Perovskite Layer Optimization of Planar Solar Cells

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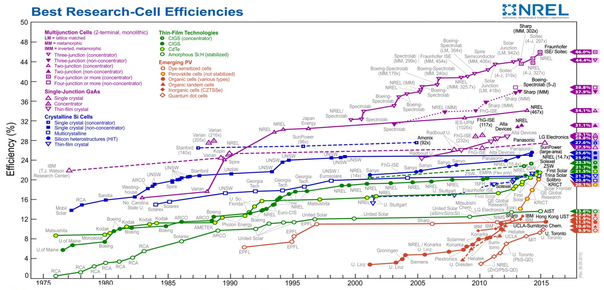
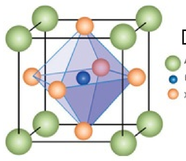
Introduction

Solar energy is abundant and is a largely untapped resource in today's world due to the high cost of materials and high processing costs. While mesoporous perovskite solar cells (PSCs), have rapidly emerged with efficiencies reaching 20% within the past 3 years, thin film planar devices remain ~12 % efficiency due to challenges in fabrication. Therefore further understanding and improvement of device fabrication is imperative for rapid commercialization of thin film planar PSCs.



([2] Efficiencies, 2015)

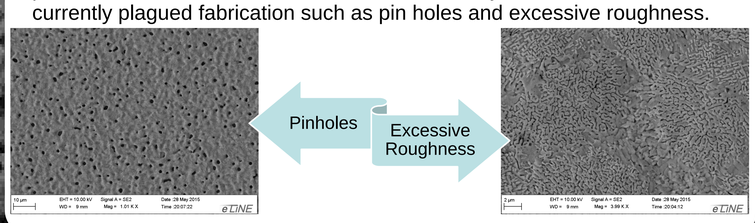


Perovskite crystal structure ([1] Photovoltaics, 2014)

- Form of ABX_3
  - A: large metal cation
  - B: smaller metal cation
  - X: binding anion
    - Oxygen (oxide perovskite)
    - Chlorine, bromine or iodine (halide perovskites)

Research Objective

We aim to develop a straightforward and reproducible approach to fabricate planar tri-iodine PSC devices that eliminated many of the issues that have currently plagued fabrication such as pin holes and excessive roughness.



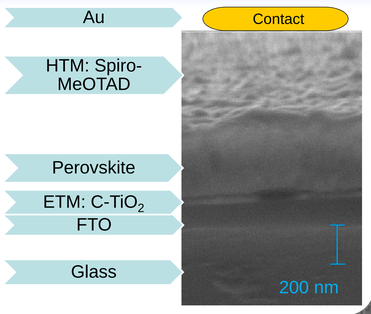
Experimentation

To control layer thickness we experimented with:

- Spin coating speeds
- Anneal temperature and time
- Perovskite wt%

To minimize roughness of the planar layer, which is a function of the crystallization speed, we tested:

- Adding toluene during spin coating
- Varied toluene deposition rates and times
- Varied substrate temperature prior to deposition of the perovskite layer



Results

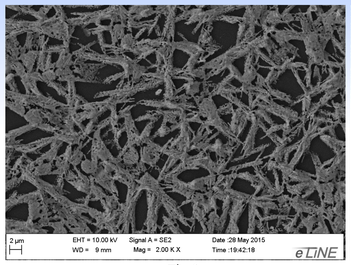


Fig.1

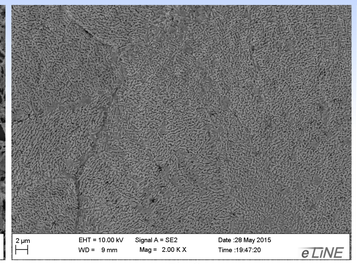


Fig.2

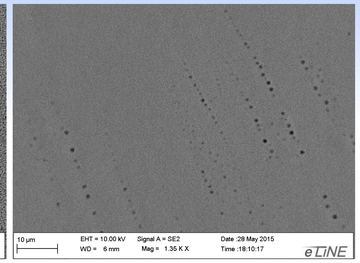


Fig.3

Figures 1 – 3 show our progression from a rough layer riddled with pinholes to a smooth, pinhole free layer

- Fig.1 - 40 wt% solution of perovskite in a 3:7 volume ratio of dimethyl sulfoxide (DMSO) and y-butyrolactone (GBL), spin coated at 4k rpm's and annealed at 150°C[3][4]
- Fig.2 - Same as Fig.1 but added toluene during spin step
- Fig.3 - Same as Fig.2 except annealed at 70°C

