

Quantum dots for future nanophotonic devices : lateral ordering, position, and number control

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Quantum Dots for Future Nanophotonic Devices: Lateral Ordering, Position, and Number Control

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Abstract—We review our recent advances in the lateral ordering, position, and number control of self-organized epitaxial semiconductor quantum dots based on self-organized anisotropic strain engineering, growth on patterned substrates, and selective area growth.

I. INTRODUCTION

Lateral ordering, position, and number control of self-organized epitaxial semiconductor quantum dots (QDs) is key to future functional nanophotonic devices [1]. We review our recent advances towards this goal based on self-organized anisotropic strain engineering, growth on patterned substrates, and selective area growth with QDs operating at telecom wavelengths.

II. SELF-ORGANIZED ANISOTROPIC STRAIN ENGINEERING

Stacked linear InAs QD arrays are formed by self-organized anisotropic strain engineering of InAs/InGaAsP superlattice (SL) templates on InP (100) (Fig. 1). SL template formation comprises InAs QD formation, thin InGaAsP capping, annealing, InGaAsP separation layer growth, and stacking which leads to one-dimensional lateral InAs structures, i.e., lateral strain field modulations on the SL template surface governing InAs QD ordering on top due to local strain recognition.

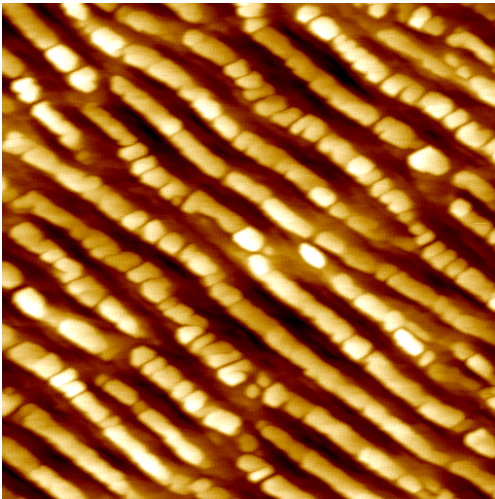


Fig. 1. Linear InAs QD arrays formed by self-organized anisotropic strain engineering of an InAs/InGaAsP superlattice template on InP (100). The arrays are oriented along [001]. The atomic force microscopy (AFM) scan field is $2 \times 2 \mu\text{m}^2$.

The emission wavelength at room temperature is tuned into the important 1.55- μm telecom wavelength region through insertion of ultrathin GaAs interlayers underneath the QD arrays with increasing interlayer thickness in successive layers. The increment of the GaAs interlayer thickness compensates the QD size/wavelength increase during strain correlated stacking. This demonstrates a three-dimensionally self-ordered QD crystal with fully controlled structural and optical properties [2].

III. SELF-ORGANIZED ANISOTROPIC STRAIN ENGINEERING ON PATTERNED SUBSTRATES

Guided and directed self-organized anisotropic strain engineering of InGaAs/GaAs SL templates is demonstrated on coarse patterned GaAs (311)B. Steps generated on shallow-patterned substrates guide the self-organization process during superlattice template evolution for formation of complex InAs QD arrays. On deep-patterned substrates directed self-organization spatially locks the QD arrays to the faceted mesa sidewalls without change of the natural ordering, providing absolute QD position control over large areas (Fig. 2). The absence of one-to-one pattern definition guarantees excellent optical quality of the position-controlled QD arrays revealed by ultra-sharp emission from individual QDs at low temperature [3].

