Full length article

Wavelength demultiplexing by chirped waveguide gratings

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Abstract

The performance of a chirped waveguide grating as a wavelength demultiplexer has been investigated. Considerations include TE-TE, TE-TM and TM-TM mode coupling for different incident angles and waveguide parameters. The spectral response of the chirped sinusoidal surface relief grating in the optical waveguide has been studied by means of Local Normal Mode Expansion (LNME) theory to account for the varying thickness of a corrugated waveguide. A matrix technique has been applied to account for the varying grating period, the grating being divided into segments with constant periods and coupling coefficients. A nonslanted first-order diffraction grating is considered and contradirectional coupling between guided modes in phase synchronism at arbitrary incident angles. We show the effect of geometry and waveguide parameters on the performance of the chirped grating as a wavelength demultiplexer. Also, we demonstrate how the bandwidth of the filtering and demultiplexing characteristics and the spectral shift between different polarization modes can be controlled.

Keywords: Coupled-mode theory; Local normal mode expansion; Matrix approach; Waveguide gratings; Wavelength demultiplexers; Chirped gratings

1. Introduction

Periodic and almost-periodic structures in waveguides can perform a variety of functions such as wave-coupling, wavefront conversion and wavelength dispersion. Applications include couplers, splitters, deflectors, reflectors, lenses, polarization converters, and multiplexers/demultiplexers [1]. Almost-periodic waveguide structures, such as chirped, tapered, or phase-shifted gratings can improve the characteristics of grating filters and have mostly been used to construct filters with side-lobe suppression [2–4]. One approximation usually used for chirped gratings is coupled-mode theory, the equations being solved either numerically [3,4] or analytically under some restrictions [2,5,6]. Another numerical approach is to divide the grating into segments with constant periods and obtain the filter response by matrix multiplication [7,8]. An overview and a comparison of the techniques for evaluating uniform and chirped gratings can be found in Ref. [9]. Chirped gratings have been experimentally demonstrated as demultiplexers for a guided-to-radiation mode coupling geometry [10,11].

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However, a large spatial shift between the coupled TE and TM modes has been experimentally observed in Ref. [12]. This effect broadens the spectral response of the grating and if used as a demultiplexer, it can completely degrade the performance. The polarization sensitivity of waveguide grating filters in semiconductor materials and the spectral shift between TE and TM modes have been investigated in Ref. [13] for different waveguide geometries.

In this paper, the performance of a chirped sinusoidal waveguide grating as a wavelength demultiplexer is evaluated. We study the spectral response of the surface relief grating in the optical waveguides by means of the LNME theory. Arbitrary angle of incidence and contradirectional guided-to-guided mode coupling in phase synchronism, i.e., small Bragg detuning, is considered via a matrix approach so as to account for the variation in the grating period. We address the polarization issue and evaluate its effect on the performance of the wavelength demultiplexer. Our performance considerations include coupling between TE and TM modes, wavelength resolution depending on the grating and waveguide parameters. We show the effect of various waveguide and grating parameters on the spectral resolution and demonstrate how the spectral shift between modes of different polarizations can be controlled by those parameters.

2. Background

2.1. Local normal mode expansion for a uniform surface corrugated waveguide grating

Excellent references on coupled-mode theory in waveguide gratings are available, e.g., see Refs. [14–18]. Coupling coefficients for TE and TM modes in ideal and LNME have been derived in Refs. [14,16] and compared for arbitrary incident angles [15]. We apply the LNME approach developed in Ref. [14] for arbitrary incident angles. The goal is to find solution to Maxwell’s equations for a refractive index distribution $n = n(x, y, z)$ where the magnetic properties are assumed to be those of the vacuum. Transverse and longitudinal components are separated and series expansion of the transverse field vectors are used in the form:

$$E_i = \sum_{\nu} a_{\nu} \varphi_{\nu}, \quad H_i = \sum_{\nu} b_{\nu} \varphi_{\nu},$$

where the summation indicates both summation over the guided modes and integration over the radiation modes. Applying a transformation to slowly varying mode amplitudes

$$a^{(+)\mu} = c^{(+)\mu} \exp \left[ -i \int_0^z \beta_{\mu} \, dz \right], \quad \text{and} \quad b^{(-)\mu} = c^{(-)\mu} \exp \left[ i \int_0^z \beta_{\mu} \, dz \right]$$

yields a set of integro-differential equations for the amplitudes of the local modes:

