Chirp Gratings for Dense WD(D)M and Optoelectronic Interconnect Applications

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ABSTRACT

The novel structure of DWD(D)M in the applications of optoelectronic interconnects is proposed, which combines of planar optics and chirp grating. The chirp grating in the devices functions as both dispersive element and lens, which makes the device cost-effective. In this paper, grating-based WDM is intruded first. Then the novel structure of DWDM based on the combination of planar optics and chirp grating is given. The issues for designing such device are discussed next. Finally the preliminary experimental work is given. The results show the WDM device based on this structure is promising in data communications and optoelectronic interconnects from board to board or from machine to machine.

Keywords: Chirp Grating, Volume Hologram, Wavelength Division (De)multiplexing, Optoelectronic Interconnects

1. INTRODUCTION

Optical communication devices and interconnection networks constitute the backbone of the information super-highway. To enhance communications throughput, higher speed optoelectronic devices need to be implemented. External modulators for cable TV and long-haul telecommunications[1, 2], laser diode arrays for computer-to-computer interconnects[3, 4], and multimode laser diodes for compact discs are some of the most successful products. To further enhance the bandwidth promised by optics, the wavelength division (de)multiplexing (WD(D)M) scheme is becoming one of the major thrusts in photonics research[5, 6]. A WD(D)M device combines several light wavelengths (colors), each travelling on a separate optical fiber, into a single fiber so that more information can be sent through the fiber link, thereby utilizing existing links to carry more information. Recently, dense wavelength division (de)multiplexing (DWD(D)M) has been paid much attention to. It can provide much more signal channel in certain wavelength window. Most wavelength division multiplexers (WDM) employ three technologies, AWG, filter and dispersive element, mainly, diffraction grating[7] . Here grating-based WDM is addressed. The structure and other related issues

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of grating approach WDM are discussed firstly. The characteristics of chirp grating for WDM and optoelectronic interconnect applications is followed next. The conclusions are given at the end of this paper.

2. GRATING-BASED WDM

2.1 The structure

The structure for diffraction grating based WDM is shown in figure 1.

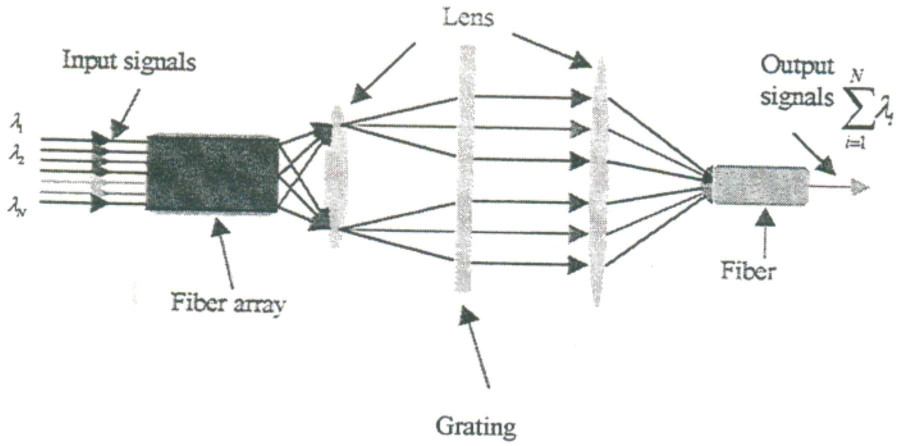

Figure 1. The diagram for the structure of grating based WDM

The light signals with different wavelengths from different channels are launched into a fiber array. The light signals from the fiber array are collimated by a lens in different directions and the grating will diffract these lights in one direction. Another lens is used to focus the light beams into one single fiber. When working in reverse directions, the devices functions as a demultiplexer. The light signals with different wavelengths traveling in a single fiber are collimated by a lens and guided in different directions by a grating. Another lens launches these light into different fibers. From the structure of the WDM, it can be seen that the core component in diffraction grating based WDM is the dispersive element, grating, which separates the light beams with different wavelengths. How large it can separate light signals in certain wavelength spacing depends on its dispersion ability.

