Higher Order Planar-Waveguide Bragg Grating on Curved Waveguide

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***Abstract*—Higher order curved planar-waveguide Bragg gratings are realized by periodic width modulation. Linear chirp is achieved by width tapering. Devices were fabricated in low loss silica waveguide platform. Characterization results will be presented.**

***Index Terms*—chirped planar-waveguide Bragg gratings, curved gratings, higher order gratings, low loss waveguide**

I. Introduction

OPTICAL fiber Bragg gratings are used for a variety of applications such as routing, filtering, and dispersion compensation in high data rate fiber optic links [1]. Long chirped gratings with weak local coupling coefficients are desired to achieve large dispersion in certain application areas. The ability to fabricate curved planar-waveguide Bragg gratings in combination with continuing efforts on minimizing waveguide propagation loss could potentially lead to long Bragg gratings in a small chip area. In addition, chip scale planar-waveguide Bragg gratings offer compatibility with standard, low cost semiconductor photolithography fabrication processes and allow device integration. In this paper, we present characterization results of curved planar-waveguide Bragg gratings fabricated in a low loss silica waveguide platform [2].

The conventional way to form fiber gratings is by UV exposure through a phase mask to produce periodic index modulation [3]. However, it is challenging to create such a phase mask for curved planar-waveguide. Our approach is to use periodic width modulation to form curved gratings [4]. The formation of the periodic width modulation occurs during the etching of the waveguide core. Fig. 1 shows a schematic of a 1st order curved grating with sinusoidal width modulation, where R is the bending radius. For single wavelength Bragg gratings, the modulation period is defined as $\Lambda=\lambda_B/(2n_{eff})$, where λ_B is the Bragg wavelength and n_{eff} is the effective index of the waveguide.

Due to photolithography resolution constraints, higher order gratings are chosen in our design to relax fabrication requirements. A perfect sinusoidal width modulated grating gives no higher order reflection. Rectangular width modulation is used to maximize higher order Bragg wavelength reflection. Simulations results for modulation depth requirement are presented in Table 1 for 1st, 3rd and 5th order gratings to achieve 40% reflectivity in a 5 mm long, 4 μm wide silica waveguide with 1.5% index contrast. Table 1 shows that for the same reflectivity the modulation depth increases as the grating order increases. This increases the minimum feature size thereby easing fabrication requirements [5].

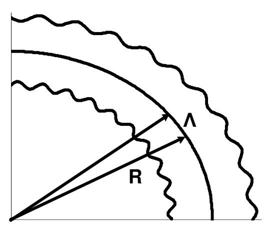


Fig. 1: Sinusoidal width modulation for 1st order curved Bragg gratings.

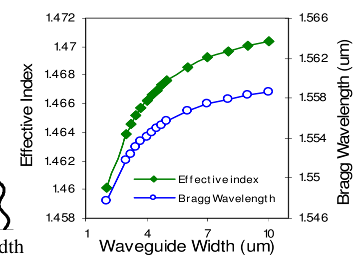


Fig. 2: Effective index and Bragg wavelength as a function of width for 1.5% index contrast silica waveguide

TABLE 1
Modulation Depth for 1st, 3rd and 5th Order Gratings

Order	Grating Period (um)	Modulation depth
1st	0.53	1%
3rd	1.59	2.5%
5th	2.65	4%

Another fabrication issue is rounding of the rectangular modulation features due to the limited resolution of the lithography. Rounding of a 50% duty cycle rectangular modulation results in sinusoid like modulation which significantly decreases reflectivity for higher orders. In contrast, the rounding effect will have less impact on the higher order reflectivity of a larger duty cycle modulation. To study the rounding effect, both 50% and 70% duty cycles were designed for 5th order gratings. In the case of no rounding effect, both 50% and 70% duty cycle 5th order gratings should give the same reflectivity since the coupling coefficient is proportional to $sin(m\pi D)/(m\pi)$, where m is the grating order and D is the duty cycle; otherwise any rounding effect should have greater impact for the 50% duty cycle gratings.

Chirp in fiber Bragg grating is commonly introduced by varying the period of index modulation along the fiber length. However, creating chirped planar-waveguide gratings with this approach would require exquisite control of the lithographic process over a large area. Using one of our chirped Bragg grating designs as an example, the increment to each period is less than 0.2 pm in order to achieve 67 ps/nm in a 10 mm long grating. It is not possible to fabricate such an increment for each period with standard semiconductor photolithography equipment. Instead, our designs implement chirped gratings by tapering the waveguide width. According to simulation results in Fig. 2, the effective index and Bragg wavelength are a function of waveguide width. Linear chirp is produced by applying a constant modulation period to a waveguide with a width taper according to the data characteristic in fig 2.