$$\frac{dc^{(+)}_{\mu}}{dz} = \sum_{\nu} \left( R^{+\nu}_{\mu} c^{+\nu} \exp \left[ i \int_0^z (\beta_{\mu} - \beta_{\nu}) \, dz \right] + R^{-\nu}_{\mu} c^{-\nu} \exp \left[ i \int_0^z (\beta_{\mu} + \beta_{\nu}) \, dz \right] \right),$$

$$\frac{dc^{-\mu}}{dz} = \sum_{\nu} \left( R^{+\nu}_{\mu} c^{+\nu} \exp \left[ -i \int_0^z (\beta_{\mu} + \beta_{\nu}) \, dz \right] + R^{-\nu}_{\mu} c^{-\nu} \exp \left[ -i \int_0^z (\beta_{\mu} - \beta_{\nu}) \, dz \right] \right),$$

where $+$ and $-$ stand for forward and backward propagating modes, respectively. The coupling coefficients are expressed as

$$R^{(p,q)}_{\mu\nu} = \frac{\rho \omega e_0}{4 p (\beta_{\mu}^p - \beta_{\nu}^q)} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{\partial n^2}{\partial z} \varphi_{\mu}^p \cdot \varphi_{\nu}^q \, dx \, dy; \quad p = +1.$$

The propagation constants $\beta_{\mu}$ in LNME are functions of $z$. The waveguide, whose modes are used for the field expansion, varies in thickness as a function of $z$ and locally coincides with the width of the real waveguide.
Hence, the modes are called local normal modes. They are superimposed to yield a solution to Maxwell’s equations that represents the field of the real waveguide. The coupling coefficients in (4) hold for modes with real values of \( \beta \) and for off-diagonal terms \( \mu \neq \nu \) or \( \mu = \nu \) with \( p \neq q \). The index distribution for the ideal and real dielectric waveguide \( n_0(x, y) \) and \( n(x, y, z) \) differ only in the vicinity of the core boundary. The deviation of the core boundary from the ideal form is given by the surface corrugation function \( x = f(z) \). The problem in the evaluation of the coupling coefficient comes from the discontinuity of the refractive index distribution at the core boundary. Because of the discontinuity of the normal electric field, the tangential and normal components are treated separately, and the abrupt changes are smoothed out. For the case of guided-to-guided contradirectional mode coupling at an arbitrary incident angle, the approximation of the coupling coefficient is:

\[
R_{\mu \nu}^{(p, q)} = 2 r_{\mu \nu} \frac{df}{dz} = \frac{\omega c_0 (n_0^2 - n_r^2)}{4P \cos \theta_0 (\beta_\mu \cos \theta_\mu + \beta_\nu \cos \theta_\nu)} \frac{df}{dz} \left[ \frac{n_r^2}{n_0^2} \left( \frac{\partial \psi_{\mu}^* \psi_{\nu x} + \partial \psi_{\mu y}^* \psi_{\nu y} + \partial \psi_{\mu z}^* \psi_{\nu z}}{\partial z} \right) \right]_{z=f(z)},
\]

where surface function \( f(z) \) of a uniform grating is assumed as

\[
f(z) = h + \Delta h \sin \left( \frac{2\pi}{\Lambda} z \right); \quad \frac{df(z)}{dz} = \Delta h \left( \frac{\pi}{\Lambda} \right) \left[ \exp \left( \frac{2\pi}{\Lambda} z \right) + \exp \left( -\frac{2\pi}{\Lambda} z \right) \right]; \quad 0 \leq z \leq L,
\]

where \( \Delta h, \Lambda \), and \( L \) are the surface corrugation depth, the grating period and the grating length, respectively. The field components are evaluated at the upper core boundary, inside the core. This approximation is valid for slowly varying surface corrugation functions.

