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► To cite this version:

Isabelle Dufour, Abdelhamid Maali, Yacine Amarouchene, Cédric Ayela, Benjamin Caillard, et al.. The Microcantilever: a Versatile Tool for Measuring Fluid Properties. 8th International Workshop on Nanomechanical Sensing 2011, May 2011, Dublin, Ireland. hal-00564861

HAL Id: hal-00564861

<https://hal.science/hal-00564861>

Submitted on 28 Apr 2022

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The Microcantilever: a Versatile Tool for Measuring Fluid Properties

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Abstract

Silicon microcantilevers can be used to measure the rheological properties of complex fluids. In this presentation two different ways will be presented. In the first method, the microcantilever is used to measure the hydrodynamic force exerted on the sphere by a confined fluid. In the second method the measurement of the microcantilever spectrum is used to extract the hydrodynamic force exerted by the surrounding fluid on the microcantilever. In both methods, using analytical equations, the complex shear modulus of the fluid is extracted.

Introduction The classical way to measure the rheological properties of fluids is to use Rheometer (cone/plate or Couette). But there are some drawbacks of such systems: the amount of fluid necessary to make the measurement is quite large (a few milliliters) and the measurement is limited to low frequency (less than 200Hz). To overcome the frequency range limitation some alternative methods have been developed and are named ‘microrheology’. It consists of the measurement of the movement of monodisperse beads (microspheres) immersed in the fluid [1]. The beads motion can be active (optical or magnetic tweezers) or passive (thermal noise) and the acquisition of the motion is performed optically. The major drawback of such devices is the long image and signal processing to extract the fluid rheological properties. The analysis of the experimental data may also be tricky. This situation is encountered when the size of the particles becomes smaller than the mesoscopic scale of the sample (mesh size of a gel for example). In this case, the beads do not feel the gel structure and diffuse as they were immersed in the solvent. In the present paper, we present two alternatives methods based on the use of silicon microcantilevers. Both methods are based on the measurement of the free-end cantilever deflection and on the use of analytical equations which allow obtaining the fluid rheological properties.

Method 1 For this method a glass sphere is glued at the free-end of a silicon microcantilever. Then, the sphere is put near a substrate surface (like tip cantilever in AFM configuration) covered by the fluid to be tested. The plane surface is then approached to the sphere and the compression of the fluid exerts a hydrodynamic force on the sphere which can be estimated by the measurement of the microcantilever deflection (Figure 1a). Another way to use this device is to shear the fluid by horizontal displacement of the substrate surface (Figure 1b). In both cases by modeling the interaction fluid/structure it is then possible to extract both the real viscosity and the elastic viscosity. Examples of results are presented in Figure 1c.

Method 2 The idea to use the spectrum of microcantilever immersed in fluid to extract properties of the fluids has been proposed by different authors [2-4]. Usually the method is based on the measurement of both the resonant frequency and the quality factor which depend on both the mass density and the viscosity. Depending on the cases, the fluid mass density and viscosity are

determined either after calibration, or semi-numerical methods or analytical equations. The major drawback of such approach is that using only one microcantilever the viscosity is determined only at one frequency and the elasticity of the fluid is not taken into account and not estimated. In the proposed method, using the spectrum of the deflection both the viscous and inertial parts of the hydrodynamic force are determined and then from these terms both the real and imaginary shear moduli are determined analytically. For this method, silicon microcantilevers allowing electromagnetic actuation and piezoresistive measurement have been design and fabricated (Figure 2). Example of results are presented in figure 1 of the paper of E. Lemaire and *al.* in NMC2011.

Conclusion and Perspective Two methods using silicon have been developed to measure rheological properties of complex fluids as function of frequency. The proof of concept is done and some improvement in the accuracy of the measurement will be achieved by better estimation of each needed parameter and by robust design to these parameter variations.

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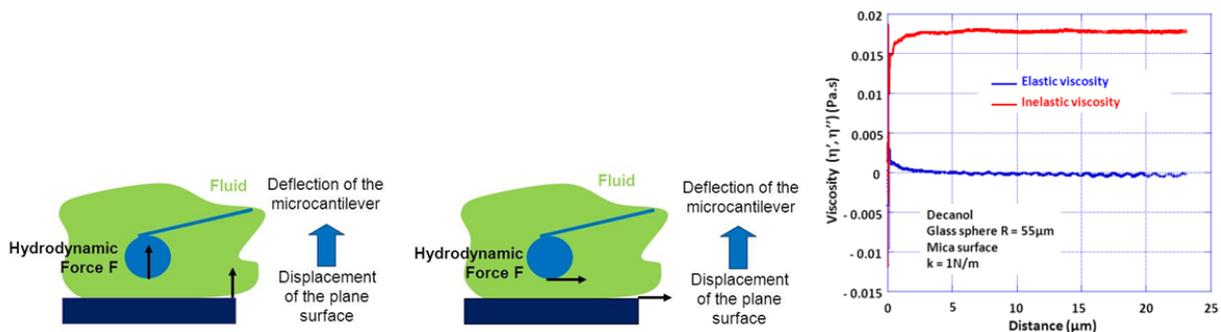


Figure 1: Two principles of the measurement of force exerted by a confined fluid on a sphere, example of measurement of the complex viscosity using a sphere glued on a microcantilever

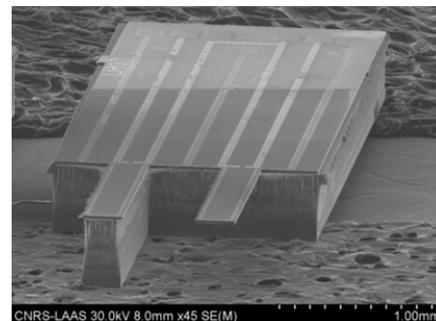
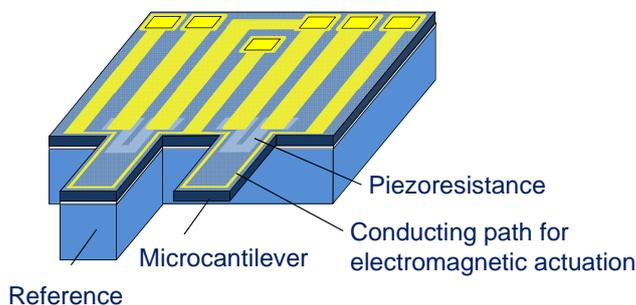


Figure 2: Silicon cantilevers with integrated actuation and measurement designed for measurement of the complex shear modulus as function of frequency