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Nanoscale Characterization of Cracking and Buckling of Cr Films on PET Substrates

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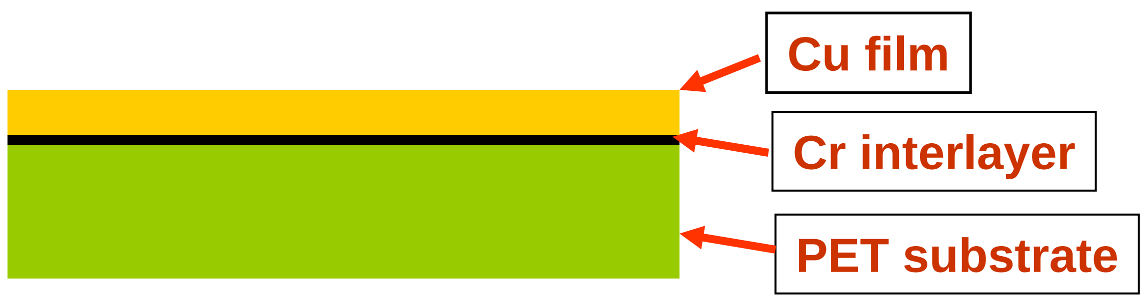
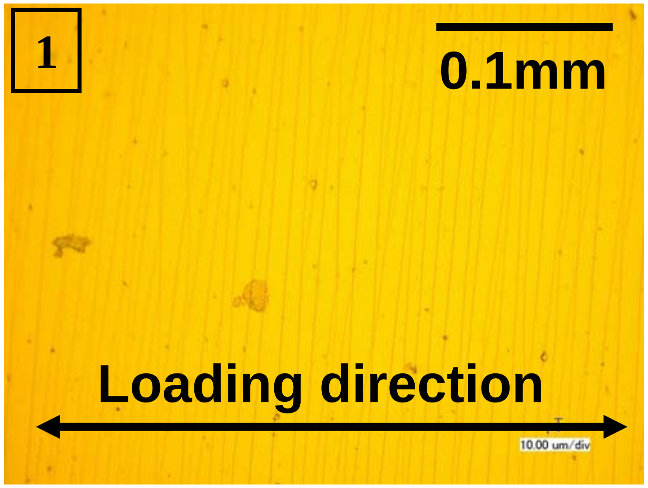
Background: Flexible Electronics

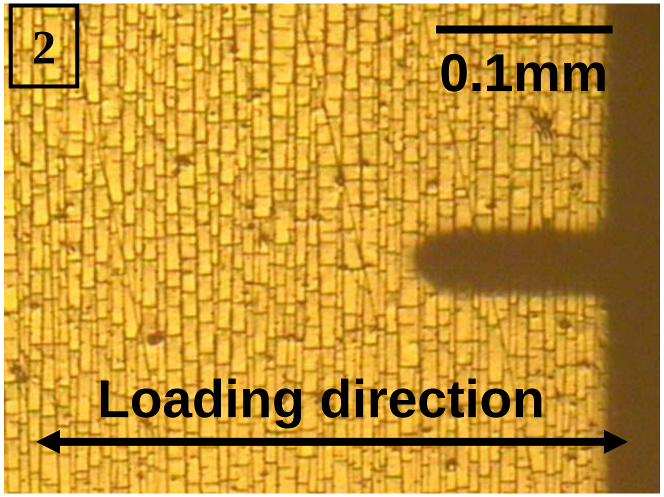
- In the field of flexible electronics, Chromium (Cr) film is used as an adhesion layer between the metal films such as Cu and the polymer substrate such as polyethylene terephthalate (PET);
- Cr interlayer has lower ductility than Cu, which causes fracture at lower strain;
- Cr films were deposited onto cleaned 50 μm thick PET films using e-beam evaporation techniques with a deposition rate of 5 Å/s.



Research Interests: Cracking and Buckling of Cr Films



Cracks formed perpendicular to the loading direction



Buckles grew parallel to the loading direction at higher strain

1. Crack spacing, crack width and depth
2. Buckle spacing, buckle width and height
3. The influence of film thickness on cracking and buckling

