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Space-charge-limited currents in inhomogeneous thin-film insulators: numerical solutions

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Abstract. Numerical solutions for SCL currents in inhomogeneous insulators with non-uniform trap distributions are presented. It turns out that the non-uniform trap distribution which may be expected in the case of real insulators should have a significant influence on SCL current–voltage characteristics. The experimental results for some organic molecular polycrystalline structures may be interpreted by using the numerical solutions obtained. A method of determination of the spatial trap distribution at the emitter by means of photo-enhanced SCL currents is also presented.

1. Introduction

When the electric current in an insulator results from movement of charge carriers injected into the insulator from electrodes, i.e. when the concentration of the injected charge carriers is greater than the concentration of the intrinsic charge resulting from the equilibrium between the valence band, the conduction band and the states in the gap, we have to deal with space-charge-limited (SCL) currents. The spatial distribution of the electric field becomes dependent on the injected charge, so the current flow is defined by the spatial distribution of the injected space charge in this case. The problem of stationary and transient SCL currents has been the subject of numerous papers (see for instance [1–6]). The traps of charge carriers have a significant influence on SCL currents. In most cases the analysis of SCL currents referred to the spatially uniform trap distribution in an insulator. There are very few papers referring to SCL currents in insulators with a non-uniform spatial trap distribution [7–9]. In this paper the problem of SCL currents in thin-film insulators with a non-uniform spatial trap distribution is discussed. The influence of the non-uniform spatial trap distribution on the shape of SCL current–voltage characteristics is presented. It turns out that some SCLC measurements for polycrystalline films of simple aromatic hydrocarbons may be interpreted if we assume that the spatial trap distribution in these layers is not uniform. The analysis presented suggests that it may be possible to find the spatial trap distribution in the region close to the emitter. The calculations were carried out for typical low-molecular-weight organic materials.

2. Description of the procedure

As we know, the trapping states have a significant influence on the SCL current–voltage characteristics. Most papers describe the case of uniform spatial trap distribution, while the

SCLC problem in dielectrics with a non-uniform trap distribution is treated in only a few papers [7–9]. The conclusions from the latter papers are as follows.

(1) The influence of the traps at the emitter is much greater than that of those at the collector.

(2) In the case of non-uniform spatial distribution of deep traps, both the current–voltage and the current–thickness characteristics change significantly [7, 8].

(3) In the case of shallow traps the non-uniform spatial distribution of traps should not influence the current–voltage curves distinctly and the current–thickness dependence is of the form [8].

$$j \propto \frac{1}{L_{eff}^3} \quad (1)$$

where L_{eff} is the effective sample thickness given by [8]

$$L_{eff} = \left\{ \frac{3}{2} \int_0^L \left[\int_0^z g(x) dx \right]^{1/2} dz \right\}^{2/3} \quad (2)$$

where L is the true sample thickness, and $g(x)$ is the function describing the spatial trap distribution. If $L - L_{eff}$ is much smaller than L (as it usually is), then $L_{eff} \approx L$ and it is not possible to detect the spatial inhomogeneity of the trap distribution from the current–thickness curves. This means that the influence of the trap distribution might become detectable if $|L - L_{eff}|$ is comparable to the sample thickness, i.e. if L_{eff} is either much smaller or much greater than the sample thickness L .

The SCLC problem in dielectrics may be described by the following equations [4]:

$$\frac{dF}{dx} = \frac{e}{\varepsilon\varepsilon_0} (n_f + n_t) \quad (3)$$

$$j = en_f \mu F \quad (4)$$

where F is the electric field intensity, e is the electron charge, ε is the relative dielectric permittivity, and ε_0 is the free-space permittivity. n_f and n_t are the concentrations of the free and trapped charge carriers respectively, j is the current density and μ is the drift mobility of charge carriers. For the purposes of the numerical procedure equation (4) was differentiated with respect to x (assuming $j(x) = \text{constant}$), so we get

$$\frac{dn_f}{dx} = -\frac{n_f}{F} \frac{dF}{dx}. \quad (5)$$

The solutions were found for the following spatial distribution of traps:

$$N_t(x) = N_1 \left(\exp\left(-\frac{x}{D}\right) + \exp\left(-\frac{(x - x_b)^2}{2\sigma^2}\right) + \exp\left(-\frac{L - x}{D}\right) \right) \quad (6)$$

which may be suggested to be suitable for a thin-film polycrystalline insulating structure with one intergrain region perpendicular to the electric field between the electrodes. x is the distance from the emitter. The spatial trap distribution at the electrode is assumed to be exponential (D describes this), while for the spatial trap concentration in the intergrain regions it is assumed that the drop of the trap concentration as a function of the distance from the electrodes is given by the gaussian distribution (σ is the standard deviation). $D = 0.1 \mu\text{m}$ [9], $\sigma = 0.1 \mu\text{m}$ [9], and $x_b = 3 \mu\text{m}$. The value of x_b gives the position of the intergrain region; it was obtained from electron micrographs of polycrystalline simple aromatic hydrocarbon films [10]. The value of D was estimated for typical thin-film structures of simple aromatic hydrocarbons. N_1 was assumed to be equal to 10^{20} m^{-3} ,

