PerTPV – Perovskite thin film photovoltaics

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Deliverable 3.1

Protocol to test junction efficiency and stability under stress

WP3

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1. Introduction

The charge recombination junction in a two terminal tandem solar cell is important as it ensures efficient current matching while minimizing a possible voltage barrier. The low voltage barrier enables the potential energy of the photogenerated charges to lead to high open circuit voltages of the cell.

In PERTPV two types of recombination junctions are foreseen, one based on inorganic semiconductors and another employing organic charge transport molecules. In the latter case, these molecules are generally partially doped to reduce resistive losses.

2. Protocol

The junction efficiency is typically determined by applying a constant current density over a junction and measuring the potential drop over it. The current densities should be in the range of what is expected for a perovskite based tandem cell, i.e. in the range of 15 to 20 mA/cm^2.

Enabling the monitoring of the potential drop over a thin junction is not trivial as they would not be easily distinguished from shorted devices. For this reason, thicker layers are used in our testing protocol and therefore the potential drop measured is an overestimation of the potential drop in real tandem cells where thinner junctions can be used.

The junctions based on inorganic metal oxides are prepared by vacuum based deposition methods such as magnetron sputtering or atomic layer deposition, whereas the junctions based on the organic charge transport molecules are prepared by vacuum based thermal evaporation.

Once prepared, the recombination junctions are contacted and the following experiments are conducted:

1. A J-V scan is taken at a fixed scan rate of 0.4 V/s.
2. The junctions are driven to a constant current density of 5, 10, 15 and 20 mA/cm^2 and the voltage is monitored over 1 minute.
3. The junction is heated to 85 °C in small steps while monitoring the voltage in J-V scans at the before mentioned constant current densities.

Considering the efficiency loss in the solar cell which arises from the tunnel/recombination junction, we can approximately define the efficiency loss as;

$$Junction\ Induced\ Efficiency\ Loss = \frac{\text{voltage drop across junction when Jsc current density } (*100\%)}{\text{open−circuit voltage of the tandem cell}} \quad (1)$$

For instance, a voltage-drop of 10 mV across the recombination junction, for a tandem cell with a V_{oc} of 2V, represents a 0.5% relative efficiency loss. We deem that this is an acceptable loss for such a junction, but will consider a loss of below 0.1% (i.e. 2mV drop across the junction) as negligible.

The IEC environmental stressing protocols stipulate that the complete PV Cells (modules) must retain 95% of their initial performance after the stressing protocol. Therefore, any individual component of the cell must not induce degradation of more than 5%, and ideally much less to allow a certain tolerance for other cell components. Therefore, during environmental stressing, we do not want the tunnel junction to induce more than a 1% relative degradation in solar cell efficiency, which according to our metrics above will correspond to no more than a 20mV increase in voltage drop.

3. Experiments

1.1. Organic charge recombination junction.

As mentioned, there are two types of junctions foreseen in the PERTPV project, organic and inorganic. Possibly, at a later stage, junctions consisting of both type of materials will be evaluated as well. However, this does not alter the protocol.

For the organic charge transporting materials and their dopants the following molecules were selected which are all commercially available from Novaled GmbH.

As the hole transport molecule we selected a derivative of an arylamine, N4,N4,N4",N4"-tetra([1,1'-biphenyl]-4-yl)-[1,1':4',1"-terphenyl]-4,4"-diamine (TaTm) (Fig. 1) due to its very stable sublimation conditions and tendency to form completely amorphous films. The fullerene C_{60} was selected as the electron transport molecule as it is also easy to sublime and has proven to be an efficient electron acceptor in perovskite solar cells. For the HTL we used 2,2′-(perfluoronaphthalene-2,6-diylidene) dimalononitrile (F_6-TCNNQ) as the organic dopant whereas for the C_{60} ETL, N1,N4-bis(tri-p-tolylphosphoranylidene) benzene-1,4-diamine (PhIm) (Fig. 1)

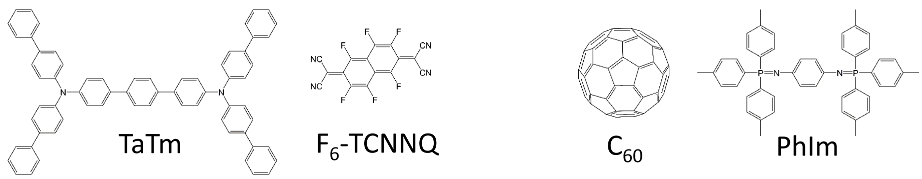

Fig. 1 Chemical structures of the organic molecules used to prepare the charge recombination junction.

