

# Size-effects in time-dependent mechanics in metallic MEMS

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## USNCTAM2010-759

### SIZE-EFFECTS IN TIME-DEPENDENT MECHANICS IN METALLIC MEMS

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#### ABSTRACT

Size-effects in time-dependent mechanics in metallic microelectromechanical systems (MEMS) are investigated here. A numeric-experimental methodology is employed to determine time-dependent material parameters from deflection-recovery measurements in  $\mu\text{m}$ -sized aluminum alloy cantilever beams. Parameters are determined to within 20% accuracy. These parameters are determined for several beams with varying grain sizes and distributions and correlated to the grain characteristics.

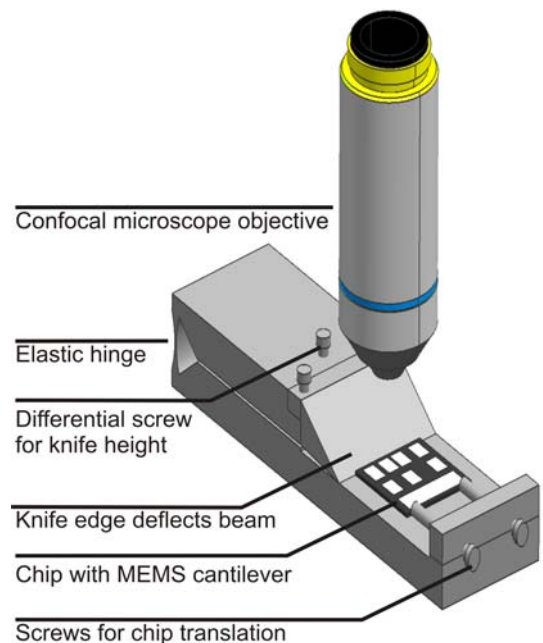
#### INTRODUCTION

Reliability of MEMS depends a.o. on time-dependent deformation such as creep and fatigue [1]. It is known from literature that this behavior is affected by size-effects: the interaction between microstructural length scales and dimensional length scales [2;3]. Not much research has focused on characterizing size-effects in time-dependent material behavior, specifically for free-standing thin films [3]. This study investigates size-effects caused by grain statistics in time-dependent deformation in  $\mu\text{m}$ -sized free-standing aluminum cantilever beams.

#### SUMMARY OF RESEARCH

A numeric-experimental method is used to determine material parameters. The experiment entails applying a constant deflection to the micro-beams for a prolonged period. The

deflection is achieved with 50 nm resolution via a micro-clamp. The beams are then released. Immediately the deformation evolution is recorded by acquiring surface height profiles with a confocal optical profiler. Figure 1 shows the setup.



**Figure 1: Schematic of the MEMS cantilever deflection experiment with a micro-clamp under a confocal optical profilometer, which captures the deflection as function of time.**

Image correlation of the full-field beam profiles is applied to correct for specimen drift and tilt. The experiment yields the tip deflection as function of time with  $\sim 3$  nm precision. In the numerical part, this data is combined with a finite element model based on a standard-solid material model. In this way material parameters describing time-dependent behavior are extracted. The time constant for the deflection evolution is determined within 20%, as verified by *predicting* a different experiment. Figure 2 shows the material model and finite element implementation, whilst Figure 3 shows the numeric prediction of an experiment. To investigate the size-effects of grain statistics, orientation imaging microscopy (OIM) is employed directly on the free-standing cantilevers, as shown in Figure 4.

