SU-8 BASED SOLID STATE DYE LASERS FOR LAB-ON-A-CHIP MICROSYSTEMS

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We present a new type of optically pumped solid polymer dye lasers, which can easily be integrated with polymer based microsystems. The widely used photoresist SU-8 has been functionalized with optical gain, by doping it with Rhodamine 6G laser dye. The laterally emitting lasers can be fabricated on any suitable substrate in a single photo lithographic step on the dye doped SU-8 resist, and the lasing wavelength is controlled by the lateral dimensions alone. The dye doped SU-8 lasers are pumped by a pulsed, frequency doubled Nd:YAG laser (wavelength 532 nm), and lasing wavelengths between 564 nm to 595 nm are demonstrated.

Keywords: SU-8, micro laser, Rhodamine 6G

Since the first demonstration of optically pumped dye lasers more than 30 years ago, this type of lasers have been intensively studied, and widely applied for spectroscopy in the visible range. For a review, see [1]. We present a new type of solid state micro cavity dye lasers. The lasers are realized by doping the photo definable polymer SU-8 with the laser dye Rhodamine 6G. Since the laser cavities are defined in a photo lithographic process, the lateral design is not imposed by any restrictions but the mask lay-out. By merely changing the lateral geometry of the cavities, we demonstrate that the lasing wavelength may be changed more than 30 nm using the same pumping laser and dye. Hence, it is possible by simple means to enhance the functionality of a Lab-on-a-Chip system by integrating a multi-colored laser array. The micro lasers are laterally emitting, enabling easy integration with e.g. polymer waveguides. This solves the common alignment difficulties between external light sources and wave guides as the lasers may be integrated on the chip.

Earlier demonstrations of miniaturized solid state dye-doped polymer lasers [2, 3] are based on casting techniques to define the laser cavity.

We have realized two different lateral designs of the micro laser. One is trapezoid shaped, Fig. 1(a), the other is triangular shaped, Fig. 1(c) - both designs have been scaled to different sizes. The cavity design is described in reference [4]. Light is guided parallel to the substrate in the dye doped SU-8 structures. The trapezoid shaped laser resonator relies on total internal reflection on three of the vertical sidewalls, and partial reflection on the fourth sidewall, where light is coupled out. Similarly, the triangular shaped cavities support modes by total internal reflection at two of the vertical sidewalls.

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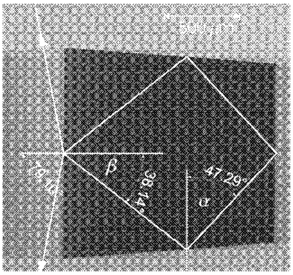
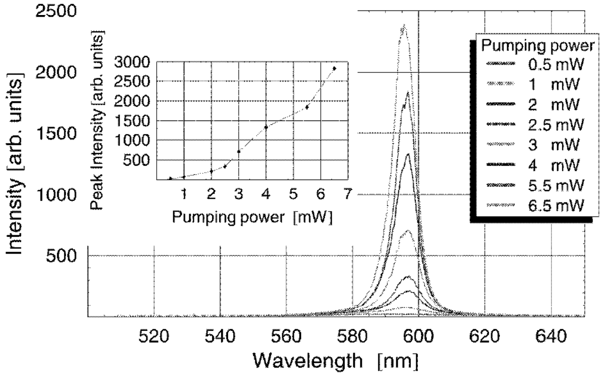
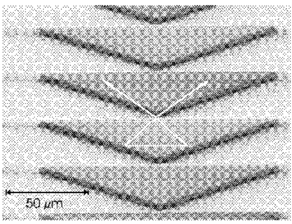
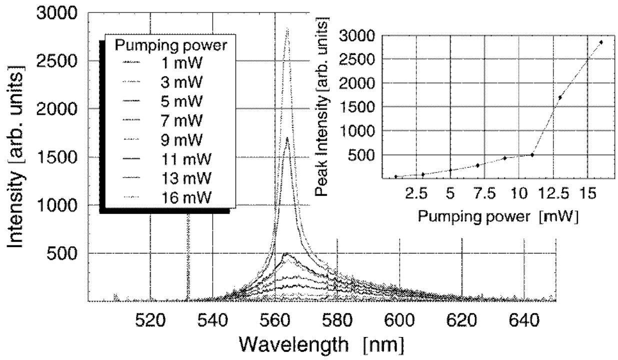




(a) $d = 4064\ \mu$m

(b) Peak wavelength: 595 nm





(c) $d = 190\ \mu$m

(d) Peak wavelength: 564 nm

Figure 1: **(a)** The SEM photo shows a trapezoid shaped cavity. The design relies on total internal reflection on three sides of the cavity. At the fourth side a reflection of 37 % is obtained. The fundamental round trip length superimposed on the picture is 4064 μm. **(b)** The spectra shows the output from the cavity described in (a) as the pumping power is increased. The insert plot maps the peak intensity as a function of the pumping power. The commencement of lasing is identified as a change of slope in the plot relating the peak intensity and the pumping power. The estimated threshold power is 2.5 mW. **(c)** The SEM photo shows a triangular shaped cavity. Due to a low angle of incidence at the output interface, a reflection of merely 5 % is achieved. The round trip length of this cavity is 190 μm. **(d)** The output from triangular cavity illustrated in (c) is depicted and the estimated threshold power is 11 mW. The peak at 532 nm is stray light from the pumping laser.

