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# HIGHER-ORDER ELASTICITY PARAMETERS IDENTIFICATION FOR OPTIMAL CANTILEVER SENSORS DESIGN

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Because of their high surface over volume ratio, the mechanical behavior of micrometer sized structures differs from that of usual macroscopic objects. Their surface plays a key role, and this property has been proposed to devise micromechanical sensors of environmental changes [1]. In particular, a significant effort has been put on the development of biological sensors [2], thus highlighting the need for a more basic understanding of coupled surface phenomena [3].

Focusing herein on cantilevers operated in static mode, the available experimental material has been mostly obtained using the optical lever technique [4] which provides the (quasi-static) deflection at the cantilever tip. Such an arrangement allowed many groups to demonstrate such a chemo-mechanical coupling for a large variety of molecular interactions (see [5] for biological applications for instance). The quantitative (and sometimes qualitative) interpretation of the retrieved experimental data is however challenging. The rationalization of these chemically-induced mechanical effects is particularly difficult because these results are usually interpreted through Stoney's equation [6], which was developed to describe the mechanical state of thin metallic films deposited onto free substrates. This formulation makes use of many assumptions, the validity of which is questionable when dealing with chemically-induced effects. In addition to this conceptual difficulty, one should add that some systems (such as DNA-DNA hybridization) yield somehow controversial experimental results [4] : for similar chemical conditions and mechanisms, the bending may be seen to occur towards or away the functionalized surface.

This contribution makes use of an Euler-Bernoulli beam theory for isotropic elastic materials based on a second strain gradient description [7]. As such a description has been proven to allow for the definition of surface tension for solids through a so-called cohesion modulus, the equations satisfied by a beam featuring a through-thickness cohesion modulus gradient are established in order to describe the behavior of micro-cantilever sensors [8]. Closed-form solutions have been obtained for chemical loadings. It is then shown that the involved material parameters seem virtually identifiable from full-field measurements and that the shape of the displacement field resulting from a chemical loading depends on the cantilever's thickness as well as on the material parameters. This makes such a theory potentially able to explain some of the experimental results found in the literature. This closed-form solution for the displacement field induced by the chemical modification of one cantilever side calls for several comments :

- It should first be highlighted that this solution may significantly depart from the field resulting from Stoney's assumptions (homogeneous curvature). Besides the rigid-body motion, it may be decomposed into the sum of two hyperbolic cosines with length scales depending on the higher-order elasticity constants.
- These higher-order elasticity constants necessary reflect the length scales characterizing the material under scrutiny, and are thus expected to strongly depend on grain size or degree of crystallinity, or more generally, on the processing conditions. The proposed framework therefore seems particularly suited to include the observed dependence on surface morphology [9].
- The role of the cantilever's thickness is much more complicated than it could be envisioned from simple beam theories. Besides the scaling effect, the thickness drives the shape of the displacement field, possibly switching the field from hyperbolic to oscillatory. One could easily imagine that such a situation experimentally observed using the (single-point) optical lever technique could lead to some data misinterpretation or ambiguity.
- Besides the thickness, the solution highlights the role of the cantilever's length which could act as a filtering parameter in order to control the amplitude of the component added to the displacement field.

As a consequence, this higher-order elasticity framework provides guidelines for the development of optimal cantilever sensor materials. It is therefore crucial to be able to experimentally access the characteristic lengths describing the cantilever's material. A platform gathering silicon nitride cantilevers featuring different thicknesses has been designed and fabricated (see Fig. 1). It is shown that using a multiple-wavelength microscope [10] and a dedicated identification procedure allows to access these higher-order elasticity parameters, thus paving the way for an optimal cantilever sensor design.

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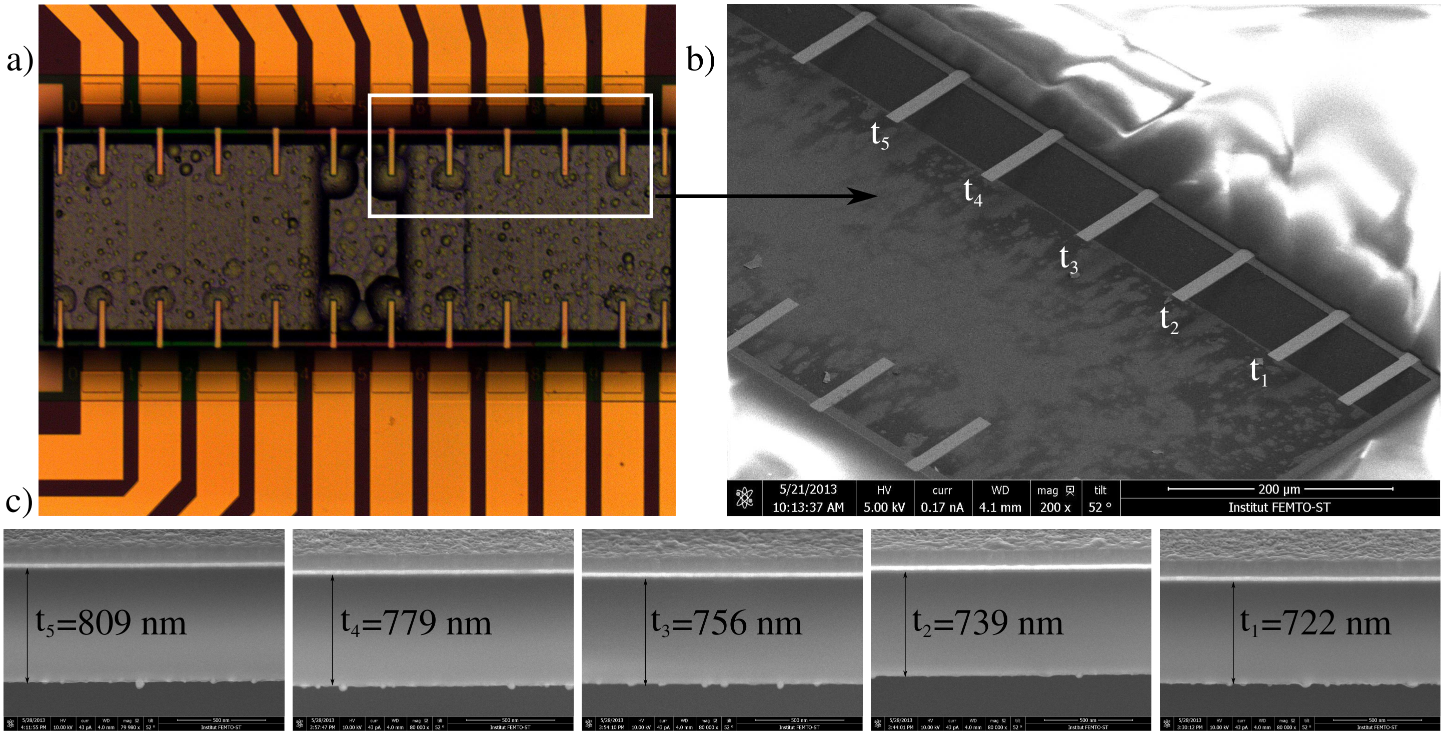

*Figure 1: a) Optical view of one group of 24 cantilevers featuring 5 different thicknesses. b) SEM picture of such a group. c) Cross-section views and thickness measurements obtained by FIB-cutting cantilevers.*