# Transient and Steady State Lateral Charge Transport in Polymeric Semiconductors

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## I. Introduction

CONJUGATED based polymer semiconductors have been explored extensively in optoelectronic applications as they offer tremendous advantages in processimg and fabricating procedures. An exciting aspect in optoelectronic devices is the lateral photovoltaic effect. Lateral photovoltaic effect (LPE) as an effective tool has been used to probe the photogenerated charge carrier dynamics in optoelectronic devices [1-3]. Whereas a great deal of attention has been paid to conventional inorganic semiconductors, LPE as a tool to investigate the charge dynamics using LPE in organic semiconductors is still not well established. We present here a discrete circuit model with spreading impedance approach for investigation of charge carrier dynamics in polymeric photovoltaic devices covering temperature dependence, frequency response, wavelength dependence and transient response of the devices. We have employed our model on a position sensing device. In earlier work from our group[4,5] this model has been found in good agreement with the experimental results within the consideration of steady state nature of the charge carriers. Now we have extended our model by incorporating the transient nature of the charge flow produced by majority charge carriers generated in the illuminated region considering gaussian distribuation for intensity of laser beam in the illuminated region unlike the previous model where it was asssumed to be uniform.

## II. Model

The model is aimed to get the lateral photovoltaic effect in a typical position sensing device as shown in fig(1). The device structure consists of a polymer-Al Schottky junction with front pair of Au electrodes. The polymer used were poly(3-hexylthiophene)(P3HT) and poly-[2-methoxy,5-(2-ethylhexoxy)-1,4-phenylene vinylene](MEHPPV). The lateral photovoltage is measured across the Au electrodes.

The lateral potential profile $\phi_{ph}$(r) has been discretized on a square lattice of nodes where potential at each node is denoted by $\phi_m$(Fig. 2). The current through each node m has a transverse and lateral component. The transverse component m comprises of reinjection of minority charge carriers made possible by the barrier reduction in the Schottky type junction. This has been modeled as a combination of diode and capacitive current which are given as following.

$$I^T_{D,m} = I_s \left[ exp\left(\frac{q\phi_m}{k_B T}\right) - 1 \right] \tag{1}$$

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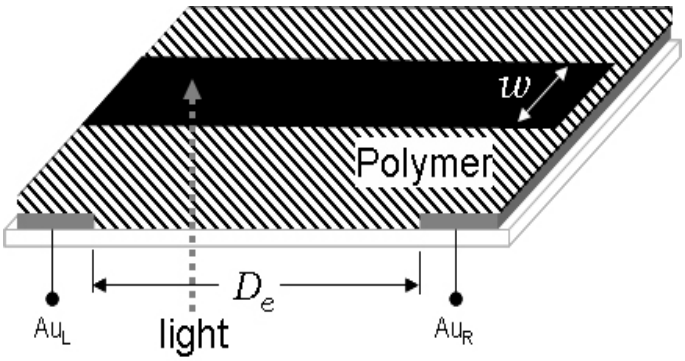


Fig. 1. Typical position sensing device(PSD) structure with polymer-Al Schottky junction of width $W$, and two front Au electrodes separated by distance $D_e$.

$$I^T_{C,m} = C_t \frac{d\phi_m}{dt} \tag{2}$$

For the illuminated node, the photogenerated majority charge carriers add to the transverse incoming current and represented by a current source $I_{ph,m}$. The lateral current has two components: a resistive component $I^L_R$ arising due to the disorder scattering of the charge carriers, and a capacitive component $I^L_C$ which is attributed to the presence of trapped states that affect the mobility of the charge carriers. The resistive and capacitive component of the current from node m to n are given as:

$$I^L_R = \frac{\phi_m - \phi_n}{R_{sp}(m,n)} \tag{3}$$

$$I^L_C = C_{sp}(m,n) \frac{d(\phi_m - \phi_n)}{dt} \tag{4}$$

where $R_{sp}$ and $C_{sp}$ are the internode spreading resistance and capacitance respectively.

In polymers as number of scattering centers increase more rapidly with internode distance $r_{mn} = |r_m - r_n|$. To take this in account in mean field manner we define a spreading function

$$g(r_{mn}) = exp\left[\left(\frac{r_{mn}}{\zeta}\right)^{\alpha}\right] \tag{5}$$

where $\alpha$ is the stretching exponent of the spreading function and $\zeta$ is the length scale which is charcteristic of the material under consideration. Using above mentioned spreading function the internode resistance and capacitance are given as following

$$R_{sp} = R_s g(r_{mn}) \tag{6}$$

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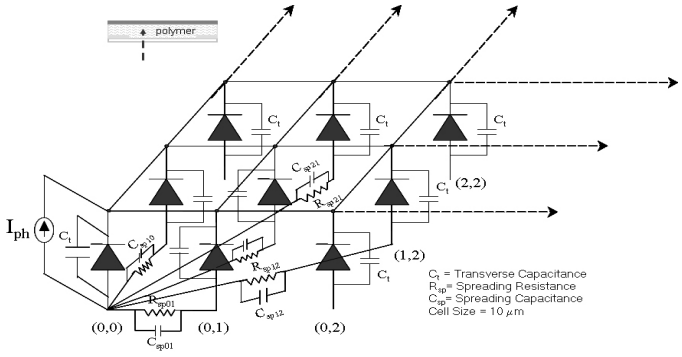


Fig. 2. Equivalent circuit spreading impedance network model of the polymeric Schottky device.

