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Temperature Dependence of S.C.L.C. in Anthracene Crystals

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Previous work [1, 2][1]) on the dark conductivity in Anthracene suggests the existence of two sorts of trapping states, one having an exponential energy distribution, and one at a discrete deep energy level.

In order to explain the very slow decay of current with time, it was assumed that equilibrium between the holes in the deep traps and those in the valence band is not reached during the measuring time e.g. 300 h. It was further assumed that the concentration, $\bar{p}$, of holes in the exponentially distributed traps is in equilibrium with the number of holes, p, in the valence band.

Although the total space charge in the crystal is constant, the charge held in the exponential traps decreases with time, causing a rise of the Fermi level which is determined by the equilibrium distribution of p and $\bar{p}$. It is therefore expected that the activation energy, E, corresponding to the Quasi-Fermi level E_f is also time dependent and decreases with time.

In order to eliminate the influence of the dark current decay on the measurement of the activation energy, changes in the crystal temperature must be brought about rapidly enough to permit a temperature within 0.1 °C of the new equilibrium value to be reached within 5 minutes.

The temperature dependence of the S.C.L.C. can be approximated [3] by:

$$j(T) = N_0\, e_0\, V\, \mu\, d^{-1} \exp\frac{-E_f}{k\,T} \cong j_0 \exp\frac{-E}{k\,T}\,. \tag{1}$$

The Fermi level, E_f, is measured from the top of the valence band. The effect of the temperature dependence [4] of μ and N_0 is to change E_f by less than 3%, and can be neglected.

For constant values of V and T the current decreases with time after voltage is applied to the crystal. Since E is determined by Equation (1), the increase of E may be calculated.

$$E_{t2} - E_{t1} = k\,T_0\,[\ln j_{t1}(T_0) - \ln j_{t2}(T_0)] \tag{2}$$

where T_0 is a constant reference temperature. Figure 1 shows E as a function of the current measured at a constant sample voltage. The curves are in agreement with Equation (2). The Boltzmann constant calculated from the slopes of the straight lines in Figure 1 agree with the tabulated value within 10%.

An expression analogous to Equation (2) is obtained for the activation energy at two different voltages (for constant j and T).

$$E_1 - E_2 = k\,T\,[\ln V_1 - \ln V_2] \tag{3}$$

The results for $j = 10^{-12}$ Amp are shown in Figure 2 for two different crystals.

The measured values for the activation energies lie between 0.65 eV and 0.95 eV. Smaller values could not be measured because of the rapid decay of dark current with time. The upper limit is set by the practical requirement that the dark current decays significantly only within several hours.

[1]) Numbers in brackets refer to References, page 329.

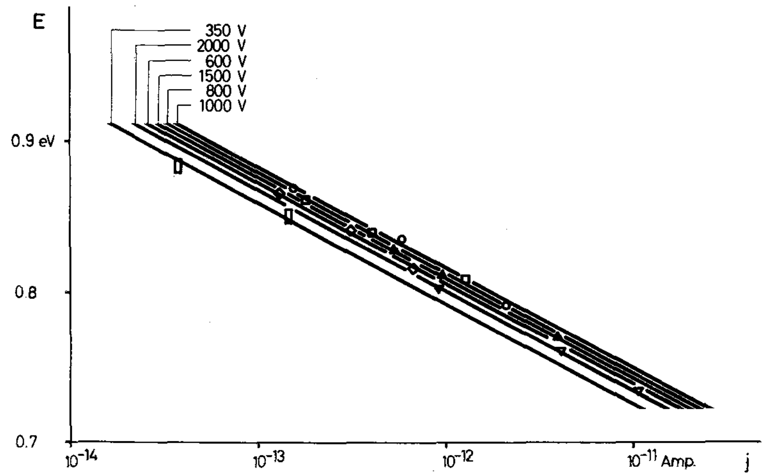

Figure 1
Activation energy E vs. dark current j (j measured at $T = 300\,^\circ K$).

