Joule

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Preview

Bright and Blue Nanocrystal Emitters

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The discovery and development of blue light emitting diodes (LEDs) enabled energy-efficient white light emission that continues to impact global energy consumption today. Alternative materials that can outcompete commercial blue LEDs based on epitaxial InGaN could have a large impact on the lighting industry and in curbing anthropogenic climate change. Recently in *Joule*, Congreve and colleagues show that metal halide perovskite nanocrystals—greatly improved by Mn incorporation—have promise for low-cost, efficient, and bright blue LEDs.

One of the largest uses of energy goes toward lighting. In 2017, the U.S. used approximately 7% of its total electricity consumption for lighting the residential and commercial sectors.[1] The adoption of energy-efficient lighting solutions can have a large impact on global energy use and plays an important role in reducing greenhouse gas emissions that drive anthropogenic climate change.[2] Technologically mature lighting solutions are based on incandescent and fluorescent light bulbs. Light-emitting diodes (LEDs) are an energy-efficient lightning technology projected by the U.S. Department of Energy to save over 5 quadrillion British thermal units (BTUs) annually by 2035. This is equivalent to about the total annual energy consumption of 45 million U.S. homes today and is a 75% reduction in energy use compared to relying on incandescent and fluorescent lighting.[3] LEDs are already galvanizing the landscape of residential and commercial lighting and have further enabled many of the great technological advances of the electronic display industry.[4] LEDs are the standard for energy-efficient screens in mobile devices, televisions, and monitors.

An important aspect of LEDs is that they can be tuned to emit light at different wavelengths, depending on the material used. By the early 1970s, LEDs that emit at wavelengths ranging from red to green had been demonstrated.[5] The development of a blue LED was significantly more challenging. Blue light emits at approximately 470 nm on the electromagnetic spectrum, corresponding to an energy of about 2.6 eV. To achieve blue emission, a high-quality semiconductor with a band-gap energy of about 2.6 eV is required. Further, materials with the right energetic band alignment that can efficiently inject carriers into the emissive layer are needed. It was not until 1994 that Shuji Nakamura and colleagues at the Nichia Corporation were able to realize this by forming a compositional blend of InGaN with the right band gap, and they developed a double-heterostructure with AlGaN to effectively confine carriers in the emitting layer, enabling a blue LED with an external quantum efficiency of 2.7%.[6] For this and prior work in this area, Nakamura and collaborators were awarded the 2014 Nobel prize in physics.

Blue LEDs were a big challenge to make, but their importance cannot be understated. The development of blue LEDs completed the visible spectrum of emitting wavelengths, enabling the development of white LEDs. White light comprises a mixture of light of different wavelengths. There are two common ways to generate white light from an LED. First, the emission of red, green, and blue LEDs can be spatially combined to form white light. Second, some of the emission from a blue LED can be harvested by red- and green-emitting phosphors and re-emitted in the right ratios to generate white light. In both cases, a blue LED is required. Today, most commercial blue LEDs are still made from InGaN heterostructures. Alternatives such as AlGaN/GaN, SiC, or ZnTe/ZnSe nanocrystals each have their own challenges and disadvantages. Continued research and development into new alternative materials for bright, energy-efficient, and stable blue LEDs is needed.

Recently in *Joule*, Congreve and colleagues demonstrate a blue LED made from metal halide perovskite nanocrystals with enhanced efficiency and brightness by incorporating manganese to the crystal lattice.[7] Metal halide perovskite nanocrystals are an emerging material with many attractive properties for light emission, including sharp luminescence linewidths, high photoluminescence quantum yield, and color tunability throughout the visible spectrum.[8] Unlike compound semiconductors used in commercial blue LEDs, these materials can be fabricated at low temperature from printable semiconductor inks. Here, the authors show that incorporating Mn into the lattice of $CsPbBr_xCl_{3-x}$ greatly improves its optical properties. They show evidence that Mn dopants passivate defects in the nanocrystal, suppressing nonradiative recombination.

