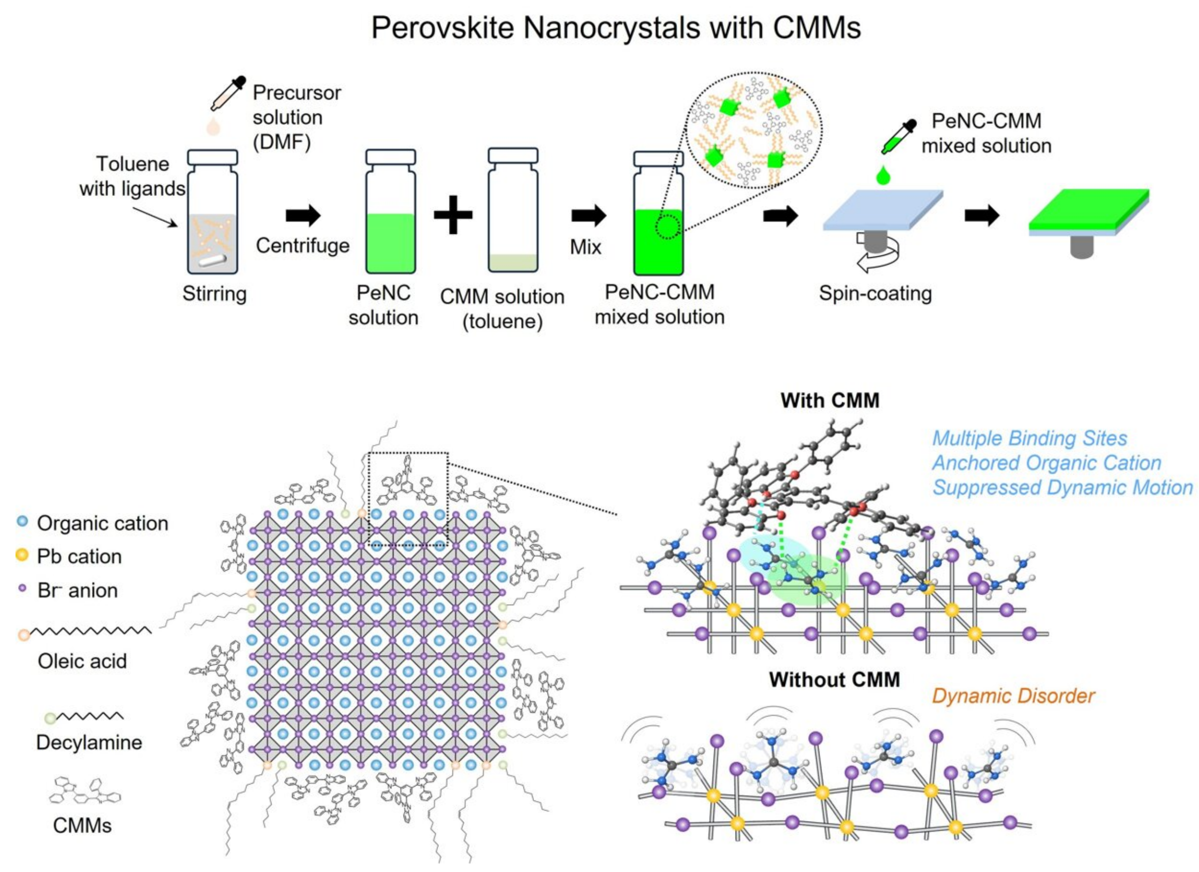
Researchers develop ultra-high efficiency perovskite LEDs by strengthening lattice

August 30 2024



Schematic diagram of the fabrication process of perovskite nanocrystal thin films with conjugated molecular multipods and the lattice-strengthening mechanism at the surface of the perovskite nanocrystals. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-49751-7

A research team has developed ultra-high efficiency perovskite nanocrystal light-emitting diodes (LEDs) by strengthening the perovskite lattice and suppressing the material's inherent low-frequency dynamics.

