Additive Manufacturing Toward the Atomic Scale

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With their unique and unconventional properties, low-dimensional and molecular materials are promising building blocks for emerging computing, communication, and sensing technologies. However, their atomic-scale nature challenges their integration into functional applications using conventional fabrication processes, as they lack the required resolution and can induce damage. Here, we bridge this gap by extending additive manufacturing toward the atomic scale using the precision and tunability of chemical synthesis. In particular, we introduce a platform of direct writing of atomic materials on chip with sub-5 nm size control and deterministic spatial placement.

We present an example of direct writing of halide perovskite quantum dots (QDs) through their site-specific growth. By controlling the nanoscale growth kinetics through localized heating, we achieve direct writing of individual perovskite QD emitters, down to ~ 4 nm in size, with tunable emission wavelengths, and sub-50 nm spatial control. Leveraging this platform, we demonstrate the first deterministic arrays of perovskite single-photon emitters with narrow linewidth and high purity up to 98% at room temperature. An example is shown in Figure 1. We further demonstrate deterministic integration of these emitters with photonic structures on chip to engineer their emission characteristics. This platform addresses a longstanding integration challenge of these materials, opening new opportunities for photonic quantum technologies. Overall, our work underscores the potential of atomic-scale additive manufacturing to overcome current limitations in integrating low-dimensional materials into functional technologies.

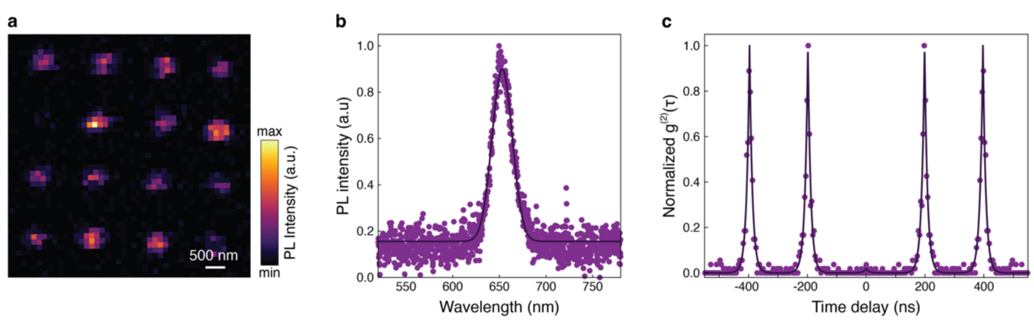

Figure 1: Direct writing of halide perovskite quantum dots: (a) Deterministic array of $CsPbI_3$ QDs fabricated using our direct write platform, demonstrating room-temperature single photon emitters with (b) narrow emission linewidth (74 meV) and (c) high single-photon purity (98%).