Large-scale perovskite light-emitting diodes enabled by quantum-wire arrays: One step closer to commercialization

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Large-scale Perovskite Light-emitting Diodes Enabled by Quantum-wire Arrays: One Step Closer to Commercialization

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Halide perovskite light emitting diodes (PeLEDs) are enticing candidates for displays and lighting. However, it remains a challenge for devices to upscale to large-area or non-planar structures with high uniformity. Recently, in *Nature Photonics*, Fan and co-workers developed perovskite quantum-wire arrays templated by porous alumina membranes to achieve highly uniform performance LEDs based on wafer-scale substrates and three-dimensional spherical structures.

Metal halide perovskites have shown great optoelectronic properties for LEDs[1], such as high photoluminescence quantum yields (PLQYs), tunable bandgap, narrow emission linewidths and high charge-carrier mobility[2,3]. Owing to the development of the strategy of defect passivation[4] and controllable growth of grains[5], the external quantum efficiencies (EQEs) of PeLEDs have achieved more than 25%[6]. Furthermore, critical interface engineering has also been developed for fabricating PeLEDs with long operational stability[7], making a key step toward practical applications and future commercialization.

Large-area LEDs with high device performance uniformity are required for commercial displays and lighting. For example, organic light-emitting diodes (OLEDs) have been used as commercial displays, which are fabricated by precisely controlling the thermal vacuum evaporating process, resulting in a highly uniform distribution of device performance. PeLEDs are mostly fabricated by the solution-processed spin-coating method, limiting their uniformity in large-scale areas. Although large-scale processes (e.g. spray-coating[8] and blade-coating[9]) have been successfully used in perovskite photovoltaics, large-scale PeLEDs have been rarely reported. Furthermore, the mainstream spin-coating method is incompatible with non-planar substrates; as such, 3D spherical PeLEDs, which are used for spatially uniform luminescence, are missing in literature.

Fan and co-workers developed wafer-scale and 3D spherical PeLEDs (Figure 1) recently in *Nature Photonics* by using quantum-wire arrays (QWAs)[10]. Highly uniform crystalline perovskite QWAs are formed in hydrophobic porous alumina membranes (PAMs) via a close-spaced vapour reaction method. In detail, PAMs with pre-deposited Pb are placed on top of organic ammine halide powder such as methylammonium bromide, methylammonium chloride and methylammonium iodide (MABr, MACl, and MAI). By heating the powder, the vapour of organic amine halides reacts with lead; therefore, a perovskite structure can be formed in PAMs afterwards. The size of QWAs can be tuned by the porous diameters as the QWAs are confined in PAMs, reaching 92% PLQY when QWAs are 6.4 nm. A narrow emission peak (the full-width at half-maximum) of 21 nm is obtained in blue and green QWAs. A record high stability of 5644 hours (the time to reach 50% of the initial PL intensity, T_{50}) is achieved in the QWAs under ambient conditions. Meanwhile, benefiting from the excellent mechanical flexibility of PAMs, four-inch wafer-scale QWAs have been successfully extended to flexible ultra-thin substrates of Al foils and Corning Willow glasses. Although cesium-based perovskite QWAs have been demonstrated in their work, a vacuum vapour process and high temperature (400 ºC) remain needed. A general strategy for the growth of both cesium and MA based perovskite QWAs in air without vacuum is still missing. Ambient and low-temperature processable growth methods for cesium-based perovskite QWAs are crucial.

The QWA PeLED performance is really encouraging. The maximum luminance is 31667 cd m^{-2} at a current density of 477 mA cm^{-2}. The maximum EQE and current efficiency is 7.3 % and 22 cd A^{-1}, respectively. Specifically, wafer-scale LED devices are demonstrated with excellent EL uniformity by adding the gridline electrodes to improve the top-contact current spread, which is a generally used technology for large-scale OLEDs. Based on the excellent scalability of QWAs, 3D geometry LEDs have been investigated, which is motivated by the great advantages of 3D light such as spatially uniform distribution of luminance. The spherical LEDs devices are proved to be spatially uniform by comparing their angular emission EL spectrum with an ideal Lambertian emission profile for common planar LEDs.

