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Simulating and Fabricating Chalcogenide-based Waveguides for Agro-Environmental Applications

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Abstract. Agriculture challenges to reduce its environmental impact and to improve control over agricultural crops of agriculture are numerous. We develop here an optical integrated probe as potential answer to some detection challenges, based on a RIB chalcogenide waveguide. Early results have shown that the fabrication process induces sidewall roughness potentially altering the sensitivity of the probe. The numerical tool used here implements an approximation allowing to take into account sidewall roughness on propagation losses. This code is based on finite element method. Results show that sidewall roughness have a higher impact on losses for narrow waveguides.

1 Introduction

Agriculture has been seeking for the past few decades new ways to reduce its environmental impact. Tremendous efforts have been deployed to develop solutions for sensing, data acquisition, data processing and data storage systems for agriculture [1]. Optics, especially integrated optics, is a very promising field of physics for developing sensors achieving remote, immediate and accurate data acquisition, saving time for various applications for which data acquisition and processing delays are crucial. Early detection of fungal diseases spores is one of these major noteworthy applications. Early and immediate sensing would allow to avoid preventive application of fungicides, restricting the application of some on very located areas where the presence of spores would have been detected.

We aim in this project at developing a GeSeTe-based optical sensor to overcome some challenges in agro-environmental field, especially the early detection of fungal diseases spores. We chose to work with a mix of germanium (Ge), selenium (Se) and tellurium (Te), and more precisely with Se-rich Ge-Se-Te films, transparent from 1 to 16 μm in the short to mid wave infrared domain where lies the spectral signature of most of the biochemical entities. The working principle of the chosen approach is based on the absorption and scattering of evanescent wave by the biological entities near the core of a straight RIB waveguide.

The waveguides fabrication process employed induces sidewall roughness, inducing light scattering and optical losses, which might alter the specifications of the probe. This may concern as for example the

signal-to-noise ratio (SNR). A bad SNR would drastically lower the sensitivity of the probe to external environment.

The motivation of this contribution is to propose a solution to model the propagation losses induced by the sidewall roughness of our RIB waveguides with tilted sidewalls. This would allow to confront *a posteriori* the simulation results with the experimental measurements of propagation losses on built waveguides in order to assess the impact of propagation losses on the sensitivity of a biosensor.

The details of the numerical setups, along with its methodology, is presented in the following section. Subsequently, the results obtained through numerical simulations are presented and discussed.

2 Material and methods

In order to design the waveguides to answer the expected specifications, we took advantage of a numerical tool to compute the effective index and light intensity distribution of the mode guided in a given structure. The numerical method used is the full-vector finite elements method (FEM), and we used the mode solver implemented by Femwell, available on a Github repository [2]. It has been exposed in a paper by Lindecrantz and Hellesø a method implementing RIB waveguides sidewall roughness into a FEM simulations to estimate propagation losses [3]. In the cross-section of the waveguide, the sidewall roughness, which scatters light, is considered as an area with a specific thickness and a specific complex refractive index.

Figure 1 shows the typical geometry generated for the simulations. We allocated to these areas a complex refractive index $n_{\text{core}} - j\kappa$, which imaginary part

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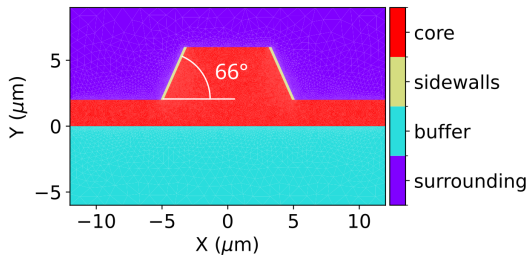


Figure 1. Geometry generated from a finite element mesh for the mode simulation. The core width is set to be 8 μm , the core layer is 6 μm -thick and etched by 4 μm . The sidewall roughness areas are 200 nm-thick. The imaginary part κ of the sidewall area has been set to 2.84×10^{-4} .

$-\kappa$ is responsible of the attenuation of light intensity during the propagation. In our simulations at wavelength of 1.55 μm , n_{core} has been set to 2.65 and κ to 2.84×10^{-4} . The imaginary part of the rest of the core layer is fixed at 2.84×10^{-6} . One can extract the attenuation coefficient α thanks to equation (1) from the complex refractive index $n_{\text{eff}} = n_{\text{eff}} - j\kappa_{\text{eff}}$ returned by the simulation as the propagated mode.

$$\alpha = \frac{-4\pi\kappa_{\text{eff}}}{\lambda} \quad (1)$$

A width of 200 nm was used as the thickness of the sidewall area. The other geometrical parameters have been taken equal to the ones used in the fabrication process: the total height of the core layer is 6 μm with an etching depth of 4 μm . The width of the waveguide, being taken at half of the etching depth, has been varied to plot the propagation losses with respect to the width of the waveguide. A reference has been simulated for each width, where the imaginary part of the refractive index in the sidewall areas has been taken equal to the one of the rest of the core layer (no differences in imaginary parts of the refractive indices). We focused here on the TE fundamental mode.

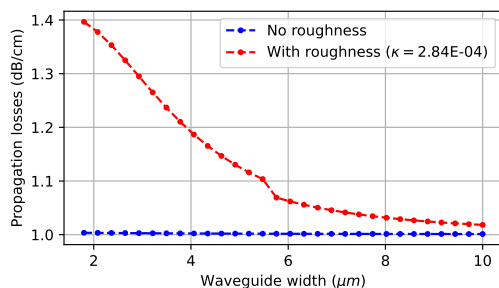


Figure 2. FEM propagation losses simulation results with respect to the width of the waveguide.

3 Results and discussions

The simulation returns the light intensity distribution of the fundamental mode propagated into the geometry with the given parameters. The light intensity distribution map reports a good confinement of light inside the core layer.

Figure 2 shows the propagation losses evolution with respect to the width of the waveguide. The reference simulations in blue shows that the width of the waveguide has a negligible impact on the propagation losses if there are no sidewall roughness, but remains non-zero because of the imaginary part of the core refractive index modeling intrinsic propagation losses. One can deduce from the red plot that the narrower the waveguide, the higher the propagation losses due to the sidewall roughness. The simulation confirmed that the sidewall roughness can have a non-negligible impact on propagation losses and thus on the specifications of an optical sensor.

Conclusion

It has been demonstrated in this work the possibilities of the finite element method to provide a mean to design a waveguide adapted for the detection of spores by taking in account the sidewall roughness. Simulation results already showed valuable information. If the waveguide is too narrow, the contribution of sidewall roughness might degrade the quality of the operation of the probe by increasing the propagation losses. Very promising perspectives are considered for this tool along with the fabrication and characterization of built waveguides, these results being presented at this congress.

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