# Efficient, Broadband and Compact Metal Grating Couplers for Silicon-on-Insulator Waveguides

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**Abstract:** Metal grating couplers for Silicon-on-Insulator waveguides are proposed. A silver grating coupler with 33% coupling efficiency is designed. A gold grating coupler prototype is fabricated using Focused Ion Beams demonstrating over 10% coupling efficiency.

**OCIS codes:** (130.0130) Integrated optics; (050.2770) Gratings

## 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, it is a big challenge to couple light efficiently from fiber to waveguide. Compact grating couplers defined by a grating etched a few tens of nanometer in the silicon core offer a very elegant solution to this coupling problem as they allow for alignment-tolerant, efficient and broadband coupling [1]. In this paper, we propose a grating coupler with comparable efficiencies that does not require etching in the silicon core. This device consists of a metal grating placed on top of the Silicon-on-Insulator waveguide. We fabricated a prototype device and measured its coupling efficiency.

## 2. Device layout

The structure we propose is depicted in Fig. 1. It consists of an SOI 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 their surroundings, the grating causes strong diffraction of light. This property can be exploited for designing efficient, broadband and compact grating couplers.

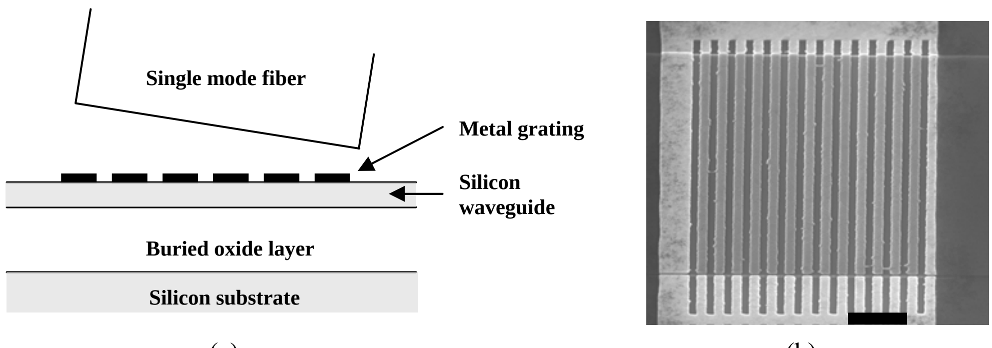


Fig. 1. Metal grating on top of an SOI-waveguide for coupling to an optical fiber.
(a) Device layout (side view), (b) SEM-image of a fabricated device (top view, bar length = 2 μm).

We studied the coupling efficiency of metal grating couplers using CAMFR, a fully-vectorial solver based on eigenmode expansion and mode propagation with perfectly matched layer (PML) boundary conditions [2]. The coupling efficiency is defined as the fraction of the power in the fundamental waveguide mode - propagating from left to right - that couples to the fiber. We considered one-dimensional gratings in two-dimensional simulations and TE polarization (electric field parallel to the grating lines). For our simulations, we used refractive indices $n_{Si} = 3.476$ and $n_{SiOx} = 1.444$ for silicon and silicon oxide respectively and took refractive index data for gold, silver and copper from reference [3]. For a number of different metal gratings, the calculated coupling efficiency is plotted as a function of wavelength in Fig. 2. For the mentioned geometrical parameters and the fiber tilted 8 degrees with respect to the vertical, a theoretical coupling efficiency of 33 % can be obtained using silver as the grating material. However, the coupling efficiency can be further enhanced by optimizing the geometrical parameters of the grating.