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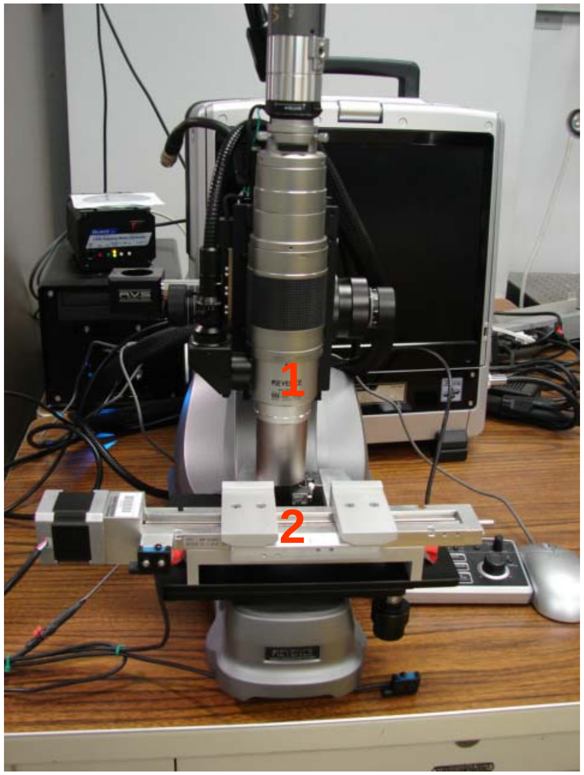
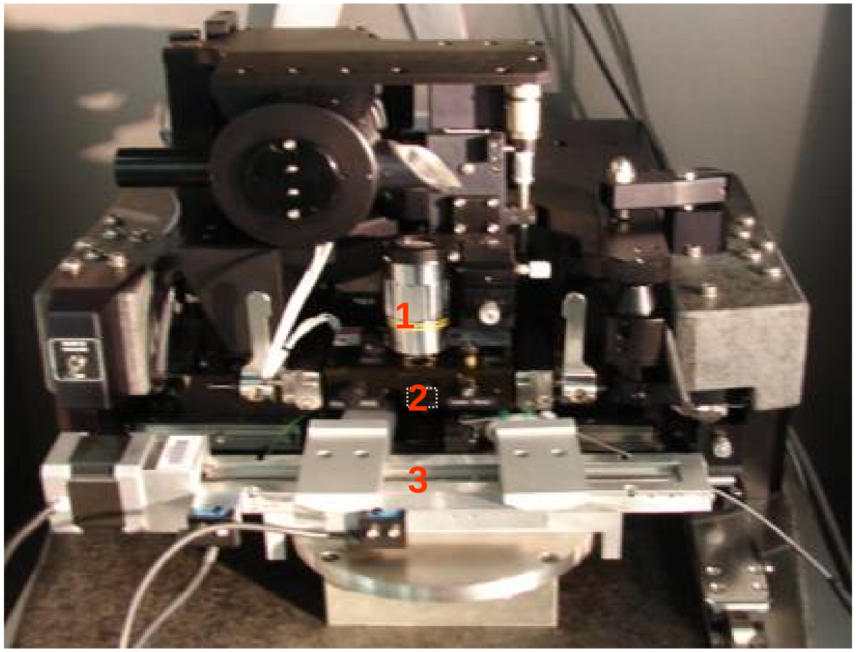
Research Approach



1- Optical Microscope
2-Microtensile tester



1- AFM scan head
2- Specimen
3-Microtensile tester

- Crack and buckle spacing were measured under optical microscope;
- Crack width and depth, buckle width and height were measured with *in-situ* AFM imaging.

