UV-based Nano Imprint Fabrication of Gold Grating Couplers on Silicon-on-Insulator

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Abstract: Fiber-to-waveguide gold grating couplers are fabricated using UV-based Nano Imprint Lithography and lift-off on top of an unprocessed Silicon-on-Insulator chip. Over 22% efficiency and a 1dB bandwidth of 36nm is demonstrated in the telecom band.

1. Introduction

Silicon-on-Insulator (SOI) is emerging as an interesting platform for integrated optics due to the high refractive index contrast between the silicon core and the oxide cladding ($\Delta n \approx 2$), enabling large density photonic integrated circuits. Due to the large mismatch in mode size and shape between the fundamental mode of SOI waveguides and the mode of an optical fiber, coupling light efficiently from fiber to waveguide is rather challenging. In this paper, efficient and broadband gold grating couplers as compact as 10 µm x 10 µm are fabricated using UV-based Nano Imprinting and lift-off. Simulation of this metal grating coupler shows that its coupling efficiency is highly dependent on the filling factor of the grating. This is validated experimentally by fiber-to-fiber transmission measurements using the fabricated gold gratings for coupling to and from the top silicon waveguide layer of an SOI substrate.

2. Simulation

The grating coupler layout consists of an SOI slab waveguide structure with a metal grating on top of the silicon waveguide layer. Due to the high refractive index contrast between the metal teeth and the surroundings, the grating causes strong diffraction of light allowing for efficient and broadband fiber-to-waveguide coupling [1,2]. In Fig. 1 the coupling efficiency of a gold grating coupler is simulated for an SOI layer structure with a top silicon layer thickness of 220 nm and a buried oxide layer thickness of 2 micron. The plot illustrates the influence of the grating filling factor on coupling efficiency and spectral properties of the gold grating coupler. For the simulation, we use CAMFR, an in-house developed modelling tool based on eigenmode expansion [3]. We assume no reflections at the fiber facet.

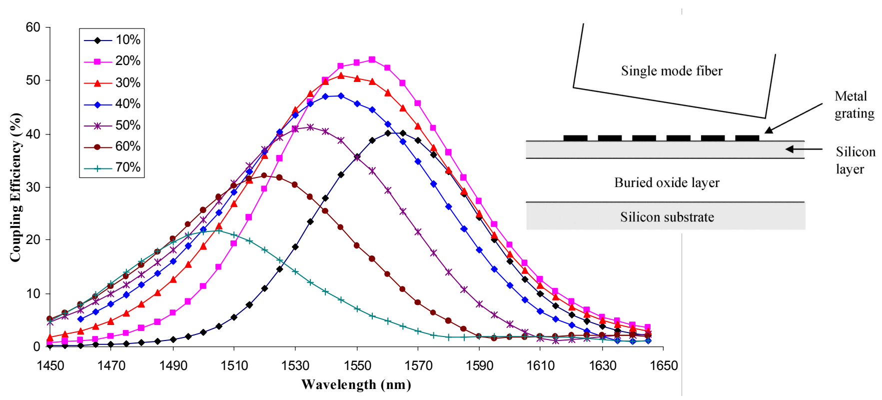

Fig. 1. Simulation of the coupling efficiency of a gold grating coupler on top of an SOI-waveguide.Grating parameters: grating period = 610 nm, height = 20 nm, varying filling factor, number of periods = 20. Inset: device lay-out used for simulation. The fiber is tilted 10 degrees with respect to the vertical.

