Increasing the Charge Diffusion Length of $CH_3NH_3PbI_3$ to Beyond 1 μm by Solvent Annealing.

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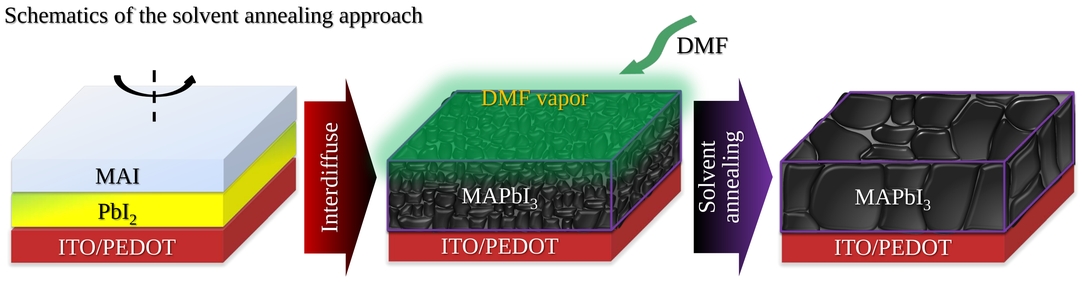
Motivation

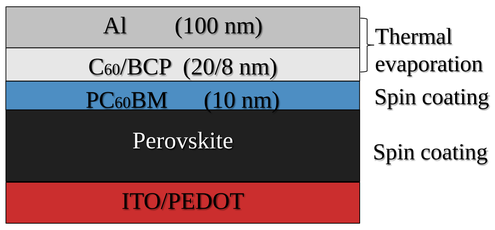
1. Increase the grain size and crystalinity of organi-inorganic hybrid perovskite film.
2. Increase the carrier diffusion length of triiodide $CH_3NH_3PbI_3$ perovskite up to >1 μm.
3. Fabricate high efficiency device using thick perovskite film (up to > 1 μm) Increase the thickness of the perovksite layer to increase the absorption of perovskite device in the red to infrared range.
4. Increase the high efficiency device yield for the scalable manufacture techniques which the thickness of the film can not be precisely controlled like doctor blading, printing et al.

Methods and Device Structure

Schematics of the solvent annealing approach

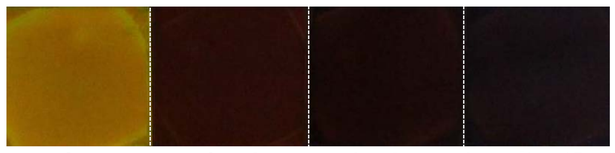


Device structure (planar structure)