$3 \times 10^{20} \text{ m}^{-3}$ and 10^{21} m^{-3} . These values are results for real concentrations of traps in comparatively good (the first value) and in imperfect (the last one) molecular crystals [11]. The occupation of traps is given by

$$n_t(x) = (N_t(x) + N_0) / \left(1 + \frac{N_e}{gn_f} \exp\left(\frac{-E_t - E_c}{kT}\right) \right) \quad (7)$$

where N_e is the effective density of states in the conduction band, g is the degeneracy factor, and N_0 is the spatially uniform concentration of traps characteristic of comparatively perfect monocrystals. N_0 was assumed to be equal to 10^{19} m^{-3} . E_t is the energy of the trapping level and E_c is the energy of the bottom of the conduction band.

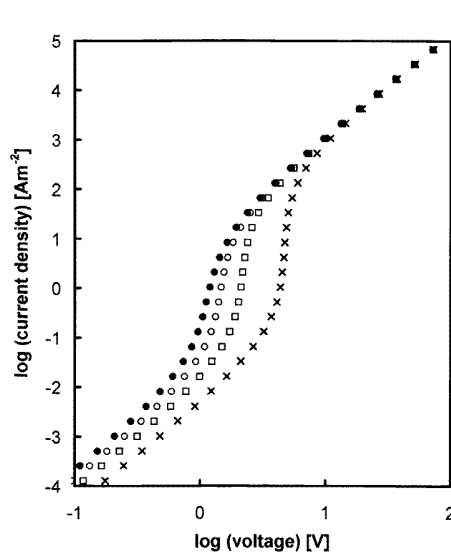


Figure 1. SCL current–voltage dependencies for various surface concentrations of traps: ●, $N_1 = 0$; ○, $N_1 = 10^{20} \text{ m}^{-3}$; □, $N_1 = 3 \times 10^{20} \text{ m}^{-3}$; ×, $N_1 = 10^{21} \text{ m}^{-3}$. $N_0 = 10^{19} \text{ m}^{-3}$. $E_t = 0.65 \text{ eV}$. Sample thickness: $L = 6 \mu\text{m}$.

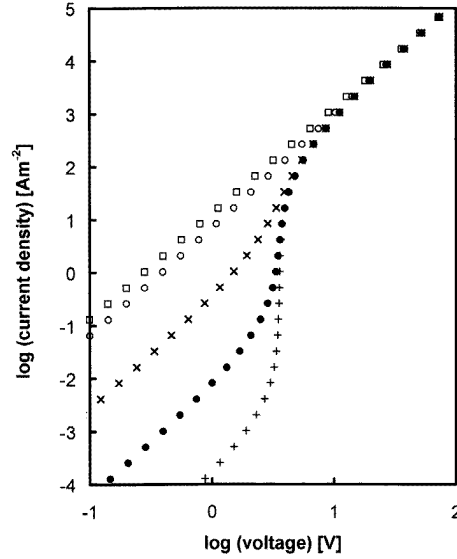


Figure 2. SCL current–voltage dependencies for various trap depths: □, 0.35 eV; ○, 0.45 eV; ×, 0.55 eV; ●, 0.65 eV; +, 0.75 eV. $N_1 = 3 \times 10^{20} \text{ m}^{-3}$. $T = 300 \text{ K}$. Sample thickness: $L = 6 \mu\text{m}$.

In the case of the photo-enhanced SCL currents the occupation of traps depends also on the light intensity, and is given by [12]

$$n_t(x) = (N_t(x) + N_0) / \left(1 + \frac{N_e}{gn_f} \left\{ \exp\left(\frac{-E_t - E_c}{kT}\right) + \frac{A\kappa I(x)}{\nu} \right\} \right) \quad (8)$$

where A is the quantity transforming the light intensity $I(x)$ into free carriers, κ is the absorption coefficient, and ν is the thermal collision factor. The light intensity is given by

$$I(x) = I_0 \exp(-\kappa x) \quad (9)$$

where I_0 is the incident light intensity.

