Live long and prosper

Solution-processing of light-emitting devices is attracting much attention due to low manufacturing costs and access to new materials. In this month's Focus issue we highlight some of the advances and challenges in the field.

While at Eastman Kodak in 1987, Ching Tang and Steven Van Slyke co-invented efficient organic light-emitting diodes (OLEDs) (*Appl. Phys. Lett.* **51**, 913; 1987). The small molecules used in these types of devices are readily deposited by thermal evaporation in a vacuum. However, thermal and vacuum thin-film deposition can be more costly than other processes.

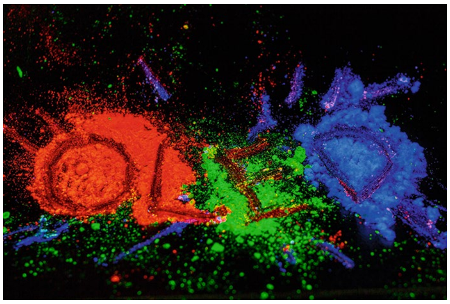
Deposition using liquid solutions, that is, solution processing, does not require a vacuum, can be relatively inexpensive and is scalable to large areas. One example is inkjet printing. Another process, spin coating, is simple and results in uniform thin films down to nanometre thicknesses.
It is achieved by liquid spreading on a rotating substrate . Although uniformity obtained by spin coating is hard to beat, the approach is somewhat limited in scalability to large areas, and substrates must be flat.

There are a number of solution processes that offer some combination of attributes, such as scalability, coating of complex shapes, use of flexible substrates and roll-to-roll processing. Alternatives include: (1) dip coating, in which a substrate is dipped into, and withdrawn from, a solution; (2) slot-die coating, where solution is flowed through a moving head with a slot; (3) blade coating, involving passing a blade over a solution-coated substrate. Slot-die and blade coating, for example, can be scaled to fabricate areas that are practically unthinkable with vacuum processes.

Solution processing also opens the door to high-molecular-weight molecules, enabling a multitude of emission wavelengths, or other properties, for light-emitting (or harvesting) devices. A classic example is polymer light-emitting diodes (LEDs).

It's no wonder that in recent years excitement surrounds solution-processed light emitters, from diodes to lasers. This month, *Nature Photonics* presents a Focus issue, highlighting recent advances in solution-processed light emitters.

Near-infrared (NIR) light is useful due to applications such as bio-imaging and optical communications. While III–V inorganic semiconductor light emitters with high external quantum efficiency are available, cheaper alternatives and unavailable properties are desired.



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For a general round-up of the advances in solution-processed NIR LEDs, see the Review by Maria Vasilopoulou, Azhar Fakharuddin and colleagues. OLEDS (organic LEDs), perovskite LEDs and quantum-dot LEDs are discussed and challenges related to radiance and device lifetime are highlighted.

Some platforms, such as perovskite LEDs, are hampered by device lifetime issues. And inconsistent characterization of the stability makes it hard to compare systems directly. Occasionally, stability is not even disclosed in a manuscript, calling into question the worth of other claimed performance parameters, such as efficiency. Nevertheless, progress is being made as outlined in a Comment by Seung-Je Woo, Joo Sung Kim and Tae-Woo Lee. Procedures for characterization of stability of perovskite LEDs are detailed and lifetime trends are analysed and there is hope.

For solution-processed emitters, it does appear that there is more progress on efficiency than device lifetime. In a Q&A, North Carolina State University professor Franky So, highlights that stability is indeed the most difficult and important challenge. So speaks to the issues holding back solution-processed emitter stability, from ion migration to morphological changes over time. However, So also points out that organics can be stable, and that respectable stability can be had. He is also enthusiastic about colloidal quantum dots and notes decent stability has already been shown for red and green colours.

Quantum dots are also one of the candidates for achieving solution-processed electrically pumped lasers. With optically pumped CW (continuous wave) colloidal quantum-dot lasers, and optical gain with electrically pumped quantum dots both demonstrated, the race for practical electrically pumped quantum-dot lasers is on. Significant progress in overcoming hurdles like Auger recombination, and instability under required high (~1000 A cm^{-2}) current densities, is highlighted by Heeyoung Jung, Namyoung Ahn and Victor Klimov in their Review on the prospects and challenges of colloidal quantum-dot laser diodes.

On the topic of lasers, see also the Q&A with Chihaya Adachi, a professor at Kyushu University whose group works on electrically driven organic semiconductor lasers. The group has shown indications of lasing from an OLEDbased architecture. There has also been progress by others, including electrically driven lasing from an organic FET (field-effect transistor) structure. The promise of engineerable lasing wavelengths from blue to NIR is attractive, if the device stability issue can be solved.

The many different systems above actually involve similar physics and challenges. This could even be said of related light-capturing devices, like organic photovoltaic cells; there are differences, but many core issues, particularly related to ion migration and morphology changes over time, are not entirely different; as hinted at in the interview with So, perhaps the solutions to problems in one type of device, such as a new material with better properties, may be immediately impactful across a range of solution-processed optoelectronic device types.

We do not know what the breakthrough will be, but the common hurdle is clear — stability and device lifetime. Paraphrasing the co-inventor of the OLED, Ching Tang, from the interview with So: "efficiency without lifetime is meaningless". ❐

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