Optimizing the Lasing Threshold: Impact of Pitch and Nanowire Diameter in InP PCSELs

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Electrically driven 2D photonic crystal (PhC) lasers hold significant promise for on-chip coherent light sources in photonic integrated circuits, addressing the need for speed, performance, and size. This study investigates the impact of the photonic lattice constant (the pitch) and the nanowire diameter on the lasing threshold of optically pumped wurtzite InP nanowire photonic crystal surface emitting lasers (PCSELs) at 77 K. The InP nanowire PhC arrays were grown by selective area epitaxy on an InP substrate. The undoped InP nanowires were coated with a 10 nm-thick Al_2O_3 film to suppress atmospheric oxidation and band-bending effects. The InP nanowires have atomically smooth crystal facets revealing lasing thresholds of 10 μJ/cm^2 which is comparable to silicon-on-isolator (SOI) grown PhC arrays [1].

PhC arrays with pitches of 500, 570 and 630 nm and with nanowire apothems ranging from 76 to 93 nm have been investigated by power dependent measurements using a Ti:Sapphire laser providing 150 fs pulses at a center wavelength of 730 nm as excitation source. Fig. 1 shows the pump fluence dependent laser emission versus wavelength of a PCSEL array with 630 nm pitch, 87 nm nanowire apothem and of 1 μm nanowire height. Polarization dependent measurements reveal that the laser emission from the PCSELs originates from the TE polarized photonic Γ-point band edge mode. The experimental results are compared with finite-difference time-domain (FDTD) band structure simulations and theoretical laser rate equation analysis. The FDTD results support the experimental finding that the PCSEL emission is a TE polarized lasing mode. The calculations also reveal that the lasing emission from InP nanowire arrays with a PhC resonator energy considerably higher than the electronic bandgap energy cannot be solely explained by population inversion between the conduction band and the valence A-band. We suggest that a transient quasi-Fermi level in the valence B-band is responsible for the occurrence of lasing. A simple 3-band model considering band inversion in the B-band supports this interpretation.

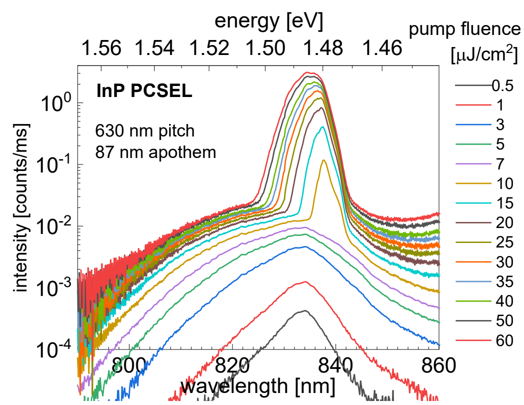

Fig.1. Pump fluence dependent laser emission versus wavelength of an InP PCSEL array with 630 nm pitch and 87 nm nanowire apothem.

In general, arrays with the lowest thresholds result from a pitch/diameter combination with a slow Bloch mode (SBM) that is resonant with the A- or B-band edge emission. PhC samples with off-resonant higher SBM energy display higher thresholds and are predominantly caused by the population inversion between the conduction band and the B-band. InP nanowire arrays with optimized pitch and diameter for low threshold operation are an important step towards electrically pumped PhC lasers.

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References

[1] C. Tu, M. Fraenzl, Q. Gao, H. Tan, C. Jagadish, H. Schmitzer, H. P. Wagner, Adv. Optical Mater. **9**, 2001745 (2021).