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

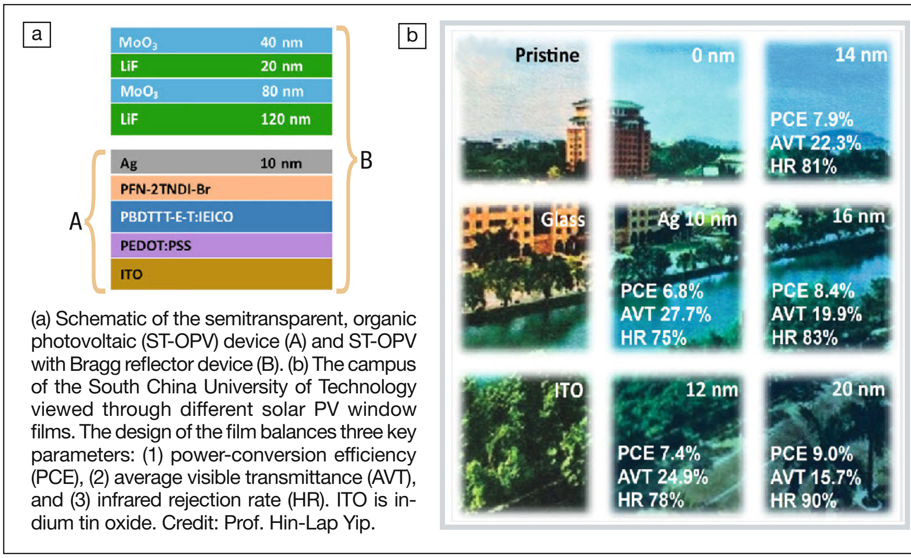
Researchers from South China University of Technology and the Chinese Academy of Sciences have developed a multifunctional, semitransparent, organic photovoltaic (ST-OPV) device that can generate electricity and at the same time block infrared (IR) light, which is responsible for heat generation. The 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

NV-25, P-18ARL, and PR70. The PR70 solar film inspired the heat rejection design in this study as it utilizes a sophisticated photonic-crystal design with alternating thin films of high- and low-refractive-index materials forming a DBR.

The advanced engineering of materials and optimization of the optics result in 6.5% efficient solar cells and AVT of 25% with IR radiation rejection rate over 80%. According to estimated calculations by Hin-Lap Yip from South China University of Technology, in a 15 m^2 window area in a 100 m^2 house, the ST-OPV can cut down 30% of electricity cost per household. When the ST-OPV is combined with the heat rejection properties, then the electricity reduction could reach ~50%. "Heat insulation is already a huge market, and [the introduction] of light harvesting will be a great added advantage," Yip says.



(a) Schematic of the semitransparent, organic photovoltaic (ST-OPV) device (A) and ST-OPV with Bragg reflector device (B). (b) The campus of the South China University of Technology viewed through different solar PV window films. The design of the film balances three key parameters: (1) power-conversion efficiency (PCE), (2) average visible transmittance (AVT), and (3) infrared rejection rate (HR). ITO is indium tin oxide. Credit: Prof. Hin-Lap Yip.

Kui Zhao from Shaanxi Normal University, who was not involved in this study, says, "This study has demonstrated for the first time a dual-functional ST-OPV device. The device exhibits high performance with heat rejection properties comparable with those of commercial window films. This novel design concept is expected to open up a new approach to developing multifunctional yet efficient semitransparent organic solar cells."

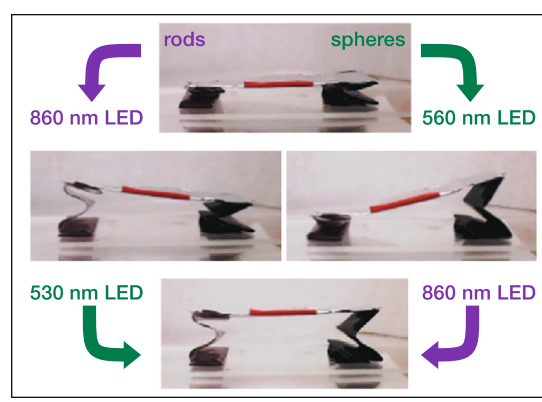
Enrique Gomez from The Pennsylvania State University, who was also not involved in this study, says, "This is a clever approach to manage the optical properties of polymer solar cells that further demonstrate their potential as semitransparent windows. Although a techno-economic analysis is still needed, I expect that this approach will bring semitransparent organic solar cells closer to commercialization as window materials."

Rahim Munir

Nano Focus

Gold nanoheaters enable optically controlled soft robots

The multicomponent structure of shape-memory polymers allows different phases in the material to melt or flow at different temperatures. Subsequently, actuation of these devices requires controlled heating. Remote control using light to drive complex processes will enable new applications in soft robotics. Joseph B. Tracy from North Carolina State University, along with his former graduate student, Sumeet R. Mishra, embedded gold nanoparticles into a shape-memory polymer and achieved sequentially controlled actuation. Essential to their success was the control over geometrical shapes of plasmonic gold nanoparticles. In turn, materials dissimilarly absorb different colors of light and, subsequently, photothermally heat in fine-tuned responses to specific optical wavelengths. The researchers embedded these optically powered nanoheaters into a polyurethane shape-memory polymer, which is thermoplastic and has a component with a low glass-transition temperature, and bent strips of these materials into accordion-shaped legs. Different wavelengths of light then selectively drove the unfolding of these legs. The researchers published their discovery in a recent issue of *ACS Applied Nano Materials* (doi:10.1021/acsanm.8b00394).



A wavelength-controlled stage with accordion legs containing gold nanorods (left) and gold nanospheres (right). The sequence of illumination by light-emitting diodes (LEDs) positioned next to each leg (not shown in photographs) remotely controls the tilt angle and height of the stage. Credit: Sumeet R. Mishra.

"This is an important advance because it directly connects the tunable optical properties of noble metal nanoparticles with remote triggering of sequential processes for applications in soft robotics, such as biomedical implants," Tracy says. "Selection of light sources and several parameters, including peak wavelength, power, and distance from the sample have to be carefully balanced to achieve sequential actuation within a few seconds," Mishra adds.