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Research

Comparative Performance Analysis of Square- and Triangular Corrugated Optical Waveguides as Optical Filters

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Abstract: *We have reported comparatively the influences of square- and triangular corrugations on the optical waveguide to be used as optical filter. To do this, the performance parameters, reflectance and transmittance have been derived for the two types of periodic corrugated waveguides. By visualizing reflectance and transmittance characteristics, it is found that both types of corrugated optical waveguide act as optical filter. It is also found that triangular corrugated filter gives better elimination than square corrugated waveguide filter. This study would be very helpful for the development of efficiency in the optical fiber communication systems.*
Keywords*: Optical waveguide, optical filter, reflectance, transmittance*

Introduction

With the development of the technology of communication, optical fiber communication system has attracted much more attention due to its some advantageous characteristics, such as high speed transmission, greater bandwidth, better reliability, more flexible and cost-effective.[1–5] Optical communication systems transmit information optically through fibers. Basically, optical fiber communication system consists of light sources such as laser diode, optical fiber and photo detector at the receiver.[2] However, the light emitting from the laser diode practically contains some harmonics near the fundamental frequency which may cause pulse spreading due to dispersion during transmission.[6] Moreover, edges of the core-cladding boundary are straight in case of theoretical optical waveguide but practically, unfortunately there exists some ripples in the edges.[7] Some optical power radiates through these ripples unintentionally, therefore power confinement through the fiber decreases for all transmission wavelengths. Therefore, it is great importance not only to filter the unwanted harmonics of emitting light but also to eliminate or reduce the negative impact of waveguide ripples on the performance of the optical fiber communication systems.

If the ripples are added in a definite shape such as square, triangular at the waveguide edges as shown in Fig. 1(a), then the waveguide acts as optical filter shown in Fig. 1(b). Some wavelengths of transmitting light are radiated out completely through these ripples while some wavelengths are confined through waveguide guiding layer as can be seen from Fig. 1(b). As a result, the dispersion losses of the waveguide are minimized and efficiency of the optical waveguide increases.[7,8] In this study, we therefore, have analyzed and compared the influences of square- and triangular corrugations on the optical waveguides to be used as optical filters.