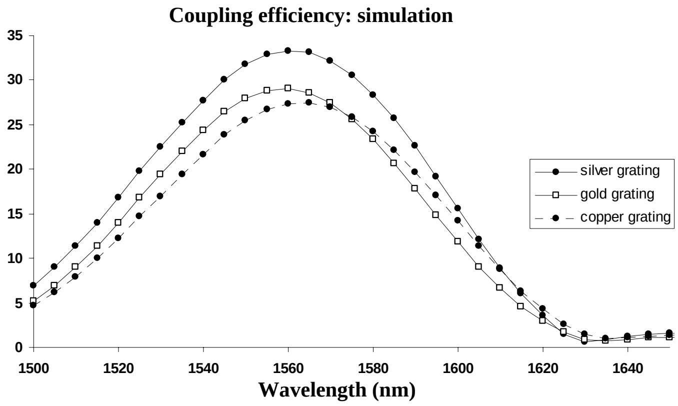


Fig. 2. Coupling efficiency (in %) as a function of wavelength of three gratings made of different metals. SOI parameters: 220 nm Silicon waveguide layer, 1 μm buried oxide layer. Metal grating parameters: period = 620 nm, fill factor = 50 %, grating height = 20 nm, number of periods = 20.

## 3. Fabrication and measurement results

We fabricated a number of prototype gold grating couplers. First, a thin layer of gold was locally deposited on top of broad shallowly etched SOI waveguides using lift-off. Next, the grating was defined by etching in the gold layer using a Focused Ion Beam (FIB) of Gallium-ions with an ion density of 31.1 $Ga/cm^2$ (Nova 600 Dualbeam, *FEI*). Prior to the FIB etching process, a thin layer of alumina was deposited onto the waveguides to protect the silicon from etching and ion implantation. We note that this additional layer will lead to a lower coupling efficiency when compared to the theoretically predicted efficiency that follows from the simulation results in Fig. 2. In particular, a coupling efficiency of 15 % is calculated for this device. Fig. 1 (b) is a SEM-image of a fabricated gold grating on top of an SOI waveguide. Two such gratings separated approximately 5 mm were fabricated on one single waveguide. Transmission measurements were performed by coupling laser light in via the first grating coupler and coupling the light out via the second. The raw data are plotted in Fig. 3. To this end, a fiber-to-waveguide coupling efficiency exceeding 10 % was experimentally demonstrated with a central wavelength of about 1580 nm and a 1dB bandwidth of 40 nm. The obtained efficiency is in good agreement with our simulation results.

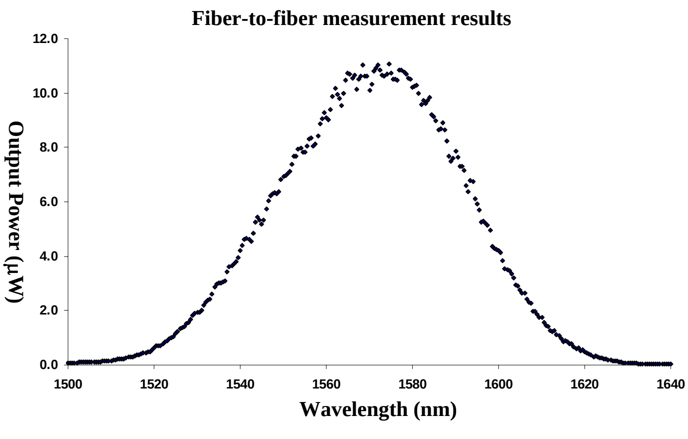


Fig. 3. Fiber-to-fiber measurement of a prototype device consisting of two gold grating couplers for in- and out-coupling on top of a 12 μm wide and 5 mm long SOI waveguide. Input power = 1 mW. An output power of 10 μW corresponds to 1 % coupling efficiency from fiber to fiber and thus to 10 % coupling efficiency from fiber to waveguide.

## 4. Conclusion

A metal grating coupler for coupling light between SOI waveguides and optical fibers was proposed. Over 30 % coupling efficiency was theoretically predicted for a silver grating. As a proof of principle, we fabricated gold grating couplers by Focused Ion Beam etching demonstrating over 10 % coupling efficiency at 1580 nm.

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