An Experimental and Theoretical Comparison of Different Narrow Linewidth Bragg Gratings

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Abstract: We fabricate and characterize low kappa gratings on an ultra-low loss Si_3N_4 waveguide for narrow linewidth laser reflectors. DUV lithography is used to demonstrate kappa as low as 0.23 cm^{-1} with 12 dB of SMSR.

Introduction

Bragg gratings have been an integral part of the integrated photonics toolkit due to their widely variable bandwidths for telecommunications and ability to suppress high order longitudinal modes in distributed Bragg and distributed feedback lasers [1]. Generally, on chip waveguide losses and high index waveguides have limited the grating lengths to less than a few mm, and higher perturbations to the waveguide were necessary to increase the overall reflection. With a low loss waveguide platform, lower kappa values can be utilized to lengthen the grating, thus reducing the linewidth to fiber Bragg grating type performance [2]. These narrow bandwidths will pave the way for sub-kHz linewidths with monolithically integrated lasers. In this paper, we demonstrate extremely low kappa designs in three different waveguide perturbation geometries, and show kappa values ranging from 0.23 cm^{-1} to 1.2 cm^{-1}, useful for grating lengths up to 100 mm on the low loss Si_3N_4 waveguide platform.

Design of low kappa gratings

Figure 1a shows the 3 different grating concepts, termed “post”, “sampled”, and “high order”, that are designed to produce similar reflectivity over a fixed length of 7.8 mm by tailoring the gap, duty cycle, or waveguide width difference from a nominal waveguide width. The post gratings are designed to yield a low loss quarter wave perturbation by placing a post of core material separated by a gap (g) 0.8 µm to 1.6 µm away from nominal waveguide widths (w_o) of 2.8 µm and 3.0 µm. The higher order gratings have a period (Δ) of 5λ/2 or 3λ/2 to reduce the perturbation, with a triangular or square waveguide width difference (Δw) from 0.2 µm to 0.3 µm, facing outwards from the waveguide. The sampled gratings have a similar Δw, a burst period of 40.128 µm, and each bursts contains 4, 8, 11, or 15 teeth that act as symmetric sidewall gratings. The sampled gratings have a similar perturbation as [3], which demonstrated kappa values between 13 cm^{-1} to 310 cm^{-1}. We simulated an effective index of 1.468 for the fundamental TE mode, yielding a half wave Δ of 528 nm at 1550 nm. For the post gratings, we simulated perturbation levels on the order of $\Delta n_{eff} \approx 10^{-5}$, as required for kappa values less than 1 cm^{-1}.

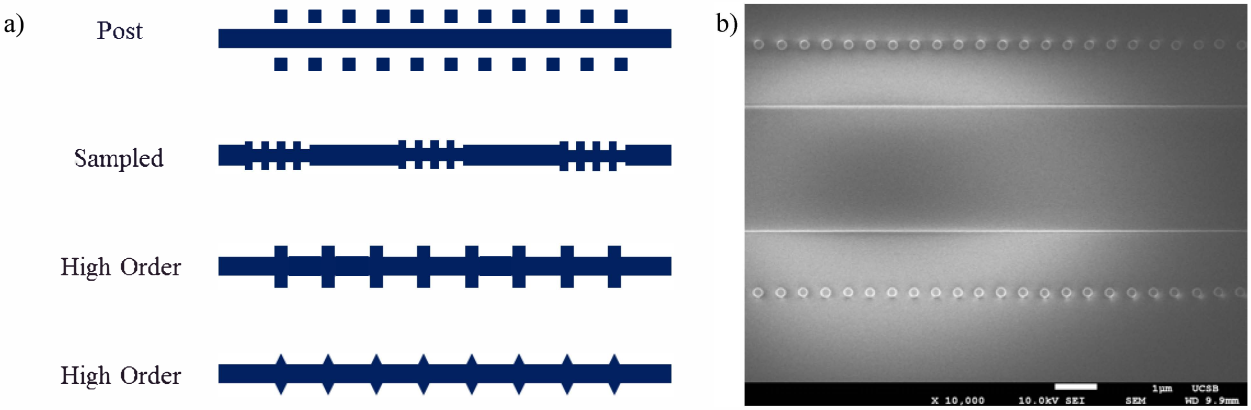

Figure 1. a) Mask layout of the grating geometries studied in this paper. b) SEM of a completed post grating device.

Fabrication

15 µm of silicon dioxide was grown on a bare 100 mm silicon wafer by dry oxidation, followed by a 90 nm layer of Si_3N_4, grown by low-pressure chemical vapor deposition. The growth techniques deposit on both sides of the wafers, which maintains wafer flatness to allow high-resolution lithography, despite the high intrinsic stress of these layers. The Si_3N_4 was patterned using a 248 nm projection lithography system. The photoresist was smoothed by a 150°C reflow, then the grating pattern and waveguide strip were both etched simultaneously using $CF_4/CHF_3/O_2$ inductively coupled plasma. Following cleaning, the wafer was annealed at 1050°C in a tube furnace for seven hours to drive off residual hydrogen from the silicon nitride. The upper cladding of the waveguide consists of silicon dioxide deposited by reactive ion sputtering. The sputtered

film was then placed in a rapid thermal annealer at 800°C for 1 minute. The completed wafers were separated into devices by a dicing saw and edge-polished to form facets for characterization. An SEM of the completed post gratings are shown in Figure 1b, which show a rounded profile due to etching, a measured period of 531 nm, and a post diameter of 227 nm.

