Supporting Information

Material Structure and Mechanical Properties of Silicon Nitride and Silicon Oxynitride Thin Films Deposited by Plasma Enhanced Chemical Vapor Deposition

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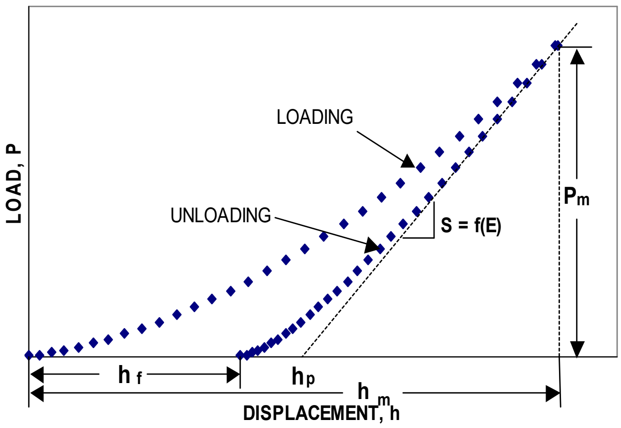


Figure S1. Schematic illustration of the thin film mechanical property measurement by nanoindentation.

Figure S1 is a representative load-displacement curve of a nanoindentation test. In the test, a small diamond indenter with a known geometry is pressed into the material surface. Unloading starts after the pre-designated load or displacement is reached (after some dwell time). The hardness of the material (H) is given by Equation S1:

$$H = \frac{P_m}{A_c} \qquad \text{(S1)}$$

where P_m is the peak load, and A_c is projected contact area. The contact area can be determined from the residual displacement (h_f) and the type of the indenter tip used.

The elastic modulus of the film, E, is related to the elastic modulus of the indenter (E_i) and the reduced modulus obtained from the experiment, following the contact mechanics relationship:

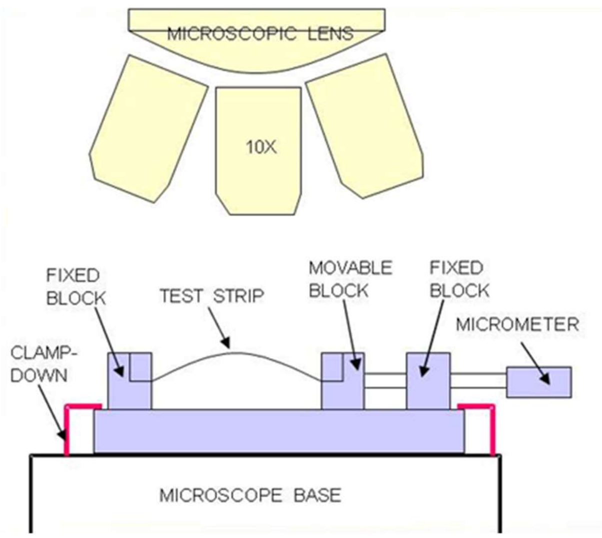
$$\frac{1}{E_r} = \frac{1-\upsilon_i^2}{E_i} + \frac{1-\upsilon^2}{E} \qquad \text{(S2)}$$

where the subscript i denotes the property of the indenter. Typically, E_i=1140 GPa and υ_i= 0.07 are taken for the diamond indenter. υ is the Poisson ratio of the film.

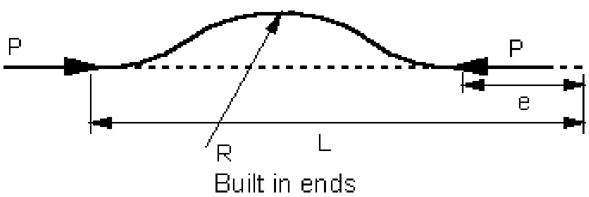
E_r is obtained from the unloading stiffness (S) according to:

$$E_r = \frac{1}{\beta}\frac{\sqrt{\pi}}{2}\frac{1}{\sqrt{A_c}}S \qquad \text{(S3)}$$

where S is directly acquired from the unloading curve, as shown in Figure S1. β is a geometrical constant taken to be 0.75 for a Berkovich indenter.



(a)



(b)

Figure S2. (**a**) Schematic illustration of the controlled buckling test jig to measure the fracture toughness of thin films. (**b**) Buckled beam with ends clamped.

Figure S2a is a schematic illustration of the controlled buckling test. The film, coated on one side of the substrate, is positioned on the tension side (top side in this illustration) of the bending beam. The test jig is placed on the platform of an optical microscope so that the initiation of cracking in the thin film can be directly observed. The film fracture is expected to occur at the point of maximum curvature at the centre of the testpiece. Based on the lateral displacement, *e*, at the point of crack initiation (Figure S2b), the film fracture strain can be calculated using the following steps based on a large deflection of the slender beam [S1]:

$$\frac{e}{L} = 2\left[1 - \frac{E(k)}{K(k)}\right] \qquad \text{(S4)}$$

where L is the length of the beam, $K(k)$ and $E(k)$ are the complete elliptic integrals of the first and second kind, respectively. Once k is solved from Equ. (S4), the radius of curvature, R, can be obtained from:

$$\frac{L}{R} = 8kK(k) \qquad \text{(S5)}$$

When the film is much thinner than the substrate, the critical strain, ε_c, is approximately uniform through the thickness of the slender beam and is given by

$$\varepsilon_c = \frac{(h_s + h_f)}{2R} \qquad \text{(S6)}$$

where h_s and h_s are the thicknesses of the substrate and film, respectively. Once the critical fracture strain ε_c is obtained, the fracture toughness can be calculated following Equation (1) in the main text.

Reference:

S1. S.J. Britvec, The Stability of Elastic Systems, Pergamon Press, New-York NY, 1973.