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Experimental demonstration of coupling to silicon photonic wires using a grating coupler formed by subwavelength structures

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Summary

We present experimental results on a novel fiber-chip grating coupler for silicon photonic wire waveguides. By using subwavelength grating structures, which act as an averaged effective medium inside the grooves of the diffraction grating, the grating strength can be varied continuously to optimize the mode overlap of the diffracted beam with the fiber mode. Grating couplers and photonic wire waveguides are fabricated in a single etch step. We have measured maximum fiber-to-photonic wire coupling efficiencies of approximately 40% for the transverse magnetic (TM) mode.

Introduction

Surface gratings are a preferred means of coupling light from an optical fiber to silicon-on-insulator (SOI) planar waveguide devices. Grating couplers can be efficient, relatively easy to fabricate, they eliminate the need for polished waveguide facets and make wafer scale testing of devices possible. Most grating couplers to date have been used for the transverse electric (TE) mode of silicon wire waveguides. However, optimized evanescent field waveguide sensors make use of the superior surface sensitivity of the TM mode of thin wire waveguides [1]. Here we present experimental results of surface grating couplers for the TM mode, which include subwavelength structures to optimize grating strength, as described in a previous theoretical study [2].

Experiment

Grating structures were fabricated from commercial SOI substrates with a Si layer thickness of 0.26 μm and a buried oxide (BOX) layer thickness of 2 μm using electron beam lithography and inductively coupled plasma reactive ion etching. All structures and waveguides were defined in a single etch step. In Fig. 1 SEM images of gratings are shown. The grooves of the diffraction grating consist of a subwavelength periodic arrangement of silicon segments and air gaps. This structure acts as an effective medium with an averaged index of refraction that is determined by the duty ratio of the subwavelength grating (SWG) [3]. The effective medium effect allows one to apodize the grating strength by varying the duty ratio of the SWG as shown in Fig. 1b. Both apodized and unapodized structures were fabricated. For measurements of the coupling efficiency, two grating couplers with areas of 15 μm $\times$ 15 μm were

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connected to each other with 3.7 mm long and 0.45 μm wide wire waveguides using adiabatic mode expanders. Light from a tunable laser was incident on the input grating from a cleaved optical fiber (SMF-28) at an angle of 12° from the surface normal and coupled to another fiber at the output grating. Figure 2 shows transmission spectra of grating coupled waveguides from 3 different chips, with results for unapodized and apodized gratings in Figs. 2a and 2b, respectively. The spectra are corrected for waveguide loss and the vertical scale is the coupling loss for a single grating coupler. For both types of gratings the maximum efficiency is approximately 40% (-4 dB loss) with 3 dB bandwidths of 55 nm and 75 nm for unapodized and apodized gratings, respectively. The superposition of spectra from 3 different chips indicates good fabrication reproducibility. These grating couplers are suitable for use with photonic wire evanescent field biosensors.

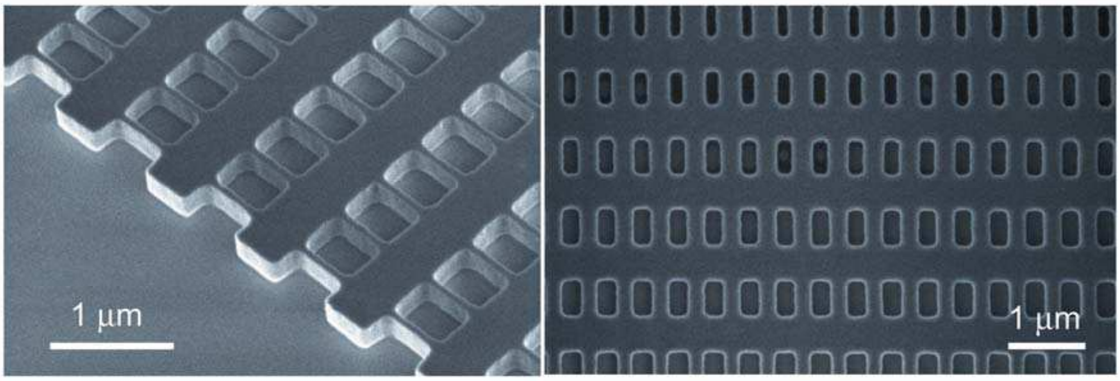

Fig. 1: SEM images of a) an unapodized and b) an apodized grating coupler using subwavelength structures inside the grating grooves.

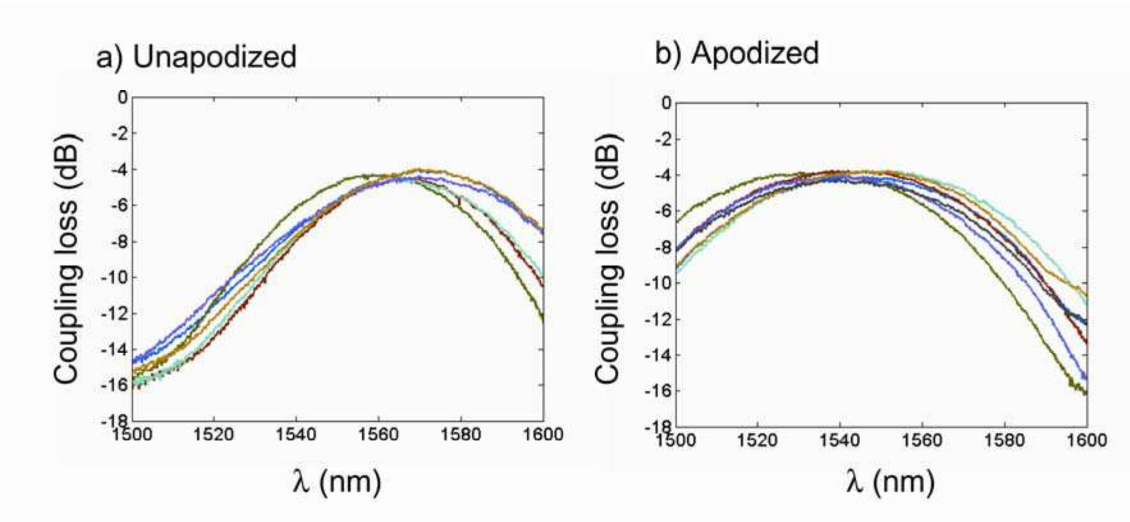

Fig. 2: Coupling loss spectra of grating couplers. A superposition of grating patterns from 3 different chips is shown, demonstrating good fabrication reproducibility.

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