



Original research article

Refractive index sensing using silicon-on-insulator waveguide based modal interferometer

Ranjeet Dwivedi*, Arun Kumar

Department of Physics, Indian Institute of Technology Delhi, New Delhi 110016, India



ARTICLE INFO

Article history:

Received 10 September 2017

Accepted 13 December 2017

Keywords:

Refractive index sensor
 Integrated optical waveguide
 Modal interference
 Silicon-on-insulator

ABSTRACT

We propose a refractive index sensor based on modal interference between the first two TE modes in a silicon-on-insulator dual-mode waveguide. It is shown that by appropriately choosing the waveguide dimensions one can achieve a large variation of the modal effective index difference with the ambient refractive index (ARI) as well as a smaller group effective index difference between the two modes, resulting in an extremely high RI sensitivity in the wavelength interrogation scheme. The RI sensitivity of the proposed sensor is found to be ~ 9100 nm/RIU for the ARI ~ 1.33 , which is the highest reported RI sensitivity achieved in the integrated optic modal interferometers till date. The figure of merit is also found to be extremely high and is more than 2800.

© 2017 Elsevier GmbH. All rights reserved.

1. Introduction

Optical waveguide RI sensors have unique features of high sensitivity, immunity to electromagnetic interference, compact size etc. Among various kinds of optical RI sensors [1–10], modal interference based sensors are of particular interest due to their simpler design, ease of fabrication and the freedom they offer in tailoring the transmission spectrum. In the recent past such sensors are reported in both the intensity [5–7] as well as the wavelength [8–11] interrogation schemes. The wavelength interrogation scheme is preferred over the intensity interrogation because in the latter scheme, the performance may be degraded due to the possible fluctuations in the power coupled to the waveguide. Considering only the two mode interference, the RI sensitivity of these sensors in the wavelength interrogation scheme can be increased by (i) increasing the variation of the modal effective index difference (Δn_{eff}) with ARI (n_a) i.e. $\partial \Delta n_{\text{eff}} / \partial n_a$ and (ii) decreasing the group effective index difference (ΔN_{eff}) of the two modes [11]. In a recent paper [9], we have proposed a sensor having RI sensitivity ~ 5280 nm/RIU, by enhancing $\partial \Delta n_{\text{eff}} / \partial n_a$ due to the metal under-cladding between the doped silica core and silica substrate of a ridge waveguide. However, there is a scope to further increase the RI sensitivity of such sensors by selecting the appropriate materials and/or waveguide parameters.

In this paper we present the RI sensing characteristics of a sensor based on the interference between the fundamental and the first higher order TE modes in a dual mode silicon-on-insulator (SOI) ridge waveguide. We have observed that both $\partial \Delta n_{\text{eff}} / \partial n_a$ as well as ΔN_{eff} of the two modes are highly dependent on waveguide dimensions and one can achieve both high value of $\partial \Delta n_{\text{eff}} / \partial n_a$ as well as low value of ΔN_{eff} by properly selecting the dimensions of the SOI waveguide. The RI sensitivity of the proposed sensor is found to be as high as ~ 9100 nm/RIU for the ARI ~ 1.33 , which is equivalent to a RI

* Corresponding author.

E-mail addresses: ranjeetdwivedi2@gmail.com (R. Dwivedi), akumar@physics.iitd.ac.in (A. Kumar).

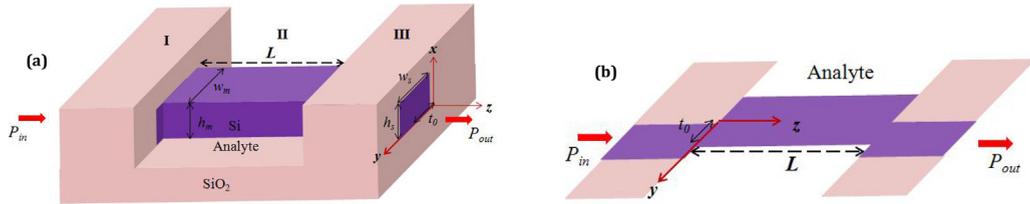


Fig. 1. Schematic of the (a) 3-D and (b) y–z cross-sectional view of the proposed sensor.

resolution $\sim 1.1 \times 10^{-7}$ for 1 pm resolution in the wavelength measurement. The figure of merit is also found to be extremely high and is more than 2800. Further, the proposed sensor is highly compact and can be fabricated with the CMOS technology.