The above equations cannot be solved analytically. In order to obtain numerical solutions the Turbo Pascal procedures for ordinary differential equations were used [13]. The numerical solutions obtained were tested in a standard way by solving the equations for various values of the integrating step. The solutions for the trap-free case were also obtained, and they proved to be identical with the well-known analytical solutions.

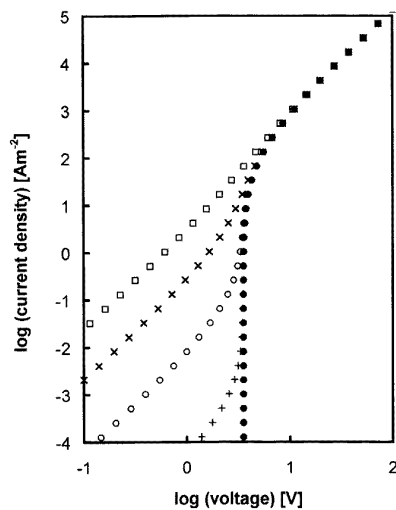


Figure 3. SCL current–voltage dependencies for various temperatures: ●, 50 K, 100 K, 150 K and 200 K; +, 250 K; ○, 300 K; ×, 350 K; □, 400 K. $N_1 = 3 \times 10^{20} \text{ m}^{-3}$. $E_t = 0.65 \text{ eV}$. Sample thickness: $L = 6 \mu\text{m}$.

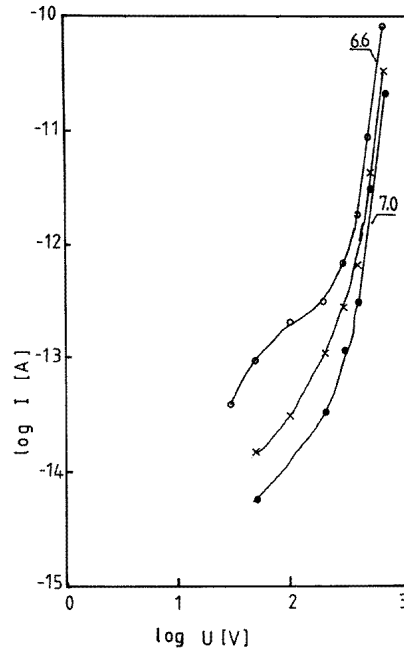


Figure 4. The current–voltage dependence for the Au/polycrystalline p-quaterphenyl film/Au structure at various temperatures: ●, 303 K; ×, 323 K; ○, 353 K. Film thickness: $5 \mu\text{m}$. Redrawn after [15].

3. Results

Figure 1 shows the current–voltage curves for four different values of N_1 including $N_1 = 0$. The assumed value of the trap depth $E_t = 0.65 \text{ eV}$ is characteristic of polycrystalline p-terphenyl films [14]. As we see, the inhomogeneities given by equation (6) with real values of trap concentrations have a measurable influence on the current–voltage characteristics.

In our previous paper the solutions of the SCLC problem for deep traps were presented [9]. Equations (3), (5), (6) and (7) enable us to solve the problem for traps of any depth. Figure 2 shows the current–voltage curves for various trap depths at room temperature. As we see, the traps shallower than about 0.4 eV do not have a detectable influence on the current–voltage curves at this temperature, which means that the inhomogeneities with shallower traps cannot be detected at room temperature in this way. However, the detection of the shallower traps can be carried out at lower temperatures, as is shown in figure 3. This is understandable if we take into account that, according to equation (7) shallower and shallower traps are occupied with decreasing temperature.

Differentiating the SCLC cases with uniform and non-uniform spatial trap distributions is a very important problem. As was shown earlier [9], it is possible to tell the difference between the two cases thanks to the analysis of the $\log(I/V^2)$ versus $\log L$ dependence, provided that T_c/T differs from unity (T_c is the so-called characteristic temperature [8]). In the case of shallow traps the thickness dependencies are usually very similar for the uniform and non-uniform trap distributions [8]. However, from figure 3 we can see that the

effective ‘shallowness’ of traps depends on the temperature, i.e. the decrease in temperature may enable us to detect the inhomogeneities containing comparatively shallow traps.

