Bright Single InAsP Quantum Dots at Telecom Wavelengths in Position-Controlled InP Nanowires

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Optics based quantum information technologies require high brightness quantum light sources, and single semiconductor quantum dots show great promise for this application. Using site selected InP nanowires containing single InAsP quantum dots we have demonstrated both highly efficient single photon emission and bright entangled photon pairs in the 900 to 1000 nm wavelength range. There is great interest in extending the emission of these sources to longer wavelength to make use of telecommunication based fibre to transmit these photons over large distances. In this contribution we show how you can modify our present nanowire growth to produce high brightness nanowire structures emitting in the telecom 1310 nm and 1555 nm wavelength ranges.

The nanowires used in this study were grown using the selective area VLS growth technique by chemical beam epitaxy (CBE). They consist of a wurtzite InP nanowire core containing an InAsP quantum dot, where the diameter of the core is determined by the Au seed particle. The growth mode is then switched from axial to radial to increase the nanowire diameter and control the tapering of the nanowire tip to provide efficient coupling of the dot emission to the collection optics. To extend the dot emission to longer wavelength we use a combination of higher As flux and longer growth time for the dot.

We demonstrate a dramatic dependence of the emission rate on both the emission wavelength and the nanowire diameter. With an appropriately designed waveguide, tailored to the emission wavelength of the dot, an increase in the count rate by nearly 2 orders of magnitude (0.4 to 35 kcps) is obtained for quantum dots emitting in the telecom O-band, showing high single-photon purity with multiphoton emission probabilities down to 2%.

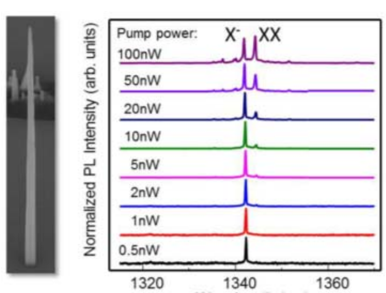

Figure 1 Power-dependent spectra for a dot with a charged exciton ground-state emission λ = 1342 nm

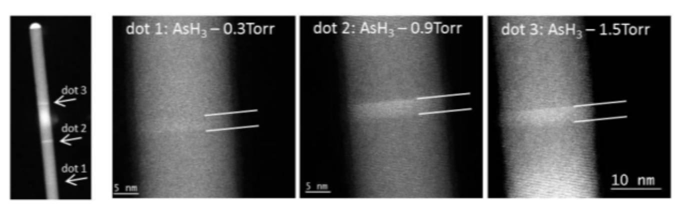

Figure 2 HAADF TEM image of a nanowire containing three dots grown under different AsH3 flux.

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Nanowire growth is performed on SiO_2 coated (111)B InP substrates that have been patterned using e-beam lithography to create circular openings. The size of these openings is determined by the length of a HF wet etch step. The diameter of the completed clad nanowire structure could be adjusted through control of the opening diameter in the SiO_2 mask and the growth conditions

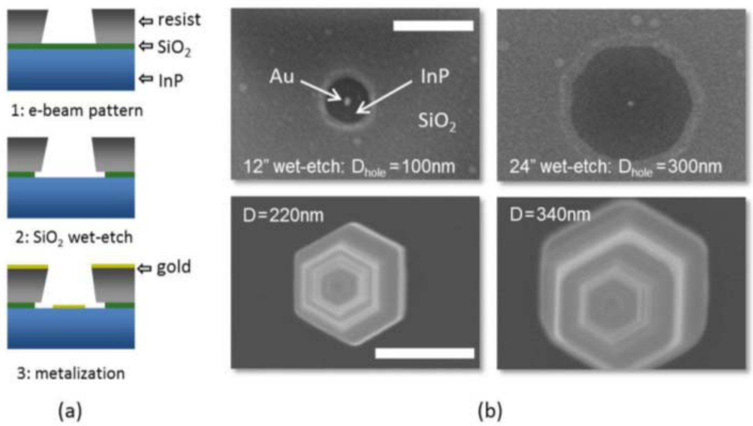

Figure 3 Processing steps for the preparation of the growth substrate. (b) Upper panel: SiO_2 hole opening for different etch times. Lower panel: top-view SEM of nanowires grown in the different size openings. Scale bars are 200 nm.

The emission energy of the InAsP quantum dots in the InP nanowire could be adjusted through the As flux and growth time. Figure 4a shows overlaid spectra from 50 individual nanowires each containing two dots grown with different As fluxes. Figure 4b shows PL emission from ensembles of nanowires that each contain a single quantum dot.

