# AN EFFICIENT REFLECTION GRATING BEAM SPLITTER IN PLANAR INTEGRATED OPTICS

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الخلاصة —

باستخدام خاصية انعكاس شعاع الليزر عن طريق محزز الحيود البصرى
والمصنع على هيئة طبقات مختلفة في معامل انكسارها الضوئي
أمكن عمل تحليل رياضي لمقسم طاقة شعاع الليزر بالتساوى
ويكمن فائدة هذا المقسم في التطبيقات المختلفة للدوائر
المتكاملة الضوئية وخاصة في معالجات الاشارات الضوئية
ومحللات الطيف البصرى .

ABSTRACT

In this paper we present a theoretical analysis of a new integrated optical beam splitter based on the reflectivity of planar dielectric multilayers.

Symmetrical angular splitting can be achieved by such a technique with equal amount of splitted intensities. In the analysis we used the spatial Fourier plane wave spectrum to represent a well collimated gaussian laser beam, and the matrix method for the reflectivity calculations.

## 1-INTRODUCTION

Planar integrated optics is still an active field of research and a considerable progress has been made toward realizing high performance optical devices using guided-wave techniques. Optical beam splitters are one of the key components in a wide range of integrated optic signal processors[1],[2]. Spatial splitting of the guided optical energy in planar waveguides is thus of fundamental importance.

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Thick transmission gratings fabricated in planar glass waveguides can be used as optical energy spatial distributers .but the problem of unequal diffraction efficiencies of different diffraction orders limit the use of such gratings .To overcome this problem we propose to use a thick reflection dielectric multilayers to achieve equal splitting of guided light energy in different directions.
The success of such device requires a periodic variation of the reflection coefficient of the multilayers as function of the angle of incidence .This requirement is met very well with a proper choice of multilayers parameters as will be explained latter .

## II- ANALYSIS

A guided laser beam (confined in the Y-direction) having a lateral gaussian distribution is incident at an angle $\theta_i$ on a region of thickness "d" consisting of a succession of thin zone of high ($n_o$ ) and low ( $n_1$ ) index of refraction as shown in figure 1 . The difference $n_o - n_1$ is small: typically of the order of $10^{-3}$. Such multilayers can be fabricated very easily using the double-ion exchange technique [3] .

Figure 2 shows the geometry and coordinate systems used in the derivations .We assume that the gaussian beam at z = − h has its electric field polarized along the y-direction with a time dependence $e^{-j\omega t}$ where $\omega$ is the optical angular frequency.

In the ( $x_i$ , $z_i$ ) coordinate system, the gaussian beam has an electric field distribution at $z_i$ = 0 given by [4],[5]

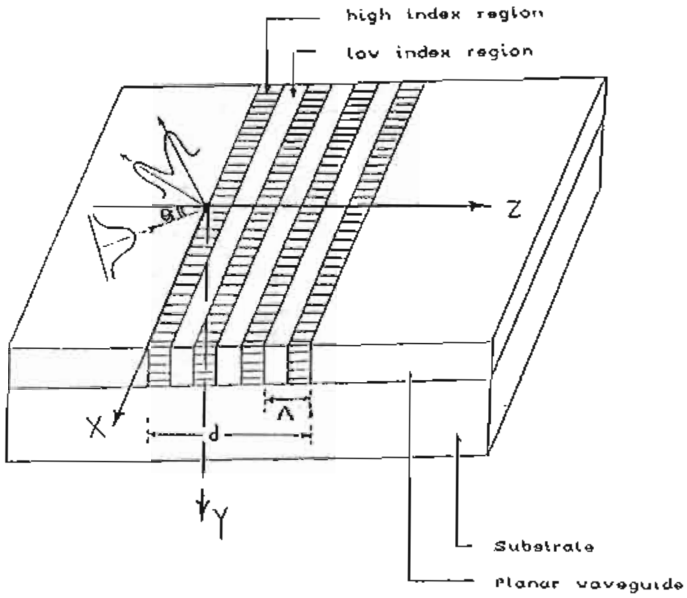


Fig.1 Optical reflection grating structure

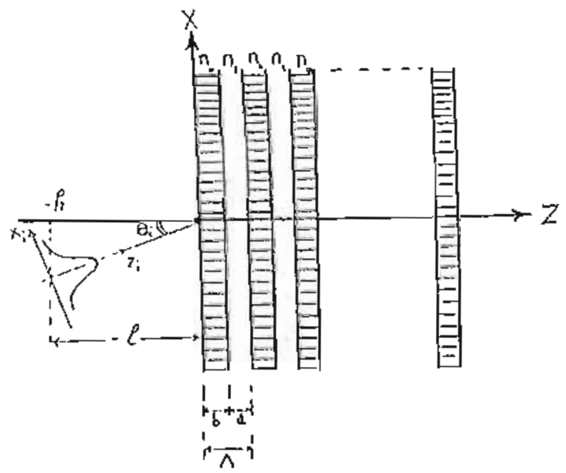


Fig.2 Geometry and coordinate systems for the beam splitter.

