A NANOIMPRINTED MICROFLUIDIC DYE LASER

Daniel Nilsson, Søren Balslev, Theodor Nielsen, and Anders Kristensen
MIC – Department of Micro and Nanotechnoloy, Technical University of Denmark (DTU),
Building 345east, DK2800 Kongens Lyngby, Denmark
E-mail: dn@mic.dtu.dk
www.mic.dtu.dk

We present a polymer based microfluidic dye laser suitable for integration into micro total analysis systems, fabricated by nanoimprint lithography (NIL) [1] in the thermoplastic polymer COC (cyclo olefin copolymer) [2]. The device (se figure 1 and 2) consists of microfluidic channels, with sizes ranging from several mm down to 16 µm, and optical waveguides, all fabricated in one single NIL step. For the laser device, Rhodamine 6G dissolved in ethanol acts as active material, and the cavity is based on multiple reflections from a periodic structure of 16 µm wide, parallel microfluidic channels. Pyrex glass wafers are used both as substrate wafer and cover wafer, and since the refractive index of pyrex is lower than COC they also work as buffer and cladding layers for the waveguides in the structure. Lasing from the device is observed at 577 nm (see figure 3), when pumped with a frequency doubled Nd:YAG laser emitting at 532 nm where Rhodamine 6G has its absorption maximum.

The device described here has been presented earlier [3], where it was defined in the photodefinable polymer SU-8 and bonded to a pyrex cover wafer using a 5 µm PMMA film. The device presented in this paper however has a number of substantial improvements. By using NIL we can eliminate processing variations critical to the operation of the laser because the same stamp may be used many times to produce identical devices. Sub-µm features for optical frequency selective elements may be integrated with mm sized microfluidic parts and fabricated in the same single fabrication step. Furthermore, the use of COC also gives a number of important advantages. COC has significantly lower optical loss than SU-8, and is transparent down to 300 nm. COC is also chemically resistant to a large number of common polar solvents, which is of great importance for microfluidic applications. We have earlier shown that it is possible to perform optical lithography and metal lift off on top of a nanoimprinted COC structure, and that COC is an excellent thermoplast for NIL since it has a low viscosity, short relaxation time and low stiction to the stamp [4].

The NIL stamps are defined in silicon by optical lithography. Vertical sidewalls with low surface roughness are essential to the nanoimprint process and to achieve optically smooth structures. This is achieved with a combination of deep reactive ion etching (Inductively Coupled Plasma etcher from STS) to obtain vertical sidewalls, 400 nm wet thermal oxidation to smoothen out surfaces, and a complete removal of the oxide by a BHF etch. This results in vertical sidewalls with a roughness of approximately 15 nm. Finally, the stamp is coated with an anti-sticking coating from a C_4F_8 plasma to achieve good release between the stamp and polymer after nanoimprint. The substrate wafer is spin coated with an 11 µm COC film. The stamp has a protrusion height of 10 µm, and because of the good NIL properties of COC, the stamp is completely submerged into the polymer leaving a residual layer of approximately 1 µm. A thin residual layer is essential for optical applications to have good control of optical modes. The NIL is performed in a home-built machine where the COC is heated to 170 °C, i.e. 90 °C above the glass transition temperature, during imprint. When the elevated temperature is reached, the stamp and substrate are pressed together with a force of 2000 N, which is kept for 10 min, and then cooling is applied. When the temperature has reached 70 °C the force is released and the stamp and sample are separated. Finally, the imprinted device is bonded to a second Pyrex wafer coated with a 300 nm COC film. Bonding is performed in the same tool as NIL, but at 90 °C (i.e. 10 °C above glass transition temperature).

References:
[1] S. Chou, Appl. Phys. Lett. **67** (1995) 3314
[2] The COC used here is sold under the name Topas® by Ticona www.ticona.com
[3] S. Balslev, A. Kristensen, to be presented at CLEO/IQEC 2004
[4] T. Nielsen, D. Nilsson, F. Bundgaard, P. Shi, O. Geschke, P. Szabo and A. Kristensen, to be presented at EIPBN48 2004

Figures:

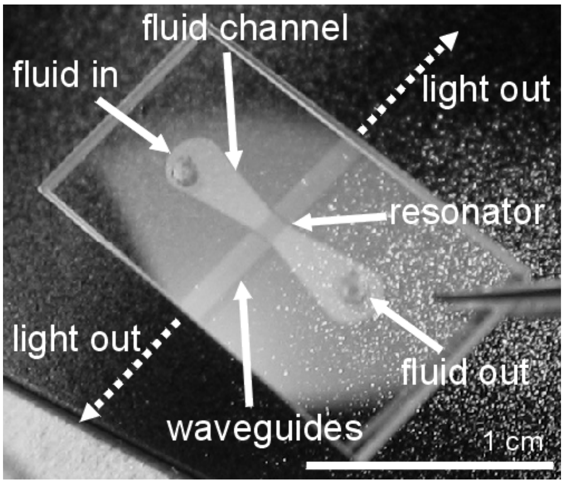

Figure 1. Overview of the device. The laser resonator indicated in the figure, comprising of several parallel microfluidic channels, can be seen in detail in figures 4 to 6.