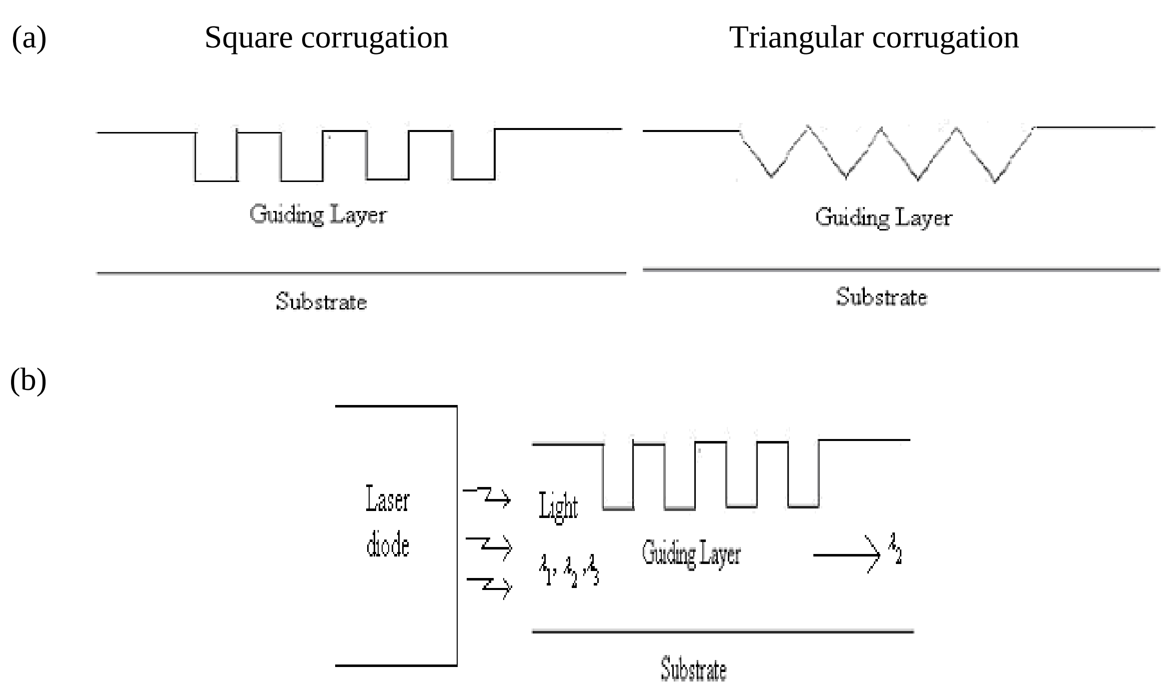


Fig. 1. (a) Square- and triangular corrugations on the optical waveguide (b) use of corrugated optical waveguide as optical filter.

Mathematical Analysis and Simulation

The schematic diagram of a square corrugated section of an optical waveguide with incident, reflected and transmitted intensities, and the forward and backward propagating waves inside the corrugated section are shown in Fig. 2 (a) and 2(b), respectively. When a light signal is incident to the square corrugation section as shown in Fig. 2(a), some wavelengths of incident light are reflected back from different positions of corrugation section due to variation in refractive index and some other wavelengths transmitted through the waveguide.

(a)

(b)

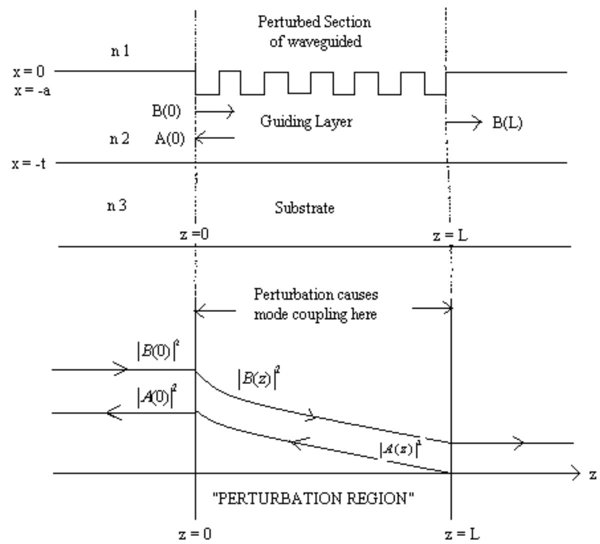


Fig. 2. (a): A square corrugated section of a waveguide with incident, reflected and transmitted intensities (b) forward and backward propagating waves inside the corrugated section.

Constructive interference occurs among those reflected wavelengths that follows the Bragg law, $\beta = {l\pi}/{\lambda}$ where l is a integer.[9] In this way, forward propagating wave $A(z)$ and backward propagating wave $B(z)$ in the propagation direction z form as shown in Fig. 2(b). The forward and backward propagating modes in one optical waveguide may be coupled according to the coupled mode theory.[7] The coupled mode equations play a major role in guided wave optics. The couple mode equations can be described for this structure as

$$ {dA}/{dz} = \kappa B exp[-i2(\Delta\beta)z] \quad \text{Eq. (1)} $$

$$ {dB}/{dz} = \kappa A exp[i2(\Delta\beta)z] \quad \text{Eq. (2)} $$

Where κ =Coupling coefficient between forward and backward waves, $\Delta\beta = \beta - \beta_0 = \beta - {l\pi}/{\wedge}$, $\wedge =$ corrugation period, and z is the propagation direction.

The equation of coupling coefficient, κ for square (κ_S)- and triangular (κ_T) corrugations have been derived as follows:

For square corrugation,

$$\kappa_S \approx \frac{2\pi^2 s^2}{3l\lambda} \frac{\left(n_2^2 - n_1^2\right)}{n_2} \left(\frac{a}{t}\right)^3 \left[1 + \frac{3}{2\pi} \frac{\lambda / a}{\left(n_2^2 - n_1^2\right)^{1/2}} + \frac{3}{4\pi^2} \frac{\left(\lambda / a\right)^2}{\left(n_2^2 - n_1^2\right)}\right] \qquad \text{Eq. (3)}$$

