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Optimization of Diffraction Efficiency and Polarization Dependence Loss in Photopolymer Grating for Use in Multichip Module

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ABSTRACT

We in this paper propose a model to increase the diffraction efficiency of a holographic grating at 1550 nm for multiplexing application. To use such a grating, polarization dependence loss is introduced analytically and then optimized for its minimum value. A configuration of holographic grating is proposed based on both maximum diffraction efficiency and minimum polarization dependence loss. The proposed grating is expected to find importance in optoelectronic multichip module.

Keywords: Multiplexing; Demultiplexing; Modulation Index

1. Introduction

Wavelength division multiplexing (WDM) technology plays an important role for the next generation telecommunication network [1-3]. Today the exponential increase in world wide data traffic highly demands for a communication network of large bandwidth. This demand is now fulfilled by fiber-optic communication system using wavelength division multiplexing. The wavelength division multiplexing (WDM) based networks are now very popular option to gradually upgrade network transport capacity without huge investment in lying new optical cables. Several technologies are used to carry out wavelength separation for demultiplexing a composite signal. Very common technologies are thin film filters, arrayed waveguide grating (AWG) [4], fiber Bragg grating (FBG), free space diffraction grating [5-7]. FBGs based on diffraction have been used to constitute multichannel Mux/DeMux devices, in which all discrete filters must be cascaded in a serial manner. The insertion loss is increased with the channel number, and the channel uniformity becomes poor. Apart from the high cost of individual filters, the combination with other technologies, optical circulators for FBGs, will further increase system costs. It is proven that these types of DWDM Mux & DeMux devices are not suitable for high channel count use in view of the cost and performance. Furthermore, these types of devices have higher chromatic dispersion (±50 ps/nm - ±200 ps/nm), making these technologies unsuitable for high data transmission rate applications, such as 40 Gbit/s. AWG and Free space diffraction grating are widely used because AWG demultiplexers are having compactness in size and their potential to offer very high channel count and free space diffraction grating show many advantages including simplicity, the low crosstalk and low cost.

We in this paper presented a model to increase the diffraction efficiency of a holographic grating that can be used in AWG. To use such a grating for multiplexing application, polarization dependence loss is introduced analytically and then optimized for its minimum value. Then a configuration of holographic grating is proposed based on both maximum diffraction efficiency and minimum polarization dependence loss. The proposed grating is expected to find importance in opto-electronic multichip module.

2. Theory

We consider a volume transmission grating structure composed of N-index modulation grating recorded in a single-mode wave guiding layer such that the reconstructing angle "θ_R" satisfies the constructive interference Bragg's condition given by the following equation

$$\theta_R = \sin^{-1}\left(\frac{\lambda_R}{\lambda_W} \times \sin\theta_S\right) \tag{1}$$

where λ_R is the recording wavelength and θ_S is the incident angle of signal beam, λ_W is incident wave length.

The angular separation $\Delta\theta$ in terms of grating period Λ and reconstruction angle θ_R is given by [8]

$$\Delta\theta = \frac{\Delta\lambda}{\Lambda \times \cos\theta_R} \tag{2}$$

The diffraction grating has different efficiency according to incident polarization state and the index modulation amplitude. The diffraction efficiency relating to input polarization is expressed by the Kogelnik's wave theory [9,10].

The diffraction efficiency for p-polarization and S-polarization [11] can be found to be

$$\eta_P = \sin^2\left[\frac{\pi \cdot \Delta n \cdot d}{\lambda_R\left(\cos\theta_{ri} \cdot \cos\theta_{si}\right)^{1/2}}\right] \tag{3}$$

and

$$\eta_S = \sin^2\left[\frac{\pi \cdot \Delta n \cdot d}{\lambda_R\left(\cos\theta_{ri} \cdot \cos\theta_{si}\right)^{1/2}}\right] \times \cos\left(\theta_{si} - \theta_{ri}\right) \tag{4}$$

where Δn is the refractive index modulation amplitude θ_{ri} and θ_{si} are the reconstruction and signal beam angles inside the material. d is the thickness of the material.

The schematic diagram for the optical interconnect is shown in **Figure 1**. Where "G_1" and "G_2" represent input and output gratings. In **Figure 2** the principle of one such grating is shown. "$G_1(x)$" and "$F_1(z)$" represent the field transmitted through the grating in two mutual perpendicular directions.

A new type of grating known as Dynamic Phase Modulated Grating is attracted much attention in recent years due to its high diffraction efficiency.

The refractive index modulation and phase modulation under small reaction limit for such grating can be represented as [12]

$$\begin{aligned}\Delta n &= \left[\frac{\left(n_0+2\right)^2}{600 \cdot n_0}\right]\sum_{i=1}^{2} R_i \cdot \Delta C_i \\ &= \left[\frac{\left(n_0+2\right)^2}{600.n_0}\right]\left(R_1 \cdot \Delta C_1 + R_2 \cdot \Delta C_2\right)\end{aligned} \tag{5}$$

where n_0 is the mean refractive index of the medium, R_1 and R_2 are molar refractive coefficients, ε_1 and ε_2 are the molar extinct coefficient and ΔC_i is the deviation from the average concentration.

