Crystal photonic based SPR sensor for high-sensitivity applications

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Context

Biological and chemical sensors are becoming increasingly important for environmental monitoring, medical diagnostics, and other industries such as the food industry and security. These sensors can be used to measure contaminants such as air pollutants and hazardous chemicals in air, water, or soil, and can help to provide faster, more reliable, and low-cost medical diagnostics. In addition, biosensors can be used to detect chemical contaminants in foods for ensuring safety and quality. The use of sensors in security and defence is also growing, with applications in areas such as explosives detection and bioterrorism.
The photonic sensor consists of a surface in contact with the analyte, a light source, and a photodetector. The interaction of the propagating light with the surface changes its parameters or properties. Most often, it is desired to measure the variation in the refractive index related to the capture of substances surrounding the surface with the interferometry technique or by determining the spectral shift of the optical resonance. This technique allows a real-time measurement of the density of captured substances.
One of the most efficient sensor categories is plasmonic sensors based on the use of the highly selective properties of surface plasmons (optical or more generally electromagnetic modes at the interface between a metal and a dielectric) which have demonstrated their superiority as chemical and biological sensors [1], [2]. These plasmonic sensors exploit the variation of light as it interacts with the surrounded medium of interest. This category of unlabelled sensors is more interesting because it does not require a preparation step to attach labels (such as fluorescent molecules) to the analytes that takes a long time to prepare, which is sometimes critical, and allows biological functions to be preserved.
Another family of sensors is the one based on optical resonators where the principle is to excite a specific mode in the ring. The presence of the analyte around the resonator modifies the mode condition. The insertion of photonic crystals makes it possible to control the light, guide it and thus improve the sensitivity of the sensor. It is a form of hybridization with the aim of improving the volume of light/matter interaction [3]. Photonic crystals consist of a periodic lattice of holes or rods in the substrate.
Compact sensors are needed for large scale use and deployment. Silicon photonics platform offers mature technology that could deliver innovative components integrated on a single chip. Heterogeneous III-V technology on silicon makes it possible to offer high-performance laser sources and photodetectors integration with passive components on silicon. The use of silicon photonics has many advantages such as the compactness of the compactness due to its high refractive index, low cost and its compatibility with CMOS technology.
The objective of this thesis is the design of a hybrid sensor based on photonic crystals and localized surface plasmon resonance offering high-sensitivity detection. This photonic sensor operates at telecom wavelengths in order to benefit from heterogeneous III-V silicon technology.
This study of this sensor topology is the first one at the Esycom laboratory, but it will benefit from the expertise of the supervisor team in modeling of metasurfaces, silicon photonics, surface plasmon devices and photonic crystals.

Thesis topic

1. Various national and international works on different types of plasmonic and photonic sensors have been done. Recent works focus on the development high-performance biosensors that satisfy Point-of-Care criteria and offer detection at the intervention places, whether at the bedside, in a doctor's office, etc. The main purpose of these sensors is to reduce the time required for analyses, to be able to make the fastest therapeutic decision [4] or in the case of environmental monitoring.

2. The major objective in this thesis is: (i) the hybridization aspect of the two described sensors, (ii) exploit the progress of silicon photonics to design an integrated and compact sensor. This type of hybridization has already been studied as in [5] where the detection scheme is based on the resonance shift. We propose to also analyse the phase of the transmitted light as a function of the refractive index change because it is expected to have a better sensitivity. Also, full integration of the photonic sensor with the laser diode and the photodetector will be considered.
3. Publications in IEEE Sensors, IEEE J Quantum Electronics, Optics Letters.

Expected planned work

The study will focus in the beginning on the modeling of simple surface plasmon architectures (Kretschmann or Otto configurations) and also on simple silicon photonic crystal sensor architectures. The best silicon configuration base on rods or holes of different diameters will be selected. Dispersion diagram (band structure) for these devices will be determined. The modeling tools will be developed using the Fourier Modal Method (FMM) which is an original and very efficient calculation method allowing to analyze the propagation and diffraction of light through periodic structures [6], [7]. It is a rigorous electromagnetic method once it solves Maxwell's equations in all their generality without any approximations. With this method, different coefficients can be determined such as reflection, transmission or absorption but also maps of the electric and magnetic fields throughout the structure. The intensity and phase of the electric field are thus accessible. It would also be possible to combine an optimization method with FMM and exploit the parallel computing appreciated for complex structures.

Next step concerns the optimization of the hybrid sensor with the selection of metallic materials and the analysis of the sensor technological dispersion. The excitation of localized surface plasmons depends strongly on the metal, the periodicity of the lattice, and the diameters of the photonic crystals.

The realization of the sensor will be considered in a non-optimal version. The integration of the laser and photodetector source with the sensor will depend on collaboration/technological opportunities and the progress of the thesis work. Indeed, the time required to produce a chip with heterogeneous III-V silicon technology is longer than classical technology.

The last step will deal with the sensor quantification to evaluate the sensitivity and the factor of merit based on the choices made in the previous step.

Candidate profile

1. The phD candidate should have a multidisciplinary background with a special focus on: Material sciences, applied physics, applied mathematics, nanotechnology and sensor.
1. The necessary knowledge to carry out this thesis project are of two kinds: (i) the candidate must have a solid knowledge of the physical principles of wave/matter interaction, electromagnetism and numerical methods allowing him/her to approach the study of plasmonic structures and photonic crystals envisaged in the thesis and (ii) experimental skills will be appreciated.

Contact

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The ESYCOM laboratory *is involved in the engineering of communication systems, sensors and microsystems for the city, the environment and people.*
More specifically, the topics covered are:

- *antennas and propagation in complex media, photonic components - microwaves;*
- *microsystems for environmental analysis and depollution, for health and the interface with living organisms;*
- *micro-devices for mechanical, thermal or electromagnetic ambient energy recovery.*

Bibilography

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