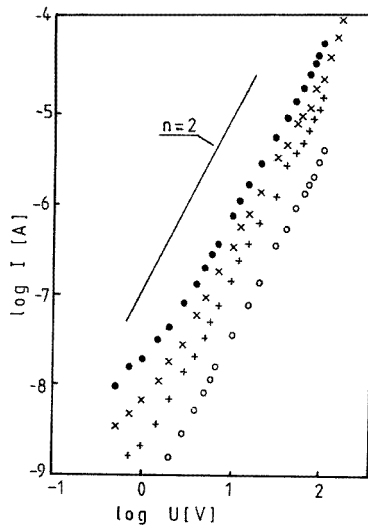


Figure 5. Current–voltage curves for p-quaterphenyl oriented films at various temperatures: ○, 113 K; +, 173 K; ×, 233 K; ●, 373 K. Film thickness: 4 μm. Au–Al electrodes. Redrawn after [16].

The experimental results obtained by Szymański [15] and Kania *et al* [16] may confirm the existence of non-uniform trap distributions in polycrystalline organic thin films. Figure 4 shows the SCL currents in polycrystalline p-quaterphenyl film [15]. The current–thickness dependence is of the form $j \propto 1/L^k$ where $k \approx 7.5$. What is more the relation between the exponents

$$j \propto \frac{V^{l+1}}{L^{2l+1}} \quad (10)$$

is not fulfilled. The above relation is valid for both the exponential and gaussian energetic distributions of traps in the forbidden gap provided that the spatial trap distribution is uniform [17]. l is the parameter depending on the energetic distribution of traps and the temperature. As the relation does not hold in the present case, this may suggest the influence of the non-uniform trap distribution on the current–voltage characteristics. Figure 5 shows the current–voltage curves for the so-called oriented p-quaterphenyl polycrystalline films. The structure of the oriented films is much more perfect than that of ordinary polycrystalline layers. The electron micrographs suggest that the oriented layers consist of comparatively big grains. The size of the grains is equal to the sample thickness, i.e. no intergrain inhomogeneity exists on the way of charge carriers between electrodes. As we see from figure 5, the current–voltage curves differ significantly from those in figure 4. The curves in figure 5 consist of an ohmic part and of a $j \propto V^2$ part, which may suggest either the trap-free case or the shallow-trap case. In other words, deep traps have not been detected in the oriented films though they may be supposed to exist in the ordinary polycrystalline p-quaterphenyl layers, as seems to be the case in figure 4. The intergrain regions containing the deep traps may also be detected via dielectric measurements at low frequencies [18, 19]. Dielectric measurements confirm that intergrain regions with deep traps do not exist in large-grained films [18, 19].

The illumination of a specimen changes the occupation of traps at the illuminated electrode and has an influence on the current–voltage SCL dependencies provided that the

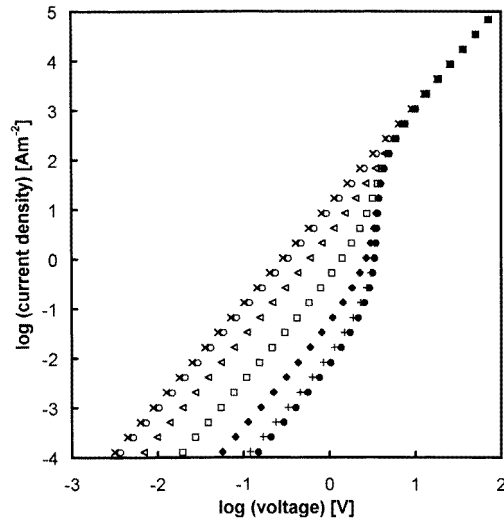


Figure 6. Current–voltage curves for various incident light intensities: ●, $I_0 = 10^{16}$ quanta $\text{cm}^{-2} \text{s}^{-1}$; +, $I_0 = 10^{17}$ quanta $\text{cm}^{-2} \text{s}^{-1}$; ◆, $I_0 = 10^{18}$ quanta $\text{cm}^{-2} \text{s}^{-1}$; □, $I_0 = 10^{19}$ quanta $\text{cm}^{-2} \text{s}^{-1}$; △, $I_0 = 10^{20}$ quanta $\text{cm}^{-2} \text{s}^{-1}$; ○, $I_0 = 10^{21}$ quanta $\text{cm}^{-2} \text{s}^{-1}$; ×, $I_0 = 10^{22}$ quanta $\text{cm}^{-2} \text{s}^{-1}$. $E_t = 0.65 \text{ eV}$. $N_1 = 10^{21} \text{ m}^{-3}$. $\kappa = 10^6 \text{ m}^{-1}$. $A = 10^{-22} \text{ m}^3$. $T = 300 \text{ K}$. Sample thickness: $L = 6 \mu\text{m}$.

