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Temperature Dependant Performance Of Perovskite Solar Cell: A Device Simulation Study

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Abstract: Performance of 3rd generation solar cells like perovskite based devices under different climatic conditions/ambient temperature is one of the recent areas of research. To do this away by experiments is highly challenging and energy consuming task. In this paper extremely thin perovskite based functional solar cell device has been simulated at different operating temperatures for getting insights into the performance. As it is known that temperature is the key factor which can affect the performance of any well design laboratory level solar cells. Hence, it is of utmost importance to see through any possible changes those may occur with real climatic temperatures. In this device simulation, temperature of the ultrathin solar cell configured as ITO/PEDOT:PSS/P3HT:PCBM/Al has been tuned between 270 and 370 K to trace the optimal performance as energy conversion device. In addition to the active layers, suitable front and back metal contacts are taken into the consideration in the form of ITO and Al, respectively. Such type of device level simulation analysis will help experimentalists to get benefitted in designing/implementing their resources towards development of more robust and capable PSCs which can be operated at wide temperature range.

Keywords: Perovskite, PEDOT:PSS, ZnO, ambient temperature, open circuit voltage, maximum power point

1. Introduction

Device level simulation of various functional photoelectric devices is one of the trending fields of research in recent years. Since few decades, computational physicists have provided an ample amount of theoretical suggestions and future strategies to the wide research community. Among all photoelectric devices, solar cells have gained much attention due to high energy demand and green route for energy generation. Different solar photovoltaic technologies like crystalline silicon (Si), a-Si, CdTe, CIGS, dye sensitized solar cell (DSSC), organic solar cells (OSC) [1-5], polymer solar cells [6, 7], perovskite solar cells (PSC) [8, 9] and generic solar cells [10-14] have been explored both, theoretically and experimentally. Recently, perovskite based solar cells have shown tremendous potential and hence advancement in the realization of high efficient solar energy conversion devices. However, in spite of being potentially viable technology, PSC is struggling a lot in large scale applications [15, 16-19]. Moderate to poor device stability and low transparency are few of the limiting factors behind leisurelier acceptance of PSCs. In our recent study, we have reported accounting of individual photon while they pass through the device either utilised or unutilised.

In the present work, we have tried to explore the real time variation that may occur once the PSCs get installed in the field at different locations having wide range of ambient temperature. We have focused ourselves in finding out the device performance under varied temperatures.

2. Perovskite solar cell configuration

For the present simulation, a perovskite solar cell consisted of ITO/PEDOT:PSS/P3HT:PCBM/Al was adopted. PSC was configured of two active layers and appropriate metal contacts for the collection of photogenerated charge carriers. Temperature was varied from as low as 270 K to relatively very high 370 K to simulate device for the solar cell IV characteristics. We have also studied the comparative current-voltage (IV) analysis based on device simulations under rest of the standard test conditions.

3. Device simulation

PSC was simulated with the help of gpvdm software to collect their performance as solar cell under different temperatures. To do that away, an AM 1.5 G light source was used for recording IV spectra of the PSC. Applied voltage range was restricted between -0.1 and 1.4 V to get the quantitative information about the photogenerated carriers which ultimately resulted in photocurrent. Optimal and suggestive parasitic resistances were chosen by default with the help of electrical simulation tool. Resulted output in the form of IV response and images have been recorded and presented to compare the power conversion efficiencies (PCE) of PSC.

