Supplementary Information

Intersubband Quantum Disc-in-Nanowire Photodetectors with Normal-Incidence Response in the Long-Wavelength Infrared

Mohammad Karimi,[1,2] Magnus Heurlin,[1,3] Steven Limpert,[1] Vishal Jain,[1,2] Xulu Zeng,[1] Irene Geijselaers,[1] Ali Nowzari, [1]Ying Fu,[4] Lars Samuelson,[1] Heiner Linke,[1] Magnus T. Borgström[1] and Håkan Pettersson[1,2]*

[1]Solid State Physics and NanoLund, Lund University, Box 118, SE-221 00 Lund, Sweden

[2]Department of Mathematics, Physics and Electrical Engineering, Halmstad University, Box 823, SE-301 18 Halmstad, Sweden

[3]Sol Voltaics AB, Scheelevägen 22, SE-223 63 Lund, Sweden

[4]Department of Applied Physics, Royal Institute of Technology (KTH), Science for Life Laboratory, SE-171 21 Solna, Sweden

For micro-PL (μ-PL) studies, single NWs were broken off from the as-grown substrates and mechanically transferred onto Cr-coated silicon substrates. Figure S1 shows the μ-PL of a NW comprising a single QDisc recorded at 4 K for different laser excitation intensity. Taking into account the bandgap bowing parameter of 0.1 eV for WZ InAs at 4 K[1], the estimated bandgap of $InAs_{0.55}P_{0.45}$ with 5% variation in As composition would be 0.86-0.96

eV. For the lowest laser intensity of 0.01P, where P is the maximum intensity of 2 W/cm^2, a relatively broad peak can be observed at about 0.90 eV. This broad peak contains several peaks in the range from 0.90 to 1.0 eV, reflecting complex recombination processes via multiple states inside the disc. With increasing laser intensity, the μ-PL spectrum is broadened and blue-shifted, reaching about 1.10 eV at the highest laser intensity. Possible explanations for such a spectral behavior could be state-filling, combined with developing type-II transitions from the conduction band of the InP NW to the valence band of the InAsP QDisc. Similar spectral features have recently been reported for InP/InAs/InP core-multishell NWs.[2] Moreover, the non-abrupt interfaces between the QDisc and InP with smooth potential variations would result in broadened PL signals.

