(111)-oriented Stranski-Krastanov Quantum Dots Optimized for Entangled Photon Emission

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(111)-oriented quantum dots (QDs) are a promising source for entangled photons due to their high symmetry and the low fine-structure splitting (FSS) between their bright exciton states.[1,2] Therefore, they are of great interest for developing compact, scalable quantum information devices for quantum computing and quantum encryption applications.[1]

We have previously presented results showing the Stranski-Krastanov (SK) growth of (111)-oriented tensile-strained GaAs/InAlAs QDs (TSQDs).[3-5] These TSQDs form as highly-symmetric tetrahedra (Fig. 1(a)) with very low FSS.[4] The use of tensile strain allows for their dislocation-free formation, and reduces their bandgap toward the infrared.[3] Further, TSQDs exhibit clear processing-property correlations, whereby adjusting deposition amount, growth temperature, growth rate, and V/III flux ratio allows us to control QD size, shape, and spectral emission. The resulting roadmap now allows us to optimize TSQDs for specific applications.[5]

Building on that work, here we describe the growth conditions and resultant structural and optical properties of TSQDs optimized specifically for entangled photon emission. We will present a detailed analysis of the structure of individual GaAs TSQDs; power-dependent, temperature-dependent, and time-resolved photoluminescence; and island scaling statistics. We also present experimental results of the reconstruction of the InAlAs(111)A buffer surface. Finally, we will show that we can transform the in-plane shape of the GaAs TSQDs from equilateral triangles to regular hexagons, simply by switching from As_2 to As_4. The hexagonal TSQDs exhibit improved optical quality and higher symmetry, properties that we expect to be critical for robust quantum entanglement.

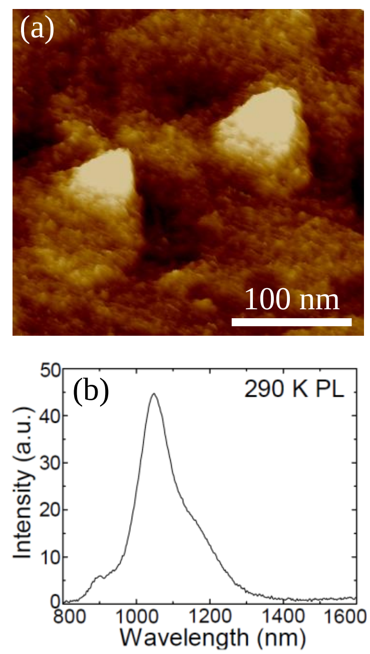

FIG. 1: (a) AFM of GaAs TSQDs. Height scale 4 nm. **(b)** Room temperature photoluminescence emission of GaAs TSQDs.

[1] Shields, Nat. Phot. 1, 215 (2007). [2] Schliwa et al., PRB 80, 161307(R) (2009). [3] Simmonds et al., APL 99, 12 (2011). [4] Yerino et al., APL 105, 251901 (2014). [5] Schuck et al., JVSTB 36(3), 031803 (2018).

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Supplementary information:

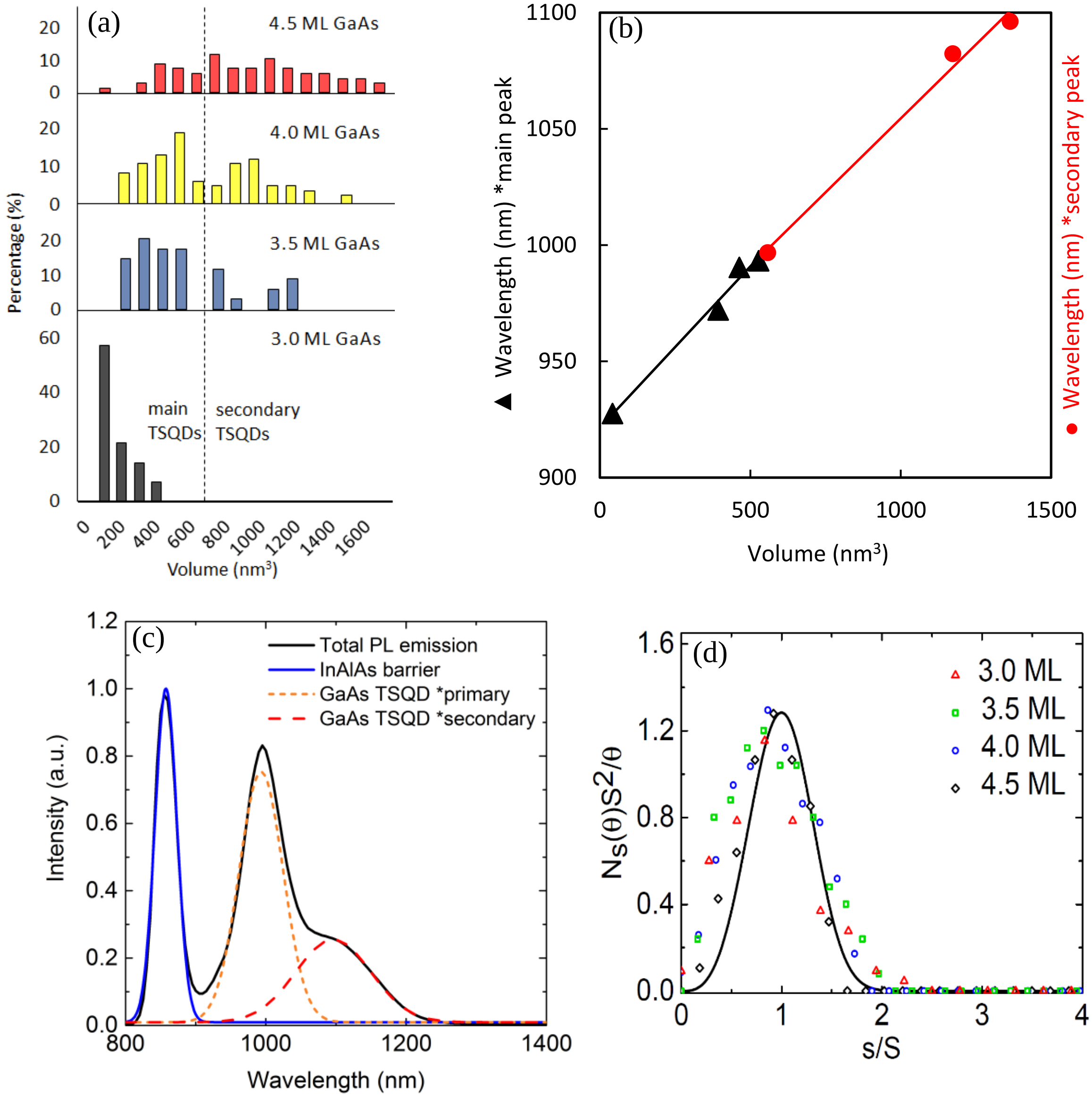

FIGURE 2: (a) Histogram of TSQD volumes at 3.0 – 4.5 ML deposition. At 3.0 ML, all TSQDs skew toward a single, small population. Increasing to 3.5 ML through 4.5 ML, a secondary population >700 nm^3 (dashed line) appears, and increases in average size and representative percentage, consistent with Ostwald ripening. **(b)** Plot of TSQD wavelength versus volume. The black line represents emission from the "main" population of TSQDs (left of the 700 nm^3 dashed line on (a)); the red line represents emission from the "secondary" TSQD population (right of the 700 nm^3 dashed line in (a)). The linear correlations are consistent with quantum confinement effects. **(c)** PL from the 4.5 ML deposition sample, with Gaussian fits for the main and secondary TSQD peaks, corresponding to the AFM results in (a) and (b). **(d)** Island scaling plot of 3.0 – 4.5 ML deposition, showing TSQD growth is consistent with island scaling theory. At 485 °C, GaAs(111)A TSQDs have a critical cluster size of 4 atoms (black curve).