2. Proposed structure and theoretical analysis

The schematic of the proposed sensor structure is shown in Fig. 1, which consists of three sections. First and third sections are identical single mode waveguides (SMWs) while the middle section is a dual mode waveguide (DMW) of length L . The substrate and core of each waveguide is considered to be made up of silica and silicon, respectively. The cladding region of the first and third waveguides is considered to be of silica whereas the analyte is considered to act as the cladding of the middle waveguide. The height and width of the DMW core are denoted by h_m and w_m whereas h_s and w_s represent the height and width of the SMWs core. The axes of the input and output SMWs are considered to be shifted in the y -direction by t_0 with respect to the axis of the central DMW such that nearly equal power is coupled (decoupled) between (from) the two modes of the DMW from (to) the input (output) SMW.

Light polarized along the y -direction is considered to be launched at the input of the first SMW and is detected at the output of the second SMW. Power launched in the input waveguide will excite the fundamental (TE_0) and first higher order (TE_1) modes of the DMW, which will coupled back to the second SMW after propagating a distance L . If P_{in} is the input power, the output power P_o will be given by [8]

$$P_o = P_{in} |c_0 e^{i\beta_0 L} + c_1 e^{i\beta_1 L}|^2 \tag{1}$$

Where c_0 and c_1 , respectively, denote the fractional modal power coupled to (from) the TE_0 and the TE_1 modes of the DMW from (to) the input (output) SMW and are given by

$$c_{0/1} = \left(\iint (E_s \times H_{0/1}^*) \cdot \hat{z} \, dx \, dy \right) \left(\iint (E_{0/1} \times H_s^*) \cdot \hat{z} \, dx \, dy \right) \tag{2}$$

where $E_s(x, y)(H_s(x, y))$ and $E_{0/1}(x, y)(H_{0/1}(x, y))$ represent the normalized electric (magnetic) modal fields corresponding to the SMW and the DMW, respectively; β_0 and β_1 are the propagation constants of the TE_0 and the TE_1 modes of the DMW.

The transmission spectrum (given by Eq. (1)) will be periodic in nature consisting of various peaks and dips, whose positions will shift if the ARI is changed. The ARI sensitivity, detection accuracy and the figure of merit of the proposed sensor structure can be obtained as discussed below;

2.1. ARI sensitivity

The phase difference between the two interfering modes is given by $\phi = \Delta\beta L = (\beta_0 - \beta_1)L$, and various peaks or dips will correspond to $\phi = 2m\pi$ or $\phi = (2m + 1)\pi$. Since ϕ is a function of λ and n_a both, any change in λ or n_a would produce a change in ϕ , given as

$$\Delta\phi = \frac{\partial\phi}{\partial\lambda} \Delta\lambda + \frac{\partial\phi}{\partial n_a} \Delta n_a \tag{3}$$

The wavelength shift for a particular peak/dip due to change in n_a can be obtained by putting $\Delta\phi = 0$, giving the RI sensitivity as

$$\eta = \frac{\Delta\lambda}{\Delta n_a} = - \frac{\partial\Delta\beta/\partial n_a}{\partial\Delta\beta/\partial\lambda} = \frac{\lambda \partial\Delta n_{eff}/\partial n_a}{\Delta n_{eff} - \lambda \partial\Delta n_{eff}/\partial\lambda} = \frac{\lambda \partial\Delta N_{eff}/\partial n_a}{\Delta N_{eff}} \tag{4}$$

where Δn_{eff} and ΔN_{eff} , respectively, are the difference of the modal effective indices (n_{eff}) and the group effective indices (N_{eff}) of the two interfering modes. The above equation shows that the sensitivity at a given λ is decided by the ratio of $\partial\Delta n_{eff}/\partial n_a$ and ΔN_{eff} . It may be noted that η is independent of L , however, in order to get a peak in the transmission spectrum at the desired wavelength of operation, L should be selected as an integer multiple of self imaging length (L_i) at

متن کامل مقاله

دریافت فوری ←

ISIArticles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات