Highly Efficient Perovskite Solar Cells Indoors via Compositional and Additive Engineering

J. Xu[1], S. K. Podapangi[1], S. H. Reddy[1], L. A. Castriotta[1], M. Luce[2], Antonio Cricenti[2], A. Di Carlo[1], T. M. Brown[1]

[1] CHOSE (Centre for Hybrid and Organic Solar Energy), Department of Electronic Engineering, University of Rome Tor Vergata, Via del Politecnico 1, 00133 Rome, Italy.

[2] Istituto di Struttura della Materia (ISM-CNR), Via del Fosso del Cavaliere 100, 00133 Rome, Italy

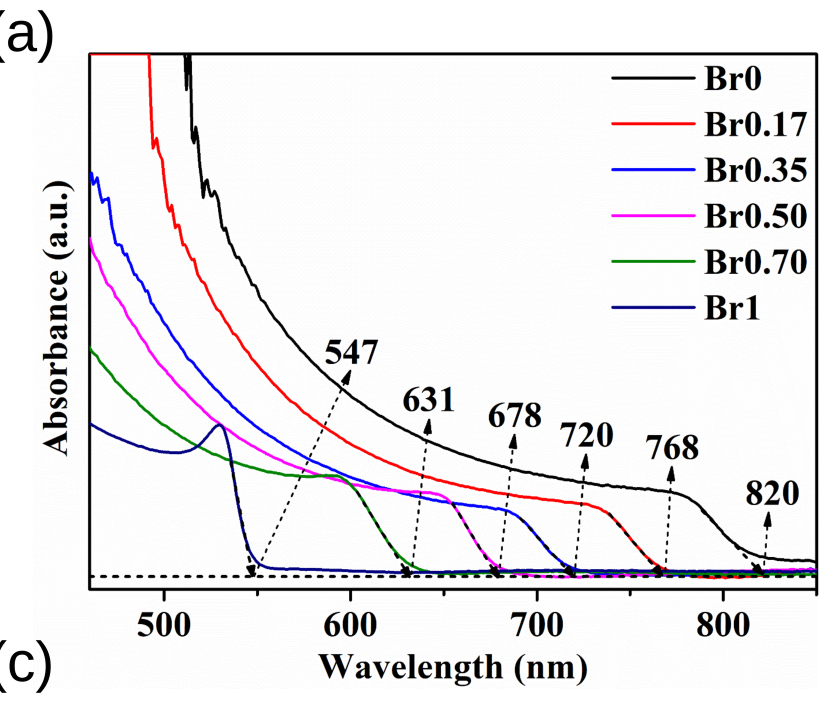
xuxjie01@uniroma2.it

Abstract

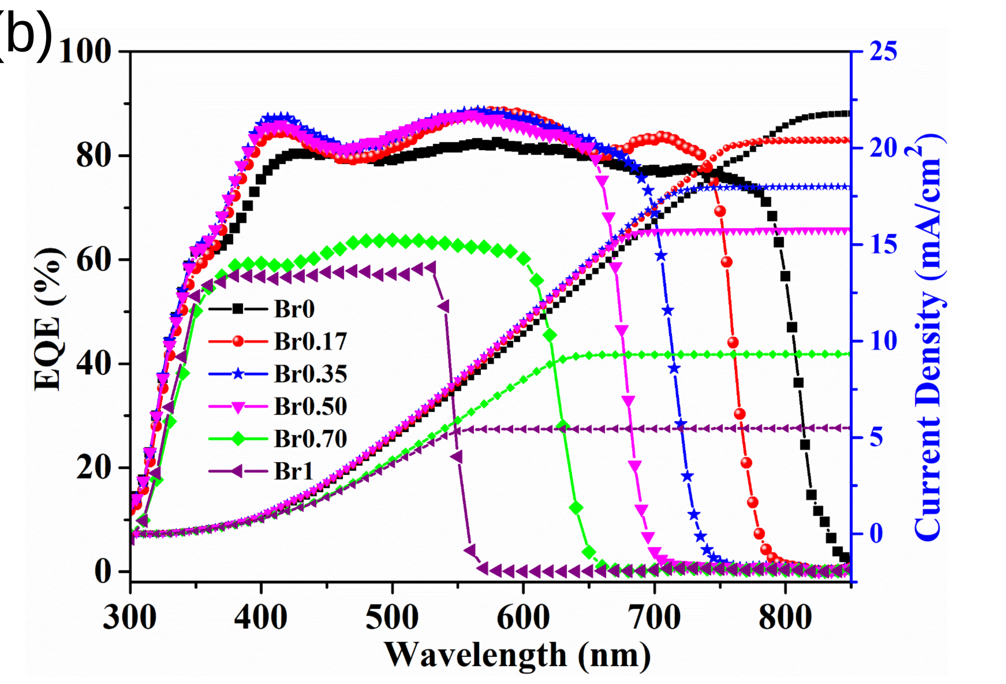
The huge market for Internet of Things (IoT) devices brings unprecedented opportunities for indoor photovoltaics (PV). Here, first, our work focuses on understanding how both indoor and outdoor PV performance of triple-cation PSCs depend on Br^- content (0 – 100 % range, with bandgap (*Eg*) varied from 1.5 to 2.3 eV). We have proposed five key parameters and associated