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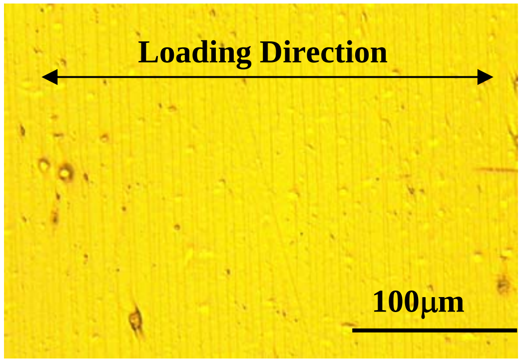
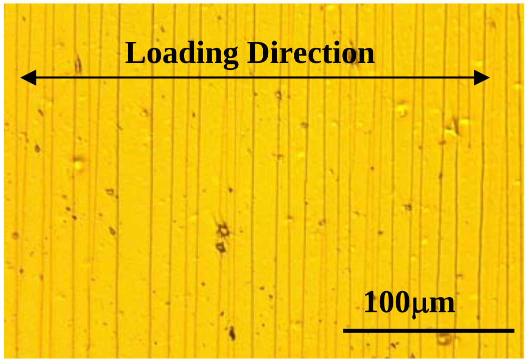
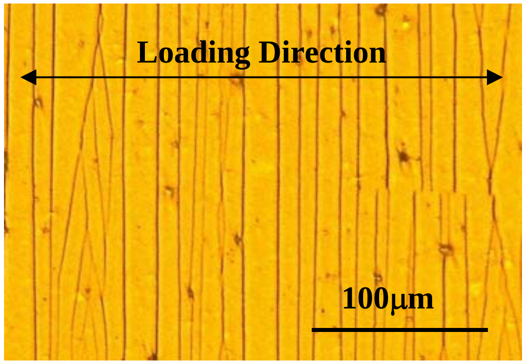
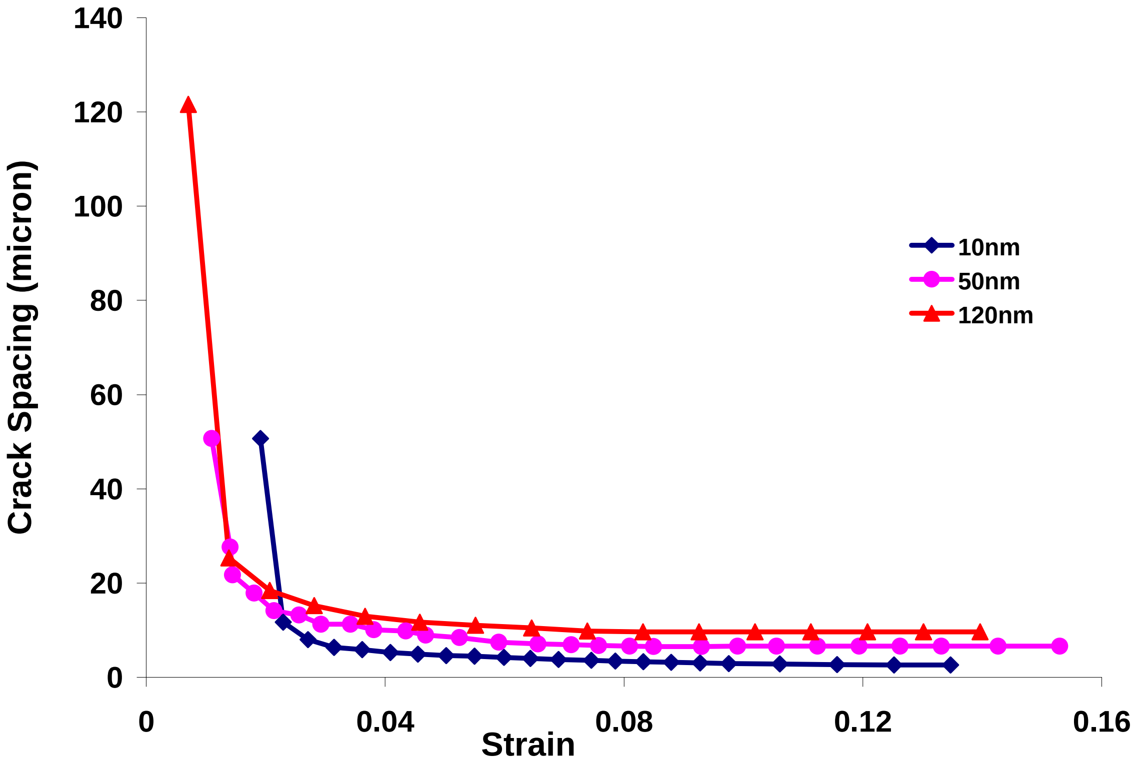
Crack Spacing

Optical images of the cracks at strain of 4.6% for these three different films









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Maximum Shear Stress of the Interface

The maximum shear stress τ_{max} is defined as a function of the fracture stress of the film, σ_{frac},

$$\tau_{max} = \frac{3}{4}\pi\frac{h}{\lambda}\sigma_{frac}$$

h - film thickness

λ- mean spacing between cracks at crack saturation

The fracture stress can be estimated

$$\sigma_{frac} \approx E_f \varepsilon_{frac}$$

E_f - the elastic modulus of the film (280 GPa)

