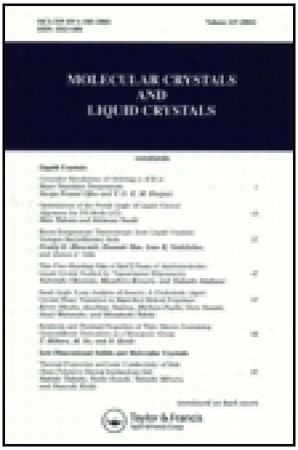

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Photovoltaic and rectification properties of In/trans-$(CH)_x$/ electrodag +502 schottky-barrier cells

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PHOTOVOLTAIC AND RECTIFICATION PROPERTIES OF In/*trans*-$(CH)_x$/ELECTRODAG +502 SCHOTTKY-BARRIER CELLS

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The electrical and photovoltaic properties of In/*trans*-$(CH)_x$/Electrodag +502 sandwich cells have been examined. The forward bias dark current obeys a modified Shockley equation. The junction reverse bias current fits the image-force lowering relationship. The capacitance-voltage characteristics were analysed. A photovoltage and a photocurrent were observed under polychromatic or monochromatic illumination. Photovoltaic action spectra are similar to the adsorption spectra. The dependence of I_{sc} and V_{oc} on the light intensity was determined. The temperature effect on I_o, C, I_{sc} and V_{oc} was also investigated.

INTRODUCTION

A fairly recent research approach to the use of organic materials in solar cells has been focused on the study of thick films of polymeric materials in sandwich configuration. In this field we have investigated the rectifying and photovoltaic (1) properties of the In/*trans*-$(CH)_x$/Electrodag +502 sandwich cells.

RESULTS AND DISCUSSION

The configuration of the sandwich cells used in this work is shown in figure 1. The undoped polymer forms rectifying junctions with indium and ohmic contacts with Electrodag +502.

The current-voltage characteristics measured under vacuum ($\sim 10^{-5}$ Torr) are represented in figures 1 and 2. The forward bias (V_F) dark current (In ⊖) is found to obey the following modified Shockley equation (2) :

$$I = A_j I_o \left[\exp\left[q(V-R_sI)/nkT\right]\left(1-\exp\left[-q(V-R_sI)/kT\right]\right)\right] + (V-R_sI)/R_{sh} \qquad [1]$$

with A_j : junction area (~ 0.08 cm^2) ; I_o : diode saturation current ; R_s : series resistance ; R_{sh} : shunt resistance ; T : absolute temperature ; k : Boltzman constant ; q : electronic charge ; n : diode ideality factor.

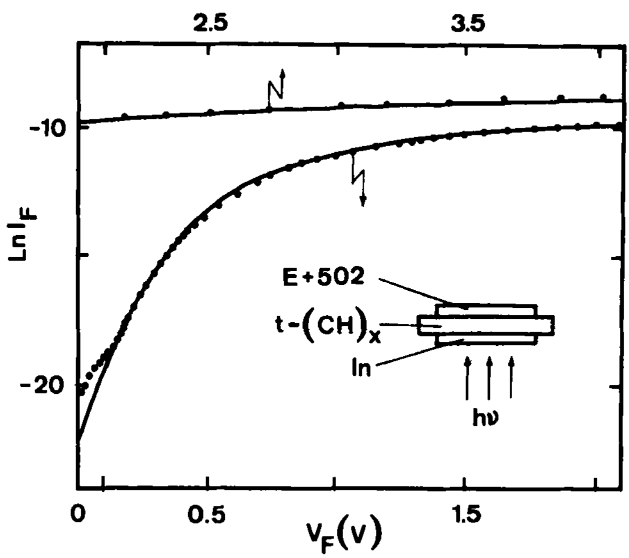

FIGURE 1 I_F-V_F forward characteristic of a typical In/*trans*-(CH)$_x$/Electrodag +502 cell. Full line represents the theoretical curve and (•) represent experimental points.
($A_j \simeq 0.08$ cm^2, film thickness t $\simeq$ 75 µm)

The theoretical curve shown in figure 1 corresponds to computer calculations using equation [1]. The parameters used in the theoretical calculations are given in table IA. They were estimated from the experimental I-V characteristics. The I_F-V_F characteristics at lower or higher as well as room temperature (between -52°C and 110°C) obey the relation [1].

The reverse bias (V_R) dark current (In ⊕) delivered by the junction fits the relationship expressed by equation [2] (see figure 2) :

$$I_o = A^* T^2 \exp\left(-q/kT\left[\emptyset_b - (q^3 N_A (V_c - V)/8\pi^2 \varepsilon_s \varepsilon_d{}^2)^{1/4}\right]\right) \quad [2]$$

with A^* : modified Richardson constant ; $\emptyset_b$: barrier height ; N_A : acceptor (or trap) concentration ; V_c : contact potential ; ε_s : semiconductor dielectric constant ; ε_d : image-force dielectric constant ($\varepsilon_s \simeq \varepsilon_d \simeq 5$).

