

Proton beam writing of dye doped polymer microlasers



Sudheer Kumar Vanga*, Andrew A. Bettiol

Centre for Ion Beam Applications, Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117551, Singapore

ARTICLE INFO

Article history:

Received 25 July 2014

Received in revised form 23 December 2014

Accepted 12 January 2015

Available online 2 February 2015

Keywords:

Proton beam writing

Whispering gallery mode cavities

Microlasers

Optical pumping

ABSTRACT

Proton beam writing is employed to fabricate smooth sidewall whispering gallery mode microcavities in dye-doped polymer. These microcavities acts as microlasers under optical excitation in ambient atmosphere. Different cavity designs are implemented to obtain directional laser emission from the whispering gallery mode lasers. The microcavities are fabricated in Rhodamine B doped SU-8 polymer and are optically pumped with 532 nm pulsed laser. These microlasers emit light within the emission band of Rhodamine B with operational wavelength around 600 nm and the required pumping laser threshold is lower than 3 $\mu\text{J}/\text{mm}^2$ for all the micro-lasers.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Proton beam writing (PBW), a high resolution direct write lithographic technique, is becoming increasingly interesting because of its continuous improvement in spatial resolution [1,2] as well as its applicability to wide range of materials. PBW was initially applied to create structures in polymers [3] however, in recent years the technique is applied to various materials due to development of different post processing techniques [4,5]. By controlling the beam energy and the post processing conditions three dimensional high aspect ratio structures could be realized using this technique [6,7]. With PBW the fabricated structures have straight and smooth sidewalls and hence they are well suited for optical applications [8,9].

Whispering gallery mode (WGM) microcavities are circular dielectric structures in which the optical mode is confined along circumference of the cavity. Because of high confinement of optical fields within cavity, these cavities have ultra high quality factors in variety of materials [10,11]. The high-Q cavities have wide range of applications in different fields [12,13]. One of the applications is microlaser, as a result of high quality factors low linewidth lasers can be realized. Conventional WGM lasers emit light in all directions because of its circular symmetry and this makes these lasers incompatible to implement in a photonic integrated circuit. The directionality in these WGM microlasers was achieved by breaking the symmetry of the cavity design [14,15].

In this work, PBW was applied to the fabrication of microlasers in dye doped polymer layers. Both conventional and directional WGM microlasers were fabricated and their emission characteristics were measured.

2. Materials and methods

2.1. Fabrication

WGM microdisk cavity fabricated in SU-8 polymer using PBW has been reported previously with a quality factor of the order of 10^4 in telecommunication wavelength range [16]. Along with the same microdisk cavity other cavity designs are implemented for microlaser cavity. The cavities have been assigned labels as follows.

1. Cavity A – Microdisk
2. Cavity B – Spiral disk
3. Cavity C – Spiral disk with extended waveguide
4. Cavity D – Ellipse with a notch in the middle
5. Cavity E – Spiral ellipse with extended waveguide

The design parameters for all the cavities are discussed here. The Cavity A is designed with a radius of 25 μm . For Cavities B and C, the spiral shape is defined by the following equation.

$$r = r_0 \left(1 + \frac{\epsilon}{2\pi} \phi \right) \quad (1)$$

where r_0 is the inner radius of the spiral and ϵ is the aspect ratio and ϕ is the radial angle. In the case of Cavity B, ϵ is 0.1 and r_0 is

* Corresponding author.

E-mail address: physkv@nus.edu.sg (S.K. Vanga).

13.6 μm , and for Cavity C, ϵ is 0.1 and the inner radius is 50 μm . The Cavity D is designed such that the ellipse major to minor axis ratio is 1.25 and a wavelength size notch is introduced in the middle of the cavity in the minor axis direction. The major axis dimension of the ellipse is 125 μm . The Cavity E is designed such that the ellipse major to minor axis ratio is 2 with major axis dimension 80 μm and the waveguide width is 5 μm .

For the fabrication of these cavities, first a 5 μm thick Rhodamine B doped SU-8 polymer was spin coated on a 4 μm thermally grown silicon dioxide on silicon substrate. The dye doped polymer composite preparation and the optimization of the dye concentration (1% by weight) was carried out and was reported [17]. Proton beam writing was then performed by focusing the 2 MeV proton beam down to a 100 nm spot size and the beam was scanned to obtain the desired cavity design. The optimized proton fluence of 80 nC/mm² was used for fabrication of all the cavities. The SEM micrographs of all the fabricated microlasers can be seen in Fig. 1.

