나노구조 무/유기 하이브리드 태양전지
(Nanostructured inorganic-organic hybrid solar cells)

28 October, 2013

석상일

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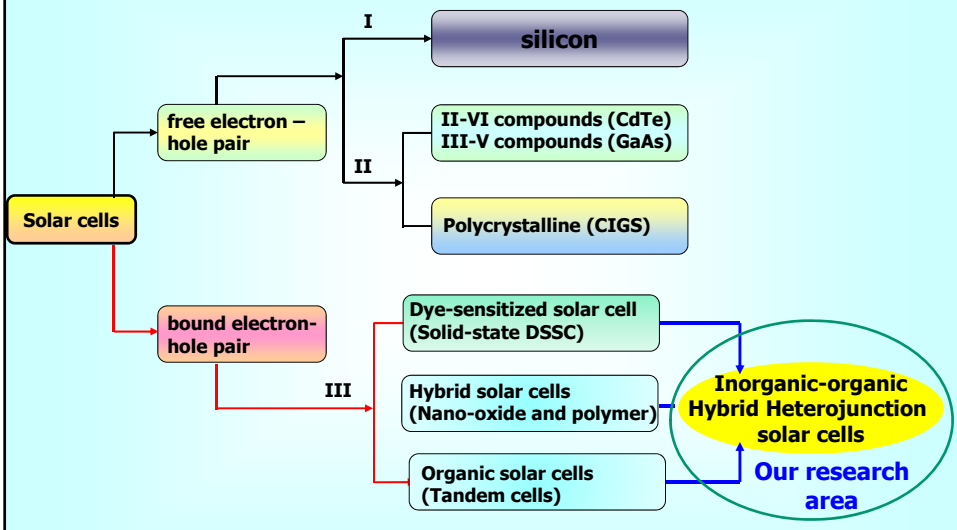
Outline

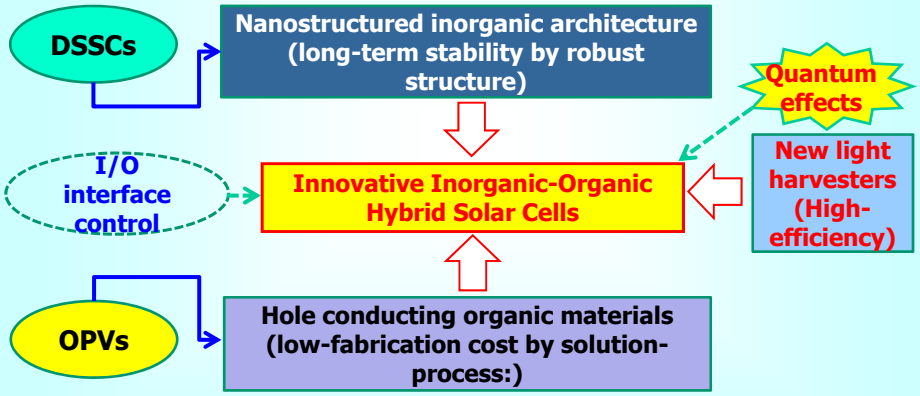
- State-of-art of solar cells
- Research scheme: Why nanostructured inorganic-organic hybrid solar cells?
- Efficient inorganic-organic heterojunction hybrid solar cells
  - ✓ Sb_2S_3/P3HT, Sb_2S_3/PCPDTBT system
  - ✓ $CH_3NH_3Pb(I_{1-x}Br_x)_3$ (x=0 ~1)/PTAA system
- Summary

State-of-the- Art of Solar cells



Research scheme

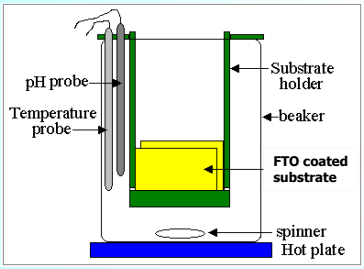
Strategies: Integration of nanostructured architecture, and solution-processable organic/inorganic materials and new light harvesters that have high absorption-coefficient



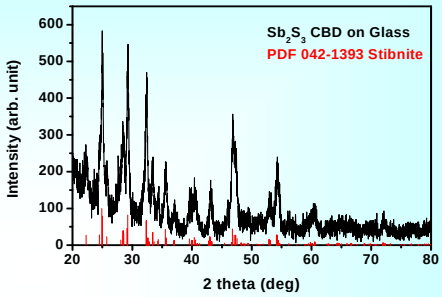
Sb_2S_3/P3HT heterojunction solar cells

Sb_2S_3: a high absorption coefficient (1.8 × 10^5 cm^{-1} at 450 nm) and optimum bandgap (E_g = 1.7 eV)

