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SCLC TRANSIENTS IN a-Si:H - NEW FEATURES AND POSSIBILITIES

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The new possibilities and advantages of SCLC limited TOF transients are demonstrated. First, the effects related with the realistic absorption profile, screening current and effective thickness are used to explain the shift of the "cusp" position with the increasing laser pulse intensity. The model of a full charge extraction is used to explain the observed "extraction" time (t*) and exemplified by c-Si diode. The first results on a-Si:H p-i-n junctions together with the corresponding theory are presented.

1. INTRODUCTION

The drift mobility (μ_D) and deep trapping time (τ_D), characterizing transport of non-equilibrium carriers in amorphous hydrogenated silicon (a-Si-H) are usually deduced from a "small signal" TOF (Time of Flight) measurement, in which the charge generated by light ($Q_o = e \cdot L$) is smaller than the charge on electrodes (CU). Although a high light intensity substantially improves the signal detection, its use is rather limited due to an apparently complicated interpretation of the resulting Space-Charge-Limited Current (SCLC) transients. Recently we have used[1] integral mode TOF under SCLC conditions for finding the transit time (t_{tr}) in the subnanosecond time region. In another paper we have documented[2] that the initial value of the SCL-current provides a reliable method for finding μ_D even at very low temperature (T).

The aim of this paper is to illustrate the other new possibilities and advantages of the SCLC transients, the schematic diagram of which is shown in fig.1. Up to now region II has been studied almost exclusively and the position of a "cusp" was used for finding the transit time. Here we will discuss mainly regions II-IV for which a detailed grasp of region I is important.

2. EXPERIMENTAL DETAILS

The TOF measurements have been done on top quality a-Si:H p-i-n junctions of different thickness,with the negatively charged illuminated p-side. It means we have studied transport of electrons. The standard TOF set-up in the current mode has been used[2].

3. EXPERIMENTAL RESULTS

What happens after the charge generation by a laser pulse for the case that $Q_o > CU$ is illustrated in fig.2. At the beginning all Q_o charges start to move (the starting velocity - dx/dt is the same, see fig. 2b) and this leads to a high screening[3] current (spike in region I - fig.1). The electric field in the generation region ($0 - x_o$) is very quickly ($t < t_{tr}$) screened, the carriers in this region stop ($dx/dt \rightarrow 0$ for $x<x_o$, see

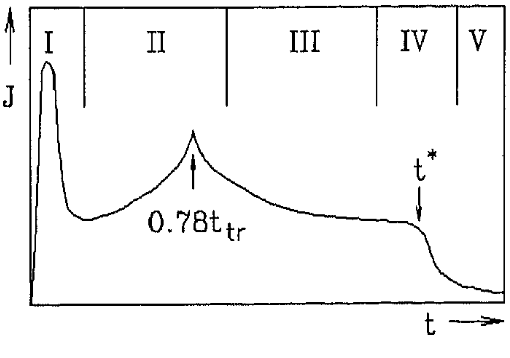

FIGURE 1
The schematic illustration of a typical SCL-Current transient. Divided time regions represent: I - screening, II -extraction of the fastest carriers, III - deep trapping and recombination, IV full charge extraction and V - postextraction transient (see text)

fig. 2b) and only the charge $Q = CU$ continues to move.

The fact that this charge starts to move from $x_0 = (1/\alpha) \cdot \ln L'$ (where $L' = eL/(CU)$) effectively decreases the sample thickness (d).

Fig. 3 shows the room temperature current transient in the small signal case, $L' < 1$, from which t_{tr} was easily deduced and the set of transients with increasing laser intensity for $L' > 1$ (SCLC mode).

First surprising observation was that the position of the "cusp" which should be at 0.78 t_{tr} moves with increasing L' to even shorter time and the initial SCLC current increases with increasing L' above the theoretical value $J_0 = CU/(2t_{tr})$. Both these observations are related with the fact that the effective thickness $(d\text{-}x_0)$ decreases with increasing L', as it is illustrated in fig. 2 a. The full line in the inset of fig.3 is computed for an effective thickness and reasonably follows the experimental results.

A question of basic importance is what information we can gain from region III (see figs. 1 and 3) and what the meaning of time t* is.

