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Shuai Wang[1], LiLi Wu[1]*, Xia Hao[1,2]*, Jingquan Zhang[1], lianghuan Feng[1], Tapas Mallick[3], Lingzhi Xie[2]
[1]College of Materials Science and Engineering, Sichuan University, Chengdu, China
[2]Institute of New Energy and Low-carbon Technology, Sichuan University, Chengdu, China
[3]Environment and Sustainability Institute, University of Exeter, Exeter EX4 4PY, U.K
E-mail: wulili@scu.edu.cn, hao.xia0808@scu.edu.cn

Abstract. It is a reasonable way to increase power generation and reduce the expensive solar cell materials by combining low-cost concentrator and solar cells. The characterization of low concentration CdTe solar cell under standard test condition (STC) and monochromatic light were carried out. The application of concentrator significantly increases the power output of CdTe solar cell. The monochromatic I-V results suggest that the FF of CdTe solar cell was critically affected in the wave length range of 525 to 780 nm. Also the effect of the anti-reflective film on the low concentration CdTe solar cells were revealed, and the results imply that the anti-reflective effect is magnified mainly at the wave length range of 525 to 780 nm.

Keywords: Low concentration CdTe solar cells, IV Characteristics

1. Introduction

Cadimium telluride (CdTe) solar cells are commercially available, low cost PV devices. CdTe has an ideal direct band gap of 1.45eV and a high absorption coefficient, which implies that 2 μm is enough to absorb most of the visible light. The highest efficiency of CdTe thin-film cell is 22.1% and average production module efficiency is up to 18.6%[1]. Improving the power output by further optimizing device performance will contribute to the reduction of production cost of CdTe solar cells. Alternatively, one may utilize a concentrator to improve the power output by increasing the incident light intensity. Currently the research on concentrator PV devices is mainly focused on GaAs, III–V multi-junction and silicon solar cells. The advantages of low temperature coefficient, high coefficient of absorption and good stability make CdTe solar cells quite competitive with the conventional Si concentrator solar cells[2]. Meanwhile, thin film solar cells can be deposited on flexible substrates[3], which will have a wide range of application at building integrated concentrating photovoltaic (BICPV) systems. However, the fundamental studies on thin-film concentrator solar cells are not carried out to date. In the present work, we studied the current density-voltage (J-V) characteristics of CdTe solar cell without and with concentrator under standard test condition (STC) and monochromatic light. The performance of CdTe solar cell at non-uniform radiation condition were also analysed.

2. Experimental

2.1. Device fabrications

The structure of CdTe thin film solar cells in this study was glass/SnO_2:F (FTO)/TO/CdS/CdTe/ZnTe:Cu/BC. The FTO with a thickness of ~400 nm substrates were purchased from Pilkington. FTO was mechanically polished for 15 minutes and successfully cleaned by acetone, ethanol and deionized water. After that, a ~40-nm-thick SnO_2 high resistivity transparent (HRT) layer was deposited followed by a CdS window layer deposition. The CdTe absorber films (~4μm) were deposited by vapour transport deposition and the ZnTe:Cu (~75 nm) back contact was deposited by thermal co-evaporation. Finally, the Au back electrodes were deposited by vacuum evaporation. For the devices utilized to clarify the effect of antireflective layer, an extra 80-nm-thick MgF_2 was deposited on the front side of FTO by thermal evaporation. The compound parabolic concentrator with an theoretical concentration ratio of 4× was placed on top of the CdTe solar cells while demonstrating the concentration effects, as shown in Figure 1. The detailed parameters of 4×concentrator be found in the literature[4].

2.2. Characterization

The current density-voltage (*J-V*) characteristics were carried out under simulated AM1.5 illumination at 1 sun by using a class A solar simulator. The external quantum efficiency (EQE) of the device was determined by a QEX10 Solar Cell Spectral Response from PV Measurements, Inc. Monochromatic light collection efficiency (MCE) measurements were performed at 470, 525 and 780 nm. The intensity of monochromatic light was the same as the intensity of the corresponding wavelength in the solar spectrum of AM1.5.