4. Results and discussion

At a very first instance, it is worth remembering that the overall power conversion efficiency of any solar cell would be at the highest precedence while optimizing the rest of the criteria. Hence, we have straight away focused ourselves to look into the IV curves of PSC under study at varied temperatures and are presented in Fig-1 (a) for comparison purpose. As one can notice that, at all the provided device temperatures very high short circuit current density (Jsc) was observed. However, open circuit voltage (V_{oc}) has shifted by approximately 0.35 V. In addition, eye catching square IV curves assured high fill factor of 84% is due to selectively chosen parasitic resistances. It is worth referring Table-1 for the temperature dependant IV parameters like open circuit voltage, maximum power, maximum power point voltage and resulted efficiency. It is interesting to observe that PSC improved its performance as energy generating device at elevated temperature. Maximum power that can be generated from such device at different temperatures has been presented in Fig-1 (b). It is clearly seen that point of maximum power point also got shifted towards higher voltage as the temperature was increased. To pinpoint out the exact effect of increase in temperature on P_m, V_{oc} and efficiency; we have shown their behavioural plots against the range of temperature in Fig-2 (a), (b) and (c), respectively. Spectral profile of photo generation in each of the layers, we have snapped the profile with the help of gpvdm and presented in Fig-3. As it can be seen from Fig-3, PEDOT:PSS layer get exposed to incident AM 1.5 G source and available photons start travelling under the effect of natural band bending and the applied potential (while recording the IV). It is believed that both, absorption and photo conversion solely depends on the material aspects and not on their interface/s. As in our previous report, spectral profiles of successfully absorbed photons in devices PSC-1, PSC-2 and PSC-3 would guide in providing pathway for analysing the depth profiling of effective photo-generated carriers. It was very interesting to note that photons also get utilized at back metal junction and produce photogenerated electron-hole pairs contributing in the photocurrent. Considering

all this analytical observations derived based on device level simulation study, one can notice that excess temperature of even ultrathin active layer hinders the efficient utilization of each photon and overall PCE. Such theoretical study will enhance the selectivity of potential solar cell technologies for the deployment in a specific locations possessing wide range of ambient temperatures.

5. Conclusion

In conclusion, we have reported the effect of temperature on the solar cell performance consisting of ultrathin layers of PEDOT:PSS/P3HT:PCBM. Effect of such a wide range of temperature on Voc, Pm and hence PCE was studied in detail to better understand the inherent materials response to the real climatic conditions (i.e., temperature). PSC showed a noticible improvement in the PCE from 6.47% to 8.87% as the operating temperature raised by 100 K. Profiles of photogenerated carriers in different layers in addition to the temperature dependant IV curves provide a pathway to design and implement large scale installation of perovskite based solar cells.

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Table 1 Perovskite solar cell parameters obtained at different temperatures.

Temperature (K)	V_{oc} (V)	P_m (W/m^2)	n (%)
270	0.91	64.77	6.47
285	0.96	68.35	6.83
300	1.01	71.99	7.19
315	1.06	75.56	7.55
330	1.11	79.18	7.91
345	1.16	82.76	8.27
360	1.21	86.36	8.63
370	1.25	88.75	8.87

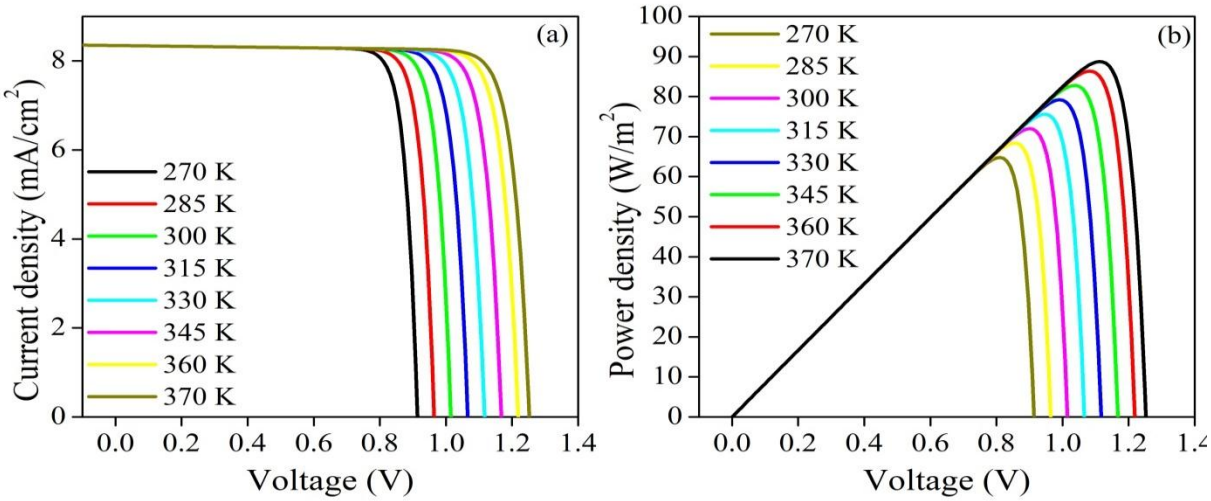

Figure 1 (a) IV and (b) PV characteristic curves of PSC at different temperatures (from 270 to 370 K)