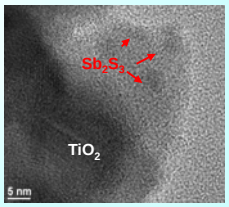
Precursors: $SbCl_3$ and Sodium thiosulfate



CBD Process

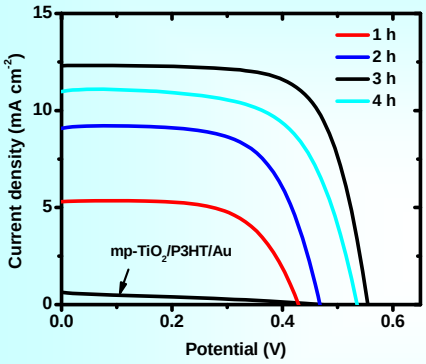


XRD pattern of Sb_2S_3 annealed at ~300 °C after CBD

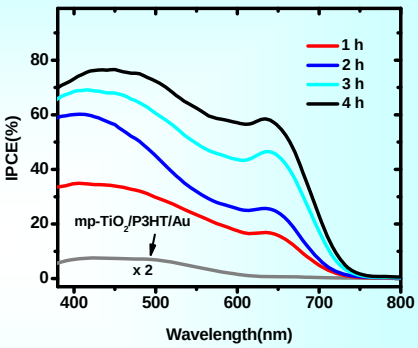


Sb_2S_3/P3HT heterojunction solar cells

Current density-voltage (*J-V*) curves



Incident-photon-to-current conversion efficiency (IPCE)

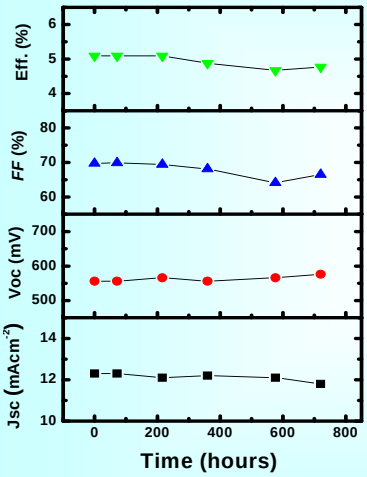


CBD time (h) for Sb_2S_3	J_{sc}[mA cm^{-2}]	V_{oc}[mV]	*FF*[%]	*Eff.*[%]
0	0.63	475	29.2	0.092
1	5.3	424	64.1	1.48
2	9.1	465	65.5	2.92
3	12.3	556	69.9	5.06
4	11.0	535	63.8	3.97

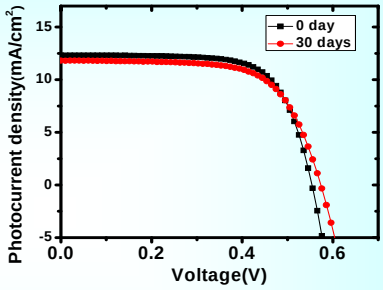
Nano Letters, 10, 2609 (2010)

Nanostructured Sb_2S_3/P3HT heterojunction solar cells

Stability with time



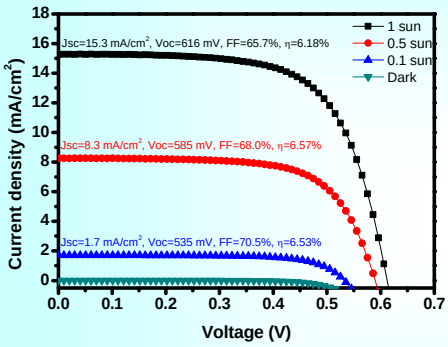
Reproducibility: OK !

