St. Petersburg Polytechnic University Journal. Physics and Mathematics. 2024. Vol. 17. No. 3.2
Научно-технические ведомости СПбГПУ. Физико-математические науки. 17 (3.2) 2024

Conference materials
UDC 538.9
DOI: https://doi.org/10.18721/JPM.173.210

Peculiarities of the local electromagnetic field distribution in non-van-der-Waals $InGaS_3$ thin layers slot waveguides

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Abstract. $InGaS_3$ thin layers are promising nanostrures in the field of nanophotonics owing to the broad bandgap, sufficiently high refractive index and the simplicity of fabrication. Here we numerically investigate a system based on $InGaS_3$ waveguides, standing side by side. We demonstrate the localization of the electromagnetic field inside the gap between two waveguides and obtain the refractive indices and losses for the slot waveguide modes at a wavelength of 505 nm. Transmittance spectra of considered configurations of different geometrical parameters were obtained The waveguiding cut-off related to the absorption inside the material and the delocalization of the electromagnetic field was determined. The obtained results open the possibility for fabrication of novel photonic devices based on $InGaS_3$ thin layers.

Keywords: $InGaS_3$, slot waveguide, transmittance, thin layer, numerical simulations

Funding: This work is supported by the Russian Science Foundation (grant no. 24-22-20064).

Citation: Zavyalova E.S., Kuznetsov A., Bolshakov A.D., Peculiarities of the local electromagnetic field distribution in non-van-der-Waals $InGaS_3$ thin layers slot waveguides, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 17 (3.2) (2024) 57–61. DOI: https://doi.org/10.18721/JPM.173.210

Материалы конференции
УДК 538.9
DOI: https://doi.org/10.18721/JPM.173.210

Особенности распределения локального электромагнитного поля в щелевых волноводах на основе не-ван-дер-Ваальсовых тонких слоев $InGaS_3$

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Аннотация. Тонкие слои $InGaS_3$ являются перспективными наноструктурами в области нанофотоники благодаря широкому диапазону прозрачности, высокому показателю преломления и простоте фабрикации. В данной работе численно исследовалась наноструктура на основе волноводов $InGaS_3$, расположенных рядом друг с другом. Была продемонстрирована высокая локализация электромагнитного поля внутри зазора между двумя волноводами и получены значения показателей преломления и оптических потерь для мод щелевого волновода на длине волны 505 нм. Получены спектры пропускания рассматриваемых конфигураций волнводов с различными геометрическими параметрами. Определена волноводная отсечка, связанная с поглощением внутри материала и делокализацией электромагнитного поля. Полученные результаты открывают возможность создания новых фотонных устройств на основе тонких слоев $InGaS_3$.

Ключевые слова: $InGaS_3$, щелевой волновод, пропускание, тонкие слои, численное моделирование

Финансирование: Работа выполнена при поддержке Российского научного фонда (грант № 24-22-20064).

Ссылка при цитировании: Завьялова Е.С., Кузнецов А., Большаков А.Д. Особенности распределения локального электромагнитного поля в щелевых волноводах на основе не-ван-дер-Ваальсовых тонких слоев $InGaS_3$ // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2024. Т. 17. № 3.2. С. 57–61. DOI: https://doi.org/10.18721/JPM.173.210

Introduction

Nowadays, the research of new materials for the development of new element and component basis of integrated nanophotonics is important. One of the main task of integrated photonics is to increase the surface packing density of the functional elements, which can be achieved using an optically dense material, operating in the range of shorter wavelengths, for example in visible [1]. Also, the material should be technologically versatile in the context of circuits fabrication technology [2].

$InGaS_3$ is a semiconductor with a large bandgap (2.73 eV) and high refractive index (< 2.5) [3]. It is a novel layered material with hexagonal symmetry of the crystal lattice, however, it is not Van der Waals: the bonds between the layers are covalent, but in the plane of the layer they are distributed inhomogeneously and their density per unit area is rather small, which makes it quite easily to separate the layers from each other by various methods [3]. From the optics point of view, it is extremely promising in the context of developing passive elements of integrated optical circuits. By the example of other layered materials (MoS_2, $MoSe_2$, WS_2, WSe_2, etc.) the possibility of separating thin layers of a given thickness and transferring them onto different substrates has been demonstrated [4]. The layered structure of the material allows the exfoliation method to separate the layers with monolayer accuracy, which will allow to integrate $InGaS_3$ into the processes of planar technology and control the geometry of elements precisely.

