

Fabrication and characterization of organic solid-state lasers using imprint technologies

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The basis for small and portable optical sensor systems are inexpensive light sources. Light emission is utilized in optical detection schemes such as laser-induced fluorescence, absorption or evanescent field sensing. While organic and inorganic light-emitting diodes are comparatively cheap and small, certain applications require a laser light source [1]. Here, organic solid-state lasers are a promising choice as their fabrication involves only few steps and they cover a wide spectral range from ultraviolet to near-infrared. We investigate the fabrication of optically-pumped organic solid-state lasers consisting of a nanostructured substrate coated with an active laser material. The periodically nanostructured substrate forms a 1D- or 2D-photon crystal resonator providing the necessary optical feedback for lasing. The feature size of the resonator structure is as small as 200 nm. Aluminum tris(8-hydroxyquinoline) (Alq_3) doped with the laser dye 4-dicyanomethylene-2-methyl-6-(p-dimethylaminostyryl)-4H-pyran (DCM) is used as active material. As the refractive index of the active layer is chosen to exceed that of the substrate, a planar waveguide is formed supporting the laser mode.

We investigate the fabrication of the laser resonators by UV and thermal nanoimprint technologies. One goal of our work is the development of a process for the cost-efficient fabrication of organic laser in a wafer-scale production. Furthermore, the combination of the organic lasers with polymeric waveguides is demonstrated. This opens the way to a further integration into chip-based microfluidic sensors.

The master structures for both imprint technologies are fabricated by e-beam lithography on an oxidized silicon wafer. The 70 nm deep resonator structures are transferred onto a silicon wafer via reactive ion etching. The wafer is then coated with a metal seed layer and a nickel shim is formed by electroplating.

For UV nanoimprinting the inorganic-organic hybrid material Ormocer® is used as the resonator material. Ormocer® is a very stable material with low absorption in the visible wavelength region. In order to protect the nickel shim we employ a secondary master fabricated by hot embossing in the Cyclo-Olefin-Copolymer Topas®. The nickel shim is shown in figure 1 and a picture of the imprinted structures can be seen in the inset of figure 2. After high-vacuum deposition of the active organic material Alq_3 :DCM on top of the Ormocer® resonator, the material is optically excited by a UV-laser. Figure 2 shows the dependency of the laser wavelength and threshold on the resonator periodicity. This demonstrates the feasibility of the UV nanoimprint technology for the fabrication of high quality laser resonators. Fabrication of multimode waveguides with Ormocer® using UV lithography [2] has been demonstrated, thus the combination of laser resonator structures and waveguides for integrated systems is possible.

In our second approach we fabricate organic lasers on polished poly (methyl methacrylate) (PMMA) wafers using thermal nanoimprint lithography (also referred to as hot embossing). This material is commonly used in micro-optics and micro-fluidics. It is transparent in the visible and infrared region and is biocompatible. Another unique feature is the possibility of directly inscribing waveguides and waveguide-based devices like couplers and tapers [3]. This can be done by changing the refractive index of PMMA through deep ultra-violet (DUV) radiation.

We combined the imprint technology and the DUV-modification of PMMA to fabricate waveguide-coupled organic lasers. After imprinting the resonator structures directly with the nickel shim, waveguides are defined by a subsequent lithographic step using a deep UV light source (200-240 nm) and a chromium mask. The waveguides are patterned either in the immediate vicinity to or across the resonator structure as shown in figure 3.

For the characterization, the active material is pumped optically using a short pulse UV-laser. The resulting laser emission is coupled into the waveguides by evanescent field coupling. The guided laser light is detected at the end facet of the waveguide using a fiber coupled spectrometer. The laser emission is centered at the Bragg wavelength of 643 nm with a full width-half maximum of 0.4 nm (see figure 4).

In order to fabricate a complete analytical system, microfluidic channels can be combined with the organic laser sources by a second imprinting step or by using a tool which combines channel and resonator structures. This is a

step towards the wafer-scale production of an integrated optical sensor system.

In conclusion we have demonstrated the feasibility of both UV and thermal nanoimprinting as fabrication tools for organic laser resonators. In conjunction with the realized waveguide coupling an important step towards an integrated organic laser source for optical sensor systems is presented.

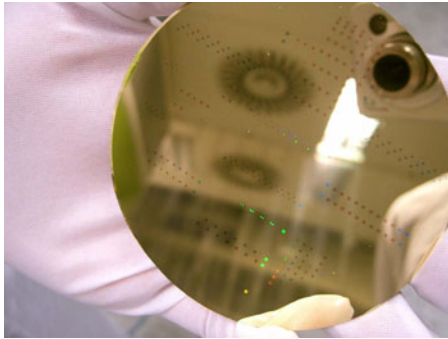


Fig.1 Photograph of the nickel shim with laser resonator structures.

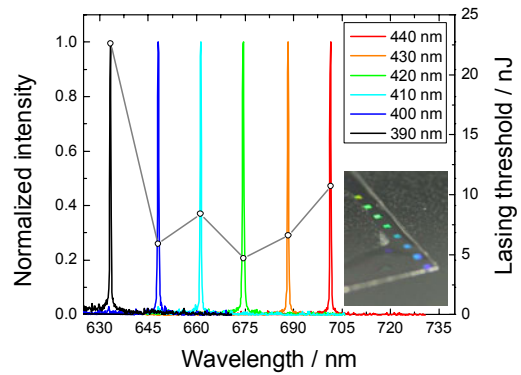


Fig.2 Emission spectra and lasing thresholds of the Alq₃:DCM lasers with different resonator periodicities. Inset: Photograph of the imprinted structures.

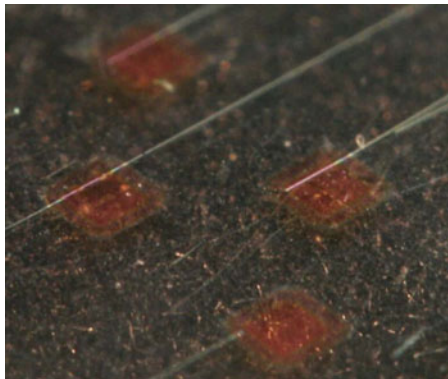


Fig.3 Photograph of the waveguide-coupled organic lasers. The patches are the laser resonators with the active material on top, the thin lines are the waveguides defined by DUV-modification in PMMA.

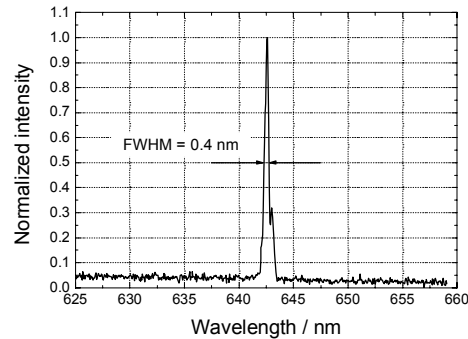


Fig.4 Spectra of the emission of an Alq₃:DCM laser measured at the end facet of the waveguide.

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