Nanowire-based Sources of Non-classical Light

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Sources of non-classical light based upon semiconductor quantum dots embedded within a photonic nanowire are reviewed. Details of the epitaxial growth and photonic nanowire design are examined in relation to optimising source performance metrics such as brightness, emission linewidth and single photon purity. Multiplexed sources using multiple quantum dots coupled to a single photonic nanowire as well as efforts to extend the emission wavelength to those suitable for telecoms applications are discussed, along with possible routes to integration with the silicon photonics platform.

INTRODUCTION

Sources of non-classical light, single photons or entangled photon pairs, are a necessary resource for many quantum information, communications and imaging applications. On-demand sources with high emission rate, high generation and collection efficiency and high purity are desirable; traits that have been convincingly demonstrated by solid state emitters such as semiconductor quantum dots [1,2].

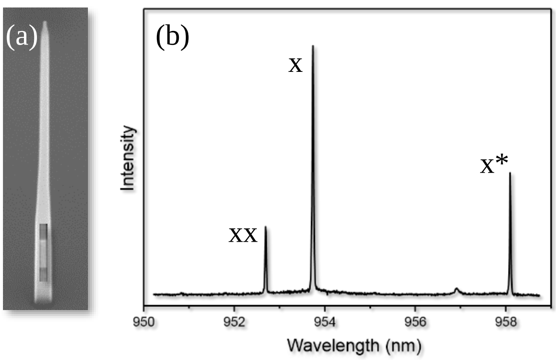

Figure 1. (a) Scanning electron microscope image of a nanowire with the quantum dot shown schematically in the wire core. (b) Photoluminescence spectrum of quantum dot emission.

In the work presented here we discuss the design and realisation of InAs-InP semiconductor quantum dot sources in which the emitter is placed along the axis of a Wurtzite InP nanowire grown by Chemical Beam Epitaxy. A scanning electron microscopy image of a typical nanowire along with a representative emission spectrum is shown in Fig. 1. The nanowire core is grown using a vapour-liquid-solid epitaxy technique, with the nanowire core and quantum dot diameter (~20nm) controlled to within a few nm by the size of a gold catalyst located within a dielectric-defined opening on the substrate surface. After growth of the nanowire core and quantum dot emitter, growth conditions are altered to promote radial growth in contrast to axial growth, producing a tapered InP photonic nanowire with a base diameter

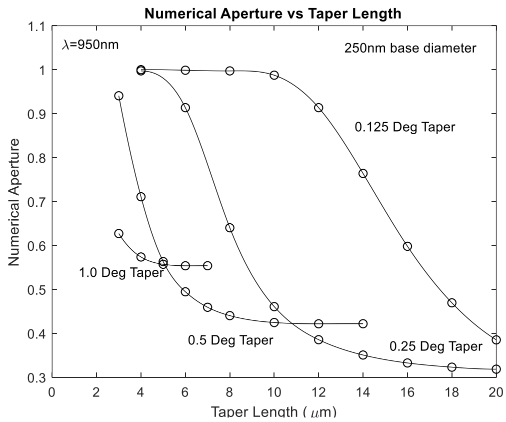

Figure 2. Effect of taper length and angle on the numerical aperture of the source.

of ~250nm, suitable for efficient coupling of photons from the quantum dot into the Gaussian-like HE11 mode of the nanowire waveguide. The effects of taper length and angle on the numerical aperture of the nanowire source are shown in Fig. 2. With appropriate taper design, efficiencies in excess of 90% can be achieved for coupling of the HE11 mode to single mode optical fibre [3].

OPTICAL PROPERTIES

InAs-InP quantum dot nanowires emitting around λ=950nm have demonstrated >85% coupling efficiency into the nanowire HE11 mode, with a multi-photon emission probability $g^{(2)}(0)=0.002$ and near transform limited line widths of 4μeV. By modifying the growth conditions, the emission wavelength can be tuned in the range from approximately λ=880nm to beyond λ=1500nm, suitable for fibre-based transmission, as shown in Fig.

3. However, as can be seen in the inset of Fig. 3, the shift of emission to longer wavelengths is accompanied by a considerable drop in emission rate.

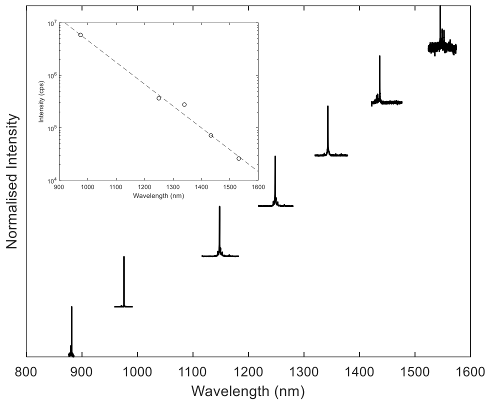

Figure 3. Normalised Photoluminescence spectra showing emission tuning with variation in growth parameters. Inset shows the drop in measured count rates.

ROUTES TO PHOTONIC INTEGRATION

The tapered nature of the InP nanowire described above produces an expanding, less confined optical mode as photons propagate towards the nanowire tip. If the nanowire is brought into the vicinity of a SiN waveguide, photons can be transferred from the nanowire, into the waveguide and can be made available for further processing as part of a photonic integrated circuit. Such a coupled nanowire-waveguide is shown below in Fig. 4.

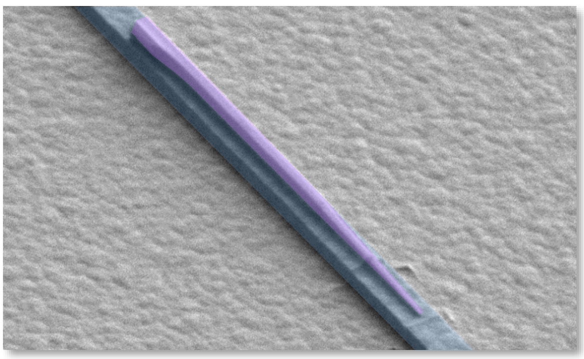

Figure 4. Scanning electron microscope image of an InAs-InP quantum dot nanowire placed on top of a SiN waveguide for evanescent coupling.

A coupling efficiency of 74% for photons propagating towards the nanowire tip has been demonstrated for structures of this type along with a single photon purity (1- $g^{(2)}(0)$) of 89% [4].

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