threshold values to be surpassed that enable to achieve indoor power conversion efficiency (PCE) greater than 25% (1000 lx). Based on the understanding from first work, we further developed and investigated the impact of $EuCl_3$ doping on the indoor PV performance of PSCs. $EuCl_3$ doping reduced unreacted residual PbI_2, resulting in the formation of larger perovskite grains, more uniform films and fewer defects, with doubling of carrier lifetimes. Finally, indoor PCE jumped to 30.0% from 27.4% at 1000 lx with incorporation of $EuCl_3$. Furthermore, under thermal stress test at 85 ºC, t50 (the time at which PCE halves) was more than double that of cells fabricated without $EuCl_3$. These works open up new avenues for realizing efficient and stably indoor PSCs for IoT applications.

1. Perovskite composition engineering

(a)



(b)



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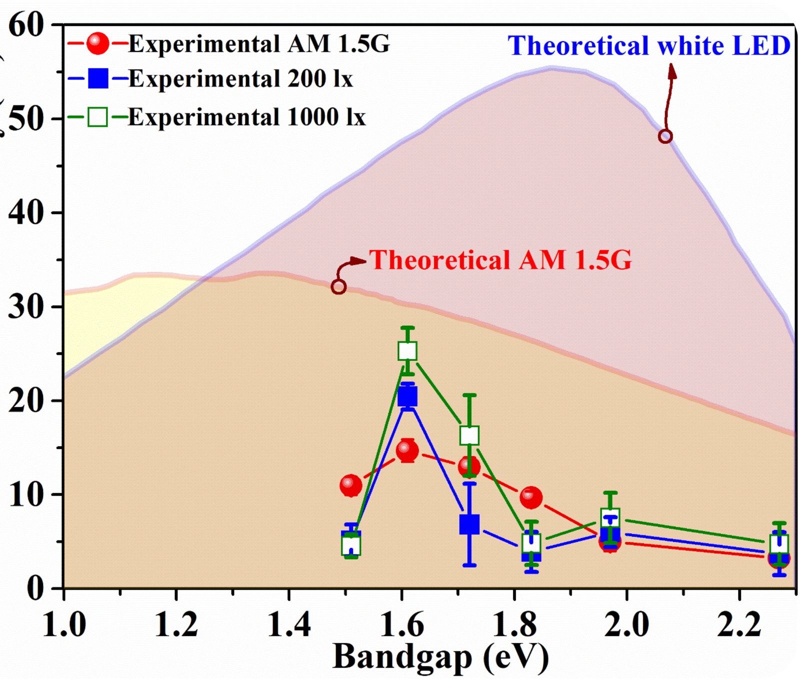
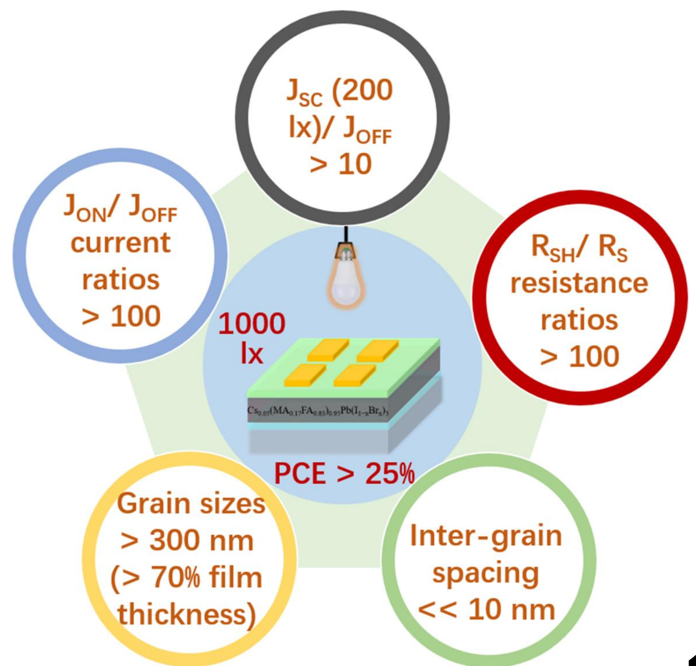


