Fabrication of Nanophotonic Circuit Components by Thermal Nano Imprint Lithography

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Abstract: Nanophotonic components are fabricated using thermal nano imprint lithography (NIL). A silicon-on-insulator Mach-Zehnder interferometer with 20 dB extinction ratio is demonstrated. Grating couplers fabricated by a two-step imprint process demonstrate over 14% coupling efficiency.

OCIS codes: (130.3120) Integrated optics devices; (050.2770) Gratings

1. Introduction

Material platforms with a high refractive index contrast are very interesting for future integrated photonic circuits. Ultra-compact waveguide and photonic crystal based components for passive as well as active functions have been demonstrated in high refractive index platforms such as Silicon-on-Insulator (SOI) or Indium Phosphide (InP) membranes or a combination of both [1,2]. In the context of transferring membrane-based nanophotonics from research to applications it is of high relevance to assess methods of volume manufacturing such components and systems without compromising flexibility towards choice of materials and substrate shapes. Nanoimprint Lithography (NIL) is emerging as a cost-efficient fabrication approach providing this type of flexibility and capable of nanometer-to-micrometer-scale pattern definition in a parallel process [3]. In this paper, we demonstrate the fabrication of nanophotonic components in SOI using thermal NIL [4]. Also demonstrated is the integration of grating couplers for alignment-tolerant fiber access using a double-step imprinting process.

2. Nano Imprint Lithography Fabrication

The fabrication of the SOI-based nanophotonic devices was done using thermal NIL using a 5 x 5 cm stamp containing the desired pattern. The stamp was cut out of an 8 inch silicon wafer patterned by Deep UV-lithography and inductively coupled plasma (ICP) etching and treated with an anti-stiction coating of FDTS using MVD (Applied Microstructures, Inc.). The nanophotonic devices are fabricated in a 5 x 5 cm SOI substrate cut out from an 8 inch SOI wafer purchased from Soitec (220 nm silicon layer on top of a 2 µm buried oxide). A 190 nm thin 50k PMMA film was spin coated onto the SOI substrate and imprinted using a force of 5 kN for 1 hour in a parallel plate imprint tool (EVG 520HE) at a temperature of 190°C. The nanoimprinted patterns were then transferred into the top silicon layer of the SOI by SF_6-based RIE etching.

For optical characterization of the fabricated components, the SOI sample was thinned down to a thickness of about 300 µm for facilitating the cleaving of facets. Light from a tuneable laser was butt-coupled into the devices and the output was monitored. A picture of a fabricated Mach-Zehnder interferometer is shown in Fig.1 (a). The measurement result is shown in Fig. 1 (b).

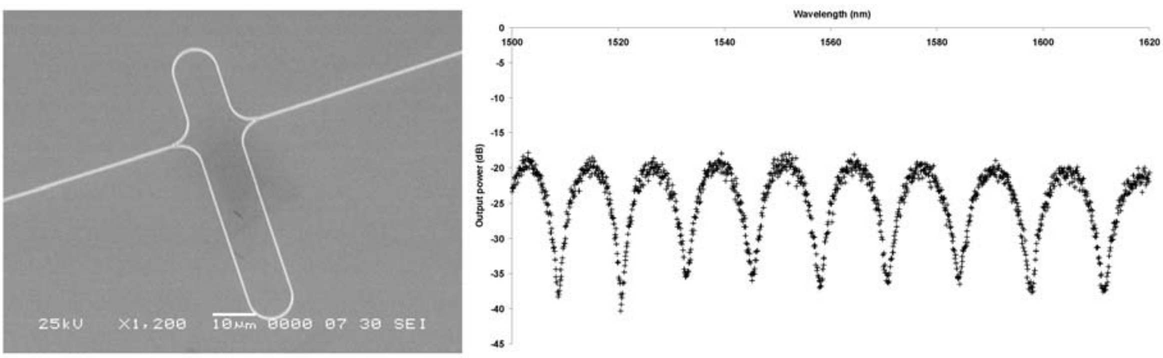

Fig. 1. SOI Mach-Zehnder interferometer fabricated by a single-step thermal Nanoimprint Lithography (NIL) process. (a) SEM-picture. (b) Measured output power as a function of wavelength.