The research findings were published in the journal *Nature Communications* on July 24. The team was led by Professor Tae-Woo Lee from the Department of Materials Science and Engineering at Seoul National University, in collaboration with Professor Andrew M. Rappe of the University of Pennsylvania,

Perovskite is a semiconductor material composed of cube-shaped nanocrystals consisting of organic cations, metal cations, and halogen elements. Perovskite light emitters have garnered attention as promising next-generation emitters due to their excellent color purity, tunability, and cost-effectiveness.

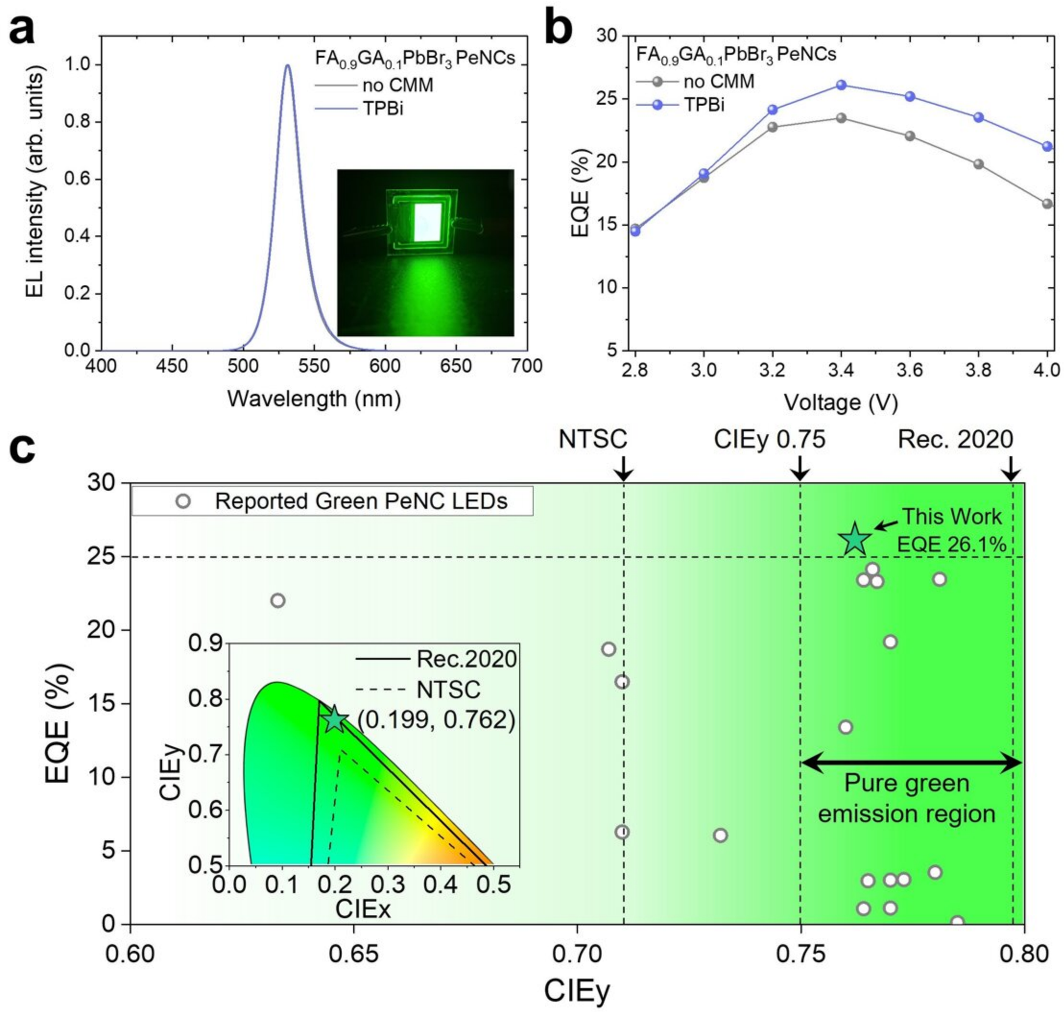
However, prior to 2014, perovskites were primarily used in solar cells, as their luminescence was not bright enough to be visible at room temperature. Despite this limitation, Professor Lee recognized the potential of perovskite as a next-generation emitter early on and secured a portfolio of fundamental patents for perovskite light-emitting materials in 2014.