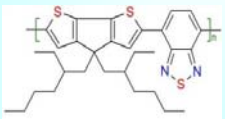


Time [hours]	Jsc [mA/ cm^2]	Voc [mV]	*Ff* [%]	*Eff.* [%]
0	12.3	556	69.7	5.09
72	12.3	556	69.9	5.09
216	12.1	566	69.4	5.09
360	12.2	556	68.1	4.88
576	12.1	566	64.1	4.66
720	11.8	576	66.5	4.77

Sb_2S_3/PCPDTBT heterojunction solar cells

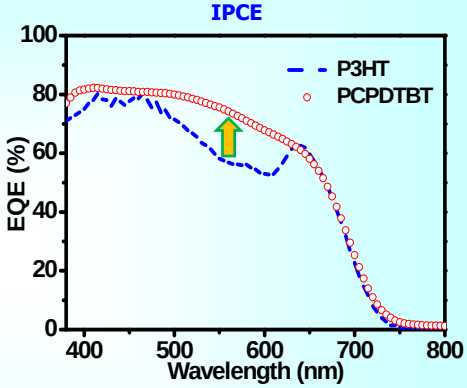
J-V curves over a range of intensities





PCPDTBT

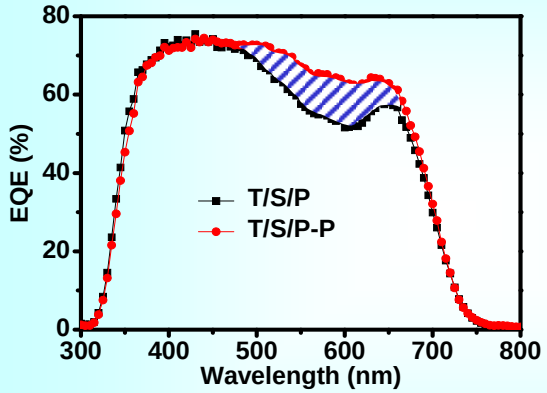
IPCE

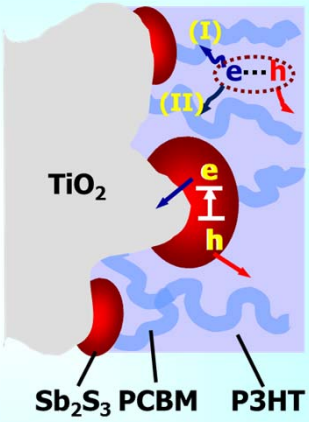


Nano Lett. 2011, 11, 4789–4793

Sb_2S_3/P3HT(PCBM) heterojunction solar cells

Panchromatic Photon-Harvesting by Hole-Conducting Materials

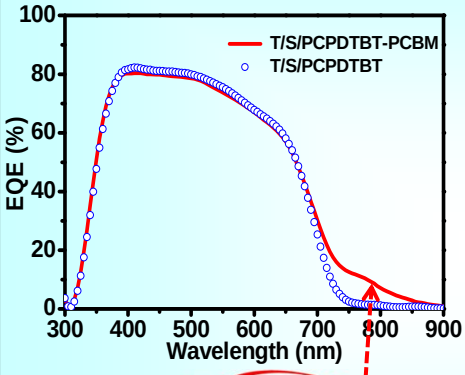


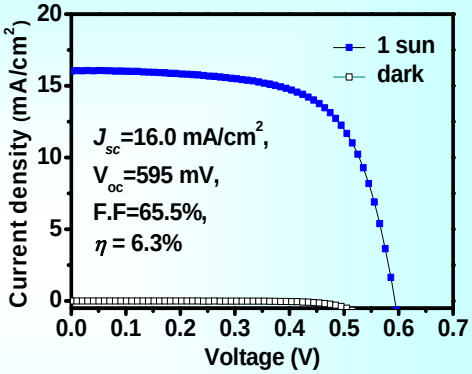


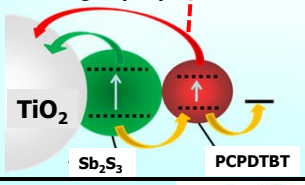
PCBM : [6,6]-phenyl-C_{61}-butyric acid methyl ester

