Size-effects in time-dependent mechanics in metallic MEMS

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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 µm-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 µm-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.

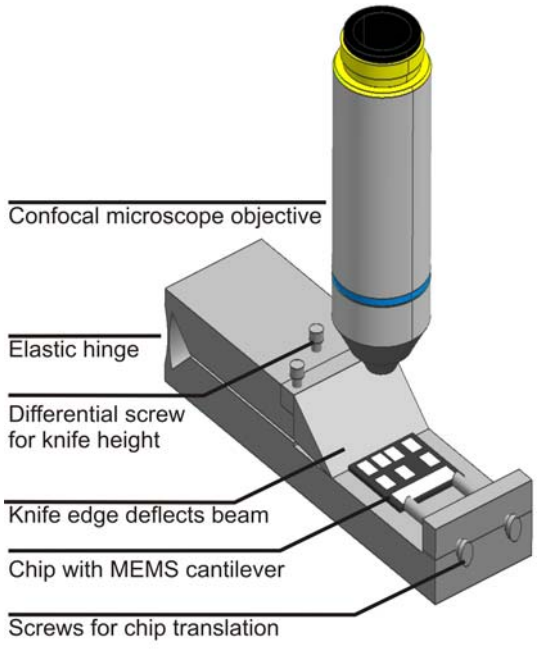

Figure 1: Schematic of the MEMS cantilever deflection experiment with a micro-clamp under a confocal optical profilometer, which captures the deflection as function of time.

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 ~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.

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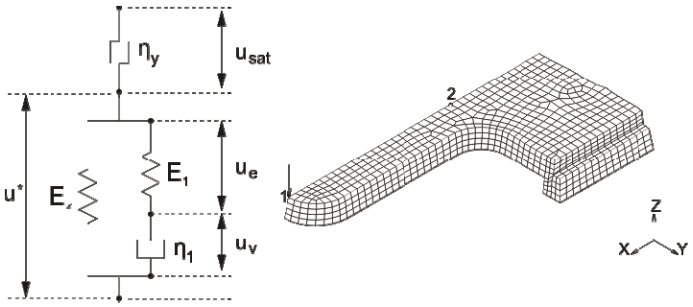

Figure 2: A finite element model of the exact beam geometry based on a standard-solid material model is used to extract parameters describing time-dependent behavior from the experimental data.

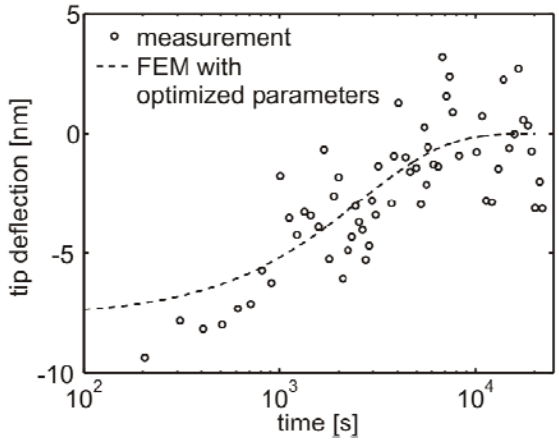

Figure 3: Resulting prediction by FEM of a different experiment based on material parameters using the numerical-experimental procedure.

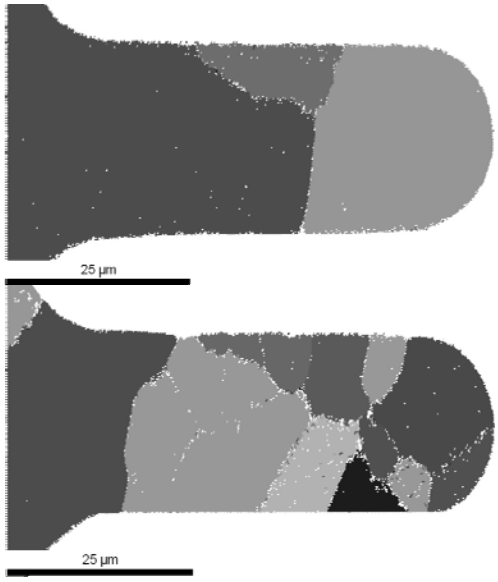

Figure 4: Grains in cantilever beams visualized by OIM for a specimen containing (t) few grains and (b) many grains.