Designing New Inverted Colloidal Quantum Dot Solar Cells for Flexible Applications

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Abstract

Motivation. Lead sulfide (PbS) colloidal quantum dots (CQDs) are promising materials for flexible solar cells because they can be easily deposited as a thin film onto a variety of substrates using straightforward solution processed methods. One of the main factors limiting the performance of PbS CQD solar cells is the poor quality of the current hole transport layer (HTL) material.[1] Here, we report on methods to develop efficient inverted PbS CQD solar cells that will enable us to more easily incorporate novel HTL materials to improve the efficiency of our solar cells.

Methods.

Simulations: SCAPS-1D[2]

Fabrication: Colloidal synthesis, spin-casting, evaporation

Measurements: Illuminated current-voltage (JV) testing

Results.

- Improving Inverted Device Performance
    - Effect of vacuum drying
    - Effect of number of ZnO layers
    - Effect of ZnO spin speed
- SCAPS[2] Simulations: Novel HTL Materials

Introduction

A CQD solar cells consists of 3 primary semiconductor layers and 2 electrical contacts. As shown in the below figure, Fluorine- or indium-doped tin oxide (FTO or ITO) are used as a transparent conductor and gold or aluminum are used as the top contact, depending on the architecture being used. The three semiconductor layers are the absorbing layer, the electron transport layer (ETL), and the hole transport layer (HTL). PbS CQDs are temperature sensitive, which limits the deposition methods that can be used for the HTL in a standard device. The benefit of an inverted device is that the HTL is deposited directly on the substrate, and we can therefore employ a larger range of deposition methods to deposit the HTL.

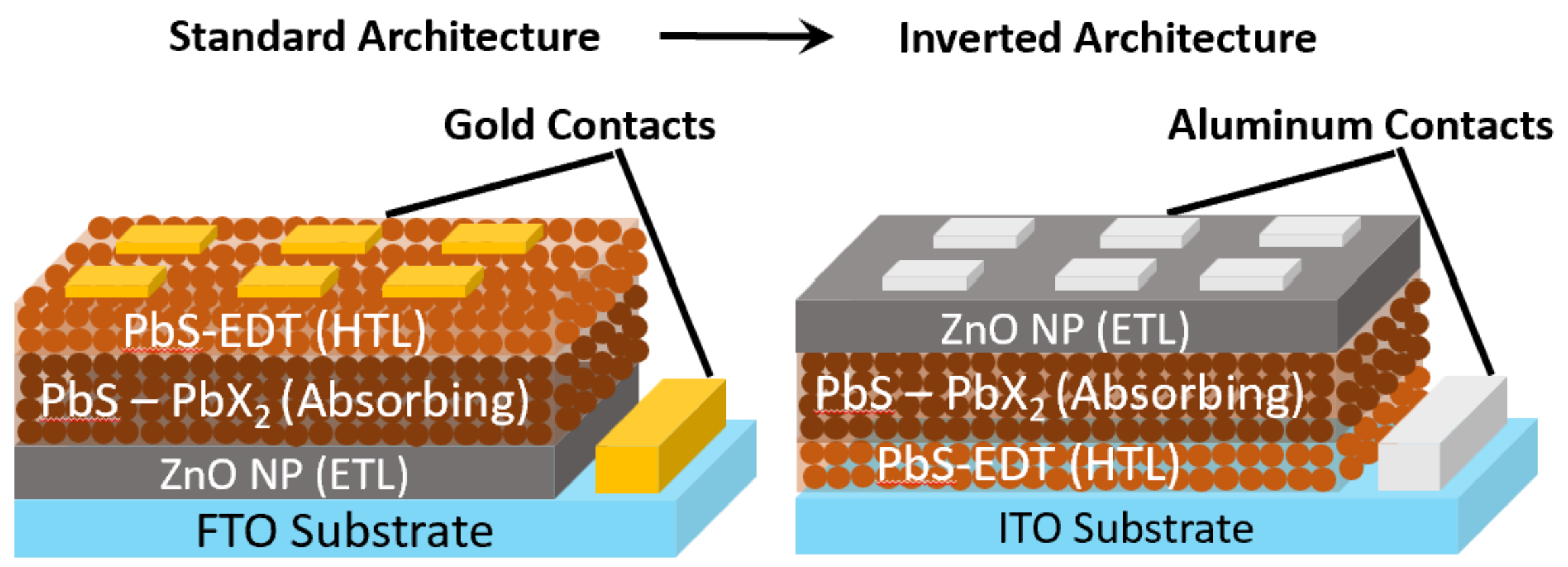

Figure 1. Structure of a standard (left) and inverted (right) CQD solar cell.

