A Novel Wavelength Sensor Using A Structure Of Optical Directional Coupler

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Abstract : This paper proposes a wavelength sensor based on the optical directional coupler. The finite-difference time-domain (FDTD) is used in analysis of the field intensity of the light propagating thorough the structure. The device with the width of 0.4 μm and the thickness of 0.4 μm, which corresponding with the coupling length of 40μm, would provide the linear relationship between the coupling efficiency against the wavelength. The device can sense the wavelength in a range between 1.5μm and 1.6μm, with continuous resolution. The wide wavelength could be also done by paralleling the light to a number of wavelength-sensing modules with particularly required bands. Therefore, it could be employed as the wavelength sensing for most optical communications, optoelectronics, laser applications and etc.

1. Introduction

In these years optical signals have been interest for a lot of applications such as optical communications, remote sensing, spectroscopy and etc. The wavelength is one of the parameters influencing for the analysis of the applications. The technique frequently used for most wavelength meters, is motorized grating [1]. The resolution of the equipment depends on the pitch of the grating and the resolution of the stepping motor. The latter parameter is rather limited by the mechanical dimension of the motor. This paper proposes a structure of the device with ability of optical wavelength measurement. The device is in the optical directional coupler structure, which is described below.

2. The Structure and Analysis

The device structure is illustrated in Fig. 1. Two silicon waveguides (with refractive index n_f) are fabricated on the silicon dioxide base (with refractive index n_s), which forms a directional coupler. The guiding parts are wide w, thickness T and long L, with a separating gap g. The light, to be measured, is fed in on of the guide, and detects the intensity at the other end of the other guide. The light from the entrance is coupled into the other with coupling efficiency κ [2]:

$$\kappa = 2\sqrt{n_f^2 - n_s^2}\,\frac{k}{\beta\; n_{eff}}\exp\left(-(g+\frac{w}{2})\sqrt{\beta^2 - n_s^2 k^2}\right) \quad (1)$$

where β, k and n_{eff} are the phase constant, propagation constant of the light and effective refractive index due to the propagation mode and guiding structure, respectively.

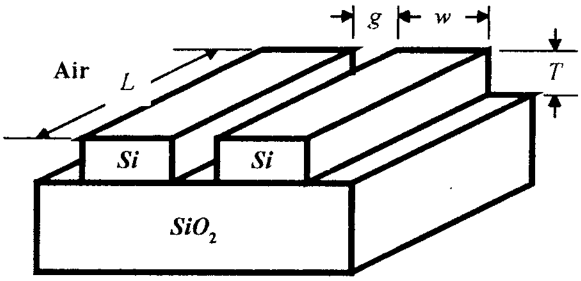


Fig. 1 Configuration of the wavelength sensor using the optical directional coupler.

This parameter indicates energy transfer from first on to the other. As the wave propagates along the guides, the energy will be couple forth and backwards. This makes the coupling energy sinusoidal flows between both guides, follows the factor K.

$$K = \frac{P_2}{P_1} = \sin^2(\kappa L) = \sin^2\left(\frac{\pi}{2}\frac{L}{L_c}\right)$$

where P_1 and P_2 are the power in the guide 1 and the guide 2 , respectively. L_c is the coupling length, where the energy completely transferred from the first guide to the other, and

$$L_c = \frac{\pi}{2\kappa}$$

From κ in Eq. (1) for the proposed structure, the light with different wavelength and propagation mode would get different coupling lengths and coupling efficiency. This paves the way for a technique to eliminate wavelength of the light by considering the appropriate propagation mode and parameters of the structure: w, T, L and g.

Since the coupling efficiency decays with the gap g, so it should employ the gap as narrow as possible. Recently, the silicon technology could fabricate the structure with the as narrow as 0.18μm [3], then the value will be use in further analysis.

3. Results

In the analysis, the finite-difference time domain (FDTD) [4-6] is employed as the tool to find the light propagation in the device. The mentioned parameters are varied in the analysis, and the coupling efficiency is then extracted for particular conditions. The parameters of the structure used in the analysis are concluded in Table 3.1.

Table 3.1 Parameters used in the simulation

Waveguide Parameters	Unit	
G	0.18	μm
W	0.2, 0.4, 0.6	μm
T	0.2, 0.4, 0.6	μm

The electric field of the light can typically be calculated using FDTD as illustrated in Fig. 2. The light propagation mode, either transverse electric (TE) or magnetic (TM), has also defined therefore the field components could be set for the analysis.

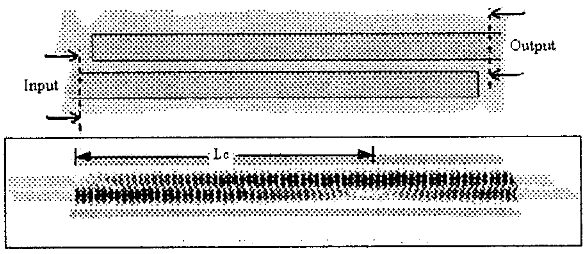


Fig. 2. The field intensity of the light propagates in the directional coupler

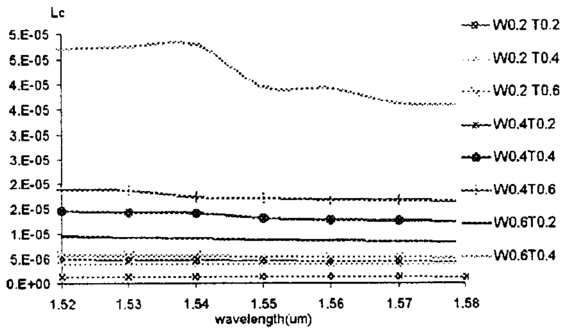
For the TE mode, the coupling length and efficiency of the structure are shown in Fig. 3(a) and (b), respectively. In the same manner, the results for the TM mode are illustrated in Fig. 4(a) and (b), respectively. It is obviously found that the structure with the *w* of 0.4 μm and the *T* of 0.4 μm would provide approximately linear variation with the wavelength. This shows that one structure of the optical directional coupler with the width of 0.4μm and the thickness of 0.6μm, which corresponding to the coupling length of 40μm could be employed as the wavelength sensing. The output intensity would linearly vary with the wavelength of the incoming light as displayed in Fig. 5.

