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Investigation of phase shift in waveguides with chalcogenide glasses

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Abstract. The paper presents a numerical study of the propagation of the waveguide mode in a waveguide with films of chalcogenide glasses, a numerical analysis of the phase change of the waveguide mode depending on the phase state of chalcogenide glass and geometric parameters of the structure.

Keywords: integrated optics, chalcogenide glasses, phase shift

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Исследование фазового сдвига в волноводах с халькогенидными стеклами

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Аннотация. В статье представлено численное моделирование распространения волноводной моды в волноводе с пленками из халькогенидных стекол, численный анализ изменения фазы волноводной моды в зависимости от фазового состояния халькогенидного стекла и геометрических параметров структуры.

Ключевые слова: интегральная фотоника, халькогенидные стекла, сдвиг фазы

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Introduction

Currently, chalcogenide materials are widely used to create memory cells. Such devices are based on the principle of changing optical and electrical properties when the phase state of the glass film changes from amorphous to crystalline. The phase state is switched using heat from laser or electric pulses.

Special attention is paid to the study of Ge–Sb–Te (GST) glasses, which have high optical contrast [1] and short phase-state switching time (< 50 ns) [2]. GST-225 has a high refractive index in both crystalline (n = 8.03) and amorphous (n = 4.69) phase states [3, 4]. In the work, the possibility of creating a discrete phase shift using elements based on GST-225 thin films was investigated.

The idea of generating a discrete phase change employing materials based on GST-225 thin films was studied during the course of the investigation. Calculations were performed for waveguide architectures based on SOI for wavelength λ = 1.55. The BPM numerical calculation was used to undertake a numerical analysis of the phase shift based on the geometric parameters of the structure and the GST-225 film's phase state. The obtained results provided the optimal thickness of the film and the buffer layer separating it from the waveguide. A numerical model of the Mach-Zehnder interferometer with discrete phase adjustment was built based on the study's findings.

Results and Discussion

The major goal of the research investigation was to find the optimal shape for a waveguide with a thin GST film that could provide the required phase shift while minimizing absorption losses in the GST layer. When the GST layer is on the surface of the waveguide, there is a rapid (on the length about 0.1 micron) transfer of signal into the GST layer [5]. A buffer layer is put between the waveguide and the thin film to prevent this. The GST layer therefore 'captures' only the mode's edge, preventing signal from passing into a thin layer and reducing losses. Fig. 1 shows the final geometry of the structure and the distribution of the field in the plane of the waveguide's cross-section.

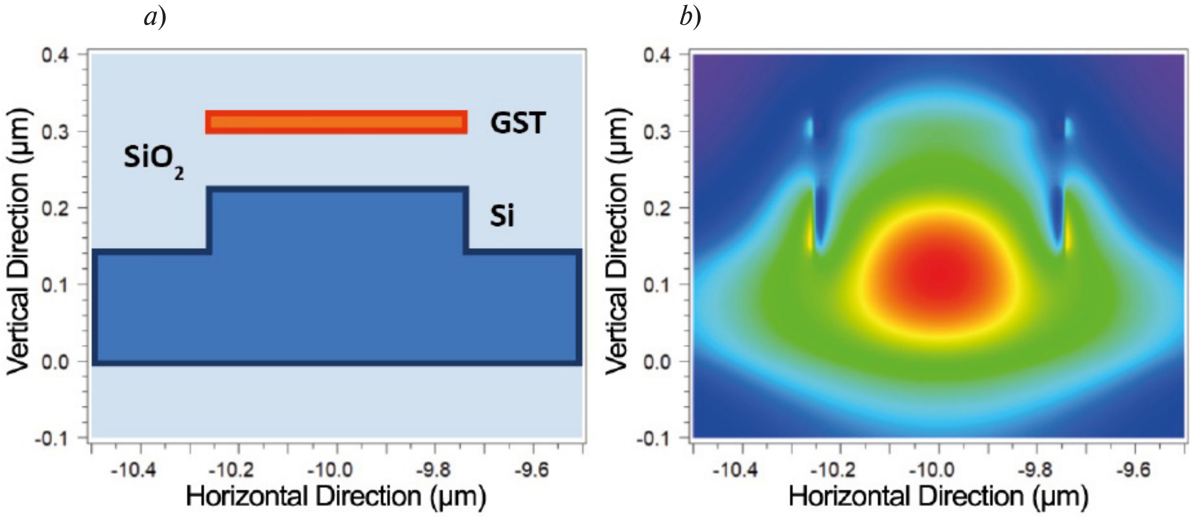

Fig. 1. Waveguide geometry (*a*) and field distribution in the waveguide (*b*)

