A crack-on-chip fracture mechanics method for freestanding ultra-thin films from brittle to ductile down to 2D materials

Sahar Jaddi[1], Malik M. Wasil[2†], Bin Wang [2, 3], Michael Coulombier[1], Jean-Pierre Raskin[2], Thomas Pardoen[1]

[1]*Institute of Mechanics, Materials and Civil Engineering, UCLouvain, 1348 Louvain-la-Neuve, Belgium*

[2]*Institute of Information and Communication Technologies, Electronics and Applied Mathematics, UCLouvain,1348 Louvain-la-Neuve, Belgium*

[3]*School of Physics and Electronics, Hunan University, China*

Abstract

The characterization, control, and enhancement of the cracking resistance of freestanding thin films and 2D materials are major concerns for flexible electronics, MEMS/NEMS devices, and structural or functional coatings. In particular, environmentally-assisted cracking phenomena affect the reliability of many thin films/2D materials-based systems as a result of among others the adsorption, absorption, and surface reaction mechanisms with oxygen or moisture. This is a complex subject, along with the determination of the fracture toughness that constitutes an important subject that is insufficiently studied mostly because of experimental issues. The objective of the present research is to present a new on-chip technique ables to extract the static fracture toughness and to study the environmentally-assisted crack growth in freestanding thin films, 2D materials, as well as multilayers built from a combination of these films and 2D materials. The present method relies on a residual-stress-based-on-chip concept taking advantage of MEMS-based fabrication principles. The test configuration consists of a notched specimen attached to two long actuator beams involving tensile internal stress. Upon release, the relaxation of the residual stress leads to the deformation of the specimen. A crack initiates at the notch tip, propagates, and finally arrests. A data reduction scheme based on accurate finite element simulation of the test structures is used to determine the static fracture toughness. The method also provides the variation of the crack growth rate (*da/dt*) as a function of the stress intensity factor (*K*) under different temperature conditions and humidity levels. Several materials were tested over the last 4 years with this method varying from nominally brittle materials like SiN, SiO_2, Al_2O_3 to ductile materials such as Cu, Ni and Al/Al_2O_3 multilayers revealing several interesting effects that will be presented. 2D materials like graphene (Gr) and heterostructures of graphene and hexagonal boron nitride (h-BN) were also successfully studied providing probably the first rigorous fracture mechanics statistically representative data on these materials.