitation was studied in the temperature range 80 - 305K, in a-Si:H samples prepared by glow discharge and sputtering. The decay was interpreted in terms of bimolecular diffusion limited recombination involving dispersive transport of electrons and was used for the determination of the dispersion parameter α. It was found to be a linear function of T in the glow-discharge sample while it was weakly T-dependent in the sputtered sample. In addition, a first measurement of the time evolution of the PA spectrum is reported.

INTRODUCTION

Photoinduced sub-bandgap absorption (PA) under steady illumination has been observed in tetrahedrally bonded amorphous semiconductors.[1] A first study of the relaxation of PA in doped and undoped a-Si:H following pulsed excitation has also been recently reported.[2] In this work the recombination of excess carriers was found to follow a diffusion limited bimolecular kinetics with a time dependent rate coefficient $b = B/t^{1-\alpha} (0 < \alpha < 1)$. This is a consequence of the dispersive nature of the transport characteristic of amorphous materials.[3] In this paper we extend the previous work to PA decay studies in a-Si:H as a function of sample preparation. We found different temperature dependences of the dispersion parameter α in the samples prepared by glow discharge (GD) and sputtering (SP); this indicates different modes of carrier transport in the two kinds of materials. We also measured time evolution of the PA spectrum in the sputtered a-Si:H sample at 305K. The shift of the band with increasing time towards higher energy is consistent with the idea of thermalisation of trapped carriers.

EXPERIMENT

The photoinduced absorption was excited by a dye laser pumped with a N_2 laser with the following parameters: photon energy $\simeq$ 2.1eV, repetion rate 20Hz, pulse energy 15μJ, pulse duration 10ns. The estimated carrier density produced by each exciting pulse is $\simeq 10^{18} cm^{-3}$. The transient absorption was probed with radiation from a tungsten lamp in the energy range from 0.7 to 1.4eV. The detection system consisted of a Ge photodiode (Judson J-16 LD), a broad

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band preamplifier followed by a boxcar integrator (PARC 162) and an x-y recorder. The time resolution of the experiment was 500ns. For measuring the time evolution of the PA spectrum, a monochromator was placed between the sample and the detector. The average energy resolution in the spectral range of interest was ≃ 0.03eV.

We report the results obtained on a GD sample with 16 at % H_2 and a SP sample with 19 at % H_2.

RESULTS AND DISCUSSION

Figure 1 shows a log-log plot of the fractional transmission change, $-\Delta T/T$, as a function of the delay time after the laser pulse for several temperatures between 80 and 306K. We note that for both the GD and SP samples the curves approximate a straight line, indicating a power law response, for almost three decades in time. The decay is faster at higher temperatures and is weaker than t^{-1} at all temperatures in both samples.

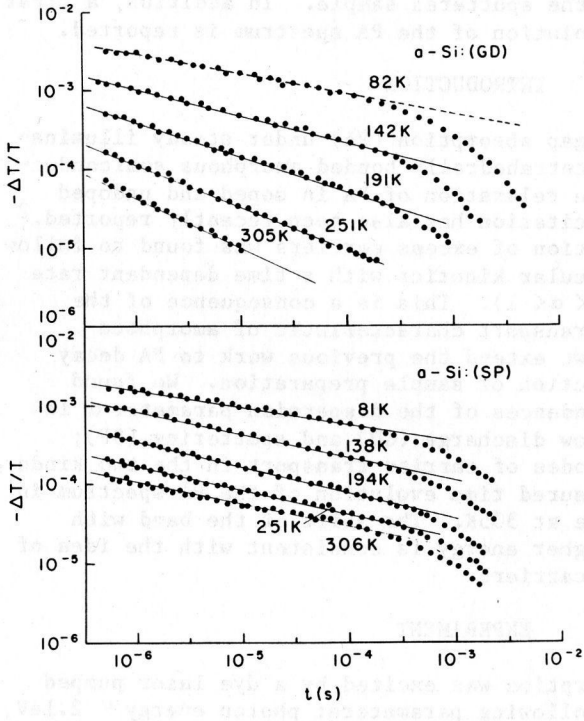

Fig. 1 - PA decay in (a) glow discharge and (b) sputtered a-Si:H as a function of temperature. The dashed line in (a) is a theoretical fit to equation (5) in Ref. 2 with $N_o = 5 \times 10^{18} cm^{-3}$, $B = 2.0 \times 10^{-17}$ and $\alpha = 0.24$.

The straight line portions of the curves in Fig. 1 are followed by a faster decay at longer times. This decay is exponential and its time constant does not depend on temperature. We will not consider these last decays in this paper and in the following will discuss the origin of the decay represented by the straight lines in Fig. 1.

It was proposed that the PA band is due to photo-induced transitions of holes trapped in states close to the valence band into the valence band.[4] In this model, the decay of the PA band is due to the disappearance of the holes by recombination with electrons. Since the mobility of electrons is much higher than that of holes the decay characteristics give us information about the transport of electrons.

