Asymetry effect in holographic apodized phase mask for multichannel fiber Bragg gratings

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Abstract: The way complex apodization function of the diffraction efficiency of a holographically made phase mask is implemented has an effect on the spectral response of multichannel fiber Bragg gratings. Theoretical and experimental results are presented.

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Introduction

Diffraction effects play a significant role in fiber Bragg grating near-contact writing [1]. In this presentation, we will study some aspects relevant to the design of complex phase masks for the generation of multichannel fiber Bragg gratings. Sinc-sampling applied to the diffraction efficiency of a phase mask is one way to produce multiple channel devices [2]. Another way is to calculate the complex apodization function using the summation of the different sinusoids corresponding to the different channels. This approach enables dispersion slope compensation and the resulting apodization function then exhibits a chirped sampling period. To fabricate such complex phase masks, a multiple phase shift grating structure is obtained with a holographic recording technique and the depth of the corrugations is varied to follow the desired apodization function. The way the phase increments and apodization are implemented has an impact on the multichannel spectral uniformity. In particular, a lens effect is shown to be a cause of asymmetry. We first present the calculation model used for the simulations. We next present the grating structure comprising the phase shifts and which forms the underlying grating whose efficiency will be apodized. We present some ways to implement the apodization and compare them with theory.

Simulations

The calculations are done in a simple way, with the use of numerical FFTs. First, the grooves depth and phase are defined. In order to obtain the uniformity of the multichannel spectrum and information about the isolation and sidebands amplitude, one just need to define the corrugations over one equivalent sampling period, that is over about a 1 mm length for a 4-100 GHz-channel device. However, they can be defined on the complete length of the complex phase mask if fine scale features of the reflectivity spectrum are desired. For simplicity, sinusoidal shape grooves are used. The FFT of the phase modulated incident wave is taken, giving the angular plane wave spectrum. These plane waves are propagated through the mask to fiber distance. Numerical filtering of some orders can be used at this step. FFT of the propagated angular spectrum is taken and its modulus squared, giving a quantity proportionnal to the index of refraction. Bragg amplitude response in the optical frequency domain is obtained after another FFT. In the figures, we give the intensity distribution (squared modulus of this last FFT).

Multiple phase shift structure

Masks for multichannel generation require quasi-periodic phase shifts of $\pi/2$. These phase shift will be translated to π phase shift into the optical fibre. Holographic recording of the desired phase pattern is possible using a double exposure and proper masking and phase control techniques.

Apodization of the multiple phase shift structure

In order to get only a specific number of channels in the reflectivity spectrum, apodization of the phase mask diffraction efficiency is required. This will lead to low side modes and good isolation between channels. In order to implement the desired complex function for diffraction efficiency, one needs corrugation depths going from 0 on some locations to maximum depth on others. This can be done in three ways : apodization of the bottoms (type 1, fig. 1a), apodization of the tops (type 2, fig. 1b), apodization of both tops and bottoms of the structures (type 3, fig. 1c).

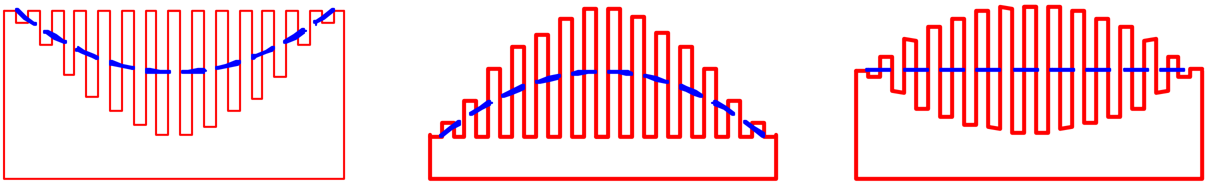

Fig. 1 : a) Apodization of the bottoms of the structures. b) Apodization of the tops of the structures. c) Apodization of the tops and bottoms of the structures. The dash line follows the surface of an equivalent lens generated by the structure.

As there is less glass material in the center of the structure shown in fig. 1a, apodization of type 1 adds a diverging lens-like effect. Inversely, apodization of type 2 leads to a converging lens-like effect. Lens effect is avoided using apodization of type 3. For a 4-channel design, the lobes of the apodization profile, shown in figure 2, have widths of about 250 µm and 500 µm. The depth of the grooves is on the order of 240 nm giving a lens thickness of about 120 nm. Assuming a plano-concave/convex profile, the focal length is around 13 cm for the small structures of 250 µm and 52 cm for the 500 µm ones. Translating a focused UV beam across such a mask clearly shows angular beam scanning due to this effect.

