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Perovskite solar cell towards lower toxicity: a theoretical study of physical lead reduction strategy

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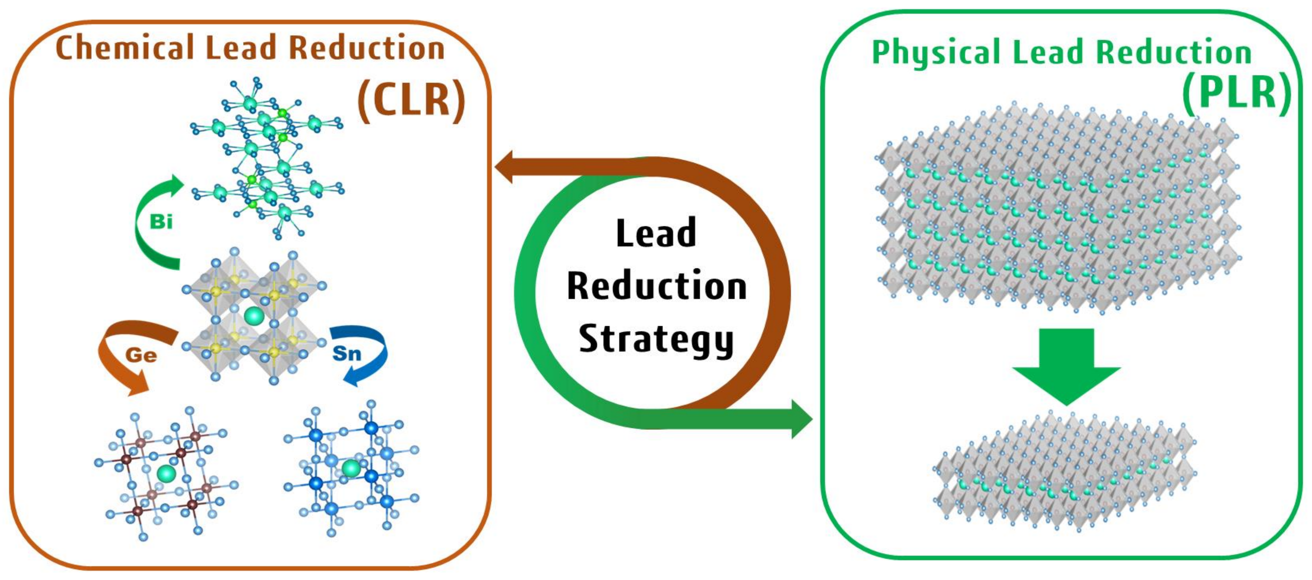
Lead Reduction Strategy

The explosive growth of power conversion efficiency (PCE) from 3% to over 25% within ten years. Despite the high PCE, the exhibition of low processing cost, scalable fabrication possibility, and flexible substrate compatibility, making OHPSC as a front runner in the next generation photovoltaic technology for the sustainable development of human civilization. However, contamination of health hazardous components still holds back its sustainable applications. To reduce the lead usage, many group has tried chemical lead reduction (CLR) solutions: substitute the lead by other group 14 metals to realize the lead-free OHPSCs. Unfortunately, neither in PCE nor the stability, lead-free OHPSCs all lags far behind the state-of-the-art OHPSCs.



In this work, we provide a physical lead reduction (PLR) concept (decreasing the perovskite film thickness) to decrease the overall consumption of OHPs in the device while maintaining the high PCE.

Physical Lead Reduction(PLR)

