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Characterization of sol-gel derived grating couplers for sensing application

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ABSTRACT

In this work, grating couplers fabricated by sol-gel technique are studied for sensing application. Assuming that the measurand is the refractive index of a film acting as a cover layer, the expression for homogeneous sensitivity, defined as the change of effective refractive index of the guiding mode to the change in cover layer refractive index, is first derived using the basic grating coupler theory. Next the dependence of homogeneous sensitivity and waveguiding condition on grating thickness and period respectively for different grating materials are studied. Thereafter, several characterizations of the fabricated grating couplers are done and the waveguiding characteristics of the fabricated couplers are analyzed based on the developed theory. Finally, the sensing property of the fabricated coupler is also established.

1. Introduction

Diffraction grating as a tool to analyze the spectrum of light has been used by many scientists for many decades. They are still used in the application of spectroscopy, but some of their recent applications include optical interconnects for computer systems, integrated optical devices and optical communications where they are primarily used as grating coupler [1–5]. Another important application of grating coupler is in waveguide based sensing. Here the sensing mechanism is based on the dependence of the grating couplers' functionality on the effective refractive index of the underlying waveguide. Overview of some grating based planar waveguide sensors are given in [6,7].

In this work, the theory of grating coupler as a sensor is discussed and its homogeneous sensitivity expression is derived. Analysis of the homogeneous sensitivity and waveguiding condition on the different structural parameters of the fabricated sol-gel derived grating coupler is done. Next the fabricated gratings are characterized to find the grating period, angle of diffraction and diffraction efficiency and the grating coupling condition for sensing application. The application of the fabricated grating coupler as a sensor is also verified.

2. Theory of grating coupler as a sensor

In this work, the sensing application of the grating fabricated by sol gel technique has been studied. The grating having period Λ is assumed to be made on a thin sol gel film made from suitable materials having refractive index n_F on a substrate having refractive index n_s. The measurand in the form of refractive index of a film acting as a cover layer of refractive index

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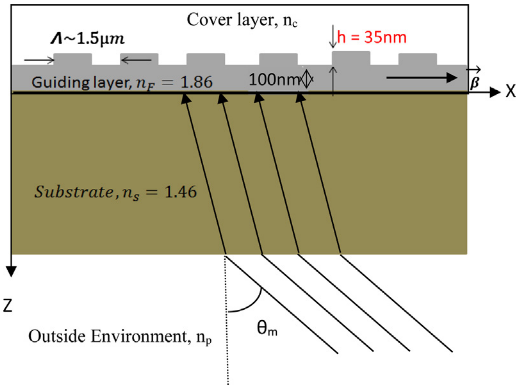

Fig. 1. The schematic of the grating coupler structure.

n_c is placed on top of this grating. The incident angle that will cause coupling of the m-th diffraction order to excite a mode having an effective refractive index N through the grating waveguide is the coupling angle θ_m and can be expressed as [8]

$$\sin\theta_m = n_p^{-1}\left(N - m\frac{\lambda}{\Lambda}\right) \tag{1}$$

where λ stands for wavelength. The change of refractive index of the cover of the waveguide results from the changes of effective refractive indexes. In the present work, only the change of refractive index of the cover is investigated, i.e., it has been assumed that the measurand is homogeneously distributed in the cover. The outside refractive index is assumed to be n_p, and the coupling process is indicated in Fig. 1. When the changes of refractive index of the cover n_c are small, then the corresponding changes of in-coupling angle can be written as [9]

$$\Delta\theta_m = \left(\frac{\partial\theta_m}{\partial n_c}\right)\Delta n_c = \left(\frac{\partial\theta_m}{\partial N}\right)\left(\frac{\partial N}{\partial n_c}\right)\Delta n_c \tag{2}$$

where $\left(\frac{\partial\theta_m}{\partial n_c}\right)$ is the angular sensitivity of the sensor structure to the changes of the refractive index of the cover, $\left(\frac{\partial\theta_m}{\partial N}\right)$ stands for the coupler's sensitivity to the changes of the effective refractive index, and $\left(\frac{\partial N}{\partial n_c}\right)$ stands for homogeneous sensitivity. The change of the coupling angle $\Delta\theta_m$ depends on its initial value θ_m and on the sensitivity constants $\left(\frac{\partial\theta_m}{\partial N}\right)$ and $\left(\frac{\partial N}{\partial n_c}\right)$. For the steady wavelength λ, the sensitivity constant $\frac{\partial N}{\partial n_c}$ depends on the refractive index n_F and the thickness d of the waveguide film as well as on the refractive indexes of the substrate n_b and the cover n_c. This equation is the basis for the grating coupler sensors used here.

For the diffraction gratings to couple light into the single mode waveguide, the diffraction gratings have to diffract the incident light in such a way that the effective index of the diffracted wave matches the effective index of the mode in the waveguide. The effective index of a diffracted wave is the ratio of the tangential component of the diffracted wavevector to the wavevector of free space. This quantity is very important in the design of the grating coupler. The other design parameters are the grating period, angle of incidence, grating depth, and waveguide thickness. This analysis first addresses input coupling and the effect of grating period and angle of incidence are discussed.

In general, for a grating period that causes free space coupling, eventually all diffractive orders other than the zero order are cutoff, meaning that the tangential component of the wavevector of the diffracted order is greater than the magnitude of the wavevector of that medium and therefore the field is evanescent in that medium. The cutoff condition of the diffractive orders depends on the refractive index of the transmitted medium. The higher the refractive index of the transmitted medium, the smaller the grating period must be before the diffractive orders in that medium are cutoff.

In substrate mode coupling, the grating period is such that the diffractive orders in air are cutoff. The transmitted orders in the substrate stay inside it due to total internal reflection. If the period of the diffraction grating is decreased further, the diffractive orders in substrate also are cutoff, and only orders in the waveguide layer can exist. When this occurs, the light actually couples into the mode supported by the waveguide and this is the grating period that is to be found out. However, it is important to note that this type of coupling only happens if the effective indices of the +ve and −ve diffractive orders match the effective index of the mode supported by the waveguide, which is only the case if the diffracted beam into the film is within a very small range of angles.

From the above analysis it is clear that in a grating coupler, the effective index of the diffracted wave matches the effective index of the mode in the waveguide. Thus it is important to analyze a solution to a mode equation for the effective refractive index N of guided $TE_m$and TM_m modes (mode number m = 0, 1, 2 ...) characterizing a three-layered slab waveguide. A