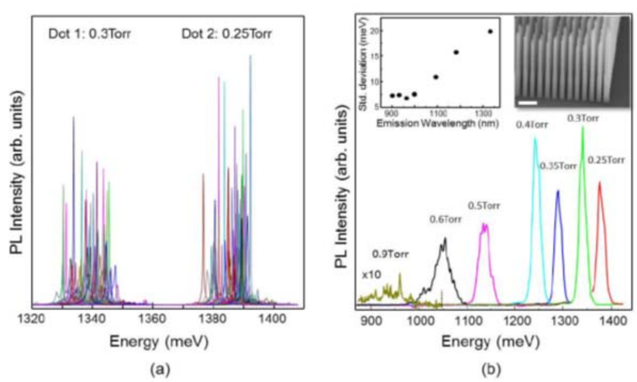

Figure 4 (a) PL spectra from 50 double dot nanowires. (b) PL spectra from nanowire arrays with dots grown using different AsH3 flux. Right inset show an SEM image of one of the arrays (scale bar is 1μm). Left inset shows the energy spread dependence on emission wavelength.

The quantum dot emission intensity is found to be strongly dependent on the ratio of the diameter of the clad nanowire to the emission wavelength (D/λ). This is a consequence of the modification of the spontaneous emission rate into the fundamental HE_{11} waveguide mode of the nanowire, as shown in figure 5.

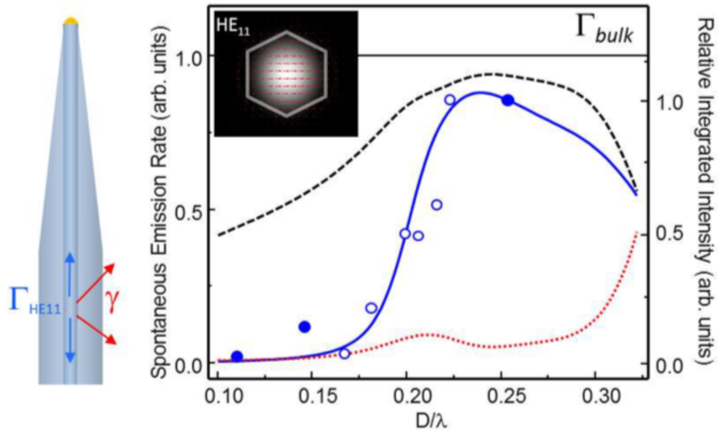

Figure 5 Calculated spontaneous emission rate into the fundamental HE_{11} nanowire waveguide mode ($\Gamma_{HE_{11}}$, blue solid line) and into leaky modes (γ, red dotted line) of an artificial atom placed on the axis of an InP nanowire as a function of the normalized wire diameter (D/λ). Black dashed line is $\beta = \Gamma_{HE_{11}}/(\Gamma_{HE_{11}} + \gamma)$. Open and filled circles are measured integrated PL intensities from nanowire samples. Inset shows the calculated electric field intensity of one of the two orthogonally polarized HE_{11} modes.

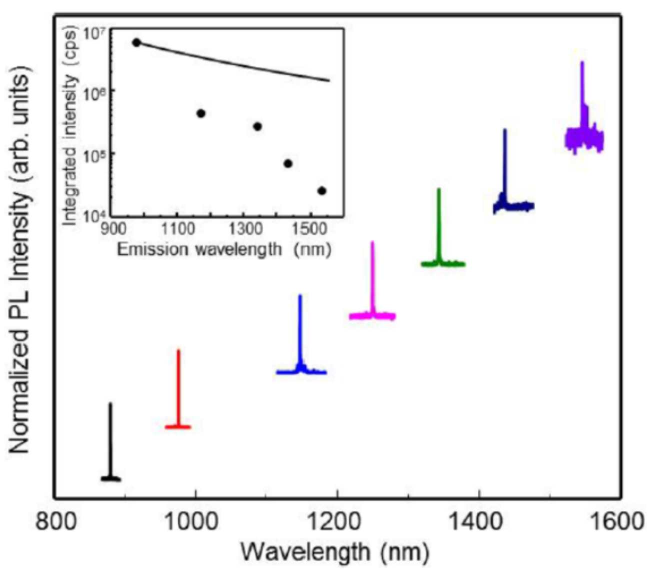

Figure 6 Normalized PL spectra of single InAsP/InP nanowire quantum-dot emitters in tailored photonic waveguides. Inset shows the emission-wavelength dependence of the count rate at the first lens (circles) as well as that of a radiating dipole (line).