CHARACTERIZATION OF MEMS MATERIALS

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Summary Mechanical characterization of MEMS materials is increasingly important in view of improving reliability and assessing the life time of new devices. In this paper a number of testing methods are described. These methods include tensile, torsion and fatigue testing of specially designed microstructures, as well as wave propagation methods based on an optical pump probe setup to test thin films. Difficulties arise from manufacturing and handling of small structures and the determination of its geometrical dimensions, which directly affect the accuracy of material parameters extracted from the experiments. In addition the measurement of the mechanical parameters like small forces and torques or strains on small specimens or with ps time resolution pose challenges. This paper focuses on size effects in copper foils of thickness between 10 and 250 microns as determined from tensile testing and probing of inhomogeneities caused e.g. by diffusion at interfaces in thin films.

INTRODUCTION

With increasing use of miniaturized systems a strong need arises for the mechanical characterization of the materials used. In particular for polycrystalline materials it is often not possible to use properties obtained from macroscopic experiments, as the microscopic elements have particular microstructures, which are related to the special manufacturing processes used. Therefore, specimens need to be tested in their “small” configurations in view of measuring the relevant design parameters.
In this paper an overview of a set of measurement techniques is given, which complement the well known nanoindentation technique: Mechanical wave propagation techniques based on laser generated ultrasound for determining elastic properties, and tensile, torsion and fatigue tests with high crack resolution on specially manufactured microscopic specimens. These techniques are applied to probe material property gradients in thin film structures and to investigate size effects in thin rolled copper foils, respectively.

THIN FILM TESTING USING AN OPTICAL PUMP PROBE SETUP

When wave propagation techniques are to be used to determine elastic properties, very high frequencies need to be generated because of the small size of the specimens: The wavelength needs to be small compared to the relevant geometrical parameters. Such high frequency waves can be generated and measured in a contactless manner using a pump probe set-up with an ultra short pulse laser. [1] (Fig. 1) In a project called “Nanosonics” this set-up is used to characterize thin films, their adhesion to the substrate and material property gradients. [2]
A short pulse laser is used to excite mechanical pulses thermoelastically by means of a pump pulse. Echoes of these mechanical pulses reaching the surface are causing a slight change in the optical reflectivity, which is superimposed on the reflectivity change caused by the temperature change. The surface reflectivity is scanned vs. time with a probe pulse by varying the relative time shift between the incidence of pump pulse and probe pulse with a variable delay line. Thus the time of flight of the acoustic pulse is measured. In Fig. 1 a typical record of reflectivity vs. time is shown.

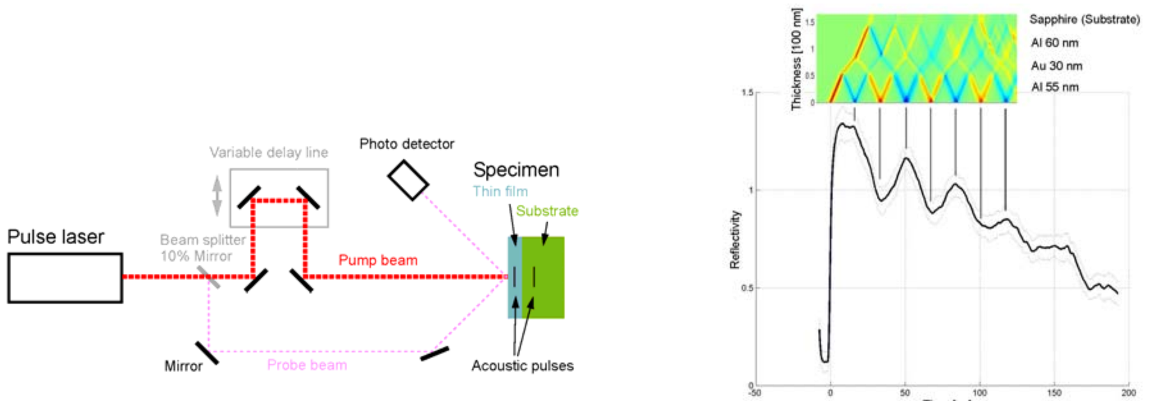
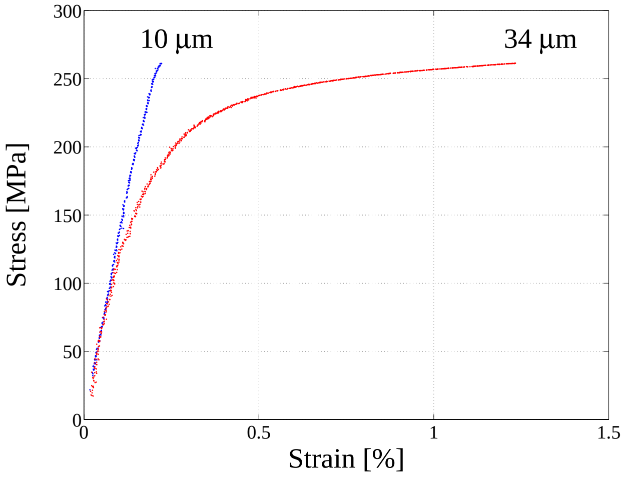