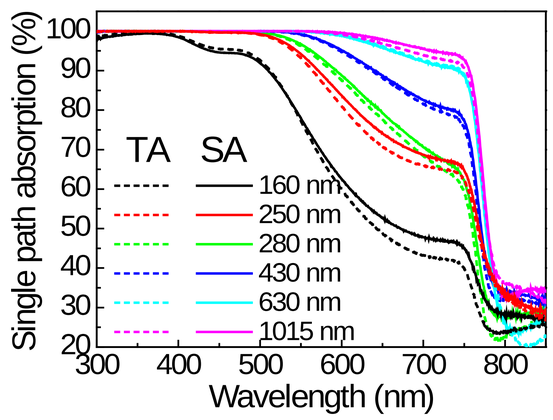


Perovskite Film Characterization

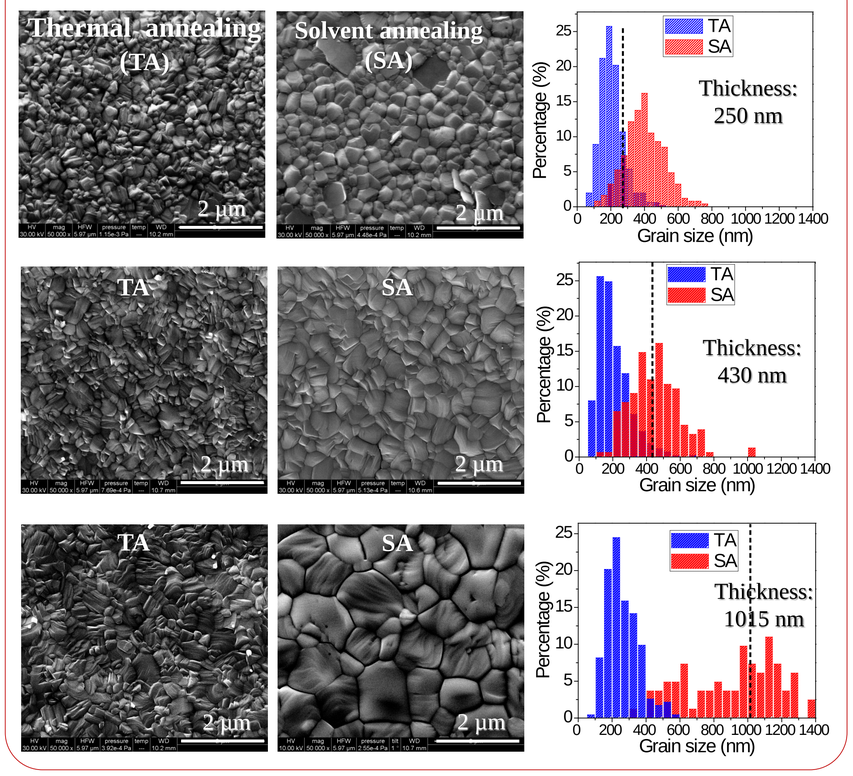
Photo-images of the films



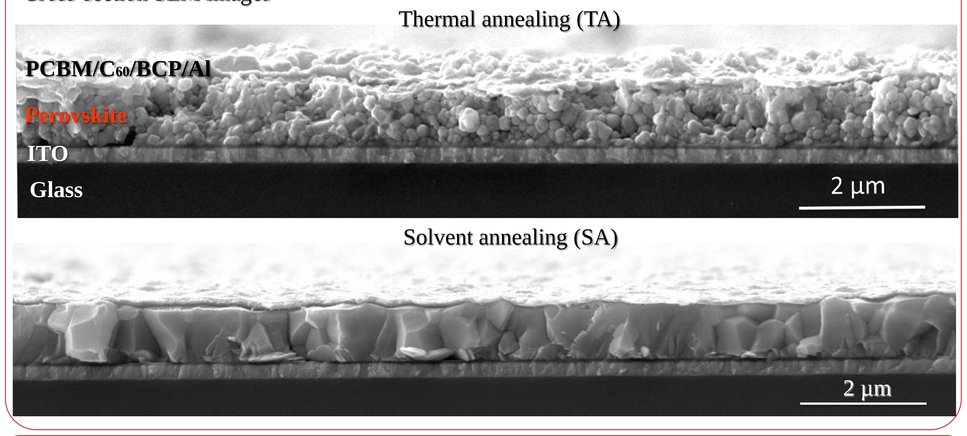
Absorption of perovskite films after annealing at 100 °C for 1h.



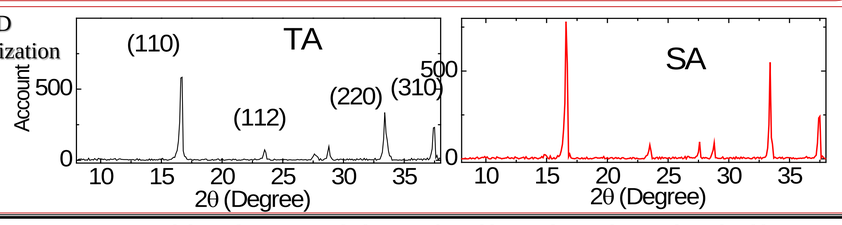
SEM surface characterization.



Cross-section SEM images



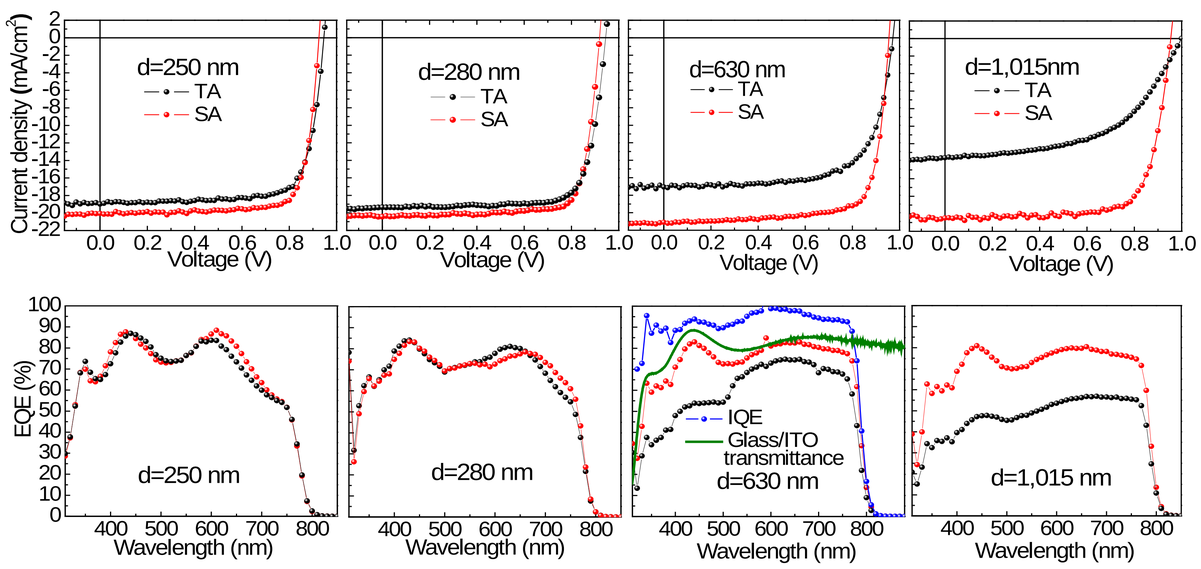
XRD characterization



1. The average grain size of the solvent annealed perovskite film is always larger than the film thickness, while the grain size of the thermal annealed perovskite film kept at around 250 nm.
2. The crystallinity of the perovskite film is increased.
3. There is single grain along the vertical direction of the device, so that the photo-generated carriers can be transported through single brain before collected.