The study presents computational analysis of the phase change of the waveguide mode and waveguide losses as variables of the phase state of the GST film and the geometric parameters of the structure: the thickness of the film (10–30 nm) and the thickness of the buffer layer (0–100 nm). The graph of the relative phase shift (Fig. 2,*a*) in two channels has a stepped structure for all variants with a buffer layer. This is explained by the fact that light propagation takes a zigzag shape in the area with GST (Fig. 2,*c*). The "capture" of the mode's edge by the glass increases the size of the waveguide with the film, and it changes the profile of the main mode. As a result, the phase difference between the two channels rises where the mode approaches the GST layer and remains nearly constant where the mode returns to the silicon waveguide.

The GST film's width might vary within extremely tight limitations. It is technically challenging to create a layer thinner than 10 nm. Losses grow significantly when the layer thickness is increased to 20 nm or greater.

The buffer layer thickness was selected with the features of propagation and the amount of the necessary phase shift. The research investigated the feasibility of producing a customizable phase shift within 15° by using numerous sections coated with a GST film. The graphs show results of numerical modeling of structures coated with a thin GST coating. Fig. 2,*a* shows the phase shift dependence on the thickness of the buffer layer between the waveguide and the GST layer. The phase difference is calculated at the output of two waveguides, one with a crystalline layer of GST and the other with an amorphous layer of GST. Figure 2,*b* shows dependence of losses in a waveguide with a GST layer in the crystalline phase of the thickness of the buffer layer; losses in the amorphous phase layer are significantly lower. At a length of about 2 microns, the buffer layer width of 75 nm enables a phase shift of up to 5° with relatively low losses. A buffer layer with a thickness of 75 nm was chosen for this particular task because the resulting shift diminishes dramatically with slightly reducing losses as the layer thickens. A significant rise in losses takes place in a thinner layer, limiting the final interferometer model from being built.

