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Studies on *I-V* characteristics of dark and photoconduction in methylbixin

DILIP GHOSH, PRABIR PAL, K M JAIN† and T N MISRA*

Optics Department, Indian Association for the Cultivation of Science, Jadavpur, Calcutta 700 032, India

†Permanent Address: Department of Physics, Government Model Science College, Rewa 486 001, India

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Abstract. Dark and photoconductivities in methylbixin have been studied as a function of applied field and temperature. The results suggest that a single discrete trapping level is involved in charge carrier generation and the dominant trapping level is different for dark and photoconduction. Space charge limited current theory has been used to evaluate various transport parameters. The effective drift mobility is shown to be field dependent.

Keywords. Organic semiconductors; dark and photoconductivities; current-voltage characteristics; polyene semiconductors.

1. Introduction

Electrical conduction in biological compounds has been studied in the context of its playing a role in biological function (Kasha and Pullman 1962). The charge transport mechanism through these materials is, therefore, of much interest.

The variation of current through a sample with applied d.c. voltage is one of the easiest to measure and is also a very powerful technique for drawing conclusions about the characteristics of some transport parameters e.g. effective drift mobility of the carriers, density of trapping states, trap depth etc. The current voltage (*I-V*) characteristics are interpreted by considering the injection of space charge into an insulator by ohmic contacts. The non-ohmic behaviour in the *I-V* curves is the manifestation of the space charge limited current (SCLC).

We have measured dark and photo currents of methylbixin, a long chain polyene, as a function of temperature and field. The analysis of the *I-V* characteristics is made using SCLC theory. The results are interpreted in order to understand the charge transport mechanism and the dominant trapping level behaviour involved in methylbixin. In this paper, we present our results.

2. Experimental

The compound under investigation is a gift from the Hoffman-La Roche Co., Switzerland, and is used without further purification. The powdered sample was taken

* To whom all correspondence should be addressed.

in a sandwich cell with stainless steel and SnO_2 coated glass electrodes for conductivity measurements. The cell was placed in a suitably designed conductivity chamber (Mallick *et al* 1979) with a quartz window for photoconductivity studies. The applied d.c. voltage source were dry batteries. For current measurement, an electrometer (Model EA 815 of the Electronic Corporation of India Ltd.) was used. Temperature measurement was made using a copper constantan thermocouple attached at the top of the metal electrode. A high pressure 200 W mercury lamp was used for steady state photoconductivity work. Several measurements were made in order to ensure reproducibility of results both in vacuum and in an atmosphere of dry nitrogen. To get reproducible results, it was necessary to wait at least 45 minutes between changes in voltage to ensure that true equilibrium was attained.

3. Results and discussion

Figure 1 shows the *I-V* plots for methylbixin under dark and illuminated conditions at room temperature ($\approx$ 33°C). At high fields the square law behaviour is observed

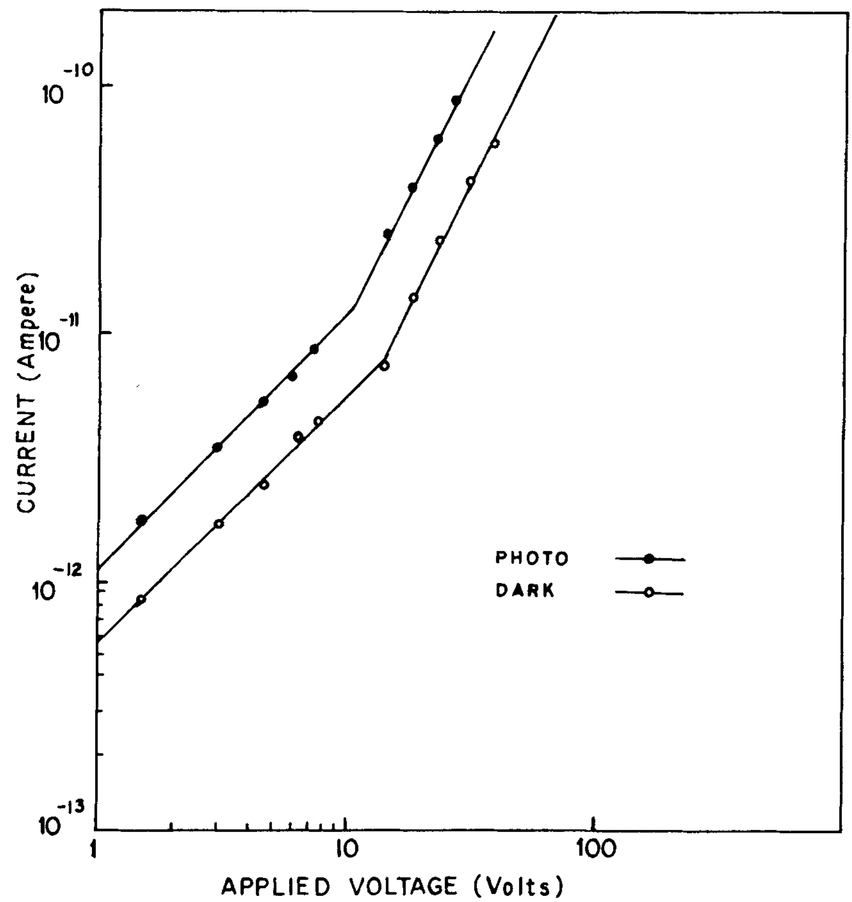

Figure 1. I-V characteristics of methylbixin in the dark and on illumination.