light flux is strong enough. The numerical results obtained so far suggest that this is not possible for finding the spatial trap distribution deep in the sample bulk, so only the results for the surface trap distribution (given by equation (11)) under illumination are presented in this paper. Figure 6 shows the influence of the illumination on the current–voltage curves for the spatial distribution of traps given by

$$N_t(x) = N_1 \exp\left(-\frac{x}{D}\right) \quad (11)$$

i.e. the trap concentration decreases exponentially as a function of the distance from the surface. It may be supposed that such an assumption is justified for many thin-film systems in which the structural imperfections and surface pollution are the main factors giving rise to the formation of traps. The values of A and κ used for the calculations are typical of the simple aromatic hydrocarbons, but the method may also be used for any other insulating thin-film system. Let us pay attention to the fact that for sufficiently strong light flux the current–voltage curve becomes identical to that of the trap-free case. This is understandable if we take into account the fact that according to equation (8) the occupation of traps decreases with increasing intensity of the light flux.

3.1. Determination of the spatial distribution of traps at the emitter

The determination of the spatial distribution of traps may be an important problem—in fact, crucial for microelectronics. It turns out that the measurements of the dark and photo-enhanced SCL currents may make it possible to find the spatial trap distribution in the thin layer adjoining the emitter. Two similar methods of determination of the spatial distribution of traps are presented in this paper. In both of them it is assumed that the trap concentration at the emitter is given by equation (11). It is also assumed that the trap depth is known from

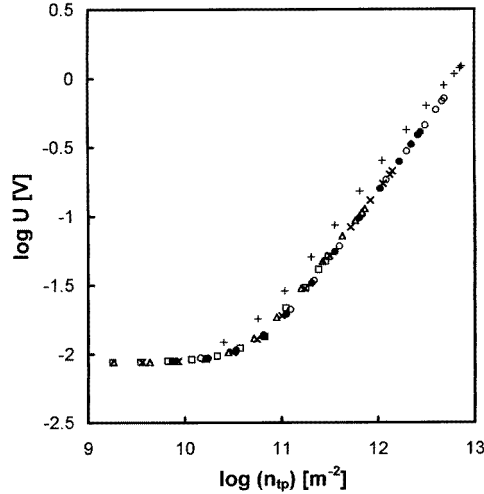


Figure 7. The voltage (at current density 10^{-3} A m $^{-2}$) as a function of the number of trapped charge carriers (per unit sample area) for various incident light intensities and trap concentration decay coefficients: $I_0 = 10^{16}$, 3×10^{16} , 10^{17} , 3×10^{17} , 10^{18} , 3×10^{18} , 10^{19} , 3×10^{19} , 10^{20} , 3×10^{20} , 10^{21} , 3×10^{21} , 10^{22} quanta cm $^{-2}$ s $^{-1}$; \square , $D = 3 \times 10^{-9}$ m; \triangle , $D = 10^{-8}$ m, \times , $D = 3 \times 10^{-8}$ m; \bullet , $D = 10^{-7}$ m; \circ , $D = 3 \times 10^{-7}$ m; $+$, $D = 10^{-6}$ m. $E_t = 0.65$ eV. $N_1 = 10^{21}$ m $^{-3}$. $\kappa = 10^6$ m $^{-1}$. $A = 10^{-22}$ m 3 . $T = 300$ K. Sample thickness: $L = 6$ μ m.

other experiments, for instance from the measurements of thermally stimulated currents. The first method enables us to find D if the value of the trap concentration at the surface, N_1 , is known. The second one makes it possible to find both D and N_1 but the method may only be used when the reciprocal of the light absorption coefficient κ^{-1} is smaller than D .

It may be shown that if the concentration decay coefficient D is much smaller than the sample thickness, then the sample voltage (for a constant current density) is only a function of the number of trapped charge carriers in the thin layer at the emitter. The number of trapped charge carriers (per unit sample area) was calculated using the expression

$$n_{tp} = \frac{n(\text{trapped})}{S} = \int_0^d N_1 \exp\left(\frac{-x}{D}\right) / \left\{ 1 + \frac{N_{eff}}{n_f(x)} \left[\exp\left(\frac{-E_t - E_c}{kT}\right) + \frac{A\kappa I(x)}{\nu} \right] \right\} \Delta x$$

$$\approx \sum_{i=1}^n \left(N_1 \exp\left(\frac{-x_i}{D}\right) / \left\{ 1 + \frac{N_{eff}}{n_f(x_i)} \left[\exp\left(\frac{-E_t - E_c}{kT}\right) + \frac{A\kappa I(x_i)}{\nu} \right] \right\} \right) \Delta x \quad (12)$$

