Design and Simulation of SiO_xN_y Thin Films Based Planar Optical Waveguide for Integrated Optics

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Abstract

From the previous work on the investigation "Ellipsometric and Rutherford back scattering spectroscopy studies of SiO_xN_y Films Elaborated by plasma-enhanced chemical vapor deposition technique", we present a contribution to the study of a SiO_xN_y thin films based planar optical waveguide. The SiO_xN_y waveguiding layer can be prepared by the same PECVD technique from the following reactive gases: N_2O, NH_3 and SiH_4 at different ratios. Simulation results show that the transverse electric and magnetic waves are quite confined and optical losses are low. We also optimized the dimensions of planar waveguides for a single mode optical waveguide to reduce optical losses.

1. Introduction

In recent years, the need for the rapid transfer of data and information has greatly increased by introduction of new applications like the worldwide web.

Today, SiO_xN_y thin film has been increasingly employed in different integrated optics devices such as optical waveguides [1, 2, 3]. The application of this film in these devices has been mainly motivated by their excellent optical properties, such as high transparency and low absorption losses in the visible and near infrared wavelength range. In addition, the refractive index of SiO_xN_y thin films can be easily varies on a wide range of 1.45 (SiO_2) to 2 (Si_3N_4). This large flexibility in choosing the refractive index add to the attractiveness of this film for use in communication devices such as the design of planar optical waveguides [4, 5, 6, 7].

Based on our previous work [8], we present an investigation into the condition of single mode propagation of SiO_xN_y thin films based planar optical waveguide of limiting losses spread over a multimode waveguide causing loss information due to overlapping of pulses.

2. Modeling

The waveguiding structure we will propose is a stack of three layers (Figure 1).

- A substrate layer of silicon dioxide (SiO_2) of refractive index $n_s = 1.45$.
- A core layer (waveguiding) of silicon oxynitride of refractive index n_f.
- A cover layer of air with a refractive index $n_c = 1$.

The refractive indexes n_s, n_f and n_c are chosen so that $n_f > n_s > n_c$. In our work, we take the following indexes: $n_f = 1.60$, 1.75 and 1.92.

For the single mode propagation condition, some conditions are to respect, and the refractive index contrast between the SiO_xN_y core (waveguiding layer) and those cover and substrate (Cladding layers) must be high enough to preserve the conditions of total refection.

The values of these refractive indexes are valid for a wavelength of 830 nm. The values of the refractive indexes of the waveguiding layer are taken from the results of optical characterization of SiO_xN_y films previously studied [8].

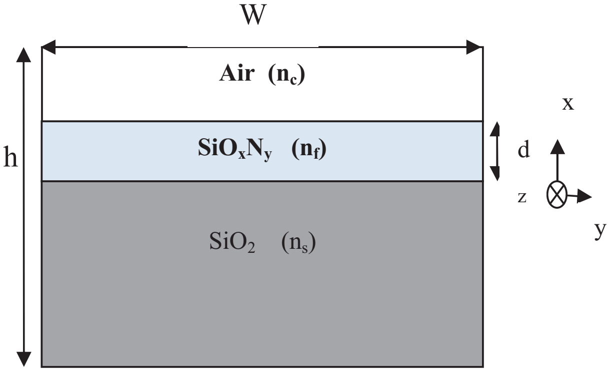

Fig. 1. SiO_xN_y based planar optical waveguide structure.

The dispersions equations such as this structure are as follows [9,10]:

For the transverse electric mode (TE):

$$d\sqrt{k^2n_f^2-\beta_{TE}^2}\ \text{-arctan}\left[\sqrt{\frac{\beta_{TE}^2-k^2n_c^2}{k^2n_f^2-\beta_{TE}^2}}\right]\ \text{-}\ \text{arctan}\left[\sqrt{\frac{\beta_{TE}^2-k^2n_s^2}{k^2n_f^2-\beta_{TE}^2}}\right]= m\pi \tag{1}$$

For the transverse magnetic mode (TM):

$$d\sqrt{k^2n_f^2-\beta_{TM}^2}\ \text{-}\ \text{arctan}\left[\frac{n_f^2}{n_c^2}\sqrt{\frac{\beta_{TM}^2-k^2n_c^2}{k^2n_f^2-\beta_{TM}^2}}\right]\ \text{-}\ \text{arctan}\left[\frac{n_f^2}{n_s^2}\sqrt{\frac{\beta_{TM}^2-k^2n_s^2}{k^2n_f^2-\beta_{TM}^2}}\right] = m\pi \tag{2}$$

Where: d is the thickness of the SiO_xN_y waveguiding layer and n_f of their refractive index, and β_{TE} β_{TM} are the propagation constants of the TE and TM waves, respectively, k is the wavenumber, $k = 2\pi / \lambda$ (λ: wavelength), n_c and n_s are the refractive indexes of the cover and substrate layers and m is the mode number.

These equations can be resolved by various analytical and numerical methods or directly by simulators.

In our work, we used an appropriated software simulation for solving these equations.

3. Results and discussion

3.1. Field distribution

We observe in the figures below the transverse electric TE wave is quite confined and losses are low. For confined guides, components of the electric fields must be located in the SiO_xN_y waveguiding layer or in the immediate vicinity of this layer. Figure (2) represents the transverse profile of the fundamental mode at the inlet of the SiO_xN_y layer based waveguide, obtained by injection of a TE Gaussian wave in the waveguide with a wavelength $\lambda = 830$ nm. The effective index of the fundamental mode is $n_{eff} = 1.558276$.

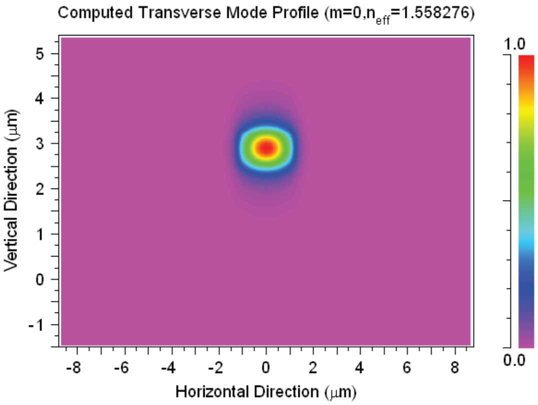

Fig. 2. Tranverse electric (TE) wave profile of the fundamental mode in the SiO_xN_y layer based planar waveguide.

In figure (3), we visualize the transverse profile of mode 1 at the entrance of the silicon oxynitride layer based planar waveguide. The effective index of this mode is $n_{eff} = 1.538081$.

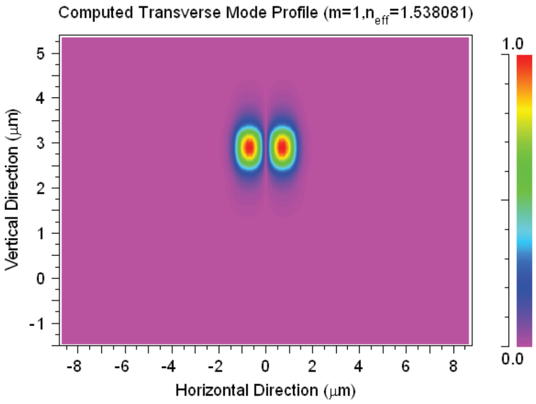

Fig. 3. Tranverse electric (TE) wave profile of the mode 1 in the SiO_xN_y layer based planar waveguide.

This figure shows the appearance of two waves confined in the SiO_xN_y waveguiding layer.

The transverse profile of an electric wave mode 2 to the input of our SiO_xN_y layer based planar waveguide shown in figure (4).

This figure shows the appearance of three waves at the entrance to waveguide. The effective index of this mode is $n_{eff} = 1.505202$.

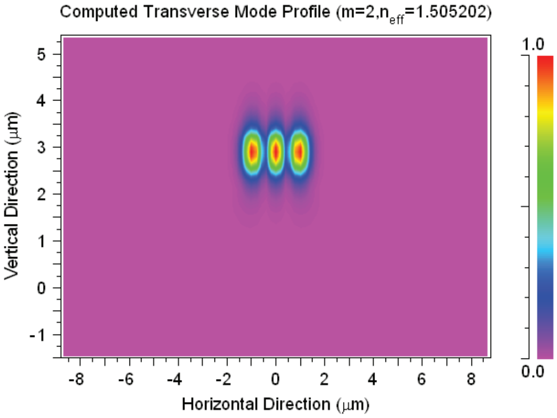

Fig. 4. Tranverse electric (TE) wave profile of the mode 2 in the SiO_xN_y layer based planar waveguide.

3.2. Evolution of the effective index as function of the SiO_xN_y layer thickness

To determine the single mode character of our waveguide, by varying the thickness of the waveguiding layer (SiO_xN_y) fix in the thickness of the waveguide structure studied.

a) For the refractive index n=1.60

The refractive index of the core waveguiding layer (1.60) is the refractive index of the SiO_xN_y film deposited with a gas flow rate of N_2O = 500 sccm. Fig (5) shows the evolution of effective index of the asymmetrical planar waveguide with SiO_xN_y waveguiding layer as a function of SiO_xN_y layer thickness (d) of refractive index 1.60.

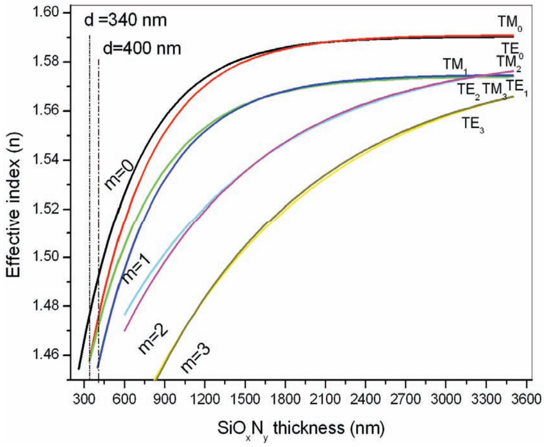

Fig. 5. Variation of effective index of the TE and TM modes as a function of SiO_xN_y thickness.

According to this figure, we observe that the effective index of both TE and TM modes gradually increases when the thickness of the SiO_xN_y waveguiding layer increase. It approaches the value 1.60 corresponding refractive index of the SiO_xN_y waveguiding layer. We also note that the structure can hold more guided modes when increasing the thickness of the SiO_xN_y waveguiding layer.

From these curves, we can determine the thickness of cut associated with each mode. So that the waveguide is single mode, it is necessary that the thickness of the SiO_xN_y waveguiding layer is less than 340 nm in the case of TE polarization and less than 400 nm in the case of a TM polarization. Beyond these two SiO_xN_y layers thickness the waveguide structure becomes multi-mode.

b) For the refractive index n=1.75

The curves plotted in Figure (6) illustrates the evolution of the effective index of the TE and TM modes of an asymmetric waveguide structure as a function of SiO_xN_y layer thickness of refractive index n_f= 1.75.

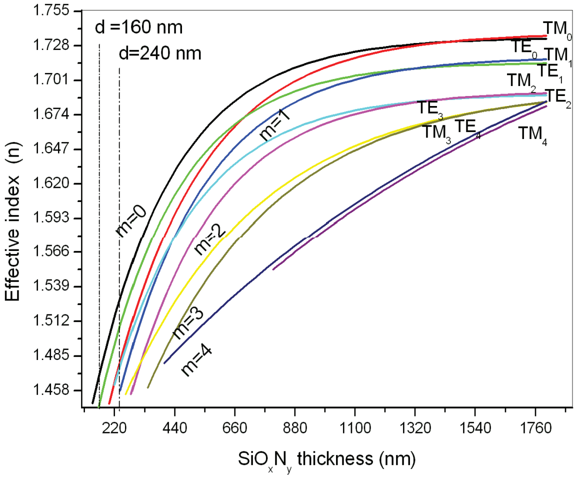

Fig. V.6. Variation of effective index of the TE and TM modes as a function of SiO_xN_y film thickness.

The single mode character of this waveguide has been obtained, when the thickness of SiO_xN_y waveguiding core layer is less than 160 nm for transverse electric TE mode and less than 240 nm for transverse magnetic TM mode.

c) For the refractive index n=1.92

In the case of a SiO_xN_y waveguiding layer of refractive index 1.92, the single mode character of the waveguide structure is obtained when the thickness of this layer is less than 132 nm for the TE polarization and at 160 nm for TM polarization (Fig.7).

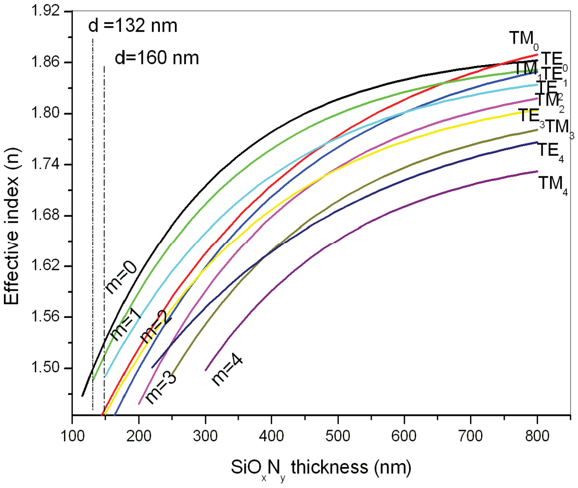

Fig. 7. Variation of effective index of the TE and TM modes as a function of SiO_xN_y thickness.

4. Conclusion

The aim of this work is to exploit the optical properties (refractive index) of SiO_xN_y thin films prepared by the PECVD technique in integrated optics based on the results of the optical properties previously studied and theory of guide's waves. We optimized the dimensions of asymmetric planar waveguides for a single-mode optical waveguide character for two propagation modes TE and TM to limit the propagation loss due to overlapping pulses in the waveguide, and therefore cause a loss of information. Based on the optimized parameters, the SiO_xN_y thin films can be prepared by PECVD technique by varying the gases flow ratio of precursors used and the deposition time.

5. References

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