RESEARCH HIGHLIGHTS: Perovskites

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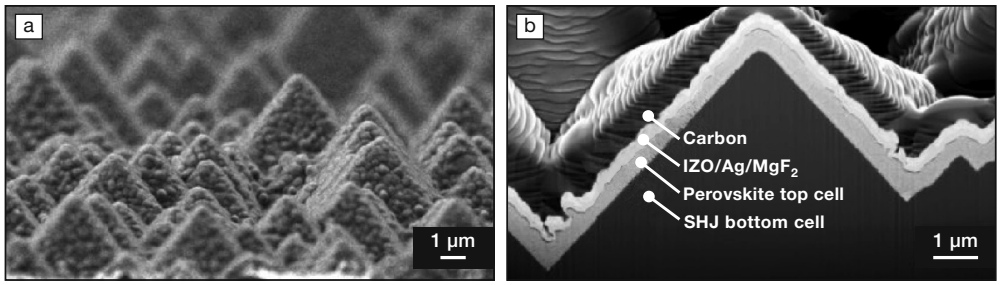
Research on perovskites has progressed rapidly, with new solar-cell efficiency records being set at a regular pace. There are hints of the first commercial products reaching the market by 2020, just a decade since perovskite photovoltaics were first realized. MRS Bulletin *presents the impact of a selection of recent advances in this burgeoning field.*



(a) SEM image of a perovskite layer. (b) Cross section of perovskite on a perovskite-Si tandem cell. SHJ, silicon heterojunction; IZO, indium zinc oxide. Credit: *Nature Materials*.

Silicon solar cells are quickly reaching their theoretical efficiency limit of 29.4%. Combining perovskites with silicon could allow researchers to cross the coveted power-conversion efficiency mark of 30% because the materials absorb light from different parts of the solar spectrum. The challenge with tandem cells is depositing the top perovskite cell while maintaining the quality of the bottom silicon cell.

Scientists in Switzerland have developed a simple process that allows the deposition of a perovskite layer directly on top of a standard silicon cell using existing production lines that should enable efficiencies above 30% at a reasonable cost. The team from École Polytechnique Fédérale de Lausanne has used the method to make tandem solar cells with 25.2% efficiency, as reported in *Nature Materials* (doi:10.1038/s41563-018-0115-4).

The surface of standard silicon solar cells is textured, with micrometer-sized pyramids that help to trap light. Perovskites deposited on the textured Si surface by a normal spin-coating method would accumulate in the valleys. One way to make tandem devices is to use a polished silicon surface. However, the polishing step leads to higher production costs, more reflection losses, and poor light trapping.

So the Swiss team first deposited a spirobifluorine hole-selective layer on the textured silicon surface using evaporation. Then they used a special two-step deposition process to make the perovskite layer, which evenly coated the pyramids.

The two-step process involves co-evaporating a porous lead iodide and cesium-bromide scaffold before spin-coating an organohalide solution. The solution enters the pores of the lead-cesium scaffold, and any excess is thrown off the substrate during spin coating. This prevents any accumulation of organohalides in the pyramid valleys.

UK-based startup Oxford PV announced recently that it created tandem solar cells with a certified efficiency of 27.3%. The company aims to add another percentage point over the next year, with hopes of reaching 30% efficiency and having a product on the market by 2020. They are also working on making their proprietary material more stable in addition to more efficient.

A method to make arrays of cesium lead halide perovskite nanocrystals reported in the *Journal of the American Chemical Society* (doi:10.1021/jacs.8b04803) could "open up new ways to design tandem perovskite solar cells and tunable display devices," say its developers at the University of Notre Dame.

Nanocrystals of cesium lead halide perovskites are promising alternatives to semiconductor nanocrystals for making light-emitting diodes, lasers, and other photonic devices. But pure $CsPbX_3$ nanocrystals are highly reactive, and they easily swap their halide ions with other nanocrystals to form mixed-halide perovskites. This makes it difficult to create films or suspensions

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with two or more types of halide nanocrystals with different optical properties that exist simultaneously.

Prashant Kamat and colleagues have previously found that covering $CsPbX_3$ nanocrystals with lead sulfate-oleate prevents exchanging halide ions and line up like peas in a pod. They produced an electrophoretic deposition method to assemble films of these peapod nanostructures on a substrate. The method led to the peapods forming bundles that lined up vertically on the surface. By making single layers or multiple layers of different halide nanocrystals, the researchers made films that glowed different colors, including white.