Both steady state[1] and transient[2] PA measurements in a-Si:H have indicated that the recombination is diffusion limited bimolecular at the carrier densities produced in the present experiment and obeys the equation

$$dN/dt = -bN^2 \qquad (1)$$

If the coefficient b is constant (time-independent) then N(t) decays as t^{-1} at long times, in contradiction with experimental results. As shown in Ref. (2) we obtain good agreement with experiment if we assume that b is time dependent. The time dependence of b is due to the same dispersive mechanism as that of the mobility μ ($b \sim \mu$)[5]. Taking $b \sim t^{-(1-\alpha)}$ gives at long-times $-\Delta T/T \sim t^{-\alpha}$. Therefore, the values of α could be determined from the slope of the lines in Fig. 1; they are plotted in Fig. 2 as a function of temperature and sample preparation. In a-Si:H sample prepared by glow discharge α was found to be a linear function of temperature $\alpha = 0.075 + 1.9 \times 10^{-3}T$ in the range $82 \leq T \leq 306$K. At 6K the measured α was 0.14; this suggests a saturation of α at low temperatures (T < 80K) indicated in Fig. 2 by the dashed line. In the sputtered sample, α was only weakly temperature dependent.

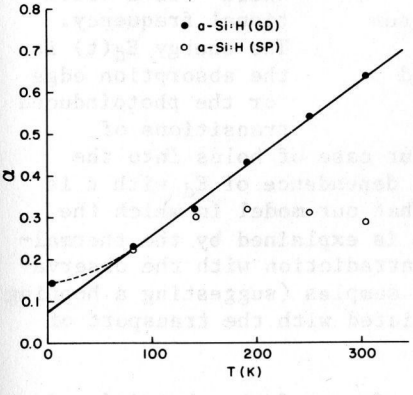

Fig. 2 - Temperature dependence of the dispersion parameter for glow discharge and sputtered a-Si:H.

In the dispersive regime, electron transport occurs either through multiple trapping or hopping. In the GD sample the fairly strong temperature dependence of α shows that trap controlled transport dominates.[6,7] However, the saturation of α at low temperatures and the fact that α(T) curve does not pass through the origin indicate that hopping transport persists as a parallel mode even at the highest temperatues. The dominating linear temperature dependence in the GD sample is consistent with an exponential distribution of trapping states under the conduction band edge, in accordance with the recent observation by Hvam and Brodsky in a-Si:H:P prepared by glow discharge.[8]

The weak temperature dependence of α in SP samples can be attributed to a predominantly hopping mode of transport. The dominance of the hopping transport may be associated with a higher overall density of traps in SP films, perhaps with non-exponential distributions.

The PA spectrum was measured for the sputtered a-Si:H sample at delay times 2μs, 20μs, 0.2ms and 2ms (Fig. 3) The structures which appear in the curves are due to thin film interference fringes which could not be completely averaged out. The spectrum shifts to

higher energy with increasing delay time t and the shifts are approximately equal when t changes by a decade.

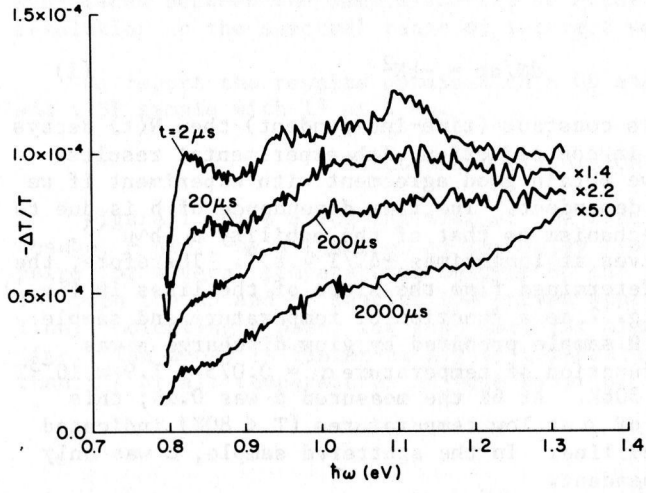

Fig. 3 - Time evolution of the PA-spectrum in sputtered a-Si:H at 305K. Curves at 20 s. 0.2ms and 2ms have been multiplied by factors shown in the figure.

This is in agreement with the model that we proposed for the PA band and the suggestion by Tiedje and Rose, and Orenstein and Kastner (to be published) that the highest occupied trap state of energy (measured from the band edge) moves with time according to the relation

$$E_d = kT \ln (\nu t) \qquad (2)$$

where ν is a vibrational frequency. The energy $E_d(t)$ is the absorption edge for the photoinduced transitions of carriers from traps into the band (in our case of holes into the valence band); the observed logarithmic dependence of E_d with t is consistent with Eq. (2). Let us note that our model in which the time dependence of the PA band spectrum is explained by the thermalization of holes in traps, is not in contradiction with the observation of temperature independent α in SP samples (suggesting a hopping transport mechanism) because α is associated with the transport of electrons.

In conclusion, we have measured the decay of the photoinduced absorption in a-Si:H and interpreted the result with bimolecular diffusion limited kinetics with dispersive transport. The temperature dependence of the dispersion parameter α shows that the transport is predominantly trap-controlled in glow-discharge samples while in sputtered samples hopping transport dominates. The main advantage of this method for determining α over the usual transient photocurrent or drift mobility measurements is that the temperature dependence of α could be measured to very low temperatures. A measurement of the time evolution of the PA spectrum was performed on the SP sample and could be qualitatively explained by thermalization of trapped holes.

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