Proposition de SUJET DE STAGE M2R/Ingénieur-3A

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Photothermal effect for high-performance silicon photonics sensors

SCIENTIFIC PROJECT:

Silicon photonics allows the realization of ultra-compact circuits that can be cost-effectively fabricated reusing CMOS pilot-lines. In addition, silicon has a unique potential to integrate electronic and optic functionalities in a single chip. Thus, **Si photonics is considered an enabling technology for the realization of next generation lab-on-a-chip biosensors**. These devices hold the promise to allow the widespread of high-impact applications like non-invasive medical diagnostics, food quality control and air pollution monitoring. For example, by monitoring exhaled human breath, lab-on-a-chip biosensors could provide precise and real-time information of full panels of bio-markers, which could be used for early diagnostics or medication control applications.

One of the most performant and flexible means of multi-target detection is absorption spectroscopy. By monitoring the unique optical absorption fingerprint of different target molecules, absorption spectrometers have been able to provide unprecedented specificity and sensitivity. The problem is that current devices rely on bulky free-space implementations that are high cost and difficult to operate out of the lab. **Silicon photonics could allow the realization of miniaturized on-chip absorption spectrometers, that would leverage the low-cost of this technology**. While most of the technology development in Si photonics focused in near-infrared wavelengths (matching the transparency windows of the optical fiber), most molecules show their major absorption peaks in the mid-infrared. This means it is necessary to develop a new mid-infrared Si photonics technology.

One of the key challenges of on-chip mid-infrared technology is the detection. Photons in the mid-infrared have a comparatively low energy, which means that mid-infrared photodetectors become very sensitive to thermal noise. In the free space implementations, this limitation is overcome by means of stringent cooling systems (e.g. liquid nitrogen). Unfortunately, this solution is not feasible and cost-effective for on-chip miniaturized devices. One very promising alternative approach is the indirect detection exploiting the photothermal effect [1,2]. The energy absorbed by the target molecules is released in the form of heat. This way, detection of mid-infrared absorption can be carried out with two beams: a pump signal in the mid-infrared for molecule excitation and a probe signal in the near-infrared to probe the photothermally induced change in the local refractive index. Hence, mid-infrared absorption could be sensed using high-performance integrated near-infrared photodetectors, obviating the need for complex cooling systems. Using a surface mid-infrared illumination and a guided near-infrared pump, photothermal detectors have already demonstrated very promising results, with some pioneering demonstrations of single-molecule detection (see Fig. 1). **Researchers at MIT have theoretically shown that confining both, pump and probe, signals within the same optical micro-resonator could provide a drastic amplification of the photothermal effect [3]. However, this approach has not been experimentally demonstrated yet.**

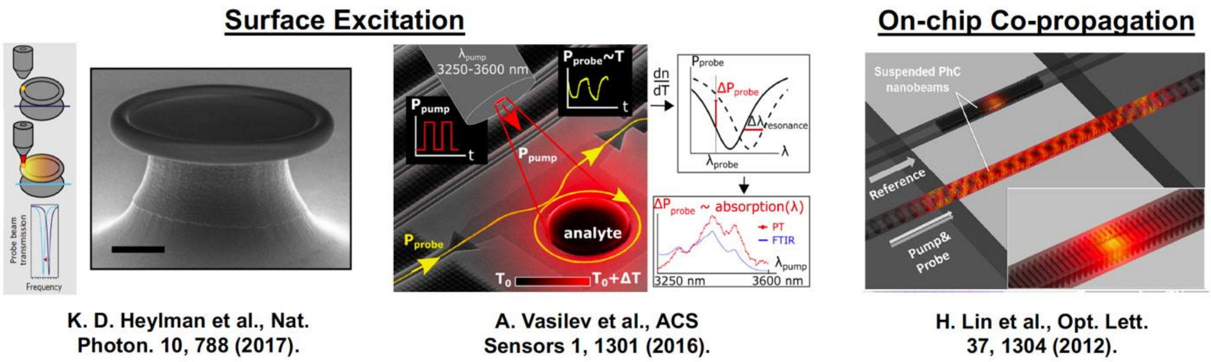

Fig. 1: Examples of silicon photothermal sensors based on surface illumination and on-chip co-propagation of pump and probe signals.

The goal of this internship will be to model, design and characterize novel Si photonics micro-resonators for the implementation of ultra-compact on-chip co-propagating photothermal sensors, targeting ultra-tight light confinement and resonant enhancement of the light-matter interactions.

The research activity developed during the internship will include theoretical study and multi-physics simulations of the Si micro-resonators to understand the key parameters that determine the pump absorption by the target molecules, the heat generation and transmission, the photothermal induced index change and the effect on the resonance of the probe signal. Special attention will be devoted to the realization of realistic device designs, considering the constraints of our nanofabrication processes, for further experimental validation. During his/her stay, the student will be actively involved in the current research activity of the group, collaborating with PhD students, postdocs and researchers of different research backgrounds and nationalities.

This project can be continued and expanded within the frame of a PhD (ANR, European Union, or European Research Council projects).

METHODOLOGY OF THE STAGE

1) Bibliography study: Reading of a pre-selection of the main papers related to the topic, e.g. [4], to understand the main physical physical phenomena involved in the device and their inter-relation.

2) Multi-physics simulation of photothermal Si micro-resonators: Optical, thermal and absorption characteristics of the micro-resonators will be analysed coupling commercial softwares (Lumerical, Comsol), numerical tools developed by MIT (MEEP, MPB) and multi-parameter models.

3) Experimental characterization Si micro-resonators: Aiming to understand the fabrication and characterization requirements of Si micro-resonators, the student will participate in the experimental characterization of novel high-performance resonators recently developed by the group.

VALUED QUALITIES IN THE STUDENT

- Curiosity for novel research experiences and fields.

- Creativity and pro-activity in the search for innovative solutions and approaches.

- Capability to communicate and share results in a multidisciplinary and multi-nationality environment.

BIBLIOGRAPHY RELATED TO THE TOPIC

[1] H. D. Heylman, *et al.* "Optical microresonators as single-particle absorption spectrometers," *Nat. Photon.* **10**, 788 (2017). https://doi.org/10.1038/nphoton.2016.217

[2] A. Vasilev, *et al.* "On-chip mid-infrared photothermal spectroscopy using suspended silicon-on-insulator microring resonators," *Sensors* **1**, 1301 (2016). https://doi.org/ 10.1021/acssensors.6b00428

[3] H. Lin, *et al.* "Double resonance 1-D photonic crystal cavities for single-molecule mid-infrared photothermal spectroscopy: theory and design," *Opt. Lett.* **37**, 1304 (2012). https://doi.org/10.1364/OL.37.001304