In air characterization of the mechanical properties of single bacteria based on multimode tracking of squared nanomechanical resonators

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Nanomechanical resonators have emerged as excellent tools in microbiology due to their extraordinary capability to characterize the mass and mechanical properties of a variety of microbiological entities, such as human cells, bacteria, viruses and proteins [1]. Researchers have succeeded on characterizing individual human cells in liquid environment. However, the mechanical characterization of single bacteria, viruses or proteins is usually limited to vacuum condition, being far from their intrinsic conformation.

In this work, we use a previously developed technique in order to deposit individual bacteria cells in controlled positions of squared shaped nanomechanical resonators (40µm length and width, 100 nm thickness). We simultaneously track multiple mechanical resonance frequencies of the sensor before and after the adsorption of the bacteria cells (Figure 1.a). In particular, we monitor the 1st and 2nd flexural modes, together with the 1st torsional and 1st U-shape modes. Notably, the associated mode-shapes of these modes are very different, which allows disentangling the mass and stiffness effects induced by the analytes adsorption. The method is performed in air, enabling the characterization of the bacteria properties close to their intrinsic conformation. We apply this technique for two kinds of bacteria: *Staphylococcus Epidermidis* and *Escherichia Coli* (Figure 1.b-c). We demonstrate that we obtain very accurate information about the analyte masses and their different stiffness components [2]. Importantly, accessing the different stiffness components of the bacteria allows us to determine their shape, which is essential to univocally identify them [3].

In the near future, we plan to extend this technique for liquid operation, which will strongly impact the biomedicine and biophysics fields. For example, to monitor in real time the bacteria properties while applying antibiotics, notably, at the single level, may allow to in-situ study their responses, providing a very powerful tool to delve into antimicrobial resistance emergence. Moreover, the developed technique may find applications for many other microbiological analytes, going from human cells to viruses.

References

[1] J. Tamayo, et al., Chemical Society Review, 42 (2013) 1287.
[2] J. J. Ruz, et al., Journal of Applied Physics, 128 (2020) 104503.
[3] A. Aparicio-Millan, et al. In preparation.

Figures

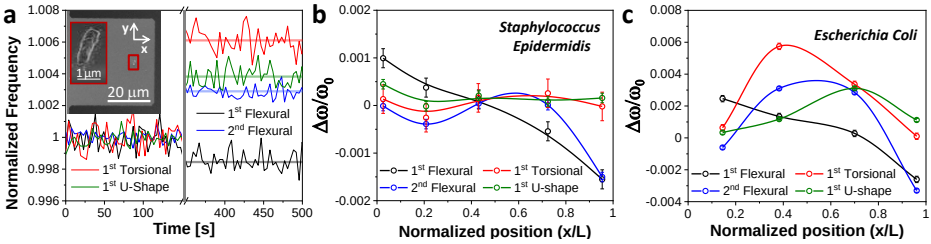

Figure 1.a. Normalized frequencies (ω/ω_0) of the first four mechanical modes of the sensor (1st flexural, 1st torsional, 2nd flexural and 1st U-shape) before and after the adsorption of an *Escherichia Coli* cell. Insets show scanning electron microscope images of the nanomechanical squared resonator (40µm length and width, 100 nm thickness) with the adsorbed *Escherichia Coli* cell. Solid lines indicate the averaged normalized frequencies after the bacterium adsorption. **b-c.** Relative frequency shift of the first four mechanical modes of the sensors induced by the adsorption of *Staphylococcus Epidermidis* and *Escherichia Coli* cells, respectively, versus the normalized longitudinal position (x-axis). All the cells are adsorbed on the sensors central position respect to the y-axis. Solid lines are guides to the eye.