A team of researchers from China and the UK has made inverted perovskite solar cells with the highest recorded power-conversion efficiency of 20.9%, approaching that of regular architecture cells. Their study appeared in the journal *Science* (doi:10.1126/science.aap9282).

Inverted cells have a simpler structure than regular ones. They are easier to fabricate, compatible with flexible substrates, and could lead to high-efficiency multijunction cells. But so far, their low open-circuit voltage has limited their efficiencies.

The low voltage is due to the trapping of charge carriers at defects found at the interface between the perovskite film and charge extraction layers. The trapped carriers recombine without generating a photon. The researchers were able to eliminate this nonradiative recombination by using a two-step method to make perovskite films. They first deposited a mixed-cation lead mixed-halide perovskite from solution, followed by another growth step using guanidinium bromide.

This gave a wide bandgap near the top surface of the film and a more *n*-type bottom layer. Researchers believe the wide bandgap keeps charge carriers away from the top surface where defects exist and allows extra electrons that occupy the defects or traps for an *n*-type perovskite. Together, this reduces nonradiative recombination overall.

The Achilles' heel of perovskite solar cells is their penchant to decompose in the presence of moisture, oxygen, and heat. In a new study in *Nature Energy* (doi:10.1038/s41560-018-0192-2), engineers at the University of Toronto showed that local strains in the perovskite crystal lattice lead to defects, which ultimately lead to degradation because of their affinity for oxygen and water molecules. The researchers also showed that swapping some of the large ions in the structure with smaller ones can relax lattice strain and boost the material's stability and performance. The choice of dopant is key; the researchers used cadmium.

The new Cd-containing cells showed significantly higher stability even when unencapsulated compared to state-of-the-art mixed perovskite solar cells. They maintained more than 90% of their initial power-conversion efficiency after 30 days of storage in ambient air at a relative humidity of 50%. They also showed an order of magnitude longer of maximum power point operation under those conditions.

Energy Focus

Semitransparent organic PV generates power while reducing heat

Researchers from South China University of Technology and the Chinese Academy of Sciences have developed a multifunctional, semitransparent, organic photovoltaic (ST-OPV) device that can generate electricity and at the same time block infrared (IR) light, which is responsible for heat generation. The ST-OPV would be capable of producing energy while reducing the overall consumption of electricity in a household or office. The heat rejection properties of the solar cell is comparable to commercial ones (NV-25, P-18ARL, and PR70). The work was reported in a recent issue of *Joule* (doi:10.1016/j.joule.2018.06.006).

The amalgamation of power generation and heat insulation is carried out with a simple OPV structure of indium tin oxide (ITO)/PEDOT:PSS(*p*-type interlayer)/PBDTTT-E-T:IEICO(active layer)/PFN-2TNDI-Br(*n*-type interlayer)/Ag. Light enters from the ITO side. The absorbing polymer blends are promising candidates as the active layer in nonfullerene OPV and have weak absorption in the visible range. The 2,2′-((2Z,2′Z)-((5,5′-(4,4,9,9-tetrakis(4-hexylphenyl)-4,9-dihydro-s-indaceno[1,2-b:5,6-b′]dithiophene-2,7-diyl)bis(4-((2-ethylhexyl)-oxy)thiophene-5,2-diyl))bis(methanylylidene))bis(3-oxo-2,3-dihydro-1H-indene-2,1-diylidene))dimalononitrile (IEICO) acceptor is of particular importance in the multifunctionality of the device, as the absorption edge of this material is extended to 900 nm, which helps to generate photocurrent while utilizing the near-IR (NIR) photons. Moving a step forward toward blocking NIR light, a four-layer distributed Bragg reflector (DBR structure) (LiF/MoO_3) is deposited on top of the Ag electrode, which reflects the NIR photons back while maintaining transparency for visible wavelengths.

The transmittance and power-conversion efficiency (PCE) in these devices are optimized through varying the thickness of the Ag electrode, from 10 nm to 20 nm. The PCE (6.8–9%) of the ST-OPV device is found to be linearly dependent on the average visible transmittance (AVT) (28–17%). The thickness of the Ag electrode has a significant impact on the IR reflectivity as well. When the thickness of Ag increases from 10 nm to 20 nm, the IR rejection also increases from 75% to 90%, which is comparable to those of commercialized films for heat reduction such as