MICROFLUIDIC DROPLET DYE LASER BASED ON A FABRY-PEROT CAVITY

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ABSTRACT

This paper reports an original microfluidic dye laser based on microdroplets flowing through an on-chip Fabry-Perot cavity. This combination allows fast laser emission at distinct wavelength over a wide bandwidth. The switching time from one wavelength to another, monitored by the droplet production system, can be reduced to the millisecond range. Alternation of rhodamine 6G and sulforhodamine 640 dye droplets have been performed to generate laser emissions at 567 and 625 nm.

KEYWORDS: Optofluidics, Droplet, Dye Laser, Fabry-Perot

INTRODUCTION

Microfluidic dye lasers are compact laser light sources that can serve for biochemical sensing in micrototal analysis systems. Spectroscopy is one main technique allowed by lasers. The emission wavelength is crucial in this application. Monitoring the laser emission is therefore one key point in the development of microfluidic dye lasers. This issue can be addressed by tuning the dye concentration or the optical cavity [1,2]. Another way is to switch from a continuous flow to droplets. Compared to previous works on droplet systems where the droplet itself constitutes the optical cavity [3,4], the new architecture proposed here is based on an integrated Fabry-Perot cavity. The droplet becomes only a vector for the amplifying medium. Our system is thus flexible as there is no specific requirement on optical liquid refractive indexes or on the droplet's shape.

The present paper describes the principle of this microfluidic droplet dye laser, the experimental set-up and the characterization of the device on the microfluidic and optical levels.

EXPERIMENTAL

A schematic of the device is presented in Figure 1. The optical cavity is integrated on the chip. The active medium is supplied in droplets that are confined in the microfluidic channel. The droplets flow through the cavity where they are optically pumped. Laser emission is determined by the dye solution and tunability of the wavelength is insured by the generation of droplets containing different dyes. Switching time between two output wavelengths is directly related to the flow speed and the distance between two droplets. This design leads therefore to a multiple wavelength laser source with a fast switching time.

The performed chip integrates two droplet generators and a laser cavity. Two optical fibres are cleaved and metallized on the ends to act as mirrors. They are placed face to face to shape a Fabry-Perot cavity. Droplet production is obtained using two identical T-junctions in series and monitored via the liquid flow rates. Alternation of two dyes is possible to achieve a bicolour laser.

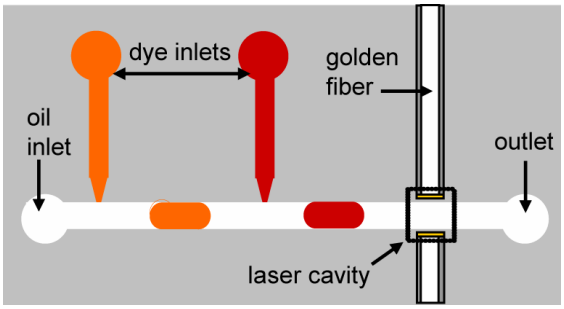

Figure 1: Schematics presenting the principle of the device

The mould was made using soft photolithography. SU8-2100 was spin coated to obtain a 125µm thick layer. Once the pattern of the channel is obtained, cleaved optical fibres are placed face to face to mould the laser cavity. Polydimethylsiloxane (PDMS) is poured on top of it and cured at 80 °C for 2 h. The PDMS layer is peeled off; the fibres are removed and replaced by metallized ones. These new fibres were previously cleaved and metallized on the ends with 5 nm Ti/ 200 nm Au and 5 nm Ti/ 50 nm Au corresponding respectively to their role as back mirror and output mirror in the cavity. The channels were sealed on a glass wafer with a 30 s irreversible plasma treatment. Droplets were produced upon a passive T-junction shaped system. Either rhodamine 6G (Rh6G) or sulforhodamine 640 (Su640) were dissolved in glycol at

the concentrations of 10^{-3} and 5.10^{-3} mol/L respectively. The continuous phase liquid is a fluorinated oil (FC40 3M Corp). Channels are 125 µm high and 130µm wide.

Flow rates are controlled using independent syringe pumps. The microfluidic dye laser is optically pumped perpendicularly to the chip using a frequency doubled Nd:YAG laser emitting at 532 nm with an average power of 25 mW and a pulse duration of 0.5 ns. The pump beam is focalized in the microfluidic channel between the optical fibres via a x4 microscope objective. The microfluidic laser signal is directly extracted out of the chip via the fibre that served also as the output mirror. At the end, light is collected by a multimode fibre and analyzed by a spectrometer (Ocean Optics USB2000+).

The device is composed of two distinct parts, one microfluidic and one optical, which are the droplet production and the laser cavity, presented in the next section.

RESULTS AND DISCUSSION

First the droplet production has been characterized by determining the frontiers between droplet regime and jet regime. As the droplet production is composed of two identical passive generators, it is dependant on the crossing geometry, the fluids' properties and flow rates. Different flow rates have been scanned to draw the phase diagram depicting the relationship between flow rate and droplet morphology for glycol-FC40 oil liquids. As shown in Figure 2, the whole phase diagram for one T-junction has been obtained to precisely determine the working range of the device. In the following of the experiments, flow rates' couples have been chosen in the droplet regime for both generators.