Additionally, in 2015, his team published the first research paper demonstrating the enhancement of the efficiency in perovskite LED from a mere 0.1% to 8.53%, comparable to the level of phosphorescent OLEDs. This achievement has inspired researchers worldwide to conduct intensive and in-depth research on improving the efficiency of perovskite emitters.

Professor Lee's team further advanced perovskite self-emissive devices in 2022, achieving an external quantum efficiency (EQE) of 28.9% (nearly theoretically achievable maximum), peak brightness of 470,000 nits, and an operational lifetime of up to 30,000 hours. Moving towards commercialization, Professor Lee's startup company, SN Display Co. Ltd., showcased TV and tablet display prototypes at the CES (Consumer Electronics Show) in 2022 and 2023, making a great appeal to industry insiders.

However, the research team realized the need to address a key challenge: the reduction in luminescence efficiency due to the inherent ionic nature of the perovskite. Unlike traditional inorganic semiconductors, perovskite materials are composed of weak ionic bonds, and large-amplitude displacement of the atoms in their crystal lattices can cause dynamic disorder. This dynamic disorder interferes with the radiative recombination process in perovskite materials, leading to exciton dissociation and reduced luminescence efficiency.

Despite the need to overcome this critical limitation, there has been little research on how dynamic disorder affects the luminescent properties of perovskites or on strategies to improve efficiency by reducing dynamic disorder.



(a) Electroluminescence spectrum of the perovskite nanocrystal LEDs. (b) External quantum efficiency (up to 26.1%) of the perovskite nanocrystal LEDs. (c) Graph of EQE versus CIEy coordinates for perovskite nanocrystal LEDs without light outcoupling enhancement techniques. Credit: *Nature Communications* (2024). DOI: 10.1038/s41467-024-49751-7

In collaboration with Professor Rappe of the University of Pennsylvania in the US and Professor Omer Yaffe of the Weizmann Institute of Science in Israel, Professor Lee's team suggested a novel mechanism that enhances the luminescence efficiency of the perovskite emitters by incorporating conjugated molecular multipods (CMMs).

The mechanism is that when CMM binds to the surface of the perovskite lattice, the lattice is strengthened, suppressing low-frequency dynamics and reducing dynamic disorder in the perovskite lattice. This consequence finally led to improved luminescence efficiency in perovskite materials.

A particularly noteworthy achievement is the realization of ultra-high-efficiency LEDs with an EQE of 26.1%. This value is among the highest efficiency in perovskite nanocrystal LEDs and is especially significant because the efficiency improvement was achieved by enhancing the intrinsic emission efficiency of the material itself, rather than through engineering the device structure that enhances light outcoupling efficiency.

The perovskite emitters developed by Professor Lee's team are recognized for their high potential as next-generation display emitters. Because green color contributes the largest portion of the Rec. 2020 color standard for ultra-high-definition displays, achieving high color purity and high-efficiency green emitters is essential for display development.

The LEDs developed by the research team exhibit electroluminescence wavelengths that nearly approach the green primary color in the Rec. 2020 standard. This achievement is expected to significantly accelerate the commercialization of next-generation displays.

Professor Lee stated, "This research presents a new material-based approach to overcoming the intrinsic limitations of perovskite light emitters. We anticipate that this will significantly contribute to the development of high-efficiency, long-lifetime perovskite light-emitting devices and the commercialization of next-generation displays."

Professor Rappe agreed, saying "Together we have shown the power of molecules in strengthening perovskites and making them better light emitters. By combining the powers of molecular chemistry, physics, mechanics, and optics, we are inventing new materials to lead us into a bright and energy-efficient future."

More information: Dong-Hyeok Kim et al, Surface-binding molecular multipods strengthen the halide perovskite lattice and boost luminescence, *Nature Communications* (2024). DOI: 10.1038/s41467-024-49751-7

Provided by Seoul National University College of Engineering