Increasing Photoluminescence Quantum Yield by Nanophotonic Design of Quantum-Confined Halide Perovskite Nanowire Arrays

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Abstract: High photoluminescence quantum yield (PLQY) is required to reach optimal performance in solar cells, lasers and light-emitting diodes (LEDs). Typically, PLQY can be increased by improving the material quality to reduce the non-radiative recombination rate. It is in principle equally effective to improve the optical design by nanostructuring a material to increase light out-coupling efficiency and introduce quantum confinement, both of which can increase the radiative recombination rate. However, increased surface recombination typically minimizes nanostructure gains in PLQY. Here a template guided vapor phase growth of perovskite nanowire (NW) arrays with unprecedented control of NW diameter from the bulk (250 nm) to the quantum-confined regime (5.7 nm) is demonstrated, while simultaneously providing a low surface recombination velocity of 18 cm s^{-1}. This enables an obvious PLQY enhancement from 0.33 % up to 42.6 % for $MAPbI_3$ quantum wires, and up to ~ 90 % for $MAPbBr_3$ quantum wires, exclusively using nanophotonic design, which will be promising for LEDs applications with high external quantum efficiency (EQE). They have been fabricated into LEDs on rigid and flexible planar substrates with a single device size up to 4-inch wafer scale. Intriguingly, thanks to the conformity of the vapor phase growth approach, unique three-dimensional (3-D) spherical LEDs with outstanding uniformity have been demonstrated. The result suggests the approach developed here can be generalized to fabricating other unconventional 3-D LEDs in the future. The simple extension of this technique to a wide variety of semiconductors and the ultra-high density of vertical QWs may also provide interesting opportunities in quantum transport, electronics and memory devices in the future.