Wafer scale quantum dot growth control for scalable multi single photon sources technology

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A key component for photonic quantum devices is a high-fidelity single photon source. Semiconductor quantum dots (QDs) in photonic cavities offer a promising route to create such devices. However, noise processes can hamper solid-state emitters [1]. Major contributors to decoherence and low efficiency include random charge rearrangements in the semiconductor environment or the QD itself [2], caused by processes such as Meitner-Auger recombination [3] or photoionization [4]. Therefore, it is crucial to meticulously control the molecular beam epitaxy (MBE) machine's vacuum and effusion cells to grow wafers of the highest possible quality. Another important aspect is heterostructure design: embedding quantum emitters in a diode can stabilize the charge state and shield against fluctuations [5].

Even for ternary matrix material local droplet etched QDs [6,7], we demonstrate that this approach can lead to blinking-free, transform-limited emission [8]. To make QDs a scalable technology, even more demanding requirements must be met:

1. The QD density must range from 0.1 to 10 QDs/µm² across the whole wafer, which is extremely challenging for strain-driven self-assembly [9,10].
2. The emission wavelength of a substantial portion of the QDs must be within the tuning range of the design wavelength.

Wafer rotation stop enables material gradient growth. Newly discovered implications of this well-known method, such as periodic modulation of QD density [10] and QD emission wavelength [11], will be presented. The gradient growth method is also the basis for identifying ideal growth parameters [11,12] for wafer-scale production of homogeneous QD density and QD wavelength material. Figures 1 and 2 show photoluminescence results of our wafer-scale attempts to homogenize these parameters for LDE-grown GaAs QDs and LDE-grown InAs O-band QDs [12,13].

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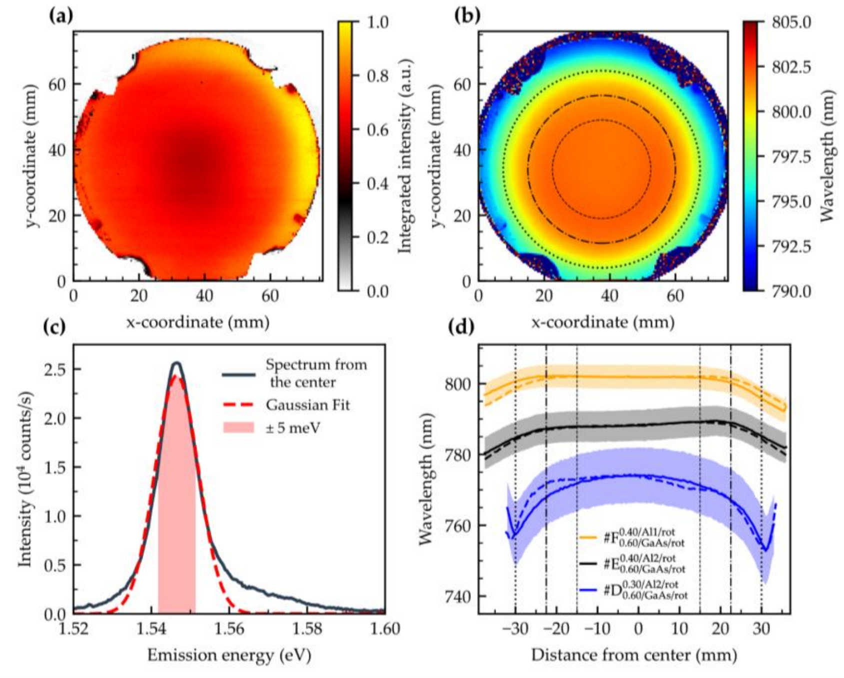

Figure 1: Wafer map photoluminescence of LDE-grown GaAs QDs. (a) A homogeneous intensity of QD luminescence indicates a uniform QD density. (b) The emission wavelength shows minimal variation across the wafer. (c) Photoluminescence (PL) spectrum at the centre of the wafer. (d) Wavelength as a function of position for three different wafers. The orange line corresponds to the wafer shown in (a). The black and blue line are from wafer growth attempts that yield less ideal wavelength distribution. The shaded area indicates the FWHM distribution.

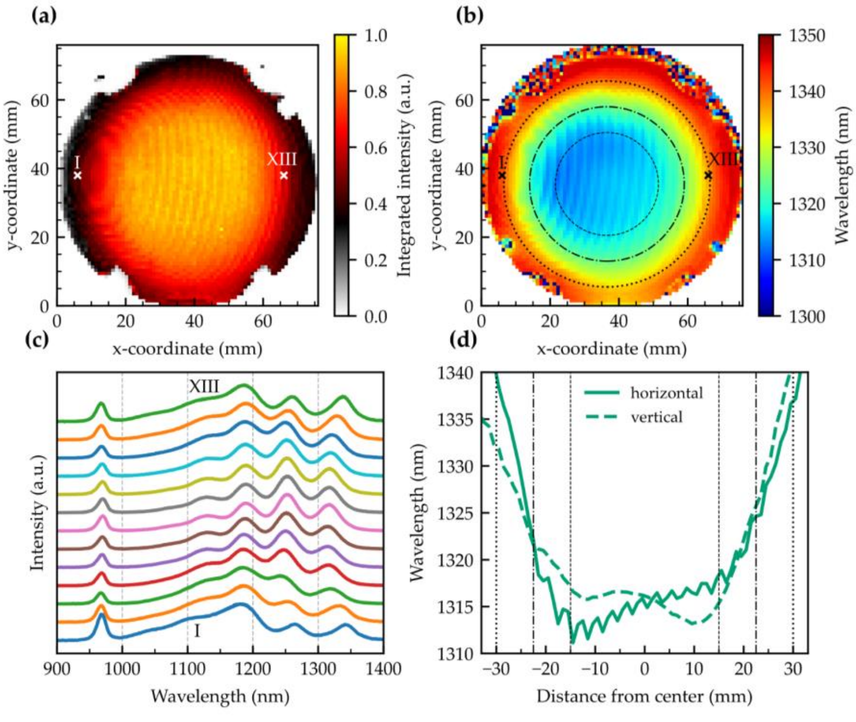

Figure 2: Wafer map photoluminescence of LDE-grown InAs QDs. (a) Intensity map. (b) The wavelength map shows O-band emission around the wafer centre. (c) PL spectra at points I to XII in (a). A clear shell structure is visible indicating good homogeneity. (d) Wavelength as a function of position. A central region with a diameter of 45 mm yields O-band QDs.