The junction was prepared in the n-p configuration. The results are depicted in Figure 2, respectively.

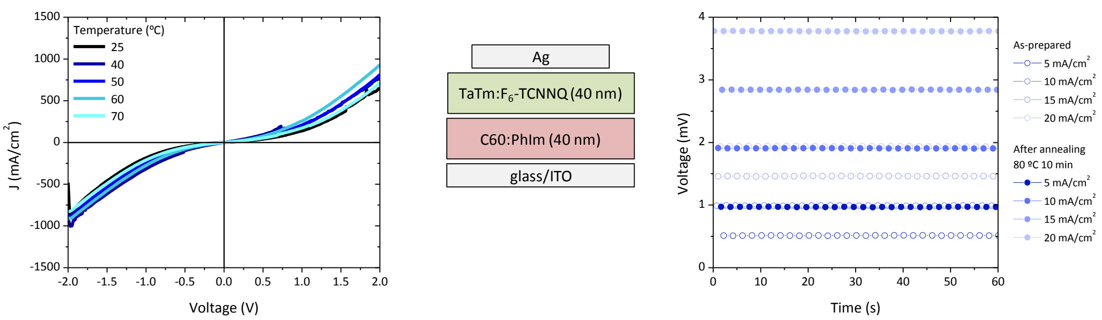

Fig. 2 Organic material based charge recombination junction. The left graph shows the J-V scan at different temperatures, whereas the right graph shows the voltage vs time at different fixed current densities before and after annealing at 80 °C. A schematic of the junction is shown in between the two graphs.

1.2. Inorganic charge recombination junction.

For the inorganic recombination junctions, a combination of magnetron sputtering and atomic layer deposition will be used for deposition. A plethora of inorganic materials can be tested both as a hole transport and an electron transport layer.

As an example, a recombination junction in n-p configuration was fabricated using glass as a substrate covered with silver as a bottom electrode, followed by sputtering of 10 nm of indium tin oxide or aluminium-doped zinc oxide as an electron transport layer. Then, 10nm of nickel oxide was deposited as a hole transport layer using RF magnetron sputtering. The structure was capped with a silver top electrode.

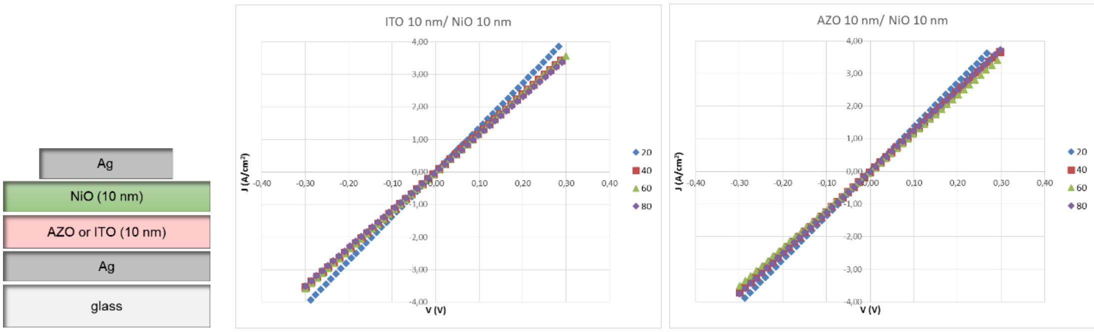

Fig. 3 Inorganic material based charge recombination junction. The left picture is a schematic of the junction, the graphs at the center and on the right show the J-V scans at different temperatures for ITO/NiO and AZO/NiO, respectively (heating in air).

4. Conclusions

From these results we can conclude that under the J_{sc} which we expect to deliver in the all-perovskite tandem solar cells ~15 to 20mAcm^{-2}, the voltage drop across the organic tunnel junction is only ~3mV. According to Equation1, this corresponds to an ~ 0.15% efficiency loss, if the tandem solar cell has a V_{oc} of ~2V. For both the inorganic recombination junctions, the voltage drop at 15mAcm^{-2} is ~ 1.5mV, which corresponds to a 0.075% efficiency drop. The conclusion is that both inorganic and organic recombination junctions will induce negligible efficiency losses due to recombination resistance in the as made solar cells.

This structure represents a good structure to run through independent, dark current and temperature stability stress test, in order to assess the long-term stability, separated from the complete cell structure. The stressing protocol will involve:

1. Placing junctions at 85C for up to 1000 hours, while periodically monitoring their voltage drop at 10, 15 and 20mAcm^{-2} current density.

2. Driving 20mAcm^{-2} current density through the junction for up to 1000 hours.