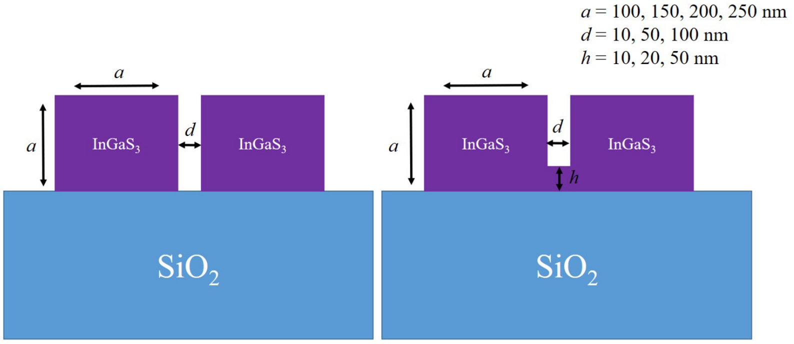

Fig. 1. Schematic of model geometry for numerical simulation

Materials and Methods

In this work, we study two different configurations of the $InGaS_3$ slot waveguides by numerical simulation methods, namely finite difference frequency domain (FDFD) and finite difference time domain (FDTD) in Ansys Lumerical software (see Fig. 1 for schematic). An inhomogeneous grid was modeled with a minimum grid step of 1.5 nm in the case of the FDFD solver and 7 nm of the FDTD solver. The absorbing boundary conditions were chosen in order to obtain a minimum reflection of the incident light [5]. The optical constants used were taken from the work [3]. The systems with the following geometry and parameters were investigated: two square waveguides with a 5 μm long, standing side by side, placed on SiO_2 substrate. The square side varied from 100 to 250 nm with step of 50 nm. The gap between two $InGaS_3$ waveguides varied from 10 to 100 nm by the same step. For the second configuration with an extra layer of the material between waveguides, the thickness of the unetched layer was 10, 20 and 50 nm. The waveguides properties of the considered system were studied at a wavelength of 505 nm. A model mode source was used to obtain the transmittance spectra in the range of 400 to 800 nm.