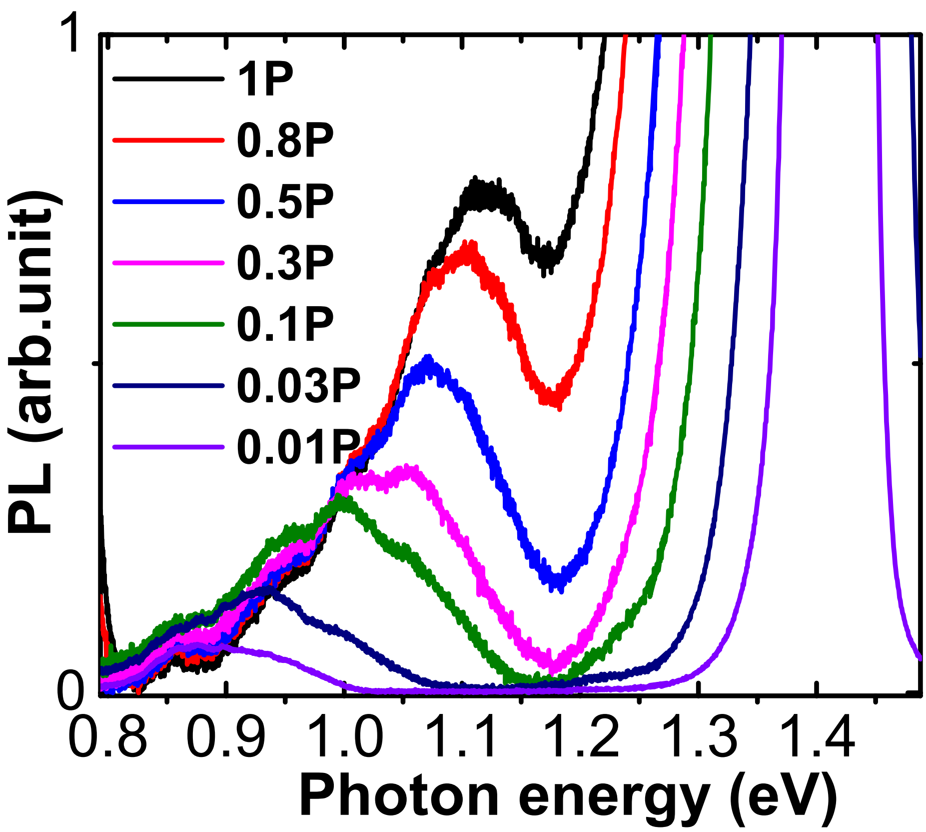

Figure S1. μ-PL spectra of a single NW comprising a single QDisc recorded at different laser intensity. The maximum intensity P amounts to 2 W/cm^2

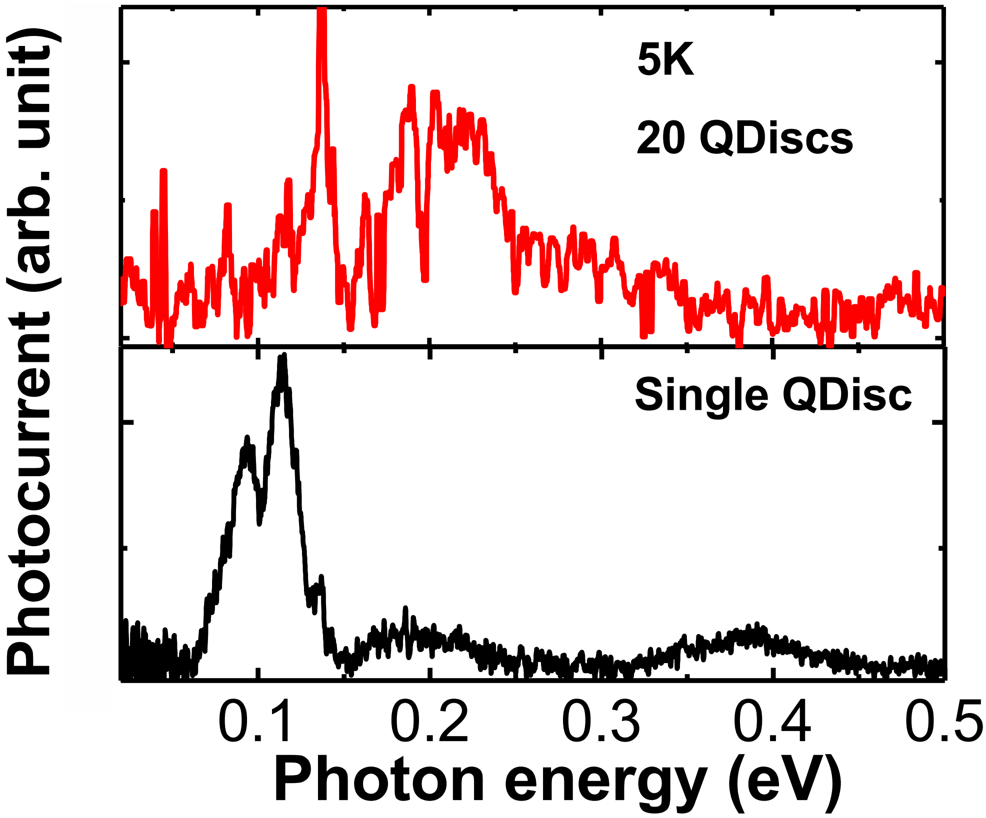

Figure S2. The upper panel shows the spectrally resolved PC for a fully processed 20 QDiscs-in-NW photodetector with 4-6 nm thick QDiscs (1 s growth time). The lower panel shows the corresponding PC for a single-QDisc-in-NW detector with thicker discs (7-8 nm, 2 s growth time). The spectrum in the lower panel is taken from Figure 4a.