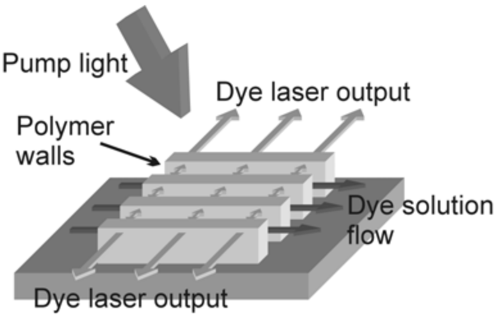

Figure 2. Schematic picture of the resonator.

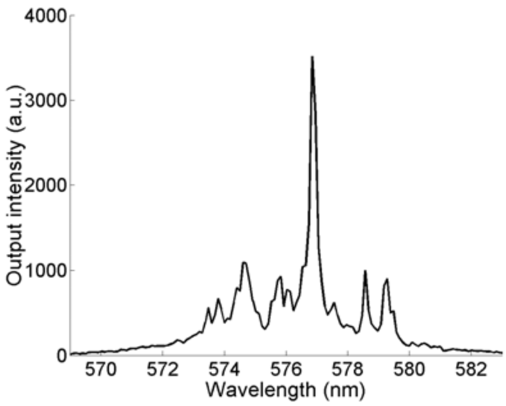

Figure 3. Output spectra from the microfluidic dye laser when pumped by a frequency doubled Nd:YAG laser at 532 nm. The laser peak is observed at 577 nm.

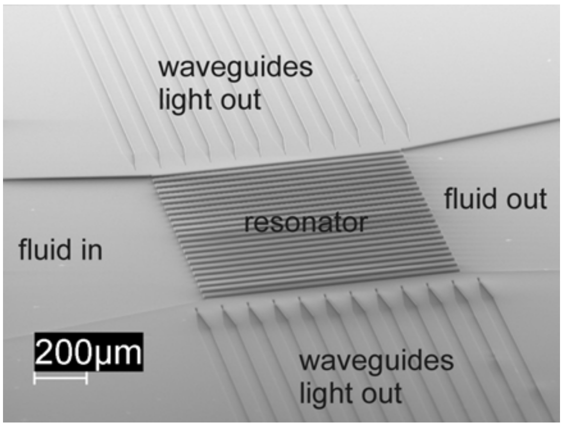

Figure 4. SEM image of the imprinted polymer device (the polymer is coated with a thin metal film).

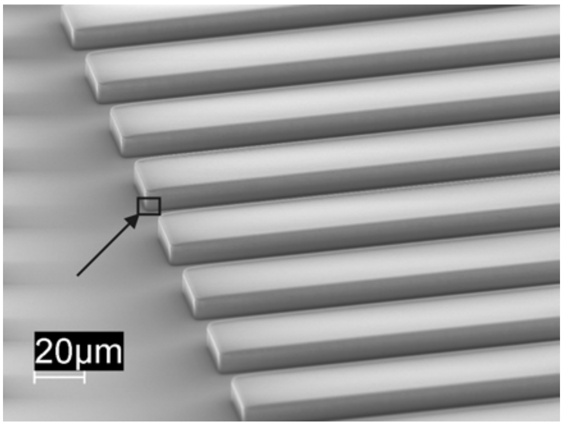

Figure 5. SEM image of the periodic microfluidic channels in the laser resonator. The arrow indicates the section enlarged in figure 6.

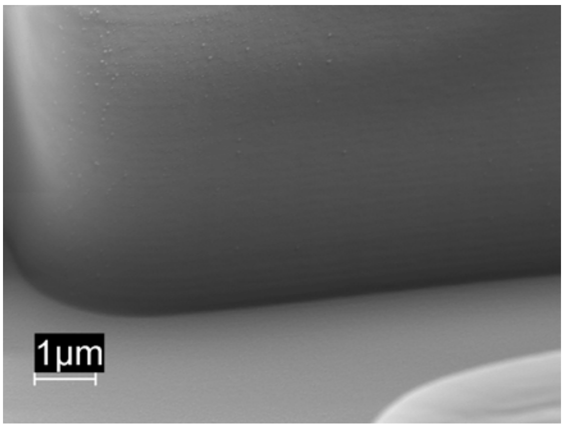

Figure 6. SEM image of the sidewall of an imprinted microfluidic channel, close-up. The surface roughness is estimated to be of the order of 15 nm.