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Systematically Varying the Active Material Volume in a Photonic Crystal Nanolaser

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Ultra-small and efficient laser sources is an emerging technology for realizing optical on-chip interconnects [1]. A line defect cavity formed by omitting a number of holes in a photonic crystal membrane with embedded quantum dot or quantum well gain material shows promise as a candidate for realizing lasers with small mode volumes and low threshold powers, while allowing direct modulation at several gigabits per second [2]. Further, the slow-light phenomena occurring in passive line defect photonic crystal waveguides results in enhanced gain [3]. As such the gain material is a key component of the nanolaser. For good thermal operation of the nanolaser the gain material is embedded in an InP membrane [4] which in turn makes optical characterization of the gain material difficult.

Process developments have allowed fabrication of selectively defined buried heterostructure active regions, see Figure 1(Left), and here we present an investigation of laser characteristics where the extent of the gain material is varied while the photonic crystal cavity is kept constant. This systematic variation gives control of the total gain material in the cavity as well as confinement factor and allows for systematic investigations, e.g. of the role of slow-light effects on the threshold gain.

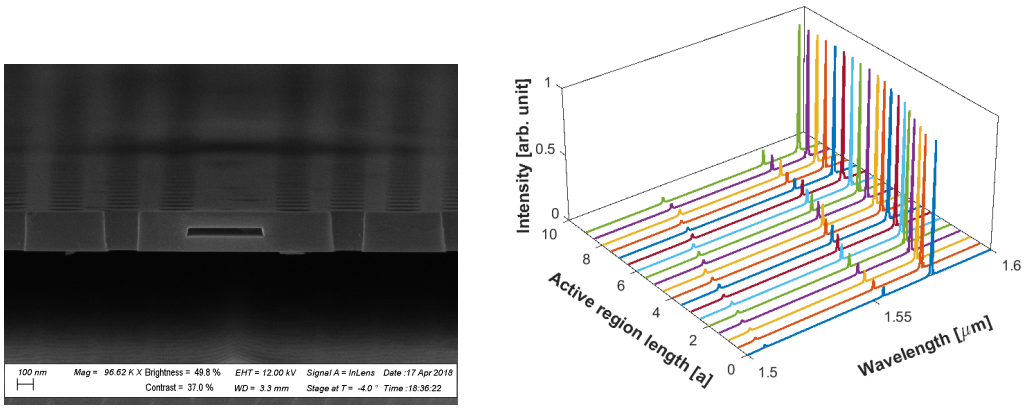

Fig. 1: Left: SEM image of a fabricated sample where the buried heterostructure is visible. The quantum wells have been selectively etched away to highlight the buried heterostructure region. **Right:** Spectra obtained from passive FDTD simulations as the length of the buried heterostructure is varied in terms of photonic crystal period, a. All peaks are seen to redshift as the buried heterostructure gets longer.

The characterization is carried out for a simple line defect laser with seven holes removed and an optimized design with four holes shifted to optimize Q [5,6]. An out-of plane pumping and collection setup is used for data collection. The input-output curves can be fitted to a laser rate equation model and laser parameters can be extracted [7].

The experimental results are compared to full 3D finite difference time domain (FDTD) simulations of the corresponding passive cavities. Spectra obtained from preliminary simulations can be seen in Figure 1(Right). The spectra are seen to redshift corresponding to the longer region with a higher refractive index.

References

[1] D. Miller, "Device requirements for optical interconnects to silicon chips", Proc. IEEE, **97**, 1166 (2009).
[2] K. Takeda, T. Sato, A. Shinya, K. Nozaki, W. Kobayashi, H. Taniyama, M. Notomi, K. Hasebe, T. Kakitsuka and S. Matsuo, "Few-fJ/bit data transmissions using directly modulated lambda-scale embedded active region photonic-crystal lasers", Nature Photonics, **7**, 569 (2013)
[3] S. Ek, P. Lunnemann, Y. Chen, E. Semenova, K. Yvind and J. Mørk, "Slow-light-enhanced gain in active photonic crystal waveguides", Nature Communications, **5**, 5039 (2014)
[4] W. Xue, L. Ottaviano, Y. Chen, E. Semenova, Y. Yu, A. Lupi, J. Mørk and K. Yvind, "Thermal analysis of line-defect photonic crystal lasers", Opt. Express, **23**, 18277 (2015).
[5] Y. Akahane, T. Asano, BS. Song and S. Noda, "High-Q photonic nanocavity in a two-dimensional photonic crystal", Nature, **425**, 944 (2003).
[6] K. Maeno, Y. Takahashi, T. Nakamura, T. Asano, and S. Noda, "Analysis of high-Q photonic crystal L3 nanocavities designed by visualization of the leaky components", Opt. Express, **25**, 367 (2017).
[7] W. Xue, Y. Yu, L. Ottaviano, Y. Chen, E. Semenova, K. Yvind, and J. Mørk, "Threshold Characteristics of Slow-Light Photonic Crystal Lasers", Phys. Rev. Lett, **116**, 063901 (2016).