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Investigating the Detection of Lipids Gel/Fluid Phase Transition by Change of Scattering Light and Coupling Factor into Optical Microresonators

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Summary: The present paper describes biophotonic sensors realized by way of inexpensive processes. As hybrid silica/polymer resonators, they are suited to detect biological molecules in gel/fluid phase transition at infinitesimal concentrations (sphingomyelin lipids). The photonic structure is made of specific amplified deep UV210 photoresist-polymer waveguides coupled by a sub-wavelength gap with racetrack microresonators allowing a minimal dependence in temperature. Then, temperature dependent wavelength shifts characterizing the optical resonances of the device have been evaluated, highlighting a quite low thermal feature of the sensor advantageous for relevant applications. With an appropriate vesicle lipid deposition process, specific in biology, together with an apt experimental bio-thermo-photonic protocol, the dynamic evolution of the sphingomyelin lipid phase transition has been assessed. The ability to detect their gel/fluid transition phase and melting temperature has been demonstrated with a mass product factor value 1.4×10^7 lower than that of classical methods. The equilibrium regimes of the resonators and the scattered part of the light are clearly highlighted as markedly modified by the dynamic of the sphingomyelin during its own phase transition.

Keywords: Integrated photonics, Sensors, Micro-resonators, DUV210 polymer, Soft matter Processes, Gel/fluid phase transition, Sphingomyelin lipids.

1. Introduction

Optical microresonators (MRs) are generic components most valuable to design and fabricate integrated photonic devices fostering the development of numerous applications in science. Relevant resonant quantifications met in physics are due to a geometric recirculation of whispering gallery modes of light: they address convenient integrated photonics regarding a significant set of optical versatile applications such as: sensors for metrology with platform analysis and their relevant detection procedures, label-free detection of a wide variety of biochemicals, biological agents and biomedical materials [1-3]. Sphingomyelin (SPH) is a type of sphingolipid that can also be classified within sphingophospholipids found in animal cell membranes.

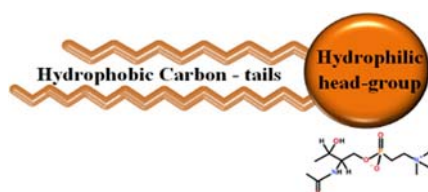


Fig. 1. Sphingomyelin: symbolic representation.

SPH is prominent in myelin and represents more than 80 % of all sphingolipids within human beings (nerve tissues, red blood cells...), participating in many signaling pathways. Then, this work is aimed at investigating easily reproducible polymeric biophotonic sensors. Such devices are devoted to identify the SPH lipid first order phase transition, while considering a gel-liquid state-change and its related melting temperature determination [4].

2. Materials, Methods, Realization of the Optical Bio-Sensor

2.1. Processes and Nanotechnology

A key point refers to the use of the DUV210 polymer, as a photoresist chemistry product, hinging on deep UV processes and light/matter interactions. We take advantage of such a deep UV lithography approach at 248 nm, far below the so-called i-line conventional peak at 365 nm. Such an organic exposure to deep UV radiation at $\lambda_{\text{flash}}=248$ nm enables valuable realizations of sub-wavelength photonics structures as regards the gap between waveguides and micro-resonators.

2.2. Methods: Atomic Force Microscopy, Micro-Raman Spectroscopy and Lipids Deposition

Strict quality controls of the chip (materials, properties, geometries, sub-micron dimensions, surface aspects ...) are then necessary, by way of various technologies and instrumentations regarding imaging and analysis: optical and atomic force microscopy together with Raman micro-spectroscopy and imaging. Considering micro-Raman spectroscopy analyses and detection of various signal signatures of materials, it is also possible to image on 2D the waveguide/MR structure, to get high quality control on geometry and observe the polymer material aspect.

After implementation of the fusion vesicle method deposition, that is specific in biology with a view to building a multilayer Sphingomyelin-gel structure upon the sensing surface of the device, we may

proceed through a specific protocol regarding experimental measurements [4] so as to monitor the dynamic evolution of the sphingomyelin lipid phase transition (see Fig. 3).