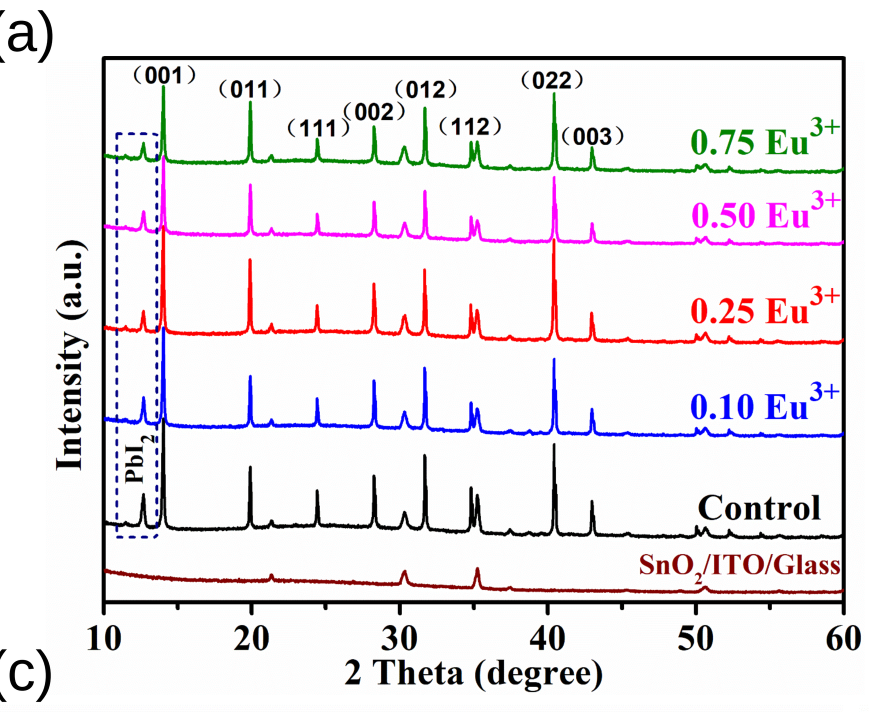
- A linear dependence of E_g with **Br^- contents (0≤x≤ 100%)** was observed: **E_g/eV= 0.75x +1.48** [1]
- At Br^- content of x=0.17 (**E_g=1.61 eV**, instead of the one close to the **theoretical bandgap 1.9 eV**) the PCE was maximum, i.e. 27.1% (1000 lx)

- We have proposed **five key parameters** and associated **threshold values** to be surpassed that enable to **achieve indoor efficiencies greater than 25%** (1000 lx) for this type of solar cells [1]



2.2 Effect of $EuCl_3$ doping on film morphology and photoelectrical properties

(a)