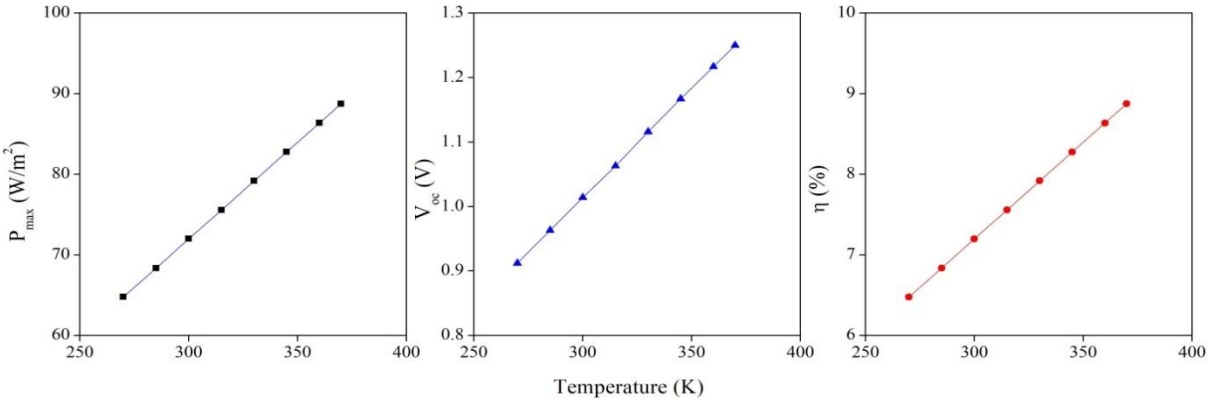

Figure-2: Variation of (a) maximum power, (b) open circuit voltage and (c) efficiency of perovskite solar cell operated between the temperatures 270 and 370 K.

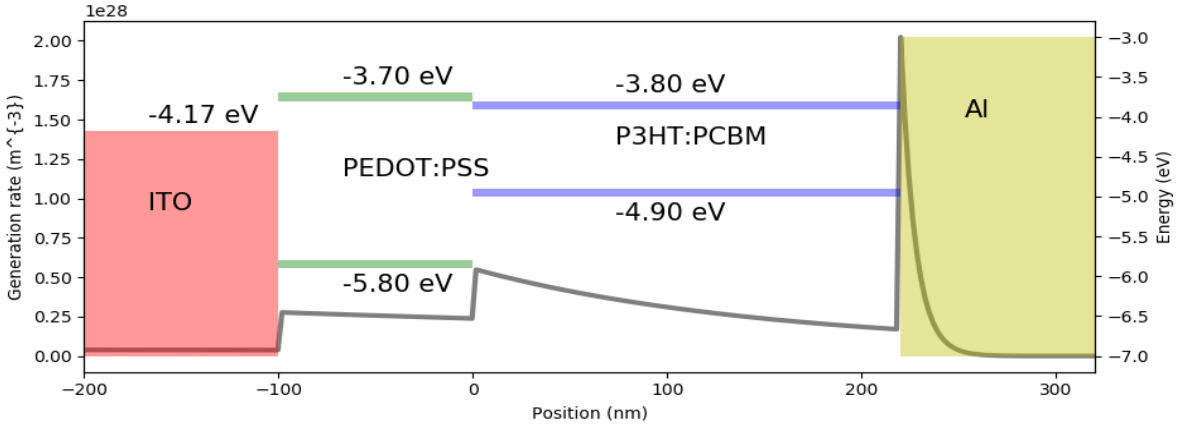

Figure-3: Spectral profile of generation rate across all the layers of perovskite solar cell utilizing