Exploring the internal structure of pyramidal quantum dots

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Over the past two decades, semiconductor quantum dots (QDs) have become a focal point for making quantum information technology a reality, with an endeavor to develop platforms that exceed classical computation and communication. To make quantum networking a reality, the biggest challenge is to achieve large arrays of site-controlled reproducible entangled photon generators which can be integrated into photonic circuits - to date, a difficult requirement to realise. Semiconductor QDs are ideal candidates as they allow photons to be generated on demand, however, existing QD systems are limited by a lack of symmetry, allowing only a small number (1/100 or worse) of effective QDs per photonic chip. Here, a novel pyramidal QD system is presented, which is capable of delivering arrays of highly symmetric and uniform QDs, resulting in an exceptionally high density of entangled-photon emitters [1, 2]. These QDs are fabricated by metal-organic vapour-phase epitaxy (MOVPE) growth inside pyramidal recesses that are lithographically patterned on a (111)B GaAs substrate. The pyramids consist of differently composed III-V (Al)GaAs layers and an InGaAs QD layer. The GaAs substrate can be removed by back-etching to orient the pyramidal structures in an upright position which enhances the photoluminescence extraction efficiency [3]. Moreover, this system allows the precise stacking of two or more highly symmetric QDs, see Figure 1, further allowing the ability to tune the final optical properties [4].

Until now, the QD formation and entangled photon source location have been somewhat inferred. This study reveals for the first time, the complex internal structure of these pyramidal QDs using high-resolution scanning transmission electron microscopy (STEM). Fundamental and functional aspects of the system such as crystal structure, chemical diffusion, coupling of stacked QDs and exact information with respect to the growth process are revealed. Furthermore, this study utilizes low-loss electron energy loss spectroscopy (EELS) to map the local variation in band gap across the stacked QDs, allowing an in-depth understanding of the electronic properties at play on the atomic scale and how they feed into the functional properties experimentally measured at the microscale (via optical and electrical excitation). The data presented in this study provides an extraordinary route to reveal the coupling mechanisms ultimately responsible for tuning the optical properties of stacked pyramidal QDs both locally and as a large-scale device, which in turn will undoubtedly bring quantum networking devices several steps closer to real-life applications.

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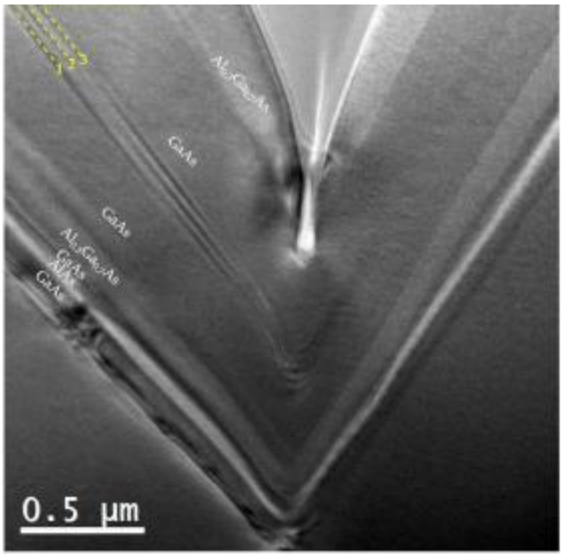

Figure 1: *Transmission electron microscopy (TEM) cross-sectional overview of a triple pyramidal QD system. The position of the InGaAs (QD) layers is marked by 1, 2 & 3.*