In the case of a sinusoidal deviation from the ideal surface, only two of the infinite number of wave amplitudes can be considered. The restriction always imposed is that the deviation is slight and varies slowly, so that the change in the field amplitudes is very slow compared to the wavelength. This assumption allows us to consider a perturbation solution where the incident mode is large and the coupling is weak. We consider \( \beta_{\nu}^{(q)} - \beta_{\mu}^{(p)} \approx 0 \) and modes which violate this are not coupled efficiently. Assuming a single-mode waveguide, this relation is satisfied for two of the modes. Therefore, only forward-to-backward coupling of guided-to-guided modes are considered and the system is further simplified. Replacing Eqs. (5) and (6) into (3) and averaging over one period \( 1/\Lambda \), the cosine term disappears, while the amplitudes and their derivatives do not change much. Terms that do not have nearly zero phase are neglected, as required by the "synchronous approximation". Eqs. (3) are simplified to:

\[
\frac{d\psi_{\mu}^+}{dz} = r_{\psi_{\mu}^+} \psi_{\mu}^+ \exp(2i\delta z), \quad \frac{d\psi_{\mu}^-}{dz} = r_{\psi_{\mu}^-} \psi_{\mu}^+ \exp(-2i\delta z),
\]

where \( 2\delta(z) = \beta_{\mu} + \beta_{\nu} - K(z) \) is the detuning parameter, \( K(z) \) is the grating vector and \( \mu \) and \( \nu \) correspond to TE and TM guided modes: \( \mu = \nu \), TE-TE or TM-TM coupling, \( \mu \neq \nu \), TE-TM coupling. With the substitution for the forward and backward propagating waves

\[
c_{\mu, \nu}^+ = R(z) \exp(-i\delta z), \quad c_{\mu, \nu}^- = R(z) \exp(i\delta z)
\]

and imposing the boundary conditions for a reflection grating \( R(0) = 1 \), and \( S(L) = 0 \), the solution for the reflected and transmitted amplitudes are

\[
c^+ (z) = \exp(i\delta z) \frac{\alpha \cosh(\alpha z) - i\delta \sinh(\alpha z)}{\alpha \cosh(\alpha L) + i\delta \sinh(\alpha L)}, \quad c^- (z) = \exp(-i\delta z) \frac{r \sinh(\alpha z)}{\alpha \cosh(\alpha L) + i\delta \sinh(\alpha L)},
\]

where \( \alpha^2 = r^2 - \delta^2 \).
By substituting (6) into (5) and using the known relations from the solutions of the planar ideal slab waveguide [17], the coupling coefficients \( r \) are obtained as

\[
r_{TE-TE} = \frac{\pi}{\Lambda} \frac{\Delta h}{h_{effTE}} \frac{N_{effTE}^2}{N_{effTE}^2} \frac{\cos(2\theta)}{2 \cos^2(\theta)},
\]

for the TE-TE coupling; incident TE mode coupled to a reflected TE mode (\( \mu = \nu \));

\[
r_{TE-TM} = \frac{j\pi\Delta h}{2\Lambda} \left( \frac{n_{effTE}^2}{N_{TE}^2 - N_{TM}^2} \right)^{1/2} \left( \frac{n_{effTM}^2}{N_{TM}^2 - N_{TE}^2} \right)^{1/2} \left( N_{TM}^2 - n_c^2 \right)^{1/2} \times \frac{\sin(\theta_\mu + \theta_\nu)}{\cos \theta_\nu (N_{TE} \cos \theta_\mu + N_{TM} \cos \theta_\nu)};
\]

for the TE-TM coupling; incident TE mode coupled to a reflected TM mode (\( \mu = \nu \));

\[
r_{TM-TM} = \frac{\pi}{\Lambda} \frac{\Delta h}{h_{effTM}} \frac{N_{effTM}^2}{n_{effTM}^2 N_{TM}^2} \left( N_{TM}^2/n_{TM}^2 + N_{TM}^2/n_{TM}^2 - 1 \right)^{1/2} \cos^2(\theta)
\]

for the TM-TM coupling; incident TM coupled to a reflected TM mode (\( \mu = \nu \)).

### 2.2. Matrix approach for a chirped surface corrugated grating

A matrix approach is applied to evaluate the performance of the chirped grating. The waveguide grating is divided into \( N \) uniform segments of length \( l_j \), "\( j \)" being the segment index. Coupling coefficients \( r_j \), detuning parameters \( \delta_j \) and \( \alpha_j \) are assumed constant throughout each segment. The matrix for a single grating segment is derived from Eqs. (7)-(8) based on solutions in the form

\[
R_j(z) = R_{j,1} \exp(\alpha_j l_j) + R_{j,2} \exp(-\alpha_j l_j),
\]

\[
S_j(z) = \frac{1}{r_j} \left[ (\alpha_j + i\delta_j) R_{j,1} \exp(\alpha_j l_j) + (-\alpha_j + i\delta_j) R_{j,2} \exp(-\alpha_j l_j) \right].
\]

