Among emerging solar technologies, perovskite solar cells have so far come closest to the ideal of high efficiency, low cost and simple manufacturability. Most major photovoltaic (PV) manufacturers and a bevy of start-ups are investigating perovskites as a near-term complement and potential long-term successor to crystalline silicon. However, long-term device stability remains an open question: it is not yet clear how to engineer perovskites to reach the 25-year lifetime typically expected of commercial PV modules.

One potential strategy to tackle stability is to reduce the perovskite dimensionality. Both layered two-dimensional (2D) films and nanocrystal quantum dots (QDs) have shown promise for more stable solar cells than conventional 3D perovskite films. In addition, wide-bandgap perovskite QDs have shown increased phase stability, compositional tunability, and open-circuit voltages compared to perovskite thin films with similar compositions, potentially making them an ideal absorber for the top cell in tandems with perovskites, silicon or copper indium gallium selenide (CIGS). However, long-term device stability limited the efficiency of charge extraction4,5. Following these previous reports, the researchers mix CsPbI₃ and FAPbI₃ QDs and monitor the exchange of Cs and FA cations between the parent QDs. Unlike previous work, however, they intentionally increase the concentration of oleic acid ligands in the solution — these ligands help solvate the cations, stimulating the formation and diffusion of A-site vacancies and expediting the exchange reaction (Fig. 1). This seemingly minor change has a major impact on the QD optoelectronic properties and solar cell performance.

The resulting Csₓ₋₁FAₓPbI₃ QD solar cells reach a higher short-circuit current and open-circuit voltage than those prepared without excess oleic acid. The researchers propose that without excess ligands, insufficient ligand coverage of the QD surfaces allows more defects to form during the cation exchange reaction. Their hypothesis is supported by experimental evidence — with the oleic-acid-rich preparation, they observe increased photoluminescence lifetimes and reduced defect counts in high-resolution scanning tunnelling electron microscopy (STEM) images.

The ligand-assisted cation exchange technique allows Hao and co-workers to achieve a certified efficiency for QD solar cells of 16.6%. This represents a substantial step forward in QD PV efficiency. Importantly, these high-performance devices are also relatively stable, losing less than 10% of their initial efficiency after 600 hours under open-circuit conditions in inert atmosphere, compared to over 20% for bulk control devices with the same perovskite compositions.

Besides further improvements in efficiency and stability, substantial challenges to commercialization of QD solar cells remain. Two key challenges include developing high-throughput deposition methods and reducing materials cost. Commercial silicon PV modules today
routinely exceed 19% efficiency over square metre areas, with record cells surpassing 26% — the small-area single-junction perovskite QD cell record of 16.6% will likely need to break 20% to be commercially relevant for tandem applications, and even higher for single-junction applications. Cell and module stability must be proven over longer time periods and under practical operating conditions, with maximum power point tracking, variable temperature and different environmental conditions.

The current method used to deposit perovskite QD films — layer-by-layer spin-coating — involves alternating deposition and solvent treatment of thin (<100 nm) QD layers to remove long-chain surface ligands. This makes the QD film more electrically conductive and resistant to re-dissolution and allows a thick film to form. However, layer-by-layer deposition cannot easily scale to high volume production. A promising ink-based approach has been demonstrated for lead chalcogenide QDs7,8, but has not yet been proven for perovskite QDs.

Finally, QD PV material costs remain too high. The device structure used by Hao and colleagues employs expensive contact materials (for example, Spiro-OMeTAD and gold). Even more critically, the cost of synthesizing QDs is a major barrier — recent calculations suggest that the present perovskite QD synthesis cost per watt, even assuming an optimistic 20% cell efficiency that is likely needed to be commercially relevant, is more than the cost per watt of an entire silicon PV module7. The purification (crash out) step is particularly expensive, as it is labour intensive, has substantial yield loss and uses expensive solvents — Hao and colleagues use two crash out cycles, similar to previous reports. New low-cost, high-throughput synthetic methods are needed for perovskite QDs. Ultimately, to enter the PV market and achieve scale, QD solar cells may need to address niche, high-value applications where cost is not the only variable in the purchasing decision.

While the aspects above become relevant when thinking of industrial manufacturing, achieving a competitive power conversion efficiency is the cornerstone of any emerging PV commercialization strategy. The work by Hao and colleagues takes a major step in this direction for perovskite QD solar cells, while also providing a foundation for the development of other high-performance QD optoelectronic devices.

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Competing interests
The author is a founder and chief executive officer of Swift Solar, a US company developing perovskite photovoltaics.