MBE Grown InAs/GaAs Quantum Dot Platforms with Spatial and Spectral Control for Quantum Devices

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Epitaxially grown semiconductor quantum dots (QDs) have been well studied in the past few decades and have shown great promise as single photon emitters, and as a basis for potential qubits. These features of quantum dots grown on a semiconductor matrix make it a desirable platform/building block for quantum devices which has a wide-range of applications in quantum information, quantum sensing and quantum computing. For a complete epitaxially grown quantum device, spatial, spectral and structural homogeneity, optical tunability, and scalability are the key requirements. Recent work from our group has shown a method for site controlled QD growth where InAs QDs are grown on site-templated GaAs substrates with arrays of fabricated nano-pits. [1] However, achieving spectral homogeneity and good optical quality to ensure scalability is still a big challenge due to the size distribution of the QDs during growth, and impurities introduced in the regrowth surface from the fabrication processes respectively. This work addresses these challenges and explores three different objectives, first one being the domain of quantum dot columns (QDCs) as a buffer layer for the top QD-arrays of interest while burying defects/impurities underneath the QDCs. Additionally, initial experiments on spectral control of InAs/GaAs QDs by an in-situ method called ‘cap and flush’ are discussed, and the concept of quantum dot molecules (QDMs) is introduced for optical tunability in site-templated scalable device platforms.

[1] J. Vac. Sci. Technol. B 38, 022803 (2020).

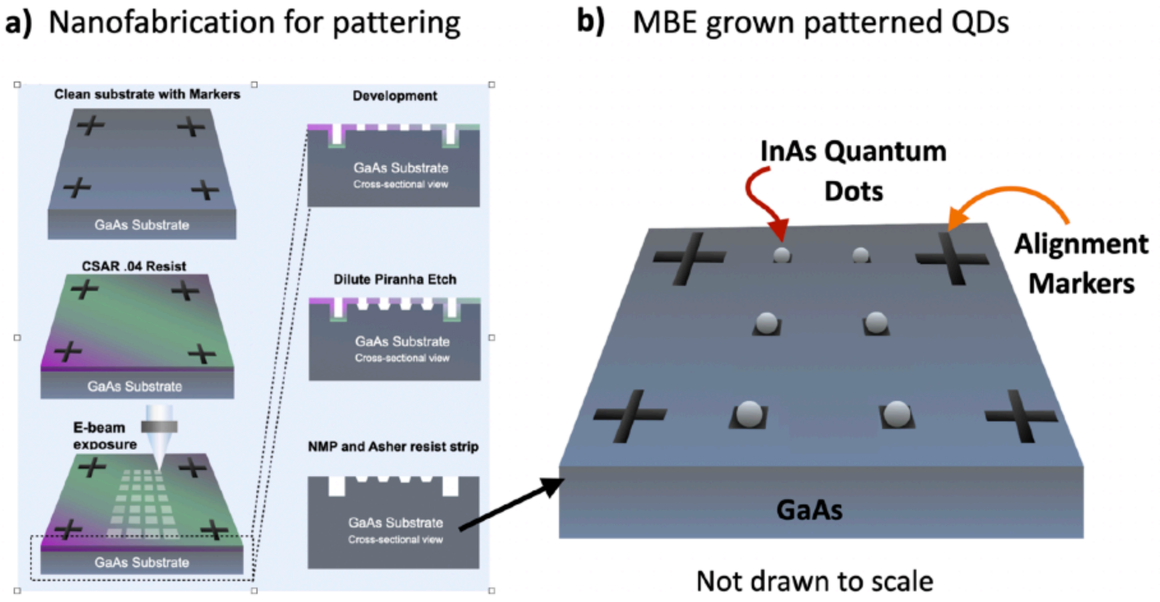


Figure.1 [Not drawn to scale]

(a) Nano-fabrication steps to create arrays of nano-pits and alignment markers for patterned GaAs substrates before quantum dot (QD) growth by molecular beam epitaxy (MBE).

(b) Schematic diagram of quantum dot growth by MBE on a patterned substrate.