Figure 1. Nanosonics: Pump probe set-up for testing of thin films (left) and typical result of a reflectivity curve vs. time (right) showing an exponentially decaying part due to a temperature change and superimposed echoes of mechanical waves. A Lagrange diagram at the top shows the theoretical arrival times. The system investigated consists of 55nm Al, 30 nm Au, 60 nm Al on a sapphire substrate.

TENSILE TESTING

While elastic properties do not seem to vary with the size of the specimen [3,4], for other quantities large discrepancies might arise. When testing Ni specimens made with the LIGA technology it was found, that the ultimate strength was considerably higher than for macroscopic specimens [5]. An overview of possible size effects is given in [6]. Fleck et al. have explained size effects in copper wires in torsion using a strain gradient plasticity theory [7]. Thin rolled copper foils were tested in tension in order to minimize effects of strain gradients. Nevertheless, a large change was observed in its plastic deformation when decreasing its size. [8] The specimens in [8] consisted of two plates and a small connecting testing region, were made of 99.9% pure copper foils (Goodfellow) and had ratios of thickness to width to gauge length of 1 to 20 to 200, which was kept constant when downscaling. The thickness range considered was 10µm to 250µm. The specimens were manufactured by photolithography and etching and had the longitudinal axis in the rolling direction. They were tested using the setup described in [9]. While foils with a thickness of 34 µm and more show large plastic deformation, foils of 10 µm thickness behave macroscopically rather brittle. (Fig. 2, left) This behavior is also reflected in the SEM pictures of the fracture surface. (Fig. 2, right) The 10 µm foils show quite a flat fracture surface, while the 34 µm foils show voids and dimples. In terms of fracture strain, when going from 100 µm to 10 µm thickness, the fracture strain is reduced dramatically from 15% to 0.2%. The reason for this discrepancy is unclear at the moment. Considerable efforts are currently made to characterize the specimens used in terms of surface roughness (about 0.2 µm), grain shapes, orientations, size, dislocation densities, etc. Because of the small size this turns out to be quite difficult though. The latest characterization results will be reported.



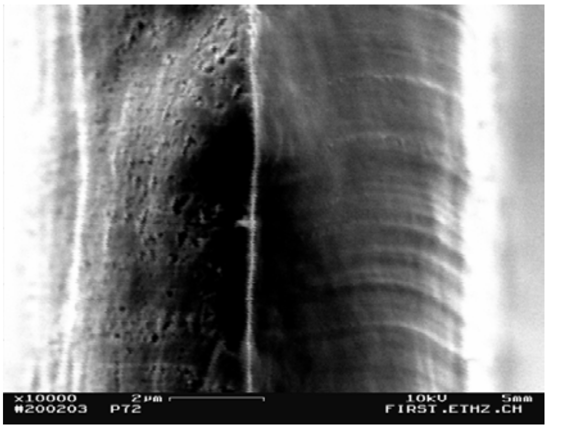


Figure 2. Engineering stress - strain curves for geometrically similar specimens of copper with foil thickness of 10µm and 34µm and SEM picture of fracture surface for the 10 µm thick specimen (right) of copper in tensile testing.

SUMMARY AND OUTLOOK

In addition to the well-known nanoindentation technique a number of other methods for material testing of micromaterials exist, which have received increasing attention. They offer insight into many interesting phenomena like size effects (bending, microtensile and torsion tests) or probing of continuous interfaces (pump probe pulsed laser set-up). Together with elaborate manufacturing possibilities as known from MEMS and IC fabrication, they offer possibilities of probing material behaviour in the nm range. With this it is hoped that an improved understanding of processes important for the life time and reliability of MEMS components will be possible in the near future.

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