ε_{frac}- fracture strain that is observed *in-situ*

Average Maximum Shear Stress = 52.2 MPa

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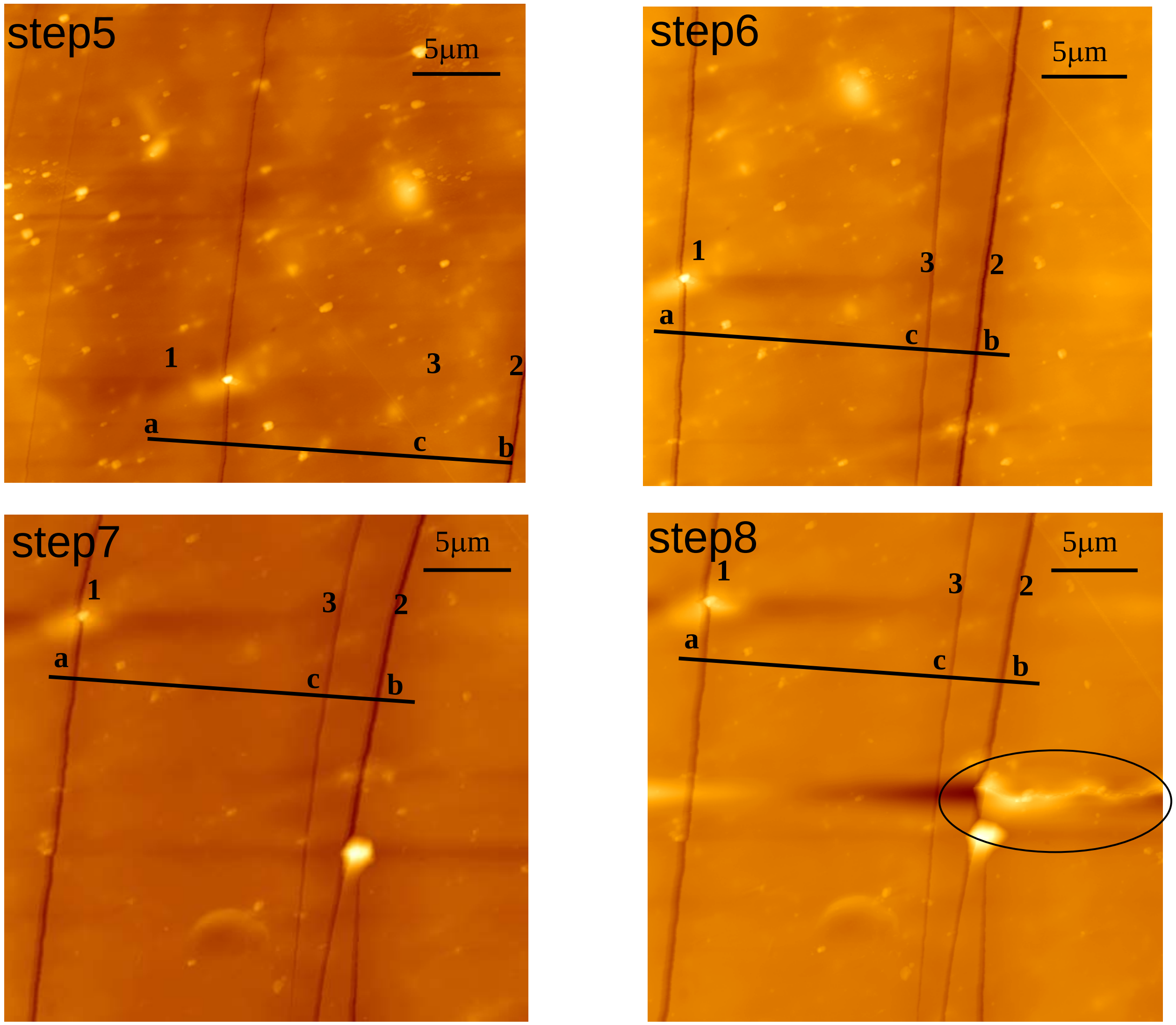
Crack Growth during the Tensile Loading



AFM image of cracks on 120 nm thick Cr film at different strain level, step5: 3.19%; step 6: 5.18%; step 7: 6.21%; step 8: 7.11%

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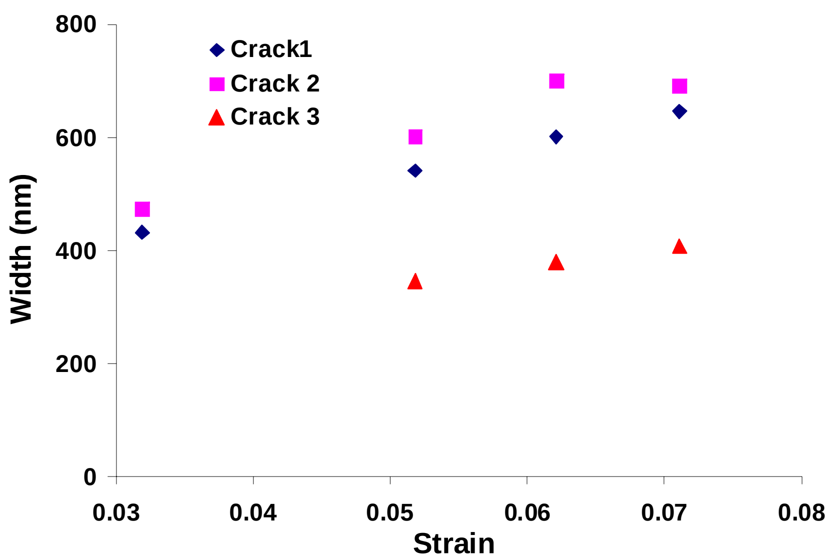
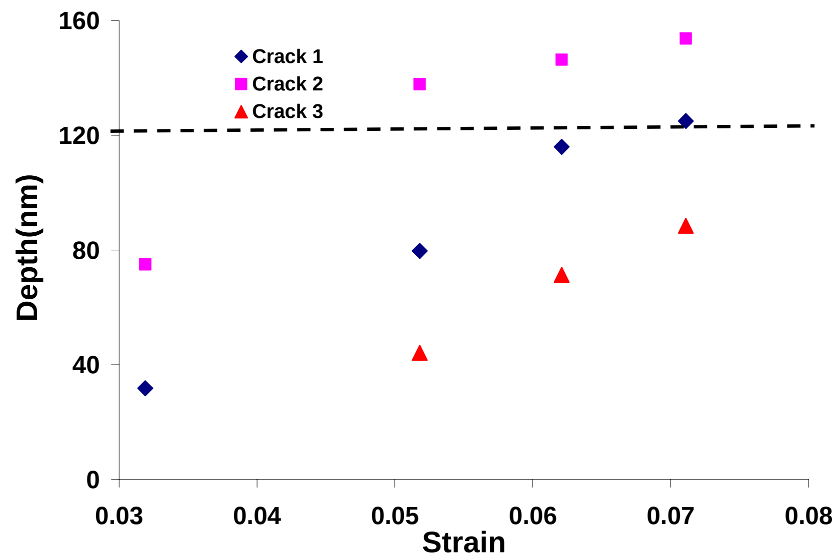
Crack Growth during the Tensile Loading

