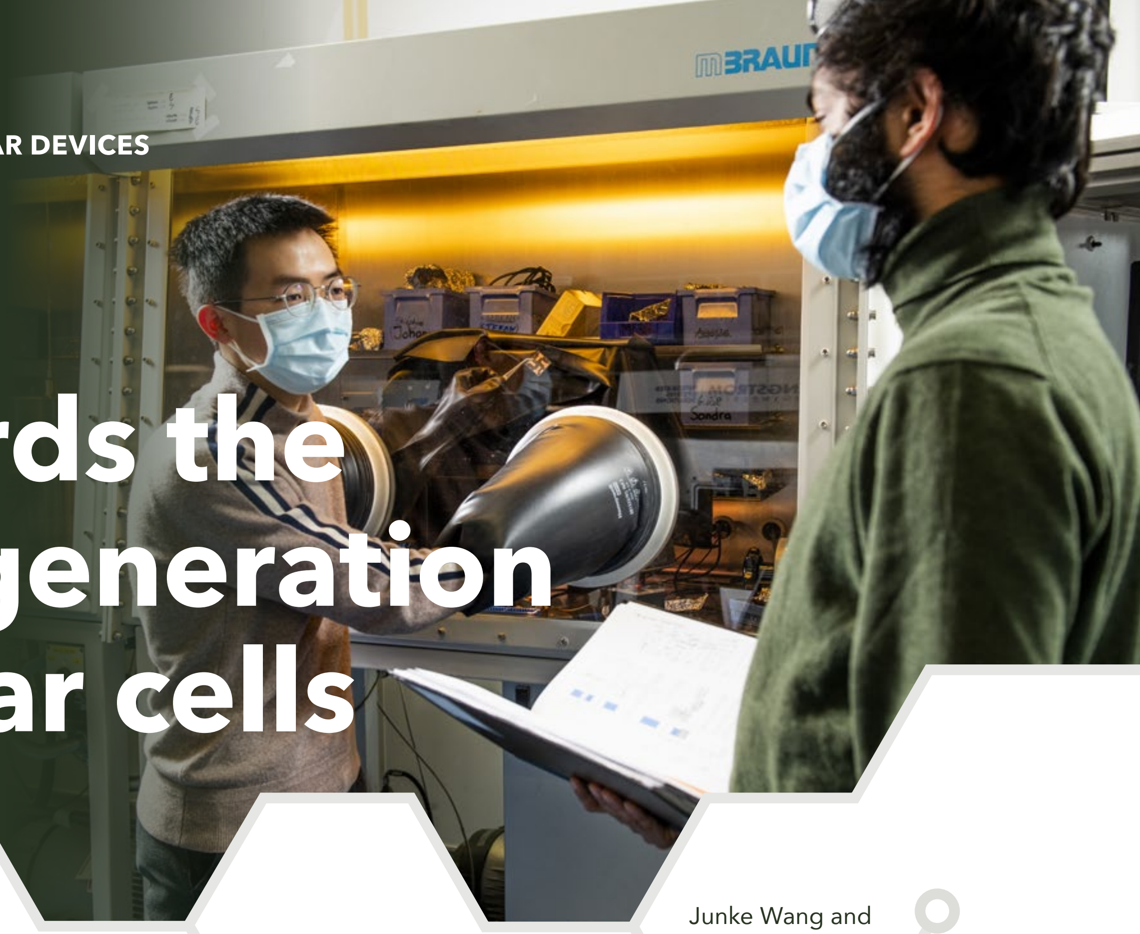
MOLECULAR DEVICES

Towards the next generation of solar cells



Junke Wang and Kunal Datta

Together with colleagues at Solliance Solar Research, ICMS researchers have made significant progress in the development of next generation solar cells based on perovskite materials. In a paper in Nature Communications, they present a triple-junction perovskite cell with 16.8% conversion efficiency. Resulting from the PhD research of Junke Wang and Kunal Datta, these cells pave the way towards multi-layered perovskite tandem cells with record-breaking efficiencies.

Of course, silicon-based solar cells already cover many roofs and there are ample plans for solar farms to generate massive amounts of sustainable energy. Yet, there is still plenty of room for improvement. At the Molecular Materials and Nanosystems group led by René Janssen, researchers are pushing hard to develop the next generation of solar cells. These are based on perovskite materials; hybrid inorganic-organic crystalline compounds that can be easily manufactured from cheap raw materials and thus allow for rapid and cost-effective industrialized fabrication. "This combination of low cost, easy processing and high conversion efficiency would really bring solar energy conversion to the next level," says Kunal Datta. "It could provide a tremendous boost to realize the terawatt-scale solar industry that is essential for realizing the sustainable energy transition." Already start-up companies are exploring the opportunities of perovskites, he adds.