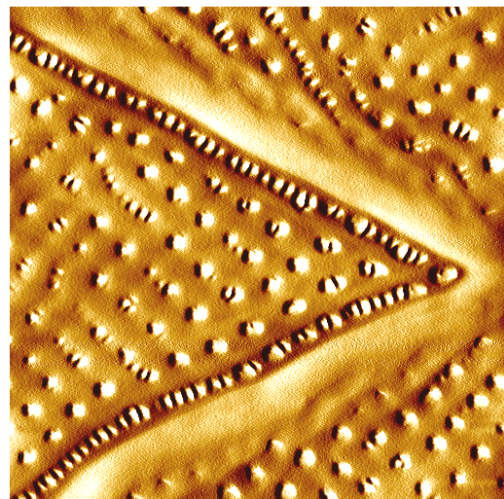


Fig. 2. Position controlled InAs QD arrays formed by directed self-organized anisotropic strain engineering of an InGaAs/GaAs superlattice template on deep-patterned GaAs (311)B. The acute zigzag angle points towards [-233]. The AFM scan field is $5 \times 5 \mu\text{m}^2$.

IV. SELECTIVE AREA GROWTH

Lateral position, distribution, and number control of InAs QDs is demonstrated on truncated InP (100) pyramids by selective-area growth. The QD distribution and number are governed by the shape of the pyramid base and the size and facet composition of the pyramid top area. Close to pinch-off, positioning of four, three, two, and a single QD is achieved on elliptical, triangular, hexagonal, and circular based pyramids, respectively (Fig. 3). The single QDs reveal ultra-sharp emission at low temperature at 1.55 μm [4]. Lateral regrowth of InP around the pyramids establishes submicron active-passive integration for efficient nanolasers and single photon sources and their implementation in photonic integrated circuits.

V. CONCLUSIONS

In conclusion we have reviewed our recent advances in the lateral ordering, position, and number control of self-organized epitaxial semiconductor QDs based on self-organized anisotropic strain engineering, growth on patterned substrates, and selective area growth. The demonstrated control over QD formation is key for the realization of future functional nanophotonic devices.

ACKNOWLEDGEMENT

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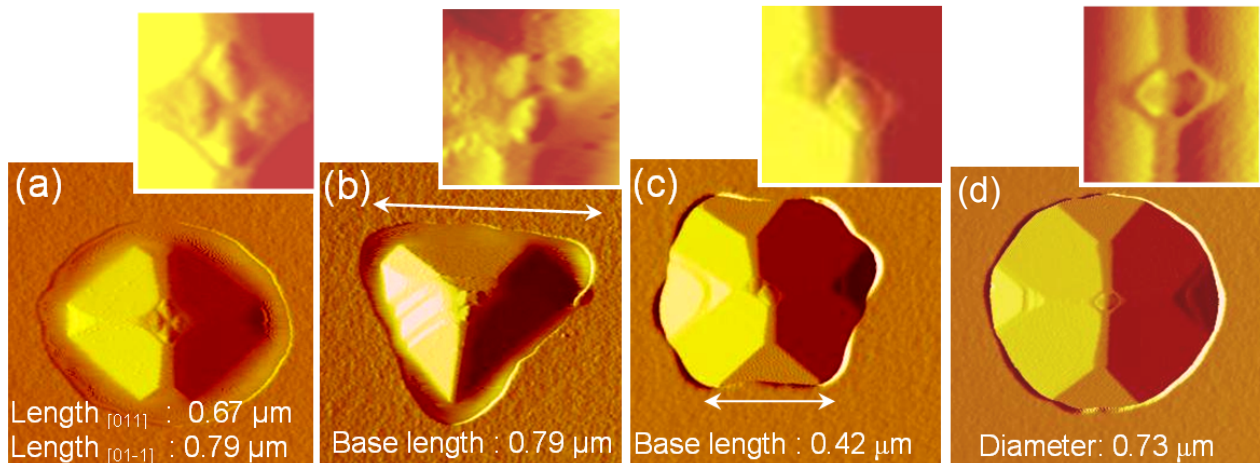


Fig. 3. Selectively grown InP pyramids close to pinch-off together with magnified images of the InAs QDs on top for (a) elliptical, (b) triangular, (c) hexagonal, and (d) circular base. The AFM scan fields are $1 \times 1 \mu\text{m}^2$ and $0.2 \times 0.2 \mu\text{m}^2$.