whereas currents at low fields are ohmic in nature. The cross-over field from ohmic to square law region is $\approx 2{\cdot}68 \times 10^3$ V/cm for dark and $\approx 2{\cdot}08 \times 10^3$ V/cm for photoconduction.

This square law behaviour may be interpreted in terms of either a single discrete trapping level or of exponential trap distribution.

For exponential distribution of traps, the current is given by (Rose *et al* 1955; Lampert *et al* 1964):

$$I = q\mu N_c VA/d \ [\varepsilon_0 \varepsilon V/qd^2 N_t(e)]^{(T_c/T)}, \tag{1}$$

whereas for a simple case of single discrete trapping level it is:

$$I = (9/8)\varepsilon_0 \varepsilon \mu [N_c/N_t(S)] A \exp(-E_s/kT)(V^2/d^3), \tag{2}$$

where q = electronic charge; μ = mobility; N_c = the effective density of states in the conduction band; V = applied voltage; d = interelectrode separation; A = area of the cell; ε_0 = free space permittivity; ε = dielectric constant; $N_t(e)$ = the total density of electronic levels in the exponential distribution; T_c = the characteristic temperature of the exponential trap distribution; T = working temperature in Kelvin; $N_t(S)$ = the density of trapping levels situated at an energy E_s below the conduction band edge and k: the Boltzmann constant. The quantity $[N_c/N_t(S)]\exp(-E_s/kT)$ is usually denoted by θ which is the ratio of free to trapped charges.

Equation (1) gives the square law dependence of I on applied voltage for $T = T_c$. Thus, the linear dependence of I on V^2 obtained at a constant temperature is insufficient evidence in favour of any particular type of trap distribution. From (1) and (2), we see that a plot of $\log_{10} I$ against $1/T$ should yield a straight line in both the cases and thus such a plot obtained at a single voltage does not remove the ambiguity in interpretation. However, the two types of trapping behaviour may be distinguished using measurements of the variation of current with temperature for a range of different constant voltages. For a single discrete trap level, the slope for such a plot is $[-(E_s/k)\log_{10} e]$ and is independent of applied voltage, whereas for exponential trap distribution the slope is $T_c \log_{10}[\varepsilon \varepsilon_0 V/qd^2 N_t(e)]$ which is voltage dependent.

We, therefore, studied the field dependence of the slopes from ohmic to SCL regions. A series of curves at different applied voltages as shown in figure 2 give a constant value of slope indicating the involvement of a single discrete dominant trapping level for photo and dark conduction.

We now proceed to evaluate some transport parameters involved in semi and photoconduction. The ohmic current (I_Ω) is given by

$$I_\Omega = n_0 q \mu (A/d) V, \tag{3}$$

where n_0 is thermally liberated free carrier density.

The onset of the SCLC injection takes place at cross-over voltage

$$V_t = (8/9)(qd^2 n_0/\varepsilon_0 \varepsilon \theta), \tag{4}$$

which can alternately be written in terms of ohmic relaxation time $\tau = \varepsilon/\sigma$ as,

$$V_t = (8/9)(d^2/\mu_e \tau \varepsilon_0) = (8/9)(d^2 \sigma/\mu_e \varepsilon \varepsilon_0), \tag{5}$$

where σ is the room temperature conductivity at the cross-over voltage and $\mu_e = (\mu \cdot \theta)$ is the effective drift mobility of the carriers. The above equations can be used to analyse the experimental I-V curves. The dielectric constant for β-carotene is 2·5 (Misra *et al*

