Hybrid nanomechanical-microfluidic devices for stiffness and compressibility characterization of in-flow cells

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The developement of versatile tools for measuring multiple physical properties of single micro and nanoparticles is a matter interest in a wide range of fields as material science or solid-state physics. But, biology is perhaps the field demanding the most this kind of tools in the nanoscale. Mechanical properties as mass density or Young's modulus have been demonstrated to be useful parameters not only for discerning among different biological particles, but also because they have a fundamental biological significance [1]. Suspended microchannel resonators (SMR, Fig. 1a) [2] are the result of the convergence of two promising techniques in this scope: microfluidics and nanomechanics. SMR devices have been demonstrated to be really usefull to measure some mechanical properties as mass or density [3]; however, the hydrodynamic forces, widely used in microfluidics, remains unexploited in these devices [4], leading to missing information of high physical and biological relevance.
In this work, we have theoretically studied the hydrodynamic lateral force actuating on a flowing particle crossing a SMR (Fig. 1a) and how this force is transmited to this resonator (hydrodynamic load), changing its resonance frequency. After that, we have elucidated how the SMR devices must be designed so as to compliment the mass measurements with these hydrodynamic forces (Fig. 1b), which have never been measured yet. Moreover, we demonstrate that the measurement of this hydrodynamic load can be used in the case of soft particles (e.g., biological cells, Fig. 1c) to measure mechanical properties as stiffness (Fig. 1c) or compressibility. These results open the door to a new generation of SMR devices capable of performing a simultaneous multiplexed individual cell analysis combining mass and optical [5] characterization with these stiffness measurements.

References

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Figures

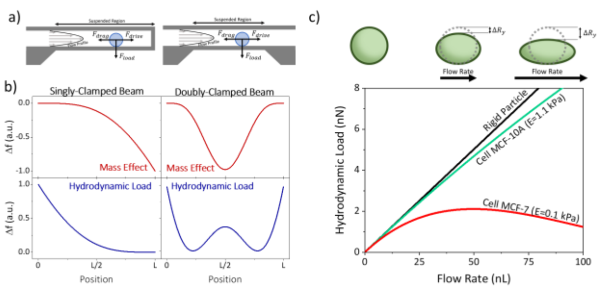

Figure 1: a) Schematic of a singly-clamped (right) and doubly-clamped (left) suspended microchannel resonator and the hydrodynamic forces actuating on a particle crossing it. b) The change in the resonance frequency caused by the passing particles can be divided into two effects: mass effect (red lines, up) and hydrodynamic load effect (blue lines, down). c) Schematic of the effect of the hydrodynamic force on a soft particle shape (up) and hydrodynamic load as a function of flow rate for rigid (black line) and for different cell types (green and red lines).