3. Two-step Nano Imprint Lithography Fabrication

A mold was designed for defining grating couplers into SOI waveguides for alignment-tolerant, efficient and broadband coupling between the silicon waveguides and single-mode optical fibers. This second mold was fabricated using e-beam lithography on a silicon wafer. 630 nm pitch gratings were written using a 100 kV electron beam tool (JEOL JBX9300FS) in ZEP520Aa resist. After development, deposition of 30 nm of Al and lift-off, the written structures were transferred 280 nm into the silicon substrate by RIE. An anti-stiction coating was applied to finalize the mold. 500 nm PMMA was spin-coated on top of an SOI sample that contains waveguides. Prior to imprinting, the mold was aligned to the substrate so that the position of the grating lines was perpendicular to the waveguides. Imprint was performed using the same parameters as described above. After the imprint the gratings were transferred 60 nm into the SOI waveguide by SF_6-based RIE etching. A picture of the fabricated device is depicted in Fig. 2 (a).

The coupling efficiency of the fabricated grating couplers was determined experimentally. Transmission measurements were performed by coupling laser light in via a first grating coupler and coupling the light out via a second coupler integrated on the same waveguide. An index matching fluid was applied between the fibers and the grating couplers. Assuming lossless transmission between the two grating couplers and assuming that both couplers are equally efficient, the coupling efficiency can be calculated. The result of this calculation is plotted in Fig. 2 (b). To this end, a fiber-to-waveguide coupling efficiency of 14 % was demonstrated with a central wavelength of 1570 nm and a 1dB bandwidth of slightly less than 40 nm.

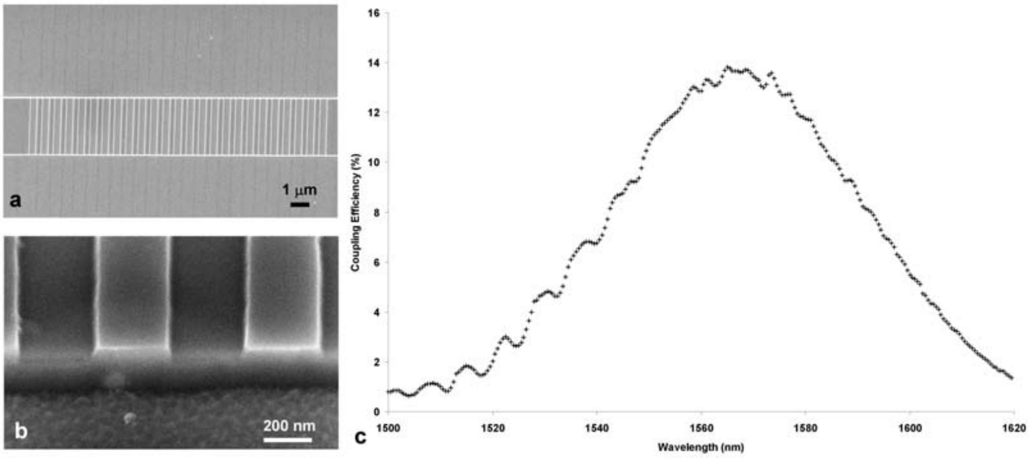

Fig. 2. Fiber grating couplers for SOI waveguides fabricated by a two-step thermal Nanoimprint Lithography (NIL) process. (a) SEM picture of the fabricated grating coupler with a 630 nm period, 50 % filling factor and grating etch depth of 40 nm. (b) Detail of the grating teeth. (c). Experimentally determined fiber-to-waveguide coupling efficiency as a function of wavelength.

4. Conclusion

Nanoimprint lithography is a flexible and cost-efficient fabrication approach for high index contrast based nanophotonic circuits and systems. We demonstrated and optically characterized SOI nanophotonic circuit components fabricated by thermal nanoimprint lithography (NIL). A single-step nano imprint approach allowed for the fabrication of a Mach-Zehnder interferometer with 20 dB extinction ratio. A two-step nanoimprint approach allowed for the fabrication of fiber grating couplers with 14 % coupling efficiency. Ongoing work focuses on further optical characterization of the imprinted SOI components. This will allow a study of the uniformity of the fabricated devices within dies and between dies. Moreover, it will allow comparing the results obtained here to conventional processing approaches such as DUV-lithography.

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