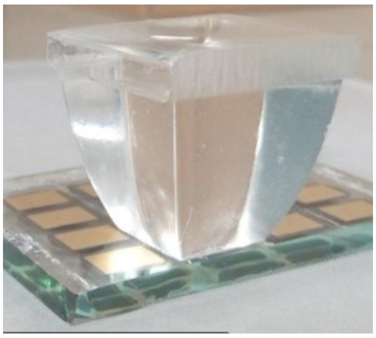

Figure 1. The photo of the concentrator element

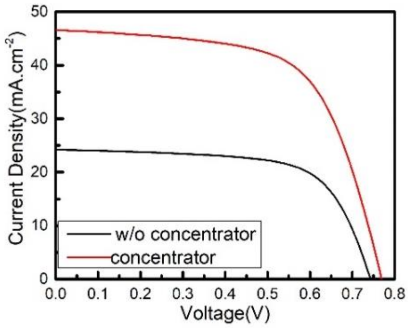

Figure 2. The current density-voltage characteristics of CdTe without (black line) and with (red line) concentrator

3. Results and discussion

3.1 J-V characteristics of CdTe solar cells without and with concentrators

Table 1. The photovoltaic parameters of CdTe solar cells without and with concentrator (Sample ID: X-1)

	Eff (%)	FF (%)	Voc (mV)	Jsc (mA·cm^{-2})	Pmax (mW)
W/o concentrator	11.93	64.65	721	25.57	11.93
With concentrator	4.37	63.58	746	36.80	17.48

In this study, the open-circuit voltage (Voc), short-circuit current (Jsc) and fill factor (FF) of the CdTe solar cell were 743 mV, 24.20 mA/cm^2, and 0.67, respectively. The photovoltaic parameters of CdTe solar cells without and with concentrator were summarized in Table 1. The device exhibits quite different performance after the application of concentrator, reflected by the varied photovoltaic parameters. This variation is mainly due to the increase of the incident light intensity. As shown in Figure 2, After concentrating, the Jsc and Voc increases significantly in turn to increase the power conversion efficiency. Rs and Rsh dropped obviously due the high-level injection at the CdS/CdTe junction. On the contrary, the electrical property of FTO keeps unchanged with the varied light intensities, which make the voltage drop on this layer[5]. Meanwhile, the actual concentration ratio (the $Jsc_{concentrated}$ / $Jsc_{non\text{-}concentrated}$) was 1.44, which is seriously deviated from the theoretical value (4×). It

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is suggested that when we simply placed the concentrator on top of the front side of solar cells, severe optical loss occurred at the glass/concentrator interface and this may be greatly improved if the encapsulation is introduced.