where S is the sample area, and d is much smaller than the sample thickness but great enough for the value of the expression to become independent of n . The calculations were carried out for $\Delta x = 1$ nm and $n = 2000$ (for $n > 500$ the result becomes independent of n , which means that the number of carriers trapped outside the narrow layer adjoining the emitter is negligible for the assumed values of N_1 and D). The values of the concentration of free charge carriers were found from numerical solutions of equations (3) and (5). The solutions were obtained for the following values of the incident light intensity and the concentration decay coefficient: $I_0 = 10^{16}$, 3×10^{16} , 10^{17} , 3×10^{17} , 10^{18} , 3×10^{18} , 10^{19} , 3×10^{19} , 10^{20} , 3×10^{20} , 10^{21} , 3×10^{21} , 10^{22} quanta cm $^{-2}$ s $^{-1}$; $D = 3 \times 10^{-9}$, 10^{-8} , 3×10^{-8} , 10^{-7} , 3×10^{-7} , 10^{-6} m. The voltages found from current-voltage characteristics

referred to the current density 10^{-3} A m^{-2} . All of the calculations presented in this paper were carried out for the sample thickness $L = 6 \mu\text{m}$.

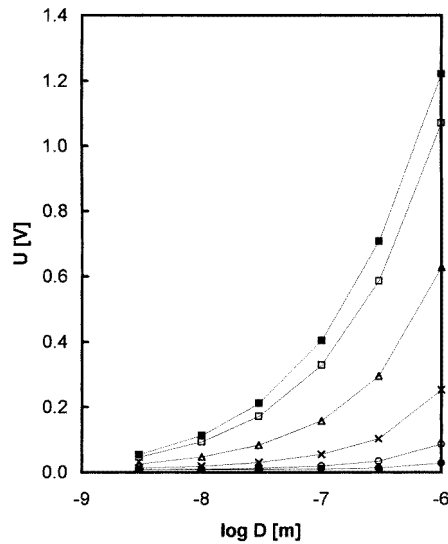


Figure 8. The voltage (at current density 10^{-3} A m^{-2}) as a function of the concentration decay coefficient D for various incident light intensities: \blacksquare , $I_0 = 10^{16}$ quanta $\text{cm}^{-2} \text{ s}^{-1}$; \square , $I_0 = 10^{17}$ quanta $\text{cm}^{-2} \text{ s}^{-1}$; \triangle , $I_0 = 10^{18}$ quanta $\text{cm}^{-2} \text{ s}^{-1}$; \times , $I_0 = 10^{19}$ quanta $\text{cm}^{-2} \text{ s}^{-1}$; \circ , $I_0 = 10^{20}$ quanta $\text{cm}^{-2} \text{ s}^{-1}$; \bullet , $I_0 = 10^{21}$ quanta $\text{cm}^{-2} \text{ s}^{-1}$. $E_t = 0.65 \text{ eV}$. $N_1 = 10^{21} \text{ m}^{-3}$. $\kappa = 10^6 \text{ m}^{-1}$. $T = 300 \text{ K}$. Sample thickness: $L = 6 \mu\text{m}$.

Figure 7 shows the dependencies of the voltage on the number of charge carriers trapped in the thin layer adjacent to the emitter. As we see, the dependence is unique for $n_{tp} > 3 \times 10^{10} \text{ m}^{-2}$ up to $D = 0.3 \mu\text{m}$ but for $D = 1 \mu\text{m}$ the function becomes dependent on D . The results presented in figure 7 and other calculations for various values of the sample thickness L and the decay coefficient D enable us to conclude that if the value of D is smaller than the sample thickness by at least an order of magnitude, then the dependence shown in figure 7 is unique and enables us to find n_{tp} if the voltage is known. On the other hand, there exists a unique dependence of the number of trapped charge carriers n_{tp} on D (if we assume that the concentration at the surface, N_1 , and the incident light intensity are known). The above conclusions mean that there exists a unique dependence of the voltage (at a constant current density) on the concentration decay coefficient D . The dependence for the sample considered is shown in figure 8. This figure may be used for determination of D in the sample considered ($N_1 = 10^{21} \text{ m}^{-3}$ was assumed; this value is characteristic of very disordered polycrystalline structures of typical aromatic hydrocarbons). The quantities which must be known to obtain such a figure are the voltages (at a constant current density), and in the case of the photo-enhanced SCL currents, the incident light intensity I_0 , the absorption coefficient κ , and the quantity transforming the light flux $I(x)$ into free carriers A^\dagger .

If the reciprocal of the absorption coefficient, κ^{-1} , is smaller than D , then it is possible

\dagger In the case of organic molecular crystals, the photo-generation of charge carriers from traps may arise from photon-trapped carrier interaction, but usually arises from exciton-trapped carrier interaction. The value of A may be dependent on the wavelength. For how to estimate A , see [12].

