Static fracture toughness and environmentally assisted cracking in thin freestanding SiO_2 and SiN films using a crack-on-chip testing

Sahar Jaddi[1], 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

Abstract The understanding and control of the cracking resistance of thin films is a key requirement for proper functionality and durability of many micro-and-nano-scale devices. The cracking resistance evolves with time as a result of materials aging due to environmental effects. A large number of films are prone to subcritical crack growth as a consequence of, for instance, adsorption, absorption, and surface reaction mechanisms with oxygen or moisture. However, there are few studies on environmentally-assisted cracking of thin films due to the experimental challenges. The objective of this research is to extend and validate a fracture mechanics test method dedicated to subcritical crack growth and adapted to sub-micron freestanding films. The majority of the techniques developed so far were applied to thin films on a substrate, in which is often difficult to deconvolute the substrate effect from the extracted driven force. The present test configuration consists of two long actuator beams pulling on a notched specimen by taking advantage of the released tensile internal stress after etching the underlying sacrificial layer. Hence, a crack initiates at the notch tip, propagates, and finally arrests when the energy release rate has decreased down to its critical value. Here, several improvements of the method are worked out to minimize the presence of a mode III component and to avoid crack kinking out of a straight trajectory. In the present work, the focus is given to silicon dioxide (SiO_2) and silicon nitride (SiN) freestanding thin films with a thickness of 140 nm and 50 nm, respectively. The mean static fracture toughness value is ~0.73 MPa$\sqrt{m}$ and 2.6 MPa$\sqrt{m}$ for SiO_2 and SiN, respectively. The combined experimental and finite element studies provide an insight into 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. This variation is described using a Paris-like-law exhibiting a higher cracking rate under high *K* loading configurations. These *K-da/dt* curves indicate a crack extension rate which is two orders of magnitude higher in the laboratory air compared with dry nitrogen. The effect of temperature on the crack growth rate is more critical than the humidity level. Therefore, an increase in temperature by 1°C leads to around 15 times faster crack growth as compared to 1% increase in the humidity level.

Subcritical crack growth rates are compared with reported values in the literature for both similar films and bulk silica and SiN.