Results

The completed devices were first tested for propagation loss using a 0.5 m Archemidean spiral test structure, and a Luna OBR system to monitor the backscatter vs. length. Losses below 5 dB/m were achieved across the C+L band, and <3.5 dB/m near 1550 nm. The gratings were then tested using an Agilent tunable laser, circulator, and 2 µm spot size lensed fiber. The input facet was angled at 15°, and the TE mode was excited by optimizing the reflected power. The facet loss was measured to be 0.85±0.1 dB/facet, and the TM mode did not show appreciable reflection. Figure 2a shows the results of all 8 splits for the post gratings, in which the two groups correspond to the two different waveguide widths mentioned above. Figure 2b shows examples of reflection spectra from all three grating concepts, in which similar power reflectivity and bandwidths were obtained for the different grating designs. We performed a nonlinear least squares fit to match the effective index of the gratings and kappa values using coupled mode theory. Tables 3a-c summarize the main results of the different grating geometries, all of which achieved a kappa value less than 1 cm^{-1}.

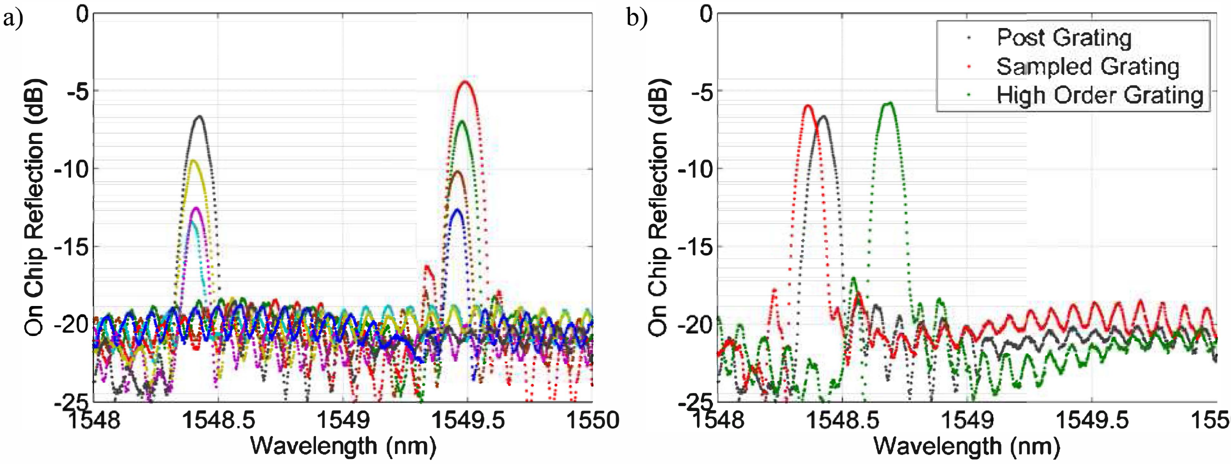

Figure 2 a) Results of post gratings for 2 waveguide widths and different gaps. b) Comparison of the three grating designs.

Post

w_o (µm)	g (µm)	κ (cm^{-1})	FWHM (pm)
2.8 µm	1 µm	0.62	100
	1.2 µm	0.43	94
	1.4 µm	0.30	83
	1.6 µm	0.25	79
3.0 µm	0.8 µm	0.90	109
	1 µm	0.60	89
	1.2 µm	0.41	84
	1.4 µm	0.29	75

Sampled

Δ/burst	Δw (µm)	κ (cm^{-1})	FWHM (pm)
4	0.20 µm	0.23	93
	0.25 µm	0.33	86
8	0.20 µm	0.40	75
	0.25 µm	0.70	88
11	0.20 µm	0.57	87
	0.25 µm	0.76	108
15	0.20 µm	0.69	93
	0.25 µm	1.2	116

High Order

Order	Δw (µm)	κ (cm^{-1})	FWHM (pm)
3, triangle	0.20 µm	0.50	84
3, square	0.20 µm	0.73	98
3, square	0.25 µm	0.89	105
3, square	0.30 µm	0.72	93
5, triangle	0.20 µm	0.35	74
5, square	0.20 µm	0.49	88
5, square	0.25 µm	0.45	89
5, square	0.30 µm	0.47	88

Table 1 Results of the post, sampled, and high order gratings after removing measurement system and facet coupling losses.

Conclusion

We have demonstrated low kappa gratings with narrow bandwidths on an ultra-low loss Si_3N_4 waveguide platform. Kappa values ranged from 0.23 cm^{-1} to 1.2 cm^{-1}, with fitted bandwidths of 74 pm to 116 pm, which will find applications in narrow linewidth integrated lasers and narrow bandwidth filtering. This research was supported by ARL under STTR Phase I contract W911NF-14-P-0021. The authors thank Wayne Chang, Michael Gerhold, and Michael Belt for helpful discussions.

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