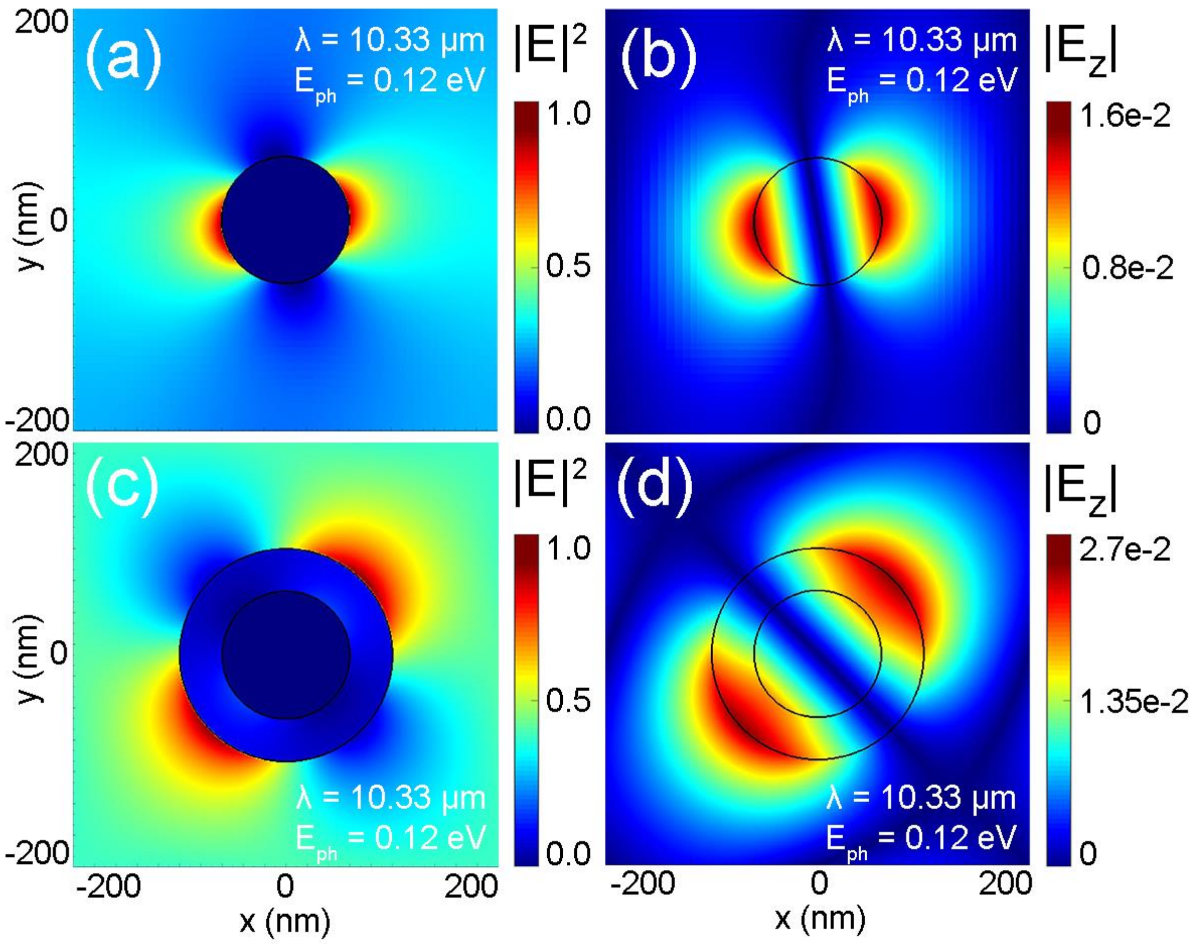

Figure S3: 2D FDE model results for a periodic InP NW array and for a periodic InP NW array with SiO_2 shells and photoresist infill. Fields are normalized such that the maximum electric field intensity, |E|^2, is 1. (a) Electric field intensity of the first mode at λ = 10.33 μm for a periodic InP NW array. (b) Ez component of the first mode at λ = 10.33 μm for a periodic InP NW array. (c) Electric field intensity of the first mode at λ = 10.33 μm for a periodic InP NW array with SiO_2 shell and photoresist infill. (d) Ez component of the first mode at λ = 10.33 μm for a periodic InP NW array with SiO_2 shell and photoresist infill. Note the difference in the color scale maximum between (b) and (d) indicating an enhanced Ez component in the latter case.