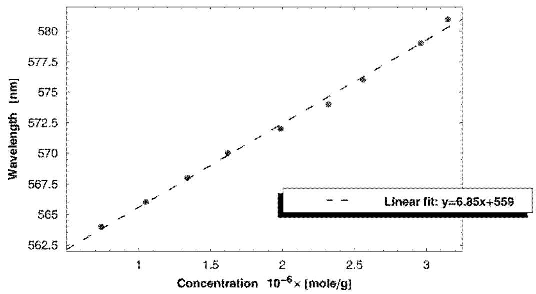


Figure 2: The lasing peak wavelength versus Rhodamine 6G dye concentration measured on a 4.8 μm thick SU-8 film on a gold/silicon substrate.

The SU-8 based micro cavities are defined on a Pyrex glass substrate by the standard photo lithographic process steps: spin-coating, soft-baking, i-line UV exposure, post-exposure baking, and development. The cavities were 4.5 μm high and the Rhodamine 6G concentration was $3.15 \cdot 10^{-6}$ mole/g. A detailed description of the fabrication process is given in [4].

The dye-doped SU-8 lasers are optically pumped by a pulsed, frequency doubled Nd:YAG laser at a wavelength of 532 nm, pulse length 5 ns and repetition rate 10 Hz. Rhodamine 6G has optical gain in the wavelength range from app. 550 nm to 620 nm. The pumping laser beam, with a spot diameter of 6 mm, is coupled into the laser cavity through the top surface. The laterally emitted light is collected by an optical fiber, connected to a spectrometer, with a wavelength resolution of 0.5 nm. Fig. 1(b) and Fig. 1(d) show emission spectra from a trapezoid and a triangular device respectively. The triangular device shows a lasing peak at 564 nm, and the trapezoid device lases at 595 nm, hence it is possible to vary the lasing wavelength more than 30 nm by change of the lateral design only.

The lasing peaks observed are a superposition of several modes. By considering the ratio of the FWHM to the free spectral range, the number of modes comprising the observed peak may be estimated. The free spectral range may be expressed as $\Delta\nu = c/nd$ where c is the speed of light in vacuum, $n = 1.59$ is the index of refraction for SU-8, and d is the round trip length which is outlined in Fig. 1(a), (c). The trapezoid shaped laser cavity has a round trip length of $d = 4064$ μm and combined with the observed FWHM of 8 nm, the number of modes supported is estimated to 145. Due to a shorter round trip length $d = 190$ μm in the triangular shaped device, the free spectral range is larger and the gain is reduced compared to the trapezoid shaped device. Hence, fewer modes are supported and with an observed

FWHM of 5 nm, the number of modes supported is estimated to be 5.

The lasing frequency may be estimated by considering the absorption and emission cross sections of the laser dye together with the properties of the cavity and the dye concentration, N. The cavity properties are expressed by the constant $C_{\mathrm{res}} = \ln(1/R)/d$ where R is the total mirror reflectance and d is the cavity round trip length. In [1] these parameters are employed in deriving an expression for the lasing frequency, ν, that increases monotonously with C_{res}/N. Hence, the lasing wavelength may be reached at longer wavelengths as the cavity length, the reflectance, or the dye concentration is increased. This is qualitatively observed when the lasing wavelength $\lambda = 595$ nm in the trapezoid shaped laser is compared to the wavelength from the smaller triangular shaped laser cavity that has a lower reflectance at the output interface. In this device lasing is observed at $\lambda = 564$ nm. The model could not be compared quantitatively to the experimental data, due to lack of precise knowledge of the emission- and absorption cross sections for Rhodamine 6G in SU-8. The relation between lasing wavelength and dye concentration has been measured separately in a 4.8 μm thick dye doped film on a gold/silicon substrate. The results, presented in Fig. 2, are also in agreement with the model.

In conclusion, we have realized a new type of optically pumped solid polymer dye lasers, which have been designed for lateral emission. The devices are fabricated by a single UV-lithography step on SU-8 photoresist, which is doped with Rhodamine 6G laser dye to achieve optical gain. The lasing wavelength is controllable by the lateral dimensions of the polymer microcavities and lasing wavelengths between 564 nm and 595 nm are demonstrated. The combination of lateral emission, controllable wavelength, and simple fabrication and integration makes this type dye laser an attractive and versatile component for microsystems.

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References

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[1] F. P. Schäfer, "Dye Lasers", Springer-Verlag, Berlin (1990)

[2] C. Hu and S. Kim, "Thin-film dye laser with etched cavity", Appl. Phys. Lett. **29**, 582 (1976)

[3] Y. Li, M. Sasaki, and K. Hane, "Fabrication and testing of solid polymer dye microcavity lasers based on PMMA micromolding", J. Micromech. Microeng. **11**, 234, (2001)

[4] S. Kragh and A. Kristensen, "Miniaturized solid state lasers based on a photodefinable polymer", Proc. Eurosensors 2003, (2003)