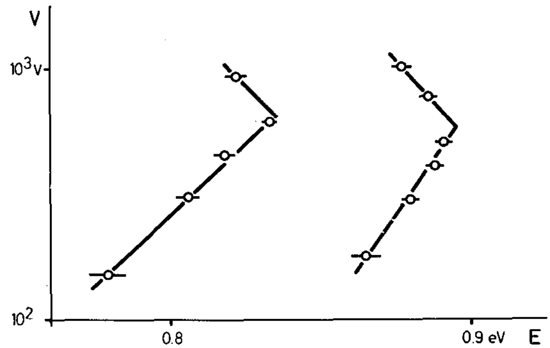

Figure 2
Activation energy E vs. V, for a constant value of j.

The experimental results agree with the theory for voltages below $V_{TFL} \simeq 800$ V. Above this limit the behaviour of E is altered. This is demonstrated, for example in Figure 2, where the slope of the curve changes sign above 800 V. It may be that the space charge distribution changes above V_{TFL}.

Recently we published the spectrum of the photoresponse between wave lengths 2 μ and 0.4 μ [1, 5]. We found three photopeaks at approximately 0.42 μ, 0.6 μ (triplet peak) and 1.06 μ.

For the temperature dependence of the space charge limited photocurrent, assuming an energy independent activation probability of a hole, we found the following relation to be valid [1]:

$$j(T)_S \propto \exp\{A(S)\ T\} \tag{4}$$

where S is the light intensity and A is a parameter.

Assuming that only holes in the exponentially distributed traps may be activated by the light, either directly with the aid of previous formation of excitons (using wavelengths of 0.42 μ or 0.6 μ), the intensity dependence of the current at constant temperature was shown to be [1]:

$$j(S)_T \propto \frac{N_0}{T} S^{(l-1)/l} \left\{\frac{c}{N_0 v_{th} \sigma}\right\}^{(l-1)/l} . \tag{5}$$

A similar formula was given by HELFRICH [6].

$l = T_c/T$ is a constant describing the distribution of the exponential traps, in our case [2] $l \cong 2.2$. σ is the capture cross-section of the traps for holes, $v_{th} \cong 10^5$ cm/s and c is the probability per unit time that one trapped hole is activated by the light.

We have now shown that the relations (4) and (5) are valid in all three of the mentioned wavelength regions.

For most of these measurements the light intensity was limited by our monochromator and the 50 W-tungsten lamp. However for $\lambda = 0.6328$ μ we have checked these relations with a He-Ne-laser up to 5 mW/cm².

Experimentally we observed $j \propto S^{0.5}$, measured at temperature $T = 20$ °C. With $l = 2.2$ Equation (5) yields $j \propto S^{0.55}$.

In Figure 3 the photocurrent is plotted versus $1/T$. It can be seen that the relation (4) is valid. Using values of A obtained from the slopes in Figure 3, we get the intensity dependence of A shown in Figure 4, where $T_c = 660$ °K.

Using the substitution $l = T_c/T$, A may be calculated from Equation (5) [1]:

$$A(S) = \frac{1}{T_c} \ln \frac{N_0 v_{th} \sigma}{c S} . \tag{6}$$

This also indicates a linear relationship between A and $\ln S$. However the slope of the experimentally determined straight line is about five times greater than that calculated from Equation (6), which gives a T_c five times too small. For this we do not have an explanation up to now.