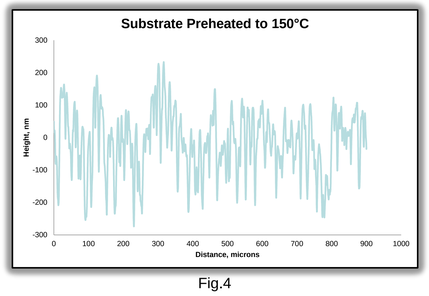


Fig.4

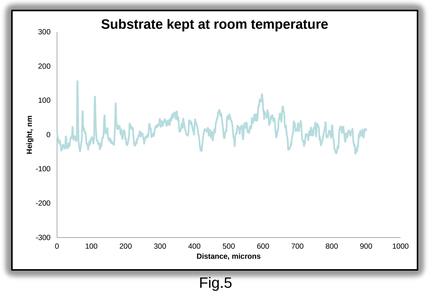
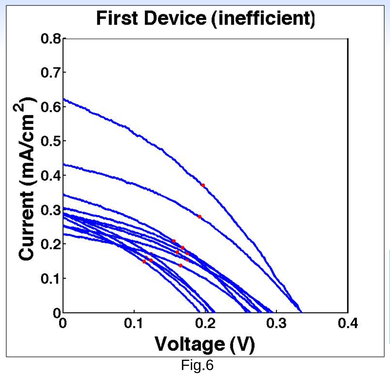


Fig.5

Fig. 4 & 5 – Heating the substrates before spin coating the perovskite solution caused layers that looked very uniform to the eye. When profilometer measurements were taken we discovered that while the perovskite layers appeared very uniform, they were exceedingly rough and caused the formation of pinholes due to rapid crystallization of the perovskite solution.

Solar Cell Performance



Avg (Best)
Eff%: 2.95(4.60)
Voc: 0.94(0.98)V
Jsc: 5.10(7.03)mA/cm^2
FF: 0.61(0.69)

Fig.6

Avg (Best)
Eff%: 0.03(0.07)
Voc: 0.24(0.34)V
Jsc: 0.36(0.61)mA/cm^2
FF: 0.33(0.37)

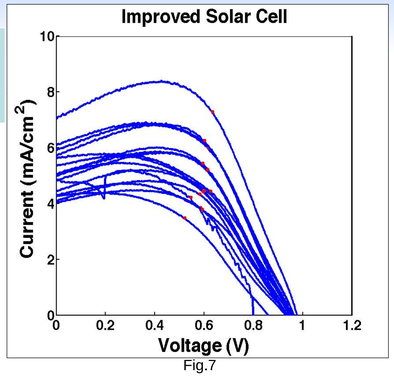


Fig.7

Fig. 6 & 7 - We tested our devices using a solar simulator and to quantify the improvements in efficiency (Eff%), open circuit voltage (Voc), short circuit voltage (Jsc), and fill factor (FF) as a function of perovskite smoothness.

Conclusions

We discovered that the biggest contributing factors for perovskite smoothness (and therefore a better device) were the addition of toluene via a slow drip method during the ramp phase while spin coating at 4000 rpm's for 60 seconds, and using a 40 weight% solution of perovskite in dimethyl sulfoxide and y-butyrolactone.

The goal was to create devices using the thinnest film we could while still being able to make the devices efficient. A spin speed of 4000 rpm's gave us the best overall performing devices. At higher spin speeds, the film did become thinner but our ability to control the smoothness of the device was greatly compromised.

The addition of toluene allowed us to control the evaporation rate of the solution which creates smaller, more uniform perovskite crystals. This was the single biggest factor in creating smooth layers. It was then determined that adding the toluene to the spin step at a rate of ~40 µl/s for 10 seconds greatly reduced the occurrence of pinholes in the film.

Future Work

Using the baseline for smooth efficient layers established in this research, the next step is creating ultrathin perovskite layers to allow Electrochemical Impedance Spectroscopy (EIS) to characterize the interfaces between the layers without interference because tri-iodine perovskites have a diffusion length of <100nm. Creating ultrathin layers would also help to reduce cost and allow this technology to be incorporated into translucent objects such as currently existing building windows. Transient Absorption Spectroscopy (TAS) and Time Resolved Photoluminescence (tr-PL) would then be used to study the poorly understood charge carrier lifetimes of the perovskite with regard to the different types of losses (series resistance, recombination resistance, and contact capacitance).

References & Acknowledgments

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