BIREFRINGENCE COMPENSATION IN DOUBLE-CORE OPTICAL WAVEGUIDES

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Abstract: A new concept for birefringence compensation in planar optical waveguides applying a double-core structure is introduced. It is demonstrated on waveguides fabricated in silicon oxynitride technology for application in optical telecommunication.

Introduction

In optical communication systems, the polarization state of the optical data is mostly unknown and changes continuously with time. Therefore, it is of major importance that the performance of the integrated optical devices is polarization independent. For most technologies, the polarization dependence of geometrically well-defined waveguiding channels is due to stress-induced material birefringence. To reduce this polarization dependence, which is usually in the order of 10^{-3}, various techniques have been proposed, based on stress reduction (I), compensation by adaptation of the form birefringence (II), or introduction of compensating devices (III):

a) stress releasing grooves next to the waveguide /2/ (I)
b) thick silicon layer on top of the structure /3/, /4/ (I)
c) waveguide geometry /5/, /6/ (II)
d) Si_3N_4 patch at some separation below the core /8/ (II)
e) polarization converters /1/, /7/ (III)
f) polarization diversity (III)

These techniques can be classified according to the compensation either distributed over the structure (a-c) or implemented into additional functions (d-f).

In this paper, the channel birefringence compensation (BC) will be achieved by applying a thin additional layer with an increased refractive index just below the core layer, resulting in a double-core waveguiding structure. One of the advantages of this structure is the simplicity of its technological realization. The BC-effect will be demon-strated on a SiON-based waveguiding structure /9/, origi-nally having a channel birefringence of $\Delta n_{eff} = n_{eff,TM} - n_{eff,TE} = 1.7\text{x}10^{-3}$ and a low compensating effect of the channel dimensions ($d(\Delta n_{eff})/ d(d_{core}) < 3\text{x}10^{-4}\ \mu\text{m}^{-1}$).

Birefringence compensating layer structure

The birefringence compensating double-core waveguiding structure is schematically shown in Figure 1. The dependence of the BC on the refractive index and thickness of the birefringence compensating layer (BCL) has been simulated by applying the vectorial multigrid finite difference method of 'SELENE' /11/. For simplicity, we assume the material birefringence of each layer to be homogeneous and independent of all layer thicknesses. The applied parameters of the core and cladding layers are given in Table 1. The waveguide width is 3 µm. The BCL refractive index n_{BCL} has been varied between 1.5 and 2 and its material birefringence has been kept constant at $\Delta n = n_{TM} - n_{TE} = -8.5\text{x}10^{-3}$. The BCL influences the channel birefringence in two ways: 1) by means of its material bi-refringence which is of opposite sign as the birefringence of the core material and 2) by a geometrical effect, i.e. the high index BCL causes a different influence on the field profiles of the TE and TM modes. The assumption that Δn is independent of n_{BCL} allows the two BC-mechanisms to be decoupled.

Fig. 1: Double-core waveguiding structure with birefringence compensating layer (BCL)

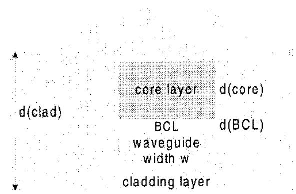
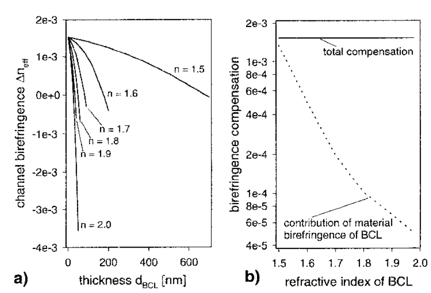


Table 1: Parameters of core and cladding

Layer	n_{TE} λ=1550 nm	n_{TM} λ=1550 nm	d [µm]
Cladding	1.4633	1.4642	> 10
Core	1.4825	1.4846	2.5

Fig. 2: Channel birefringence vs. BCL thickness (a), illustration of birefringence compensating effect (b)



The dependence of the channel birefringence on the variation of the BCL thickness is shown in Figure 2a for various values of the BCL refractive index. By increasing n_{BCL}, the thickness, at which compensation is achieved, is decreased. The BC-effect is large and can be as high as $d(\Delta n_{eff})/d(d_{BCL})=6\text{x}10^{-2}\ \mu\text{m}^{-1}$. The contribution of the BCL material birefringence to the total compensation (Figure 2b) b) decreases at higher BCL index. Therefore, in multilayer structures, where the stress interactions between the layers are not exactly known, application of high-index BCL material is recommended.

Realization and measurement

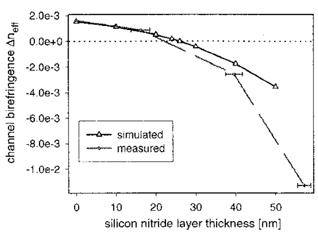
The core and cladding layers of the waveguiding structures have been grown by PECVD /9/ and the BCL material, silicon nitride (Si_3N_4), has been deposited by LPCVD. The refractive index of the latter material is around 2 and its material birefringence is $\Delta n = -8.5 \times 10^{-3}$ /10/. For demonstrating the BC-effect of the Si_3N_4 layer, samples with a BCL thickness varying between 0 and 50 nm have been prepared. The channel definition has been carried out by reactive ion etching /9/.

The channel birefringence Δn_{eff} was measured by polarimetry, coupling linearly polarized light of a broadband LED source into the waveguiding channels that have been cleaved to a length of 50 mm. The out-coupled light has been measured with a spectrum analyzer after having passed through a wave plate and a polarizer. The wave plate enables the determination of the sign of Δn_{eff}.

Results and discussion

The measured channel birefringence as a function of the silicon nitride layer thickness is shown in Figure 2. Indeed, channel birefringence compensation applying the double-core structure is feasible.

Fig. 3: Measured and calculated channel birefringence vs. silicon nitride thickness



When comparing the measured and simulated values, it is evident that in the lower thickness range, the compensating effect has been well-predicted. The higher the thickness, however, the more the measured and simulated values diverge. This can be attributed to stress interactions between the silicon nitride and the PECVD layers. Indeed, at increased silicon nitride thickness, the layer system will show stronger deflection and thus an additional birefringence compensating effect appears.

Furthermore, the measurements have shown that the optical loss in the waveguiding channels has not been increased by the addition of the thin silicon nitride layer.

Conclusion

A simple, generally applicable concept for compensating the polarization dependence of integrated optical devices has been developed. The concept is based on com-pensating the material birefringence by applying a double-core waveguide with a thin, high-refractive-index layer below the basic core layer. This approach allows distribution of the compensation over the entire device structure and can easily be implemented into the fabrica-tion technology by adding a single deposition step.

For compensating layers with a high refractive index, the birefringence compensation was shown to be dominated by difference in influencing the field profiles of the TE and TM modes. The contribution of the material birefringence of the compensating layer was found to be negligible, which is relevant for a stress-independent device design.

The birefringence compensating effect of the double-core concept has been demonstrated for a PECVD silicon oxynitride-based layer structure, in which LPCVD silicon nitride has been applied as the birefringence compensating layer. The feasibility of the concept has been shown experimentally.

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