High-efficiency SiN Grating Fiber-Chip Coupler with Bottom Reflector

Siddharth Nambiar, Abhai Kumar., Rakshitha K., Praveen Ranganath, Shankar Kumar Selvaraja
Center for Nanoscience and Engineering, Indian Institute of Science, Bengaluru -560012
Tel: : +91 80 2293 3342 , e-mail: shankar.ks@iisc.ac.in

ABSTRACT

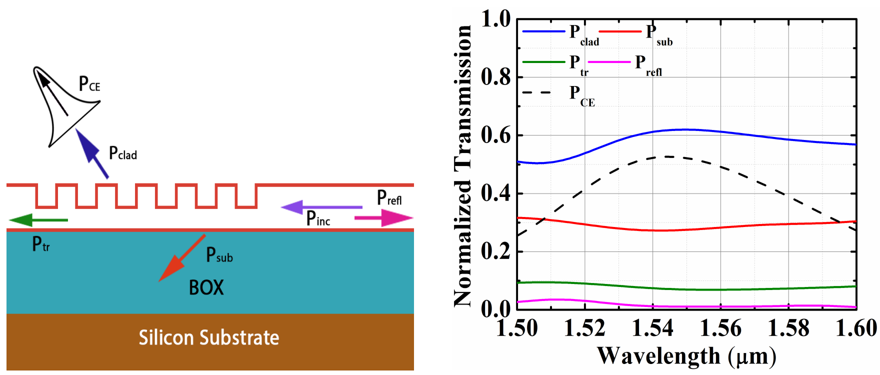
We design and experimentally demonstrate a high efficiency SiN grating coupler on a 500 nm thick platform with distributed Bragg layers as bottom reflectors. Maximum efficiency for the design is calculated to be over 73 % with a 1 dB bandwidth of 56 nm. The experimental peak coupling efficiency is observed to be 2.29 dB/coupler with a 1 dB bandwidth of 49 nm.

Keywords: Grating coupler, photonic-integrated circuits, silicon nitride.

1 INTRODUCTION

Silicon Nitride (SiN) is increasingly garnering interest as an alternative material to the established Silicon-on-Insulator (SOI) platform for building photonic integrated circuits [1], [2]. Apart from being a CMOS compatible material, SiN based devices have higher tolerance to fabrication imperfections given its moderate index contrast. These devices have a lower temperature sensitivity due to the low thermo-optic coefficient of SiN. Also, unlike crystalline silicon, SiN does not suffer from two photon absorption making it suitable for various nonlinear photonic applications. As such there has been a renewed interest to develop surface grating couplers for various Silicon Nitride on Insulator (SNOI) platforms [3], [4], [5]. Most of these couplers were realized with SiN grown using Low Pressure Chemical Vapour Deposition (LPCVD) that required high-temperature processing (>700 C°). In this work, we present a highly efficient grating coupler based on ultra rich silicon nitride film of 500 nm thickness grown using plasma enhanced chemical vapour deposition (PECVD) process. Furthermore, the demonstration is the best efficiency reported yet for a single-mode SiN waveguide configuration.

2 GRATING DESIGN AND SIMULATION



(a) (b)

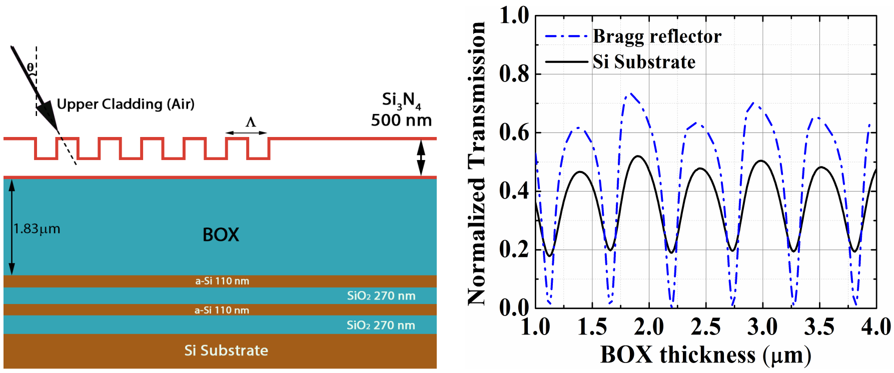
Figure 1: (a) 2D schematic of grating design layout with an illustration of the different loss channels. (b) Simulated normalized transmission or CE at optimized design of 1.05 μm, 9.5° angle, 270 nm etch depth and 55 % duty cycle along with the various associated power loss channels.