The $CsMn_yPb_{1-y}Br_xCl_{3-x}$ perovskite shows a 4-fold improvement in external

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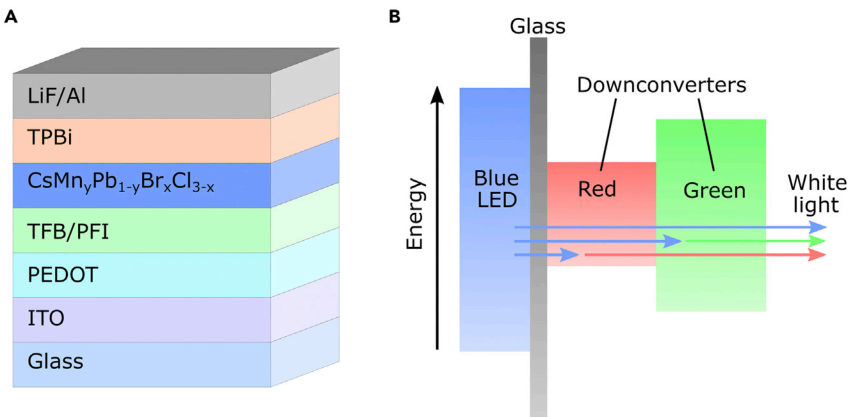

Figure 1. All-Perovskite White LED

(A) Blue Mn-doped perovskite LED architecture. Acronyms for each layer are defined in Hou et al.[7]

(B) Blue perovskite LED with red and green perovskite downconverters, emitting white light.

quantum efficiency (EQE) relative to the Mn-free control when used as the active layer in a blue LED (Figure 1A). The peak EQE of 2.12% at 466 nm is the highest reported for perovskite emitters that meet the National Television System Committee (NTSC) spectral standard for blue light to date. The device shows a maximum brightness of 245 cd/m^2 and an emission linewidth of 17.9 nm, both improved through Mn doping. The authors further demonstrate their blue LED in a proof-of-concept all-perovskite white light LED using red and green perovskite downconverters (Figure 1B). The red perovskite layer downconverts the higher energy blue photons, re-emitting them at red wavelengths. The final green perovskite layer absorbs the blue photons that were not absorbed by the red layer, re-emitting them at green wavelengths. The combination of red, green, and blue gives white light, which the authors show is near the ideal white light spectrum.

The topic of energy efficiency is well represented by energy funding agencies, such as the U.S. Department of Energy, and is often an area where some of the largest returns on investments have been realized.[9] The continued progress and development of metal halide perovskites in blue emission is an important area of material science and photonics research and an exciting emerging technology for energy-efficient lighting. Future challenges will be to not only increase the efficiency of these devices, but—equally important—stabilize them for long-term operation to reduce the levelized cost of energy for lighting solutions over the span of their lifetime. Current state-of-the-art perovskite LEDs typically degrade within minutes without encapsulation. Evaluating degradation mechanisms at early stages of development is a critical consideration for any emerging functional material to improve its chances for applications at scale in the future.[10]

1. U.S. Energy Information Administration. (2018). ANNUAL ENERGY OUTLOOK. https://www.eia.gov/outlooks/aeo/.

2. Intergovernmental Panel on Climate Change. (2018). Global Warming of 1.5 °C. http://www.ipcc.ch/report/sr15/.

3. U.S. Department of Energy. (2016). Energy Savings Forecast of Solid-State Lighting in General Illumination Applications. Energy Effic Renew Energy. https://www.energy.gov/sites/prod/files/2016/10/f33/energysavingsforecast16_0.pdf.

4. Zheludev, N. (2007). The life and times of the LED — a 100-year history. Nat. Photonics *1*, 189–192.

5. Schubert, E.F. (2006). Light-emitting diodes, Second Edition (Cambridge University Press).

6. Nakamura, S., Mukai, T., and Senoh, M. (1994). Candela-class high-brightness InGaN/AlGaN double-heterostructure blue-light-emitting diodes. Appl. Phys. Lett. *64*, 1687–1689.

7. Hou, S., Gangishetty, M.K., Quan, Q., and Congreve, D.N. (2018). Efficient Blue and White Perovskite Light-Emitting Diodes via Manganese Doping. Joule. Published online September 5, 2018. https://doi.org/10.1016/j.joule.2018.08.005.

8. Kovalenko, M.V., Protesescu, L., and Bodnarchuk, M.I. (2017). Properties and potential optoelectronic applications of lead halide perovskite nanocrystals. Science *358*, 745–750.

9. Murray, C. (2017). Public Funding of Energy Research. Joule *1*, 204–208.

10. Walton, K.S., and Sholl, D.S. (2017). Research Challenges in Avoiding "Showstoppers" in Developing Materials for Large-Scale Energy Applications. Joule *1*, 208–211.