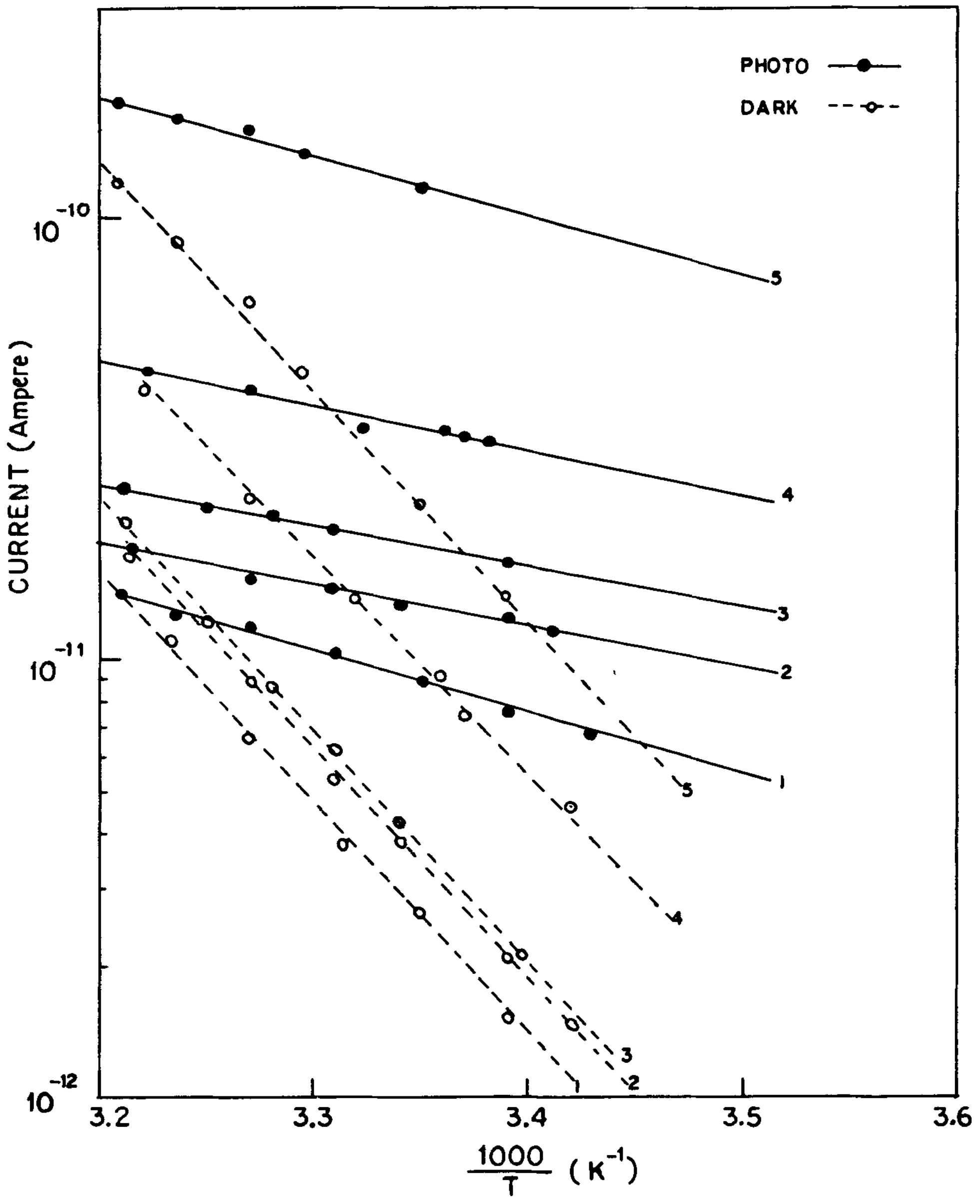

Figure 2. The plots of log I vs $1000/T$ at various applied voltages (1) 9 (2) 12 (3) 15 (4) 18 (5) 27 volts. The solid lines (——) represent dark and the broken lines (- - -) photoconductivity.

1968). We expect a similar value for methylbixin and we shall use this value for the dielectric constant of methylbixin. The effective drift mobility may now be calculated from (2) and also from (5). The value of n_0/θ can be obtained from (4). The results are summarised in table 1. It can be seen that the value of μ_e is very small. The low value of μ_e observed here suggests that the conduction mechanism through this polyene sample

Table 1. Values of transport parameters.

Nature of conductivity	μ_e calculated from (2) ($cm^2\,V^{-1}\,sec^{-1}$)	μ_e calculated from (5) ($cm^2 V^{-1} sec^{-1}$)	n_0/θ (cm^{-3} at 306 K)	E_s (eV)
Dark	$7\cdot74 \times 10^{-8}$	$7\cdot69 \times 10^{-8}$	$3\cdot1 \times 10^{11}$	0·99
Photo	$2\cdot14 \times 10^{-7}$	$2\cdot14 \times 10^{-7}$	$2\cdot42 \times 10^{11}$	0·20

is 'hopping' (Gutman and Lyons 1967). The enhancement in the effective mobility after illumination might be due to the change in θ. The different values of the slope for dark and photoconduction give the estimation of trap depths. For dark conduction it is 0·99 eV whereas it is 0·2 eV for photoconduction. The different values of trap depths are obtained due to the change in the charge carrier density and its distribution in different energy states and traps after illumination.

Information about the field dependent nature of the mobility can also be obtained by studying the *I-V* characteristics both in the dark and in illuminated conditions. If the non-ohmic behaviour of the dark current is due to the field dependence of mobility then the same behaviour is expected for photocurrents (Heilmier and Warfield 1963). Our results shown in figure 1 thus indicate the field dependence of mobility.

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