MODAL CONFINEMENT FACTOR STUDY IN PLANAR WAVEGUIDES FOR SENSING

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Abstract

Sensing devices based-on optical waveguides are finding new applications in various industries. This sensing method can benefit from miniaturization, low-power and low-cost designs. The confinement factor is a key parameter to characterize waveguide efficiency for on-chip sensing, evaluating the fraction of light that interacts with the analyte. Here we report the study of confinement factor dependence on wavelength and dimensions for vibrational spectroscopy with different waveguide architectures. For this, we first simulate the different designs using a finite difference eigenmode (FDE) numerical tool to find the eigenmodes and the group index and then calculate the confinement factor.

Background

Fingerprints provide a reliable means of identification. That is the essential explanation for why fingerprints have replaced other methods of identification. The energy of a molecule can be divided to electronic, vibrational, rotational, and translational energy. When illuminated with infrared (IR) radiation, the atoms in the molecule start to vibrate. Optical waveguides are becoming an attractive building block in a variety of systems due to their unique features such as large evanescent field, compactness, and mostly, the ability to be configured to the required application [1].

Methods

The confinement factor is widely used to characterize waveguide efficiency for on-chip sensing, assessing the portion of the radiation taking part in the interaction with the analyte. The external evanescent field confinement factor is expressed by [2]:

$$\Gamma = \frac{n_g}{n_0}\frac{\iint_{air}\epsilon|\bar{E}|^2 dx\, dy\, dz}{\iint_{total}\epsilon|\bar{E}|^2 dx\, dy\, dz}$$

Γ is the confinement factor, n_g and n_0 are the group and refractive index, ϵ is the permittivity, and $\bar{E}$ is the electric field.

By numerically solving Maxwell equations we studied different waveguide architectures to understand the dependence of the confinement factor of the waveguide's sensitivity to analytes.

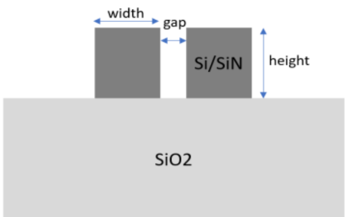

Figure 1: Cross-section of the Si/SiN slot waveguide

Results

Calculated field confinement factor Γ as a function of the slot width of slot-waveguides are shown in Figure 3 for Si and SiN based slot waveguides. It can be seen that the field confinement factor becomes higher by decreasing the slot width, while for the change in the rail width, there is an optimum value that seems to be the ideal for higher field confinement factor. The dependence in the waveguide height is different from Si to SiN based slot waveguide, when for the SiN increasing the height increases the field confinement factor, and for Si it has an optimum value. The Si based waveguide has higher confinement factor than the SiN one. It can be linked to the higher contrast of the Si to SiO2 as compared with SiN to SiO2.

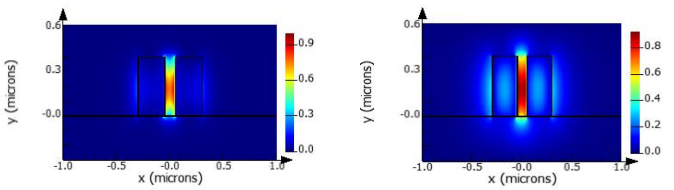

Figure 2: Electric field intensity (left) and E_x (right) distribution for the quasi-TE mode of a SOI slot-waveguide.

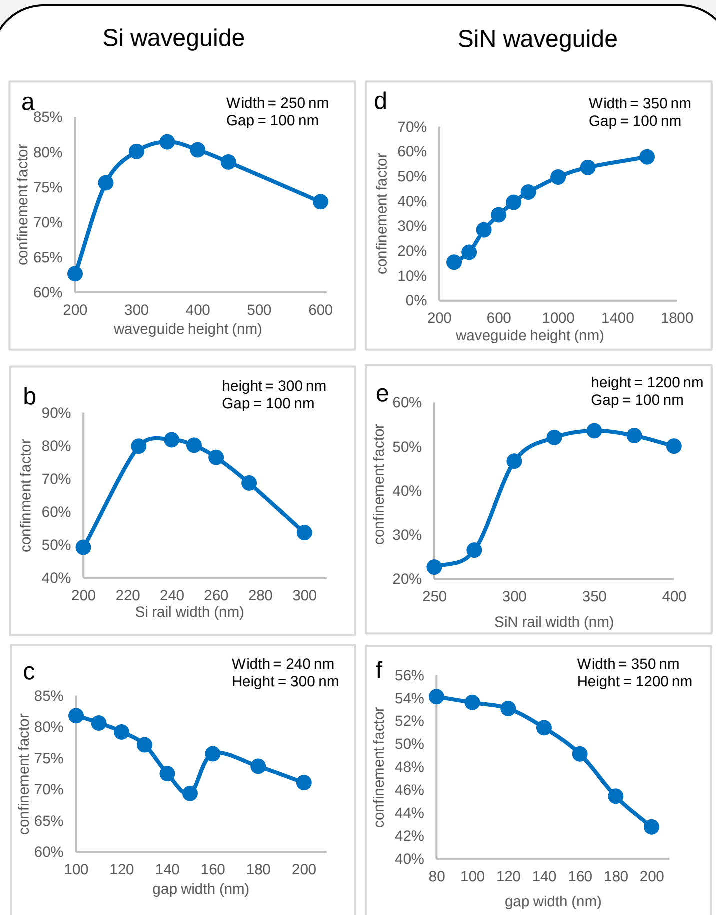

Figure 3: field confinement factor Γ for the quasi-TE mode of a Si (left) and SiN (right) slot-waveguide vs. waveguide height (a)+(d), rail width (b)+(e) and gap width (c)+(f).

Conclusions

We have numerically investigated the ability of the planar waveguide to confine a mode and to enhance the evanescent interaction with an analyte for quasi-TE modes. We have found that planar waveguides have different confinement factors which depend on the waveguide's parameters such as depth, width, materials. New spectroscopic strategies can potentially be extended to detect analytes in liquid, gas or solid states in a chip-scale label-free manner and to enhance the functionality of chemical and biological monitoring.

References

1. Karabchevsky, A., Sheintop, U., Katiyi, A., 2022. Overtone Spectroscopy for Sensing - Recent Advances and Perspectives, ACS Sensors, DOI:10.1021/acssensors.2c00655.
2. Robinson, J. T. et al. First-principle derivation of gain in high-index-contrast waveguides. Opt. Express 16, 16659–16669 (2008).