To investigate the possible use of DPMG, the volume grating in optical interconnect is replaced by Dynamic Phase Modulated Grating. To analyze the variation of polarization dependence loss with recording angle, Equations (3) and (4) are modified in accordance with Equation (5).

Polarization dependence loss for such DPMG for P and S polarization can be found as

$$\begin{aligned}&(\mathrm{PDL})_{\text{p-pol}} \\ &= -\log\left[\sin^2\frac{\left(\pi \cdot \Delta n \cdot d\right)}{\lambda_R\left(\cos\theta_{ri} \cdot \cos\theta_{si}\right)^{1/2}}\right]\end{aligned} \tag{6}$$

and

$$\begin{aligned}&(\mathrm{PDL})_{\text{s-pol}} \\ &= -\log\left[\sin^2\frac{\left(\pi \cdot \Delta n \cdot d\right)}{\lambda_R\left(\cos\theta_{ri} \cdot \cos\theta_{si}\right)^{1/2}}\right] \cdot \cos\left(\theta_{si} - \theta_{ri}\right)\end{aligned} \tag{7}$$

3. Result and Discussion

We use Equations (6) and (7) to simulate the variation of polarization dependent loss with recording angle. This simulation results show that the polarization dependence loss is zero for P-polarization in the range 1.35^0 to 1.42^0, 1.78^0 to 1.84^0 and 4.50^0 to 4.62^0 angles of recordings.

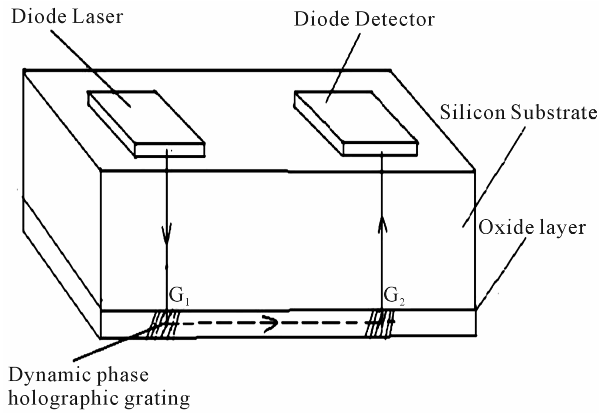

Figure 1. Schematic diagram of vertical interconnection.

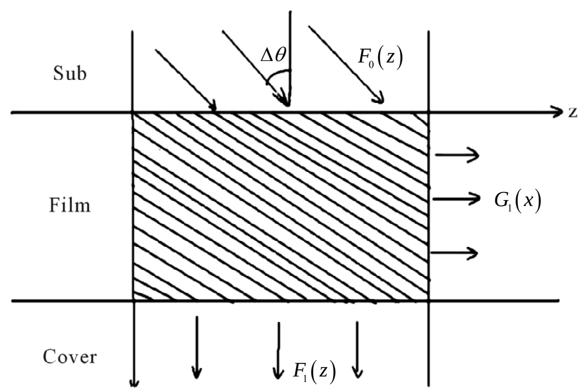

Figure 2. Schematic diagram of dynamic phase modulated grating.

However as the beam is incident normally to grating structure as in **Figure 1**, only "S" polarization will emerge out of the grating. Thus one has to optimize polarization dependence loss for S-polarization but not P-polarization. It is found that the polarization dependence loss is minimum for "S" polarization when the recording angles are in the range 1.29^0 to 1.35^0, 1.65^0 to 1.74^0 and 4.32^0 to 4.38^0.

Thickness of grating structure is an important parameter using which, the diffraction efficiency can be optimized. Polarization dependence loss (PDL) thus is expected to depend on thickness of the grating structure; PDL should be different for "P" and "S" polarization. We have simulated the variation of PDL with thickness of grating as shown in **Figure 4**. It is found from the figure that like **Figure 3**, this loss is less for "P" polarization compared to "S" polarization. But what is interesting here is that there is a wide range of thickness, where PDL is almost zero For example for thickness in the range 1.2×10^{-3} *met* to 1.6×10^{-3} *met*, 4×10^{-3} *met* to 4.36×10^{-3} *met* and 6.72×10^{-3} *met* to 7×10^{-3} *met* and the polarization dependence loss is almost zero. This suggests that at this range of thickness, diffraction efficiency is maximum. Further it is observed that in the range of thickness 2.56×10^{-3} *met* to 2.80×10^{-3} *met* and 5.3×10^{-3} *met* to 5.6×10^{-3} *met*, "S" and "P" polarization, PDL difference becomes minimum. But for grating larger thickness range 5.3×10^{-3} *met* to 5.6×10^{-3} *met* this difference becomes almost zero. This analysis leads to the following conclusion:

Thickness of the grating structure plays an important role in optimizing the PDL. For certain range of the thickness, PDL becomes almost zero, for "P" polarization and very small for "S" polarization. This difference decreases with the increase of thickness up to a certain range there after again increases. This trend is repeated as the thickness of the grating is increased.

