Temperature dependence of P3HT:ICBA polymer solar cells*

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***Abstract* - Temperature dependence of polymer solar cell with a poly (3- hexylthiophene) : indene-C60 bisadduct (P3HT:ICBA) active layer were investigated from 15°C to 50°C to evaluate their application in standard working conditions. A standard drift-diffusion model including the temperature dependent hole mobility was used as a starting point to simulate measured I-V curves. Temperature induced solar cell parameters changes indicate that there is a significant optical interference influence in the device. In order to include these effects into the simulation, a new integral absorption coefficient parameter was introduced. Simulations of experimental data were conducted for temperature dependent mobility only, and in conjunction with integral absorption coefficient. The latter simulation results are in a better agreement with the experiment.**

Index Terms – P3HT, simulation, solar cells.

I. Introduction

Polymer solar cells' bright future is held back by the lack of our knowledge of physical processes that induce their behaviour. Temperature is an important parameter that can be used to better understand these processes and to enhance polymer solar cells efficiency. On the other hand, once they are produced, polymer solar cells (PSC) are meant to be placed outside and as such, exposed to environmental effects, among which are continuous temperature changes. It is crucial to understand how they react and how their performance is affected by these changes in order to create a suitable and reliable device. To our knowledge very few papers were published with main concern of temperature dependent characteristics [1] especially with poly (3-hexylthiophene): indene-C60 bisadduct (P3HT:ICBA) active layer. To prevent unnecessary expenses, a useful model is needed to simulate temperature dependence of PSC.

II. Experiment

PSC devices with glass/ ITO/ PEDOT: PSS/ (poly (3-hexylthiophene)) P3HT: (indene-C60 bisadduct) ICBA/ Al device structure were fabricated and tested at Institute for Micromanufacturing, Louisiana Tech University. Devices were illuminated with AM1.5 spectra of 100 mW/cm^2 optical power density from Spectra Physics 66900 solar simulator. I-V curves were measured for the temperature range from 15°C to 50°C with 5°C step.

P3HT and ICBA from Sigma Aldrich with 1:1 wt. ratio were mixed with chlorobenzene separately and kept on a hot plate with magnetic stirrer at 50°C overnight. PEDOT:PSS water solution from Heraeus was spin-coated with a micropipette onto a spinning substrate at 3000 RPM to deposit about 40 nm-thick film and was then annealed at 110°C for 10 min. The P3HT:ICBA solution was then dynamically dispensed with a micropipette while the substrate was spinning at 900 RPM to deposit approximately 130 nm-thick film. The P3HT:ICBA thin film was baked at 70°C for 5 minutes to remove any residual solvent. Temperature and humidity in the cleanroom were 20.9 °C and 48%, respectively. Afterward, a 100nm aluminum layer was deposited as a cathode in the e-beam evaporator, and then the device was annealed at 150 °C for 15 min on a conventional hot plate.

To control the temperature of the solar cells for testing, thermoelectric Peltier module with a DC voltage supply, which uses voltage to change the temperature on the plates, was used. Thermometer was also used to monitor the temperature. I-V characteristics were measured using Keithley 2400 source meter. Incident optical power density was measured with Newport Oriel 91150V reference cell and meter. Fig. 1 shows experimentally obtained I-V curves under illumination. From the I-V characteristics the main parameters of solar cell such as open circuit voltage, short circuit current, fill factor, and power conversion efficiency (Inset 2 of Fig. 1), were calculated.

III. Method and Results

In order to simulate the temperature dependence of glass/ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell, we used a drift-diffusion model described in [2]. Attempting to describe the change in I-V characteristics with temperature T, we included Arrhenius type temperature dependent hole mobility [3] in the model. Simulation results obtained with this model compared to experimental data are shown in Figs. 2, 3 and 4 as dashed lines, for temperatures 20°C, 35°C and 45°C, respectively. The smallest deviation between the calculated and measured curve is achieved for T=20°C, while deviations for two other selected temperatures are pretty large.

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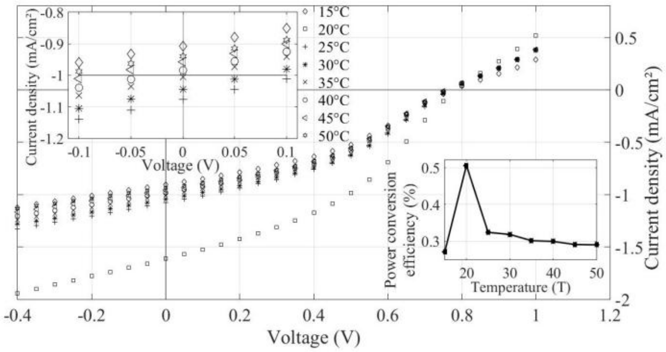

Fig.1. I-V curves for glass/ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell measured on different temperatures. Part of current axes enlarged so that I-V curves for different temperatures can be distinguished – Inset 1. Solar cell PCE temperature dependence – Inset 2

It can be seen from the Inset 2 of Fig. 1 that the PCE graph has a pronounced peak at T=20°C. Other device parameters show similar behavior. It is our assumption that this peak is caused by light interference effects in the device. Certainly, solar cell active layer thickness is affected by temperature and according to our measurements the interference maximum is reached at 20°C.

On the other hand, the P3HT:ICBA absorption coefficient used in our simulation was measured on 20.9°C, and the interference effects were not considered when its spectral shape was calculated from the optical transmittance and reflectance spectra. In fact, our absorption coefficient is the measure of total absorbed light energy in the active layer including interference and it can be denoted as an integral absorption coefficient α_{int}. With all of this in mind, it is not surprising that our calculation gives the best agreement with the experiment at 20°C because the used α_{int} approximately corresponds to this temperature. To account for interference effects on other temperatures we let α_{int} to be variable. We varied α_{int} on each temperature in order to get the best overlapping between measured and simulated I-V curves. The obtained simulation results are shown in Figs. 2, 3, and 4, for temperatures 20°C, 35°C, and 45°C, respectively. As it can be seen in Figs. 2, 3, and 4, a very good agreement between the theory and the experiment is achieved. The overall simulation results are similar for all examined temperatures.

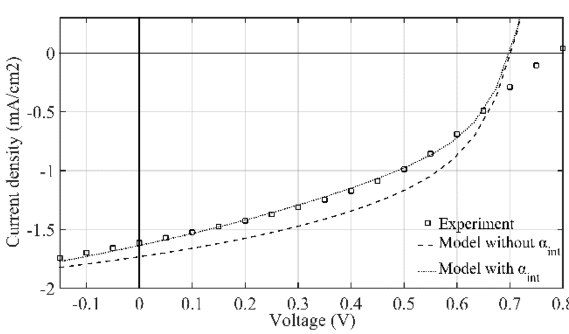

Fig 2. Experimental data points (open square symbols) and simulated I-V curves for ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell at 20°C with α_{int} measured at 20.9°C (doted curve), and with α_{int} variable (dashed curve).

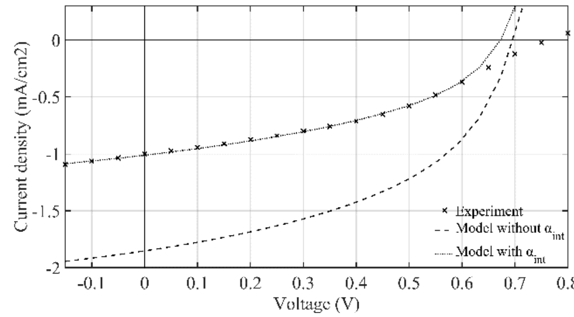

Fig 3. Experimental data points (x symbols) and simulated I-V curves for ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell at 35°C with α_{int} measured at 20.9°C (doted curve), and with α_{int} variable (dashed curve).

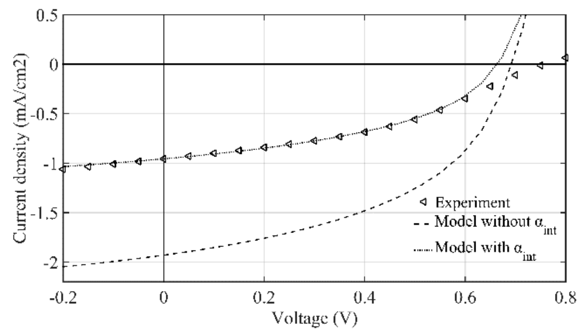

Fig 4. Experimental data points (open triangle symbols) and simulated I-V curves for ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell at 45°C with α_{int} measured at 20.9°C (doted curve), and with α_{int} variable (dashed curve).

However, certain deviation occurs for voltage values above 0.6V. Around 0.6V measured I-V curves bend in S shape indicating regime transition from ohmic to space charge behavior. Our model assumes ohmic regime for all voltage values. For further research, it would be interesting to investigate the temperature dependent optical absorption in polymer films. Are the interference effects the only ones responsible for this dependence, or do some intrinsic $\alpha(T)$ also contribute? Existing model can be improved by accounting for space charge effects as well as temperature dependent photogeneration and recombination of charge carriers.

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