Damage and fracture in thin films and other nano-objects

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Résumé-Abstract

(English abstract, lecture will be in French)

Pushing the internal or external dimensions of metallic alloys down to the nanometer scale gives rise to strong materials, though most often at the expense of a low ductility and a low resistance to cracking, with negative impact on the transfer to engineering applications. These characteristics are observed, with some interesting exceptions, in thin metallic coatings on substrates and in freestanding thin metallic films and nanowires similar to bulk ultra-fine grained and nanocrystalline metals. At the other extreme nominally brittle bulk materials like silicon or some glasses resist much better to fracture at small scales. In other words, ductile materials get more brittle at small scale while brittle materials get more ductile. This intriguing state of affairs is at the core of intense research efforts in the fracture community for more than two decades, motivated by very different fields of application: microelectronics, protective and functional coatings, MEMS, membranes technologies, nanomaterials development, flexible electronics, etc

This lecture aims first at briefly covering the test methods that can be used to address the damage and fracture properties and mechanisms in small-scale systems with at least one dimension in the submicron range. The challenges are numerous in terms of sample production and manipulation, in terms of application and measurement of extremely small loads and displacements, and in terms of in situ observations. Hence, smart solutions had to be proposed to either use macroscopic devices and address the question of testing samples order of magnitude smaller, or to directly design small-scale loading devices better suited to deform freestanding specimens up to fracture and to extend to in situ testing, as shown in Figure 1.

In the second part of the lecture, we will discuss some various thin film systems to reveal commonalities in the origins of the low or high ductility and fracture resistance, in factors governing fatigue resistance, and in ways to improve properties. More precisely, we will address the current state of the art in terms of plastic localization, damage, and cracking in (1) nominally brittle 1D and 2D freestanding micro and nanoscale systems, (2) thin metallic films on substrates due to their importance in microelectronics and flexible electronics and (3) in freestanding nominally ductile metallic films. The key factors that govern the ductility and fracture resistance of thin films involve: geometrical imperfections (which play a key role at nanoscale), state of the surface, statistical distribution of defects, grain boundary structure and chemistry (for polycrystalline films), size dependent (high) strength and often high rate sensitivity. All these factors lead to size dependent fracture resistance.

Mots clés - keywords : thin films, brittle fracture, brittle fracture, plastic localization

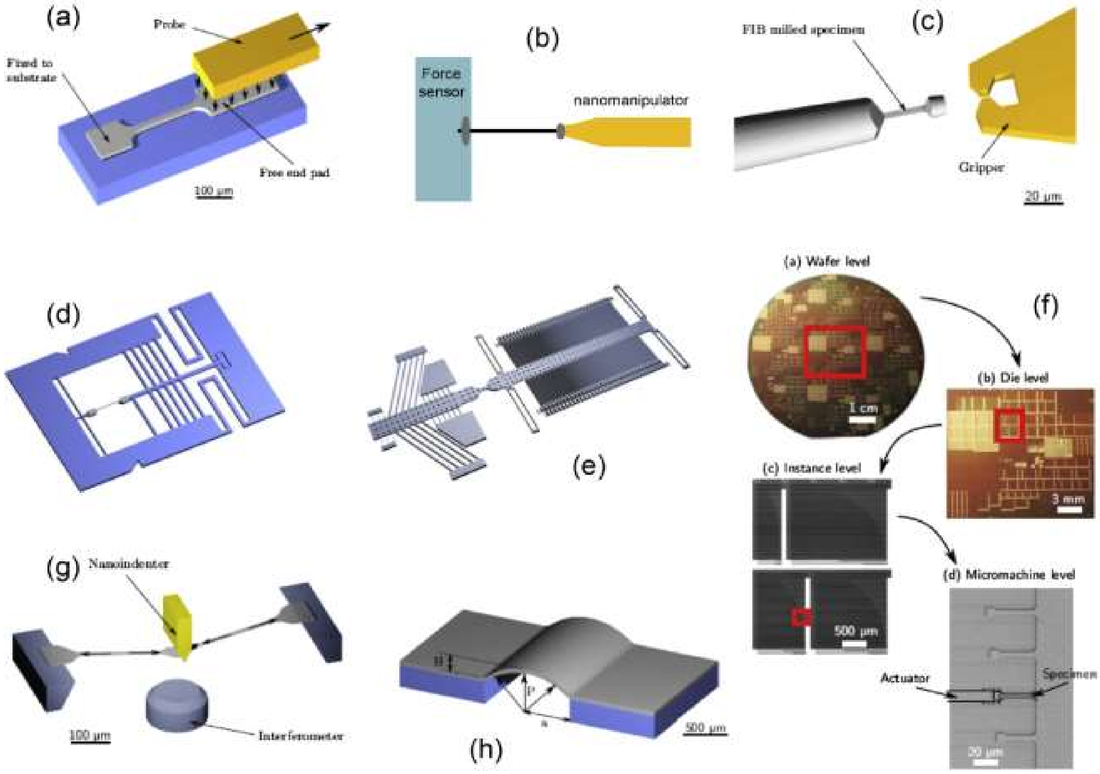

Figure 1. *Various set ups for testing the fracture and fatigue properties of freestanding thin films, nanoribbons and nanowires; (a) tensile stage by Tsuchiya and co-workers; (b) nanomanipulator directly used to apply the deformation; (c) FIB machined microgrips; (d) MEMS based test frame by Haque and Saif; (e) MEMS tensile testing stage by Espinosa and coworkers; (f) on chip nanomechanical testing laboratory with internal stress based actuated elementary structures; (g) tensile loading through deflection; (h) bulge test configuration (see [1] for references)*

References (also to go deeper in the subject)

[1] A. Pineau, A.A. Benzerga, T. Pardoen, Failure of metals – III. Fracture and fatigue of nanostructured metallic alloys, *Acta Materialia* 107 (2016) 508-544