Efficient single-etch surface grating couplers in silicon nitride platforms for telecom and datacom wavebands

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Abstract. We present designs and experiments of single-etched amorphous silicon (α-Si) surface grating couplers on a silicon nitride (SiN) waveguide, operating at the telecom (C-band) and datacom (O-band) wavebands. SiN-only grating couplers demonstrate experimental coupling loss of -3.9 dB at 1.55 μm wavelength with a 1-dB bandwidth of 37 nm. Utilizing the hybrid α-Si/SiN platform with subwavelength grating structure, we obtain improved coupling performances, with the optimized fiber-chip coupling loss of -2.0 dB and a 1-dB spectral bandwidth of 42 nm centered at 1.31 μm.

1 Introduction

Fiber-chip grating couplers, which enable low-loss coupling of light between optical fibers and on-chip waveguides, are key components for photonic integrated circuits. The coupling loss of conventional grating couplers is affected by several factors, including the choice of the material platform. An important task is to design couplers with minimal losses by optimizing grating directionality, i.e., the power fraction radiated towards an optical fiber, and field overlap between the radiated beam and a Gaussian-like optical fiber mode [1].

Low-loss couplers were demonstrated on Si platforms by using grating apodization, together with specific directionality-enhancing strategies [2-4]. However, it still remains challenging to develop low-loss surface grating couplers in silicon nitride (SiN) waveguides due to their low index contrast. Reduced index contrast lowers the grating strength, which then impacts the grating performance, yielding poor field overlap and low directionality. Improved fiber-chip coupling efficiency can be obtained with bottom mirrors [5], L-shaped geometries [6], bi-layer topologies [7] or SiN-on-SOI stacks [8]. However, these devices are complex for fabrication and require customized processing steps.

Here, we present the design and experiments of low-loss single-etch surface grating couplers, operating at the C- and O-bands, with improved directionality and increased grating strength. Our couplers utilize native SiN and hybrid α-Si/SiN waveguide platforms.

2 C-band grating couplers

Figures 1(a) and 1(b) show a 2D side views of the proposed single-etch surface grating couplers, realized on a native and a hybrid SiN photonic platform, respectively. The SiN platform consists of a 400 nm thick core and 4.5 μm and 6 μm thick buried oxide layers, while the α-Si and buffer oxide layers provide a new degree of design freedom to optimize the radiation performance of the grating couplers. Both designs couple the light from the optical fiber into a fundamental transverse electrical (TE) mode at 1.55 μm (C-band) and 1.31 μm (O-band) wavelengths, respectively. The grating couplers were analysed by finite-difference time-domain (FDTD) Ansys toolset. The devices were fabricated using e-beam lithography and reactive ion etching in a single-etch process.

Fig. 1. 2D schematics of (a) native and (b) hybrid SiN grating couplers. (c) Calculated and measured coupling loss as a function of duty cycle for native C-band-operated couplers. Inset: Coupling loss as a function of wavelength.

Figure 1(c) shows the coupling loss as a function of the grating duty cycle for designed and fabricated single-etch
SiN-only couplers, demonstrating a good agreement between FDTD predictions and experiments. The inset of Fig. 1(c) shows the coupling loss as a function of the wavelength. The peak coupling loss is -3.9 dB, which is about 0.3 dB higher compared to the nominal design with a -3.6 dB loss, and the 1-dB bandwidth is 39 nm. At a central wavelength of 1.55 μm, it is observed that the retrieved experimental results are negatively biased of about 5% in duty cycle compared to the nominal layout. The fiber-chip coupling is still limited by the power leakage into the Si substrate and by the weak grating strength, which makes it difficult to match the exponential profile of the radiated beam and near-Gaussian optical fiber mode.

### 3 O-band grating couplers

The performance of the grating coupler can be improved through additional overlay deposited on top of the waveguide grating [9,10]. Here, the surface grating is formed directly in an α-Si overlay, improving the coupling strength compared to native SiN platform, while still keeping the single-etch device fabrication. The thicknesses of the top α-Si and intermediate oxide buffer are optimized to yield the maximum radiation towards an optical fiber situated above the grating. Their optimal values are calculated as 220 nm and 50 nm, respectively. Moreover, the intrinsically large strength of the α-Si grating is optimized via subwavelength grating (SWG) metamaterial engineering [11,12]. This is achieved by non-resonant waveguide segmentations, with α-Si patterns oriented transversely to the direction of light propagation [13,14].

![Fig. 2](image-url)  
**Fig. 2.** Radiation and coupling performance of native SiN and hybrid α-Si/SiN grating couplers. (a) Directionality versus BOX thickness and (b) coupling loss versus wavelength. Inset (a): Directionality versus SiO2 buffer thickness for α-Si grating.

Figure 2(a) shows the calculated directionality as a function of the BOX thickness for uniform coupler designs in native SiN and hybrid α-Si/SiN platform, operating at 1.31 μm. In both situations, a maximum directionality of about 80% is achieved. The radiation performance is governed through the thin-film interference effect either by modifying the BOX and buffer oxide thicknesses, or by judiciously adjusting the radiation angle [2,13,14]. In practice, modifying the BOX layer thickness is not feasible, and therefore, the latter approach is used in the proposed designs.

By optimizing the grating parameters (period, duty cycle and SWG duty cycle), optimal radiation angles of -58° and -18° are found for SiN and α-Si-based gratings, respectively. Figure 2(b) shows the fiber-chip coupling loss as a function of the wavelength for both grating structures. The peak coupling loss of the SiN coupler is -3.6 dB, while the coupling loss of -2.0 dB is predicted for the α-Si-based structure with SWG metamaterial. Whereas the directionality is almost the same in both designs, the field overlap integral is substantially improved to 80% in the case of the α-Si grating coupler compared to 66% for the SiN coupler design. We foresee that the coupling performance of the α-Si/SiN grating couplers can be further improved to sub-decibel level by using grating apodization via SWG metamaterial engineering.

### 4 Conclusion

We reported on designs and experiments of efficient off-chip waveguide couplers implemented on native SiN and hybrid α-Si/SiN platforms. SiN surface grating couplers operating at the C-band, were tested yielding fiber-chip coupling loss of -3.9 dB, with only 0.3 dB loss penalty compared to the nominal design. The hybrid α-Si/SiN coupler with SWG-engineered nanostructure significantly improves the grating strength, yielding an enhanced fiber-chip coupling loss of -2 dB at the O-band wavelengths. These results open up promising prospects to deploy low-loss grating couplers in silicon nitride based photonic integrated circuits.

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### References