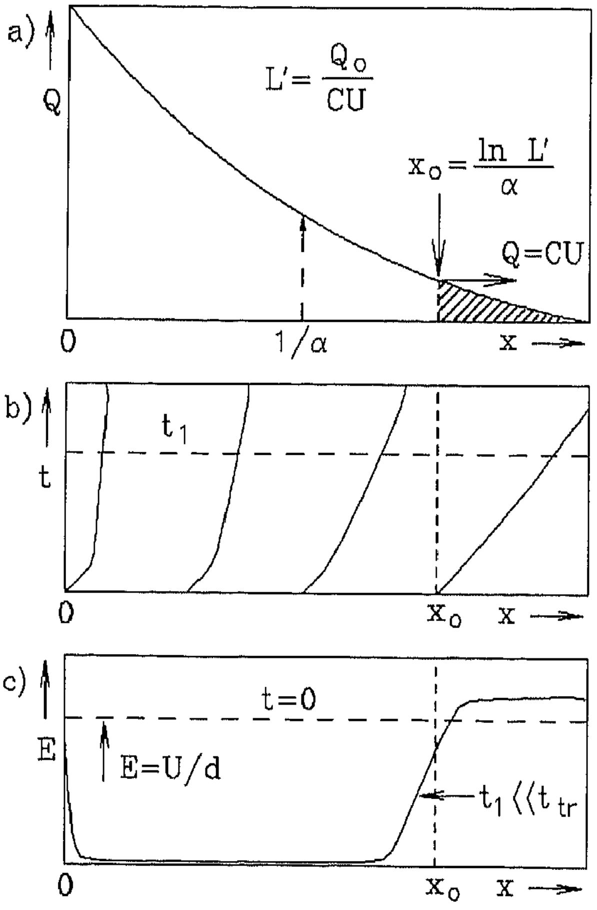

FIGURE 2
Schematic illustration of the effective sample thickness (a), charge movement (b) and el. field (E) screening process (c) following the charge photogeneration for realistic absorption profile when $Q_0 > CU$ (see text)

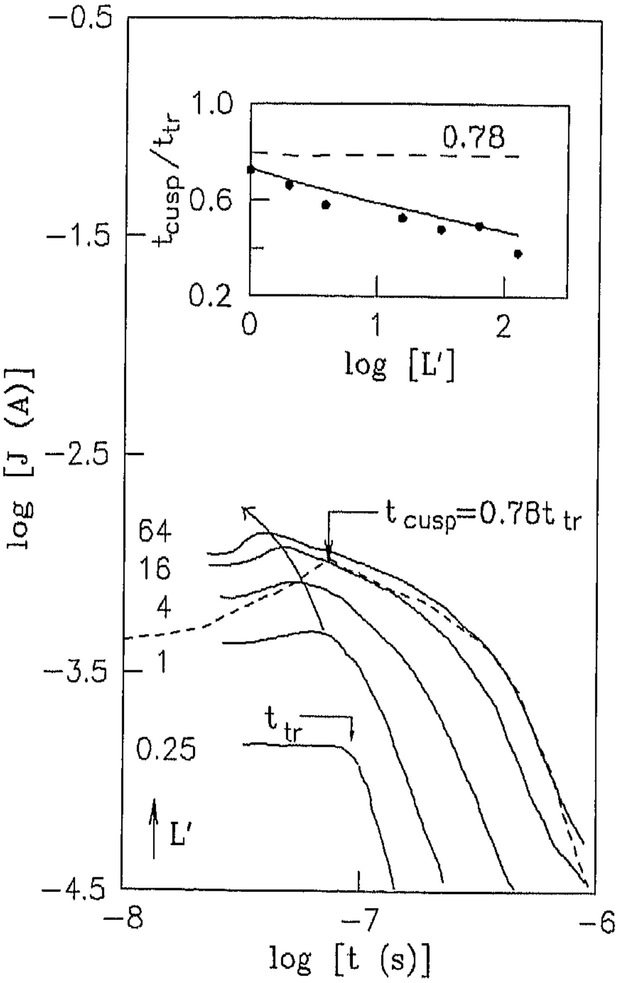

FIGURE 3
Current transient measured on a 5.47 µm a-Si:H p-i-n junction at 300 K and 2 V in small signal case (L'< 1) and SCLC case (L' >1). Shifting "cusp" position is indicated by the arrow. Theoretical SCLC curve is shown for comparison (dashed line). In the inset the normalized position of the "cusp" as a function of laser intensity is shown for theoretical SCLC (dashed line), experimental results from fig. 3 ("o") and calculated for effective thickness (full line).

When the first (CU) charge is extracted, in the current mode another charge from the charge "sitting" in the "reservoir" in the generation region can move up to the full reservoir extraction. If there is no carrier loss it is obvious that t* represents the full charge extraction which is a linear function of intensity $t^* \sim L'$. This ideal situation is convincingly illustrated in fig. 4 by transients, measured on a crystalline Si diode. (The current here was not SCLC but diode internal resistance limited. This does not change the idea).

