Improved current generation for an ITO-free semitransparent organic solar cell using a multilayer silver electrode as distributed Bragg reflector

Semitransparent organic solar cells (STOSC) exhibit promising application as power-generating windows in buildings and agricultural greenhouses. Due to their widely adjustable optical band gap, organic semiconducting materials have the potential to efficiently utilize near infrared light while maintaining semitransparency in the visible light range.[1] One challenge in improving the overall performance of STOSCs is maximizing both power conversion efficiency (PCE) and average visible transmittance (AVT) simultaneously, since intrinsically they are often in a trade-off relationship. [2] A key factor in optimizing both values, is choosing the right material for each intermediate layer of the cell. One well-established material used for electrodes in semitransparent cells is ITO. Although known for its high transparency and good conductivity, it is considered brittle and its production is cost- and energy-inefficient. Furthermore, Indium is a metal that rarely occurs in nature.[3] One alternative is using multiple interlayers of silver and Al-doped ZnO (AZO) as a distributed Bragg reflector on the backside of the solar cell. This way, the current generation can be improved while simultaneously maintaining a high transparency for the cell.

Herein we report recent progress in ITO-free semitransparent organic solar cells by implementing a multilayer silver back electrode as an infrared mirror, achieving a power conversion efficiency of 10.2% for a cell stack based on PVX-Plus with an average visible transmittance of 33.1%. Both optical modelling and experimental findings were used to maximize the photocurrent generation and the visible transmission of the solar cell.

The back electrode consists of alternating layers of Al- doped ZnO and thin silver. As the reflected part of the light passes the photoactive layer a second time, an increase in absorption is achieved. Optical simulations show that the distance between the two silver layers has an influence on the wavelength range of the reflection and thus determines the generation of the photocurrent in the cell. By optimizing the spacing between the two silver layers, it was possible to increase the photocurrent for a solar cell based on PV-X plus by 9,8% (from 19.3 mA/cm^2 to 21.2 mA/cm^2). At the same time, it was found that the fill factor decreases with an increase in the thickness of the interlayer. When using a single silver layer of 14 nm, the fill factor could be kept high enough (71,3%) that despite a comparably lower current generation (17,0 mA/cm^2) a LUE (PCE x AVT) of 3,38% was achieved.

[1] https://www.ise.fraunhofer.de/en/research-projects/adapt.html (Date 22.07.22)

[2] Wang, D., Qin, R., Zhou, G., Li, X., Xia, R., Li, Y., Zhan, L., Zhu, H., Lu, X., Yip, H.-L., Chen, H., Li, C.-Z., High-Performance Semitransparent Organic Solar Cells with Excellent Infrared Reflection and See-Through Functions. *Adv. Mater*. **2020**, 32, 2001621.

[3] Christopher J.M. Emmott, Antonio Urbina, Jenny Nelson, Environmental and economic assessment of ITO-free electrodes for organic solar cells, *Solar Energy Materials and Solar Cells*, **2012**, 97, 14-2

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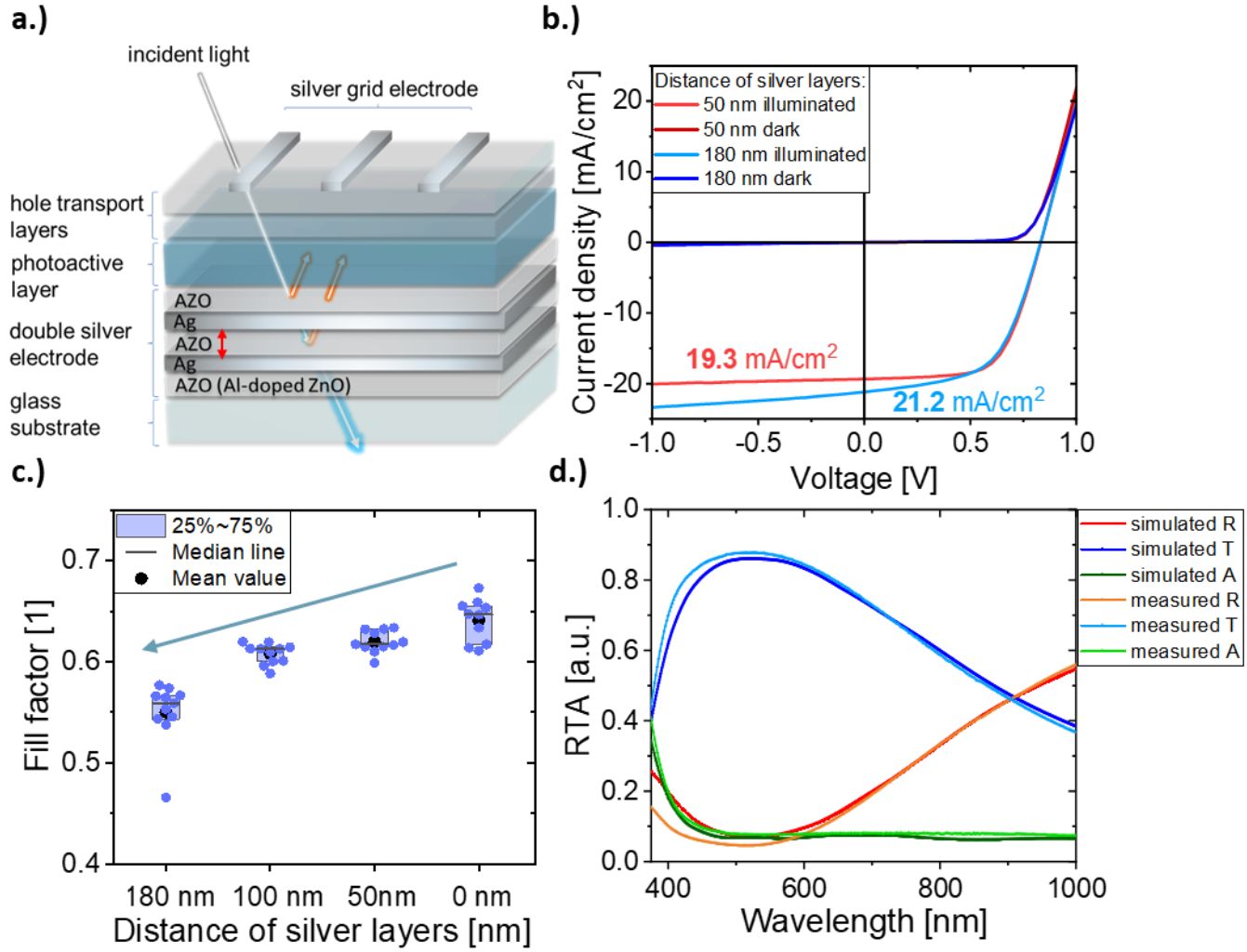

Illustration 1: ***a.)*** *Schematic representation of working principle of the multilayered silver back electrode,* ***b.)*** *IV-curve measurement comparison of two cells based on PV-X Plus as photoactive layer with 50 nm (red) and 180 nm (blue) distance between the silver layers,* ***c.)*** *Fill factor measurement results of cells based on PV-X Plus as photoactive layer with increasing respective distance between the silver layers,* ***d.)*** *Comparison of simulated and measured reflection (R), transmission (T) and absorption (A) of the electrode stack on glass at a respective distance of 0nm (single silver layer).*