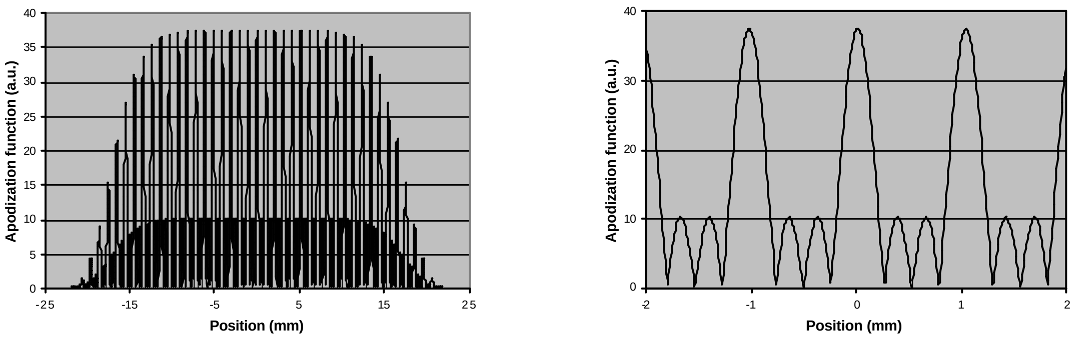

Fig. 2 : Apodization function (proportionnal to the diffraction efficiency) for the 4-channel phase mask. $\pi/2$ phase shifts occur at every minima of the function.

We have realized 4-channel phase masks with the three types of apodization presented. The masks are fabricated holographically with a period of 1068.8 nm and a chirp of 0.1 nm/cm over a length of 45 mm. The uniform masks are then apodized with photolithographic techniques that we have developped. Bragg gratings of weak strength are written in SMF28 fiber with all three apodized phase masks using a 248 nm excimer laser. The writing time is less than 10 s for the weak gratings presented here.

Some measured and calculated reflectivity spectrums are shown in fig. 3. For each phase mask, two spectrums are shown. One corresponds to having the fiber in contact with the phase mask, the other correspond to a distance between mask and fiber core of 262.5 µm. One sees that the lens effect gives rise to an asymetry of the reflectivity spectrum, reflectivity at longer wavelengths being stronger for a negative lens effect (apodization of type 1, concave lens). The asymetry is reversed for a positive lens (apodization of type 2, convex lens). One observes that the farther the fiber from the mask, the stronger the asymetry is in accordance with calculations. Asymetry is removed for apodization of type 3, which leads to a symetric structure. In this case, the spectrum stays symetric for different mask to fiber spacing.

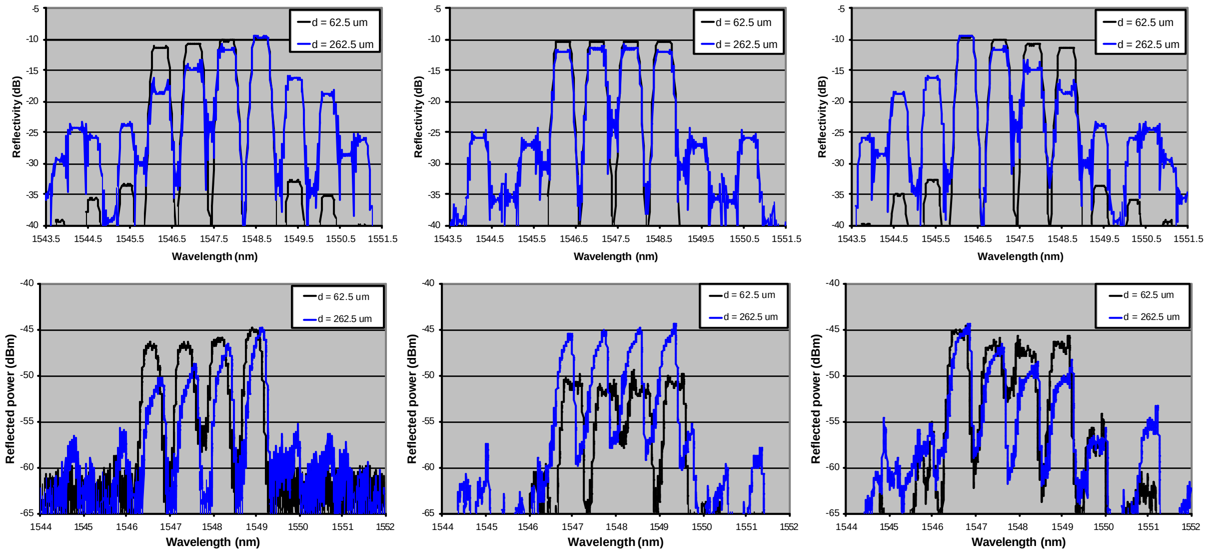

Fig. 3 : Calculated (top) and experimental (bottom) reflectivity spectrum for the 3 types of apodization. Left) Apodization of bottoms only. Center) Apodization of the tops and bottoms. Right) Apodization of the tops of the grating grooves only.

Conclusion

We have presented an asymetry effect in the reflectivity spectrum of Bragg gratings realized using a sinsum-sampled phase mask. It is due to a lens effect which is created in the apodization process of the grooves depth. The apodization of both bottoms and tops of the structures of a multiple phase shift mask is necessary to avoid this effect. Advanced analysis of other effects such as imperfections in the apodization profile could provide better understanding of the performances of multichannel Bragg gratings.

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