Mechanically Tunable Optofluidic Distributed Feedback Dye Laser

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***Abstract*—We demonstrated a continuously tunable optofluidic distributed feedback (DFB) dye laser on a monolithic poly(dimethylsiloxane) (PDMS) chip. We obtained ~60nm tuning range by mechanically varying the grating period. Single-mode operation was maintained with <0.1nm linewidth.**

I. Introduction

On-chip liquid dye lasers are ideal coherent light sources for 'lab-on-a-chip' systems in that they allow the integration of laser sources with other microfluidic and optical functionalities. Several groups have demonstrated such dye lasers using different materials and laser cavity structures [1][2][3]. Tunable output was also obtained using concentration or index tuning methods [3][4]. Recently, we demonstrated a single mode distributed feedback (DFB) liquid dye laser on a monolithic silicone elastomer chip [5]. Stable single-mode operation with narrow linewidth was obtained using a phase-shifted 15th-order Bragg gating embedded in a single mode liquid core/PDMS cladding channel waveguide. Here we show the mechanical tunability of such elastomer based on-chip liquid dye lasers.

II. Principles of Operation

As shown in Fig. 1, the optofluidic DFB dye laser was fabricated on a monolithic PDMS chip using replica molding soft lithography as described in Ref. [5][6]. A microfluidic channel when filled with liquid of higher refractive index than that of PDMS (1.406, GE RTV 615) acts as a channel optical waveguide. When the cross section dimensions of the channel are 2um by 3um and the index contrast is less than 0.003, the waveguide supports only the two fundamental E_{11} modes. The distributed feedback is provided by the periodic PDMS posts with period 3080nm inside the channel, which form a 1cm long 15th-order Bragg grating at wavelength around 570nm. A 15π phase shift is introduced at the center of the grating to ensure single frequency operation at the Bragg wavelength. The gain medium is a 2mM solution of Rhodamine 6G or Rhodamine 101 in a methanol and ethylene glycol mixture

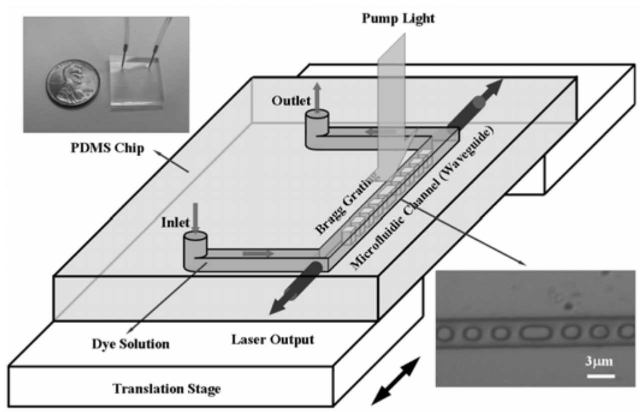

Fig.1. Schematic diagram of a tunable optofluidic DFB dye laser chip. The upper inset shows an actual PDMS laser chip. The translation stage movement stretches or compresses the PDMS chip along the Bragg grating direction. The resulting grating period change causes the lasing wavelength to shift. The lower inset is an optical micrograph of the central phase-shifted region of the laser cavity. The grating period is 3080nm and total length is 1cm. The channel is 2um high and 3um wide.

with refractive index of 1.409. The pump light are 532nm Q-switched Nd:YAG laser pulses with 10 nanosecond pulse width. The pump light is focused by a cylindrical lens to a ~100um wide long stripe aligned with the channel.

The Bragg wavelength of a DFB laser is determined by the condition

$$m\lambda_m = 2n_{eff}\Lambda \qquad (1)$$

where λ_m is the mth order resonant wavelength, n_{eff} is the effective index of the guided mode and Λ is the grating period. Therefore, the lasing wavelength can be tuned by changing n_{eff}, Λ or m as have been demonstrated in conventional DFB dye lasers [7]. The effective index can be varied by changing the core index or the cross section dimensions of the waveguide. However, due to the very low Young's modulus of PDMS (~750kPa [8]), the more straight forward tuning method is to mechanically change the grating period by simply stretching or compressing the chip. Finally, the grating order can be chosen by using different dye molecules which cover different spectral regions. The last two methods were used in this work to achieve a ~60nm tuning range from yellow to red.