Power coupling to any surface grating coupler typically depends on two factors namely the directionality and fiber mode mismatch. While the former defines proportion of total power diffracted upwards to the fiber, the latter signifies the mismatch between the grating field and the Gaussian fiber mode. For our design, we maximize the directionality by plugging substrate leakage through a bottom reflector inserted under the bottom oxide clad layer. Initially, the grating parameters are optimized using 2D FDTD. A schematic of the grating design with its associated loss mechanisms is illustrated in fig. 1(a). Accordingly, the power incident P_{inc} is expressed as:

$$P_{inc} = P_{clad} + P_{sub} + P_{refl} + P_{tr} \quad (1)$$

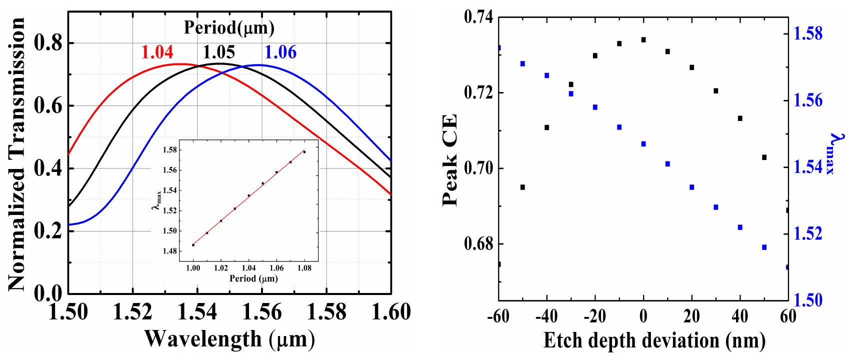
$$P_{CE} = \eta P_{clad} \quad (2)$$

where P_{clad} denotes the power extracted to the top cladding, P_{sub} the substrate leakage, P_{refl} denotes the back reflection and P_{tr} signifies the power transmitted through the grating. And η is the mode field overlap between the diffracted grating field and a Gaussian fiber mode. A parametric optimization sweep of the grating period, duty cycle, etch depth, and inclination angle is done. Maximum efficiency is observed at 52.2 % at a peak wavelength 1.544 μm for inclination angle of 9.5°, 55% duty cycle , etch depth of 270 nm and a period of 1.05 μm. Figure 1(b) summarizes the grating spectrum along with the Coupling Efficiency (CE) for an optimal device. It is observed that a substantial portion of power is leaked into substrate (>20%). To address this, a two layer Bragg reflector is added underneath the oxide (as shown in fig. 2(a)) and a parametric sweep of the oxide thickness is carried out to phase match the diffracted and the reflected field. These results are plotted in fig. 2(b). With the Bragg mirror, the peak efficiency improves to 73 % at a peak wavelength of 1.55 μm. Further optimization reveals the optimum etch depth with the mirror is slightly lower at 260 nm at an incident angle of 10°. The effect of period and etch depth on CE and peak wavelength is showcased in fig. 4. For an



(a) (b)

Figure 2: (a) 2D schematic of the grating design with a 2 layer DBR. (b) Normalized transmission at 1.55 μm wavelength as a function of BOX thickness with and without bottom reflector for optimized design.



