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Polymer Photonic Crystal Dye Lasers as Optofluidic Cell Sensors

Mads B. Christiansen¹, Joanna M. Lopacinska¹, Mogens H. Jakobsen¹,
N. Asger Mortensen², Gabriela Blagoi¹, Martin Dufva¹, and Anders Kristensen¹

¹DTU Nanotech, Department of Micro- and Nanotechnology

²DTU Fotonik, Department of Photonics Engineering

Technical University of Denmark

DK-2800 Kongens Lyngby, Denmark

mads.christiansen@nanotech.dtu.dk

Abstract: Hybrid polymer photonic crystal band-edge lasers are chemically activated to covalently bind bio-molecules or for HeLa cell attachment using an anthraquinone (AQ) UV activated photolinker. The lasers change emission wavelength linearly with inhomogeneous cell coverage.

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We present a chemical activation method for optically pumped hybrid polymer rectangular lattice band edge lasers[1,2]. The lasers are defined in a thin film of photo-definable Ormocer hybrid polymer[3], 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 (Fig. 1). A frequency doubled Nd:YAG laser (532 nm, 5 ns pulses) is used to pump the lasers from above the chip, causing them to emit in the chip plane. A typical spectrum is shown in Fig. 2.

The lasers are fabricated in parallel on a 10 cm diameter wafer by combined nanoimprint and photolithography (CNP) [4]. CNP relies on a UV transparent quartz nanoimprint stamp with an integrated metal shadow mask. 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.

Activation of the lasers is done photochemically using anthraquinone (AQ) photolinkers [5]. Fig. 3(a) and (b) show fluorescence intensities from lasers treated with AQ photolinkers with an electrophilic group (AQ-E), different concentrations of Biotin-NH₂ (highest concentration on top of the figure), and finally Cy5-Streptavidin. Fig. 3(c) and (d) are closer looks at a device spotted with 62 µg/ml of biotin-NH₂. Under green excitation (c) the laser dye is seen, and under red excitation (d) the streptavidin is seen. Note that it binds more to the polymer than the surrounding glass. Fig. 3(e) and (f) are similar images from an untreated device, showing no Cy5 signal.

Fig. 4 shows HeLa cells attached to lasers with AQ photolinker with an amino group (AQ-NH₂)[5]. Different cell concentrations are used. Device (a) and (d) are incubated with cells under the same conditions, but (d) without AQ-NH₂. It is evident that cells bind specifically to AQ-NH₂ treated surfaces. Fig. 5 shows laser tuning as a function of cell surface coverage when submerged in Phosphate Buffered Saline (PBS) (reference spectra taken in pure PBS). Prior to cell growth the lasers are washed in Ethanol, causing a 0.75 nm blueshift. The sensitivity corresponds to 5×10⁻³ nm per cell on the laser, making it possible to detect single cells, if the laser is scaled down to a 100 µm square, which should be feasible.

Our results demonstrate that nanostructured hybrid polymer lasers can be selectively chemically activated with UV sensitive photolinkers for further bioanalytical applications. This opens the possibility to functionalize arrays of optofluidic laser sensors with different bio-recognition molecules for multiplexed sensing. The linear relationship between cell coverage and wavelength indicates that the slight refractive index perturbation from the partial coverage of the sensor influences the entire optical mode, rather than breaking down the photonic crystal feedback.

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- [2] Felipe Bernal Arango, Mads Brökner Christiansen, Morten Gersborg-Hansen, and Anders Kristensen, "Optofluidic tuning of photonic crystal band edge lasers", *Appl. Phys. Lett.* **91**, 223503 (2007).
- [3] Ormocer is commercially available from micro resist technology GmbH, Berlin, Germany, www.microresist.de.
- [4] Mads Brökner Christiansen, Mikkel Schøler, and Anders Kristensen, "Integration of active and passive polymer optics", *Optics Express* **15**(7), 3931-3939 (2007).
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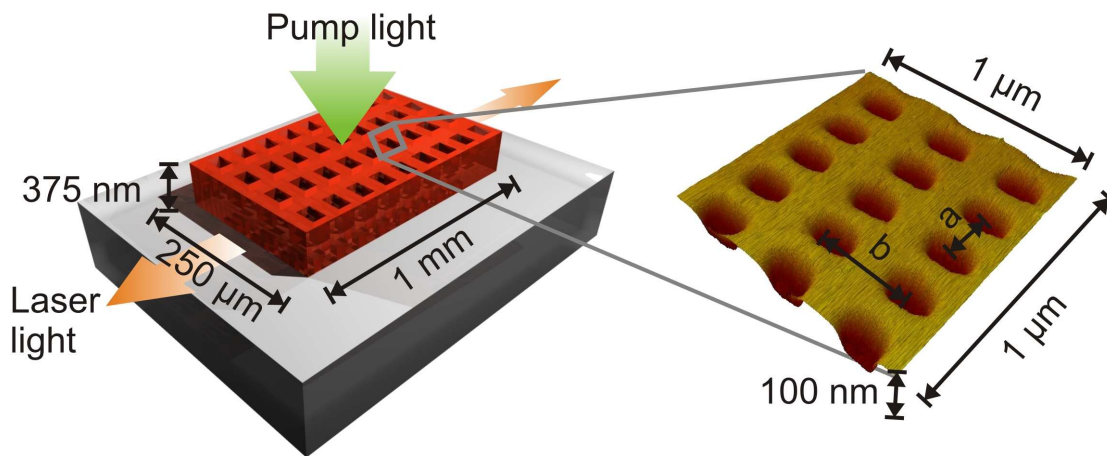