When first fabricating inverted CQD solar cells, we observed cracking of the absorbing layer when depositing the electron transport layer, leading to a low initial power conversion efficiency (PCE) of 0.5%. We attributed this issue to two factors. (1) The absorbing layer wasn't fully dry when the ETL is deposited, leading it partial dissolve when exposed to the ETL solvent. (2) The ETL solvent is harsh on CQDs and partially etches the PbS CQD layer. Based on these initial results, our SCAPS simulations, and previous work in the field,[3] we implement and report 3 strategies to improve the PCE of inverted devices. We also report on SCAPS[2] simulations of inverted CQD solar cells with novel HTL materials to determine their anticipated impact on device performance.

ZnO ETL Thickness

SCAPS simulation (not shown) indicated that inverted device PCE can be improved by decreasing the thickness of the ZnO ETL. We varied the ZnO thickness by increasing the spin casting speed to decrease the layer thickness and by varying the number of layers deposited.

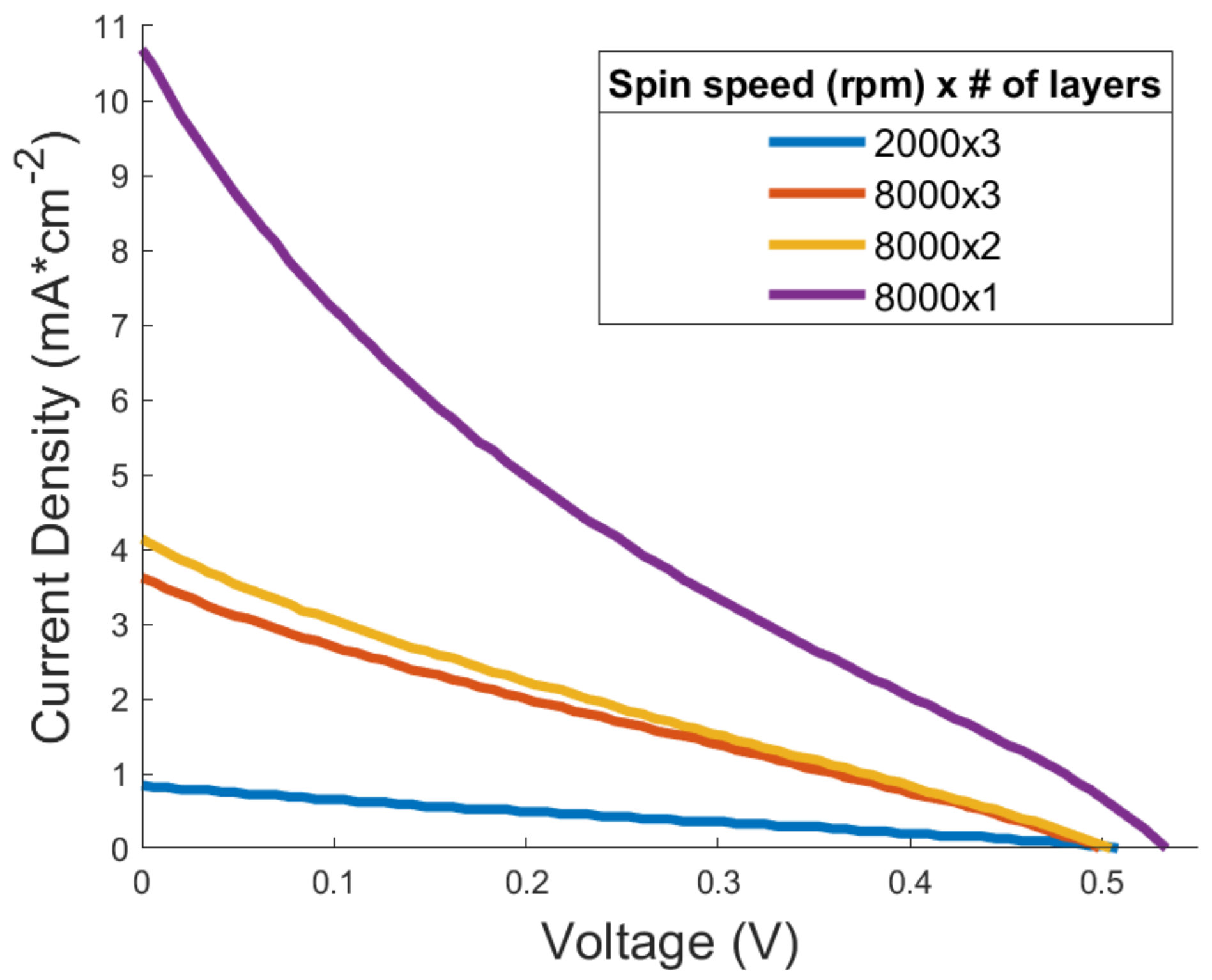

Figure 2. Illuminated JV curves for inverted devices made with different ZnO deposition conditions, as indicated in the legends. All devices in this batch used a 20-minute vacuum dry to improve absorbing layer drying. The devices in this batch achieved PCEs of 0.11%, 0.42%, 0.47%, and 1.1%, for the blue, red, yellow, and purple curves, respectively.

Based on the results shown in figure 2, the importance of ZnO spin speed became evident, which we attribute to an optimization of the layer thickness. We next optimized the ZnO spin speed.