Sb_2S_3/PCPDTBT(PCBM) heterojunction solar cells

Panchromatic Photon-Harvesting by Hole-Conducting Materials

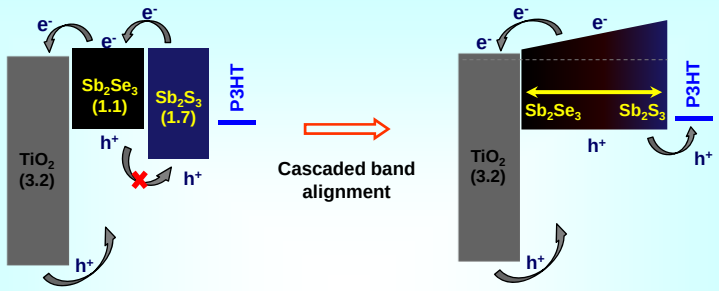


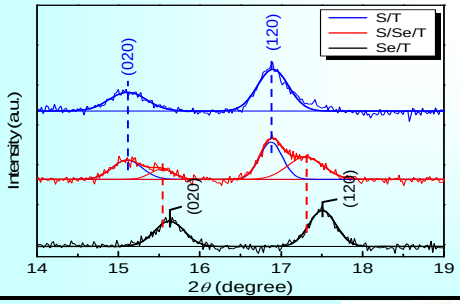




Nano Lett. 12, 1863 (2012)

$Sb_2(S/Se)_3$-/P3HT Heterojunction Solar Cells with Graded Composition

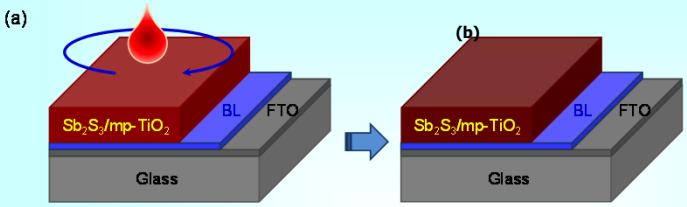




Light power (mW cm^{-2})	J_{sc} (mA cm^{-2})	V_{oc} (mV)	FF (%)	PCE (%)
100	24.9	474.8	55.6	6.6
50	14.6	424.6	60.2	7.5
10	3.0	364.3	62.3	6.8

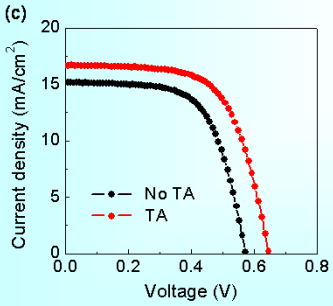
In Review(2013)

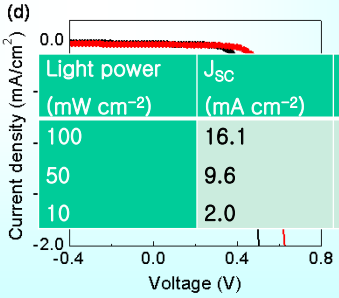
Sb_2S_3/P3HT Heterojunction Solar Cells



Spin coating with TA solutions of 0.01–0.1 g mL^{-1}

Annealing at 200–300 °C in Ar gas atmosphere



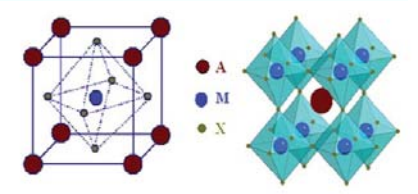


Light power (mW cm^{-2})	J_{SC} (mA cm^{-2})	V_{OC} (mV)	FF (%)	PCE (%)
100	16.1	711.0	65.0	7.5
50	9.6	672.7	67.0	8.7
10	2.0	600.1	70.0	8.4

In Review(2013)

Nanocrystalline $MAPbX_3$/PTAA heterojunction solar cells

$CH_3NH_3PbI_3$ materials as light harvester



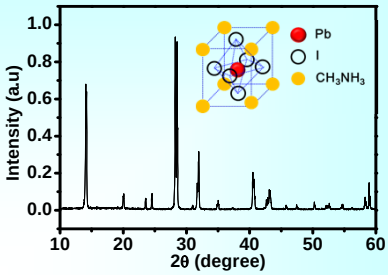
[PbX_6] octahetra form an extended 3D network by all-corner-connected type