Measurement of crack width and depth from AFM image



Crack Width



Crack Depth

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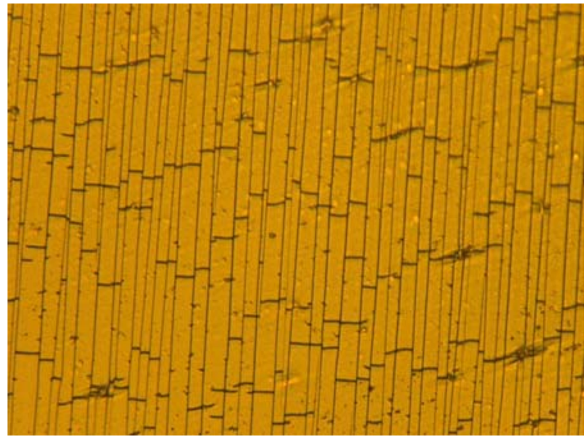
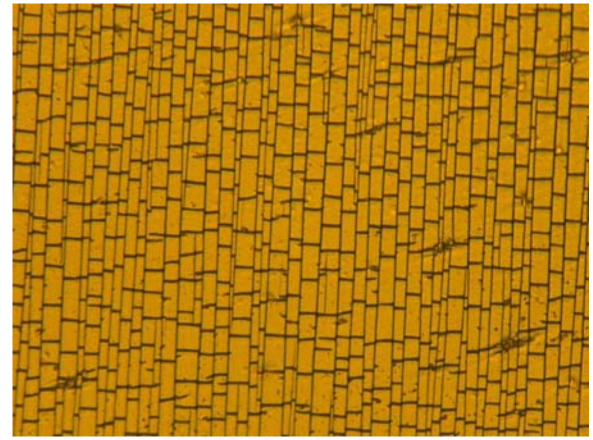
Buckling of Films

