LOW TEMPERATURE PHOTOCONDUCTIVITY IN a-Si:H FILMS

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The temperature dependence of the photoluminescence, steady state and transient photoconductivity of a-Si:H has been studied between 4 and 500 K. Below 50 K a temperature independent $n\mu\tau$-product of $10^{-11} cm^2/V$ is observed, which varies only little with the defect density. We propose that this mode of photoconduction arises from the drift of photoexcited electrons and holes during their thermalization near the mobility edges. It is shown that photoexcitation of deeply trapped holes by IR-radiation leads to an enhancement of the photoconductivity at low temperature. Time dependent studies yield information on the mechanism of trap emptying.

1. INTRODUCTION

From photoluminescence studies a detailed model for recombination in a-Si:H has been developed[1]. According to this model there should be a close correlation between the luminescence efficiency and the photoconductivity. It is commonly assumed that ionization of localized electron hole pairs is responsible for the temperature dependent quenching mechanism of the photoluminescence. This process leads to mobile carriers which give rise to photoconductivity. There are a number of investigations of photoconductivity and photoluminescence above liquid nitrogen temperature which support this view[2]. However, there are no studies of photoconductivity down to helium temperature although particularly in this temperature range such studies could help to decide whether geminate or distant pair recombination is dominant.

2. EXPERIMENTAL RESULTS AND DICUSSION

The efficiency of the photoluminescence n_{PL} increases with decreasing temperature and attains below 50 K a value of about 30 % in high quality g.d. material (Fig. 1a, PL). Considerably lower values are observed in less perfect films e.g. highly doped or sputtered a-Si:H: $n_{PL} \approx 3$ % and $n_{PL} < 0.5$ % for samples 3 and 4, respectively. There is obviously no close correlation between n_{PL} and the photoconductivity σ_{ph} at low temperature. Below 50 K, σ_{ph} becomes independent of temperature with $n_{PC}\mu\tau \approx 10^{-11} cm^2/V$ (Fig. 1a). It is remarkable that in contrast to the behaviour of the photoluminescence efficiency the $n_{PC}\mu\tau$-product depends only little on the quality of the films. We propose

that σ_{ph} below 30 K arises from photoexcited carriers while thermalizing in states above the mobility edges until they are localized in tail states. Therefore the thermalization time τ_{th} rather than the trapping or recombination time determines the value of the photoconductivity. Since τ_{th} is independent of the carrier density this leads for all samples to a linear dependence of σ_{ph} on the light intensity below 30 K, i.e. $\nu \approx 1$ (Fig. 1b). Furthermore τ_{th} does not depend on the density of defects but is an intrinsic property of the amorphous silicon network, being determined by the density of states near the mobility edges.
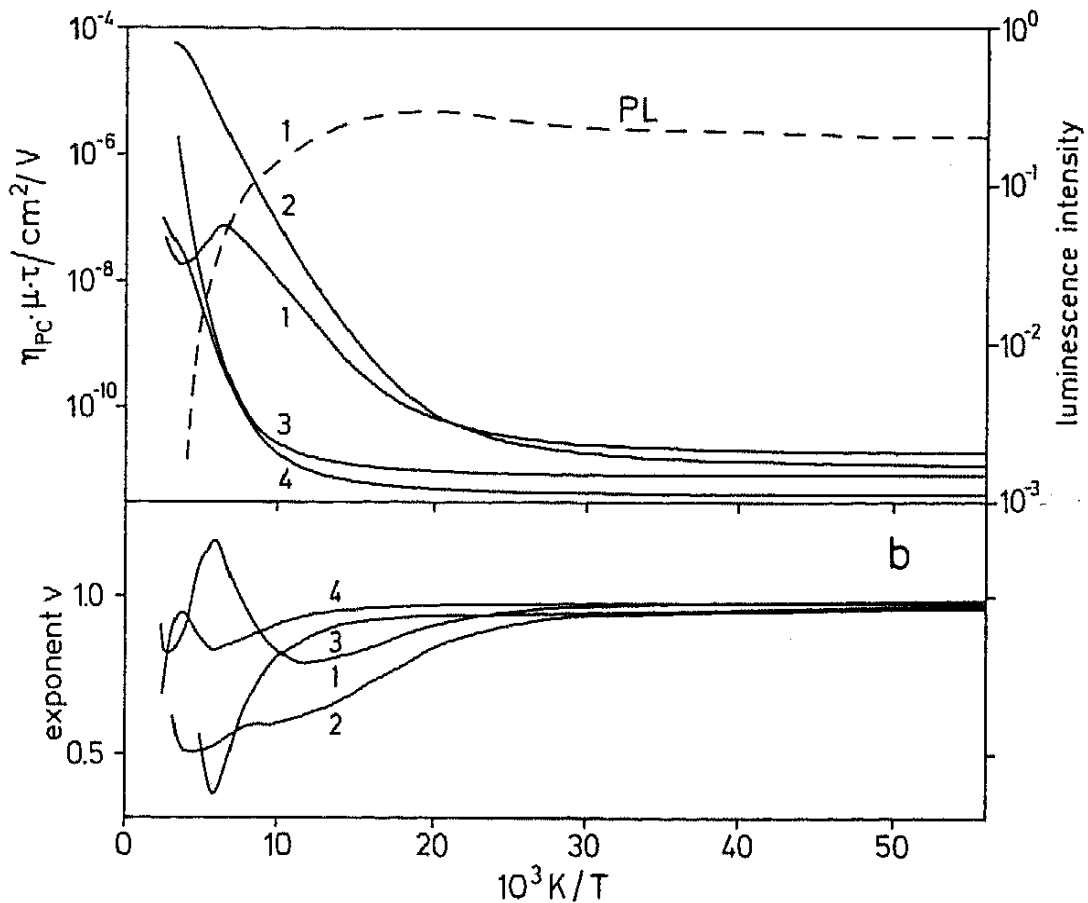