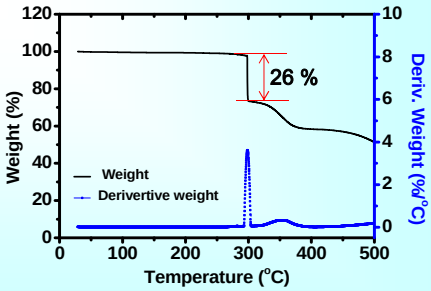
CH_3NH_3I

PbI_2

in γ-butyrolactone

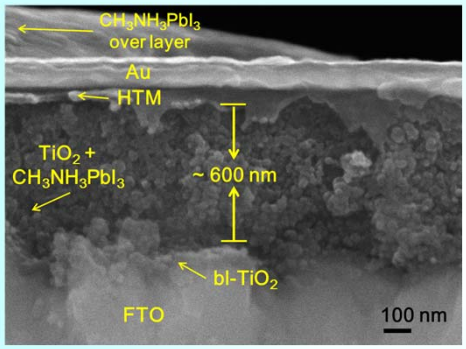
$CH_3NH_3PbI_3$ solution



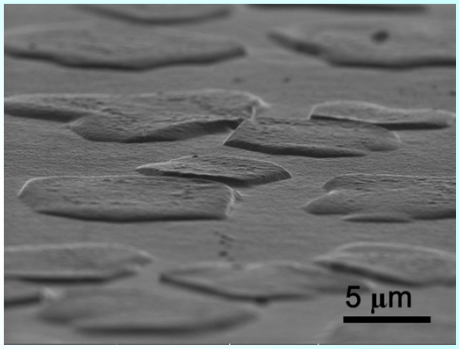


Perovskite/PTAA heterojunction solar cells

SEM cross-sectional image

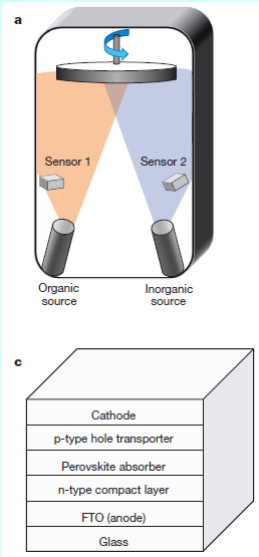


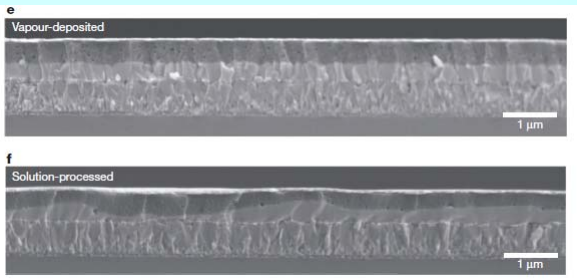
SEM surface image

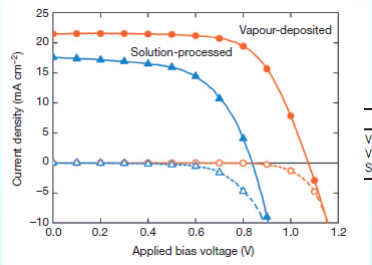


→ **Dense nanocomposite and thin upper layers**
→ **Is different with conventional dye-sensitized structure**
→ **Perovskite $CH_3NH_3PbI_3$ as both light harvester and hole conductor**

Efficient planar heterojunction perovskite solar cells by vapour deposition







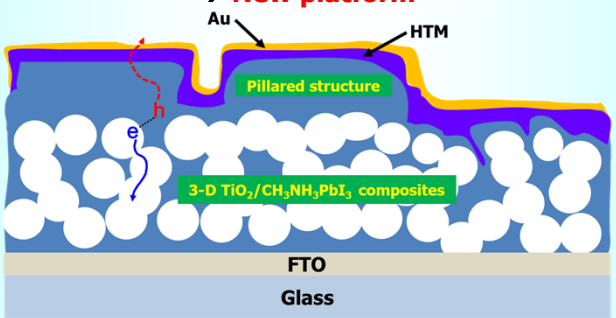
	Efficiency (%)
Vapour-deposited	15.4
Vapour-deposited (average ± s.d.)	12.3 ± 2.0
Solution-processed	8.6

H.J. Snaith et al., Nature, 2013, 501, 395–398

Perovskite/PTAA heterojunction solar cells

→ Dense nanocomposite and thin upper layers
→ Operate differently with conventional DSSC
→ Perovskite $CH_3NH_3PbI_3$ as both light harvester and hole conductor

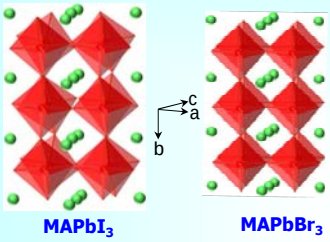
3-D mp-TiO_2/perovskite nanocomposite and thin film layer]
→ New platform