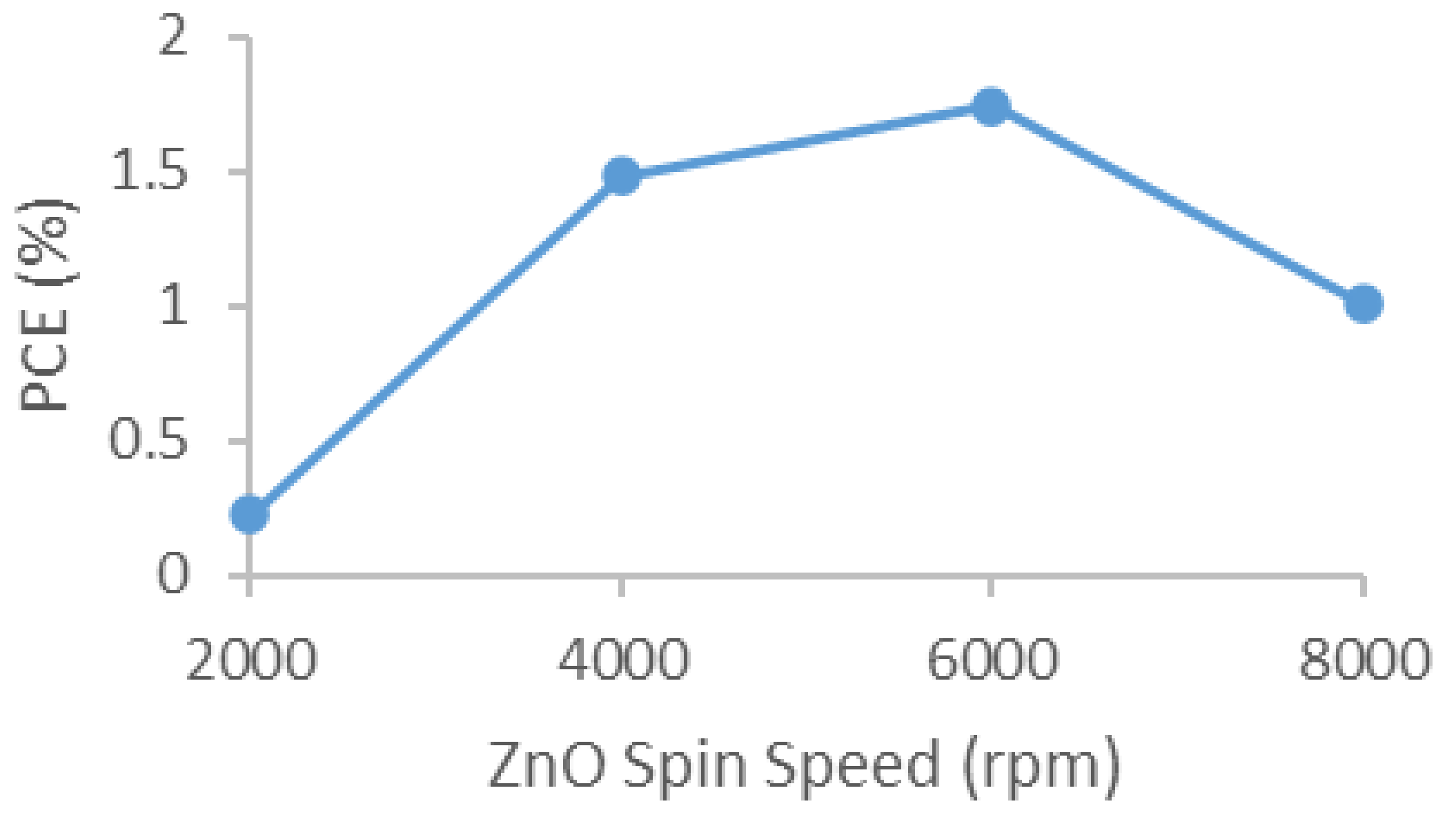

Figure 3. PCE values for inverted solar cells made using different spin speeds for the ZnO deposition. A clear maximum is observed at 6000 rpm. The best devices achieved 0.42%, 2.02%, 2.42%, and 1.36% for 2000, 4000, 6000, and 8000 rpm, respectively.

Vacuum Drying

As seen in the below results, vacuum drying the absorbing layer significantly improved device PCE, confirming our hypothesis