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PEROVSKITES

Colloidal nanocrystals for large-area LEDs

Tilting the substrate after bar-coating of colloidal perovskite nanocrystals facilitates the nanocrystal self-assembly process and enables highly efficient large-area perovskite LEDs.

Kang Wang and Letian Dou

Metal halide perovskites are promising for light-emitting diodes (LEDs) because of their remarkable optoelectronic properties and outstanding solution processability. Since the first demonstration of perovskite LEDs (PeLEDs) in 2014, their external quantum efficiencies (EQEs) have been rapidly boosted from around 1%[1] to above 20% in green[2], red[3] and near-infrared[4] emission regions, approaching the efficiency of state-of-the-art organic LEDs and inorganic quantum-dot LEDs. Moving forward, one critical challenge faced by the field is to develop new fabrication techniques for large-area devices and modules. Recently, efforts have been made via spin-coating[5] and blade-coating[6] molecular precursor perovskite solutions (that is, homogeneous solutions of free molecules, cations and anions) and decent device performances have been achieved. Nevertheless, the scalable production of PeLEDs is still hindered by difficulties in controlling nucleation and growth of the polycrystalline perovskite thin films over a large area at a thickness typically below 50 nm. Alternatively, coating large-area perovskite thin films using a pre-made colloidal perovskite nanocrystal (PNC) suspension has been suggested because it allows one to decouple the crystallization of perovskite materials from the film-formation process, which could simplify the coating procedure and enable the construction of uniform large-area thin films. However, very few attempts have been made thus far and a reliable method has yet to be developed. Now, writing in *Nature Nanotechnoloy*, Tae-Woo Lee and co-workers report[7] a modified bar-coating (m-bar-coating) method to fabricate high-quality large-area PNC thin films and demonstrate highly efficient PeLEDs with a peak EQE of over 20% with an active area of 900 mm^2.

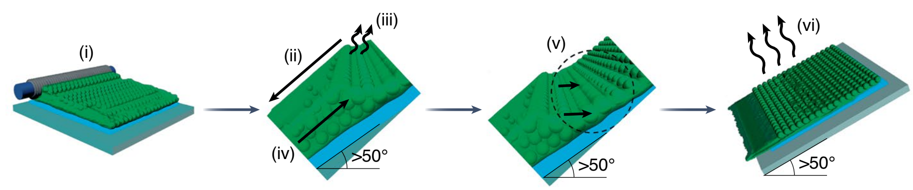

Fig. 1 | Modified bar-coating of large-area uniform PNC films. (i) Bar-coating of colloidal PNC solution onto the substrate. (ii) PNC meniscus movement driven by gravity-induced-stress after titling the substrate at an angle of >50°. (iii) Fast solvent evaporation. (iv) PNC moving along with the convective flow to compensate solvent evaporation. (v) PNC self-assembly through attractive capillary forces. (vi) Highly emissive and uniform PNC films after solvents are fully dried.

The colloidal PNCs used in Lee's work were synthesized using a simple solubility-difference-assisted recrystallization method at room temperature in air[8]. This method is inherently more scalable than the conventional hot-injection method, which requires much higher temperatures and inert gas conditions. In addition, the synthesis method described in this work can effectively retain the organic ligands on the surface of the nanocrystals during purification and thin-film fabrication, proving to be highly favourable compared with standard purification protocols that normally cause the detachment of organic ligands. This is important because the surface-capping organic ligands were found to be critical to improving the optical and electronic properties as they can suppress ion migration, passivate defects and prevent charge trapping, as well as provide dielectric confinement that promotes radiative recombination. These advantages together lead to a very high photoluminescence quantum yield of over 90% for the PNCs in the solid state.

To obtain a uniform large-area thin film, a novel m-bar-coating method was developed by innovatively tilting the substrate at an angle of $\geq 50°$ with respect to the horizontal surface immediately after the bar-coating of PNC solution (Fig. 1). Intriguingly, this angle was found to favourably balance the effects of gravity-induced stress and convective flow-capillary force during the solvent evaporation and PNC self-assembly processes. As a result, PNC films fabricated by this m-bar-coating method exhibit superior uniformity in both topography and optoelectronic properties over a large area up to 900 mm^2. The overall film quality is comparable to or even better than spin-coated small-area film (for example, 4 mm^2). On incorporating these bar-coated PNC films into LED devices, the team achieved a peak EQE of 23.26% with a pixel size of 4 mm^2, which is on a par with that of spin-coated PNC-PeLEDs (EQE = 23.12%). More importantly, the m-bar-coated PNC-PeLEDs maintained a high EQE of 22.5% and 21.46% in devices with larger areas of 102 and 900 mm^2, respectively. These values are significantly higher compared with previously reported large-area PeLEDs. It's worth noting that the EQEs of PNC-based PeLEDs are greatly improved over the molecular precursor-based PeLEDs (for example, EQE <1%) that use the same m-bar-coating process, which again demonstrates the advantage of PNCs for large-area device fabrication.

Looking forward, based on such exciting innovations, it will be interesting to see whether this technology can further scale up to make even larger uniform thin films and higher-efficiency devices. New coating techniques for the electron and hole transporting layers may be developed to enable truly high-throughput module production. Besides scalability, several other critical challenges still need to be addressed prior to commercialization. For example, the stability of the devices needs to be improved and the toxicity of lead also needs to be seriously considered.

Introducing conjugated organic ligands into perovskites[9] has been recognized as a promising strategy to substantially suppress ion migration, enhance the intrinsic stability and facilitate the charge injection. Thus, ligand design may advance the exploration of PNC application in efficient, stable and large-area PeLED. Furthermore, there have been efforts to develop lead-free perovskite and perovskite-like emitters[10], but more fundamental understandings on both materials and device interfaces are demanded to enhance the device performance. In short, although several challenges remain, the study by Lee and co-workers presented here, m-bar-coating of uniform colloidal PNC films and their implementation into large-area PeLEDs, represents a key milestone towards the development of perovskite emitters for next-generation displays and solid-state lighting. ❐

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Published online: 18 May 2022
https://doi.org/10.1038/s41565-022-01123-2

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Competing interests

The author declares no competing interests.