Optofluidic Distributed Feedback Dye Laser Using Corrugated Sidewall Structure

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Abstract: An optofluidic distributed feedback laser is demonstrated with a threshold fluence of $133\ \mu J/cm^2$ in a polydimethylsiloxane device. The cavity is comprised of a corrugated sidewall structure filled with a Rhodamine 6G ethylene glycol solution.
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1. Introduction

Optofluidic devices have been used for a host of applications including the sensitive detection of single bioparticles in liquid [1]. Up to six-fold multiplexed detection of single viruses has been demonstrated with planar optofluidic devices which incorporate solid optical waveguides with microfluidic channels which double as leaky optical waveguides [2]. To do so, multiple fluorophores are used to label the particles of interest. Therefore, multiple optical sources are necessary to perform the experiment. Distributed feedback laser cavities allow for the simultaneous creation of multiple resonances in the visible band simultaneously. Therefore, a single cavity could be used to excite multiple fluorescent dyes with a single optical pump [3]. Here, a novel cavity is presented which incorporates a corrugated sidewall into a microfluidic channel to provide optical feedback for a fluorescent dye dissolved into a high index liquid. Optically pumped laser emission is demonstrated using Rhodamine 6G dissolved in ethylene glycol as the laser medium.

2. Device Design and Experimental Setup

A distributed feedback cavity is formed by corrugating the sidewall structure of a polydimethylsiloxane (PDMS) microfluidic channel. The laser cavity is created by filling the corrugated microfluidic channel with an ethylene glycol solution in which the fluorescent dye Rhodamine 6G (R6G) is dissolved. The refractive index of the ethylene glycol solution is laser than the PDMS cladding, enabling waveguiding via total internal reflection. Feedback is provided at wavelengths (λ_m) which satisfy the Bragg condition: $\lambda_m = \frac{2 \cdot \Lambda \cdot n_{eff}}{m}$ where m is an integer, n_{eff} is the effective index of the guided mode and Λ is the Bragg spacing which describes the periodicity of the sidewall corrugation. The devices are designed with $\Lambda = 6\ \mu m$ which provides a $m = 29$ resonance within the fluorescence emission spectrum of R6G ($\sim 570 - 650\ nm$) at $\lambda_m = 590.5\ nm$. A microscope image of the unfilled device is found in figure 1. The microfluidic channel has a total grating length $L = 4\ mm$, a corrugation depth $d = 5\ \mu m$ and cross-sectional dimensions of $\sim 5\ x\ 5\ \mu m$ in the narrowest region. On the chip, a solid-core optical waveguide is fabricated in-line with the microfluidic channel, following the process reported in [4]. This solid-core waveguide runs to the edge of the chip and is used to collect the emitted light from the device with an optical fiber.

To test the devices, the microfluidic channel is filled with a 5mM R6G solution via negative pressure (vacuum) and the solution is continually pulled through the device during testing. Emission is produced using a pulsed 532 nm optical pump (Teem Photonics Microchip) which illuminates the dye within the microfluidic channel. In free space, the beam is formed into an elliptical shape using a cylindrical lens and is then aligned to the microfluidic channel from below. The emitted light is launched into the parallel solid-core waveguide. An optical fiber is used to collect light from the device and the output optical powers and emission spectra are collected as a function of input optical power.

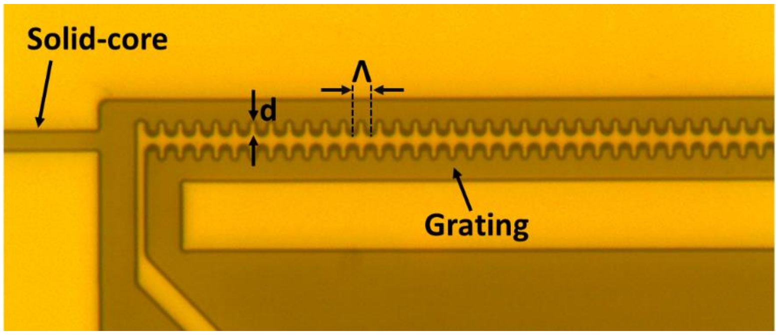

Figure 1. A microscope image of the unfilled distributed feedback device. A microfluidic channel with corrugated sidewalls creates a Bragg grating ("Grating") which provides feedback for a 5 mM R6G ethylene glycol solution. The device has a total grating length of 4 mm, sidewall grating depth $\boldsymbol{d = 5\ \mu m}$ and Bragg spacing $\boldsymbol{\Lambda = 6\ \mu m}$. Additionally, a solid-core optical waveguide ("Solid-core") is integrated in-line on chip to guide the emitted light to the edge of the device.

3. Results

The resulting average output optical powers as a function of average input optical powers clearly show a change in the slope indicative of lasing as seen in figure 2 (left). The two linear portions of the curve are fit, and a threshold pump power of $222\ \mu W$ is extracted, which corresponds to a threshold fluence of $133\ \mu J/cm^2$. Figure 2 (right) shows the R6G solution's fluorescence emission at low pump powers (average power $90\ \mu W$) and a clear narrowing of the spectrum above threshold (average power $1.3\ mW$). The lasing peak is found at $586.4\ nm$ which is near the theoretically anticipated $590.5\ nm$.

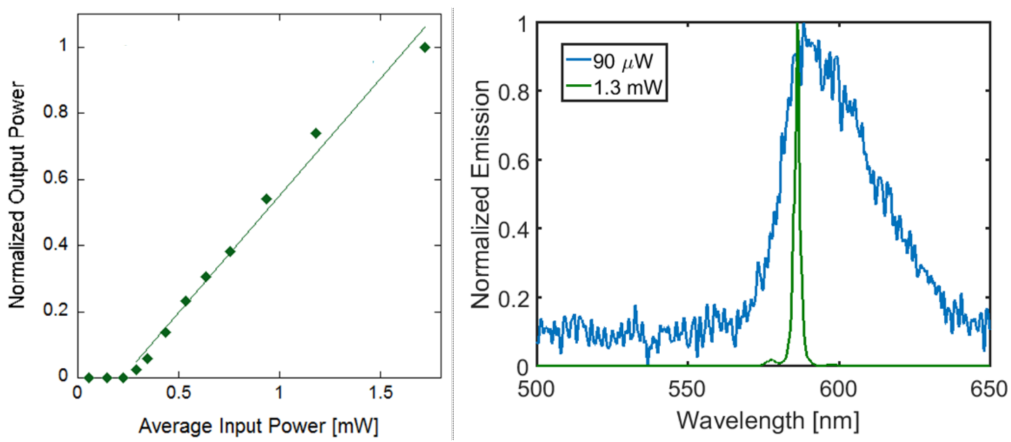

Figure 2. Normalized average output optical powers as a function of input average optical powers show a change in slope above threshold. The emitted spectra demonstrate broadband fluorescence of R6G below threshold (blue; average input power $\boldsymbol{90\ \mu W}$) and a clear narrowing above threshold (green; average input power $\boldsymbol{1.3\ mW}$) with a peak position of 586.4 nm.

In summary, a novel corrugated sidewall optofluidic distributed feedback dye laser has been demonstrated at $586.4\ nm$ with a R6G ethylene glycol solution. The lasing threshold fluence was found to be $133\ \mu J/cm^2$. The fabrication process is compatible with integration of the laser as an on-chip light source for single molecule optofluidic detection. Moreover, the cavity can be filled with a solvent mixture to tune the core index or a mixture of fluorescent dyes to achieve multi-color lasing for spectrally multiplexed particle detection.

4. Acknowledgments
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5. References

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