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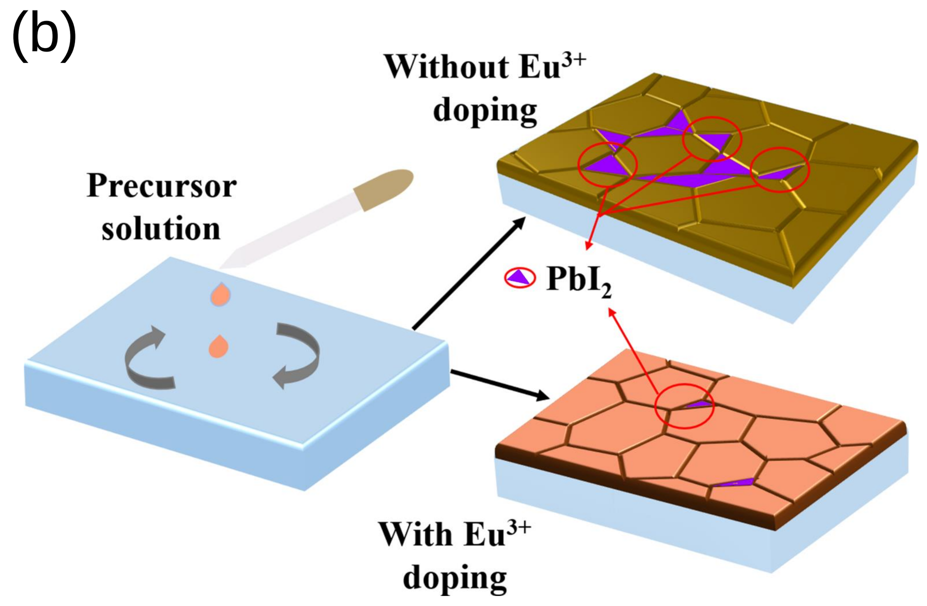

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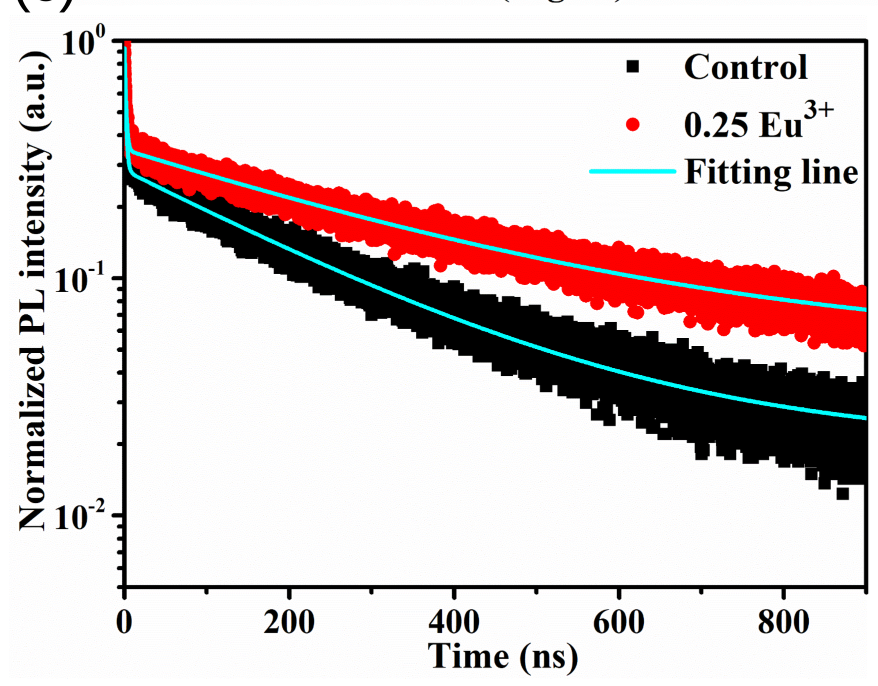
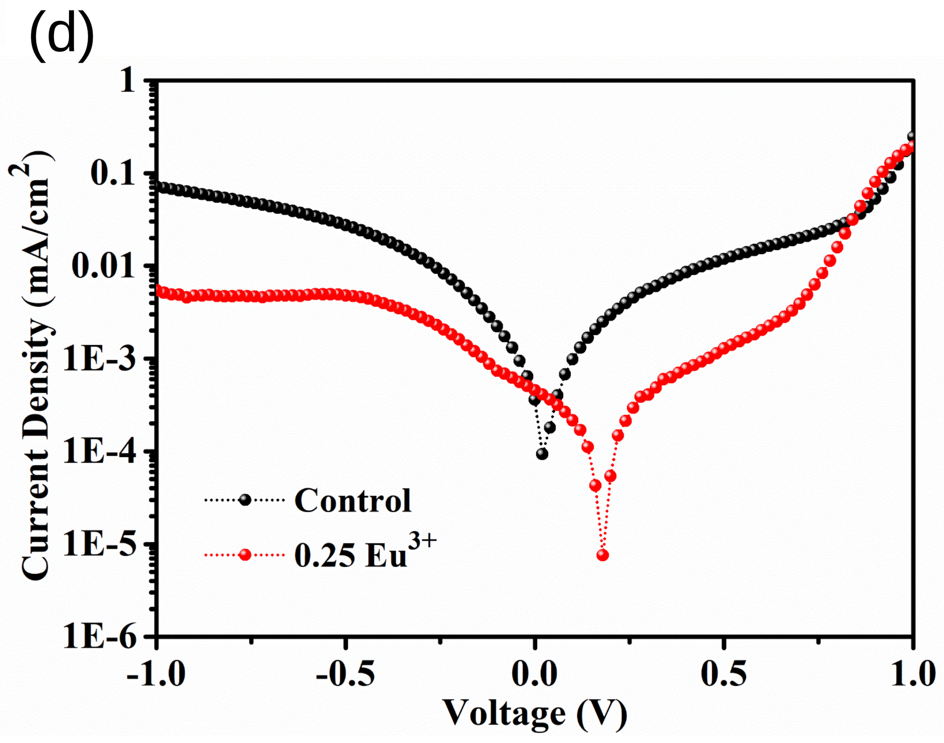