2.2 Dispersion ability

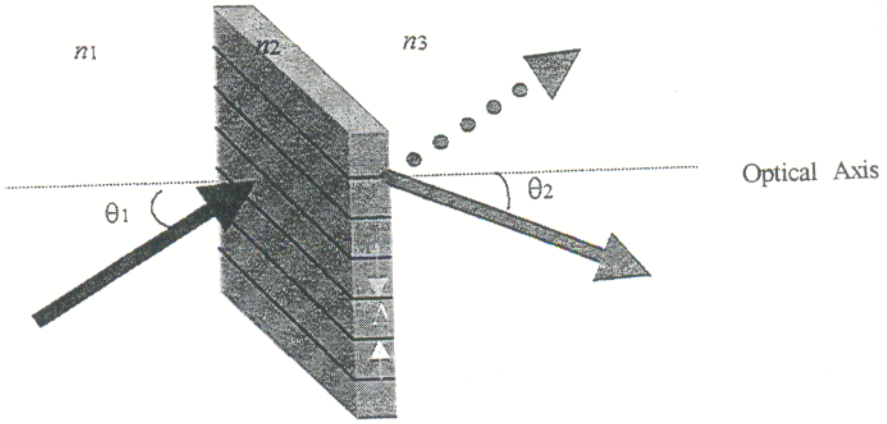

Figure 2. The diagram of illumination and diffraction of the grating

Figure 2 shows the illumination and diffraction of the grating. A light beam of wavelength λ incidences the grating at angle θ_1. The light will be diffracted in θ_2 direction. The grating has a period of Λ. The grating equation is given by Ref. 8

$$\Lambda(n_3\sin\theta_2 \pm n_1\sin\theta_1) = m\lambda / n_3 , \qquad m = 0, \pm1 \pm2, \ldots \tag{1}$$

where θ_1 and $\theta_2$are the incident and the diffraction angles of the optical signals in the holographic grating region at the center wavelength of λ (in the air), respectively, n_1, n_2 and n_3 are the average refractive index of the medium. m represents the mth order for forward diffraction. Let θ_2 be the designed diffraction angle in the medium of refractive index n_3. The dispersion of the grating can be derived by differentiating Eq. (1), which gives

$$\frac{d\theta_2}{d\lambda} = \frac{m}{\Lambda n_3{}^2 \cos\theta_2} = \frac{n_3\sin\theta_2 \pm n_1 \sin\theta_1}{\lambda n_3 \cos\theta_2} \tag{2}$$

From Eq. (2), we can see that in order to get large dispersion ability the diffraction angle θ_{diff} should b large. In that case, the nonlinearity of the dispersion ability will be large since it is given by

$$\frac{d^2\theta_2}{d\lambda^2} = \frac{m^2 \sin\theta_2}{\Lambda^2 n_3{}^4 \cos^3\theta_2} = \frac{(n_3\sin\theta_2 \pm n_1\sin\theta_1)^2 \sin\theta_2}{\lambda^2 n^2{}_3 \cos^3\theta_2} \tag{3}$$

Therefore, grating is not used at large diffraction angle in WDM applications. In order to separate light signals with different wavelengths a long propagation distance is needed. Here the device becomes bulky.. If we can find a way to let light signals travel in zig path and get rid of lens the dimension of the device and cost will reduce. Combinating of planar optics and chirp grating can serve this purpose.

3. CHIRP GRATING WDM

3.1 Structure

The idea for WDM based planar optics and chirp grating is schematically shown in Figure 3.

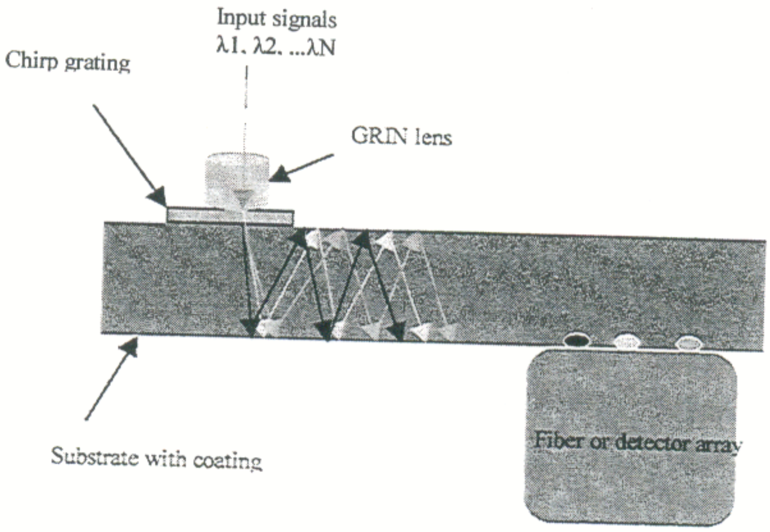

Figure 3. The diagram for the structure of the WDM based on planar optics and chirp grating