For triangular corrugation,

$$\kappa_T \approx \frac{i\pi s^2}{3n_2 l^2 \lambda} \left(\frac{a}{t}\right)^3 \left[n_1^2 \left\{1 + \frac{2}{\pi} \frac{\lambda / a}{\left(n_2^2 - n_1^2\right)^{1/2}} + \frac{3}{2\pi^2} \frac{\left(\lambda / a\right)^2}{\left(n_2^2 - n_1^2\right)}\right\} + n_2^2 \left\{3 + \frac{4}{\pi} \frac{\lambda / a}{\left(n_2^2 - n_1^2\right)^{1/2}} + \frac{3}{2\pi^2} \frac{\left(\lambda / a\right)^2}{\left(n_2^2 - n_1^2\right)}\right\}\right] \text{Eq. (4)}$$

Where $s =$ transverse mode number, $n_1 =$ refractive index of cladding layer, $n_2 =$ refractive index of core or guiding layer, $a =$ corrugation depth, and $t =$ width of the guiding layer

It is known that, Relectance, $R_{eff} = \frac{Power\ of\ the\ refelcted\ wave}{Power\ of\ the\ incident\ wave}$

Transmittance, $T_{eff} = \frac{Power\ of\ the\ transmiited\ wave}{Power\ of\ the\ incident\ wave}$

Therefore, for the corrugation section as shown in Fig. 2(b),

$$R_{eff} = \left|\frac{A(0)}{B(0)}\right|^2 \text{ and } T_{eff} = \left|\frac{B(L)}{B(0)}\right|^2$$

By mathematical analysis, the equations of R_{eff} and T_{eff} have been derived as follows:

$$R_{eff} = \frac{(\kappa L)^2 sin^2h\left[\sqrt{(\kappa L)^2 - (\beta \Delta L)^2}\right]}{(\kappa L)^2 cos^2h\left[\sqrt{(\kappa L)^2 - (\beta \Delta L)^2}\right] - (\beta \Delta L)^2} \qquad \text{Eq. (5)}$$

$$T_{eff} = \frac{(\kappa L)^2 - (\beta \Delta L)^2}{(\kappa L)^2 cos^2h\left[\sqrt{(\kappa L)^2 - (\beta \Delta L)^2}\right] - (\beta \Delta L)^2} \qquad \text{Eq. (6)}$$

Where $\Delta\beta L = \left[(\omega - \omega_0)\, {}^{L}/_{c}\right] n_{eff}$, $\omega = {}^{2\pi c}/_{\lambda}$, $\omega_0 =$ center or mid gap frequency $= {}^{2\pi c}/_{\lambda_0}$, $L =$ corrugation length, $c =$ velocity of light and $n_{eff} =$ effective refractive index.

The R_{eff} and T_{eff} have been visualized for both square- and triangular corrugations by using Eqs. (3), (4), (5) and (6) to evaluate reflectance and transmittance spectra for these structures.

Results and discussions

(i) Transmittance and reflectance characteristics of a corrugated section

The transmittance and reflectance characteristics of square waveguide have been visualized in Fig. 3 as a function of the detuning $\Delta\beta L = \left[(\omega-\omega_0)L/c\right]n_{eff}$.

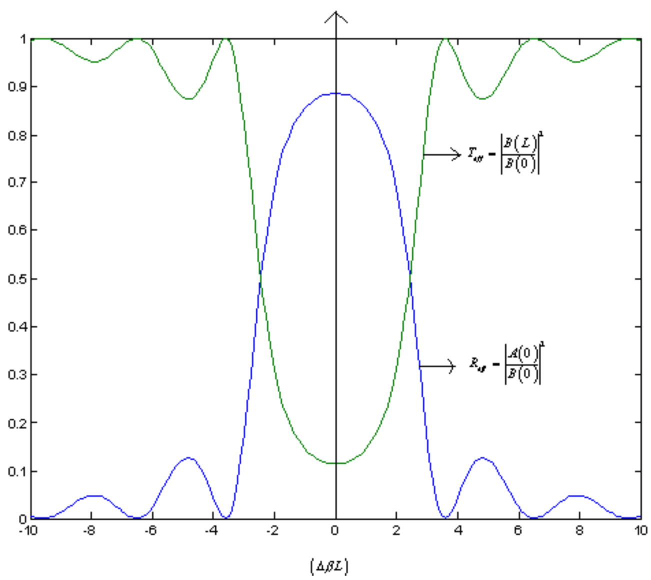
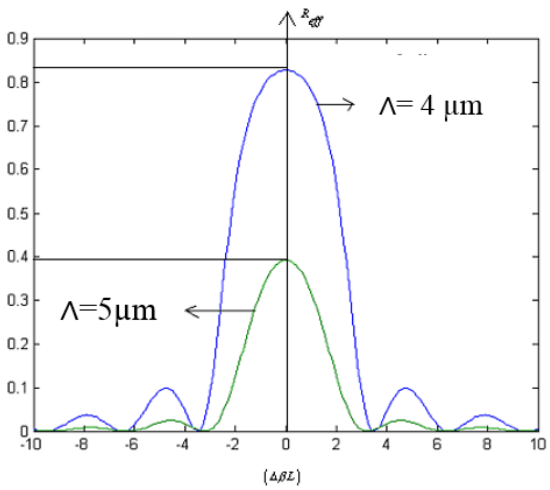