(d)



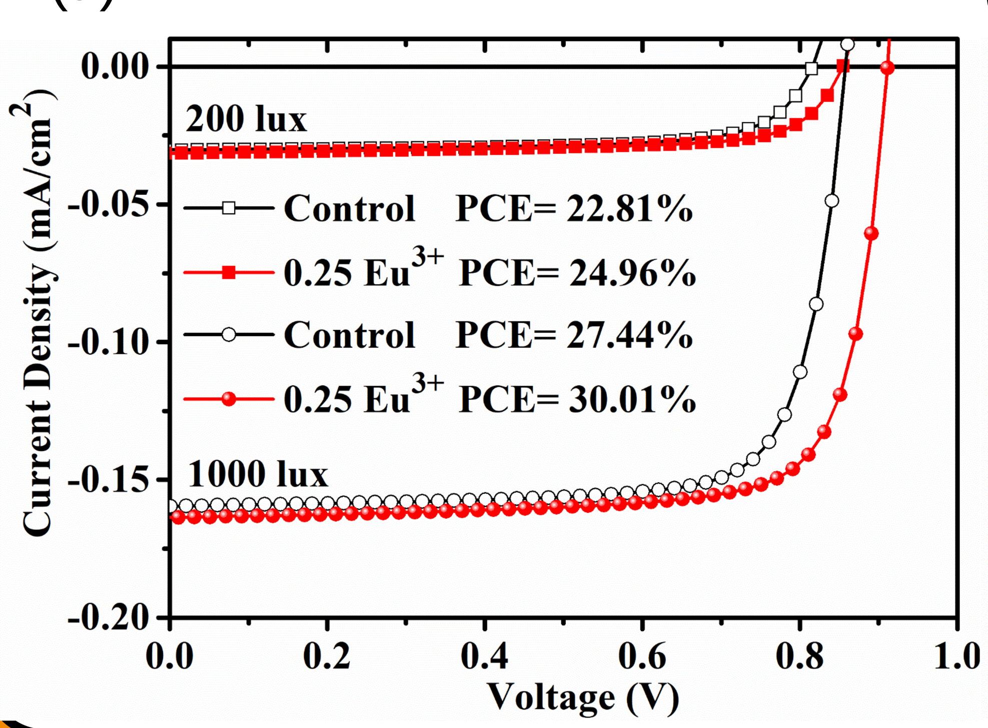
- $EuCl_3$ doping **reduce unreacted residual PbI_2**
- $EuCl_3$ doping in cells suppresses the charge carrier recombination **leading to a longer carrier lifetime**
- $EuCl_3$ doping in cells **reduces leakage current density by more than an order of magnitude** compared to control cells [2]

2. Additive engineering

2.1 PV performance

- The **indoor PCE was boosted to 30.0%** from 27.4% at 1000 lx **with incorporation of $EuCl_3$** [2]
- **Stability (ISOS-D-2 protocol)** was more than doubled with incorporation of $EuCl_3$

(a)



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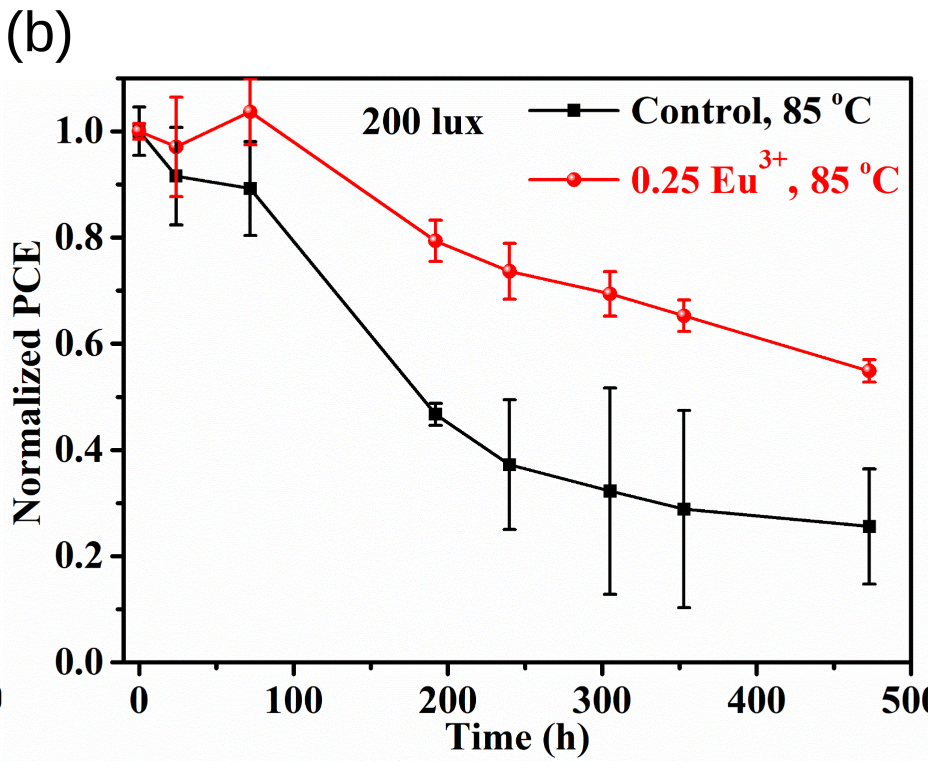

Conclusions

- **Perovskite bandgap** was optimized for indoor application by **substituting I with Br from 0 to 100%**
- We identified five **key parameters** and their **threshold values** that enable to **achieve high (> 25% at 1000 lx) efficiencies indoors**
- Indoor PCE **jumped to 30.0%** from 27.4% at 1000 lx with incorporation of $EuCl_3$
- **Stability (ISOS-D-2 protocol)** was more than doubled with incorporation of $EuCl_3$
- $EuCl_3$ doping **reduced unreacted residual PbI_2**, resulting in the formation of **larger perovskite grains, suppressed carrier recombination and increased shunt resistance, with doubling of carrier lifetimes**

References

[1] J. Xu et al., *ACS Appl. Energy Mater,* ***10.1021/acsaem.2c03394***

[2] J. Xu et al., Sustain. Energy Fuels, ***10.1039/d2se01312f***

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