$$E_i(x_i,0) = \frac{e^{-(x_i/w_o)^2}}{w_o\sqrt{\pi}} \tag{1}$$

where $w_o$ is half the beam width at the point where the field magnitude decreases to 1/e of its maximum value .A well collimated beam is characterized by

$$k_o n_o \omega >> 1 \tag{2}$$

where $k_o$ is the free-space wavenumber. The inequality (2) implies that $(\omega / \lambda_o) >> 1$ where $\lambda_o$ is the vacuum wavelength .The gaussian beam in the ( x,z ) coordinate system can be represented by a spectrum of plane waves as [6]

$$E(x,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \phi(k_x)\, e^{i(k_x x + k_z(z+h))}\, dk_x \tag{3}$$

where the longitudinal wavenumber $k_z$ is given by:

$$k_z = \sqrt{k_o^2 n_o^2 - k_x^2} \tag{4}$$

and $k_x$ is the transverse wavenumber .Equation (3) means that the incident gaussian field at z=0 is given by the Fourier superposition of plane waves propagating as $e^{(ik_x x + ik_z h)}$ .For each value of $k_x$, the amplitude of the reflected wave is that of the incident plane wave $\phi(k_x)e^{ik_z h}$ at the Z=0 plane, multiplied by the plane-wave reflection coefficient $\rho(k_x)$ of the multilayer periodic structure .

The gaussian field in the (x,z) coordinate system is written as [6]

$$E(x,z) = \frac{e^{-(x\cos\theta_i / w_o)^2 + jk_o n_o x \sin\theta_i}}{w_o\sqrt{\pi}} \qquad (5)$$

since the (x,z) coordinates are related to the $(x_i, z_i)$ coordinates via the following relations

$$X_i = x\cos\theta_i - (h + z)\sin\theta_i \qquad (6)$$

$$Z_i = x\sin\theta_i + (h + z)\cos\theta_i \qquad (7)$$

The spectral amplitude $\phi(k_x)$ is obtained as the spatial Fourier tranform of equation(5)

$$\phi(k_x) = \int_{-\infty}^{\infty} E(x,z)\, e^{-jk_x x}\, dx \qquad (8)$$

which upon substitution of eq.(5) yields :

$$\phi(k_x) = \frac{e^{-(w_o(k_x - k_o n_o \sin\theta_i)/(2\cos\theta_i))^2}}{\cos\theta_i} \qquad (9)$$

The plane-wave reflection cofficient $\rho(k_x)$ of the multilayer structure can be obtained easily by the well-known matrix method [7] :

$$\rho(k_x) = \frac{C\,U_N}{A\,U_N - U_{N-1}} \qquad (10)$$

where $U_N = \frac{\sin(N\,K\,\Lambda)}{\sin(K\,\Lambda)} \qquad U_{N-1} = \frac{\sin(N-1)(K\,\Lambda)}{\sin(k\,\Lambda)} \qquad (11)$

where

$N = 2d/\Lambda$ = number of layers when $a = b = (1/2)\,\Lambda$ .

$$C = e^{-jk_{1z}a}\,[(1/2)j\,((k_{2z}/k_{1z})-(k_{1z}/k_{2z}))\sin k_{2z}b\,] \qquad (12)$$

$$A = e^{-jk_{1z}a}\,[\cos k_{2z}b-(1/2)j((k_{2z}/k_{1z})+(k_{1z}/k_{2z}))\sin k_{2z}b] \qquad (13)$$

where

$\Lambda$ = period of the multilayer structure

$a$ = thickness of the low index zone

$b$ = thickness of the high index zone

$K$ is the block-wave function defined as :

$$K\,\Lambda = \mathrm{Cos}^{-1}\,(\,\mathrm{Re}(A)\,) \qquad (14)$$

Re(.) designates the real part

The axial wave numbers $k_{1z}$ and $k_{2z}$ are given by :

$$k_{1z} = k_o n_2 \sqrt{1-\sin^2\theta} \quad ;$$

$$k_{2z} = k_o \sqrt{n_o^2 - n_1^2\sin^2\theta} \qquad (16)$$

The reflected spectrum which gives the "angular" distribution of the reflected beam is readily obtained from (9) and (10) using (11) ,(12), (13) and (14) .

