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Improved Emission Properties of Polymer Photonic Crystal Lasers by Introducing a Phase-shift

Mads Brøkner Christiansen, Thomas Buß, Cameron L. C. Smith, and Anders Kristensen

DTU Nanotech, Department of Micro- and Nanotechnology

Technical University of Denmark

DK-2800 Kongens Lyngby, Denmark

mads.christiansen@nanotech.dtu.dk

Abstract: Introducing a phase-shift in nanoimprinted polymer dye lasers is shown to increase the probability of single mode lasing from 19% to 99%. Low-index lasers with only one longitudinal mode are thus superior to band-edge lasers.

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Additional key words: nanoimprint, combined nanoimprint and UV lithography.

In recent years a number of nanoimprinted polymer photonic crystal band-edge lasers have been demonstrated [1,2,3]. However, due to the low refractive index contrast in these lasers, the band gaps are not complete and the band edges are not separated very far in any crystal direction. This increases the chance of lasing at both band-edges, due to spatial hole-burning. We demonstrate that by introducing a $\lambda/4$ phase-shift in rectangular lattice photonic crystal lasers, a single longitudinal mode at the Bragg frequency becomes favourable, and this improves the single mode properties of the lasers.

The lasers are defined in a thin film of photo-definable Ormocore hybrid polymer or SU-8, doped with the laser dye Pyrromethene 597. They are 375 nm thick slab waveguides with a rectangular lattice of 100 nm deep air holes imprinted into the surface, see Fig. 1(a). The short lattice constant (a) is 200 nm, while the long lattice constant (b) is 355 nm. A compact frequency doubled Nd:YAG laser (532 nm, 5 ns pulses) is used to pump the lasers from above the chip. The rectangular photonic crystal lattice provides both laser feedback and also dramatically increases the amount of pump light being absorbed [4].

The lasers are fabricated in parallel on a 10 cm diameter wafer by combined nanoimprint and photolithography (CNP) [5]. CNP relies on a UV transparent quartz nanoimprint stamp with an integrated metal shadow mask, Fig. 1(b). In the CNP process the photonic crystal is formed by mechanical deformation (imprinting) while the larger features are defined by UV exposure through the combined mask/mold.

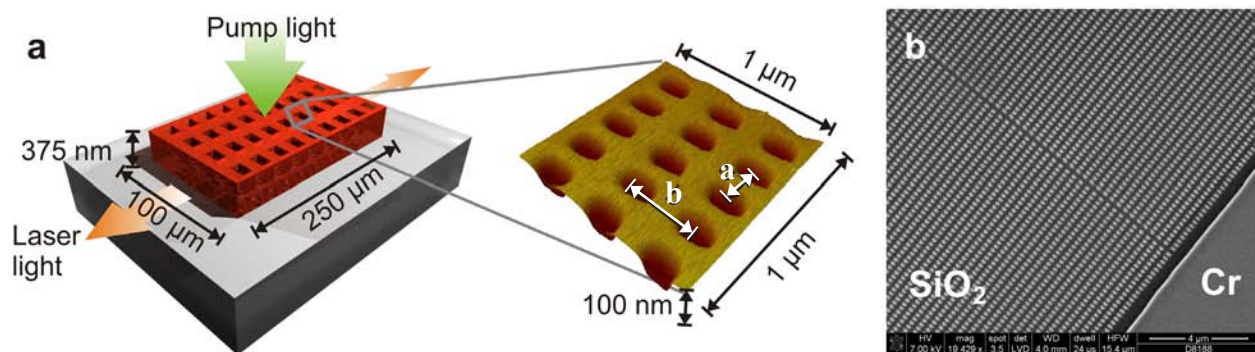


Figure 1: (a) Illustration of the polymer lasers, with an inset AFM image of the surface. (b) SEM image showing part of the stamp. The phaseshift, grating protrusions, and Cr shadow mask are seen.

Three wafers with 60 lasers were imprinted, two in Ormocore and one in SU-8. All lasers were nominally similar, except that half of them had a $\lambda/4$ phase-shift in the center. The fabrication yield was 85% for the SU-8 lasers and 58% for the Ormocore lasers. 63 of the 64 phase-shifted lasers were single mode, while this was only the case for 11 of the 58 unshifted lasers. A typical wafer map of laser properties is shown in Fig. 2, as are typical lasing spectra.