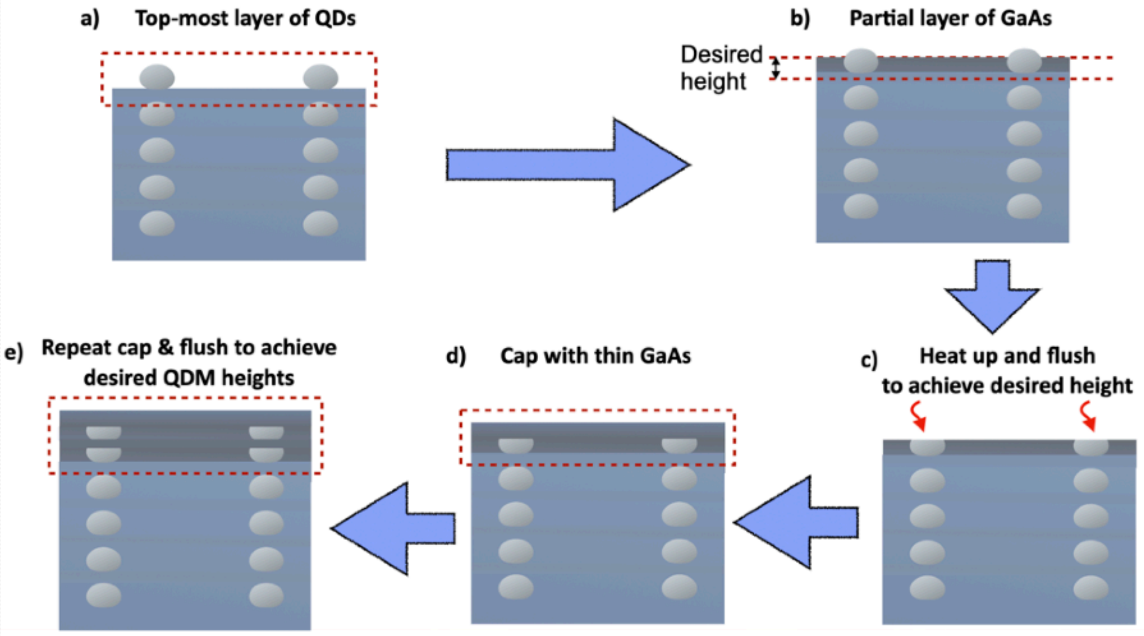
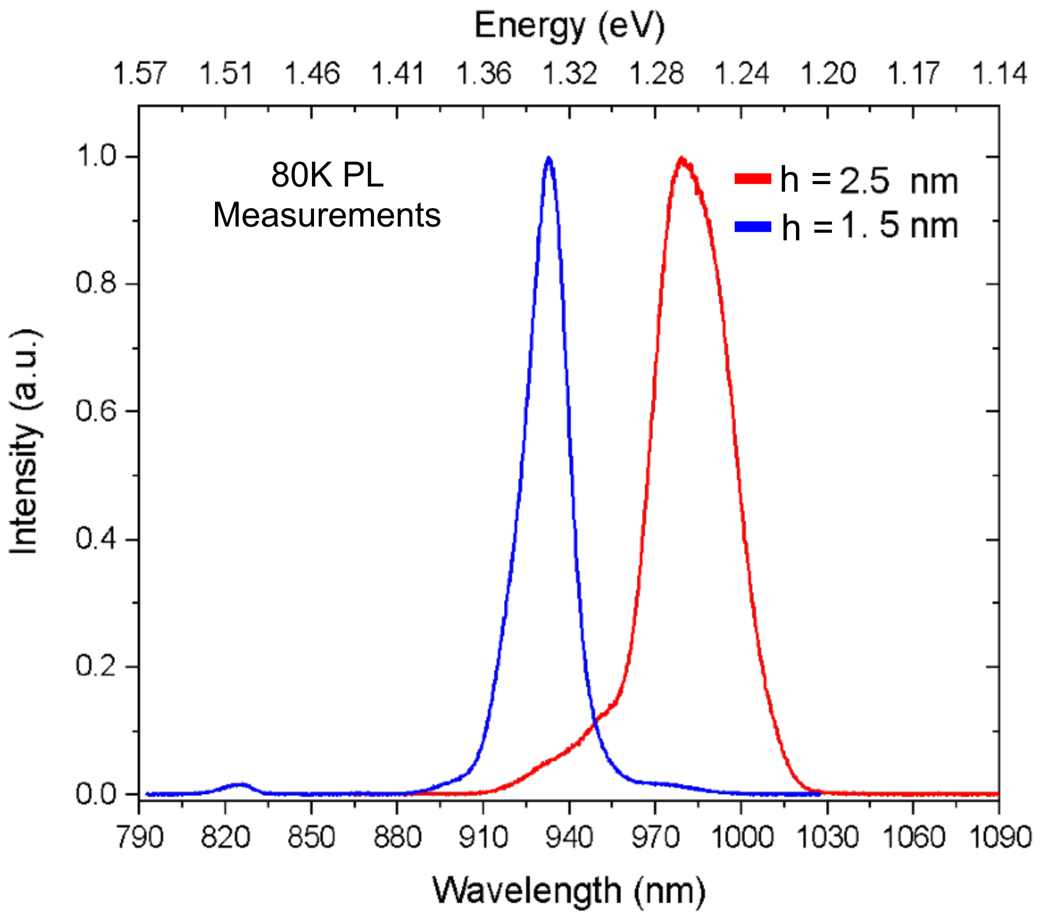


Figure.2 [Not drawn to scale]

(a) Schematic diagram of quantum dot columns to bury the impurities introduced by nanofabrication steps on the regrowth surface.

(b), (c), (d) Steps of the 'cap & flush' method to optimize the height of the topmost QD to obtain desirable optical emission, i.e., spectral control.

(e) Introducing a second layer of height controlled QDs to create quantum dot molecules (QDMs) for optical tunability.



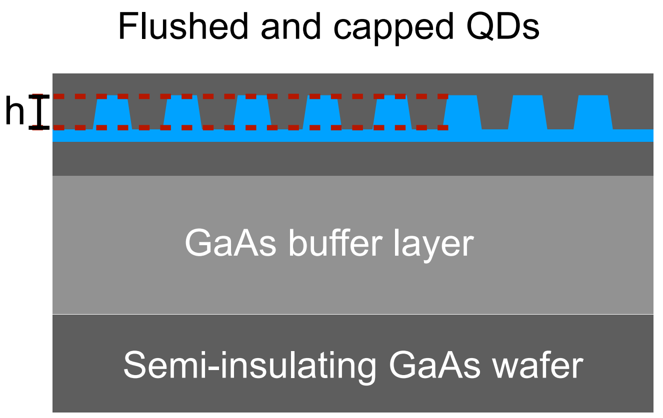


Figure.3 [Not drawn to scale]

Initial low temperature (~80K) photoluminescence (PL) results from two different samples with two different single-layer QD heights. The red and blue peaks are from 2.5 nm and 1.5 nm flushed & capped InAs QDs respectively. The shift in PL peaks from these two samples shows how the optical emission can be controlled by flushing the QDs to a desired height.