Micropositioning of Microsphere Resonators on Planar Optical Waveguides

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Abstract: Topographical structures to position microsphere resonators accurately upon planar optical waveguides have been designed and fabricated. The methods being employed to assemble the microspheres on the patterned planar waveguides are discussed.

1. Introduction

The emergence of monolithic resonators has revolutionized the field of linear and nonlinear optics where either the storage or recirculation of optical power (to achieve high intensities) is required. When compared to conventional optical resonators employing two or more mirrors, monolithic resonators are miniaturized, suitable for on-chip integration, and also deliver all the functionalities and can perform better than conventional resonators [1]. The simplest geometries of such resonators are a ring or a disc or a sphere. Although the micro ring or disc resonators have the advantage of easy integration with the bus waveguide as both of them are fabricated out of the same chip, the fabrication techniques used (photolithography and dry etching) render them with more surface roughness which limits the quality (Q) factor and finesse. On the other hand, microsphere resonators made of glass may be fabricated as spheres from the melt and therefore attain very high surface qualities. The Q factor of such resonators are ultimately limited by the material attenuation and can be as high as 10^{10} [2].

Most of the studies on microsphere resonators, so far, have utilized microspheres fabricated by melting the tip of an optical fiber and the resulting stem attached to microsphere has been useful as a tool to place the sphere at the required position while characterising the microsphere. However, for integration in all-optical devices, isolated microspheres are more convenient. Free space excitation of microsphere whispering gallery modes (WGM) is extremely inefficient due to the mismatch in the phase velocities of light in air and the WGM's. However, efficient excitation can be achieved using evanescent coupling. The most efficient coupling to date has been realised with the tapered optical fibres [3]. Although, this is the preferred method of coupling under laboratory conditions, it is too fragile and labour-intensive for device realisation, and sensitive to environmental conditions. We provide a solution for the above two limitations by positioning the isolated microspheres onto planar (buried channel or rib) waveguides by chemical or topographical means. Integration of microsphere resonators in optical waveguide circuits offers the potential for high-Q devices for wavelength filtering, nonlinear switching, pulse shaping and lasing. The planar configuration offers robust construction, and photolithographic techniques will permit multiple spheres to be placed in well-defined positions on a substrate to build up circuit functions. This paper describes the design and fabrication of such platforms to enable the positioning of microspheres on planar optical waveguides.

2. Design

The positioning of microspheres is undertaken using two methods, (i) topography and (ii) wetting and dewetting (referred to as chemical patterning from here on). Fig. 1 shows a schematic of the process steps involved in both these positioning methods. In the topographical method (a), the glass substrate containing the waveguides coated with a transparent (photoresist) overlayer in which microwells are aligned above the waveguides is placed at an incline in a liquid medium containing the microspheres. Appropriately sized individual microspheres become trapped in the microwells and the excess flows over the surface. The fabrication of the waveguides and the overlayer with the microwell patterns are described in the next section. The geometries and dimensions of the microwell patterns used in the present study are detailed in the Table 1 [4]. In the chemical patterning method (b), the same photomask used to create the microwell patterns on the photoresist layer in the topography method is used to transfer the patterns and modify the surface of

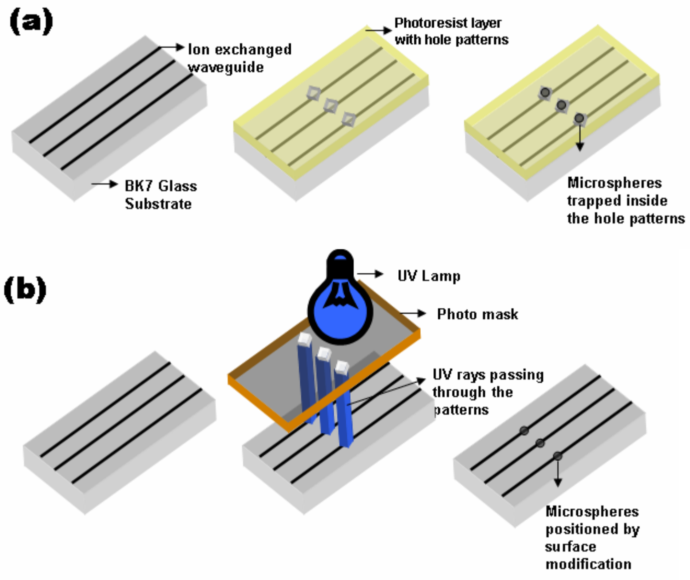

Fig. 1. Schematic of the two processes to position microspheres on planar waveguides.

the waveguides photochemically. When the microspheres flow over the chemically modified substrate, wetting will cause the microspheres to attach at the patterns. Dewetting ensures that they do not attach elsewhere.

