

## **Synergistic effect of A-site engineering and surface treatment in tin halide perovskite solar cells**

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Tin halide perovskite solar cells have attracted attention due to the less toxic nature of tin compared to lead compound. Currently, the efficiency of tin-based perovskite solar cells now reaching more than 13 % slowly catching up with that of lead-based perovskite solar cells showing the promise of tin-based perovskites. However, there are several issues with tin-based perovskites that need to be addressed in order for these materials to compete with lead-based perovskites. The susceptibility of Sn<sup>2+</sup> to oxidize into Sn<sup>4+</sup> upon exposure to air reduces the long-term device stability and this phenomenon also caused major surface recombination which will result in low open-circuit voltage. In addition, the energy levels in tin halide perovskites are shallow compared to that of lead-based perovskites which result in large energy mismatch when common charge transport carriers are used. In this work, we performed simultaneous A-site substitution and surface treatment on tin-halide perovskites to achieve efficiency of more than 10 % and device stability of more than 300 h. Upon partial A-site substitution, the energy barrier has been effectively reduced especially at the hole transport layer/perovskite interface leading to efficient hole carrier injection. While the surface passivation suppressed the formation of unreacted Sn species and hence surface recombination issue has been addressed successfully. Our hypotheses have been supported using Mott-Schottky and Electrochemical Impedance Spectroscopy measurements showing reduced intrinsic carrier density and enhanced carrier recombination resistance. Using X-ray Photoelectron Spectroscopy measurements, we confirmed the suppression of under-coordinated Sn species and oxidized Sn<sup>4+</sup>.