3.2 Wavelength dependent photovoltaic characteristics

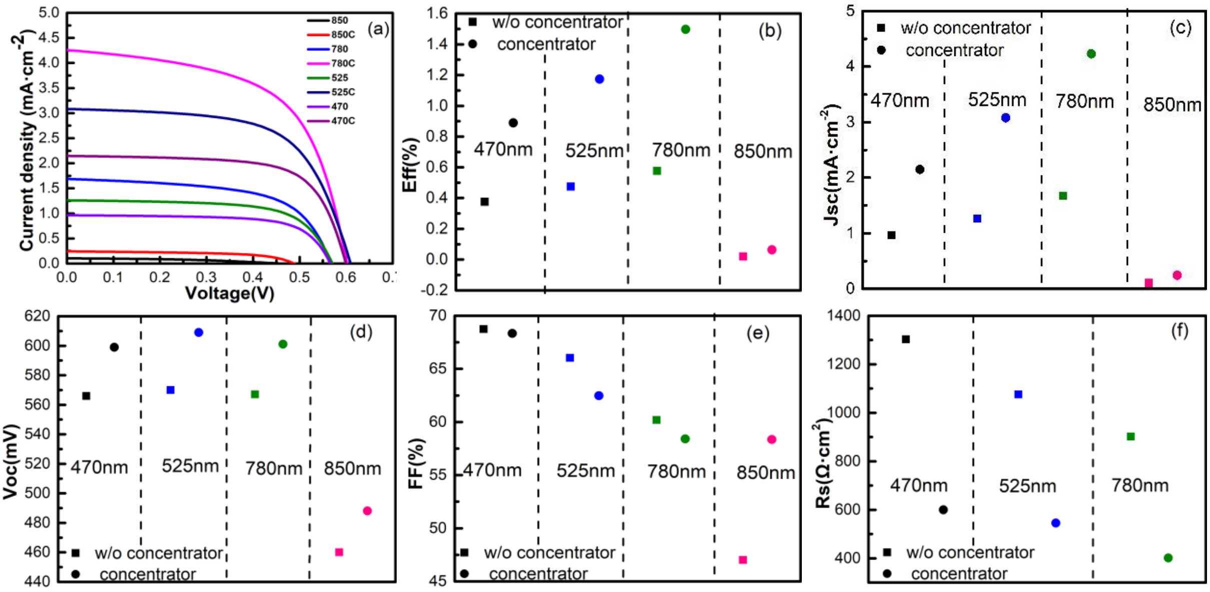

Figure 3. Wavelength dependent performance of CdTe solar cells: (a) J-V characteristics, (b) efficiency, (c) Jsc, (d) Voc, (e) FF and (f) series resistance (Rs)

Figure 3 shows the J-V characteristics of the devices under monochromatic light. In the case of CdTe solar cell without concentrator, The Jsc, Eff and Rs of non-concentrated devices increased with the increase of the wavelength below 780 nm and decreased while the wavelength keeps increasing to 850nm. Some of the light at the wavelength range of 470-525 nm was absorbed by CdS layer[6] and the generated photocurrent is small. As a result, low Eff and Jsc were obtained at 470 and 525 nm. High Eff and Jsc were achieved at the 780 due to the production and collection of generous photon-generated carriers, which also increases electrical conductivity and decreases series resistance, as shown in Fig. 3(f). However, in this case there is no obvious change in Voc. We also noticed that the performance of the solar cell at 850 nm is very poor. The possible reason could be that the photo-generated carriers were located at the back side of CdTe layer. These carriers are too far away from the built-in field. And as a result, the sweep-out speed of the carriers will be deceased. The carriers will then be trapped and recombined here rapidly. In case of the low concentrated case, the concentrator has no effect on the transmission of monochromatic light at 470-850 nm [7]. The wavelength dependence of the photovoltaic parameters is almost the same as the non-concentrating case. It is worth noted that the FF at the wavelength of 470 nm was no visible change while that at the wavelengths of 525-780 nm decreased obviously. One may speculate that in the wavelength range of 525-780 nm, the photo-generated carriers by the increased light intensity are suffered from severe charge trapping and recombination.

3.3 The effect of anti-reflection coatings on low concentration CdTe solar cell

Table 2. The photovoltaic parameters of CdTe soalr cells with anti-reflective layer (Sample ID: X-2) without and with concentrator.

	Eff (%)	FF (%)	Voc (mV)	Jsc ($mA\cdot cm^{-2}$)	Pmax (mW)
w/o concentrator	11.95	66.45	743	24.24	11.94
With concentrator	5.61	62.52	769	46.62	22.44

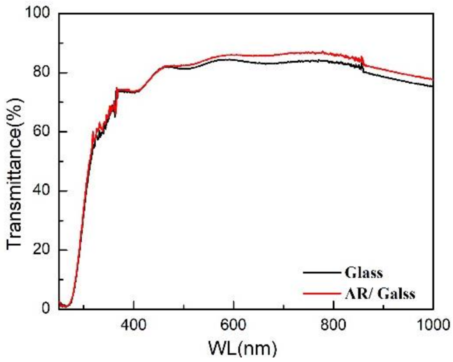

Figure 4. Transmittance spectrum of TEC-10 substrates with and without MgF_2 anti-reflective coating

