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FAST TRACK COMMUNICATION

Characterization of channel waveguides and tunable microlasers in SU8 doped with rhodamine B fabricated using proton beam writing

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Abstract
We present our results on the fabrication and characterization of buried channel waveguides and tunable microlasers in SU8 doped with rhodamine B achieved using direct writing with a 2.0 MeV proton beam. The channel waveguides, fabricated in single exposure, had an optical propagation loss of $<0.5\,\mathrm{dB\,cm^{-1}}$ at 532 nm measured using the scattering technique while the microlasers with dimensions of $250 \times 250\,\mu\mathrm{m}^2$ had a threshold of $\sim 150\,\mu\mathrm{J\,mm^{-2}}$ when pumped with 532 nm nanosecond pulses. The emitted wavelength from the microlasers was tunable to an extent of ~ 15 nm with increasing pump intensity and different pumping angles. The advantages of such micro-photonic components for the realization of a lab-on-a-chip device are discussed briefly.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Polymer based fluidic and optical devices are attractive for diverse applications such as lab-on-a-chip (LOC), telecommunications, displays and biomedicine [1–11]. Polymers are an appealing alternative for silicon and glasses for their versatility, low cost and tunability. Some of the common polymers/resists used in various lithographic techniques for fabrication of devices are polymethyl methacrylate (PMMA), cyclic olefin copolymer and SU8. The important requisite for the realization of LOC devices is the integration of passive and active structures on a single substrate enabling different functionalities and that for optofluidic devices is the realization of fluidic channels and optical structures on a single substrate. Techniques, especially those which employ direct writing, with the ability of mass replication and simultaneous production of high quality three dimensional structures are quite a few [12]. Proton beam writing (PBW) is a new direct-write technique developed at the Centre for Ion Beam Applications, National University of Singapore, for creating three-dimensional, high aspect ratio micro- and nano-structures with straight and smooth sidewalls in resists, polymers, glasses and other materials [12–28]. Direct writing with high-energy proton beams is effective in fabricating arbitrarily shaped three dimensional structures (e.g. Y-branch, Mach–Zehnder type, ring resonator structures) along with micro-/nano-fluidic channels in a variety of materials such as polymers, silicon and bio-compatible Foturan glass. Some of the earlier successful demonstrations of passive devices using this technique include SU8 channel waveguides [16, 17] with extremely high quality side walls [18] and Y-branches [19], PMMA buried channel waveguides [20], erbium doped phosphate glass waveguide

