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Perforated SiN membrane resonators for nanomechanical IR spectroscopy

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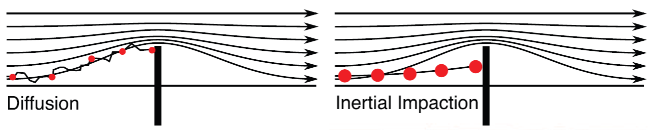
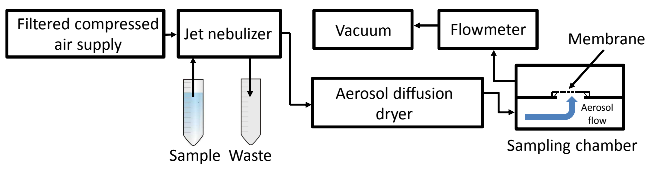
Introduction

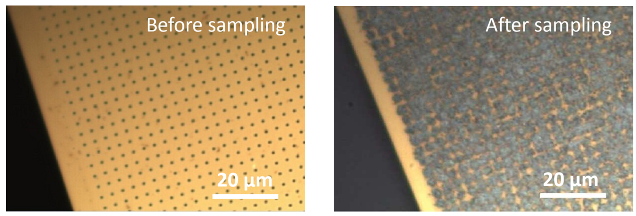
Constant progress in micro- and nanofabrication provides a great opportunity in development of micro- and nanomechanical resonators that can be used for sensing purposes. These sensors usually consist of singly-clamped cantilever beams, doubly-clamped bridges or membranes that exhibit resonant behavior. The principle of operation is based on the monitoring of the resonance frequency shift due to various external factors such as change of temperature. It has been shown that photothermal infrared (IR) spectroscopy based on nanomechanical silicon nitride (SiN) string resonators (NAM-IR) enables the exceptionally fast chemical analysis of pictograms of analyte directly from liquid solution in only a few minutes [1]. However in this technique the coupling of the IR laser beam to the nanometer-wide string resonators is difficult and inefficient. Therefore perforated SiN membranes with thickness of 100 nm, lateral dimension of 1×1 mm^2 and 2 µm perforation grid pitch were used instead of strings which makes the IR beam alignment significantly simpler while maintaining similar sampling efficiency and photothermal IR absorption sensitivity.

Sampling

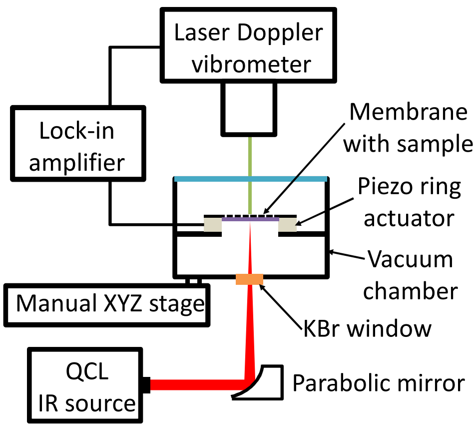
The chemical analysis of biomedical nanoparticles dispersed in liquid can be performed in just several minutes, compared to 2 days required for sample preparation and subsequent study with FTIR [2]. The sampling on perforated membranes is done by nebulizing the analyte directly from dispersion using jet nebulizer. Then the airborne samples can be captured on the resonators by two main mechanisms: diffusion and inertial impaction. In the first case the Brownian motion of the particle causes it to deviate from its original trajectory and impact on the resonator that acts as a filter. The second case occurs when particle has large enough momentum to leave the streamline that bends around the resonator and impinge on it. Operating in the inertial impaction regime significantly enhances the sampling efficiency and can be achieved by increasing the particles velocity. The sampling setup features a small orifice that effectively accelerates the particle aerosol to velocities in the inertial impaction sampling regime that is most effective for filtering micro-sized particles [3].



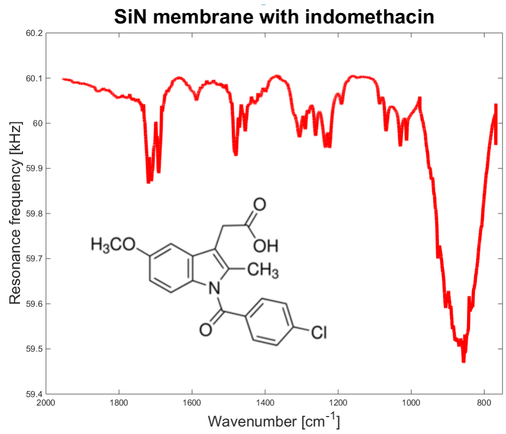


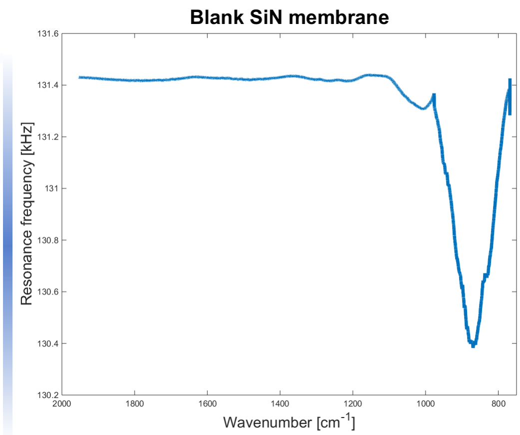


Experiments



The indomethacin was dispersed in methanol and then nebulized on the bottom surface of the membrane. The experiments were conducted at room temperature a a pressure of 1 mbar. The chips were placed on the piezo ring actuator and resonance frequency was optically measured on the top surface of the membrane using laser Doppler vibrometer. The IR radiation was emitted by the QCL in the wavenumber range of 768 – 1953 cm^{-1} and focused on the coated side of the membrane with a parabolic mirror. The fundamental resonance frequency of the resonator was monitored by means of phase-locked loop with a lock-in amplifier.





Conclusions

Particular advantage of NAM-IR is the ultra-fast and simple sample preparation and deposition on the sensor surface. The perforated membranes guarantee efficient sampling. In addition cumbersome IR laser beam alignment is simplified in comparison with string resonators. The minimum detectable mass was calculated to be 150 pg with Allan deviation value of $1{,}7\times10^{-7}$ and IR beam power of 500 µW and radius of 200 µm.

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