

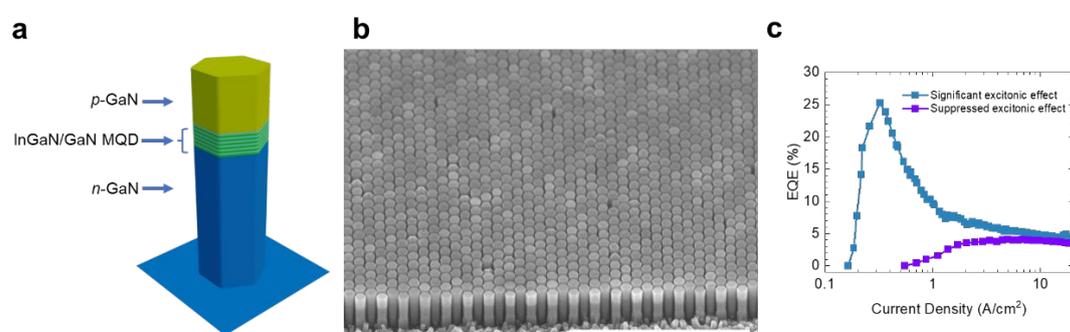
# High efficiency micrometer scale green and red light emitting diodes

Yixin Xiao<sup>1</sup>, Reddeppa Maddaka<sup>1</sup>, Yuanpeng Wu<sup>1</sup>, Yakshita Malholtra<sup>1</sup>, Yifu Guo<sup>1</sup>, Samuel Yang<sup>1</sup>, Jiangnan Liu<sup>1</sup>, Kai Sun<sup>2</sup>, Ayush Pandey<sup>1</sup>, Jungwook Min<sup>1</sup>, and Zetian Mi<sup>\*,1</sup>

1) Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109, USA

2) Department of Materials Science and Engineering, University of Michigan, Ann Arbor, MI 48109, USA

\*Corresponding author: [ztmi@umich.edu](mailto:ztmi@umich.edu)



**Figure 1.** Ultrahigh efficiency green emitting  $\mu$ LEDs. (a) Schematic of the nanowire LED design, with a green InGaN/GaN multiple-quantum-dot (MQD) structure serving as the active region. (b) Scanning electron microscope of such a nanowire array. Scale bar: 3  $\mu$ m. (c) Variation in external quantum efficiency due to differences in nanowire diameters, with the navy blue curve coming from a thin nanowire diameter array and the purple curve coming from a larger diameter array. The thinner diameter array allows for more active region formation on the semi-polar plane rather than the polar c-plane, thus allowing for radiative excitonic recombination channels that are more efficient than traditional free carrier radiative recombination for InGaN.

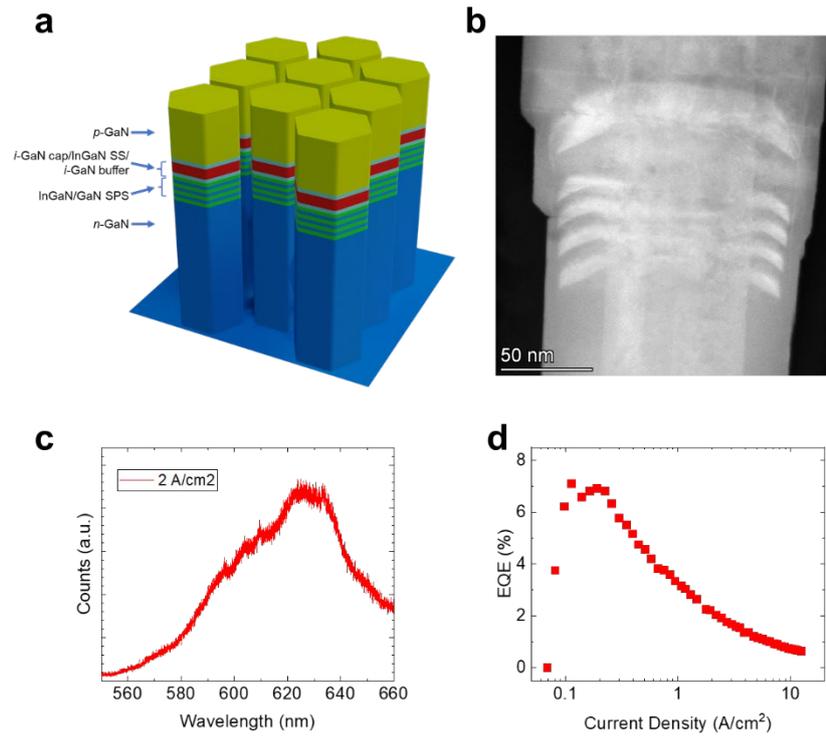


Figure 2. High efficiency red emitting  $\mu$ LEDs. (a) Schematic of the nanowire design, which employs a short-period superlattice (SPS) that allows for high levels of In incorporation in the single segment (SS) active region. (b) High angle annular dark field scanning transmission electron micrograph of such one such nanowire, where the four layers of SPS InGaN and the single segment active region InGaN are clearly visible at a higher contrast, as InGaN has a higher atomic number than GaN. (c) Electroluminescence of a red emitting  $\mu$ LED at 2 A/cm<sup>2</sup>. (d) The external quantum efficiency (EQE) of such red emitting  $\mu$ LED devices can reach >7%.