## CONCLUSIONS

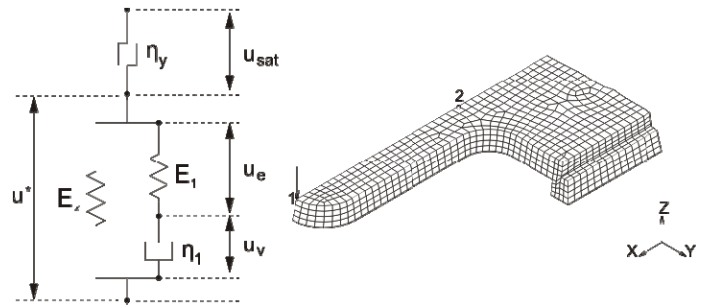
This work correlates the obtained time-dependent material parameters to the actual grain sizes, grain boundary length and texture orientation per specimen. Insights into the interplay between micro-mechanism and grain characteristic and the effect on the time-dependent material behavior are presented.

## ACKNOWLEDGMENTS

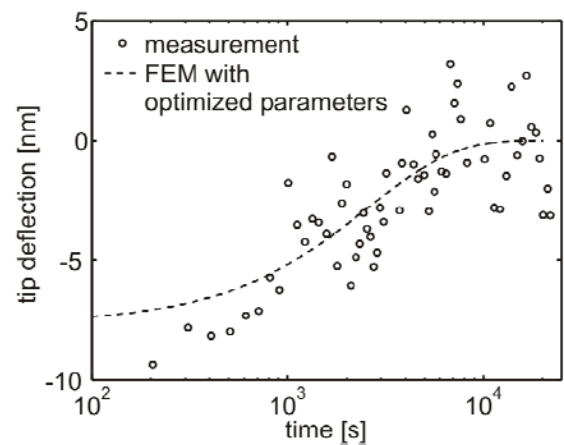
Dr.Ir. Marcel van Gils and Ir. Jeroen Bielen at EPCOS B.V. are greatly acknowledged for their cooperation and fruitful discussions in this work. This research is carried out under proj. nr. M62.2.08SDMP12 in the framework of the Research Program of the Materials Innovation Institute M2I and the Foundation for Fundamental Research on Matter (FOM) which is financially supported by the Netherlands Organization for Scientific Research (NWO).

## REFERENCES

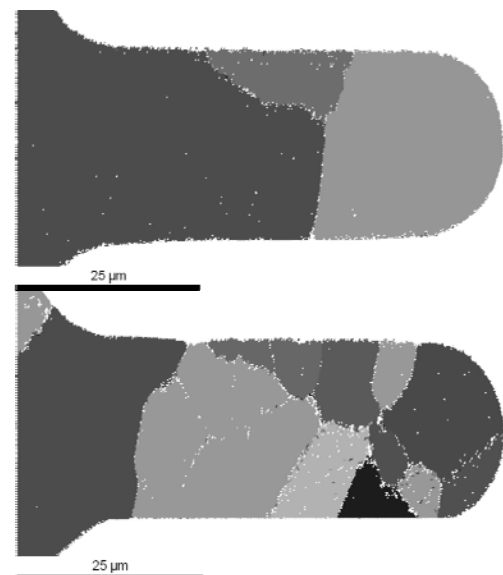
1. W. M. Van Spengen, "MEMS reliability from a failure mechanisms perspective," *Microelectron. Reliab.*, vol. 43, no. 7, pp. 1049-1060, 2003.
2. G. Dehm, C. Motz, C. Scheu, H. Clemens, P. H. Mayrhofer, and C. Mitterer, "Mechanical size-effects in miniaturized and bulk materials," *Adv. Eng. Mater.*, vol. 8, no. 11, pp. 1033-1045, 2006.
3. T. Connolly, P. E. Mchugh, and M. Bruzzi, "A review of deformation and fatigue of metals at small size scales," *Fatigue Fract. Eng Mater. Struct.*, vol. 28, no. 12, pp. 1119-1152, 2005.



**Figure 2:** A finite element model of the exact beam geometry based on a standard-solid material model is used to extract parameters describing time-dependent behavior from the experimental data.



**Figure 3:** Resulting prediction by FEM of a different experiment based on material parameters using the numerical-experimental procedure.



**Figure 4:** Grains in cantilever beams visualized by OIM for a specimen containing (a) few grains and (b) many grains.