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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)-µm sized specimens, control and measurement of sub-µN loads and sub-µm 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 µN and sub-µm 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 unfeasible 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 µm-sized aluminum cantilevers. A specially designed micro-clamp is used to mechanically apply a constant precise deflection of the beam (z_{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 ~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

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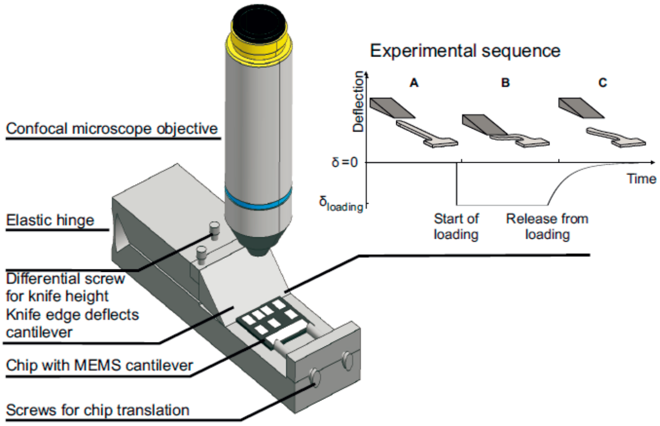

Fig. 1. Schematic of the MEMS cantilever deflection experiment with a micro-clamp under a confocal optical profilometer.

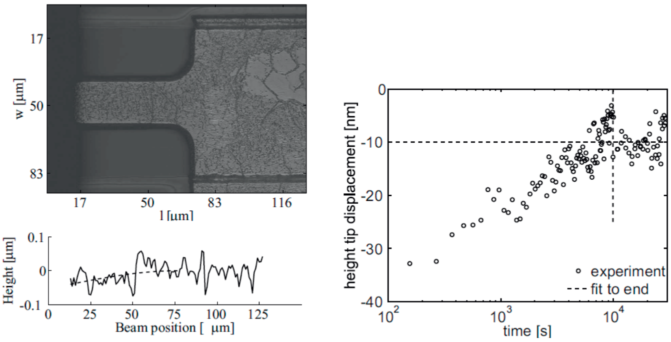

Fig. 2. (l) Top view of cantilever height profile from which cross section with deflection profile is extracted. (r) By logging profiles in time, the tip-deflection vs. time relation is measured.