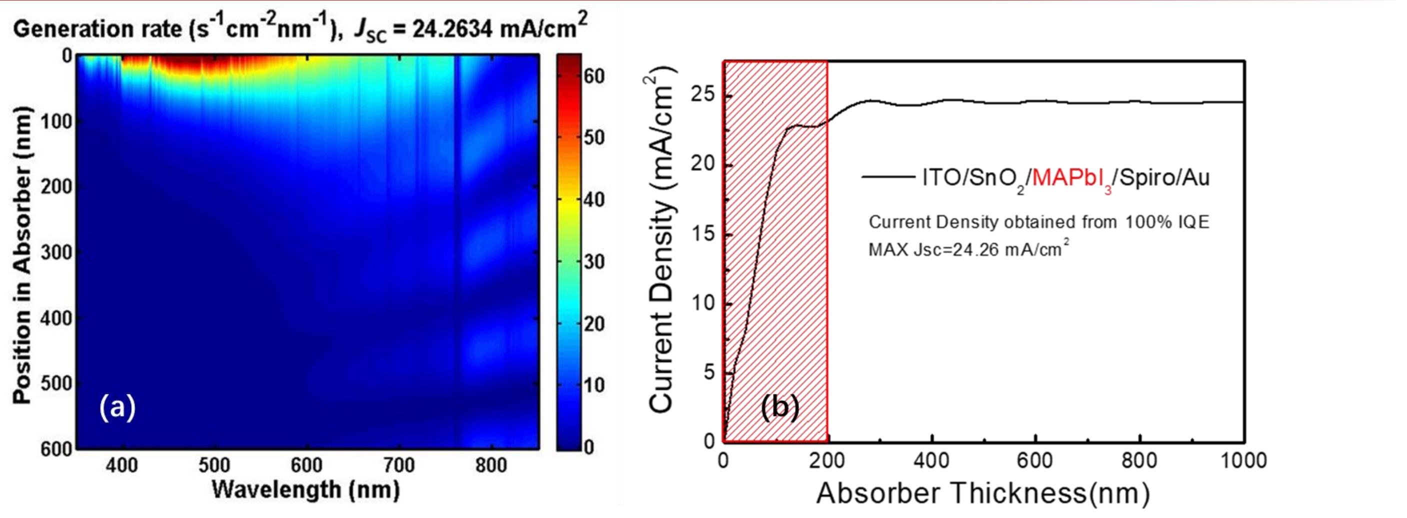


Fig.1 (a) Exciton distribution among the perovskite absorber of the conventional OHPSC. (b) absorber thickness-dependent J_{SC} in the conventional OHPSC. It was found that 200 nm thick $MAPbI_3$ can maintain the 85% of maximum J_{SC}. Hence, it is of high potential to further reduce the thickness of perovskite absorber layer.