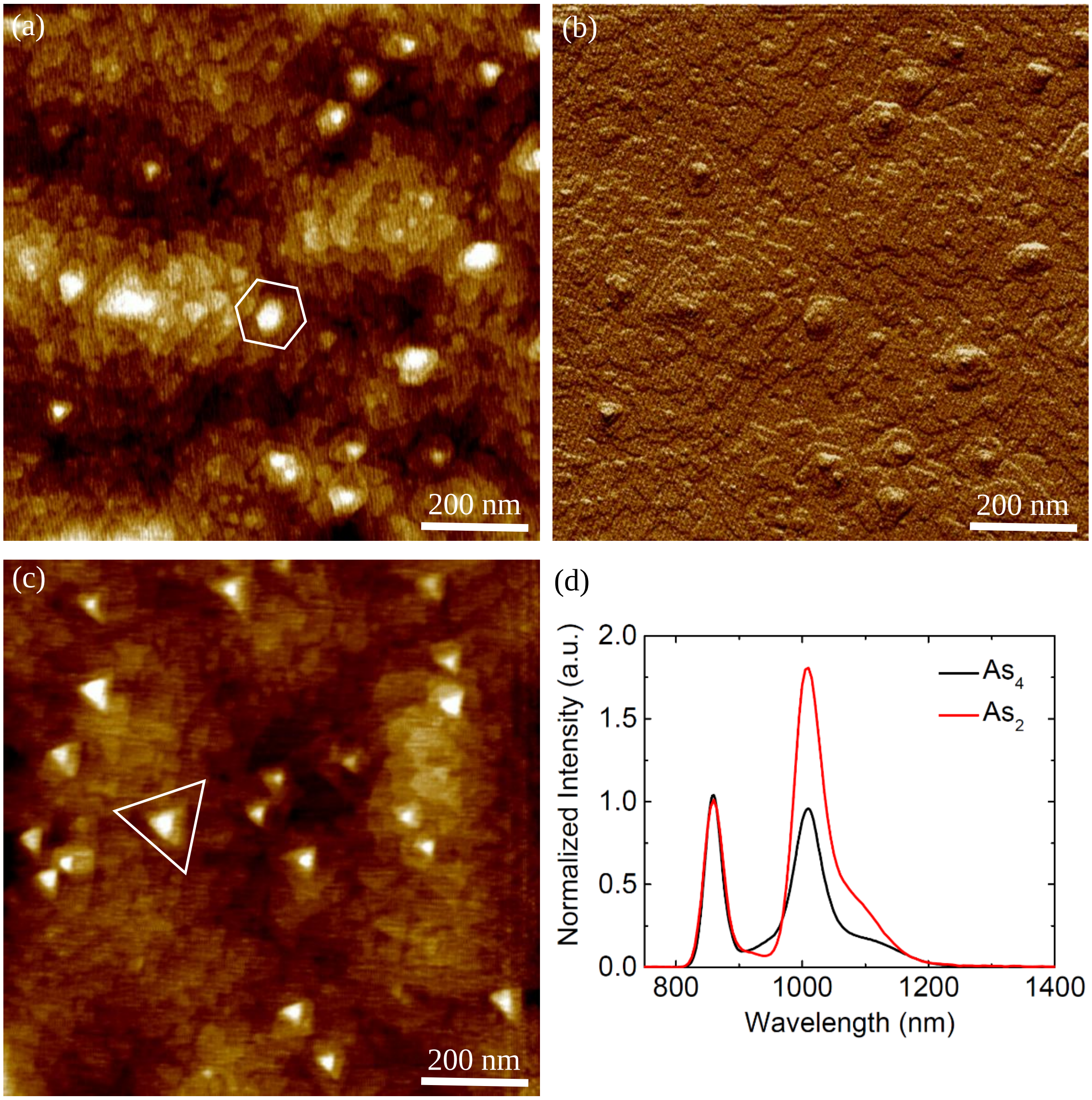

FIGURE 3: (a) AFM of hexagonal GaAs TSQDs using As_2 (4.5 ML deposition, 0.075 ML/s, 75 V/III ratio, and grown at 522 °C). Image 2 μm^2, height scale 2.5 nm.
(b) AFM voltage amplitude of GaAs TSQDs from (a), providing differential data to showcase hexagonal edges of TSQDs. Image 2 μm^2, voltage scale 35 mV.
(c) AFM of triangular TSQDs grown under the same growth conditions as in (a) except that we used As_4 rather than As_2. Image 2 μm^2, height scale 2.5 nm.
(d) PL comparing emissions from hexagonal (As_2 (a)) and triangular (As_4 (c)) TSQDs. Hexagonal TSQDs have higher symmetry, and also exhibit significantly improved emission intensity. Intensities are normalized to the InAlAs barrier emission seen at 860 nm.