ABSORBING MULTIPLE COLORS

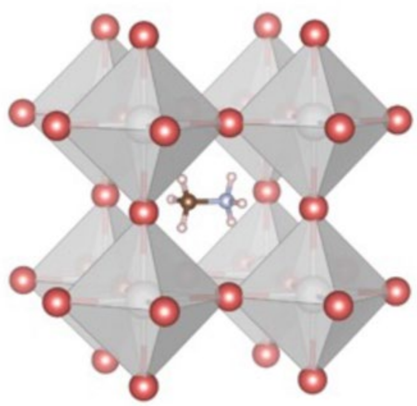
Junke Wang explains that solar cells using conventional crystalline silicon are already approaching their efficiency limit of 33 percent. "A strategy to go beyond that is to combine multiple light-absorbing layers that together can capture the full spectrum of sunlight. Perovskite offers a great way to do that since changing its chemical composition also changes the color of sunlight it absorbs." Combining multiple, different perovskite layers into one solar cell could – in theory – raise the conversion efficiency of a solar cell to a whopping 68 percent. "The concept of such tandem or multi-junction cells obviously reduces the cost per kWh," Datta says. "But then producing these cells should not require an intricate procedure, since that would counter the inherent benefits of perovskites."

"MULTIPLE LIGHT-ABSORBING LAYERS TOGETHER CAN CAPTURE THE FULL SPECTRUM OF SUNLIGHT"

The Nature Communications paper describes a simple, yet effective processing method to arrive at three distinct perovskite layers. At the heart is a two-step solution process where first, a solution of an inorganic halide compound is deposited to form a thin "precursor" layer. On top of that, a solution of an organic halide is deposited. A final thermal annealing process induces the formation (crystallization) of the actual perovskite layer whose composition depends on the contents of both solutions used in the two-step deposition process.

PROTECTIVE LAYER

Minimizing interference when repetitively using this procedure to deposit multiple perovskite layers proved a major challenge. Wang: "The problem is that the organic solvents we use to deposit the halide compounds will also dissolve a perovskite layer. So, we had to come up with a robust protective layer to preserve the integrity of an established perovskite layer during deposition of a new one. And of course, these layers themselves should not reduce the performance of the final solar cell." According to Wang, this turned out to be rather difficult. "At first we selected a deposition technology that in itself was damaging to the perovskite layer. Adding to this, the proposed protective layer introduced adversary electrical effects. It took us quite a long time to conclude that this approach would not yield any realistic device. Luckily, we then got in touch with colleagues at Solliance Solar Research at the Eindhoven High-Tech Campus, who proposed an alternative deposition technology. That enabled us to realize the protective layer and arrive at triple-junction devices with a very satisfying performance."



Crystal structure of a perovskite of the type $CH_3NH_3PbX_3$, where a central methylammonium cation ($CH_3NH_3^+$) is surrounded by PbX_6 octahedra. X represents halide ions (I, Br and/or Cl; depicted as red spheres). The ratio of I, Br and Cl determines the color of light that is absorbed by the perovskite. Replacing the lead (Pb) ion at the center of the octahedra with another metal such as tin also changes the absorption frequency.

RIVAL PERFORMANCE

Wang is proud that the 16.8% conversion efficiency of the triple-junction cell more than doubles figures reported earlier in literature. "This is quite a competitive field. Being one of the first groups to develop triple-junction perovskites is very satisfying. And in fact, we have only published proof-of-concept. We see many opportunities to go beyond 16.8%." After obtaining his PhD in December 2020, Wang is now improving the concept as a postdoc. "We hope to achieve conversion efficiencies towards 30% in the near future. With further development of individual perovskite materials, efficiencies towards 36% are within reach." That would already rival the performance of current silicon technology, yet at considerably lower cost. In the meantime, Datta is in the last year of his PhD research where he will focus on combining perovskites with a silicon cell in a hybrid tandem cell set-up – a collaboration between researchers from TU/e, Delft University of Technology, AMOLF, University of Amsterdam and industrial partners. The idea here is to complement the spectral absorption features of silicon-based devices using thin perovskite films and thereby improve performance. Datta: "Whether it will be all-perovskite or silicon-perovskite, the conclusion is clear: multi-junction cells will be the way to go in solar technology."

Junke Wang, Valerio Zardetto, Kunal Datta *et al.*, "16.8% Monolithic all-perovskite triple-junction solar cells via a universal two-step solution process," *Nat. Commun.* 11, 5254 (2020). DOI: 10.1038/s41467-020-19062-8