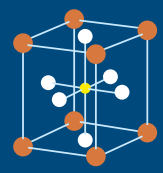


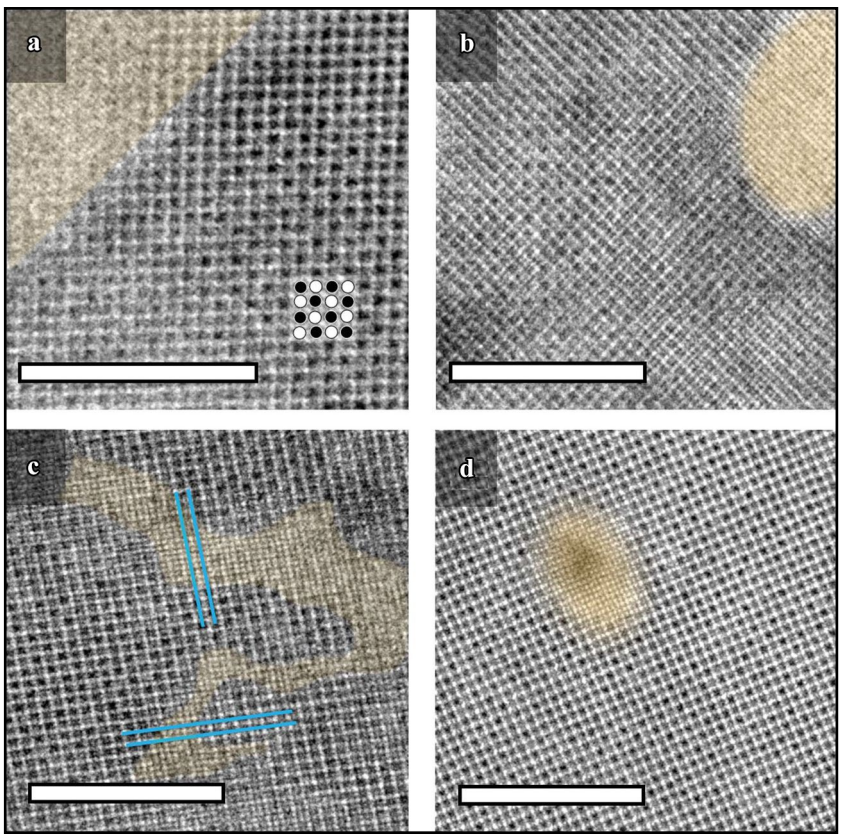
RESEARCH HIGHLIGHTS: Perovskites

By **Pabitra K. Nayak**

Perovskite solar cells are at the edge of commercial success. Device efficiency records continue to break at a regular pace, while stability and optimization are progressing rapidly. The first commercial products could reach the market very soon, just a decade since perovskite photovoltaics were first discovered. MRS Bulletin *presents coverage of the most recent impactful advances in the burgeoning field of perovskite research.*

Atomic arrangements at interfaces within halide perovskite polycrystalline thin films have been postulated to have a substantial impact on electronic properties and long-term stability of solar cells based on this class of materials. However, a clear atomic-scale picture of the grain boundaries (GBs) and information on the exact nature of GBs has been missing, though a consensus is that the GBs are benign.

In an article published in Science (https://doi.org/10.1126/science.abb5940), Nellist and Herz from the University of Oxford and co-workers reported atomic-level understanding of halide perovskites that can explain their remarkable optoelectronic performance. They used low-dose scanning transmission electron microscopy and thin-film samples of formamidinium and methylammonium lead triiodide ($FAPbI_3$ and $MAPbI_3$, respectively) prepared by thermal evaporation to unravel the atomic-level structures. Upon loss of organic cations, a degradation pathway in perovskite materials, the partially degraded films yielded exceptional regenerative properties, indicating the highly adaptive nature of the material. They further showed the role played by PbI_2 (often added in excess to the precursor solution to boost performance) precursor remnants in the film, where it seamlessly intergrows with the $FAPbI_3$ and $MAPbI_3$ lattices and shows low lattice misfit and strain. The PbI_2 domains neatly follow the perovskite structure and orientation, which results in sharp grain boundaries, coherent PbI_2/perovskite interfaces, and absence of long-range disorder. The authors suggest that the excess PbI_2, which counterintuitively improves performance, actually acts like seeds during the perovskite growth, facilitating the formation of crystalline material.



Intergrowth of PbI_2 (highlighted in light orange) and $FAPbI_3$ shown with atomic resolution. Scale bar is 10 nm. Credit: Science.

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Ruddlesden–Popper lead halide perovskites, a class of two-dimensional (2D) electronic material with wide structural degrees of freedom that define the electronic properties, have the potential to be combined with other materials to create a huge number of yet to be explored heterostructures with tailorable properties owing to the tunable optoelectronic properties of halide perovskites. However, the fragile nature of the material and the presence of mobile ions in perovskite materials make the van der Waals integration of the perovskite materials with other materials challenging.

Fu, Wright, Jin, and co-workers (Nature Nanotechnology, https://doi.org/10.1038/s41565-020-00802-2) have found a simple way to grow large-area nanosheets of phase-pure Ruddlesden–Popper perovskites with thicknesses down to one monolayer. Air and water interfaces were found to be suitable for the growth of 2D materials, which then can be transferred to the intended substrates using a poly(dimethylsiloxane) film. This work demonstrates flexibility in fabricating arbitrary vertical heterostructures with Ruddlesden–Popper lead halide perovskites. These designed heterostructures show interesting interlayer properties such as electronic carrier transfer across the interfaces and reduction in the line width of photoluminescence, which could be explored further for optoelectronic applications.

Single-junction solar cells have limitations in harnessing energy from the whole solar spectrum owing to the use of a single bandgap material. To get past the single junction limit, tandem solar cells have been developed where materials with different bandgaps are stacked. Perovskite and silicon tandem solar cells present an opportunity to go beyond the power-conversion efficiencies (PCEs) achieved for each technology. Perovskite-on-silicon tandem cells are one of the first commercial products with metal halide perovskites. There has been steady progress in PCE of this type of solar cell.

Now, Albrecht and co-workers have demonstrated a monolithic perovskite/silicon tandem solar cell with a PCE>29 percent, which is higher than the best single junction solar cell based on GaAs. They achieved this efficiency by using a perovskite material with 1.68 eV bandgap, which is suitable for tandem solar-cell applications, with Si as the lower bandgap material and optimized hole collection. Self-assembled monolayers based on customized organic molecules facilitate the hole collection, thus improving the fill factor of the solar cell. In addition, the tandem cell, even without encapsulation, showed no loss in performance for 300 hours. This work, published in *Science* (https://doi.org/10.1126/science.abd4016), shows that perovskite technology is on the right path to achieve the 30% efficiency milestone soon, where Oxford PV has already achieved a PCE of 29.5% with perovskite-Si tandem cells.

Halide perovskite materials, apart from being very interesting materials for photovoltaic and light-emitting applications, have been found also to be good for ionizing radiation detection, particularly the inorganic variant, $CsPbBr_3$.

Kanatzidis and co-workers have demonstrated devices based on $CsPbBr_3$ that can resolve ^{137}Cs 662-keV γ-rays with 1.4% energy resolution, and also x- and γ-rays with energies ranging from tens of keV to over 1 meV. The detectors showed stable operation over a wide temperature range (~2°C to ~70°C), and suitable encapsulation enables uniform performance over a period of 18 months. Large ingots of $CsPbBr_3$ with diameters up to 1.5 in. with excellent hole lifetimes (on the order of hundreds of microseconds) can be prepared, which is necessary for large-area detectors. This work, published in *Nature Photonics* (https://doi.org/10.1038/s41566-020-00727-1), shows that $CsPbBr_3$ can be used in new-generation high-energy γ-ray detectors, challenging the dominance of $Cd_{1-x}Zn_xTe$ ($x \approx 0.1$), which has high manufacturing cost.