Controlling polarization anisotropy of site-controlled InAs/InP (100) quantum dots

Jiayue Yuan, Hao Wang, René P. J. van Veldhoven, Jia Wang, Tjibbe de Vries et al.

Citation: Appl. Phys. Lett. 98, 201904 (2011); doi: 10.1063/1.3591155
View online: http://dx.doi.org/10.1063/1.3591155
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v98/i20
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Controlling polarization anisotropy of site-controlled InAs/InP (100) quantum dots


Department of Applied Physics, COBRA Research Institute, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands

(Received 3 January 2011; accepted 22 April 2011; published online 17 May 2011)

We report on the shape and polarization control of site-controlled multiple and single InAs quantum dots (QDs) on InP pyramids grown by selective-area metal-organic vapor phase epitaxy. With increasing growth temperature the QDs elongate causing strong linear polarization of the photoluminescence. With reduced pyramid base/pyramid top area/QD number, the degree of polarization decreases, attributed to the symmetric pyramid top, reaching zero for single QDs grown at lower temperature. This control of linear polarization is important for entangled photon sources operating in the 1.55 \( \mu \text{m} \) wavelength region. © 2011 American Institute of Physics.

[doi:10.1063/1.3591155]

Semiconductor quantum dots (QDs) provide the basis for novel devices in photonics and quantum information. The envisioned devices such as cavity enhanced single and entangled photon sources require precise site control of the QDs. This has been achieved by growth on truncated pyramids and nanoholes for InAs/GaAs and InAs/InP QDs with emission in the important telecom wavelength region. © 2011 American Institute of Physics.

(a) (c)
Diameter:1.39 /g541 m
Diameter:1.42 /g541 m
Diameter:0.75 /g541 m
Diameter:0.78 /g541 m

(b) (d) (e) (f)
Diameter:1.07 /g541 m
Diameter:0.96 /g541 m
Diameter:0.78 /g541 m

FIG. 1. (Color online) AFM images (2 \( \times \) 2 \( \mu \text{m}^2 \)) of the multiple and single InAs QDs grown at [(a)–(c)] 490 °C and [(d)–(f)] 515 °C on the InP pyramids with base diameters varying between 1.5 and 0.7 \( \mu \text{m} \).
ber decreases and close to pinch-off single QDs form on the symmetric diamond-shaped (100) top facet. For higher growth temperature the QDs strongly elongate along [011] and number and size increase.

The average QD width along [011] [Fig. 2(a)] increases from 50 nm for the QDs grown at 490 °C to 75 nm for the QDs grown at 515 °C with a broader distribution while the average width along [011] [Fig. 2(b)] of 50 nm remains almost unchanged. The increase in the QD number and size for higher growth temperature is attributed to the enhanced As/P exchange during QD growth, leading to more incorporation of InAs, which also accounts for the broader size distribution. The pronounced QD elongation along [011] at higher growth temperature is attributed to the increased adatom surface migration length which is generally larger along [011] and the increased QD size leading to a shape transition from round to elongated.18,19

Micro-PL spectra taken at 5 K of the capped multiple and single QDs grown at 490 °C are shown in Fig. 3. The PL spectrum of the multiple QDs on the pyramid with the largest base is centered at 1465 nm with a full width at half maximum (FWHM) of 34 nm while the PL line of the single QD is at 1471.4 nm with the FWHM of 0.6 nm limited by the spectrometer resolution. For the higher growth temperature of 515 °C, the PL spectrum of the multiple QDs is centered at 1495 nm with a broader FWHM of 59 nm while the PL line of the single QD is at 1483 nm. This PL redshift and broader FWHM are in agreement with the larger size and less uniform size distribution of the QDs grown at higher temperature. The excitation power dependent integrated PL intensity of a typical single QD grown at 490 °C, plotted in the inset of Fig. 3, increases linearly with a slope of 1.08 indicating high optical quality of the single QD.20–23

The shape anisotropy of the QDs results in distinct linear polarization of the PL. Figures 4(a) and 4(b) show the polar plot of the PL peak intensity (I) of the multiple (on the pyramids with the largest base) and single InAs QDs grown at 490 and 515 °C. 0° designates the PL polarized along [011] and 90° the PL polarized along [011]. The angular dependence of the PL intensity is fitted by $I = I_{011} \sin^2 \theta + I_{[011]} \cos^2 \theta$, where $\theta$ is the polarization angle. Most important, the DOP = ($I_{011} - I_{[011]}$)/($I_{011} + I_{[011]}$) $\times$ 100% at the PL peak position reduces with reduced pyramid base, i.e., reduced pyramid top area and QD number, plotted in Fig. 4(c). The DOP for the multiple QDs on the pyramid with the largest base area of 1.58 $\mu$m$^2$ [Fig. 1(d)] is 38%. This is comparable with polarization measurements of InAs QD ensembles on GaAs truncated pyramids.6 The DOP decreases monotonically down to 17% for the single QD on the pyramid with the smallest base area of 0.48 $\mu$m$^2$ [Fig. 1(f)]. This is attributed to an increasing influence of the shape of the shrinking pyramid top area, approaching the symmetric (100) top facet with diamondlike boundary, on the QD shape rendering it more symmetric. For the QDs grown at 490 °C, which are generally more symmetric, the slight DOP for the multiple QDs is completely eliminated for the single QD.

It is difficult to quantitatively relate the DOP to the FSS which is the figure of merit for realizing entangled photon sources and within the spectral resolution the FSS cannot be resolved directly. In general, for InAs/InP QDs the FSS mainly depends on the QD shape.14 The FSS from the intrinsic Dresselhaus term35 due to the bulk inversion asymmetry is a minor factor because of the small lattice mismatch (3%) and the strong confinement of holes. Moreover it has been reported that the FSS is directly related to the DOP.9,15,16 Hence, zero DOP implies the sought for zero FSS for our single symmetric InAs QDs grown at reduced temperature on the InP pyramids close to pinch-off.

In conclusion, we have studied the shape and polarization control of site-controlled 1.55 $\mu$m region multiple and single InAs QDs on InP (100) pyramids grown by selective-area MOVPE. The QD size increases with elevated growth temperature and the QDs strongly elongate causing pronounced polarization of the PL. Most important the DOP reduces with reduced pyramid base/pyramid top area/QD number due to increasing influence of the symmetric pyramid top on the QD shape, reaching zero for single QDs.

FIG. 2. (Color online) Histograms of (a) width along [011] and (b) width along [011] of the QDs grown at 490 and 515 °C on the pyramids with the largest base area.

FIG. 3. (Color online) Micro-PL spectra taken at 5 K of the multiple and single InAs QDs grown at 490 °C. The inset shows the integrated PL intensity at 5 K of a single InAs QD grown at 490 °C as a function of the excitation power.
grown at lower temperature. This is important for the realization of single and entangled photon sources operating in the 1.55 μm telecom wavelength region.

The authors gratefully acknowledge the support of the Smart Mix Programme of The Netherlands Ministry of Economic Affairs and The Netherlands Ministry of Education, Culture and Science.