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On-chip fracture mechanics to explore fracture toughness of freestanding ultra-thin films from brittle to ductile, down to 2D materials

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

[1]*Institute of Mechanics, Materials and Civil Engineering, UCLouvain, Belgium*
[2]*Institute of Information and Communication Technologies, Electronics and Applied Mathematics, UCLouvain, Belgium*
[3]*School of Physics and Electronics, Hunan University, China*

The characterization, control, and enhancement of the cracking resistance of thin films and 2D materials are major concerns for the development of fail safe 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. Existing approaches mostly address the cracking of films while resting on a substrate, which simplifies the testing but makes the extraction of "intrinsic" properties more difficult often requiring advanced non-linear models. The most attractive approach is thus to work with freestanding films, but the challenges are numerous due to the small sizes.

In this context, we developed a new on-chip technique to extract the static fracture toughness and to study environmentally-assisted crack growth in freestanding thin films, 2D materials, as well as thin multilayers. The method relies on a residual-stress-based-on-chip concept taking advantage of MEMS-based fabrication principles [1]. The working principles rely on internal stress actuation and on a crack arrest measurements to avoid the problem of pre-cracking. A data reduction scheme based on finite element simulations of the test structures is used to determine the fracture toughness. The method also provides the variation of the crack growth rate as a function of the stress intensity factor under different temperature conditions and humidity levels.

Several materials were tested over the last few years varying from nominally brittle like SiN, SiO_2, Al_2O_3 to ductile such as Cu, Ni and Al/Al_2O_3 multilayers, revealing several interesting effects that will be presented, e.g. [1, 2]. 2D materials like graphene (Gr) and hexagonal boron nitride (h-BN) were also successfully studied providing probably the first rigorous fracture mechanics statistically representative data on these materials.

References

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