Finally in the **Figure 5** variation of polarization de-

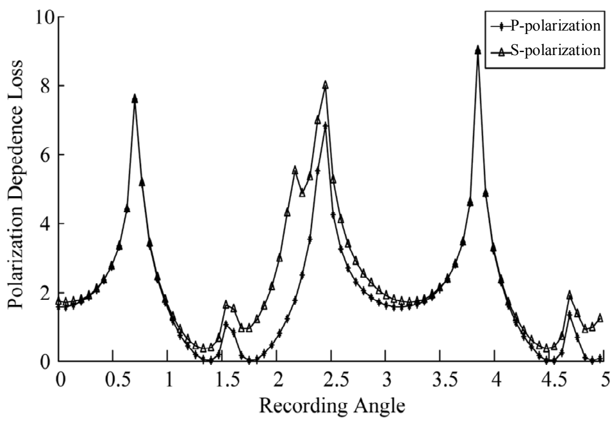

Figure 3. Variation of polarization loss with recording angle.

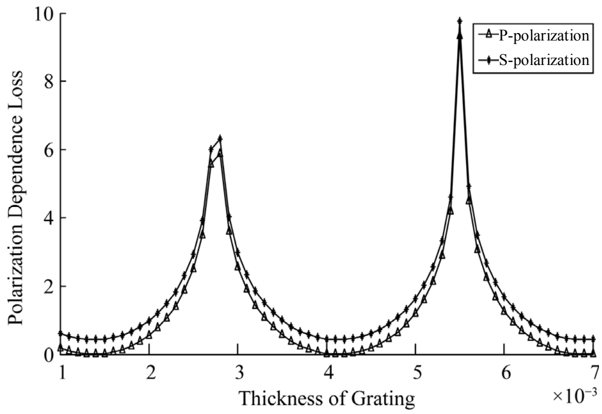

Figure 4. Variation of polarization dependence loss with thickness.

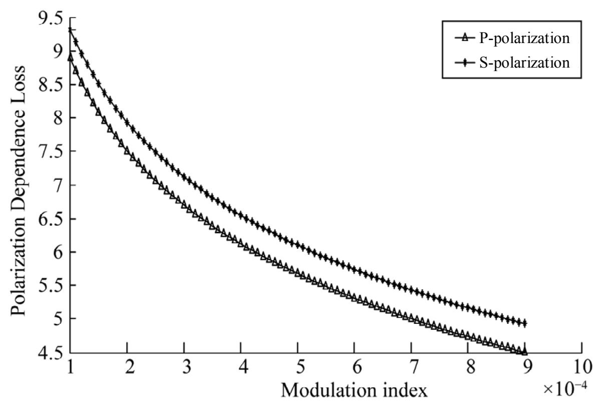

Figure 5. Variation of polarization dependence loss modulation index.

pendence loss with modulation index is shown for both "S" and "P"-polarization. The polarization dependence loss in case of P-polarization is maximum than S-polarization. However in both the cases with the increase of modulation index polarization dependence loss decreases exponentially. To increase the diffraction efficiency, polarization dependence should be minimum and hence the modulation index should be low.

For example for modulation index 1×10^{-4} the polarization dependence loss for "P"-polarization dependence loss is nearly 90%, where as for modulation index 9×10^{-4} the polarization dependence loss for "P"-polarization decreases to zero.

To sum, we have optimized a photopolymer grating, with respect to PDL varying recording angle, thickness of grating and modulation index. It is found that there exists a certain range of recording angle, thickness for which PDL becomes minimum, while PDL becomes minimum for a particular value of modulation index.

4. Conclusion

We have proposed a theory to optimize polarization dependence loss for different polarization (S and P) for a Dynamic Phase Modulated Grating for wavelength 1550 nm. From this theory, it is found that polarization dependence loss can be minimized and diffraction efficiency can be maximized if the hologram can be recorded in the range 1.29^0 to 1.35^0, 1.65^0 to 1.74^0 and 4.32^0 to 4.38^0 for S-polarization. Similarly the polarization dependence loss can be minimized and diffraction efficiency can be maximized, if a grating of thickness in the range 1.2×10^{-3} *met* to 1.6×10^{-3} *met*, 4×10^{-3} *met* to 4.36×10^{-3} *met* and 6.72×10^{-3} *met* to 7×10^{-3} *met* is used for a modulation index of 1×10^{-4}.

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