3. Fabrication

UV-based Nano Imprint Lithography at room temperature and low-pressure is used for fabricating gold grating couplers on top of a bare SOI chip. The process flow is as follows. A silicon master is made by Deep UV-lithography and ICP etching containing 220 nm deep gratings with periods of 610, 620, 630 and 640 nm, varying filling factors and with separations between the gratings ranging from 200 µm up to 1000 µm. From the master, a UV-transparant mold is fabricated in the following way: first, the structure is UV-imprinted in low-viscous PAK-01L (*Toyo Gosei*) on a quartz substrate; next, an anti-adhesive treatment is applied on the mold by plasma deposition of a thin silicon oxide layer and subsequent silanization. This mold is then used for imprinting the grating structures in a benzylmethacrylate/PDMS-based resist using an MA-6 Mask Aligner as the imprint tool. This imprint resist has very low viscosity and leaves extremely thin residual layers [4]. After a break-through etch using RIE, a 20 nm thin layer of gold is deposited by evaporation. Lift-off is carried out in acetone. The SEM pictures in Fig. 2 show an overview and a detailed view of gold grating couplers on top of an unprocessed SOI chip, fabricated according to this Nano Imprint Lithography scheme.

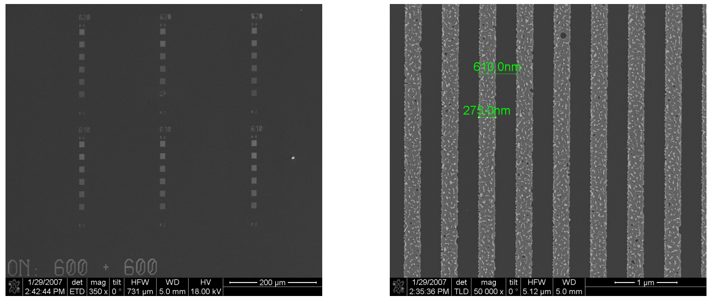

Fig. 2. Gold grating couplers on SOI fabricated by UV-based Nano Imprint Lithography.
(a) Overview image, (b) Detailed image of a gold grating coupler of period 610 nm and measured filling factor of 45 %.

4. Measurement results

We studied the coupling efficiency of the fabricated gold grating couplers experimentally and the influence of the grating filling factor in particular. Measurement data are obtained as follows: a single mode fiber connected to a tuneable laser source is positioned over the first grating coupler, a second single mode fiber connected to a detector is positioned over the second. For an input power of 800 µW, the output power is plotted in Fig. 3 as a function of wavelength. Each set of two grating couplers consists of two identical gratings with the same filling factor. The distance between the two grating couplers is the same for each set, i.e. 175 µm. Once the light is coupled into the SOI slab waveguide, it is diffracted in the waveguide plane. From our measurement data, a fiber-to-waveguide coupling efficiency of a gold grating coupler with filling factor of 45 % at a wavelength of 1575 nm is estimated to be 22 %. Higher filling factors result into a lower coupling efficiency combined with a spectral shift. This is in agreement to simulation results.

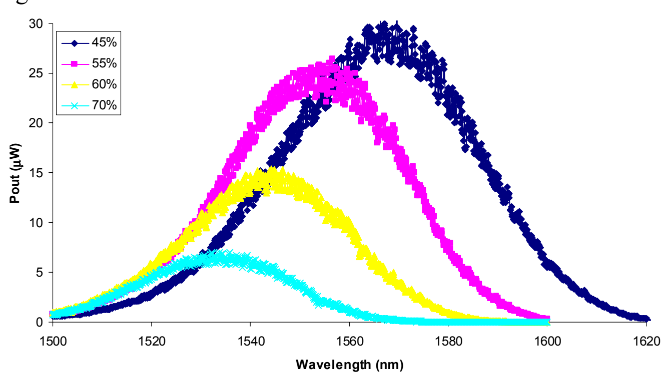

Fig. 2. Measured output power as a function of wavelength of four sets of gold grating couplers with varying grating filling factors. Each set consists of two identical gratings with the same filling factor. The other grating parameters are: period = 610 nm, grating height = 20 nm, number of periods = 20. The fiber is tilted 10 degrees with respect to the vertical.

4. Conclusion

Gold grating couplers for coupling light between SOI waveguides and optical fibers were fabricated using UV-based Nano Imprint Lithography and demonstrate over 22 % coupling efficiency. For filling factors between 40 and 70 %, the coupling efficieny decreases with higher filling factors as is expected from simulation.

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