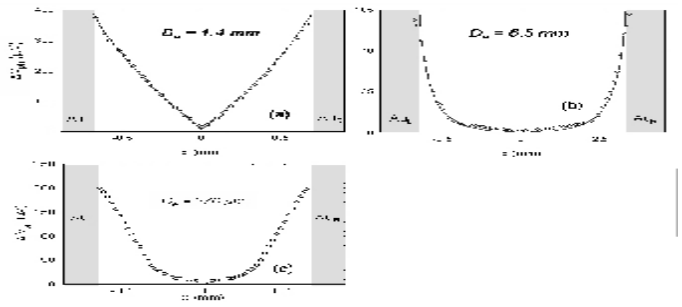

Fig. 3. LPV profiles for P3HT-devices of width $W = 1.5\ mm$ and $D_e = 1.4\ mm$ (a), $6.5\ mm$ (b) as a function of beam position. (Datasets (a) and (b) from [4,5]) The corresponding profile for an MEHPPV device of width $1.5\ mm$ and $D_e = 0.27\ mm$ is shown in (c). The bottom right panel shows the P3HT and MEHPPV structure.

$$C_{sp} = \frac{C_s}{g(r_{mn})} \tag{7}$$

where $R_s$ and $C_s$ are the sheet resistance and sheet capacitance respectively. Now we have divided the set of nodes into four mutually exclusively sets depending on whether the node is illuminated or not, and whether it is a part of electrode or not. (i) $S_{IL}$: set of nodes that are illuminated, (ii) $S_{NIL}$: set of non-illuminated non-electrode nodes (iii) $S_{LE}$:set of nodes coincident with left electrodes, and (iv) $S_{RE}$: set of nodes coincident with right electrodes. The equations for all the nodes is given as following:
For dark or non-illuminated nodes, m $\in S_{NIL}$

$$-I_s\left[exp\left(\frac{q\phi_m}{k_BT}\right)-1\right]-C_t\frac{d\phi_m}{dt}+\sum_{l\in S_{IL}}\frac{\phi_l-\phi_m}{R_{sp}(l,m)} + C_{sp}(l,m)\frac{d(\phi_l-\phi_m)}{dt}=0 \tag{8}$$

For illuminate nodes,

$$-I_s\left[exp\left(\frac{q\phi_m}{k_BT}\right)-1\right]-C_t\frac{d\phi_m}{dt}+I_{ph,l} + \sum_{m\in S_{IL},m\neq l}\frac{\phi_l-\phi_m}{R_{sp}(l,m)}+C_{sp}(l,m)\frac{d(\phi_l-\phi_m)}{dt}=0 \tag{9}$$

For left electrodes,

$$-N_L\left\{I_s\left[exp\left(\frac{q\Phi_L}{k_BT}\right)-1\right]-C_t\frac{d\Phi_L}{dt}\right\} + \sum_{m\in S_{LE},l\in S_{IL}}\left[\frac{\Phi_L-\phi_l}{R_{sp}(m,l)}+C_{sp}(m,l)\frac{d(\Phi_L-\phi_l)}{dt}\right]=0 \tag{10}$$

For right electrodes,

$$-N_R\left\{I_s\left[exp\left(\frac{q\Phi_R}{k_BT}\right)-1\right]-C_t\frac{d\Phi_R}{dt}\right\} + \sum_{m\in S_{RE},l\in S_{IL}}\left[\frac{\Phi_R-\phi_l}{R_{sp}(m,l)}+C_{sp}(m,l)\frac{d(\Phi_R-\phi_l)}{dt}\right]=0 \tag{11}$$

By solving (9)-(11) we can determine LPV ($\Delta V_{ph}$) defined by

$$\Delta V_{ph} = |\Phi_L - \Phi_R| \tag{12}$$

## III. Numerical Technique

The earlier technique is based on Fourier transform of $\phi(r,t)$ and $I_{ph}(r)$. It should be noted explicitly that the current source had been assumed to be constant in time. However, by assuming the current source to be evolving with time, we are trying to capture the exact nature of the current source. For small signal limit i.e. $q\phi << k_BT$ , the diode current was linearized. Now we are solving the differential equation direclty using finite difference technique. In this way, we hope that we will not only be able to get the transient properties of the charge carriers but also can capture the non-linear nature of the diode current.

## IV. Conclusion

We have attempted to establish lateral photovoltaic technique as an effective method to study charge carrier dynamics in polymeric semiconductors. Our effort to use LPE for investigation of steady state response of organic semiconductor devices has already proved successful [4,5]. One of the preliminary results of the model is shown in fig.3 in which the LPV profile has been shown as function of laser beam. We are next looking forward to exploit the LPE to get the transient response of the organic semiconductor devices. We are also aiming at determination of typical length scales of the devices so that we can extend our model to study the charge dynamics of other devices with different length scales which is governed by the morphology of the polymer which can be helpful for the simulation and prediction of new designs of organic optoelectronic devices.

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