II. FABRICATION AND CHARACTERIZATION

Low loss waveguide material silica (<0.02 dB/cm) with 1.5% index contrast was used in our fabrication. Minimum bend radius of 2 mm is used in curved waveguide design for negligible bending loss [4]. Etch bias of 0.45 µm is added to the 4 µm height waveguide to minimize undercut. A series of 3^{rd} and 5^{th} order single wavelength and chirped planar-waveguide Bragg gratings with various design parameters (e.g., modulation depth, and duty cycle) were designed on a photomask for fabrication. Fabrication in the silica material was performed by Enablence USA.

Optical Backscatter Reflectometry (OBR) was used to characterize the planar-waveguide Bragg gratings. The measured reflectivity varied from 2 to 18 dB lower than the design value for 3^{rd} order gratings, and from 11 to 34 dB lower than the design value for 5^{th} order gratings. The discrepancy in reflectivity between design and experiment is likely due in part to the rounding effect causing a fabricated modulation index less than the design modulation index. Fig. 3 plots the reflectivity as a function of modulation depth for 5 mm long 5^{th} order gratings for both 50% and 70% modulation duty cycles. For the same design modulation depth, the grating with 70% duty cycle have reflectivity > 7 dB higher than 50% duty cycle gratings. This suggests that rectangular modulation features have been rounded.

Fig. 4 shows the reflection spectrum of the for a 3^{rd} order single wavelength grating with 50% duty cycle. The reflection peak is within 1% of the design frequency and has a 3 dB bandwidth of ~0.15 nm. After correcting for coupling (~3.6 dB) and propagation (~0.6 dB/cm) loss, the reflectivity is ~2 dB lower than the design value.

Fig. 5a shows the reflection spectrum of a 10 mm long 3^{rd} order chirped grating. The 3 dB bandwidth is approximately 1 nm. The design bandwidth is 1.5 nm. The chirp parameter is measured via the group delay plot shown in Fig 5b. It is approximately 70 ps/nm, which is in good agreement with the design value of 67 ps/nm. The reflectivity of this chirped grating is 15 dB lower than the design value.

III. DISCUSSION

Both single wavelength and chirped planar-waveguide Bragg gratings were fabricated and characterized with results consistent with design as described in section II. The characterization results are promising given that some issues with the fabrication process were observed. Roughness and pitting were seen after core etching, which degraded the grating quality as seen in SEM images and likely degraded reflectivity and loss. This was attributed to sputtering damage to the NiCd hard mask after the protective layer of photoresist was consumed during the core dry etch process. These effects should be mitigated by selection of an alternative hard mask approach currently under investigation. Longer planar-waveguide Bragg gratings with lower loss and improved reflectivity are expected with future fabrication process improvement.

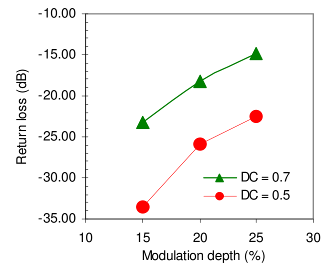


Fig. 3: Reflectivity of 5 mm long 5^{th} order single wavelength grating as a function of modulation depth for 50% and 70% modulation duty cycle

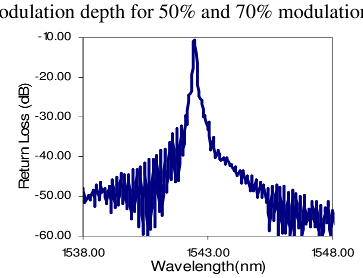
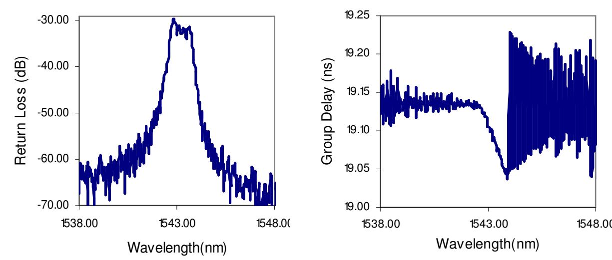


Fig. 4: Reflection spectrum for 5mm long 3^{rd} order single wavelength curved planar-waveguide Bragg grating, bend radius = 3mm



a) b)

Fig. 5: a) Reflection spectrum for 10mm long 3^{rd} order chirp planar-waveguide Bragg grating, bend radius = 5mm; b) Group delay

ACKNOWLEDGMENT

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