FIGURE 1
Temperature dependence of photoluminescence PL and $\eta_{PC}\mu\tau$ (a), exponent ν of the intensity dependence $\sigma_{ph}\sim g^{\nu}$ (b). Sample 1: g.d. undoped; 2: g.d. 100 ppm PH_3; 3: g.d. 1000 ppm B_2H_6; 4: sputtered undoped.

This interpretation is supported by measurements of the response time τ_R from the decay of the photocurrent[3]. Above 50 K, where trapping and thermal release dominate, τ_R varies between 10^{-2} and 10^{-4} s. Below 30 K the decay is fast ($\tau_R < 10^{-6}$ s) indicating that the photoresponse does not include thermal re-emission from deeper states but is due to the photoexcited carriers thermalizing near the mobility edge.

From the experimental value of the $n_{PC}\mu\tau$-product an estimate for the quantum efficiency n_{PC} can be obtained. Inserting an extended states mobility of 10 cm^2/Vs and a thermalization time $\tau_{th} \approx 10^{-12}$s, one obtains $n_{PC} \approx 1$. Since only carriers contribute to photoconduction which recombine in a non-geminate process, this rough estimate leads to the conclusion, that even at low temperature non-geminate recombination plays a major role.

A consequence of the above interpretation is, that trapping effects becomes increasingly less important when the temperature is lowered. Optical quenching of the photoconductivity is a phenomenon which is typically connected with trapping. It arises when minority carriers, i.e. holes, are transfered by optical excitation from traps to recombination centers. Such behaviour recently has been studied in detail in a-Si:H[4,5,6]. Usually a dual beam method is applied in which the sample is illuminated both with strongly absorbed light (1.9 eV) and with additional IR-light. The resultant change of the photocurrent induced by IR-light (0.7 eV) strongly depends on temperature (Fig. 2). In high quality films (sample 1) optical quenching is observed above 50 K ($\Delta I_{ph} < 0$), whereas below this temperature the photoconductivity is enhanced ($\Delta I_{ph} > 0$). In defect rich films enhancement is observed in the whole temperature range (sample 5). It is reasonable to assume that quenching and enhancement arise from the optical excitation of deeply trapped holes to the conducting states. This behaviour is closely related to the observation of photoinduced absorption[7]. In the present case absorption in the non-equilibrium distribution of deeply trapped holes leads to an enhancement of the photoconductivity at low
