Synergistic HI and Ag Doping Strategies for Efficient Lead-Free Perovskites in Indoor Photovoltaics

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With the advancement of Internet of Things (IoT) technology, businesses are seeking to substitute rapidly deteriorating batteries with more efficient, wireless, and environmentally sustainable indoor photovoltaics (IPV), such as perovskite solar cells (PSCs). Yet, lead toxicity and instability in PSCs remain critical limitations. In this study, bismuth-based perovskites, particularly FA3Bi2I9, is utilized. They offer a lead-free alternative but still suffer from poor solubility and low absorption, restricting film thickness to <150 nm and hindering efficiency. A novel hydroiodic acid (HI) addition method doubled precursor solubility (0.5 M to 1.1 M), unlocking superior film formation and structural uniformity, diminishing inhomogeneous grains and increasing their size by over 150% and further enhanced overall performance. Concurrently, a first time-reported formamidinium substitution with silver engineered an unprecedented boost in optoelectronic properties. These procedures enhanced optical absorption surged by 100%, photoluminescence intensity escalated by 60%, and crystallinity was reinforced by 400%, contributing to a thickness exceeding 300 nm. The refined bandgap of 2.14 eV, precisely within the ideal indoor range (1.8–2.4 eV), intensifies the visible light wavelength range for indoor light absorbance. Advanced stability trials under 85% RH and 85°C confirmed 100-hour operational durability, with simulation-based power conversion efficiency achieving an exceptional 23.6%. Synthesis was successfully extended to flexible PEN-ITO substrates, validating feasibility for next-generation IoT-integrated coatings. This breakthrough in lead-free perovskite engineering unlocks vast potential for smart electronics, biomedical applications, and sustainable energy solutions.

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