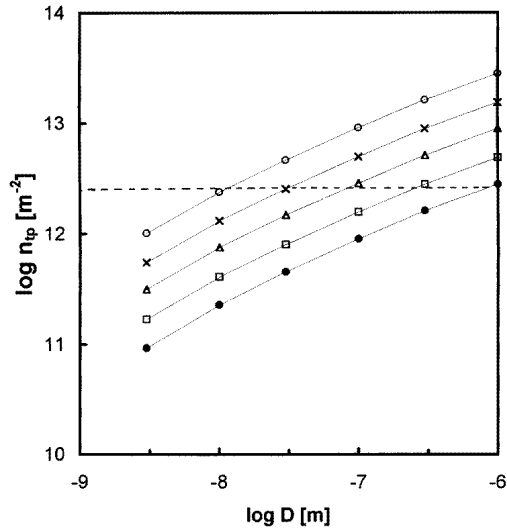


Figure 9. The number of trapped charge carriers (per unit sample area) as a function of the concentration decay coefficient D for various surface concentrations N_1 : ●, $N_1 = 10^{20} \text{ m}^{-3}$; □, $N_1 = 3 \times 10^{20} \text{ m}^{-3}$; △, $N_1 = 10^{21} \text{ m}^{-3}$; ×, $N_1 = 3 \times 10^{21} \text{ m}^{-3}$; ○, $N_1 = 10^{22} \text{ m}^{-3}$. $I_0 = 0 \text{ quanta cm}^{-2} \text{ s}^{-1}$. $E_t = 0.65 \text{ eV}$. $T = 300 \text{ K}$. Sample thickness: $L = 6 \mu\text{m}$.

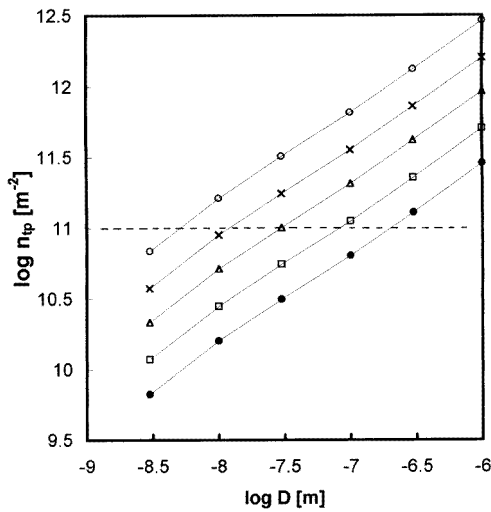


Figure 10. The number of trapped charge carriers (per unit sample area) as a function of the concentration decay coefficient D for various surface concentrations N_1 for an illuminated sample: ●, $N_1 = 10^{20} \text{ m}^{-3}$; □, $N_1 = 3 \times 10^{20} \text{ m}^{-3}$; △, $N_1 = 10^{21} \text{ m}^{-3}$; ×, $N_1 = 3 \times 10^{21} \text{ m}^{-3}$; ○, $N_1 = 10^{22} \text{ m}^{-3}$. $I_0 = 3 \times 10^{19} \text{ quanta cm}^{-2} \text{ s}^{-1}$. $E_t = 0.65 \text{ eV}$. $\kappa = 10^6 \text{ m}^{-1}$. $A = 10^{-22} \text{ m}^3$. $T = 300 \text{ K}$. Sample thickness: $L = 6 \mu\text{m}$.

to determine both D and N_1 . Figures 9, 10 and 11 show the calculated dependencies of the numbers of carriers trapped at the emitter for various concentrations of traps at the surface N_1 . As we see, the shape of the curves for the illuminated sample depends on the