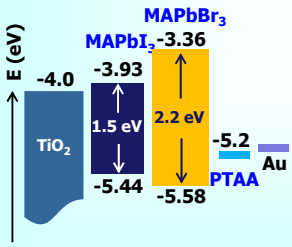


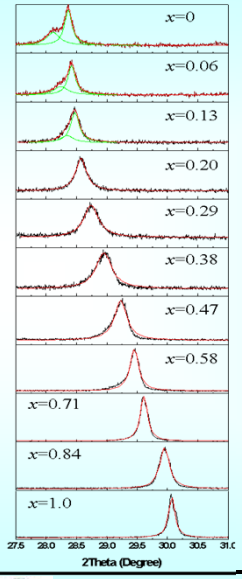
Nature Photonics, 7, 486 (2013)

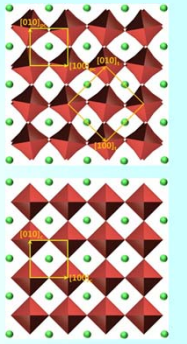
Chemical Management of Perovskite $CH_3NH_3Pb(I_{1-x}Br_x)_3$

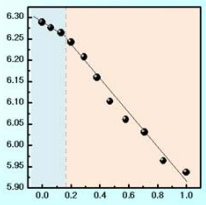
Band-gap tuning ($MA=CH_3NH_3$)





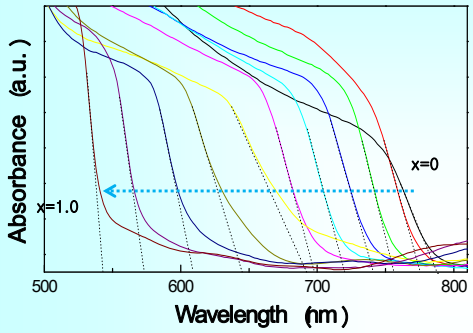


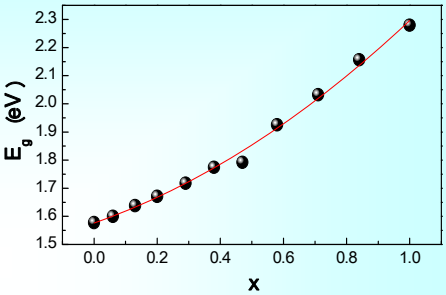




Nano Lett. 13, 1764–1769 (2013)

Chemical Management of Perovskite $CH_3NH_3Pb(I_{1-x}Br_x)_3$





$E_g[MAPb(I_{1-x}Br_x)_3] = E_g[MAPbI_3] + (E_g[MAPbBr_3] - E_g[MAPbI_3] - b)x + bx^2$

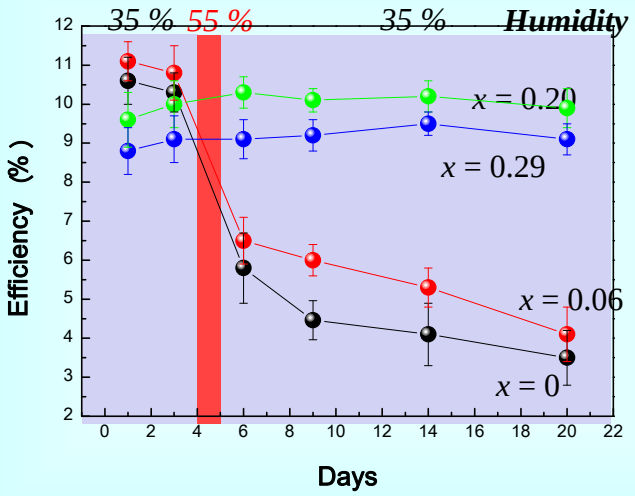
A least-squares fit: small bowing parameter (b=0.33eV)→ a great miscibility

$E_g(x) = 1.57 + 0.39x + 0.33x^2$

Nano Lett. 13, 1764–1769 (2013)

Chemical Management of Perovskite $CH_3NH_3Pb(I_{1-x}Br_x)_3$

Stability with time



Nano Lett. 13, 1764−1769 (2013)

연구 관련자료

특허

Fabrication Method of Nanostructured Inorganic-Organic Heterojunction Solar Cells, US application 13/580008

외 관련 특허 약 20편

논문

Efficient inorganic–organic hybrid heterojunction solar cells containing perovskite compound and polymeric hole conductors, Nature Photonics 외 약 40편