4. Discussion

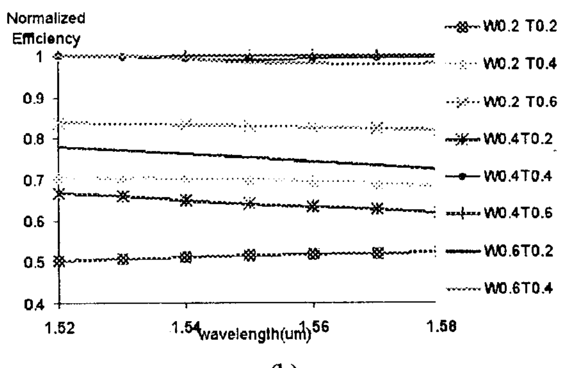
The structure of the directional coupler would have particular spectral response. The intrinsic requirement of such property may respect the high coupling efficiency. However, particular dimension of the device in conjunction with propagation mode may provide linear spectral response, which may be exploited to sense the wavelength of the incoming light. In this case, the structure with the *w* of 0.4 μm and the *T* of 0.4 μm may be employed as the wavelength-sensing device for the transverse mode light. The device can measure a range of tenth of microns, with continuous resolution. Furthermore, the wide range of the wavelength could be also done using the number of the wavelength-corresponding devices, which are fed the light in, perhaps by either an optical fiber coupler or a 1-to N waveguide. One of wide range of the wavelength sensing device is shown in Fig. 6, which is used the 1-to-3 waveguide to distribute the input light to the device to detect particular band of the wavelength.

5. Conclusions

This paper investigates the behaviour of the simple structure of the optical directional coupler using the FDTD method. The separating gap, width and thickness are the structure parameters are considered in the analysis for particular propagation mode TE and TM. One result from the structure shows the linear relationship of the coupling efficiency against with the wavelength. This, therefore, could be employed as the wavelength sensing for most optical communications, optoelectronics, laser applications and etc.



(a)



(b)

Fig. 3. The coupling length (a) and the coupling efficiency (b) of the structure for the TE mode.

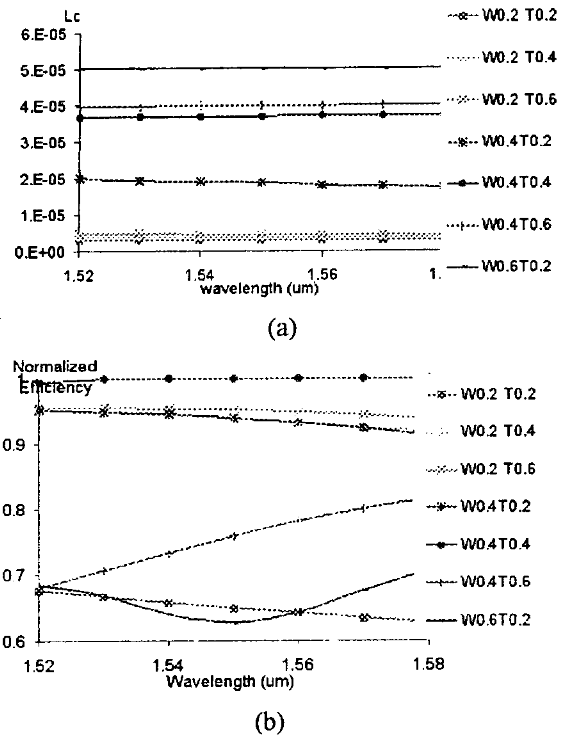


Fig. 4. The coupling length (a) and the coupling efficiency (b) of the structure for the TM mode.

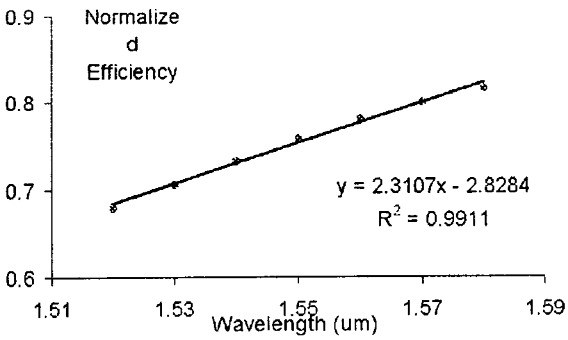


Fig. 5. The coupling efficiency varies with the wavelength of the TM mode input.

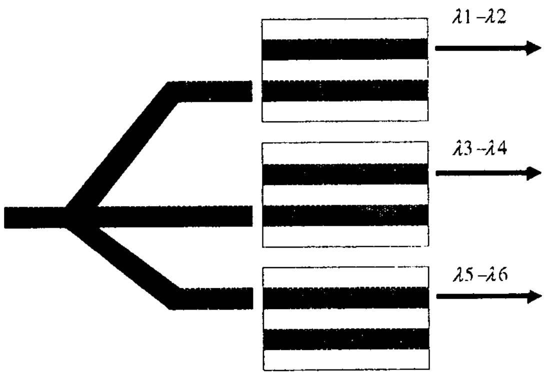


Fig. 6. A module of three wavelength-sensing devices for wide range spectra

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