TM Grating Couplers for Low-Loss LPCVD based Si$_3$N$_4$ Waveguide Platform

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Abstract: We demonstrate TM grating couplers for LPCVD silicon nitride platform with coupling loss of 6.5dB at 1541nm and 1dB bandwidth of 55nm employing optical projection lithography for low-cost and mass manufacturing of photonic integrated circuits.

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1. Introduction

Silicon-nitride based photonic integration technology has recently attracted momentous research interest as an attractive low-loss nanophotonic platform providing multiple benefits across a wide range of applications [1]. Interfacing nanophotonic waveguides with fiber based configurations has been mainly realized employing out-of-plane coupling schemes based on Grating Couplers (GCs) due to the relaxed fiber alignment tolerances that they offer compared to the edge coupling alternatives [2]. In this context, pure silicon nitride-based GCs have been reported only for TE polarization exhibiting coupling efficiencies slightly higher than 60% [3]. Despite the proven capabilities of SiN waveguides to support TM polarized light [4], TM operating silicon nitride GCs still remain an unexplored territory impeding the exploitation of complementary optical functionalities that require TM polarization, like plasmonic waveguides [5]. The low-loss characteristics of the Si$_3$N$_4$ waveguides offer an ideal photonic hosting platform for selectively depositing plasmonic waveguides with enhanced optical functionality [6-7], extending the proven advantages of converged photonic-plasmonic waveguide platforms towards increasing integration densities, while coping with the increased propagation losses of the plasmonic sections [8-9]. In this work, we demonstrate for the first time to the best of our knowledge, a fully etched TM GC with a coupling loss of 6.5 dB nm and a 1-dB bandwidth of 55 nm on low-loss LPCVD-based silicon nitride platform. Propagation losses of 0.55 dB/cm at 1550 nm are also reported for a moderate waveguide aspect ratio.

2. Design and Simulation

In our designs, we considered a 360 nm thick silicon nitride waveguide layer lying on top of a 2.2 μm thick thermally grown SiO$_2$, top cladded with 960nm of Low-Temperature-Oxide (LTO). A cross-section view of the 360x800 nm strip-based Si$_3$N$_4$ waveguide supporting a quasi-TM mode is shown in Fig. 1(a). Schematic side-views for the simulated GC are illustrated in Fig.1(b) and (c). 2D FDTD simulation results for the GC directionality and the resulting far-field angles at 1550 nm, for varied period length and air as the superstrate medium are illustrated in Fig. 2. (a) and (b), respectively. The simulated coupling loss versus wavelength for different period length and trench size are illustrated in Fig. 3(c) and (d), respectively. Simulations predicted a minimum coupling loss of 6.4 dB at 1560 nm, for a GC with a period length of 1.71 μm and a trench size of 800 nm. Peak coupling loss is maintained below 7 dB for period and trench size variations in the range of ± 30nm and ± 50nm, respectively.

3. Fabrication and Characterization

The proposed GC and strip-based Si$_3$N$_4$ waveguides were fabricated employing CMOS compatible fabrication processes using a standard 6” silicon wafer substrate with 2.2 μm of thermally grown SiO$_2$. The 360 nm thick Si$_3$N$_4$ layer was deposited in a LPCVD-based process. The structure transfer was achieved via reactive-ion-etching (RIE) with CHF3 and He chemistry. A non-planarized waveguide cladding of 600 nm thick SiO2 layer was deposited via
LPCVD. To improve the material quality and avoid additional losses due to hygroscopic properties of the cladding layer, the wafers were annealed for several hours at 1000°C. A microscope image of the fabricated GC is depicted in Fig. 3. (a). The waveguide propagation loss was evaluated through the cut-back method for eight waveguides with different lengths ranging from 1 to 4 cm by scanning the wavelength of a tunable laser source from 1500 to 1580 nm. Fig. 3. (b) shows that the propagation loss at 1550nm increases from 0.55 dB/cm to 1dB/cm at 1525nm. The increased propagation loss around that wavelength region can be attributed to the intrinsic absorption of the LPCVD-based Si$_3$N$_4$ waveguide, which stems from vibrational modes of N-H bonds [4]. A minimum coupling loss of 6.5 dB was experimentally measured for a GC with a period length of 1.7 $\mu$m and a trench size of 800 nm at a fiber coupling angle of 37 degrees, with respect to the chip surface. The 1dB bandwidth of the measured GC is almost 55 nm. Fig.3. (c) illustrates the results for the simulated and the experimentally measured coupling losses versus wavelength, revealing good agreement between design and experiment.

4. Conclusion
We have demonstrated, a fully etched TM-mode GC for LPCVD-based silicon nitride waveguide platform with a minimum coupling loss of 6.5 dB at 1541nm and 1 dB bandwidth of 55 nm. The proposed GCs extends the portfolio of currently available silicon nitride-based building blocks, allowing the effective co-integration of silicon nitride waveguides with TM-performing plasmonic waveguides [6-7]. Subsequent optimization process involving grating apodization techniques can lead to lower coupling loss-values [10].

References

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