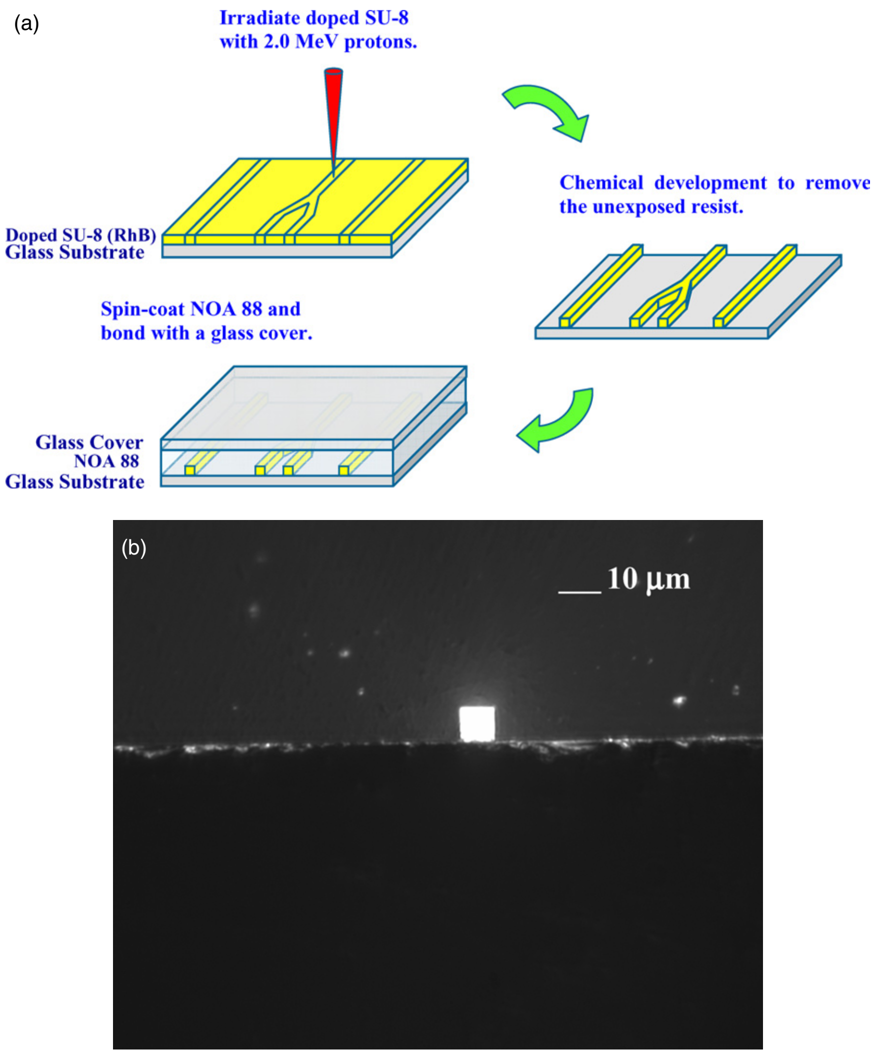

Figure 1. (*a*) Procedure for fabricating waveguides in SU-8 doped with rhodamine B. (*b*) Optical picture of end facet of the channel waveguide obtained in SU8 waveguide (doped with RhB) with white light.

amplifiers [21], micro- and nanochannels [22, 23] using direct write as well as imprinting [23], waveguides and microchannels in Foturan glass [24, 25] microlens array for tweezing applications [26] and microstructures in silicon [27]. The recent achievement of writing 22 nm structures in hydrogen silsesquioxane resist [14] highlights the potential of this technique in manufacturing high aspect ratio structures. The advantages of PBW compared with other techniques like optical or x-ray lithographies is the non-involvement of external mask and in tandem with nanoimprint lithography enables rapid prototyping of smooth, high aspect ratio three dimensional structures. The manifestation of such devices in photonic, microfluidic and LOC applications has been well established in the last couple of years [9, 10]. Recently, we had successfully fabricated microlasers in SU8 doped with rhodamine B dye and demonstrated lasing action with low threshold near the 600 nm spectral region [28]. Earlier, we had also demonstrated very low-loss passive waveguides in SU8 and this combination can result in microfluidic dye lasers essential for a variety of applications in sensing and biomedicine. Here we present our results on the fabrication of millimetre-long active waveguides in SU8 and the tunability of laser emission from the microlasers in rhodamine B doped SU8.

2. Experiment

PBW was carried out using the high-brightness 2.0 MeV Singletron facility at the Centre for Ion Beam Applications, National University of Singapore. SU8-2005 was purchased from MicroChem and used as is. Rhodamine B was dissolved in SU8-2005 (in cyclopentanone) and left in an ultrasonic bath for a few hours to obtain a clear solution. For waveguide fabrication, SU8 doped with RhB (1% by weight) was spin coated onto a glass (GE124, refractive index of ∼1.457) substrate. Upon proton beam irradiation and followed by chemical processing the cross linked SU8 was retained while the rest of the resist was washed out. We later spin coated NOA88 (a UV adhesive) over these structures to achieve buried waveguides with SU8 + RhB acting as the core. A glass plate was placed over the structure for protection and easier handling purposes. The end facets were optically polished for coupling light into the waveguides. The different steps involved in the procedure are depicted in figure 1(*a*). In