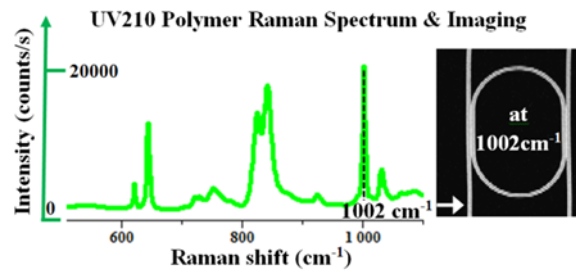


Fig. 2. Quality control. Raman spectroscopy analyses of UV210 polymer plus Raman top view imaging of the overall photonic device at 1002 cm⁻¹.

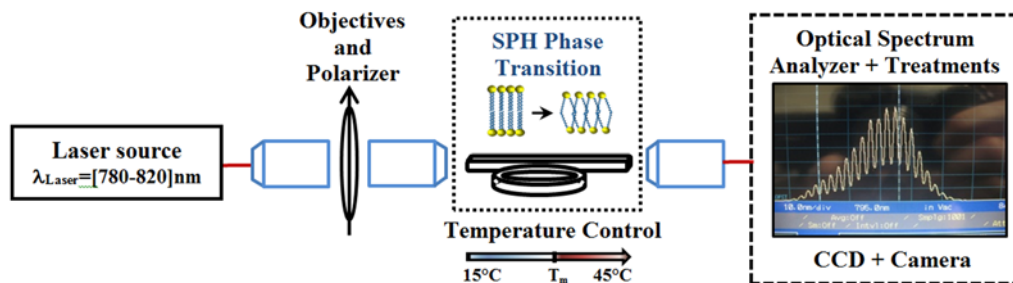


Fig. 3. Global photonics platform for SPH 'gel/fluid' phase transition detection, thermal system control, computing and signal processing ; a quantified optical spectrum example.

3. Photonics Detection of Sphingolipid Gel/Fluid Phase Transition and Results

Our sensors are based on a 'coupling plus resonance' physics, with a tunnel effect through a gap added with an optical geometric and cyclic resonance.

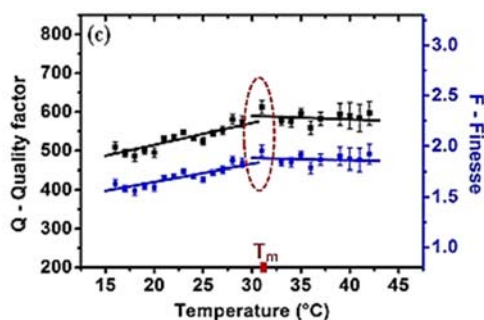


Fig. 4. Quality Detection of the gel-liquid phase transition of SPH lipids. Evolution in temperature of the Q-factor and Finesse of the photonic device under SPH test, determination of $T_m \approx [31-32]^\circ\text{C}$.

Considering the electromagnetic set of equations describing our design, the operating regimes

specifying the quantified values of the coupling factor K from the guide to the resonator are justified. Indeed, the optical transmission of such devices depends on intrinsic parameters, namely K the coupling factor and the intra-cavity losses. The equilibrium of the regime is clearly broken by the dynamic of the Sphingomyelin and its own phase transition (Fig. 4). The ability to detect the specific gel/fluid transition phase of SPH lipids and the efficiency to pinpoint the melting temperature at $T_m = 31 \pm 0.5^\circ\text{C}$ have been demonstrated. Moreover, differential scanning calorimetry thermograms and their related analysis measurements corroborated exactly the results stemming from our light-sensors.

4. Conclusions

The dynamic evolution of the sphingomyelin (SPH) lipid phase transition was assessed by relevant photonics MRs sensors: the ability to detect their own gel/fluid transition phase and T_m melting temperature has been demonstrated: the balanced regimes of the resonators were clearly observed as markedly broken by the dynamic of the sphingomyelin and their specific phase transition prior relevant detection [4].

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