Highly directional Random Laser in a HC-ARROW Microfluidic Channel Connected to a Reservoir

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Abstract: *Coherent light sources are used in optofluidic devices for real-time system control and quantitative analysis of important process parameters in general. However, generation and transport of coherent light poses high demands on material purity, quality and finish increasing the device cost by orders of magnitude when compared to simpler microfluidic devices without the optic part. In this work, we developed a laser within such a device using traditional technologies for fabrication of microfluidic devices. The laser is composed of a reservoir containing the gain media and its beam is transported by microchannel waveguides. The on-chip laser device can be pumped externally and emits a highly collimated beam.*

Key-Words*: Microfluidics; Lasers; Diffusion; Multiple scattering; Dye lasers*

Introduction: Light guiding of the emission of liquid random lasers inside special structures has been observed before and some examples are optical fibers and photonic-crystal fibers, duallayered waveguide dye lasers, and liquid waveguide gain channels based on biological scatterers. Such random lasers partly resolve the problem of beam directionality; however, the integration of these optofluidic lasers into a lab-on-chip device is only of limited practicability owing to their fabrication methods. In this work, a glass substrate containing a hollow-core antiresonant reflecting optical waveguide (HC-ARROW) reservoir and channel was used. No external pumps are required because the effect of dye bleaching is diminished by diffusion and convection inside the reservoir, which constantly replenishes the depleted dye inside the pump region. The device is optimized with respect to laser efficiency and beam radiance. When pumped, the dye reservoir emits a highly coherent and collimated beam through the channel.

Experimental: The micro-device is composed of two glass slides on top of each other with dimensions of 10 mm × 20 mm × 1 mm (Figure 1a). A reservoir connected to two waveguide channels was etched into the lower slide using conventional photolithography and humid etching, resulting in 40 µm of channel depth and 260 µm channel width. The reservoir dimensions at its center were 3.6 mm × 10 mm × 0.04 mm (WxLxH). The etched side of the lower slide and the bottom side of the cover slide received seven alternate layers of TiO_2 and SiO_2 films, using sputtering technique, to achieve a maximum reflectance of 70% at the emission wavelength (550-630 nm) of our laser, offering additional light confinement. The reservoir is transversely pumped at 532 nm by an optical parametric oscillator (OPO) with repetition rate of 10 Hz and pulse duration of 9 ns. By means of a cylindrical lens of 50 mm focal length, a beam waist was formed in the form of a stripe with a width of 200 µm.

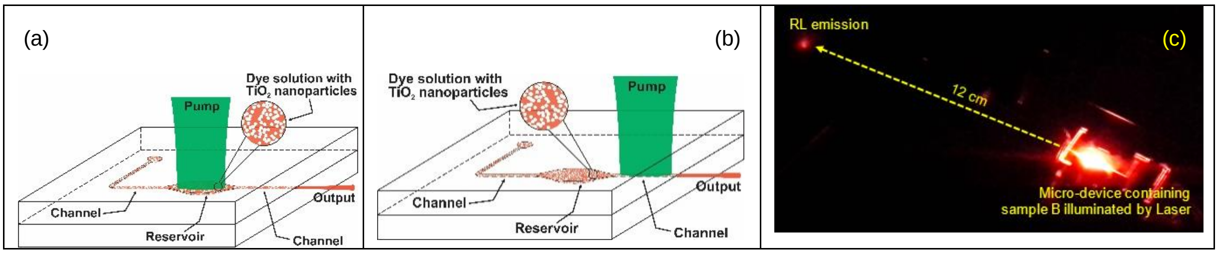

Figure 1. (a) Pump setup used to generate laser action inside the reservoir. (b) Pump setup used to generate laser action inside the channel close to the laser's output port. (c) Picture of the red laser emission pointed at a sheet of paper located 12 cm away from the device's output.