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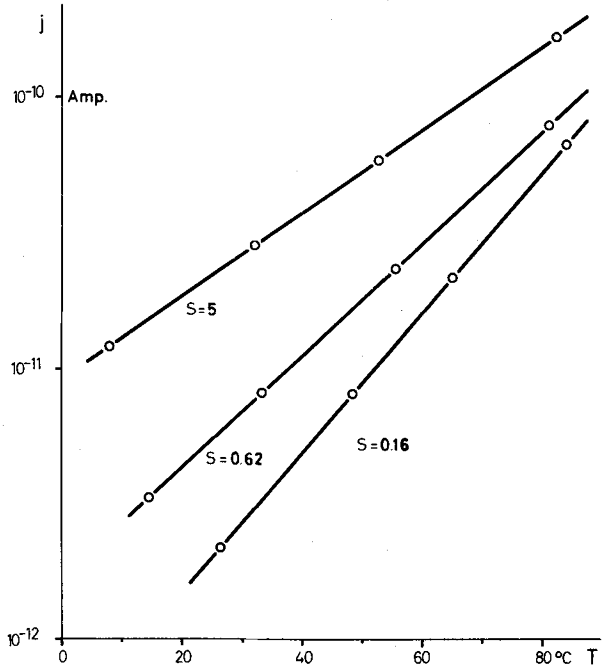

Figure 3

Photocurrent j vs. T for constant value of V.

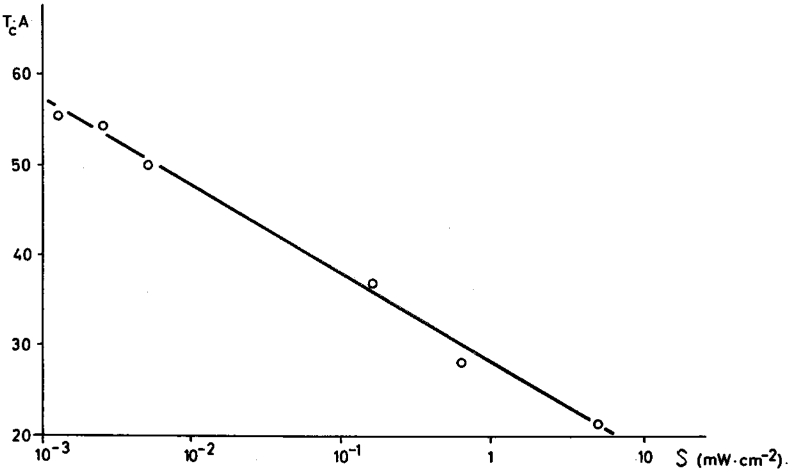

Figure 4
$T_c A$ vs. light intensity S measured at 20 °C.

REFERENCES

[1] J. ADOLPH, Helv. phys. Acta *38*, 409 (1965).
[2] J. ADOLPH, E. BALDINGER, W. CZAJA, and I. GRÄNACHER, Phys. Letters *6*, 134 (1963).
[3] A. ROSE, Phys. Rev. *97*, 1538 (1955).
[4] R. G. KEPLER, Phys. Rev. *119*, 1226 (1960).
[5] J. ADOLPH, E. BALDINGER, and I. GRÄNACHER, Phys. Letters *8*, 224 (1964).
[6] W. HELFRICH, Phys. Stat. Sol. *7*, 863 (1964).

Zusammenfassung

Aus der Temperaturabhängigkeit des Löcherstroms in Anthrazen-Einkristallen wird die Aktivierungsenergie bei verschiedenen Dunkelstromwerten gemessen. Die Aktivierungsenergien liegen zwischen 0,65 eV und 0,95 eV für Ströme von 10^{-10} bzw. 10^{-12} Ampère bei Zimmertemperatur.

Ferner wird für mehrere Temperaturwerte die Aktivierung der in Haftstellen sitzenden Ladungsträger mit Hilfe von Licht verschiedener Intensität untersucht.

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Demonstrationsversuch zur Kernresonanz mit vorpolarisierter, kontinuierlich strömender Flüssigkeit

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1. Einleitung

Der nachfolgend beschriebene Versuch über Protonenresonanz ist als Demonstrationsversuch im Hörsaal gedacht und soll den Einfluss der magnetischen Feldstärke auf die Polarisierung der Kernspins veranschaulichen.