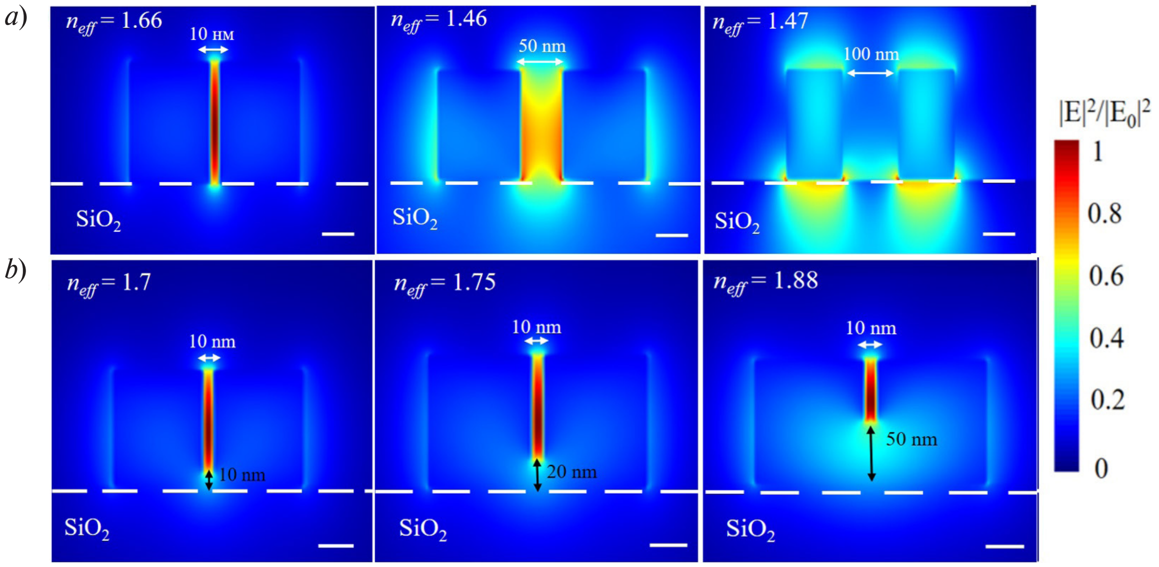

Fig. 2. Electric field distribution for slot waveguides with cross-sections of 100x100 nm^2 and gap width of 10, 50 and 100 nm (*a*) and for slot waveguides with extra layer (*b*)
The scale bar is 50 nm

Results and Discussion

Numerical simulation has demonstrated effective localization of the electromagnetic field inside the gap between two waveguides due to the high difference in refractive indices of $InGaS_3$ and air (see Fig. 2) and interaction of the both waveguides modes. The slot guided modes exist only in specific range of waveguides dimensions: for smaller waveguides it's easier for electric field to interact due to the waveguides eigenmodes worse localization. On the other hand, in case of very small cross-section field more actively penetrates the substrate and interaction between the waveguide modes fields become negligible so slot mode is no longer exist. For the thicker waveguides localization increases and slot mode is suppressed due to the shortening of the electric field evanescent tails. Adding extra layer of $InGaS_3$ to the slot region can shift the field maximum along the y-axis but it causes the mode leakage from the slot to the $InGaS_3$ (see Fig. 2, *b*). Furthermore, the bandwidth of the slot waveguide changes as the additional layer increases. These results indicate the possibility of creating an optical sensor based on $InGaS_3$ slot waveguides.

From the obtained transmission spectra, it was determined that with an increase in the gap between two waveguides, the mode inside the gap is delocalized due to less interaction of the electromagnetic field tails. Moreover, the transmission spectrum narrows in the long-wavelength region, as the gap between two waveguides increases, indicating that a tunable bandpass filter based on $InGaS_3$ slot waveguides can be fabricated.

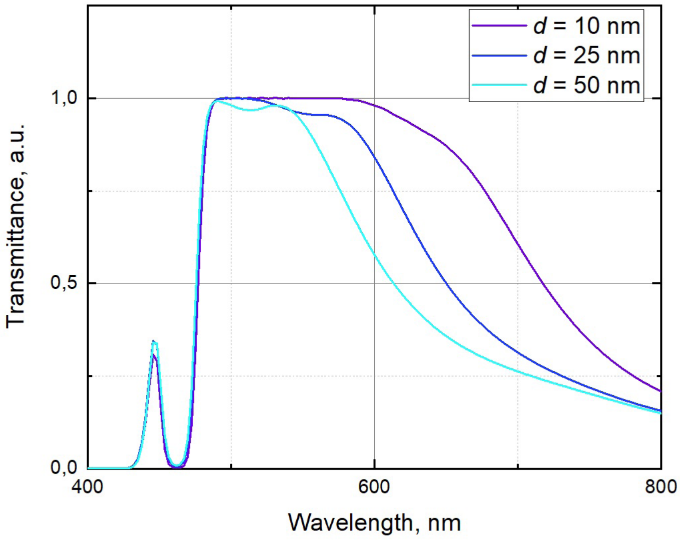

Fig. 3. Transmission spectra of 100×100 nm slot waveguides

Conclusion

We investigated the waveguide properties of the slot waveguides based on a novel layered not Van der Waals material. It was obtained, that 1) localization of the electromagnetic field between two waveguides increases due to waveguide dimension and gap decreasing; 2) the effective refractive index of the fundamental mode grows up with the increase of the waveguide dimension and the thickness of the unetched layer, and with the decrease of the gap between $InGaS_3$ waveguides; 3) with increasing gap between the two waveguides, the transmission spectrum narrows in the long-wavelength part of the spectrum. The results indicate that the slot waveguides based on $InGaS_3$ can be used as a passive element in integrated nanophotonics.

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Received 30.07.2024. Approved after reviewing 12.08.2024. Accepted 14.08.2024.