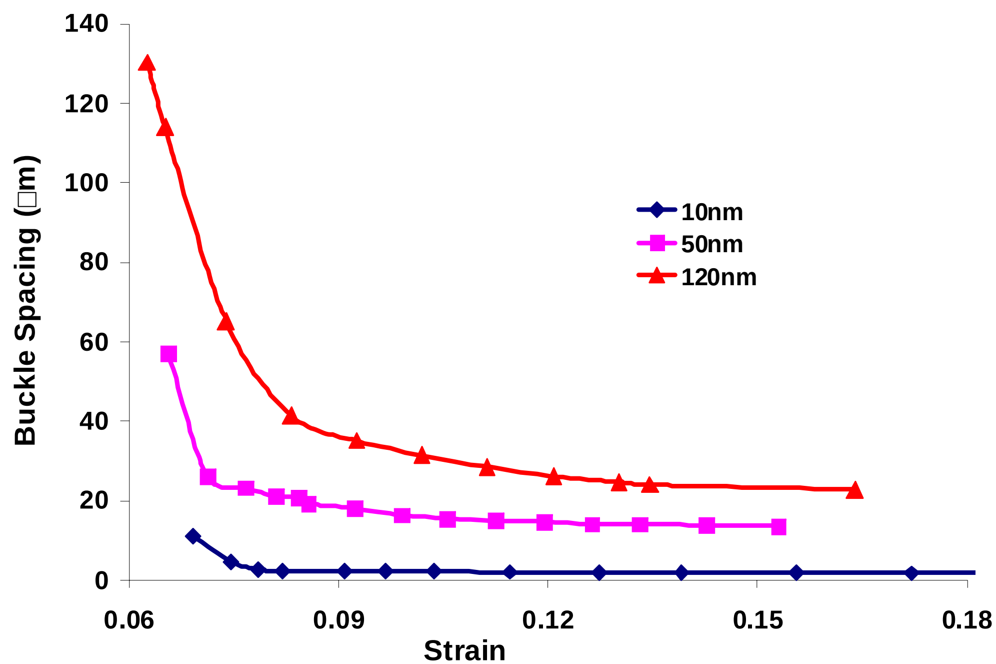
Cracking



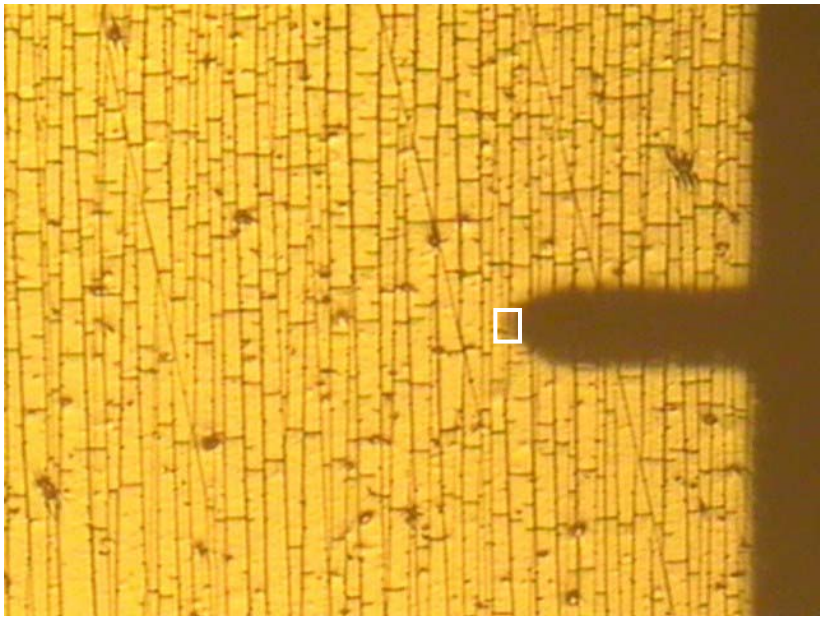
Buckle initiation

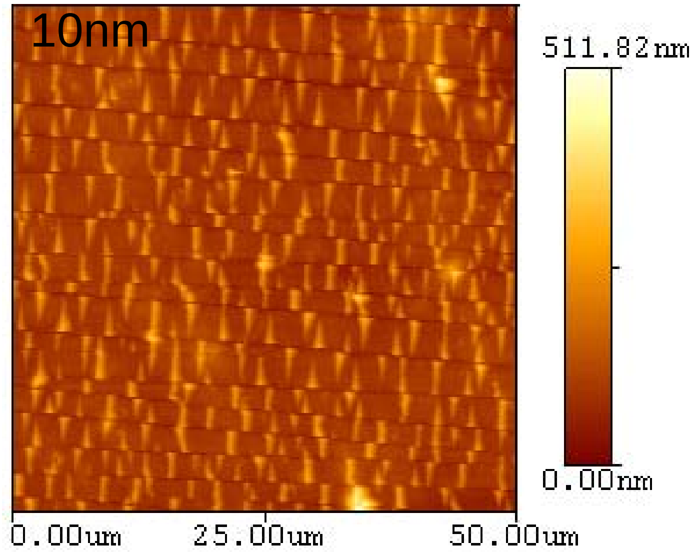


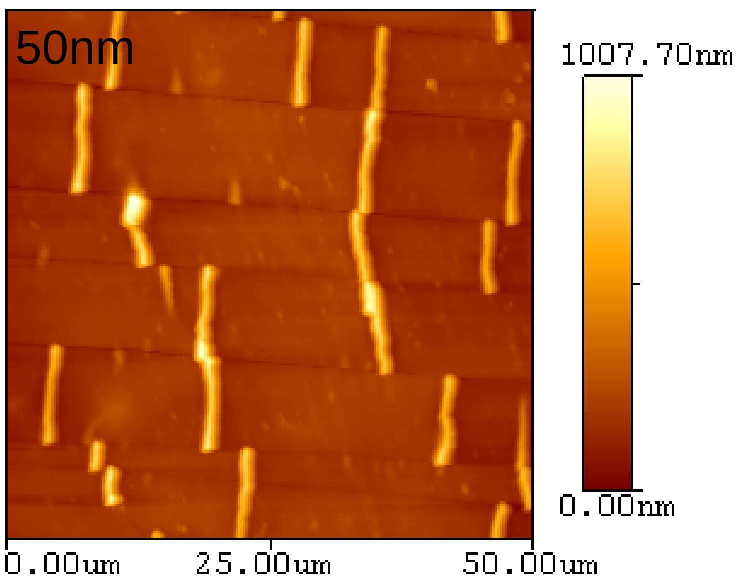
Buckle growth

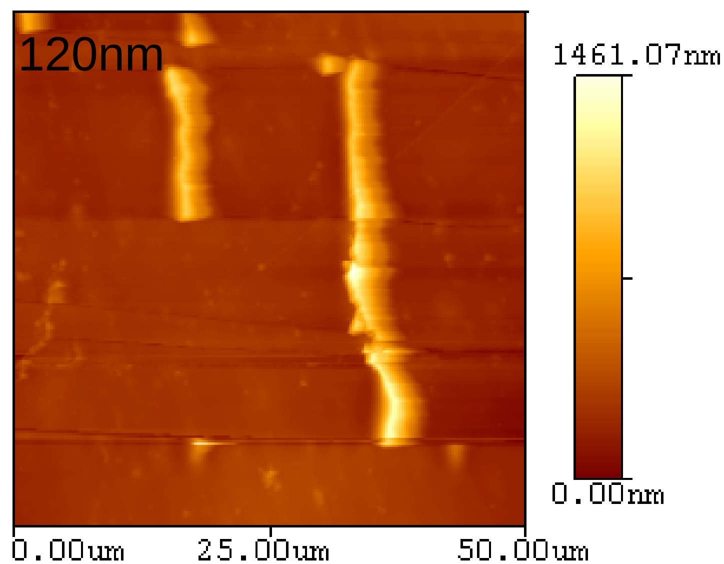


AFM Imaging of Buckles on Different Thickness Cr Films









Buckle Dimensions

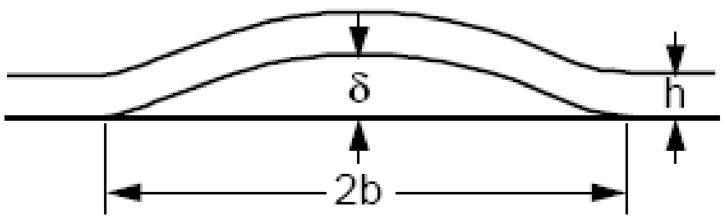
Measurement of buckle dimension from AFM images:

Buckle dimension at strain of 8.75%:

Film Thickness	Width (nm)	Height (nm)
10 nm	452.1±40.3	140.9±29.1
50 nm	1669.4±106.2	718.7±183.6
120 nm	4654.2±419.5	1039.8±195.1

Interface Adhesion Energy

Hutchinson and Suo's model:[1]



Critical buckling stress

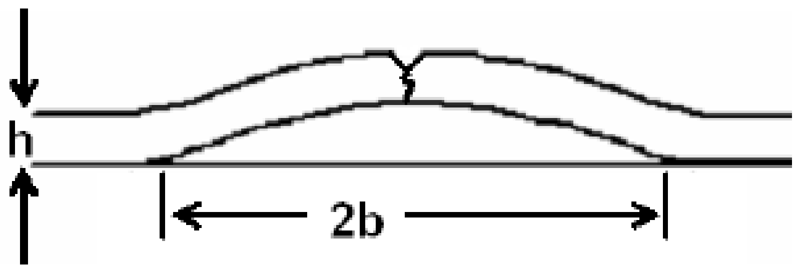
$$\sigma_b = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{h}{b}\right)^2$$

Driving stress

$$\sigma_d = \sigma_b\left[\frac{3\delta^2}{4h^2}+1\right]$$

Interfacial Fracture Energy

$$\Gamma(\Psi) = \left[\frac{(1-\nu^2)h}{2E}\right](\sigma_d-\sigma_b)(\sigma_d+3\sigma_b)$$

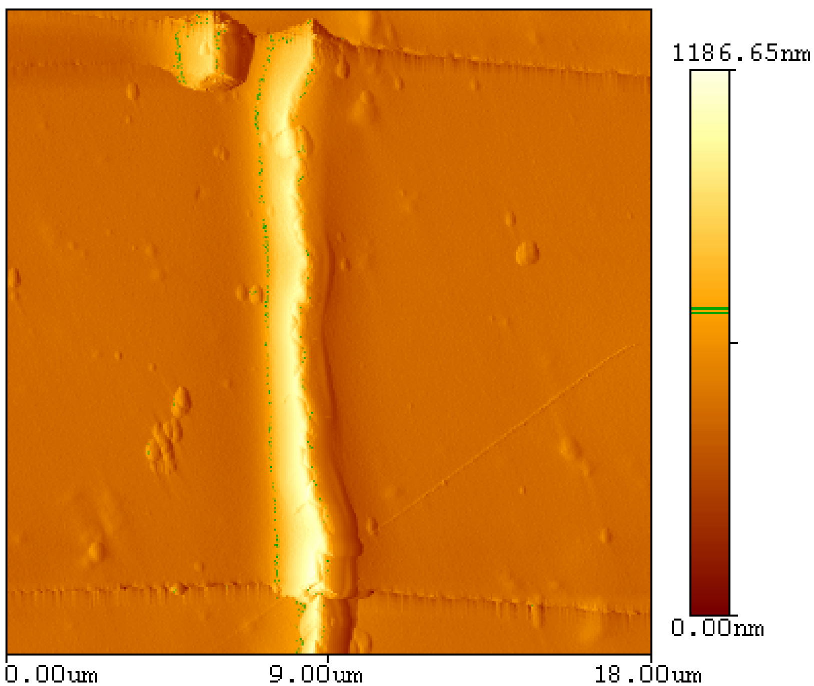


The buckle is cracked at the apex?