that the absorbing layer wasn't getting fully dried and providing a route towards improved device PCE.

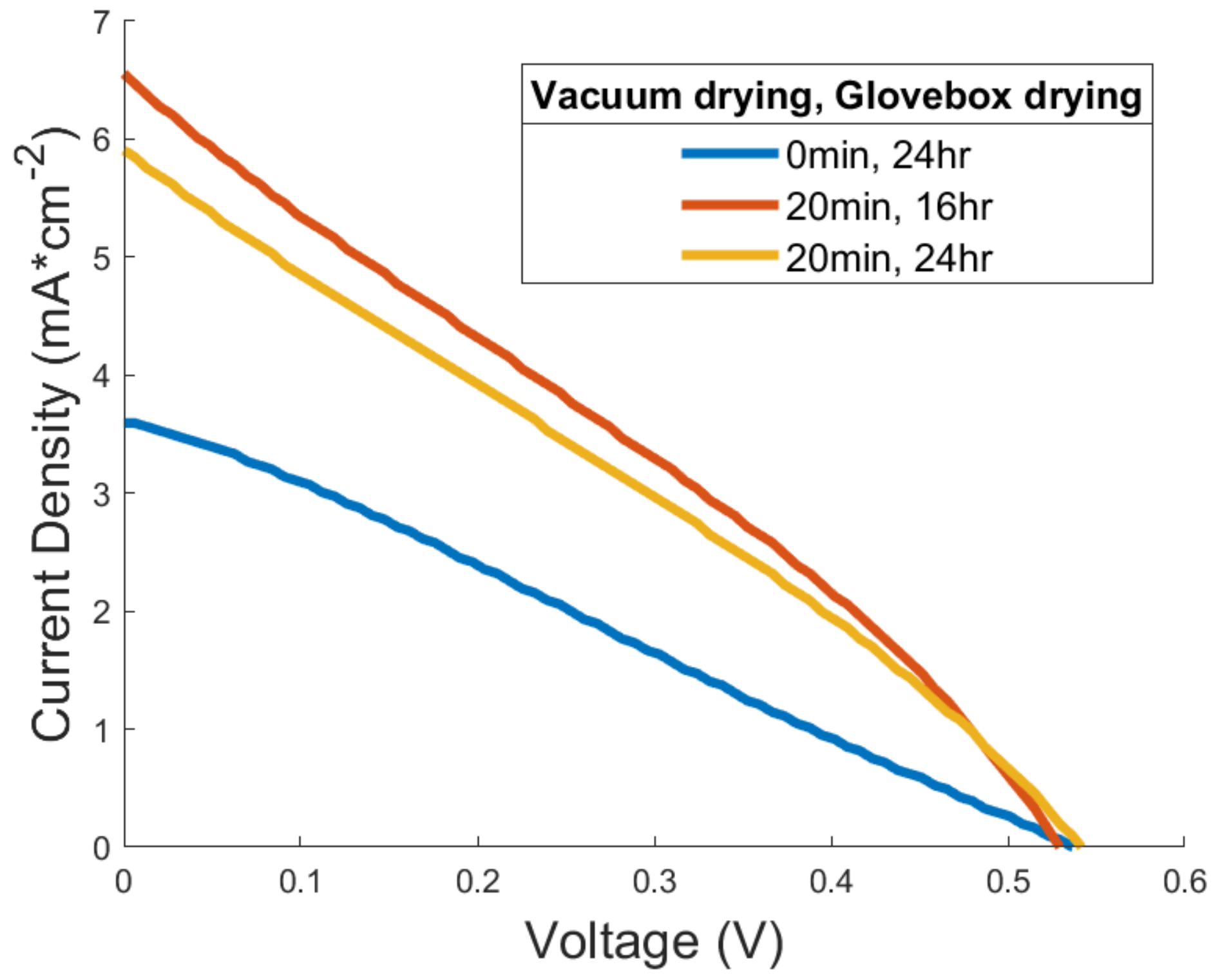

Figure 5. Illuminated JV curves for inverted devices made with the structure shown in figure 1. The drying conditions used for the absorbing layer are indicated in the legend. The devices in this plot achieved PCEs of 0.5%, 0.9%, and 1.0% for the blue, yellow, and red curves, respectively.