In the real case there is the loss of carries due to the surface recombination, the recombination in the generation region (where both carriers are present) and the deep trapping in the sample volume. In part III the SCL-current decreases with increasing time due to the volume trapping of the drifting charge. From the slope of ln J (t) in the time region $t_{tr} < t < t^*$ the deep trapping time (τ_D) can be deduced.

We have developed a theory which allows us to find the time (t') necessary to empty the reservoir. Here we illustrate a few specific cases.

For the case of monomolecular recombination in the generation region, characterized by τ_g, we have got

$$t' = \tau' \ln\left(1 + \frac{(L'-1)\ t_{tr}}{\tau'}\right) \tag{1}$$

where $1/\tau' = (1/\tau_g - 1/\tau_D)$. When there is no trapping and no recombination (as in cryst.-Si) or when $\tau_g = \tau_D$, then for $L' > 1$

$$t' = (L'-1)\ t_{tr} \tag{2}$$

The measured time t* is equal to the sum of t' and the transit time of the "last" charge in the SCLC created field $E(x) = 3/2 \cdot (U/d) \cdot \sqrt{(x/d)}$

$$t^* = t' + \frac{4}{3}\, t_{tr} \approx L' \tag{3}$$

When $L' > 1$ and $\tau_g \neq \tau_D$, then $t' \approx \ln L'$ and from the slope of this dependence τ_g can be deduced when τ_D is known (see eq.(1)).

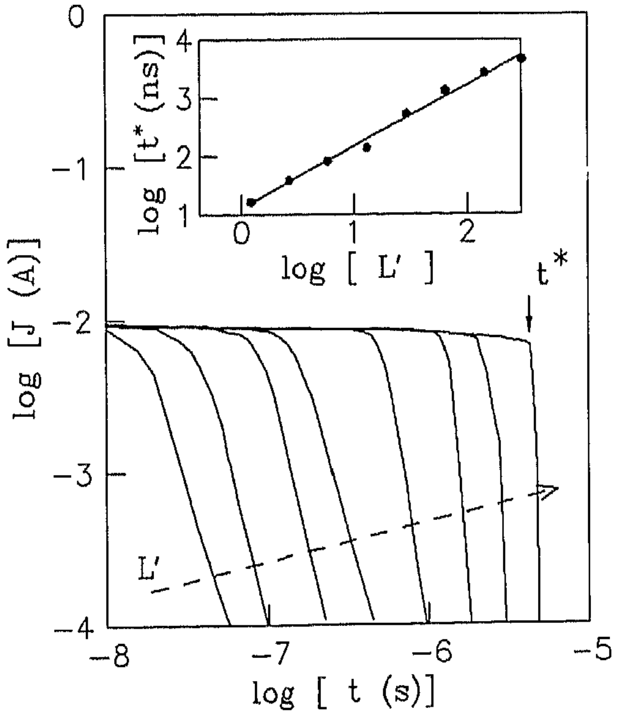

FIGURE 4
Current transients measured on a c-Si diode with laser intensity (L') increasing step by step by a factor of two. In the inset the extraction time (t*) is plotted as a function of L'.

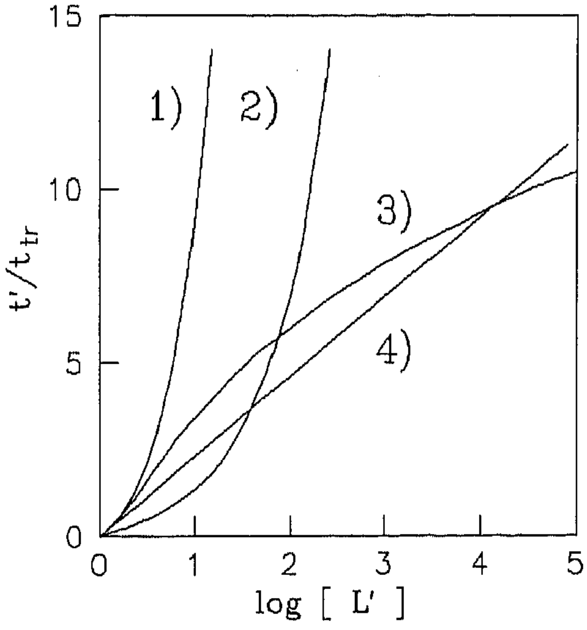

FIGURE 5
Computed time t' (see text) as a function of laser intensity (L') for no recombination and no trapping (1), surface recombination only (2), bimolecular (3) and monomolecular (4) recombination.