Fig. 3. Transmission and reflection characteristics of a square corrugated section as a function of the detuning $\Delta\beta L = \left[(\omega-\omega_0)L/c\right]n_{eff}$.

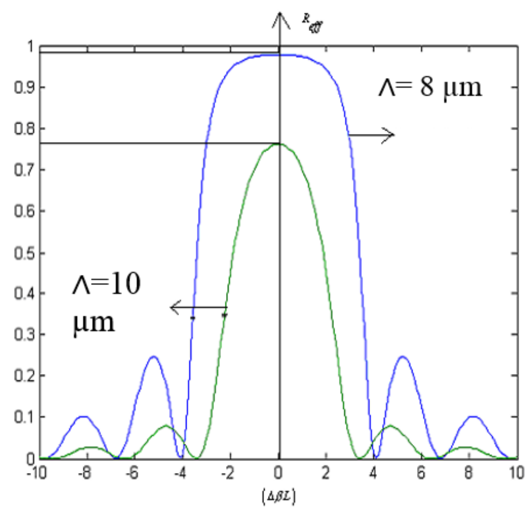
As can be seen from this figure that at a particular wavelength or frequency, the transmittance is minimum and reflectance is maximum while at some other wavelengths or frequency, the transmittance is maximum, and reflectance is minimum. Selection of any desired λ to be passed through the corrugated waveguide is depending on the coupling constant κ_s of such waveguide. As can be seen from Eqs. (3) and (5), we can change κ_s and R_{eff} by varying different parameters such as a, t, n_2, L and Λ etc. Similar result is found for triangular corrugated optical waveguide. Thus, corrugated waveguide acts as a high reflectivity mirror. So, we can say that square- as well as triangular corrugated optical waveguide can be used as an optical filter.

(ii) Reflectance characteristics of a corrugated section for varying corrugation period (Λ):

Figs. 4(a) and 4(b) show the reflectance characteristics of square- and triangular corrugated optical waveguides, respectively for various corrugation period (Λ). It is observed from Fig. 4(a) that for square corrugation, the R_{eff} is about 39% and 84% for Λ = 5 µm and 4 µm, respectively. On the other hand, for the triangular corrugation period, Λ= 10 µm, R_{eff} is more than 75% while for Λ= 8 µm, it is almost 99%. So, it can be said that the reflectance of the corrugated waveguide increases with decreasing corrugation period Λ and the value of corrugation period Λ is very effective on the reflectance characteristics of square corrugated waveguide.



(a)