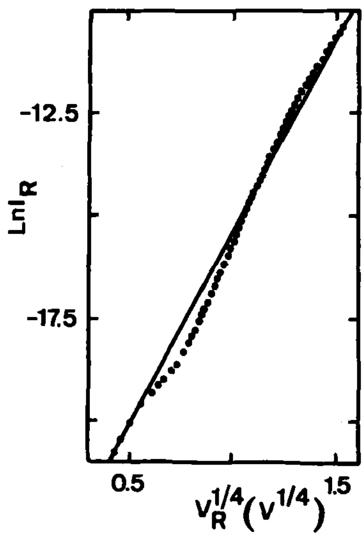

FIGURE 2 I_R-V_R reverse characteristic of In-p-type *trans*-$(CH)_x$ Schottky barrier. The (•) represent experimental points.

The remarkable linearity of this plot suggests that the image force is largely responsible for the barrier lowering which is observed with biases between 0 and 6 volts and temperatures between -52°C and 110°C. The slope (figure 2) yields the acceptor (or trap) concentration given in table IB. The effect of the temperature on I_o was determined and the plot of $\ln(I_o/A_jT^2)$ vs T^{-1} gives the barrier height ϕ_b (table IB).

The capacitance-voltage characteristics recorded at 500, 1000 and 1500 Hz are presented in figure 3 where C^{-2} is plotted as a function of V_R in order to assess the N_A value and the contact potential according to equation [3] (2) :

$$C^{-2}=(2/A_j^2qN_A\varepsilon_s)(V_c+V_R) \qquad [3]$$

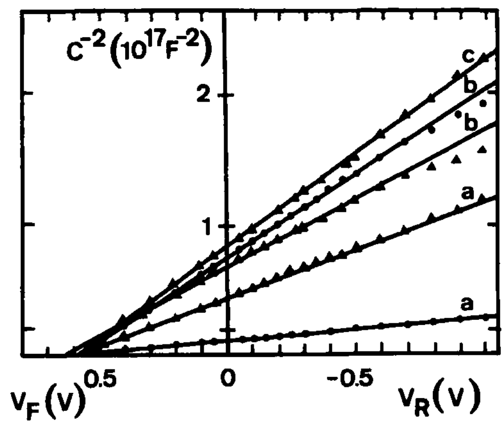

FIGURE 3 C^{-2}-V_R plot of the sandwich cell at frequencies of 500 Hz (a), 1000 Hz (b) and 1500 Hz (c). The (•) represent experimental points for a first film and (▲) represent the data for a second film ($A_j \simeq 0.08$ cm^2, t=57 μm), to show that there is some differences in C-V measurements from film to film.
($A_j \simeq 0.08$ cm^2, t ≃ 75 μm)

As shown on the graph, the junction exhibits a linear dependence of C^{-2} vs V_R up to $\sim$0.6 V and deviates slightly at higher voltage. The average values at room temperature of V_C, N_A, $C(V_R=0)$ and the width of the depletion region (W) are given in table IC. At higher temperatures (from 30 to 120°C) the capacitance is strongly frequency and voltage dependent. This dependence becomes weaker with decreasing temperatures and at low temperature (between 0 and -77°C) the capacitance is almost frequency and voltage independent. At -77°C the *trans*-$(CH)_x$ cells shows only a geometric capacitance, $C_g \simeq 0.07$ nF. This behavior is similar to the tetracene and Mg-phthalocyanine (3) sandwich cells where a transition from the low temperature geometric capacitance to depletion layer type capacitance at high temperature was also observed.

The short-circuit-current action spectra normalized at constant incident photon intensity (2.66×10^{16} photon/sec cm^2) corrected for light absorption by indium is represented in figure 4. The action spectrum fits relationship [4] discussed previously by Ghosh et *al* (4).

$$I_{sc}=q\Phi_Q N_{Phi}\Big[1-\exp(-\alpha W)+[\alpha/(\alpha+\beta)]\exp(\beta W)\times\Big(\exp[-(\alpha+\beta)W]-\exp[-(\alpha+\beta)L]\Big)\Big] \qquad [4]$$

with $\beta=L^{-1}$; L : diffusion length ; N_{Phi} : number of incident photons/cm^{2}sec ; α: absorption coefficient (cm^{-1}) ; Φ_Q : quantum efficiency.

It can be seen that a reasonable agreement between experiment and theory is obtained and is also shown in figure 4 (there is some deviation at the shorter wavelength region). The parameters used in the theoretical calculations are tabulated in table ID. The barrier width which was used agrees with capacitance measurements. The action spectra at lower or higher temperature (between -77°C and 110°C) are similar to that recorded at room temperature (figure 4).