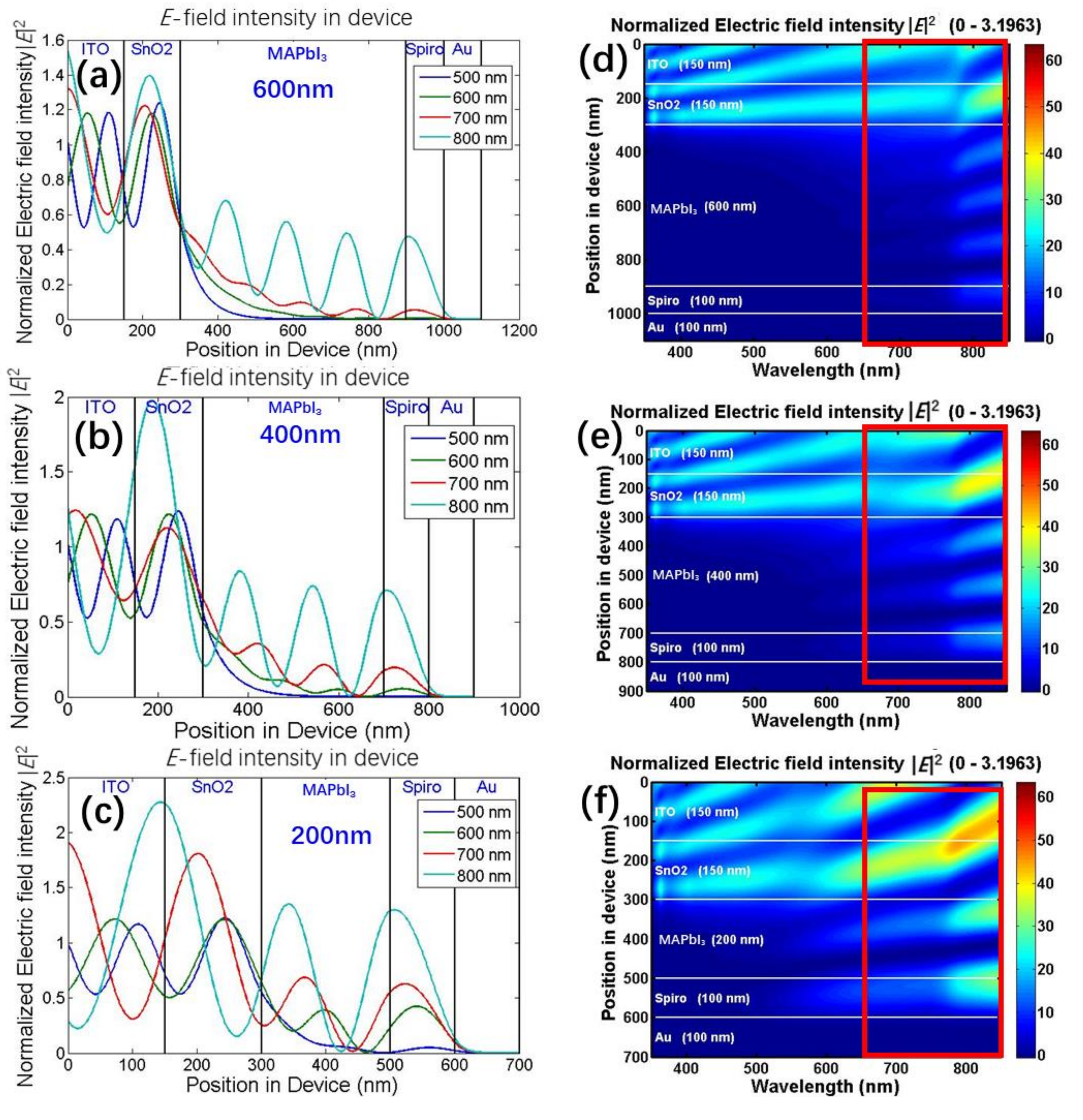


Fig. 2 Normalized electric field intensity distribution in the OHPSC with normal structure. (a), (d) with the $MAPbI_3$ thickness of 600 nm; (b), (e) with the $MAPbI_3$ thickness of 400 nm, and (c), (f) with a $MAPbI_3$ thickness of 200 nm.