The light signals with different wavelengths from a fiber are collimated by GRIN lens and launched into chirp grating. The chirp grating will focus and diffract the signals in different directions. After propagating certain distance in substrate the signals separate. The fiber or detector array is used to collect the signals. The chirp grating functions as both focus lens and dispersion element. The substrate lets the light signals travel in zig path and the focus lens is removed. Therefore, the size of device is reduced. In order to build a chirp gating based WDM device as shown in Figure 3, we need to know all the parameters for each component, for example, the dimensions of the substrate, which can be determined by following equation

$$w = \frac{\Delta w}{\Delta \lambda} \frac{\lambda n_3 \cos^3 \theta_2}{n_3 \sin \theta_2 \pm n_1 \sin \theta_1} \tan \theta_2 \tag{4}$$

where w is the width of the substrate, Δw and $\Delta\lambda$ are fiber or detector array spacing and wavelength separation respectively. Other parameters in equation (4) are the same as those in figure 2. From equation (4) we know the width of the substrate is independent of the thickness. Therefore the thickness is not so critical in the device based on this structure. For normal incident the equation (4) becomes

$$w = \tfrac{\Delta w}{\Delta\lambda}\lambda\cos^2\theta_2 \tag{5}$$

The light travelling distance l can be determined by equation (6)

$$l = \frac{w}{\sin\theta_2} = \lambda\frac{\Delta w\cos^2\theta_2}{\Delta\lambda\sin\theta_2} \tag{6}$$

For example, for $\lambda = 1.55\ \mu m$, $\Delta\lambda = 0.8\ nm$, $\Delta w = 125\mu m$, $\theta_2 = \pi/3$ we find $w = 60\ mm$, $l = 69.3\ mm$. From the structure of the device it can seen that one of the key components in the device is chirp grating. The chirp grating can be recorded holographically, which is discussed in next section.

3.2 Chirp grating recording

Hologram recording parameters

In order to reduce insertion loss of the device, the diffraction efficiency of hologram must be high, which requires phase match for the all wavevectors in holographic medium.

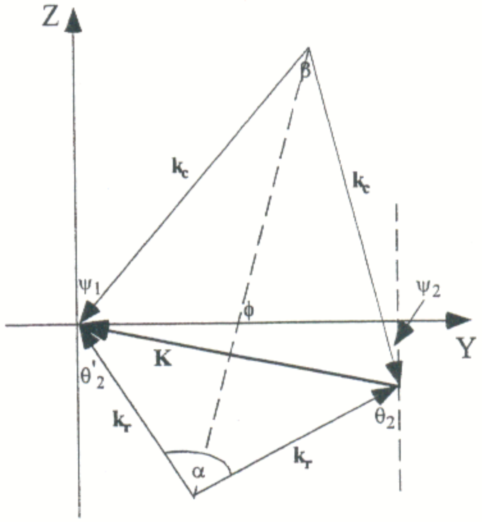

Figure 4. The diagram of phase-matching condition for recording and reconstruction of the hologram.

Fig. 4 shows the phase matching diagram for all the wavevectors in the holographic medium. The recording wave vector $\mathbf{k_c}$ ($|\mathbf{k_c}| = 2\pi n' / \lambda_c$) are phase-matched with the grating vector $\mathbf{K}$ ($|\mathbf{K}| = 2\pi / \Lambda$), and so does the reconstruction wave vector $\mathbf{k_r}$ ($|\mathbf{k_r}| = 2\pi n / \lambda$) and **K**. n' is the average refractive index of the guided-wave holographic emulsion at recording wavelength λ_c. From the geometry of Fig. 4, the recording angles in the hologram medium of the two recording beams at wavelength λ_c are derived and given by

$$\psi_1 = \pi / 2 - (\phi - \beta / 2), \tag{7}$$

and

$$\psi_2 = (\phi + \beta / 2) - \pi / 2. \tag{8}$$

where

$$\beta = 2 \sin^{-1}\{(n \lambda_c / n'\lambda) \sin[(\theta_2' + \theta_2) / 2]\}, \tag{9}$$

which is the angle between two recording beams. Note that the phase matching condition in Fig. 4 is in the holographic medium. In practice, the recording angles calculated by Eqs. (7) and (8) must be converted into those angles in the air by the Snell's law.

For chirp grating we should not only know the direction parameters for recording but also know the parameters for imaging, which can be found from the relationship between object and image. For normal incident onto the grating the formula is quite simple, as shown bellow,

$$R_o = \frac{\lambda_r}{\lambda_c} R_i \tag{10}$$

where R_o and R_i are the distances form object and image points to the surface of the hologram respectively. λ_c and λ_r in equation (10) are the recording and reconstruction wavelengths respectively.

Experimental setup

Based on the parameters calculated from equations (7)-(10) we can record the chirp grating as needed. Figure 5 shows the diagram of experimental setup for recording holographic chirp grating. A laser beam of wavelength 530nm from laser is split into two beams with the same intensity by a beam splitter. Each passes through a spatial filter. After that, they are collimated by two collimating lenses. One of collimated is focused by another lens to form a spherical wave. The other plane wave and this spherical wave illuminate holographic plate simultaneously. After recording hologram can be developed based on the development procedure.