Accounting for phase changes at each interface; \( \Phi_j = \Phi_{j-1} + (2\pi/\Lambda_{j-1})l_{j-1} \), the matrix for each segment is

\[
\begin{pmatrix}
R_j(l_j) \\
S_j(l_j)
\end{pmatrix}
= \begin{pmatrix}
\cosh(\alpha_j l_j) - i(\delta_j/\alpha_j) \sin(\alpha_j l_j) & (r_j/\alpha_j) \sinh(\alpha_j l_j) \exp(i\Phi_j) \\
(r_j/\alpha_j) \sinh(\alpha_j l_j) \exp(-i\Phi_j) & \cosh(\alpha_j l_j) + i(\delta_j/\alpha_j) \sin(\alpha_j l_j)
\end{pmatrix}
\begin{pmatrix}
R_j(0) \\
S_j(0)
\end{pmatrix}
= M_j \begin{pmatrix}
R_j(0) \\
S_j(0)
\end{pmatrix},
\]

where without loss of generality, each segment is assumed to have an integer number of periods. The matrix \( M_j \) gives the connection formula for the solutions for the forward and backward propagating modes \( R_j \) and \( S_j \) at the beginning and at the end of the \( j \)th segment \( z = 0 \) and \( z = l_j \), respectively. The continuity conditions for the forward and backward propagating modes at the interface between two adjacent segments are \( R_{j-1}(l_{j-1}) = R_j(0) \) and \( S_{j-1}(l_{j-1}) = S_j(0) \). The total response of the chirped grating is obtained by multiplying the response matrices of all \( N \) segments accounting for the phase-matching condition at the interface of adjacent segments and continuity conditions at \( z = 0 \) and \( z = l_j \):

\[
M_{total} = \begin{pmatrix}
M_{11} & M_{12} \\
M_{21} & M_{22}
\end{pmatrix} = \prod_{j=1}^{N} M_j.
\]
Applying the boundary conditions for the reflection grating, the amplitudes of the forward and backward propagating modes are obtained as:

\[ c^-(0) = -\frac{M_{21}}{M_{22}} \quad \text{and} \quad c^+(0) = \frac{1}{M_{22}}. \]  

(16)

Using the above formulations, the amplitudes and the spectral response of the diffracted modes can be evaluated at each segment. For an almost-periodic grating \( A = A(z) \), Eq. (6) is transformed into

\[ \frac{df}{dz} = \Delta h \left( \frac{\pi}{\Lambda(z)} \right) \left( -\frac{z}{\Lambda(z)} \frac{dA}{dz} + 1 \right) \left[ \exp \left( \frac{2\pi i}{\Lambda(z)} z \right) + \exp \left( -\frac{2\pi i}{\Lambda(z)} z \right) \right]. \]  

(17)

The condition necessary for dividing the grating into segments and applying Eqs. (14), (15) is \( df/dz \ll 1 \) and leads to \( \Lambda_j \ll l_j \). It is satisfied for slowly varying grating periods, as indeed required by the LNME.

3. Results and discussions

The performance of a chirped grating as a wavelength demultiplexer is evaluated for incident light of continuous spectrum at an arbitrary angle of incidence. The optical interaction of guided-to-guided modes caused by a waveguide diffraction grating with a chirped periodicity in a symmetrical nonslanted reflection geometry is studied. The planar waveguide periodic structure is schematically shown in Fig. 1 where nearly sinusoidal surface corrugation of the upper core-cladding interface is assumed, i.e., a small chirp of the grating period \( \Lambda(z) \). Gain and absorption losses are not included in the considerations. The guiding layer \( h \) is assumed to support only the lowest-order TE and TM modes and a small surface corrugation is assumed, i.e., \( \Delta h < h/10 \). The performance of a chirped grating as a wavelength demultiplexer is evaluated for incident light of continuous spectrum at an arbitrary angle of incidence. As seen from the coupling coefficients (10)-(12), at certain angles, either TE-TE, TE-TM or TM-TM coupling disappears, e.g., at normal incidence with respect to the grating lines no TE-TM coupling occurs, there is no TE-TE coupling at 45 degree, while the angle where TM-TM coupling disappears depends on the grating and waveguide parameters. For the rest of the cases, all types of mode coupling is observed with different peak reflectivities and spectral shifts, depending on incident angle, grating period and waveguide parameters. For the symmetrical grating under consideration, the diffracted light emerges from each segment at the same angle and peak reflectivity is evaluated as a function of wavelength at each segment. The length of the segment \( l_j \) is assumed to contain an integer number of grooves. To obtain the spectral response of the individual segments, the responses of two adjacent segments are subtracted. An asymmetrical waveguide with \( n_e = 1, n_r = 1.56, n_s = 1.46, \) and \( h = 1.37 \mu m \) was assumed in the evaluation. The following parameters were used: period of the grating \( \Lambda_{\text{min}} = 0.5339 \mu m \), chirp rate
Fig. 2. Spectral response of the reflectivity of a chirped grating in an asymmetrical waveguide at an incident angle where TM-TM coupling disappears. TE-TE coupling is shown by the black solid line, TE-TM coupled mode is shown by the dotted line. The waveguide and grating parameters are given in the text.

\[ \nu = \left( \frac{\Delta \Lambda}{\Lambda (1/L)} \right) = 3 \times 10^{-6}, \] depth of surface corrugation \( \Delta h = 0.08 \, \mu\text{m} \) and grating length \( L = 10.7 \, \text{mm} \) with \( N = 50 \) segments of approximately equal length \( l_j = 400 \times \Lambda_j \, \mu\text{m} \). The spectral response of the chirped grating in the wavelength range around \( \Lambda = 1.5 \, \mu\text{m} \) is shown in Fig. 2 for an incident angle where the TM-TM coupling disappears. The peak reflectivity \( \rho = |c(0)|^2 \) for the TE-TE coupled mode is shown by the black solid line, the TE-TM by the dotted line. The peak of the TM-TE coupled mode is close to the TE TM and cannot be resolved in the presented scale. The peak reflectivity of a single segment with \( \Lambda_{\text{max}} \) and a length of \( l_N \) is shown in the figure for comparison. The light reflected from arbitrarily chosen adjacent segments within the grating is shown in Fig. 3. As seen from the figure, there is a significant shift of \( \Delta \approx 4 \, \text{nm} \) between the diffracted TE-TE and TE-TM coupled modes for this geometry and waveguide parameters. The spectral shift between the modes effectively broadens the bandwidth and deteriorates the resolution. As seen, the TE-TE coupled mode partially overlaps with the TE-TM mode reflected from the next segment, e.g., longer

Fig. 3. Spectral response of adjacent segments of the chirped grating shown in Fig. 2. TE-TE coupling is shown by the black curve, TE-TM by the dotted curve.
wavelengths emerge from the previous segment and shorter wavelengths from the next segment, thus the emerging wavelengths will be mixed and the performance of the demultiplexer totally degraded. Use of polarized incident light cannot improve the performance for this configuration and parameters, because an incident TE mode is always coupled into diffracted TE and TM modes with a significant spectral shift.

At normal incidence, TE-TM mode coupling disappears. Such a configuration, however, is not suitable for a wavelength demultiplexer because the incident and diffracted modes are not spatially separated. For larger incident angles, all types of mode coupling is observed with peak reflectivities, bandwidths and spectral shifts that depend on the grating and waveguide parameters. Figs. 4 and 5, for instance, show the spectral response of the chirped grating for an incident angle of $\alpha_{inc} = 5$ degree. As seen in Fig. 5, the spectral shift is almost doubled, i.e., $\Delta \approx 6$ nm, compared to that in Fig. 3. Clearly, this grating geometry and parameters are not suitable for wavelength demultiplexing.

Fig. 4. Spectral response of the reflectivity of a chirped grating at an incident angle of 5 degree. TE-TE coupling is shown by the black solid line, TE-TM mode is shown by the dotted line, TM-TM mode by the dashed line. The waveguide and grating parameters are given in the text.

Fig. 5. Spectral response of arbitrary adjacent segments of the chirped grating in Fig. 4. TE-TE shown by the solid line, TE-TM by the dotted line, TM-TM coupling by the dashed curve.
The spectral response of the chirped grating at an incident angle $\alpha_{\text{inc}} = 45$ degree where TE-TE coupling disappears is shown in Fig. 6 for a grating period $A_{\text{min}} = 0.7028$ $\mu$m and a grating length $L = 14.05$ mm, with segment lengths $l_j$ with an integer number of grooves, i.e., $l_j = 400 \times A_j$ $\mu$m. The incident angle also affects the spectral bandwidth for the same set of waveguide parameters. Because the grating is longer, no broadening of the spectral response of the demultiplexer at this incident angle is observed compared to Fig. 2. We do see, however, a significant broadening of the response for the uniform grating of $A_{\text{max}}$ and a length $l_n$, given in the figure for comparison. The response of adjacent segments is shown in Fig. 7. As can be seen from the figure, the spectral shift is approximately the same, as in Fig. 3. The performance of the demultiplexer is degraded as well. If only a TM or a TE mode is incident on the grating, however, it will be coupled to a TM mode. This configuration works as a TE-TM polarization converter for a TE incident mode [17]. Use of polarized light incident on the wavelength demultiplexer can significantly improve the resolution for this configuration.
With smaller depths of corrugation $\Delta h$, the spectral shift is slightly reduced, the bandwidth of each segment is narrowed and so is the spectral response of the chirped grating. However, longer segments are required to achieve the same peak reflectivity. The spectral shift between the diffracted modes also decreases with decreasing refractive index difference between the guiding layer and the substrate. However, longer grating lengths are necessary to achieve stronger coupling and high reflectivity. Larger values $h$ of the guiding layer also result in reducing the spectral shift between the modes, but the thickness should be as small as to propagate only the lowest-order TE and TM modes. Reducing the spectral shift and having strong coupling at a small chirp rates are conflicting requirements. A trade-off is to be sought between grating geometry and waveguide parameters.

The performance of the chirped grating as a wavelength demultiplexer is significantly improved for a symmetrical waveguide with parameters $n_g = n_s = 1.469$, $n_r = 1.515$ and $h = 2 \mu\text{m}$ and $\Delta h = 0.16 \mu\text{m}$, as can be seen in Figs. 8 and 9. The grating parameters are the same as given for Figs. 6 and 7. At the incident angle of
45 degree, there is no TE-TE mode coupling. The spectral response of two adjacent segments is shown in Fig. 9. The spectral shift in Figs. 8 and 9 is reduced to less than 0.5 nm compared to Figs. 6 and 7. Although, there is no significant narrowing of the spectral response of the individual segments because of their short length, this configuration significantly improves the resolution and will allow a narrower channel spacing. At the angle where no TM-TM coupling occurs and for a period $\Lambda_{\text{min}} = 0.5339 \ \mu m$, a slightly larger chirp rate $\nu = 2 \times 10^{-6}$, slightly larger guiding layer $h = 2.2 \ \mu m$, depth of modulation $\Delta h = 0.19 \ \mu m$, and longer segment length $l_j = 600 \times \Lambda_j$, the peak efficiency is improved without deteriorating the spectral resolution. This is shown in Figs. 10 and 11. As can be seen, the chirped grating is nearly polarization insensitive and the spectral shift is reduced to less than 0.5 nm.

The wavelength demultiplexing devices are designed to separate a discrete spectrum of wavelengths assigned to the individual users. For instance, the chirped grating shown in Figs. 10 and 11 can demultiplex wavelengths

![Diagram](image-url)
2 nm apart. Because of a relatively broader response of the individual segments, the device is tolerant to peak wavelength shifts of the laser diode, i.e., it can accommodate slight variations of the users’ wavelengths. Chirped gratings can be implemented by holographic patterning techniques [19] where the chirp rate can be controlled by the recording set-up. The overall device design requires considering coupling to and from the grating where the spread of the beam becomes important at arbitrary incident angles.

4. Conclusions

The polarization-sensitive spectral response of a chirped surface relief grating in an optical waveguide has been studied by means of Local Normal Mode Expansion (LNME) theory to account for the varying thickness of the corrugated waveguide. Nonslanted grating in a first-order diffraction and contradirectional coupling between guided modes in phase synchronism is considered at arbitrary angles of incidence. A matrix technique has been applied to account for the varying grating period, the grating being divided into segments assumed to have constant periods and the coupling coefficients. Performance considerations address polarization sensitivity at different angles of incidence, TE-TE, TE-TM and TM-TM mode coupling for different grating geometry and waveguide parameters. We have studied the effect of geometry and waveguide parameters on the performance of the chirped grating as a wavelength demultiplexer. We have shown how the filter bandwidth, the demultiplexing characteristics and the spectral shift between different polarization modes can be controlled. For an optimized geometry and material parameters, the spectral shift between different modes can be reduced to less than 0.5 nm.

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References