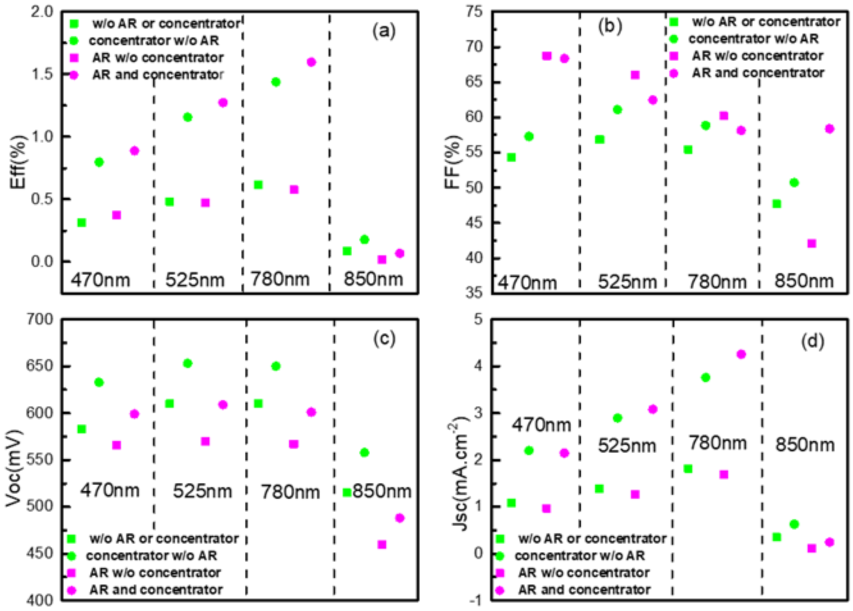

Figure 5. Wavelength dependent photovoltaic parameters of CdTe solar cells. (a) Eff, (b) FF, (c) Voc, (d) Jsc.

The effect of anti-reflective layer for concentrator devices was studied on CdTe solar cells with 80-nm-thick MgF_2 film deposited on the front glass of FTO. The transmittance spectra of glass substrate with and without MgF_2 film are dipected in Figure 4. One can find that the transmittance is mainly improved at the wavelength range of over 420 nm, which is in good agreement with the wavelength dependent J-V characteristics as shown in Figure 4. The Jsc (purple filled circles in Figure 4(d)) was sginificantly improved at the wavelength range of 525-780 nm. The anti-reflective coatings could reduce the optical losses at the wavelengths of 525-780 nm due to the increased transmittance of 500-800 nm. Similar to the device without anti-reflective layer, the optical loss also occurred at the interface of the concentrator and the front glass of FTO. Regardless of the optical loss induced by the uncompact contact between the concentrator and CdTe soalr cells, the actual concentration ratio is 1.92, which is better than the device without anti-reflective layer. The power output of devices are almost doubled by simply placing a low cost concentrator on a CdTe solar cell.

4. Conclusion
In this study, CdTe solar cell with concentrator under stand STC and monochromatic light were carried out. The power output was significantly increased after the application of concentrator and the improvement will be further magnified on the device with anti-reflective layer. The deviation of the actual concentration ratio from that of the theoretical value is mainly due to the optical losses at the interface between the concentrator and the device. The power output is finally doubled in the low concentration CdTe solar cell and it is promissing to be utilized in the BIPV application after further structural oprimization.

5. Acknowledgement
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6. Reference
[1] M.A. Green, Y. Hishikawa, W. Warta, E.D. Dunlop, D.H. Levi, J. Hohl-Ebinger and A.W.H. Ho-Baillie 2017 *Progress in Photovoltaics: Research and Applications* **25** 668-676
[2] P. Singh and N.M. Ravindra 2012 *Sol Energy Mater Sol Cells* **101** 36-45
[3] L. Kranz, C. Gretener, J. Perrenoud, R. Schmitt, F. Pianezzi, F. La Mattina, P. Blosch, E. Cheah, A. Chirila, C.M. Fella, H. Hagendorfer, T. Jager, S. Nishiwaki, A.R. Uhl, S. Buecheler and A.N. Tiwari 2013 *Nat Commun* **4** 2306
[4] H. Baig, N. Sellami and T.K. Mallick 2015 *Sol Energy Mater Sol Cells* **134** 29-44
[5] W. Li, R. Yang and D. Wang 2014 *Sol Energy Mater Sol Cells* **123** 249-254
[6] K. Nakamura, T. Fujihara, T. Toyama and H. Okamoto 2002 *Japanese Journal of Applied Physics.pt Regular Papers & Short Notes* **41** 4474-4480
[7] Sarmah, Nabin, Bryce S. Richards, and Tapas K. Mallick. 2014 *Solar Energy* **103** 390-401