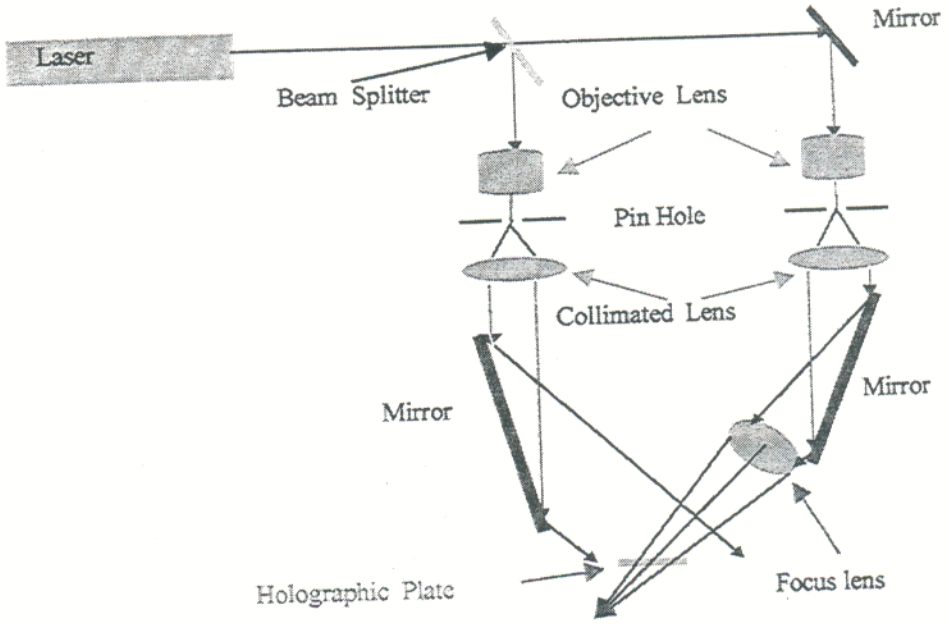

Figure 5. The experimental arrangement for recording holographic chirp grating.

Experimental results

The preliminary experimental works for recording chirp grating have been done in our lab. In the experiment, Dupont Photopolymer HRF 600X001-20 was used as recording medium. The recording wavelength is 532 nm ,which is from Verdi laser. The experimental results for the relationship between diffraction efficiencies of the gratings and exposure time are shown in Figure 6.

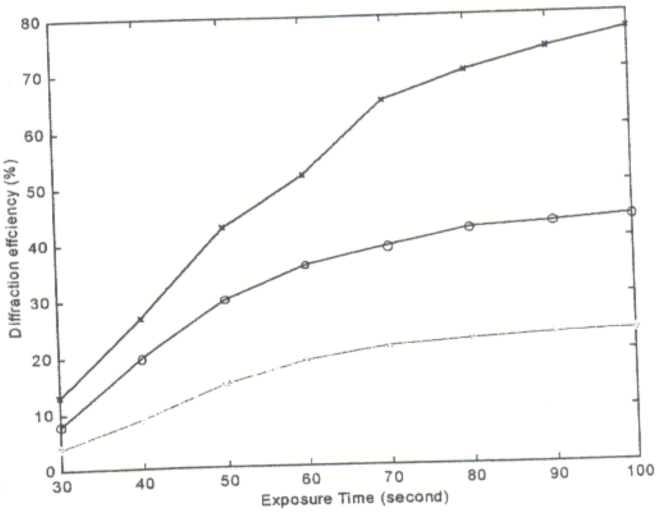

Figure 6. The experimental results for the efficiencies of the grating

In Figure 6, 'X', 'O' and '*' are used for experimental data for reconstruction wavelengths of 532, 800 and 1550 nm respectively. The laser beam intensity of 13 mW/cm^2 was launched onto the surface of holographic film in this chirp grating recording. The recording angles are 5 and 25.51 degrees for plane wave and spherical wave light beam respectively. The distance from the focus point of spherical wave to the center of chirp grating is 150 mm. After recording the hologram was cured for three minutes using UV lamp. Then it was baked for two hours at 100 degrees centigrade.

From experimental data shown in Figure 6 we can see that the efficiency of the grating is higher at shorter wavelength, especially at the same wavelength as recording wavelength. Even for wavelength of 800 nm the efficiency can reach as high as -3 dB, which is quite high in the applications of data communications and optoelectronic interconnects for board to board and from machine to machine.

4. CONCLUSIONS

The novel structure of DWD(D)M based on the combination of planar optics and chirp grating is proposed. The chirp grating in the devices functions as both dispersive element and lens. Since it is a lensless system the cost will be reduced. The planar optics lets light signals propagate in zig-zag path, which makes the dimension of the device smaller. The planar optics also makes the device more stable, which is very important in the applications of optoelectronic interconnects. The preliminary experimental results show the WDM device based on this structure is promising in data communications and optoelectronic interconnects from board to board or from machine to machine the applications. For telecommunication applications there are several issues needed addressing, such as, efficiencies and aberrations, which we are working on. The results will be published latter.

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