Table 1. Pattern geometries and dimensions for the positioning of different sized microspheres

Sphere diameter (d) (µm)	Circle diameter (D) (µm)	Equilateral triangle length of each side (µm)	Diamond shape length of each side (µm)	Depth of features of the photoresist layer (µm)
5	7	10	6	5
10	14	20	12	10
30	42	60	36	30

3. Fabrication

Photomasks for the fabrication of the waveguides and the microwell patterns were designed and made by electron beam lithography. Waveguides were formed in BK7 glass by ion-exchange from a KNO_3 melt at 350-400°C, through Al openings of 5µm width, for a duration of 4-20 hours. SU-8 photoresist layers of thickness 5, 10 and 30µm were spin coated on glass substrates containing the waveguides. The three different microwell patterns detailed in Table 1 were photolithographically reproduced in these SU-8 films. Fig. 3 shows an example of the developed diamond-like patterns in a 10 µm thick SU-8 film.

Fig. 2. SU-8 photoresist of 10 µm thickness containing diamond shaped microwells.

4. Experimental Results and Discussion

Fig. 3 shows the microspheres trapped inside the triangular patterns using the topographical method. The wedge shape aligned with the flow direction of the triangle and the diamond enables the microspheres to be positioned with great accuracy as they are forced into the pointed corner by the liquid flow. As expected, it was found that the circular patterns exhibited less accuracy in positioning unlike the triangle and diamond. The angle of the substrate containing the patterns was carefully optimised to ensure that the trapped microspheres do not come out into the sweeping liquid flow and at the same time the untrapped microspheres are completely washed away by the liquid flow.

Different pattern geometries may be preferential for particle assembly on chemically modified substrates, where capillary forces and hence pattern dimensions are more important than pattern shape [5]. The preliminary attempts towards chemical patterning were very promising and the detailed studies are in progress and will be reported elsewhere very shortly.

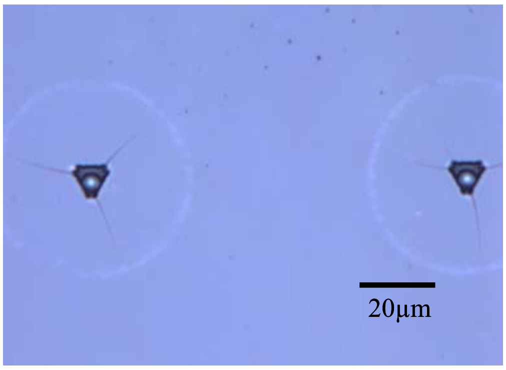

Fig. 3. 5µm microspheres trapped inside triangular microwells in a 5 µm thick SU-8 film.

The micropositioning of microspheres on planar waveguides will be useful in two ways. Initially it will render characterisation of the coupling between the microresonator and the waveguide more precise in terms of its lateral and vertical displacement from the centre of the waveguide. SU-8 microwells whose centers shift progressively from the center of each waveguide by 200 nm have been developed. This will give insight in to the coupling characteristics of the microsphere and waveguide with lateral displacement. We are also planning to use PECVD to coat SiO_2 layers of various thickness between the waveguide and the microspheres to study the coupling characteristics with vertical displacement. Once single sphere coupling is fully characterised, micropositioning will be employed to realise multifunctional planar lightwave circuit devices integrated with microsphere resonators.

5. Summary

We have proposed and demonstrated ways in which microsphere resonators can be efficiently and precisely positioned on planar waveguides. The micropositioning of microsphere resonators on planar waveguides offer opportunities for complicated device structures not possible hitherto.

This work was supported by UK EPSRC grant GR/S96500/01.

6. References

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