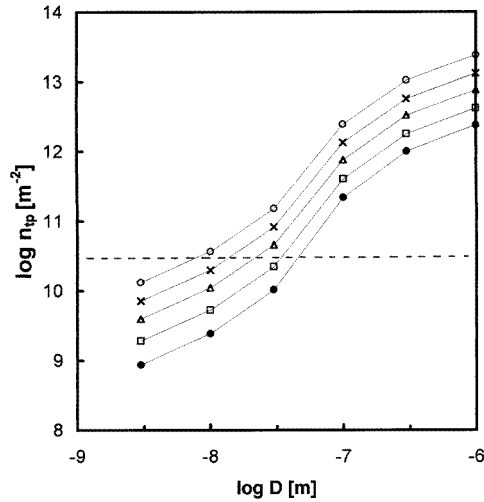


Figure 11. The number of trapped charge carriers (per unit sample area) as a function of the concentration decay coefficient D for various surface concentrations N_1 for an illuminated sample: ●, $N_1 = 10^{20} \text{ m}^{-3}$; □, $N_1 = 3 \times 10^{20} \text{ m}^{-3}$; △, $N_1 = 10^{21} \text{ m}^{-3}$; ×, $N_1 = 3 \times 10^{21} \text{ m}^{-3}$; ○, $N_1 = 10^{22} \text{ m}^{-3}$. $I_0 = 3 \times 10^{19} \text{ quanta cm}^{-2} \text{ s}^{-1}$. $E_t = 0.65 \text{ eV}$. $\kappa = 10^6 \text{ m}^{-1}$. $A = 10^{-22} \text{ m}^3$. $T = 300 \text{ K}$. Sample thickness: $L = 6 \mu\text{m}$.

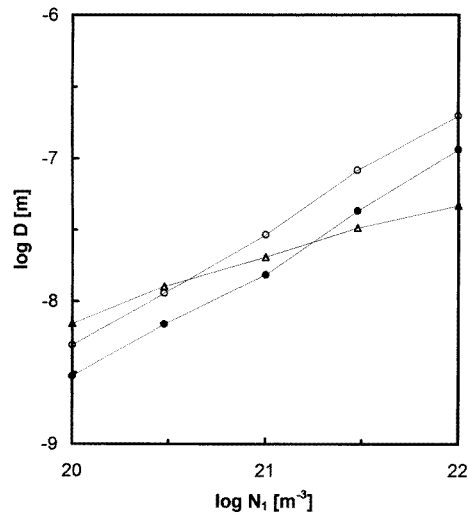


Figure 12. Dependencies of the trap concentration decay coefficient D on the surface concentration N_1 found from figures 9, 10 and 11. ●, $I_0 = 0 \text{ quanta cm}^{-2} \text{ s}^{-1}$, $n_{tp} = 2.5 \times 10^{12} \text{ m}^{-2}$ (dotted line in figure 9); ○, $I_0 = 3 \times 10^{19} \text{ quanta cm}^{-2} \text{ s}^{-1}$, $n_{tp} = 10^{11} \text{ m}^{-2}$, $\kappa = 10^6 \text{ m}^{-1}$ (dotted line in figure 10); △, $I_0 = 3 \times 10^{19} \text{ quanta cm}^{-2} \text{ s}^{-1}$, $n_{tp} = 3 \times 10^{10} \text{ m}^{-2}$, $\kappa = 3 \times 10^7 \text{ m}^{-1}$ (dotted line in figure 11).

relationship between κ^{-1} and D . As has been shown earlier, the measurements of current–voltage characteristics make it possible to find the number of trapped carriers n_{tp} . Knowing n_{tp} for dark measurements (for instance $2.5 \times 10^{12} \text{ m}^{-2}$ —the dotted line in figure 9) and the

value of n_{tp} for the illuminated sample (for instance 10^{11} m^{-2} —the dotted line in figure 10; and $3 \times 10^{10} \text{ m}^{-2}$ —dotted line in figure 11) we can find from figures 9 and 10 or 11 (depending on the value of κ) the sets of parameters N_1 and D for a given sample (see figure 12). If $\kappa^{-1} > D$ we get two nearly parallel lines (for the same sample they should be nearly the same). For $\kappa^{-1} < D$ we obtain two intersecting lines. The point of intersection for $I_0 = 0$ and $I_0 = 3 \times 10^{19} \text{ quanta cm}^{-2} \text{ s}^{-1}$ determines N_1 and D ($N_1 \simeq 1.8 \times 10^{21} \text{ m}^{-3}$ and $D \simeq 2.4 \times 10^{-8} \text{ m}$ in the case presented). In order to enhance the accuracy, the results for a few (i.e. more than two) incident light intensities I_0 should be taken into account.

4. Conclusions

The following conclusions may be drawn from the results presented.

(1) A non-uniform spatial trap distribution, which may be expected in polycrystalline insulators, may have a significant influence on the current–voltage SCL characteristics.

(2) The experimental results for small-grained and oriented polycrystalline layers of simple aromatic hydrocarbons (represented by p-quaterphenyl) may be interpreted if we assume that the SCL current–voltage curves in the small-grained films result from a non-uniform spatial trap distribution.

(3) It should be possible to find the trap concentration decay coefficient at the emitter if the surface concentration of traps is known. If the light absorption coefficient $\kappa^{-1} < D$ then the measurements of the photo-enhanced SCL currents may enable one to find both the surface trap concentration and the decay coefficient.

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