Optimization of photonic properties of a zinc-blende InP nanowire with InAsP quantum dot emitting in telecom spectral range

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$InAs_xP_{1-x}$ quantum dot (QD) in a zinc-blende InP nanowire (NW) is a novel material system for realization of a high quality single photon source. Chemical Beam Epitaxy technique has been successfully used to grow single QD/NWs without defects [1]. The growth method allows for precise tailoring of the NW and QD parameters. Unlike analogous structures commonly grown in wurzite structure, here emission wavelength can be easily tuned to telecom spectral range, where dispersion and attenuation in optical fibres are the lowest. With the right geometry design, NW can work as single mode waveguide increasing photon extraction efficiency upwards and imposing higher directionality of QD emission [2], that can be seen in Fig.1a. This addresses the issue of effective coupling and transmission through an optical fibre, which is important for performing quantum communication protocols over large distances.

Here, we present numerical simulations of the QD/NW system using finite-difference time-domain (FDTD) method in commercially available Ansys Lumerical software [3]. First, we found the optimal NW geometry within parameters space limited by growth technology, for maximal emission extraction efficiency (EE) within numerical aperture (NA) of 0.4 and 0.65 that are used in experiment. The optimized structure parameters are presented in Fig.1b. The 3-segment NW geometry was introduced to account for the presence of a gold droplet at the top of the NW, which originates from the growth method. In the next step, we studied different implementations of a mirror underneath the NW. We performed FDTD simulations of an optimized NW with a bottom gold mirror as well as distributed Bragg reflectors realized in different material systems, designed using transfer matrix method. Both solutions lead to similar results, with an increase in theoretical EE value by a factor of 2 up to 46% within 0.65 NA, at 1.5 µm emission wavelength and with a Purcell factor of 1.46. Finally, we performed micro-photoluminescence measurements in a wide spectral range on samples with the same QD sizes but different NW diameters to experimentally verify numerical calculations. We collected spectra as a function of excitation power from single NWs with diameters ranging from 160 nm up to 330 nm. The integral intensity of emission at saturation increased with NW thickness by almost one magnitude. We also showed that for a sample with 4% less As content in the QD, the emission wavelength blueshifts from telecom C-band towards telecom O-band.

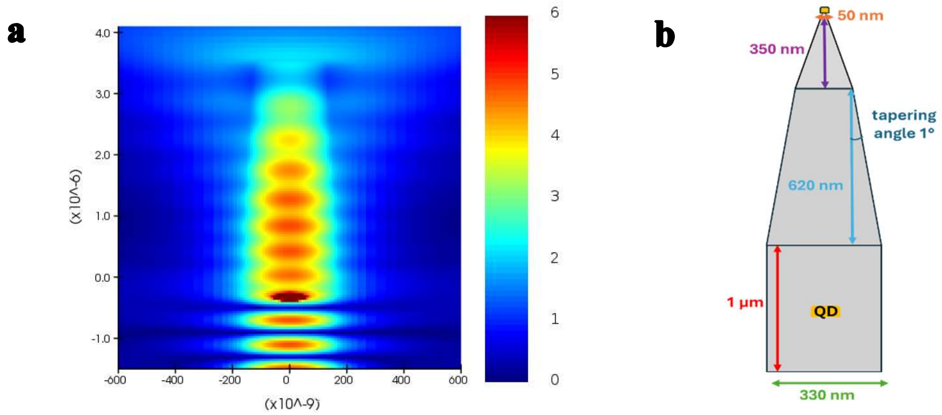

Figure 1: Numerically calculated electric field distribution in the NW (a), schematic drawing of NW with optimized geometry parameters (b)

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