

Fracture toughness and environmentally assisted subcritical crack growth in thin freestanding Al_2O_3 , SiO_2 and SiN films using residual stress-induced crack-on-a-chip testing technique

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Fracture toughness

Freestanding thin films

*Environmentally assisted
subcritical crack growth*

Abstract The control and enhancement of the fracture resistance of thin film materials represents a major concern in many field of applications, such as in flexible electronics, microelectromechanical / nanoelectromechanical systems (MEMS/NEMS) and functional coatings. The reliability of different devices is not only dependent on the fracture toughness of the layers, but also on the risk of sub-critical environmentally assisted cracking. However, there are only few studies on subcritical crack growth in thin films, even though many brittle films show a tendency to undergo degradation and crack growth due to oxygen or moisture permeation. The main originality of the present work is to perform tests on freestanding films compared to most existing studies where the films are supported by a substrate whose effect on the crack driving force is not always easy to deconvolute. More precisely, the focus is on aluminum oxide (alumina, Al_2O_3), silicon dioxide (silica, SiO_2) and silicon nitride (SiN) films. These films are extensively used in a large number of electronic applications as protective layers, dielectric materials and sacrificial release layers during a device micromachining stage. Al_2O_3 films were deposited by electron beam-evaporation technique, SiO_2 were thermally grown while SiN were synthesized by low-pressure chemical vapor deposition technique (LPCVD). The standard test techniques used for bulk materials are inapplicable for submicron and nanometer scale materials due to difficulties that are raised from load application, detection of cracking initiation, and measurement of extremely small load, etc... Therefore, the fracture toughness and environmentally assisted subcritical crack growth have been investigated using a new on-a-chip fracture mechanics test presented in Fig.1 (add reference to JMPS paper). This technique consists of two long actuators beams pulling on a notched specimen by exploiting the released residual stress inside the actuators after etching beneath the latter. A crack is initiated from the notch tip, propagates and finally stops when the energy release rate has decreased down to its critical value. All the three freestanding films are susceptible to stress corrosion, especially, in the presence of moisture. The mechanisms responsible for this slow cracking behavior are investigated as well as the subcritical crack growth rate in laboratory air and dry environments under various temperature conditions. The combined experimental and finite element studies provide an insight on the variation of the crack growth rate (v) as a function of the stress intensity factor (K) in different environments. This variation can be

described using a Paris-like-law exhibiting a higher cracking rate under high K loading configurations. The fracture toughness value is around $1 \text{ MPa}\sqrt{\text{m}}$ for both Al_2O_3 and SiO_2 films and around $2.6 \text{ MPa}\sqrt{\text{m}}$ for SiN films. These values are compared to the value obtained by push-to-pull technique (PTP) inside transmission electron microscopy (TEM) using specimens that contain a real sharp pre-crack generated during the crack-on-a-chip test.

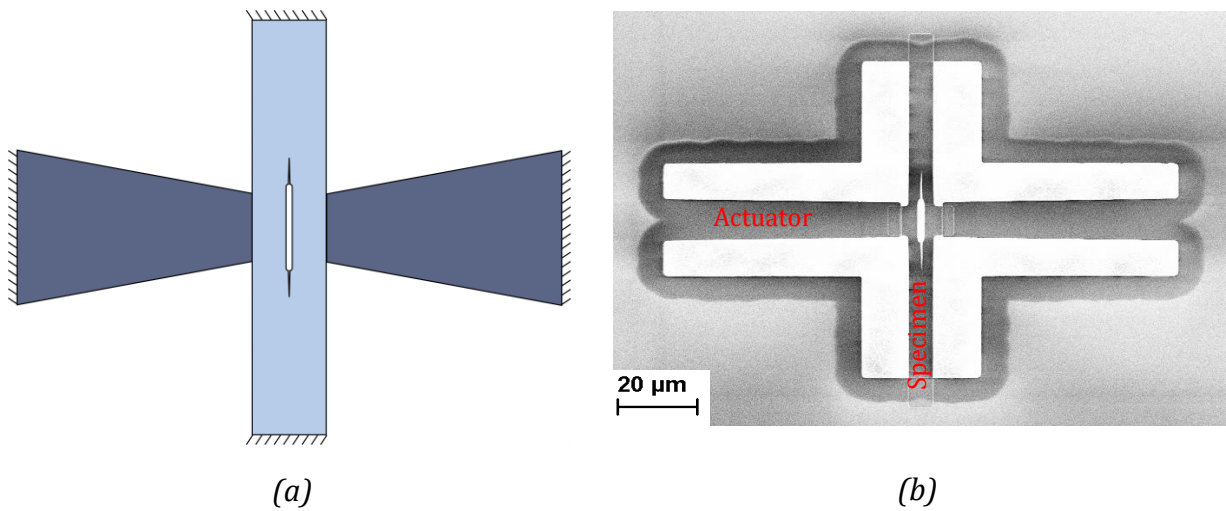


Figure 1 – (a) Schematic drawing of the crack on-a-chip testing technique. The specimen is shown in light blue attached to two beams called actuators (shown in dark blue). **(b)** SEM micrograph of crack-on-a-chip fracture test showing crack propagation and its arrest.

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- 1.4 Vibrations ☐
- 1.5 Impact and earthquake ☐
- 1.6 Combined loading ☐
- 1.7 Thermal loadings ☐
- 1.8 Other ☐

2. Environment

- 2.1 Corrosion ☐
- 2.2 High operating temperatures ☐
- 2.3 Ageing ☒
- 2.4 Other temperature effects ☐
- 2.5 Combined effects ☐
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- 2.7 Other ☐

3. Structures

- 3.1 Large structures ☐
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- 3.3 Welded structures ☐
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- 3.6 Other structures ☐

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