Investigation of the indium-flush technique on InAs/InAlGaAs/InP (001) quantum dots for 1.55 µm laser applications

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Growth of InAs/InP quantum dot (QD) materials for 1.55 µm laser applications faces two key challenges: (1) a morphological preference for elongated islands, known as quantum dashes, and (2) a large dispersion in island heights. Both issues are pronounced by the low lattice-mismatch interface of 3.2%. With respect to the optical characteristics, the former results in wire-like optical behaviour and the latter in a broadening of the photoluminescence (PL) spectra's full-width at half-maximum (FWHM). The work presented address these challenges in synchronous in pursuit of a high quality and optically active ensemble of QDs for high-performance laser applications on native and, potentially, on the important Si (001) platform.

To this end, we first optimised the island shape by reducing the indium surface migration using As_2 species [1], a V/III beam equivalent pressure (BEP) ratio of 18 [2], and an InAlGaAs buffer layer. A stable dot-like population of QDs with a high density of 4×10^{10}cm^{-2} was achieved with 5.5 monolayers (ML) of InAs. However, the deposition thickness nucleated large QDs; resulting in a room temperature (RT) PL emission wavelength greater than 1.8 µm. Additionally, a considerable dispersion in island height was presented in a ~90 meV FWHM.

Second, by employing an indium flush (IF) [3] (fig. 1), the QD heights and uniformity were reduced and improved, respectively. 4 nm of InAlGaAs was grown immediately following QD deposition to partially cap the ensemble. By raising the substrate temperature under As-pressure, indium desorption occurred in the larger exposed QDs, effectively truncating them to the height of the partial cap. Thereby resulting in a 300 nm blueshift of the emission wavelength and a substantial linewidth narrowing to 47.9 (51.0) meV for single (five)-layer structures (fig. 2(d)).

By investigating the resulting characteristics through means such as high-resolution scanning transmission electron microscopy (HR-STEM), we present key insights into the morphological changes to the QD morphology resulting from the IF technique. Furthermore, laser structures utilising the IF technique have been grown and fabricated, including additional work on enhancing the InAlGaAs buffer quality via ex-situ cyclic rapid thermal processing.

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[2] S. Banyoudeh and J. P. Reithmaier, J. of Crys. Grow., vol. 425, pp. 299–302, Sep. 2015.

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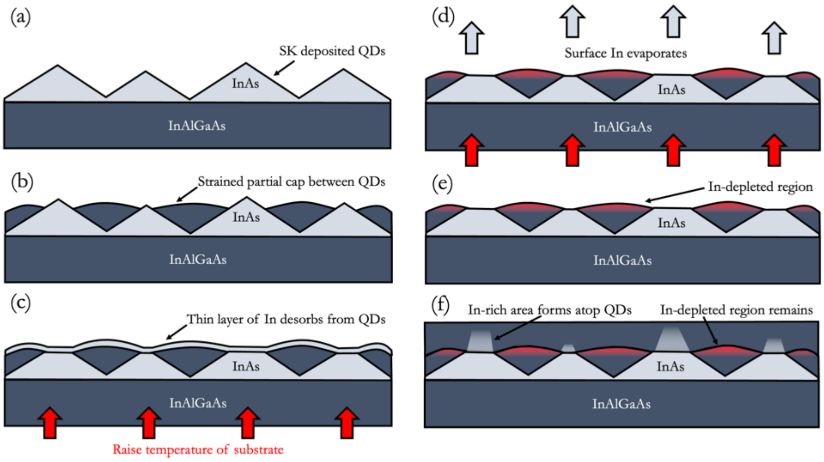

Fig. 1 – Schematic of the IF technique during QD deposition. (a) QDs are conventionally deposited using S-K growth mode. (b) A thin layer of InAlGaAs partially caps the QDs. (c) By raising the temperature of the substrate, indium desorbs from the tops of the exposed QDs and (d) evaporates from the growth surface. (e) Indium also desorbs from the InAlGaAs partial cap surface, leaving an (f) In-depleted region between the QDs and an In-rich region immediately above the QDs.

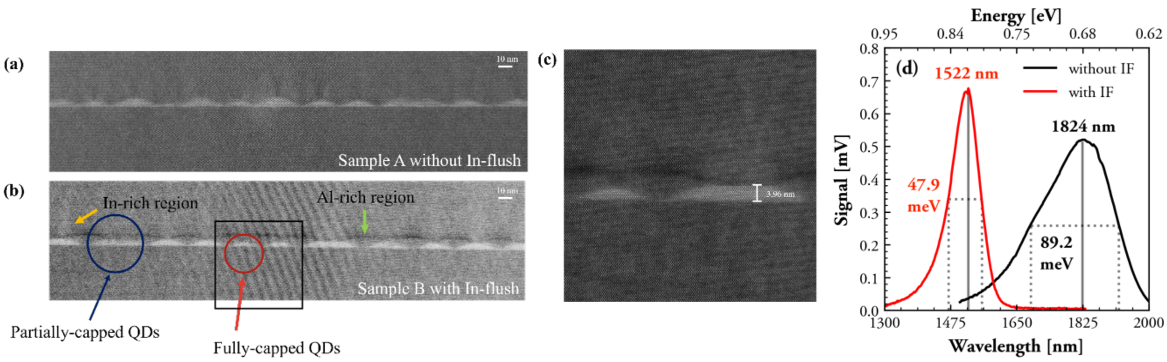

Fig. 2 – HR-STEM images of 5.5 ML QDs (a) with and (b) without the use of an IF step. (c) High magnification HR-STEM image of the two QD modes resulting from the IF: smaller, fully-capped QDs; and larger, truncated QDs. (d) PL spectra measured at RT of single-layer 5.5ML InAs QDs with and without the use of an IF step.