To check the periodicity of the plane-wave reflection coefficient $\rho(\theta)$, we calculated it for the following parameters :

$\Lambda$ = 10 $\mu$m , $n_o$ = 1.5 , $n_o-n_1$ = 0.001 , d = 10 mm .

and the optical wavelength $\lambda_o$ = 0.63 $\mu$m

Figure 3 shows the variation of the magnitude of the reflection coefficient $\rho$ as function of the angle $\theta$ ( the angle of the representative plane wave spectrum )

## III- DISCUSSION

The idea of spatial splitting a well collimated laser beam is as follows : the assumed gaussian laser beam ( whose spatial Fourier spectrum is gaussian as given in eq.(9) ) incident at an angle $\theta_i$ corresponding to one of the minima of the reflection coefficient of the multilayer will be reflected with a null at the position of the angle of incidence and two peaks located symmetrically about the angle of incidence ( since the reflection coefficient is periodic ) .
Nearly a 1:1 spatial splitting can be achieved .To check this feature, we calculated the angular distribution of the reflected beam for the following parameters :
angle of incidence $\theta_i \simeq 0.405^\circ$ , $w_o$ = 0.5 mm and the other parameters are the same as those used for the calculations of figure3. The angular distribution of the reflected beam is shown in figure 4 .
It is obvious that the reflected light is splitted symmetrical around the angle of incidence with an angular separation $0.025^\circ$ .
The ability to splitt symmetrically light beams with very small angular separation is extremely useful especially for light distribution on integrated photodetector arrays as those used in integrated optic spectrum analyziers and integrated optical signal processors .

## IV- CONCLUSION

It is concluded that spatial splitting by planar integrated multilayers can be very useful in integrated optical components .This technique can be extended to active integrated optical components since the requirement on ( $n_o - n_i$ ) $\simeq 10^{-3}$ can be realized easily on GaAs or InP substrates . The spatial periodicity $\Lambda$ can be induced

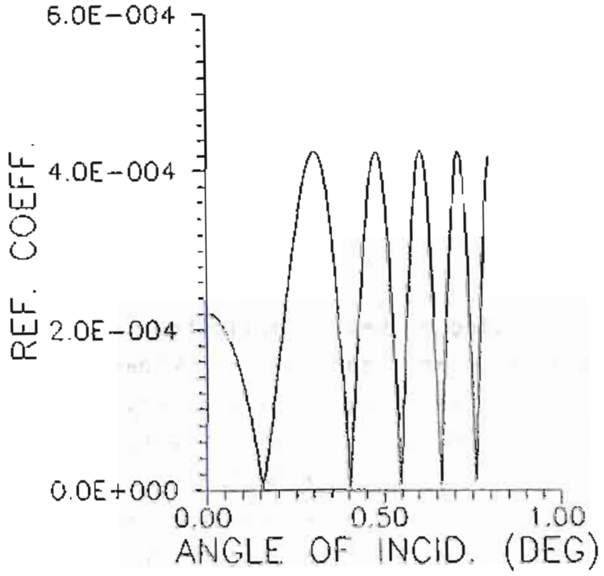


Fig.3 Varation of the reflection coefficient $\rho$ as a function of angle $\theta$.

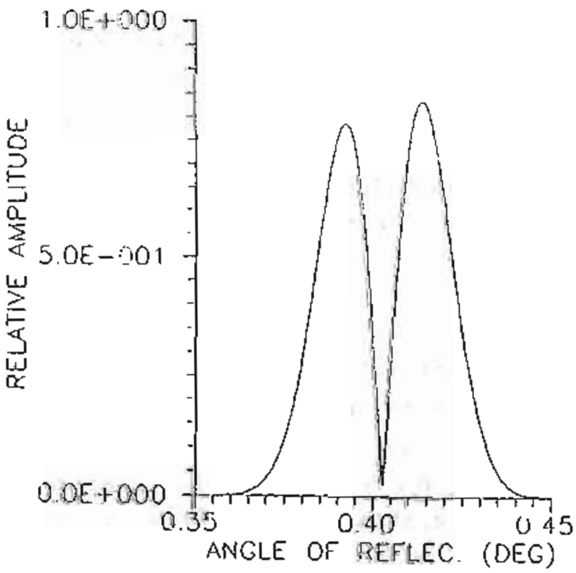


Fig.4 The angular distribution of the reflected beam

electrically via the electrooptic effect in active materials such as Lithium Niobate .
The design parameters $\Lambda$ , d , a , b and $\Delta n = n_o - n_1$ provide a flexibility to achieve efficient splitting for a wide range of laser beam widths $w_o$.

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