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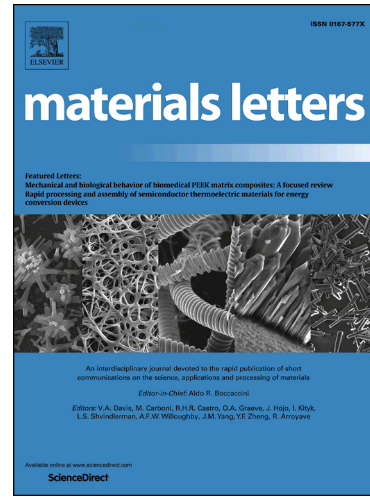


# Gas-assisted coating of Bi-based $(CH_3NH_3)_3Bi_2I_9$ active layer in perovskite solar cells

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**Gas-assisted coating of Bi-based $(CH_3NH_3)_3Bi_2I_9$ active layer in perovskite solar cells**

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**Abstract**

Methylammonium bismuth iodide, $(CH_3NH_3)_3Bi_2I_9$, is a promising lead-free perovskite active layer for solar cells. In this study, by using gas-assisted deposition method, we have successfully prepared dense and smooth $(CH_3NH_3)_3Bi_2I_9$ active layer, resulting in 25% improvement in $V_{OC}$ (from 0.548 V to 0.686 V) and 17% improvement in efficiency (from 0.070% to 0.082%), compared with the conventional 1-step method.

***Keywords:*** Perovskite solar cells; Lead-free; Bi-based; $(CH_3NH_3)_3Bi_2I_9$; Gas-assisted

**1. Introduction**

Perovskite solar cells (PSCs) have attracted much attention due to their rapidly-increased and high power conversion efficiency (PCE). Kojima et al. reported the PSCs with conversion efficiency of 3.8 % in 2009 [1]. Within only 7 years, the PCE increased up to 22.1% [2]. The high efficiency is attributed to excellent optical and electrical properties of $CH_3NH_3PbX_3$ (X=I, Br or Cl) [3-5]. However, the $CH_3NH_3PbI_3$ active layer includes toxic Pb; an alternative lead-free active layer is desired. Sn replacement for Pb has been tried to solve this problem [6,7], but durability is the most serious problem in Sn-based PSCs.

Currently, Bi-based perovskite-type compounds gather much attention [8-14]. Among them, $(CH_3NH_3)_3Bi_2I_9$ has high stability in air since $Bi^{3+}$ ions are stable, but the typical PCE of $(CH_3NH_3)_3Bi_2I_9$ PSCs are reported as 0.1-0.2%. Singh et al. have recently reported the 10-week long-term stability of $(CH_3NH_3)_3Bi_2I_9$ PSCs [10], where the performance degradation was only 25% even in the ambient conditions. This result has demonstrated the high stability of $(CH_3NH_3)_3Bi_2I_9$ PSCs. Compared with commonly used perovskites having favorable band gaps, *e.g.* $CH_3NH_3SnI_3$ (~1.3 eV [6]) and $CH_3NH_3PbI_3$ (~1.5 eV [15]), $(CH_3NH_3)_3Bi_2I_9$ has a wider band gap (~2.1 eV [8,13]). $(CH_3NH_3)_3Bi_2I_9$, however, can be an alternative for $CH_3NH_3PbI_3$ due to the high absorption coefficient ($(CH_3NH_3)_3Bi_2I_9$: $1.1\times10^5$ $cm^{-1}$ at 500 nm [13], $CH_3NH_3PbI_3$:

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