RESEARCH HIGHLIGHTS: Perovskites

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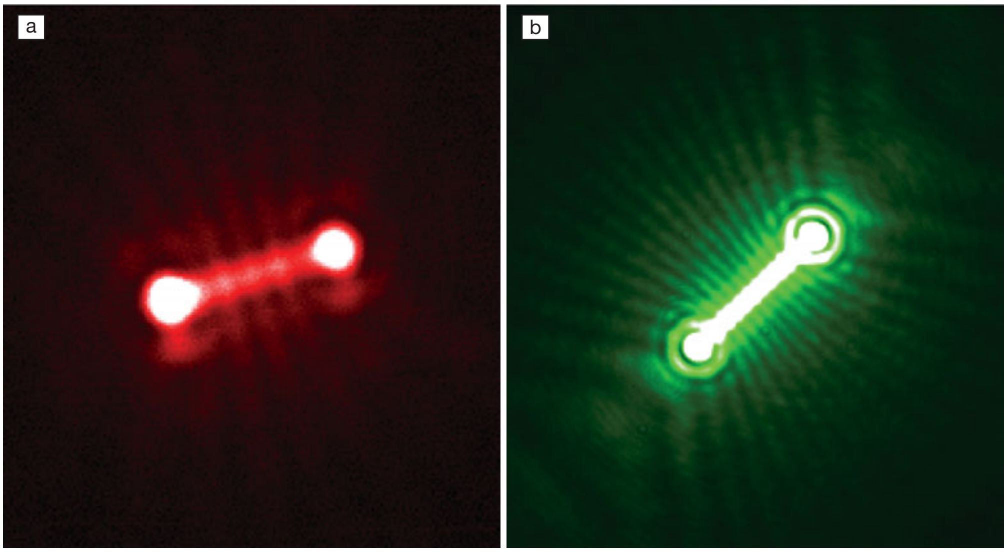
Research on perovskites has progressed rapidly since the first solar cells with less than 4% efficiency were reported in 2009. *MRS Bulletin* presents the impact of a selection of recent advances in this burgeoning field.

Perovskites are mostly being studied for solar cells. Now chemists at Columbia University and the University of Wisconsin–Madison have made tiny lasers from single-crystal nanowires of methylammonium lead halide perovskites.

Compared to nanowires made from conventional semiconductors such as zinc oxide and gallium arsenide, perovskite nanowires can be grown easily at room temperature, says Columbia University chemistry professor Xiaoyang Zhu.

As reported in the June issue of *Nature Materials* (DOI: 10.1038/NMAT4271), the researchers make the single-crystal nanowires by depositing a solid thin film of lead acetate on a glass surface and then adding a high concentration methylammonium iodide solution. This led to the growth of rectangular nanocrystals of perovskite that were defect-free and had the reflective parallel facets needed to make a laser.

Measurements showed that the perovskite nanowire lasers are 100% efficient at converting absorbed photons to laser light, at least one order of magnitude higher than other nanowire lasers, Zhu says. Another exciting aspect of the lasers is that their color can be tuned simply by changing the composition of the perovskite material.



(a) An 8.5-µm-long methylammonium lead iodide nanowire emits red laser light when excited by a 402-nm pulsed laser beam. (b) A 13.6-µm-long methylammonium lead bromide nanowire, meanwhile, lases green. Credit: *Nature Materials*.

Sang Il Seok and his research team at the Korea Research Institute of Chemical Technology have made perovskite solar cells that have a record 20.1% certified power-conversion efficiency. This efficiency competes with that of commercial silicon solar cells.

Last year, the South Korean team combined the most widely used perovskite, methylammonium lead halide, with formamidinium lead iodide to make solar cells that were 17.9% efficient. The researchers have now broken their own efficiency record by using the same materials but a new manufacturing method, which they reported in the June issue of *Science* (DOI: 10.1126/science.aaa9272).

Formamidinium-based perovskites absorb a larger portion of the solar spectrum compared to methylammonium-based compounds, leading to higher efficiency photovoltaic devices. But uniform, dense films of formamidinium lead iodide have been challenging to make. Seok and his colleagues placed a lead(II) iodide–dimethylsulfoxide (DMSO) film into a formamidinium iodide (FAI) solution. An intramolecular exchange results in FAI replacing DMSO in the lattice, resulting in a very high-quality formamidinium lead triiodide film.

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Another article published in the May issue of *Science* (DOI: 10.1126/science.aaa5333) contests the popular theory that defects and grain boundaries in perovskites are inert or benign. Perovskite solar cells perform remarkably well partly because light-generated electrons and holes travel through the film for a long period of time. Researchers have attributed this to shallow crystal defects and electrically inactive boundaries between crystal grains that cannot trap the charge carriers for them to recombine.

But when a research team from the University of Washington and the University of Oxford studied methylammonium lead halide perovskites using confocal fluorescence microscopy and scanning electron microscopy, they found that some regions of the crystal, such as individual grains, interfaces, cracks, and grain boundaries appeared dimmer than other regions. This implied the occurrence of non-radiative recombination, a process in which electrons and holes recombine to generate heat, as opposed to light-generating radiative recombination. Those dim regions also have short carrier lifetimes.

"To make a good semiconductor for a solar cell you want all the recombination in the semiconductor to be radiative so that when you shine light on it you only get recombination events that emit light," says David Ginger, co-author of the article and chemistry professor at the University of Washington.

The local variations in carrier lifetime in the dim and bright regions of the perovskite microstructure average out over the entire perovskite film to give it an overall long carrier lifetime, but fast non-radiative recombination is still happening in the dark regions, he explains. Ginger and his colleagues showed that chemical treatment with pyridine makes the dark spots in the crystal brighter by turning off this non-radiative recombination.

The results imply that state-of-the-art perovskite films could be made substantially better by removing those non-radiative recombination losses. "The good news is that by carefully processing the film and by using post-deposition chemical passivation treatments, researchers can eliminate those defective regions and improve efficiency," Ginger says.

Regardless of application, stability has been a critical issue for perovskites. The materials can degrade easily in humidity. Scientists led by Tao Xu at the Northern Illinois University in Dekalb, Ill., have now proposed a solution. In an article published online in the May issue of *Angewandte Chemie* (DOI: 10.1002/anie.201503038), they report that replacing two of three iodide ions in a methylammonium lead iodide perovskite with thiocyanate ions (SCN^-) maintains the perovskite structure, while making the films much more moisture-resistant than conventional ones.

Solar cells made with the SCN^--containing perovskite film showed no significant degradation after being exposed to air with relative humidity of 95% for over four hours. By contrast, devices made with the conventional material degraded in less than 1.5 hours, the researchers reported. Devices made from both materials had the same efficiency of 8.5%.

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