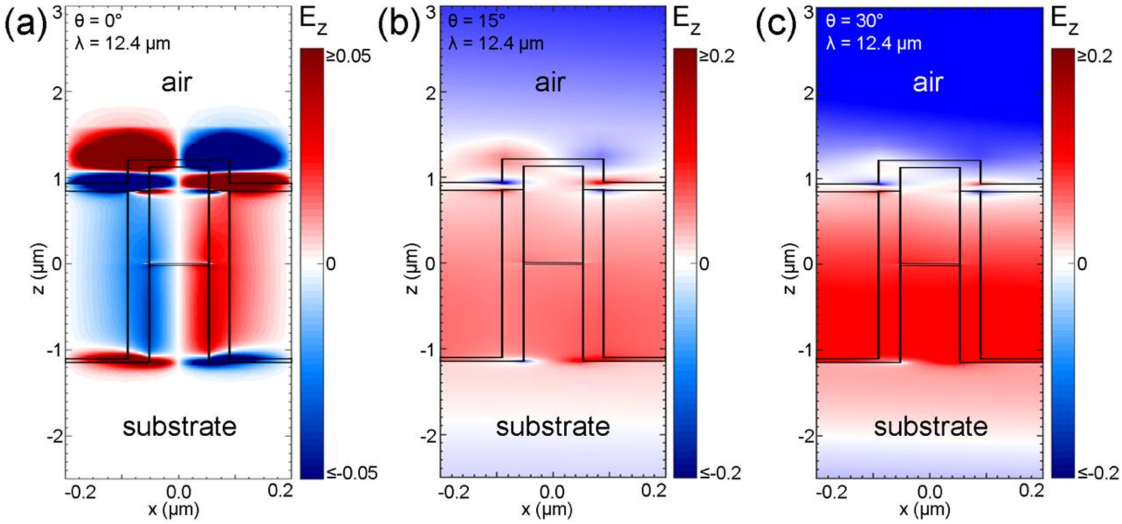

Figure S4: (a)-(c) Ez component of the electric field on a slice in the x-z plane of the 3D FDTD model for λ = 12.4 μm at angles of incidence, θ, of 0°, 15° and 30°. All simulations were performed with a source amplitude of 1 V/m. Note the change in color bar scale min/max between the 0° and 15° cases, and the non-zero Ez component in the air and substrate for the 15° and 30° cases.

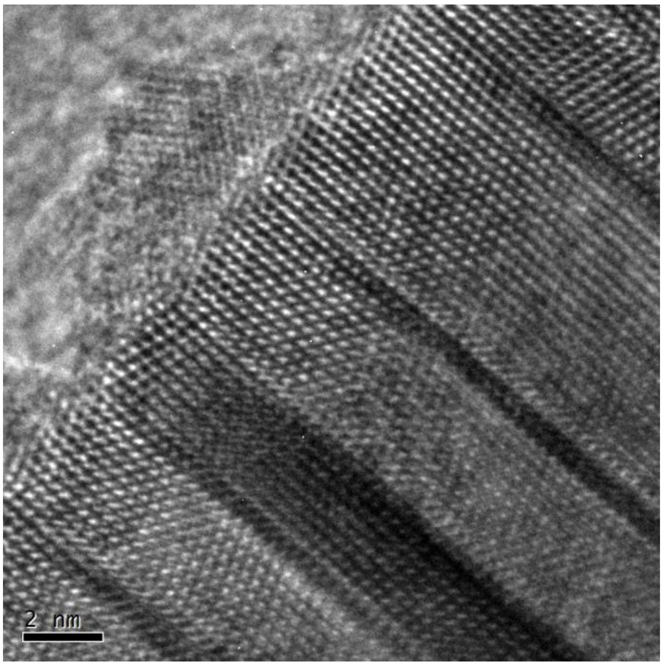

Figure S5. STEM image of a NW showing a mixed ZB/WZ crystal structure.

1. Vurgaftman, I.; Meyer, J.; Ram-Mohan, L. *J. Appl. Phys.* **2001,** 89, (11), 5815-5875.

2. Pal B, Goto K, Ikezawa M, Masumoto Y, Mohan P, Motohisa J*, Fukui T*. *Appl. Phys. Lett.* **2008**, 93(7)**:** 073105.