For bimolecular recombination with the recombination coefficient γ, the following equation is valid

$$L' = \exp\left(a^2\left(\frac{t'}{t_{tr}}\right)^2\right)\left[1+\frac{\sqrt{\pi}}{2a}\,erf\left(a\left(\frac{t'}{t_{tr}}\right)\right)\right] \qquad (4)$$

$$where \qquad a = \sqrt{\frac{\gamma}{\gamma_o}\frac{\alpha d}{2}} \qquad and \qquad \gamma_o = \frac{\varepsilon\varepsilon_o}{e\mu}$$

(μ is the sum of electron and hole mobilities.)

The theoretical curves for these cases, together with the case of the surface recombination are graphically illustrated in fig. 5.

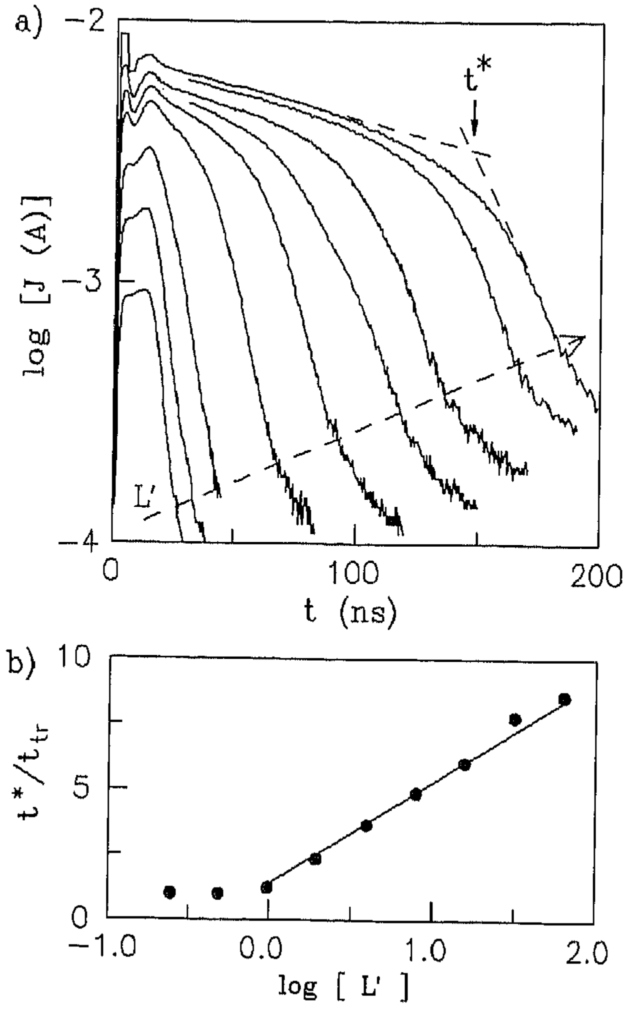

FIGURE 6
a) - Current transients measured at 300 K and 6 V on a 3.9 μm thick a-Si-H p-i-n junction, with laser intensity (L') as a parameter. L' increases step by step by factor of two. b) - The extraction time (t*) as a function of log L'. Note that contrary to the inset of fig.4, here and in fig. 5 the vertical axis is linear.

Fig. 6a shows the experimental current transients for very high L', obtained at room temperature on a 3.9 μm thick p-i-n junction. It is seen that with increasing L' curves become clearly exponential, which allows the simple finding of τ_D = 173 ns.

Extraction time (t*) as a function of log L' is shown in fig. 6b.

From the above equations and the observed dependence $t^* \sim \ln L'$ we can say that the recombination in the generation region is monomolecular and $\tau_g = 42$ ns $< \tau_D$.

We have measured also the temperature dependence of t*. From the preliminary results we have got the same activation energy as for t_{tr}. These results, together with the detailed discussion of region V, (fig. 1) will be discussed elsewhere[4].

To conclude, we have demonstrated new possibilities of SCLC transients. The main advantages, for example in comparison with the delayed-field TOF[5], are as follows. We study the recombination and trapping parameters at a high concentration of carriers, similar to the real situation in solar cells; the photogenerated carriers themselves screen the field; there are no problems with the current spikes related with RC constant and we can use these studies even for thin samples (solar cells) in the extended time region (t* instead of t_{tr}).

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