# Perovskite photovoltaics: David Mitzi addresses the promises and challenges

Interviewed by **Lynn Loo** and **Prachi Patel**

Before joining Duke University as a professor of mechanical engineering and materials science in 2014, David Mitzi spent 24 years at IBM's T.J. Watson Research Center developing new solution-processed electronic materials that outperform analogous conventional high-vacuum processed materials. There, he worked extensively on halide perovskite semiconductors before leading work on thin-film solar cells, including those made from earth-abundant elements copper, zinc, tin, sulfur, as well as selenium (CZTS). These solar cells were 12.6% efficient, representing almost a doubling of performance over the state of the art for this technology before the IBM breakthroughs. Mitzi is now busy expanding his laboratory at Duke, where his research group is pursuing low-cost, high-performance photovoltaic technologies based on chalcogenides such as CZTS and CIGS as well as on perovskites. His goals are to increase the efficiency and improve the stability of perovskite solar cells. Searching for new perovskite materials that do not contain toxic lead is also a top priority. He gave us his insights on the excitement behind perovskites and which key research areas need attention.

**MRS BULLETIN: Perovskite solar-cell efficiencies have gone from 3.8% in 2009 to over 20% in 2014. What has driven this rapid progress?**

DAVID MITZI: There are several reasons. First is the material itself. It has outstanding properties for photovoltaics (PV): a tunable bandgap in a range appropriate for the solar spectrum; a very high absorption coefficient so you can make the devices very thin; and relatively benign, shallow defects so you don't have a lot of recombination and the device can have high open-circuit voltages.

The second reason relates to where the field of solar is right now. Back in the 1970s, silicon solar cells cost on the order of $60 per watt. Nowadays, they're approaching 50 cents per watt, getting to an exciting area where PV can get to grid parity, which is unprecedented. That, combined with the need to come up with a clean energy source for environmental reasons, has put a lot of focus and research funding into PV.

Finally, perovskites are tremendously easy to make with very little equipment and financial investment. Getting high performance isn't easy, but it's very easy to get started, enabling research groups to jump in and get moving quickly.

**How do perovskite solar cells compare with silicon and organics in terms of lifetime, cost, efficiency, and the environmental concerns associated with having lead in these materials?**

Perovskite PV materials offer remarkable processing flexibility. You can imagine setting up a roll-to-roll process that operates at very high throughput using solution-based near-ambient temperature processing, which is significant for ultralow cost. This is a step above and beyond where one can imagine getting with silicon in terms of low-cost processing. You can envision using this type of processing for organics, but organics don't have the pathway yet of getting to mid-20% levels in terms of efficiency.

On the other hand, perovskites have a number of issues. Silicon is a very stable technology, and one can demonstrate a silicon panel that lasts for 30-plus years. Perovskites have not demonstrated this outstanding stability yet. Another is the hysteresis, or lack of electrical stability, in perovskite cells. You need this stability to predict a solar cell's performance. Finally, there is the issue of reproducibility and process stability, knowing that following certain steps will lead to certain performance predictability. The young field of perovskite PV needs to progress in all of these areas before perovskites can succeed commercially.

Regarding environmental concerns, a starting point might be to look at cadmium telluride. There is concern about cadmium and restrictions on cadmium in a number of markets. Proponents of cadmium telluride might argue that using cadmium in these modules is actually doing us a favor since you're pulling cadmium out of a waste stream where it might be leachable and putting it into a relatively inert form and into a life cycle that can be carefully monitored and recycled. The difference, of course, is that lead in perovskites is leachable; it's not stable. If the module's encapsulation breaks somehow, lead can easily leach out into the environment. So I think it's a serious concern.

**Why did IBM stop research on these materials?**

One of the reasons I stopped working on perovskites back in the 2000s is because I was primarily interested in them for thin-film transistors and LEDs [light-emitting diodes], and it became quickly apparent that the materials had major stability issues. I ran into device hysteresis in the transistors as well. These are the same issues that we're facing now in

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Lynn Loo, Princeton University, USA
Prachi Patel, Prachi@lekh.org

the PV devices. I was hoping to move to a chemical system that was not impacted by these problems, and that was one of the reasons I started looking at solution-processed chalcogenides.

The second reason is that IBM's core business had transitioned beyond displays and PC devices, so the company had less interest in lower-performing transistors and LEDs. With chalcogenides, there was interest, for example, in phase-change memory and a number of other applications that could resonate with some of the directions that IBM was moving in.

**Do you think we will be able to solve issues like hysteresis and stability that plague perovskite solar cells today?**

Well, if you look at methylammonium lead iodide, it has a very low formation energy, which is one of the reasons it's an easy material to make. But it also means that it's very easy to pull apart, by heat, electric field, or light. So some of the issues with methylammonium lead iodide are, to some extent, intrinsic to the material. But I would argue that one might find organic and inorganic hybrids in which this formation energy is not as low, so that the material can be made more stable.

With methylammonium lead iodide, you're also fighting against a number of other issues, such as thermodynamics and lead. So I think there will likely be some other candidate that works better. It could be incorporating another organic that has more points of contact with the inorganic framework and holds it in more stably. It could be moving away from organic–inorganic hybrid metal halides to purely inorganic systems. There are a number of different avenues to take. At present, the majority of the field is focused on methylammonium lead iodide, but perovskites are a tremendously diverse structural family that is worth exploring beyond that material.

**All the issues aside, do you think perovskite solar cells are commercializable?**

There is a compelling reason to pursue perovskite-based solar cells for commercialization: the vision of a technology that can get to a point where it's almost as cheap as painting a house. It's hard to imagine how to get to that point without a material like hybrid perovskites. As we've discussed, though, the current generation of perovskites has a number of headwinds that need to be addressed: the hysteresis, the lead, the process stability, and the device stability.

**Do you think it's likely that perovskite solar cell efficiencies will go up further?**

I think it is likely to go higher. The theoretical efficiency is somewhere in the upper 20s, maybe as high as 30%. People often look at the three parameters that dictate efficiency: the short-circuit current, the open-circuit voltage, and the fill factor. Open-circuit voltage is usually the hardest one to get into an impressive range because it has to do with the fundamentals of the junction and the material. So it's very promising or telling that in these materials, the open-circuit voltage is already pretty robust.

But what do we mean by efficiency when we're talking about hysteretic devices? It's important to standardize the efficiency of these devices. It's important to look at stabilized efficiency and to very carefully characterize how you measure the efficiency. For instance, what is your rate and direction of sweep during the current–voltage sampling, etc.?

**Silicon solar cells are currently 60 cents a watt. Do you think we can bring the cost of perovskite cells down below 60 cents a watt?**

Yes. I think it will depend on tackling some of these other issues. For example, if you have a material that needs to be very rigorously encapsulated, that will incur a cost. I think the real success of the material will be this idea of trying to create a system that can be essentially painted on that is very cheap to process. And so that will mean going to roll-to-roll-type processing or similar types of processing to get to very low cost points.

**What messages would you want to convey to the community working on perovskites?**

Many of the messages we've already gone over, namely some of the limitations that need to be better understood and controlled. One of the key messages from a recent meeting [workshop on hybrid organic–inorganic perovskites held at the Weizmann Institute of Science] was the importance of understanding the basic material properties of organic and inorganic perovskites: things like the dielectric constant and the mechanical properties; the importance of the organic cations; the critical property of ion migration; and thermal properties, again getting at the formation energy. This is important because getting this detailed understanding makes it possible to start modeling the materials more effectively and getting a picture of what's really important. How do we set up design rules to make perovskite-like materials that have high performance but without the lead, the hysteresis, etc.? ☐