Characterizing time-dependent mechanics in metallic MEMS

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1 Summary

Experiments for characterization of time-dependent material properties in free-standing metallic microelectromechanical system (MEMS) pose challenges: e.g. fabrication and handling (sub)-\(\mu\)m sized specimens, control and measurement of sub-\(\mu\)N loads and sub-\(\mu\)m displacements over long periods and various temperatures [1]. A variety of experimental setups have been reported each having their pros and cons. One example is a micro-tensile tester with an ingenious electro-static specimen gripping system [2] aiding simple specimen design giving good results at \(\mu\)N and sub-\(\mu\)m levels, but without in-situ full-field observations. Other progressive examples assimilate the specimen, MEMS actuators and load cells on a single chip [3,4] yielding significant results at nN and nm levels with in-situ TEM/SEM observability, though not without complications: complex load actuator/sensor calibration per chip, measures to reduce fabrication failure and unfearable co-fabrication on wafers with commercial metallic MEMS. This work aims to overcome these drawbacks by developing experimental methods with high sensitivity, precision and in-situ full-field observation capabilities. Moreover, these should be applicable to simple free-standing metallic MEMS that can be co-fabricated with commercial devices. These methods will then serve in systematic studies into size-effects in time-dependent material properties.

First a numeric-experimental method is developed. It characterizes bending deformation of on-wafer \(\mu\)m-sized aluminum cantilevers. A specially designed micro-clamp is used to mechanically apply a constant precise deflection of the beam (\(z_{\text{res}} < 50\) nm) for a prolonged period, see fig. 1. After this period, the deflection by the micro-clamp is removed. Full-field height maps with the ensuing deformation are measured over time with confocal optical profilometry (COP). This yields the tip deflection as function of time with \(\sim 3\) nm precision, see fig.2. To extract material parameters describing the time-dependent behavior, the experiments are simulated with FEM using a standard-solid material model and the exact test-structure geometry.

Although this method is simple, yet precise, it lacks direct determination of stress and strain. Therefore a second method is designed: measuring time-dependent tensile behavior of these cantilevers with a custom nano-tensile stage. The wafer with specimen is fixed to and manipulated with nano-precision by piezos stacked on micro-manipulators. The piezos also serve as load actuators. The stage has a custom multirange load cell providing a load range of 0-100 mN at a minimum resolution of 10 nN. An electro-static force is generated between the top flat of the specimen’s free end and a mating flat on the load cell. Full-field displacement measurements through

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SEM/AFM/COP are enabled by a compact design. A final addition is a heating element allowing testing up to 150°.

In short, the work will first discuss the performance of the numeric-experimental method for time-dependent bending deformation characterization. Secondly, it will present the performance of the time-dependent tensile testing method along with preliminary measurements of time-dependent material behaviour.

References


Fig. 1. Schematic of the MEMS cantilever deflection experiment with a micro-clamp under a confocal optical profilometer.

Fig. 2. (l) Top view of cantilever height profile from which cross section with deflection profile is extracted. (r) By logging profiles in time, the tip-deflection vs. time relation is measured.