



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics Engineering and Electrical Communications

Infrared Optical Sensor

A Thesis submitted in partial fulfillment of the requirements of the degree of

Master of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

by

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Master of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

Faculty of Engineering, Ain Shams University, 2017

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Statement

This thesis is submitted as a partial fulfillment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Thesis Summary

This thesis study integrated gas sensing in the mid infrared (MIR) range of wavelength for on chip applications. For this purpose a detailed sensitivity analysis of different waveguides in gaseous medium in the MIR have been carried out including both plasmonic and dielectric waveguides in order to determine a high sensitivity and low loss sensor. Then, MIR waveguide platforms have been proposed to serve as interconnects and to build different photonic devices. Finally, two high performance refractive index gas sensors working near the absorption fingerprints of many gases have been proposed. Intensity interrogation method is used as it offers compact and cheap sensors. The first sensor use suspended silicon waveguide and the second uses metal insulator plasmonic waveguide and both are in a Mach-Zehnder Interferometer (MZI) configuration.

The thesis is divided into six chapters as listed below:

Chapter 1:

This chapter gives a brief introduction of the motivation, objectives, major contributions and organization of the thesis.

Chapter 2:

This chapter presents a review of the chemical and biological optical sensing with focus on MIR refractive index gas sensing. In the beginning the different optical sensing techniques that are used in the chemical and biological detection are discussed. Next, we focus on the gas sensing techniques and the advantage of working in the MIR range along with the progress that have been done in this range. Then, the advantages and the basic concept of refractive index sensors are presented where the well-known MZI sensor performance parameters are derived. Finally, recently proposed refractive index gas sensors are discussed.

Chapter 3:

This chapter proposes two waveguide platforms for the mid infrared region. Firstly a rigorous and detailed modal analysis of silicon-on-sapphire (SOS) strip waveguide in its MIR transparency region is presented. The waveguide dimensions that can support optical modes in the MIR region are presented and the effect of these dimensions on the effective index is studied. Next the modal analysis of hybrid plasmonic waveguides is presented where the metal is replaced by doped silicon. The dependence of the modal area and the propagation distance of the waveguides on the excitation wavelength, as well as the dimensions are investigated. The

hybrid structures were also investigated around the doped silicon resonance wavelength to examine their ability to support slow and fast light or behave as a negative index material.

Chapter 4:

This chapter presents a rigorous sensitivity analysis of many waveguides for MIR refractive index gas sensors. Real 2D index profile waveguides including plasmonic and dielectric were analyzed using full vectorial finite difference frequency domain solver. The studied plasmonic waveguides were using doped silicon as they offer many advantages over the metals in the MIR region. In addition an asymmetric hybrid waveguide using silver is proposed as it has many advantages for bimodal MZI. The waveguides sensitivity and losses are calculated for different waveguide dimensions, wavelengths and doping concentrations.

Chapter 5:

This chapter proposes two refractive index gas sensors working in the MIR range near the absorption fingerprints of many gases. The first sensor is waveguide coupled MZI based on suspended silicon waveguide that showed to reach high waveguide sensitivity with almost zero intrinsic mode loss. The second sensor is free space coupled vertically stacked plasmonic MZI. Intensity interrogation method is used as it offers compact and cheap sensors. FDTD simulations is used in the design and optimization of the sensors. Finally, recently published refractive index sensors and their performance were discussed and compared with our proposed sensors.

Chapter 6:

This chapter gives the conclusion of the thesis and introduces several recommendations and suggestions for the future work.

Key words:

Silicon photonics sensors, Plasmonic sensors, Gas sensor, Mid infrared, Lab on chip, Doped silicon plasmonic waveguides, Refractive index sensors, Hybrid plasmonic waveguides, Mach Zehnder Interferometer, Suspended silicon, Silicon on sapphire, long range plasmonic waveguides, all dielectric plasmonic waveguides, Slow and fast light, bimodal plasmonic MZI.

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