Tensile testing at the nano-scale

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Abstract

Mechanical testing for material behavior characterization has brought much understanding into the mechanics of materials at the macroscale. Nowadays, however, miniature devices with dimensions at the sub-micrometer scale, such as MEMS, are processed routinely, which has revealed unexpectedly new mechanical micro-mechanisms. This has spurred research into new mechanical characterization techniques to understand the physical fundamentals at the (sub)-micron scale, e.g. nano-indentation [1], FIB-enabled in-situ micro-tensile testing [2], fully integrated and dedicated tensile test MEMS [3]. One important outcome of this research is that testing at the nano-scale is far from trivial [4,5]! To address this issue, a novel nano-tensile methodology is presented here for which all fundamental aspect of tensile testing have been reconsidered in its design.

A suitable testing methodology faces a number of challenges. First of all, such a methodology needs to be sensitive enough to measure the nano-Newton forces and nanometer deformations involved at this scale. Well-defined loading conditions are preferred to facilitate interpretation of the deformation state, thus favoring the uni-axial tensile test. Boundary conditions should also be carefully controlled to minimize undesired influences, such as surface roughness or friction effects, while challenges of specimen handling, loading and alignment need to be addressed as well. Furthermore, easy specimen variation is required to enable systematic studies of the influences of, e.g., mechanical size-effects. Finally, in-situ SEM testing capability is necessary to unravel the physical origin underlying (the often complex) microscopic deformation mechanics.

In the authors' opinion, the here-presented nano-tensile methodology is the first technique that meets all of these requirements simultaneously, see figure. Its design solutions and calibration routines are discussed, and the strength of the methodology is demonstrated through highly accurate measurements of uni-axial stress-strain curves of on‑chip μm‑sized free‑standing Al-(1wt%)Cu beams (used in RF-MEMS applications).

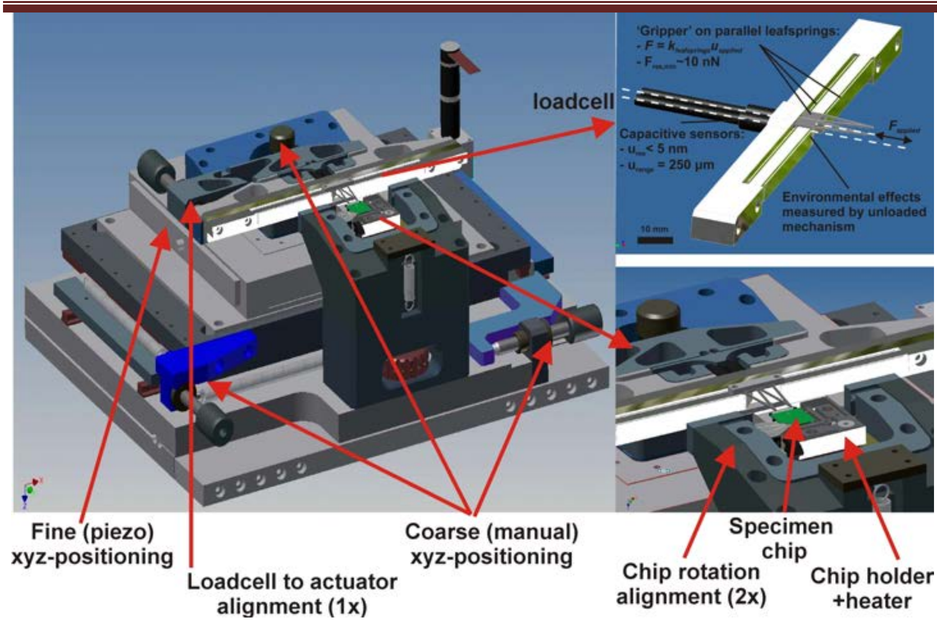
[1] Nix, Mettal.Trans.A, 1989

[2] Kiener et al. Acta Mater., 2008

[3] Haque, Saif, Exp. Mech. 2002

[4] Hemker, Sharpe, Ann. Rev. Mater. Sci., 2003

[5] Kang, Saif, J. Microelectromech. Syst., 2010


loadcell
'Gripper' on parallel leafsprings:
- $F = k_{leafsprings} u_{applied}$
- $F_{res,min}$ ~10 nN
Capacitive sensors:
- u_{res} < 5 nm
- u_{range} = 250 µm
$F_{applied}$
Environmental effects measured by unloaded mechanism
10 mm
Fine (piezo) xyz-positioning
Loadcell to actuator alignment (1x)
Coarse (manual) xyz-positioning
Specimen chip
Chip rotation alignment (2x)
Chip holder +heater