PhD topic :

Bio-inspired and sustainable photonic sensors for healthcare and environment

Scientific domain and context:

With the increase and aging of the population, the increasing risk of pandemics, the explosion of allergies and pathogens in our environment, the need to develop biomolecular analysis devices at the "point-of-care" (self-tests or field analyses) explodes. Photonic devices are of great interest for this type of application, since they can yield optical resonances that are very sensitive to the presence of analytes, while offering compatibility with physiological solutions and a high compactness which is essential for parallel analysis via integrated on-chip sensor networks. In order to be consistent with their application in the areas of health and environment, such devices must also minimize their own environmental impact, by engineering photonic structures compatible with eco-friendly manufacturing processes and materials. To achieve these objectives and offer high-performance sensors while ensuring low environmental impact, a possible strategy comes from inspiration by nature. Numerous animal or vegetal species (feathers, insect wings, leaves or petals…) have optical properties such as transparence, coloration or iridescence that are exceptional both in their performance and their diversity; such optical effects are due to a three-dimensional structuration of matter at submicronic scale [1]. Because their architectures are often complex (leading to large specific surfaces) and they yield a high resilience to imperfections, some natural photonic structures with optical resonances are highly interesting models for the design of devices for molecular analysis. However, there is a real challenge in reproducing these nanostructures and their properties, both from the point of view of technological fabrication and of the related photonic engineering [2], especially within the constraints of a sustainable fabrication.

Objectives of the PhD thesis:

The proposed project aims at creating photonic nanostructures with optical properties that are inspired from natural nanostructures and well-suited to environment and healthcare applications, using the technological tools at INL. For this purpose, photonic engineering and technological fabrication will be led in close synergy, in order to adapt the nature-derived concepts to the specificity of the fabrication tools. The first objective will be to identify a few natural nanostructures yielding the desired photonic properties (sensitivity and robustness); these nanostructures will be used as an inspiration to design new objects made of the intended bio-compatible materials (sol-gels or biopolymers) and yielding similar properties in the targeted spectral range. The proposed structures should also present architectures that can be directly fabricated using the alternative technologies available at INL, such as laser interference lithography and nanoimprint lithography. The second objective will then deal with the fabrication and experimental characterization of the nanostructures, to evaluate their potential for future applications. In a third step, the study could be extended to more complex structures, in order to optimize the optical properties and the sensitivity, and to obtain devices with higher performances for the targeted applications. The outcome of the PhD work will be the experimental demonstration of a bio-inspired device for molecular analysis.

Scientific challenges:

The proposed PhD work should tackle two scientific hurdles. The first one will deal with the design of nanostructures yielding high-performance properties (spectral and angular control of light, high interaction with the surrounding medium) while being made of low refractive index materials like polymers or sol-gel-based metal oxides. The second one is technological, and arises from mimicking three-dimensional (and often multi-scale) natural nanostructures using « top-down » fabrication techniques that are usually better suited for the fabrication of two-dimensional devices. In order to overcome these two challenges, we propose to combine the expertise of i-Lum team in the areas of photonic concepts and optical simulations with the know-how of Nanolyon technological facilities on highly-promising techniques such as laser interference lithography and nanoimprint lithography.

Expected original contributions:

Although the optical properties of natural nanostructures have already been widely studied, and the underlying light-matter interactions are well-understood, their experimental mirroring is a real challenge that still requires to set up highly-complex designs and technological processes in order to obtain the targeted performances. Hence, the development of alternative original processes enabling, at the same time, to simplify the technological fabrication and to replicate the exceptional optical properties that can be observed in nature, will constitute a major scientific advance in the area of bio-inspired photonics. This could pave new ways for the implementation of bio-inspired nanostructures in several domains of application. Additionally, the demonstration of such nanostructures in sustainable materials will be a crucial milestone for the future developments of eco-friendly photonic devices.

Expected profile of the PhD candidate:

The PhD candidate must have an engineering or master degree with a strong background in material science and/or nanophotonics. He/she should also have a first experience in micro-nanotechnologies, as well as a motivation to simultaneously lead simulation works, technological and experimental works.

Duration: 3 years (10/2025 – 09/2028)
Locations: INL, ECL and la Doua campus
Candidature deadline: 15th of May 2025

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Bibliographic references:

[1] G. Jacucci, et al., Light Management with Natural Materials: From Whiteness to Transparency, Adv. Mater. 2021, 2001215
[2] H. Butt, et al., Morpho Butterfly-Inspired Nanostructures, Adv. Optical Mater. 2016, 497