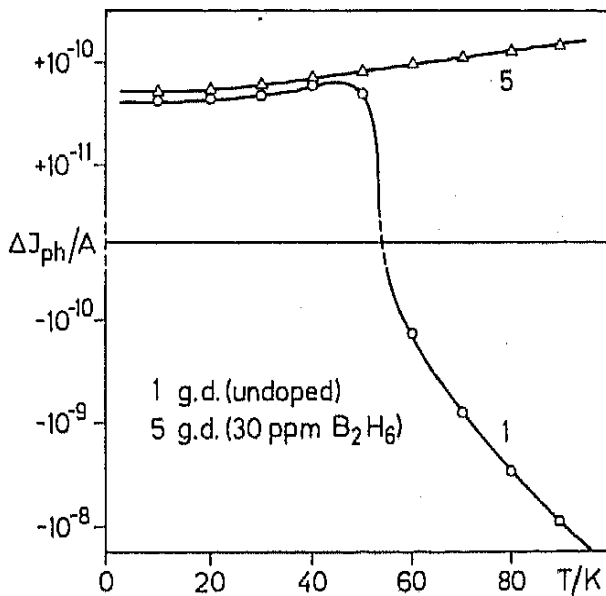

FIGURE 2
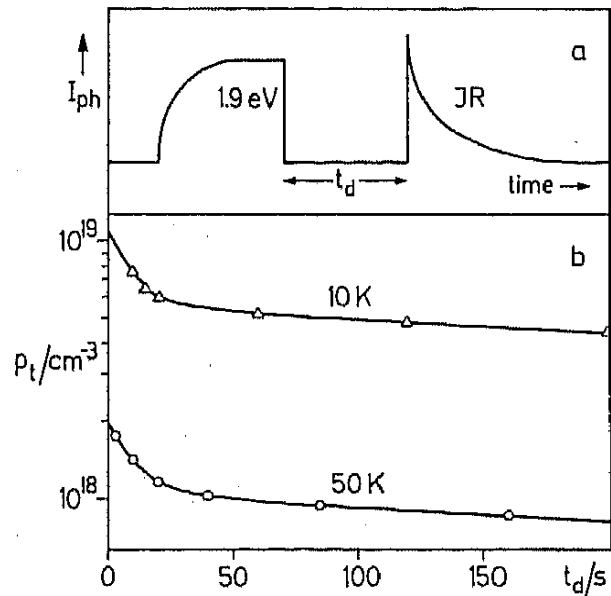ΔI_{ph} induced by additional IR (0.7 eV) versus temperature.

FIGURE 3
Time dependence of photoconductivity (a) and trapped charge density p_t as a function of t_d (b). Details see text.

temperature. It is to be expected that the optical freeing of trapped holes also leads to quenching of the photoluminescence, when electron-hole-pairs are ionized by optical excitation. We have observed this effect in the temperature range 10 - 80 K on sample 1, in which above 50 K quenching of the photoconductivity takes place.

Further information can be obtained by studying the time dependence of the photoconductivity. In this study (Fig. 3) the film is illuminated with strongly absorbed light until a stationary value of σ_{ph} is attained. After illumination, the sample is kept in the dark for a period t_d and then illuminated with IR-light. As a result a photoconductivity-transient is observed which originates from optically freed carriers (Fig. 3a). Assuming that there is no retrapping and that the released carriers move with an $\eta_{pc}\mu\tau$-product of $10^{-11} cm^2/V$ the integration of the current pulse yields for the density of the trapped holes a reasonable number, i.e. $p_t \approx 10^{18} - 10^{19} cm^{-3}$. By varying the delay time t_d the time dependence of the trap emptying during t_d can be studied (Fig. 3b). We found that the decrease of the trap population was independent of temperature between 10 and 50 K. We conclude from this result that tunneling among tail states is responsible for the trap emptying at low temperature. Similar conclusions have been drawn from the resonant changes of the photoconductivity in a magnetic field[8]. This example demonstrates that the investigation of time dependent photoconductivity, particularly at low temperature, yields valuable information on the dynamics of the trap population.

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