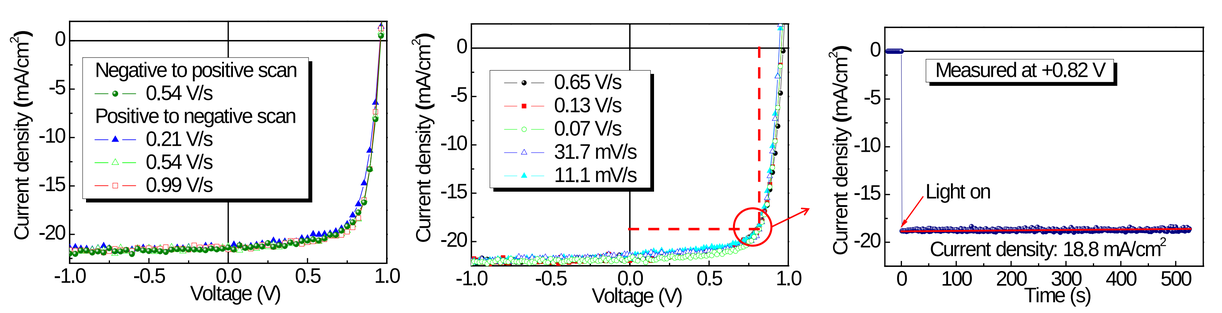
Device Performances and Characterization

J-V and EQE measurements with different thickness



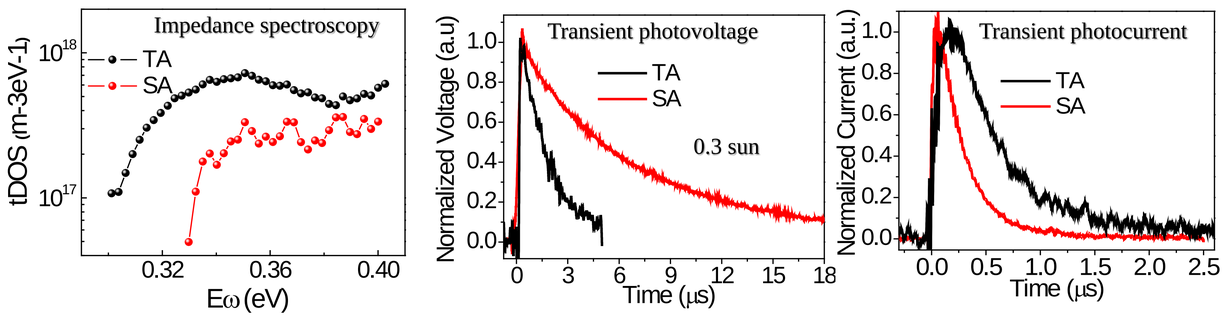
- The efficiency of the solvent annealing device kept above 14.5% when the thickness of the perovksite film changes from 250 nm to above 1 μm.
- The highest IQE of the device reached 100% indicates that the limitation of the current density is due to the reflection of the glass substrate.

Hysteresis measurement



- There is no hysteresis when we changed the scanning direction and scanning rate.

Defect density and transient measurement



- The decreased trap density indicates that the grain boundary density in the solvent annealed film is decreased
- The charge recombination lifetime of the solvent annealed device increased from 1.7 μs to 7.2 μs under 0.3 sun.
- The charge extraction rate is decreased from 0.57 μs to 0.25 μs due to the higher mobility of the solvent annealed film.

Conclusion

- The carrier diffusion length of the perovskite film was increased to above 1 μm.
- High efficiency of 15.6% was obtained using 630 nm thick perovskite film. The efficiency has a very high tolerance to the perovskite film thickness using solvent annealing. .
- The device yield is very high. 85% of the devices have efficiency higher than 14%.
- Most devices have high fill factors around 80%. The high FF should be due to the uniform and continuous films fabricated by the interdiffusion method and the device structure we used (passivation of fullerenes).

Acknowledgement

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References

1. Solvent-Annealing of Perovskite Induced Crystal Growth for Photovoltaic Device Efficiency Enhancement, Zhengguo Xiao, et al. Advanced Materials, 26, 6503-6509(2014)
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