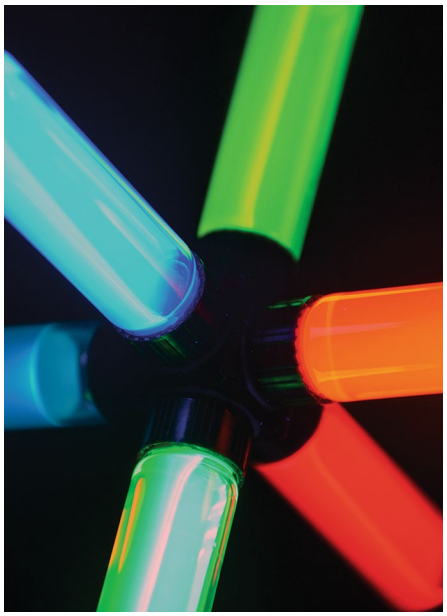
Perovskites keep on giving

Whether you like exploring the mysteries of light–matter interactions, playing with a versatile chemical platform, or developing the most efficient devices, metal halide perovskites could be the materials for you.

Rediscovered at a time when the need to switch electricity generation from fossil fuels to renewable sources has become urgent, metal halide perovskites have been in the spotlight of photovoltaics research for the past six years. The reason is easily explained: with rather simple processing steps — for instance, mixing and depositing solutions containing lead, halides and organic or inorganic cations on a substrate and heating at relatively low temperatures — it is possible to obtain films that convert light into electricity with efficiency not far from that of silicon, the material used in most commercial solar panels. Researchers have developed a few recipes, changing ingredients in the mixture or the deposition procedure, optimizing the baking temperature and time, or improving the device architecture. As a result, perovskite solar cells with 20% efficiency are now routinely fabricated, with the best devices approaching and surpassing 23%.

While this certainly sounds promising, more steps are required before perovskite panels can enter the photovoltaics industry. In a Commentary in this issue, Henry Snaith describes the present strengths and weaknesses of perovskite solar cells, and the status of technology transfer. Considerations on materials availability and extraction capabilities put metal halide perovskites in pole position with respect to their competitors. For instance, to generate 12.5 TW of electric power from solar panels, the amount of lead required could be extracted in just a few days — in comparison, it would take three years to produce the required amount of silicon, and 500 years to obtain the gallium needed by gallium arsenide solar cells. Preliminary studies also show that the environmental impact of perovskite modules would not exceed that of silicon solar cells, when the whole life cycle of these technologies is taken into account. Stability, however, is currently the main limitation: devices maintaining high efficiency for more than 1,000 hours have been demonstrated, yet stability up to 25 years should be ensured to attract investors. This requires more research on the sources of instabilities and on ways to prevent them; certainly there is no lack of scientific interest, and funding support from large national and international initiatives may help reach these goals more rapidly, as Snaith advocates.



Credit: Image by Quinten A. Akkerman and Muhammad Imran

The appeal of perovskites, however, goes well beyond solar cells. During the journey towards high-performing devices, collateral research paths have opened that are now being enthusiastically explored. The possibility to generate electric charges in such an efficient way using films that can be highly non-uniform and full of structural defects poses questions on the way light and charges interact with matter in perovskite films. At present, various hypotheses have been proposed to explain the optoelectronic properties of these materials. In a Feature in this issue, four teams discuss some of these possibilities: from the distortions and vibrations of the soft ionic crystal, which may alter the environment in which the electric charges move; to the presence of polar nanodomains that may change orientation in response of the electric field generated by a charge and modify the recombination processes; to Rashba effects that may change the energy band diagram of the films; to the peculiar chemical behaviour of some of the defects, which may explain their limited impact on charge transport and recombination. These researchers also suggest possible ways to validate such hypotheses and understand their relative effects on solar cells and other devices.

Another consequence of the so-called defect tolerance is the high luminescence demonstrated by perovskite nanocrystals (pictured), as discussed in a Review by the teams of Liberato Manna and Maksym Kovalenko. Shrinking the dimensions to the nanoscale, the interactions of charges with potentially detrimental energy traps located at the surface increase. For this reason, colloidal nanocrystals usually require specific shells to passivate such traps and achieve strong emission. In contrast, perovskite nanocrystals are extremely luminescent without any passivation layer, and compare well with the performance of the nanocrystals currently used in TV screens and phone displays. As with solar cells, chemical stability is also an issue that must be solved before these materials can become real contenders as light-emitting sources.

The ionic nature and the presence of structural defects (in particular iodide vacancies) have also been used to explain the ability of these materials to transport ions. In a recent study published in this issue, Joachim Maier and colleagues show that ion conductivity is also extremely sensitive to light illumination in methylammonium lead iodide perovskite films. The team concludes that light can trigger chemical reactions between photogenerated charges and iodide ions, forming neutral iodine atoms. This creates ion vacancies and thus a massive enhancement of ion conductivity. As pointed out by Jürgen Fleig and Markus Kubicek in a News and Views, such variations in conductivity and in the iodine chemical potential may prove useful in photoelectrochemical solid-state devices for water splitting or for photochargeable batteries. Further suggestions for the use of perovskites in an even broader range of devices, including single-photon emitters and spin field-effect transistors, will be discussed in this Focus issue. Time will tell how many of these applications perovskites will excel in. ❐

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