Optical field Optimization

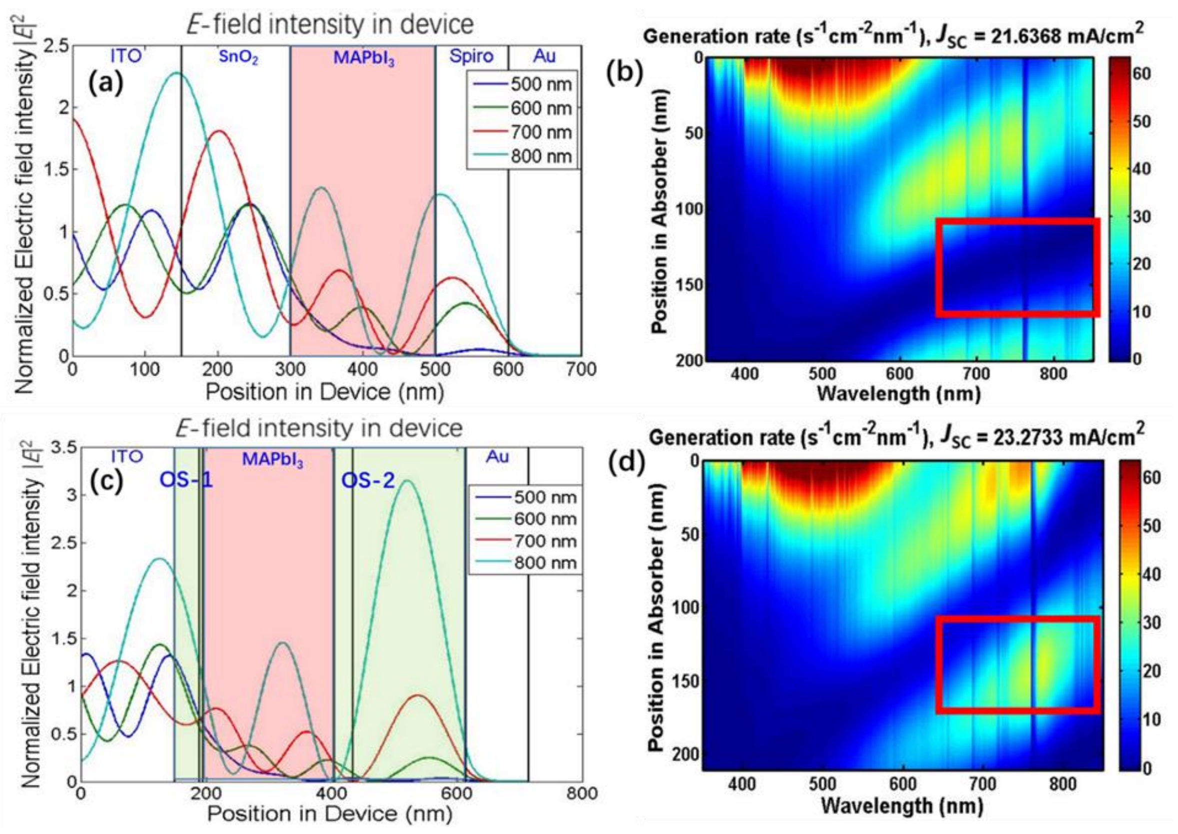


Fig.3 (a) and (c) show the optical field distribution in $MAPbI_3$-based normal OHPSC for four wavelengths of 500 nm to 800 nm. (b) and (d) are the corresponding exciton generation rates distribution among the $MAPbI_3$ layer. Red box inside the Fig.5d shows the second interference ridge. Through the calculation of TMM, we obtained the two interference ridges of cavity regime by optimizing the thickness of OS, resulting in the enhanced J_{SC} from 21.63 to 23.27 mA/cm^2.

Table 1 Simulated photovoltaic parameters of OHPSC

OHPSC Structure		Absorber Thickness	J_{SC} (mA/cm^2)	V_{OC} (V)	FF[c] (%)	PCE (%)
Normal	ITO/SnO$_2$/MAPbI$_3$/Spiro/Au	600 nm	24.26	1.36	90.71	29.93
	ITO/SnO$_2$/MAPbI$_3$/Spiro/Au	200 nm	21.63	1.34	90.60	26.25
	ITO/OS-1/MAPbI$_3$/OS-2/Au[a]	200 nm	23.27	1.34	90.60	28.25
Inverted	ITO/PEDOT:PSS/MAPbI$_3$/PC$_{61}$BM/Ag	600 nm	22.72	1.36	90.71	28.03
	ITO/PEDOT:PSS/MAPbI$_3$/PC$_{61}$BM/Ag	150 nm	20.81	1.33	90.55	25.06
	ITO/OS-3/MAPbI$_3$/OS-4/Ag[b]	150 nm	22.19	1.33	90.55	26.72

[a] OS-1: SnO_2 (40 nm)/ZnO NPs(10 nm); OS-2: MoO_3(3 nm) /Spiro (180 nm).
[b] OS-3: PEDOT:PSS (40 nm)/MoO_3(10 nm); OS-4: ZnO NPs(20 nm)/PC$_{61}$BM(50 nm).
[c] *FF* was calculated under the ideality factor n=1.

Conclusion

In summary, we proposed a PLR strategy to alleviate the health hazard worries of OHPSC by reducing the lead usage. Through the TMM simulation, we theoretically demonstrated that by introducing the optical space layer between electrode and perovskite layer, the optical field distribution inside the perovskite absorber is able to be well optimized. **As a result, the device PCE could preserve the 96% of the original maximum value while attenuating the perovskite thickness to one-third, leading to ~70% reduction of lead usage.** Without reconfiguration the combination of perovskite components, our unique approach could have board appeal as a new lead reduction strategy towards high performance and commercial available OHPSCs.

Fig. 4 This work has been published by *Science Bulletin* as cover story.

Reference & Acknowledgement

1. *Perovskite solar cell towards lower toxicity: a theoretical study of physical lead reduction strategy[J]. Science Bulletin, 64 (2019) 1255–1261.*

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Perovskites Fly into Near Space

Near Space has become the focus of attention and competition among the world's major powers. In order to utilize near space and expand human activity space, many countries have developed near-space aircraft. In addition, near space contains abundant physical phenomena to be detected and scientific laws to be discovered.

Energy technology determines the steady operation of near-space aircraft. As a recent emerging photovoltaic technology, perovskite solar cells exhibiting outstanding efficiency, high power-per-weight, and excellent radiation resistance are considered to be the new-generation energy technology for near-space application.

Recently, our collaborative team have reported the stability study of perovskite solar cells in near space. We demonstrated the preliminary attempt for the stability study of perovskite solar cells in near space. The devices were fixed on the high-altitude balloon risen from ground to near space at an altitude of 35 km in Inner Mongolian Area, China. As a result, the device based on $FA_{0.81}MA_{0.10}Cs_{0.04}PbI_{2.55}Br_{0.40}$ retained 95.19 % of its initial power conversion efficiency during the fly test performed in near space. We also expect that the stability research of perovskite solar cells in near space conditions will be helpful to extend the application of perovskite solar cells.