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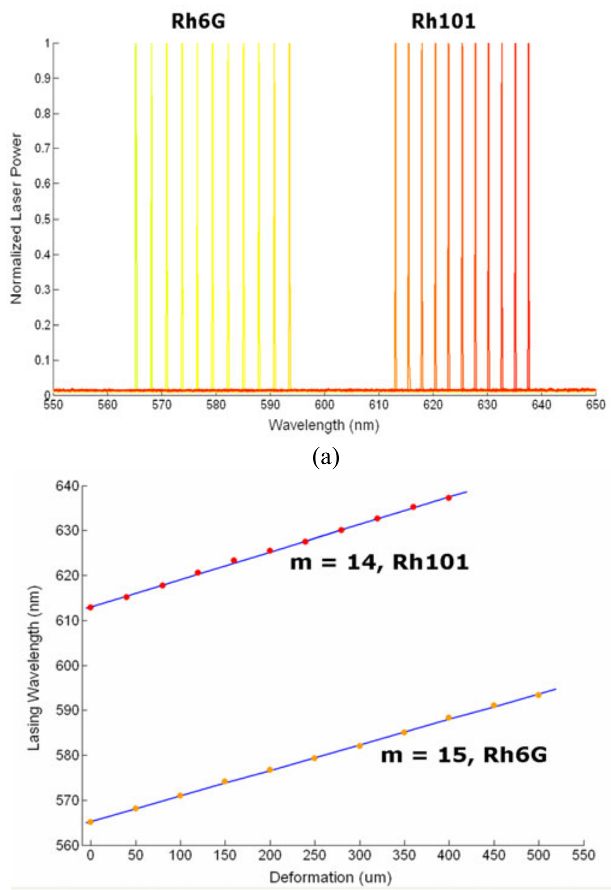
III. RESULTS AND DISCUSSION

The chip was glued to two separate stages with the laser region suspended in the middle as shown in Fig. 1. One of the stages is a high resolution micrometer with 1um sensitivity, which provides accurate control and quantitive measurement of the chip deformation. The results of mechanical tuning are given in Fig. 2. The achieved single mode tuning range for Rhodamine 6G is from 565nm to 594nm and from 613nm to 638nm for Rhodamine 101. Throughout the tuning range, stable single-mode operation was maintained with measured linewidth 0.1nm limited by the resolution of the spectrometer (Ocean Optics HR4000). When the length of the central suspended region is 1cm, the total chip deformations required to achieve the above tuning ranges are about 500um for Rh6G and 400um for Rh101, which correspond to 28nm and 25nm grating period changes respectively. Lasing wavelength changes linearly with the chip deformation as shown in Fig. 2 (b). The tuning rate is ~0.058nm/um for Rh6G and ~0.063nm/um for Rh101. The tuning is continuous and completely reversible owing to the excellent elasticity of PDMS. Under deformations larger than the above mentioned values, multiple lasing modes appeared, likely to be caused by non-uniform load. However, given the extremely large achievable elongation of PDMS (120% [9]) and the very wide gain spectral bandwidth of Rh6G and Rh101, we believe a much larger tuning range from 550nm to 700nm is achievable with optimized cavity design, dye concentration and more uniform mechanical load.

Furthermore, because of the multiple spectral resonances supported by the higher order Bragg grating, one cavity structure can provide tunable output covering from near UV to near IR spectral region as long as appropriate dye molecules and pump source are used.



(b)

Fig.2. (a) Normalized laser output power of the mechanically tunable optofluidic DFB dye laser. Different lasing peaks correspond to different grating periods. The achieved tuning range for Rhodamine 6G is from 565nm to 594nm and from 613nm to 638nm for Rhodamine 101. The measured linewidth is than 0.1nm during tuning. (b) Lasing wavelength versus the measured chip deformation. The chip length (region that can be freely deformed) is 1cm.

IV. CONCLUSION

We have demonstrated a continuously tunable DFB dye laser on a PDMS chip using a simple mechanical deformation method. Nearly 60nm tuning range was achieved with two dye molecules. The fabrication and operation of the laser chip is fully compatible with PDMS based microfluidics technology [10]. Such lasers may enable the implementation of spectrometers, biosensors and imaging systems on a chip.

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