This stripe of pump light was placed, by means of a steering mirror, along the long axis of the reservoir and aligned with both micro channels. In this way, the directional laser emission, which is preferentially along the stripe direction, was effectively collected by the waveguide channels. Alignment was easily achieved once the stripe width was less than the channel width. A dye solution of 2.1 mM Rhodamine 640 perclorate in ethylene glycol was divided into three samples containing 0.7 (A), 2.8 (B), and 11.2(C) $\times 10^{10}$ cm^{-3} of TiO_2 nanoparticles (diameter 250 nm) each. This Rhodamine concentration was chosen in order to achieve an absorption length equal to the depth of the channels (40 μm), guaranteeing good pump light absorption upon double pass through the channels. Light that was not absorbed during the first pass through the 40 μm thick channel was in part (70%) reflected by the coated bottom of the channel.

Results and discussion: Erro! Fonte de referência não encontrada. shows the emission peak intensity (figure 2a) and spectral linewidth (FWHM, Fig. 2b) as functions of the pump energy of the devices filled with sample.

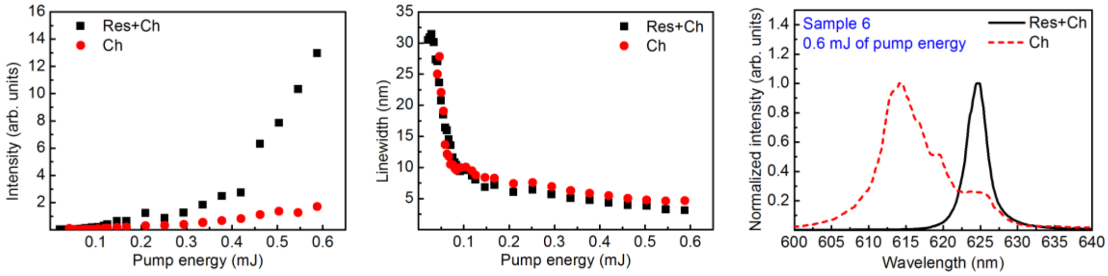

Figure 2. a) Peak emission as functions of the pump pulse energy for sample B when pumping into the reservoir (squares) and into the channel (circles). b) Respective emission linewidth (FWHM) narrowing as a function of pump pulse energy. c) Normalized intensity profile of the spectra of RES (solid line) and CH (dotted line) setups filled with sample C for 0.6 mJ of pump energy.

As seen in figure 2a) the reservoir shows clearly higher slope efficiency as well as a clear laser threshold demonstrating stimulated emission. Typical linewidth narrowing, which is the fingerprint of a random laser, is seen in figure 2b. In figure 2c), we show the normalized spectra of sample C under maximum pump pulse energy (0.6 mJ) for both setups. Even at maximum pump energy, the RES setup (solid line) shows a much cleaner emission spectrum. Not only is the emission spectrally narrower (3 nm as opposed to 4.5 nm in the CH setup), but the reabsorption in the channel also clears the lower wavelength tail, resulting in a symmetric emission spectrum. The divergence angle of the random laser emission was measured at 0.42 mJ of pump pulse energy for sample D. The full divergence angle (FWHM) of the RES setup was 68 mrad, while for the CH setup it was 129 mrad. For comparison, 68 mrad is the divergence of a Nd:YAG laser beam with a M^2 value of 10.

Conclusion: An optofluidic random laser source for lab-on-chip applications is presented. The HC-ARROW device is formed by a reservoir connected to two channels. Random laser performance was optimized as a function of scattering center density and compared for two setups: one with and the other without a reservoir. A lower laser threshold of below 100 μJ and a higher radiance was achieved in all cases when using the reservoir. Additionally, a much slower dye decay rate was observed when using the reservoir.

References and acknowledgements:

Refererences: [1] C. J. S. de Matos, L. de S. Menezes, A. M. Brito-Silva, M. M. Gámez, A. S. L. Gomes, and C. B. de Araújo, “Phys. Rev. Lett. 99, 153903 (2007).