2.2. Characterization

The Rhodamine B doped SU-8 polymer has absorption band ranges from 500 nm to 580 nm, so in the current optical set-up a pulsed, frequency doubled Nd:YAG laser operates at 532 nm wavelength was used as an optical excitation source. The laser has a repetition rate of 10 Hz and gives 7 ns pulses. The pump laser was directed on to the sample with a 45° mirror. The pump laser spot

size was reduced using a fixed 600 μm aperture to make sure that the microlaser cavity has uniform pump laser illumination. A 10× objective lens together with a fiber coupled spectrometer was used to collect the emission from the microlaser cavities. The schematic and the actual optical set-up can be seen in Fig. 2(a) and (b). This set-up also allowed us to view the emission directionality by replacing the fiber coupled spectrometer with a CCD camera.

3. Results and discussion

All the fabricated microlaser cavities were characterized using the optical set-up. The pump laser fluence is a measure of laser energy delivered per unit area and is calculated from the laser energy (E) and beam waist radius (ω_0) using the formula.

$$\text{Fluence } (F) = \frac{\text{Laser pulse energy } (E)}{\text{Effective focal spot area}} = \frac{E}{\pi\omega_0^2} \quad (2)$$

The microlaser emission intensity was collected by varying the pump laser energy from which the threshold fluence was calculated for each laser cavity. The linewidth of the microlaser emission lines was not measured because of the limitation of spectral resolution of the spectrometer used (Ocean Optics HR4000). So, we were unable to calculate the Q factor of the microlasers. A typical emission spectrum collected for spiral disk laser and the threshold curve is shown in Fig. 2(c) and (d). The emission bandwidth and the threshold laser fluence for all the cavities were mea-

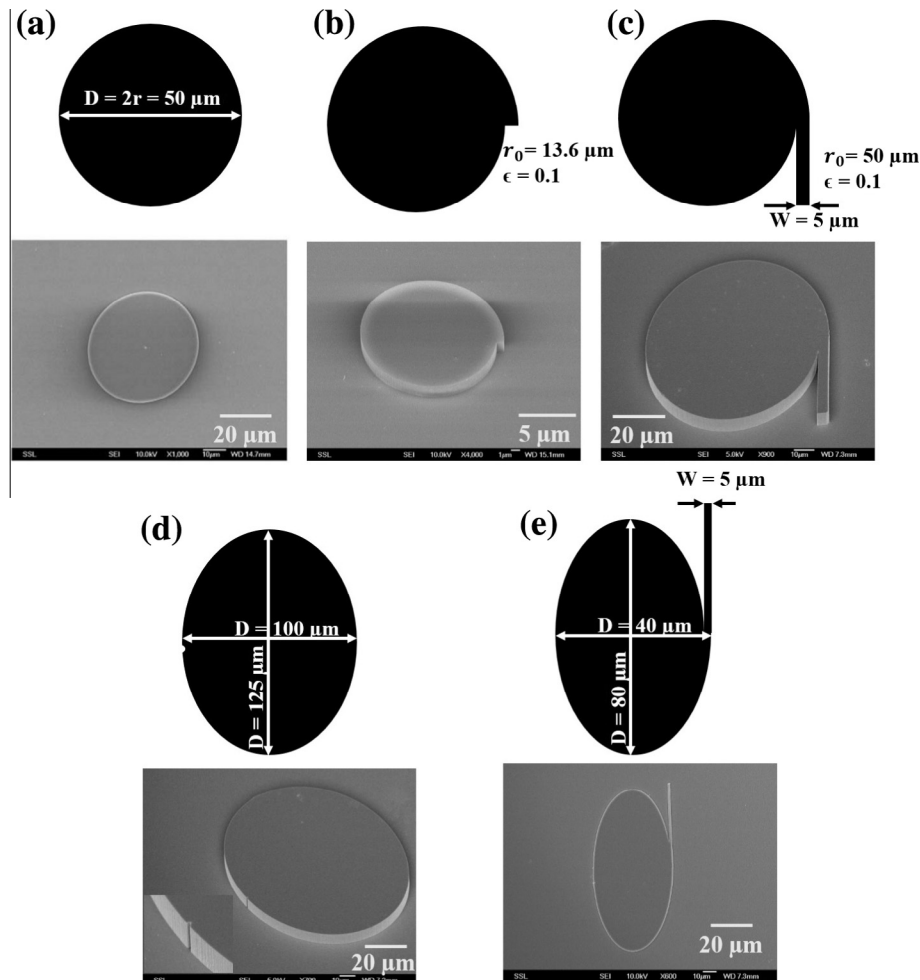


Fig. 1. The cavity design with parameters and the corresponding SEM micrographs of the fabricated WGM microlasers (a) microdisk (b) spiral disk (c) spiral disk with extended waveguide (d) ellipse with a notch in the middle, the inset shows the notch region (e) spiral ellipse with extended waveguide.

Download English Version:

<https://daneshyari.com/en/article/1680377>

Download Persian Version:

<https://daneshyari.com/article/1680377>

[Daneshyari.com](https://daneshyari.com)