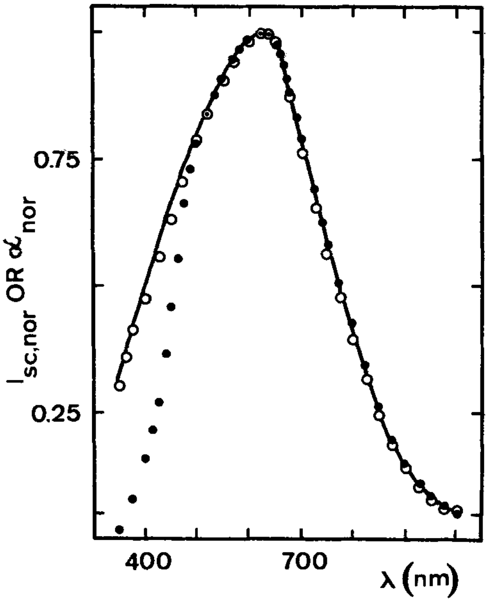

FIGURE 4 Electronic absorption spectra (o) of *trans*-$(CH)_x$. Experimental (•) and theoretical (—) short-circuit photovoltaic current action spectra with light incident on the In surface α and I_{sc} are normalized to their maximum ($\alpha_{max} \simeq 3 \times 10^5$ cm^{-1} and $I_{sc,max} \simeq 0.8$ μA).

It must be pointed out that the short-circuit current (I_{sc}) is proportional to, and the open-circuit voltage (V_{oc}) depends logarithmically on, the light illumination. I_{sc} increases and V_{oc} decreases as the temperature is raised. Upon illumination the indium electrode becomes negative with respect to the Electrodag +502 and the polarity of V_{oc} and I_{sc} is independent of the direction of illumination (back or frontal electrode).

The photocurrent-photovoltage characteristic obtained in the photovoltaic mode under constant light intensity is shown in figure 5.

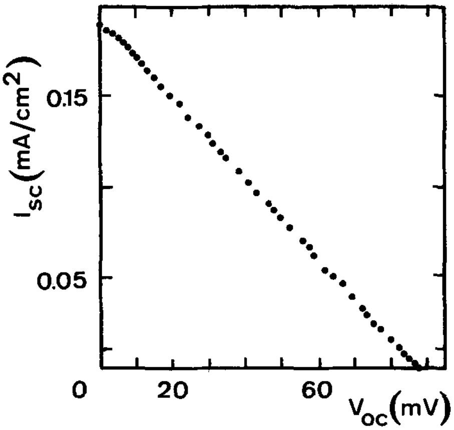

FIGURE 5 Steady state illumination photovoltaic I_{ph}-V_{ph} curves for In/*trans*-$(CH)_x$/Electrodag +502.

The plots are nearly linear under either polychromatic or monochromatic (640 nm) irradiation. The maximum light-to-current conversion efficiency (η_{max}) calculated from the open-circuit voltage and the short-circuit current is given in table IE.

As a last point which must be kept in mind with respect to any possible practical application as solar cells, it must be emphasized that our *trans*-polyacetylene cells always suffer an aging effect which reduces their efficiency after some illumination time.

TABLE I Material and Schottky barrier characteristics at 22°C.

IA I_F-V_F characteristic, In $\ominus$

R_s (Ω)	R_{sh} (Ω)	n	V_c (V)	I_o/A_j (A/cm^2)
2.74×10^4	3.34×10^7	2.41	∿0.7	1.56×10^{-8}

IB I_R-V_R characteristic, In $\oplus$

N_A (cm^{-3})	$\varnothing_b$ (V)	A_j (cm^2)	t (μm)
7.5×10^{18}	∿0.7	0.08	75

IC C-V_R characteristic, In $\oplus$

f (Hz)	N_A (cm^{-3})	V_c (V)	C (V=0) (nF)	W (Å)
500	2.34×10^{17}	∿0.6	9.3	380
1000	3.37×10^{16}	∿0.6	3.5	1000

ID I_{sc} action spectra, In $\ominus$

W (Å)	L (Å)	μτ (cm^2/V)	Dτ (cm^2)	A_j (cm^2)	t (μm)
400	220	1.9×10^{-10}	2.42×10^{-12}	∿0.1	58

IE I_{ph}-V_{ph} characteristic in the photovoltaic mode, In $\ominus$

source	V_{oc} (mV)	I_{sc}/A_j (mA/cm^2)	FF	P_{in} (mW/cm^2)	η_{max} (%)
poly-chromatic	87.5	0.19	0.25	∿24	∿0.017
mono-chromatic (640nm)	46	0.0097	0.25	∿7	∿0.0016

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