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For the SU-8 lasers the lasing thresholds are $2.6(\pm 0.7) \mu\text{J}/\text{mm}^2$ and $3.3(\pm 1.3) \mu\text{J}/\text{mm}^2$ for the shifted and unshifted lasers, respectively. This is low compared to other nanoimprinted polymer lasers [1,2], which is attributed to the efficient resonant pumping scheme. The laser wavelength of the phase-shifted lasers is $614.5(\pm 0.9) \text{ nm}$.

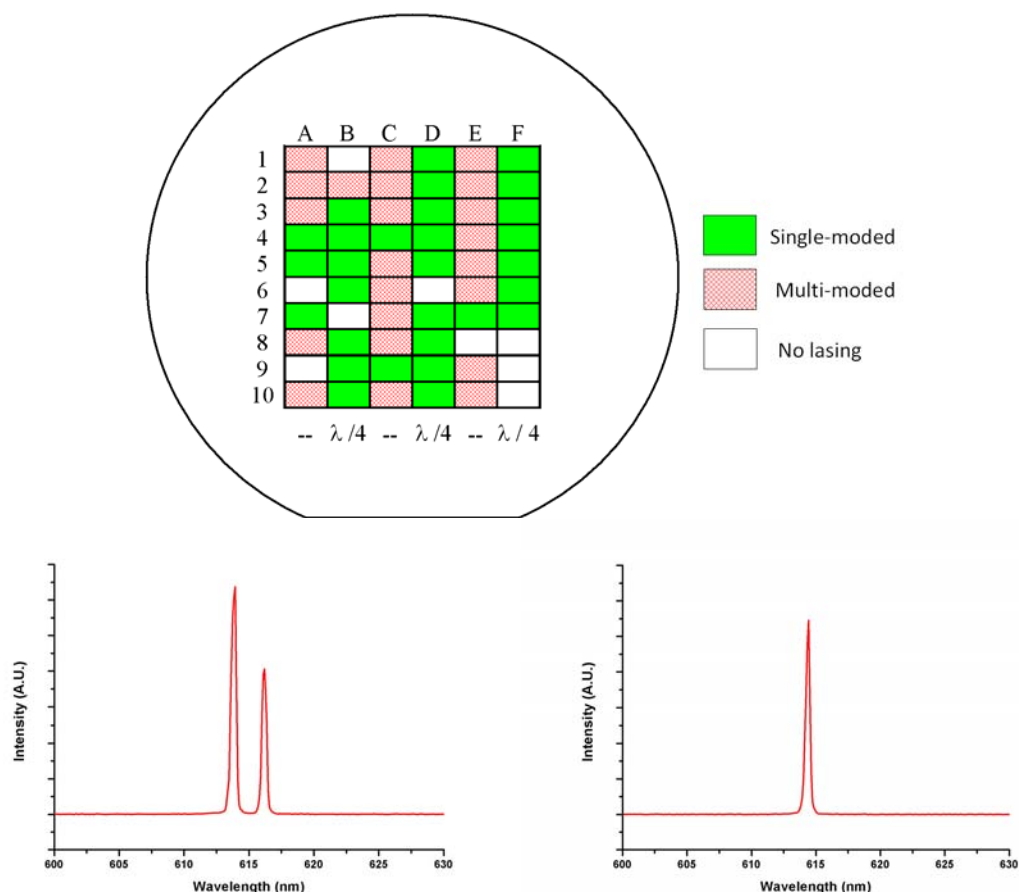


Figure 2: (Top) Distribution of single and multi mode lasers on a 4 inch wafer imprint. The phase-shifted lasers are in rows B, D, and F. (Bottom left) Typical spectrum for an unshifted band-edge laser pumped at $8 \mu\text{J}/\text{mm}^2$ (Bottom right) Typical spectrum for a quarter wave shifted laser pumped at $8 \mu\text{J}/\text{mm}^2$.

The temperature stability of the lasers is 0.06 nm/K and 0.042 nm/K for theOrmocore and SU-8 lasers, respectively. The organic laser dye is degraded during operation, giving a halflife of the lasers of 3700 pulses for the Ormocore lasers and 1090 for the SU-8 lasers.

CNP fabricated lasers are cheap to fabricate and very simple to use. They are thus well suited as tunable light sources or sensing elements [3,6] in single use lab-on-a-chip systems. We have demonstrated that by introducing a phase-shift, the reproducibility of single mode laser properties is substantially improved.

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