Fig. 1 Conceptual drawing of a photonic crystal band-edge laser. The lasers are Pyrromethene 597 dye doped Ormocore slab waveguides on a glass substrate. They emit in plane when pumped from above. The inset is an AFM image of the photonic crystal surface with the *a* and *b* lattice constants indicated.

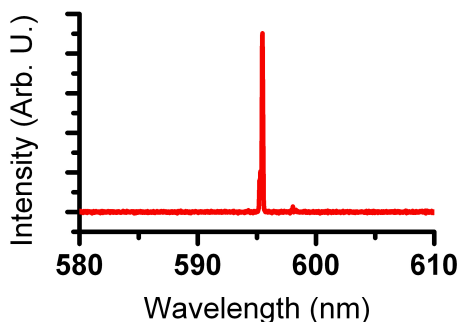


Fig. 2 A typical spectrum from a laser pumped at 4 $\mu\text{J}/\text{mm}^2$. The emission color depends on the *a* lattice constant. It is tunable from yellow/green to red.

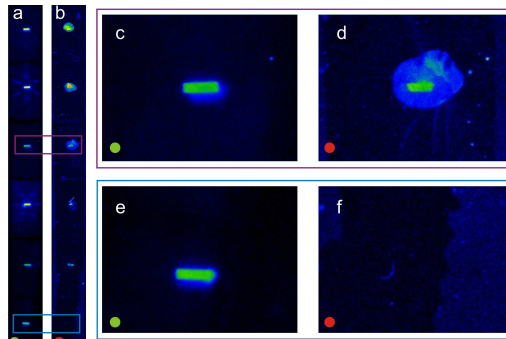


Fig. 3 Fluorescence images of laser treated with AQ-E, Biotin-NH₂ and Cy5-Streptavidin. The small dots in the lower left corners indicate excitation color. See main text for explanation

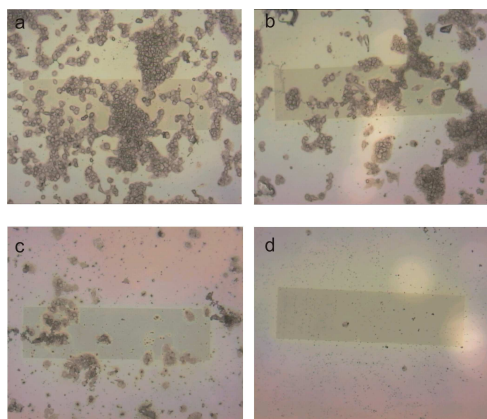


Fig. 4 Different amounts of HeLa cells grown on lasers treated with AQ-NH₂. The laser in (d) had the same treatment as the laser in (a), but no AQ-Link.

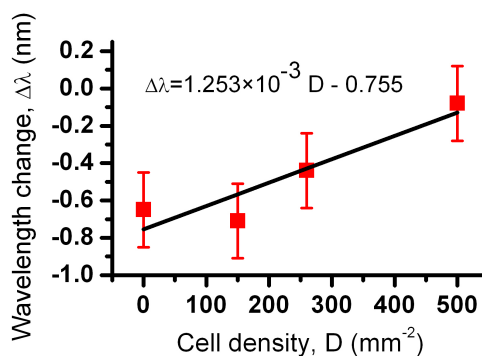


Fig. 5 Measured (■) wavelength change vs. cell density. A linear fit is also seen (-). The sensitivity is $1.253 \times 10^{-3} \text{ nm mm}^2$.