(a) (b)

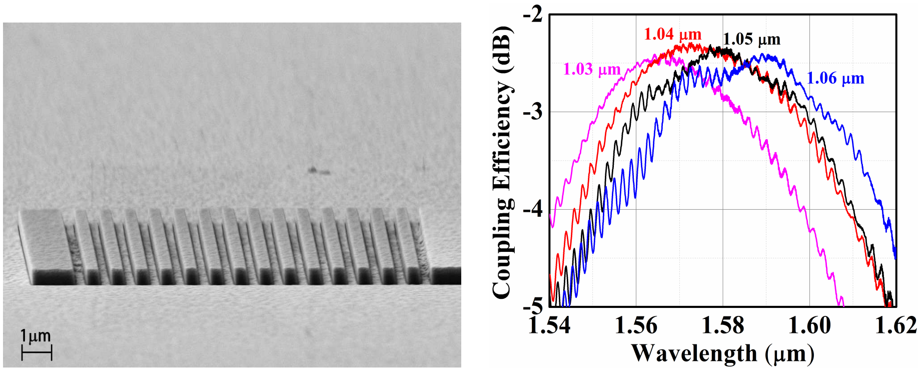
Figure 3: (a) Normalized transmission or CE for different periods. Inset shows variation of peak wavelength with period. (b) Peak CE as well as peak wavelength variation as function of etch depth at optimized period and inclination angle.

etch depth of 80 nm, the peak coupling is observed to be over 70 % with a noticeable red shift in the peak wavelength λ_{max}. Both plots indicate that there is only a marginal shift in power coupling due to deviation from the optimal design which in turn underlines the robustness of design to fabrication process.

3 FABRICATION AND CHARACTERIZATION

A clean Silicon wafer is first deposited with successive layers of SiO_2 and a-Si to from the bottom reflector. The stack consisting of SiO_2/a-Si of 270/110 nm thickness deposited using PECVD. This was followed by eposition of 1.83 μm SiO_2 and the 500 nm SiN layers also done using PECVD. Gratings of periods 1.03-1.07 μm and duty cycle between 50-60 % were written on a sample coated with MaN 2403 resist using electron beam lithography. The patterns were written on patch waveguides of 300 μm length and 12 μm width. These gratings along with patches were etched 260 nm deep in a single step etch process using inductively coupled plasma-reactive ion etching (ICP-RIE).

A SEM image of a fabricated device is depicted in Fig. 4(a). Devices were characterized using a Super-luminescent LED in the C band. Light is coupled into the grating through a polarization controller and the out-coupling fiber to an Optical Spectrum Analyzer (OSA). The device spectrum obtained from OSA is normalized



(a) (b)

Figure 4: (a) SEM cross section of the fabricated device.(b) Measured CE for best devices with different periods at inclination angle 8.5°.

to the source spectrum. The characterization results are presented in fig. 4(b). Best results are obtained for devices of duty cycle of 55 % at an inclination angle of 8.5°. Peak CE for gratings on patches observed to be -2.29 dB at 1572 nm with a 1 dB bandwidth of 49 nm, for a period of 1.04 μm.

TABLE 1: Comparison of different reported uniform SiN grating couplers in literature.

SiN Coupler	Max CE (-dB)		Band -width (nm)		λ_{max} (μm)		t_{SiN} (nm)	Deposition type	Bottom reflector
	Simulated	Experiment	Simulated	Experiment	Simulated	Experiment			
Ref[3]	3.9	4.2	67	67	1.57	1.57	400	LPCVD	N
Ref[4]	2.32	2.5	102	53	1.479	1.49	400	LPCVD	Y
Ref[5]	2.9	3.7	54	54	1.55	1.555	700	LPCVD	N
This work	1.34	2.29	56	49	1.546	1.572	500	PECVD	Y

It is noticed that the peak coupling angle as well as wavelength differs from that of simulated results. This discrepancy in data may be attributed to a less than optimum etch depth and duty cycle for the fabricated devices. Table I gives a comparative summary of selected SiN based uniform grating couplers reported so far.

4 CONCLUSION

We have designed, fabricated and experimentally demonstrated an air-clad SiN grating coupler in a 500 nm PECVD SiN platform. Measured coupling efficiency is observed to be 2.29 dB at 1.572 μm with a 1dB bandwidth of 49 nm. The minimum fabricated grating features are over 500 nm which is compatible with standard optical lithographic systems. Further improvement in the coupling efficiency could be achieved by mode profile matching through apodization.

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