Although open questions remain, large-scale and non-planar PeLEDs are really encouraging for the community. Firstly, it sheds light on the diversity of solid states of perovskite emitters beyond thin films; secondly, it reinforces our belief in the bright future of PeLEDs' commercialization; thirdly, it indicates that the next breakthrough of large-scale LEDs might lie in the device and material engineering that can further improve the EQE and EL stability, challenging but achievable.

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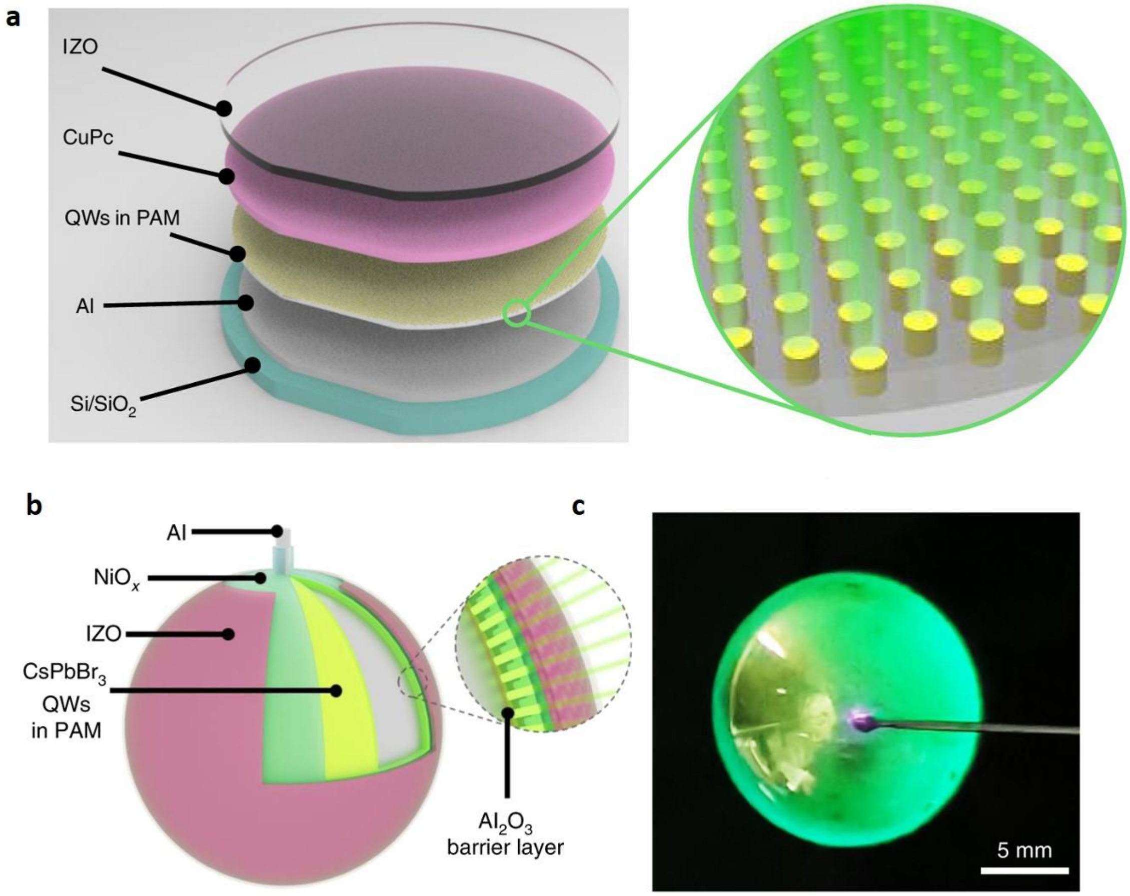

Figure 1. QWAs based PeLED discussed in this paper. **a**. planar wafer-scale device structure schematic. **b**. Three-dimensional spherical device schematic and **c**. EL image.