

Spanish Conference on Nanophotonics - CEN2021. September 20-22 2021, Virtual.

Biosensors based on optomechanical systems

Alberto Martín-Pérez, Sergio García-López, Marina L Yubero, Oscar Malvar, Priscila M Kosaka, Daniel Ramos, Eduardo Gil-Santos, Jose J Ruz, Álvaro San Paulo, Javier Tamayo, Montserrat Calleja

Bionanomechanics Lab, Instituto de Micro y Nanotecnología, IMN-CNM (CSIC), Isaac Newton 8 (PTM), E-28760 Tres Cantos, Madrid, Spain. Affiliation

A primary goal of optomechanics has been to exploit the interaction of photons with mechanical systems to cool down their fundamental mechanical vibration mode, but recently, optomechanics has also played a relevant role in the enhancement of the detection limits of nanomechanical sensors.^[1,2] Resonating nanomechanical structures have provided extreme force and mass sensitivity, in the zN and yg range, achievable due to the devices low mass and extraordinary mechanical properties at the nanoscale. Still, progress in the downscaling of the devices would have not been fruitful if not accompanied by the development of non-invasive displacement detection techniques with sub-picometer sensitivity. Optical read-out of the resonators by a laser beam probe has been a successful approach in the last decades, despite the challenges faced for mechanical systems with dimensions below the optical wavelength. We have found that semiconductor structures, as silicon nanowires, can support optical resonances associated to the light confinement within them and that such light confinement can be harnessed to achieve an unprecedented optomechanical coupling in these tiny structures.^[3,4] The result is that we can obtain regenerative mechanical oscillation with a frequency stability of one part per million, that readily translates into zeptogram mass resolution at room temperature. This approach offers significant advantages with respect to previous frequency detection methods, as it allows the detection of the Brownian motion of small nanowires, so there is no need of external excitation, which allows a high degree of simplification in the design of the sensors. The concept of exploiting internal optical resonances together with the ever-increasing control in the fabrication of nanowires opens up immense opportunities to develop robust and reliable optomechanical devices for the detection of single biomolecular recognition events in liquids and single molecule spectroscopy in vacuum. We will also discuss how strategies inspired by these phenomena applied to microscale devices have served for cancer cell characterization,^[5] and how light confinement in plasmonic particles and optoplasmonic cavities can be harnessed for the detection of attogram per milliliter concentrations of protein biomarkers.^[6] These technology advancements are now allowing us to explore the formerly elusive deep plasma proteome.^[7]

References:

- [1] Biosensors based on nanomechanical systems, J Tamayo et al, Chemical Society Reviews 42 (3), 1287 (2013)
- [2] Mass and stiffness spectrometry of nanoparticles and whole intact bacteria by multimode nanomechanical resonators O Malvar, JJ Ruz, PM Kosaka, CM Domínguez, E Gil-Santos, M Calleja, J Tamayo, Nature communications 7, 13452 (2016)
- [3] Silicon nanowires: where mechanics and optics meet at the nanoscale, D Ramos, E Gil-Santos, O Malvar, JM Llorens, V Pini, A San Paulo, M Calleja, J Tamayo, Scientific reports 3, 3445 (2013)
- [4] Optomechanics with silicon nanowires by harnessing confined electromagnetic modes, D Ramos, E Gil-Santos, V Pini, JM Llorens, M Fernández-Regúlez, A San Paulo, M Calleja, J Tamayo, Nano letters 12 (2), 932-937 (2012)
- [5] Mechano-optical analysis of single cells with transparent microcapillary resonators, A Martín-Pérez, D Ramos, E Gil-Santos, S García-López, ML Yubero, PM Kosaka, A San Paulo, J Tamayo, M Calleja, ACS sensors 4 (12), 3325-3332, 2019
- [6] Detection of cancer biomarkers in serum using a hybrid mechanical and optoplasmonic nanosensor, PM Kosaka, V Pini, JJ Ruz, RA Da Silva, MU González, D Ramos, M Calleja, J Tamayo, Nature nanotechnology 9 (12), 1047 (2014)
- [7] Optomechanical devices for deep plasma cancer proteomics, PM Kosaka, M Calleja, J Tamayo, Seminars in cancer biology 52, 26-38 (2018)