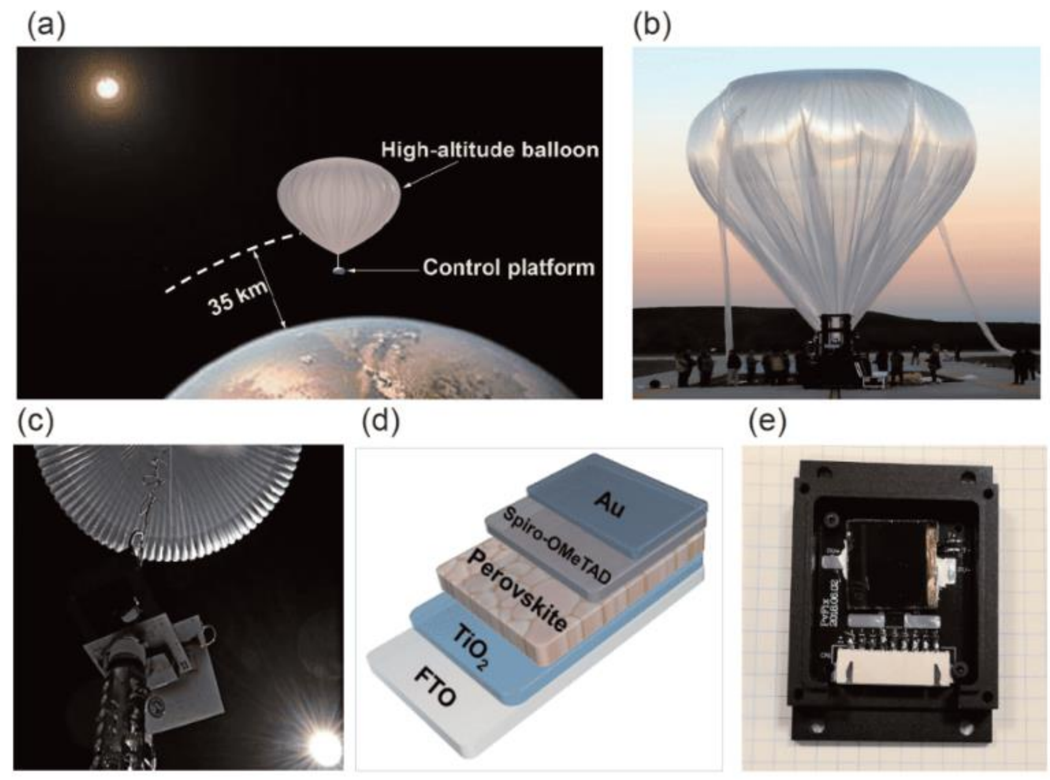

Fig. 5 (a) Representative schematic showing the relative position of the Sun, the high-altitude balloon and the Earth (courtesy of National Aeronautics and Space Administration website); (b) photograph of launch site; (c) photograph of the high-altitude balloon with a pod in near space; (d) device configuration; (e) unit module (the large-area perovskite solar cell was soldered on the integrated circuit board).

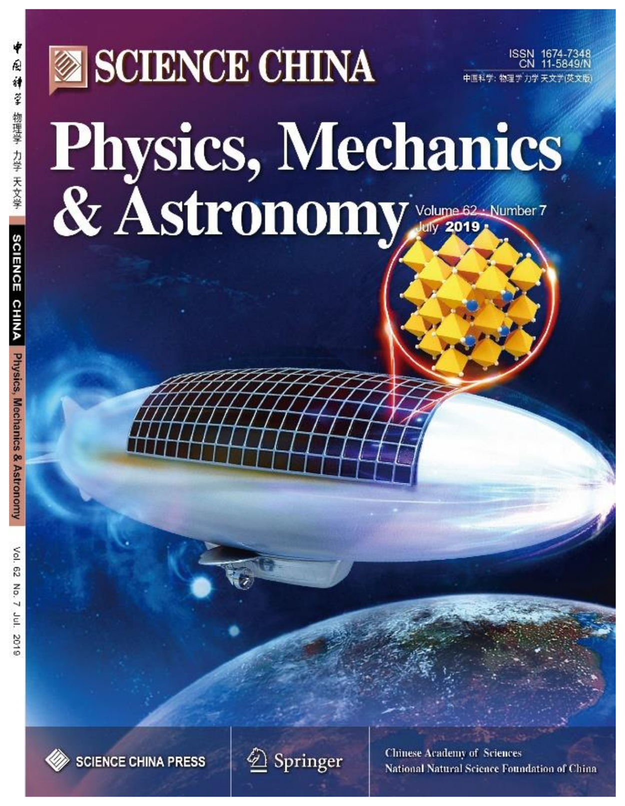

Fig. 6 This work has been published by *Science China - Physics, Mechanics & Astronomy* as cover story.

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