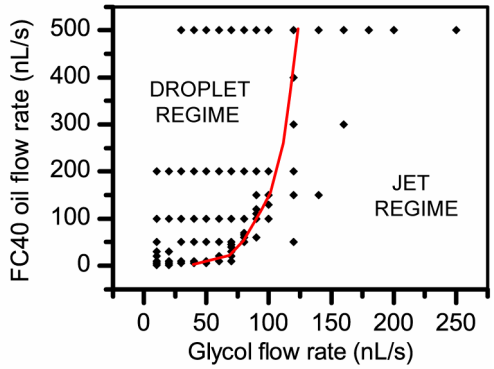

Figure 2: Phase diagram depicting the relationship between flow rate and droplet morphology for glycol-FC40 oil liquids

Secondly we have compared the optical properties of the Rh6G droplet laser with the Rh6G continuous phase laser. Only one droplet generator is used in this case. Oil flow rate is 30 nL/s while glycol's flow rate is 10 nL/s for the droplet laser. The Rh6G continuous phase laser means that only one liquid phase is used and glycol's flow rate is 30 nL/s. Laser spectra are similar with an emission at 567 nm as shown in Figure 3(a). Laser thresholds are also similar with a value around 30 µJ/mm^2 for both lasers (Figure 3(b)). So providing the amplifying medium in droplets has no influence neither on the output wavelength nor on the laser threshold. Moreover, compared to the continuous phase laser, encapsulating different active mediums in droplets enables fast switching of the laser wavelength. For this Rh6G droplet laser, the droplet frequency rate has been pushed up to 1.28 kHz leading to a switching time less than 1ms.

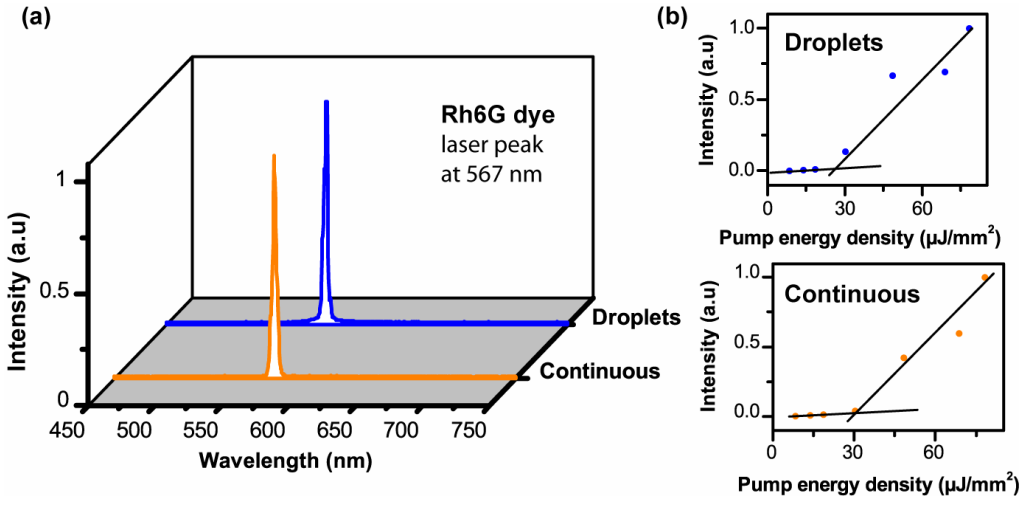

Figure 3: Comparison of optical properties for microfluidic dye lasers supplied with a continuous stream of dye solution and a droplet stream: (a) laser output spectra, (b) laser intensities as a function of the pump energy density

Finally, to illustrate the potential of multiwavelength emissions using this architecture, the two droplet generators are provided with two different dyes. The first one contains Rh6G at 10^{-3} mol/L and the second one Su640 at 5.10^{-3} mol/L in glycol solution. Adjusting the flow rates enables to generate an alternation of Rh6G and Su640 droplets. Figure 4 presents the laser output when such an alternation of Rh6G and Su640 droplets flows through the cavity. A bicolour laser signal is registered at 567 nm and 625 nm.

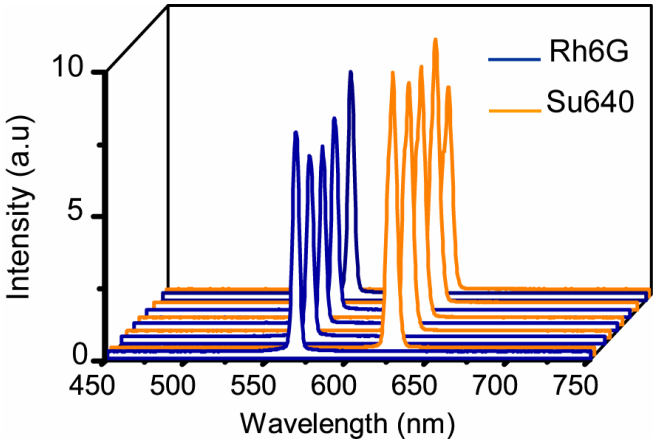

Figure 4: Spectra of laser emission for an alternation of Rh6G/Su640 dye droplets

CONCLUSION

We have demonstrated for the first time an integrated bicolour droplet laser device based on a Fabry-Perot cavity. Having dye solutions encapsulated in droplet enables fast switching of the laser wavelength, small consumption of reagent and avoids cross-contamination between different dyes. Finally, using this Fabry-Perot architecture, samples inside or outside the dye droplet can be analyzed via intracavity measurements without any labelling or functionalization. If coupled with active droplet production systems such an integrated device will enable to increase the range of wavelength available on chip to perform a true wavelength-on demand analysis system.

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