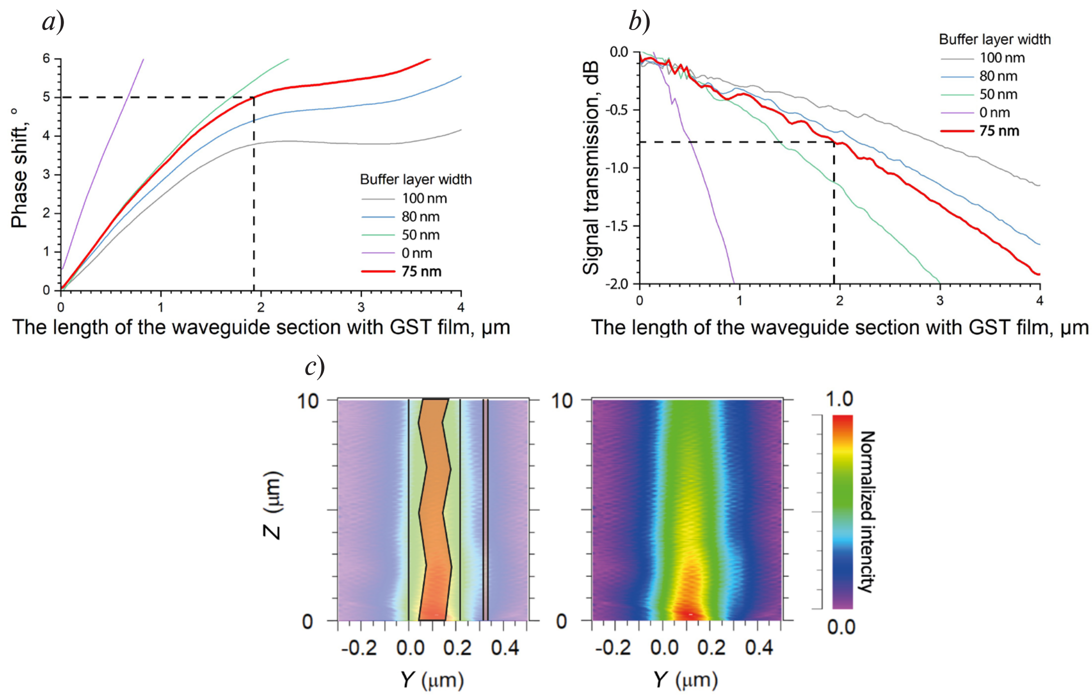

Fig. 2. Dependence of the phase shift on the width of the buffer layer (*a*) and dependence of the amplitude loss on the width of the buffer layer (*b*); propagation of the waveguide mode in a waveguide with GST (*c*)

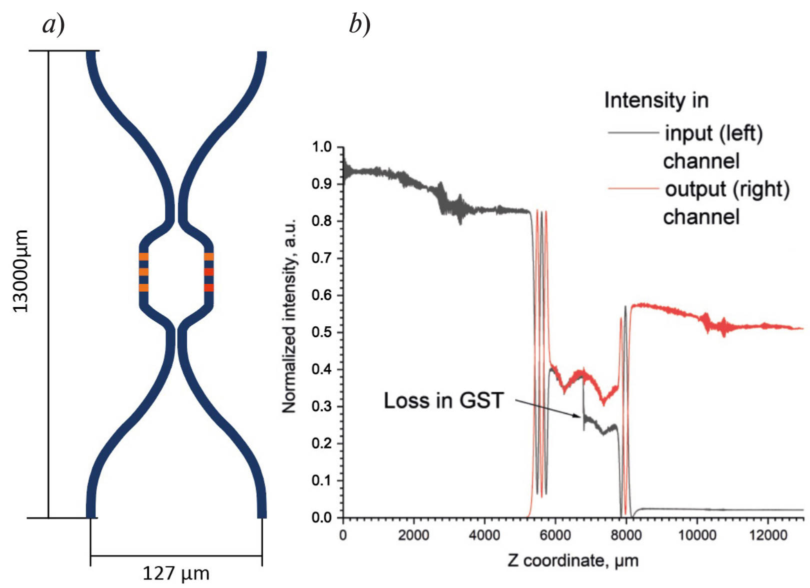

Fig. 3. Scheme of optical switching device based on Mach–Zehnder interferometer with GST (*a*) and dependence of the intensity in the channels on the distance from the entrance (*b*)

Based on the results, a model of switch device based on the Mach-Zehnder interferometer was created (Fig. 3,*a*). The phase difference between signals traveling in different arms must be 45 degrees for the switch to function correctly. However, generating an exact phase difference is challenging since it requires an optical path difference between the two channels of just /8, which in the case of a wavelength h = 1.55 microns is approximately 0.2 microns. To implement the correction, separate sections of GST film were produced in both arms of the interferometer. It is possible to shift phase by 5–15 degrees by switching phase state of the GST, providing the exact final phase shift of 45 degrees required for switch operation. In the model phase shift about 35° is implemented geometrically and 10° phase shift is implemented by using GST. Fig. 3,*b* shows the intensity in the interferometer channels as a function of distance from the input. Significant intensity losses appear when reaching areas with GST in the crystalline phase state.

Conclusion

An investigation of the effectiveness of structures with different geometry was performed using mathematical modeling. The dependence of the resulting phase shift and losses in waveguide configurations on the thickness of the buffer layer between the waveguide and the GST thin film is studied. It is demonstrated that the ideal width of the buffer layer is 75nm due to the peculiarities of light propagation in the suggested structure. This makes it possible to achieve the highest phase shift with the fewest losses in the area containing GST in the crystalline phase. Based on the results, an optical switch model based on a Mach–Zehnder interferometer with a customizable discrete phase shift is created.

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