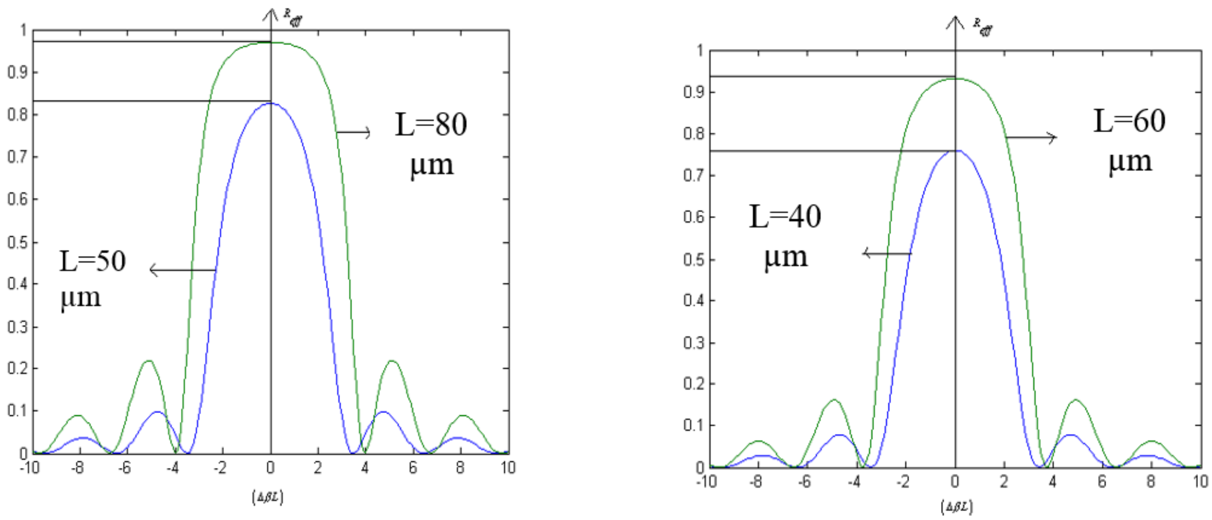


(b)

Fig. 4. A comparison of reflectance for various corrugation period (Λ) of (a) square (b) triangular corrugated optical waveguide.

(iii) Reflectance characteristics of a corrugated section for varying corrugation length (L)

Figs. 5(a) and 5(b) show the reflectance characteristics of square- and triangular corrugated optical waveguides, respectively for different corrugation length (L). It is observed from Fig. 5(a) that for square corrugation, the R_{eff} is about 84% and 98% for L= 50 µm and 80 µm, respectively. On the other hand, for the triangular corrugation length, L= 40 µm, R_{eff} is more than 76% while for L= 60 µm, it is about 93%. So, it can be said that the reflectance of the corrugated waveguide increases with increasing corrugation length L and the value of corrugation L is relatively less effective on the reflectance characteristics of square- and triangular corrugated waveguides.



(a) (b)

Fig. 5. A comparison of reflectance for various corrugation length (L) of (a) square (b) triangular corrugated optical waveguide.

(iv) Comparison between square and triangular corrugations

The reflectance characteristics of square and triangular corrugated optical waveguides have compared in Fig. 6 for the same parameters of optical waveguide.

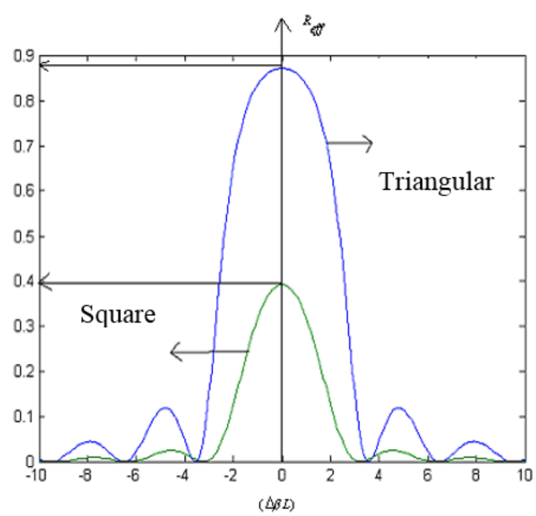


Fig. 6. A comparison of reflectance between (a) square (b) triangular corrugated optical waveguides.

As can be seen from this figure that the reflectance for square perturbation is 40% but for triangular perturbation it is almost 88% whenever the corrugation parameters are kept same. The reflectance of the corrugated optical waveguide increases significantly whenever triangular corrugation is used rather than square corrugation. Thus, triangular corrugated optical waveguide is better to be used as optical filter in the optical fiber communication systems.

Conclusion

The influences of square- and triangular corrugations of the optical waveguides have been analyzed and compared to be used as optical filter. To obtain this, the equations of reflectance and transmittance have been derived and visualized. It is found that both types of corrugated optical waveguide act as optical filter. Moreover, it is also found that triangular corrugated filter gives better elimination than square corrugated waveguide filter. This study would be very helpful for the development of efficiency of the optical fiber communication systems.

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Dedication

Dedicated to our parents.

Conflicts of Interest

There are no conflicts to declare.