SCAPS[2] Simulations: WSe_2 HTL

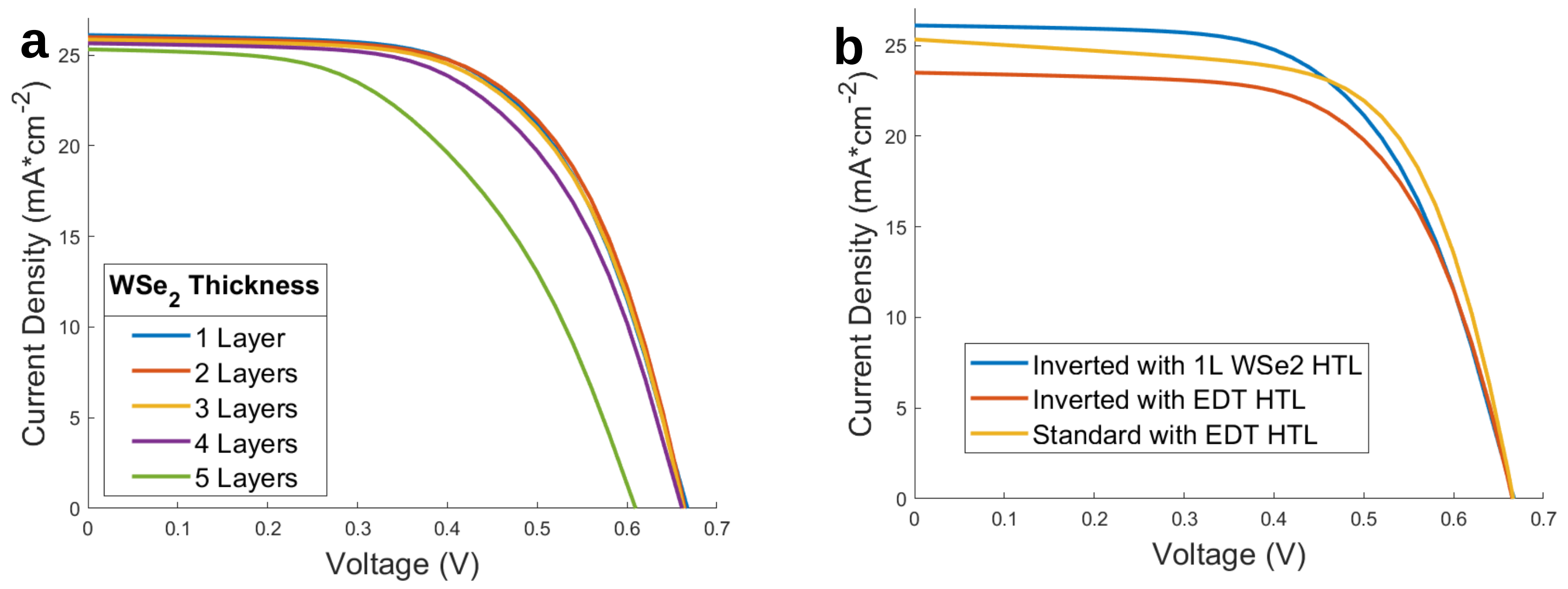

Figure 4. Simulated illuminated JV curves using SCAPS-1D[2]. (a) Simulations of an inverted CQD solar cell employing 2D WSe_2 of various thickness (b) Simulations of both standard and inverted solar cells with PbS-EDT and 2D WSe_2 HTLs, as indicated in the legend. The associated PCE values are shown in the table to the right.

HTL Material	PCE
$1L\ WSe_2$	10.7%
$2L\ WSe_2$	10.8%
$3L\ WSe_2$	10.6%
$4L\ WSe_2$	10.0%
$5L\ WSe_2$	7.8%
EDT	9.9%
EDT (Standard Device)	11.0%

Acknowledgements

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References

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