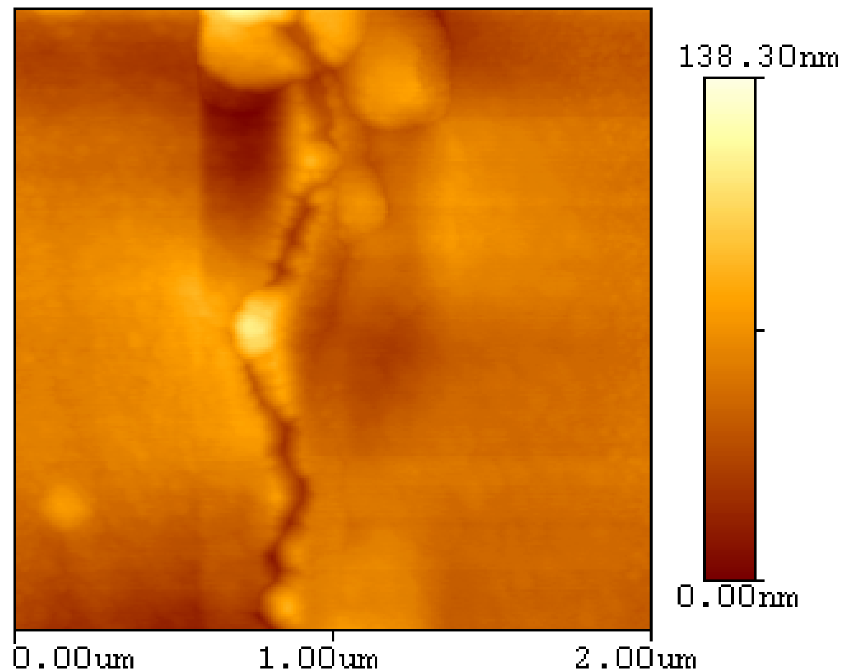
1. Hutchinson, J. W., Suo, Z, Mixed-mode cracking in layered materials, *Advances in Applied Mechanics,* (1992), 29, 63-191.

Cracking at the Apex of Buckles

AFM image of a buckle on 120 nm Cr film at the global strain of 7.5%:



(a) AFM topography image;



(b) zoom-in scan to clearly show the crack at the buckle apex

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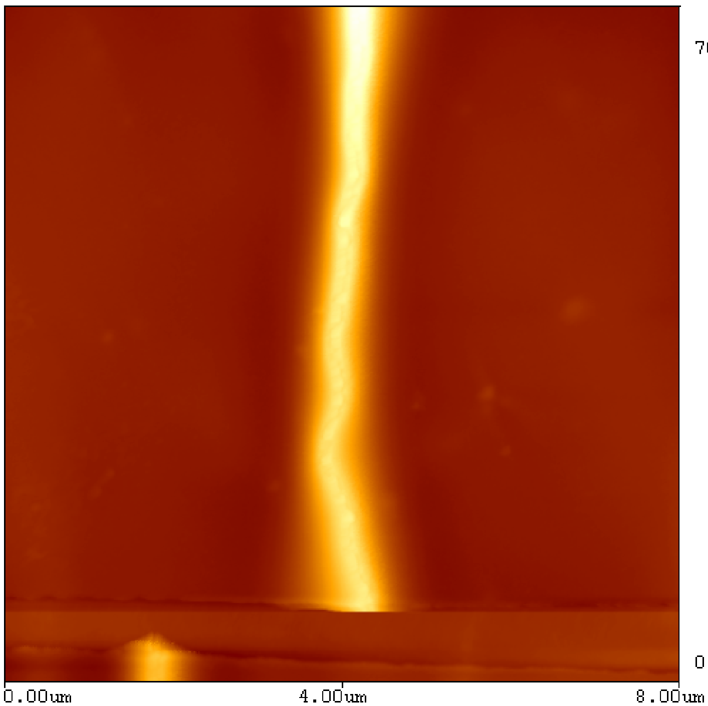
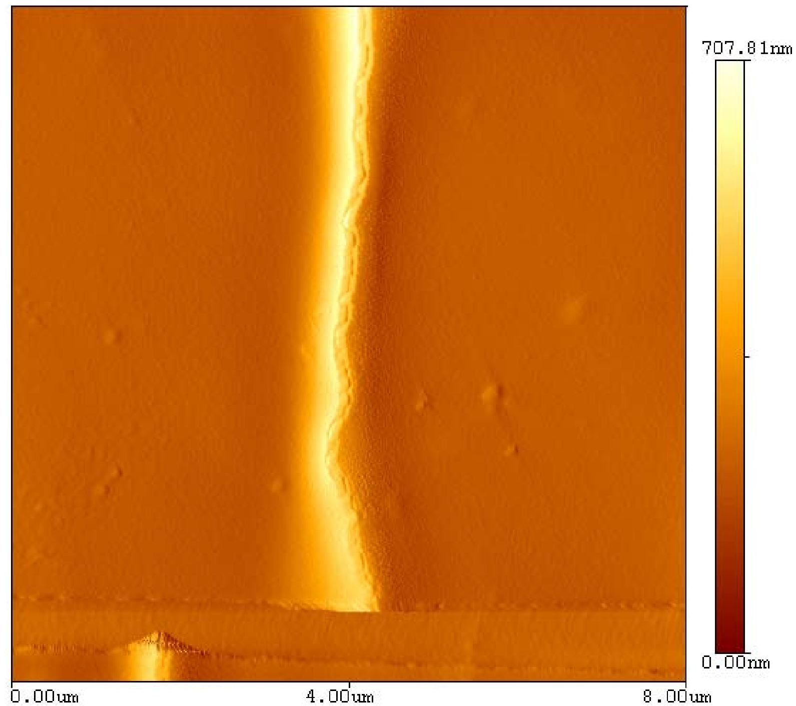
Cracking at the Apex of Buckles

AFM image of a buckle on 50 nm Cr film at the global strain of 11.5%.



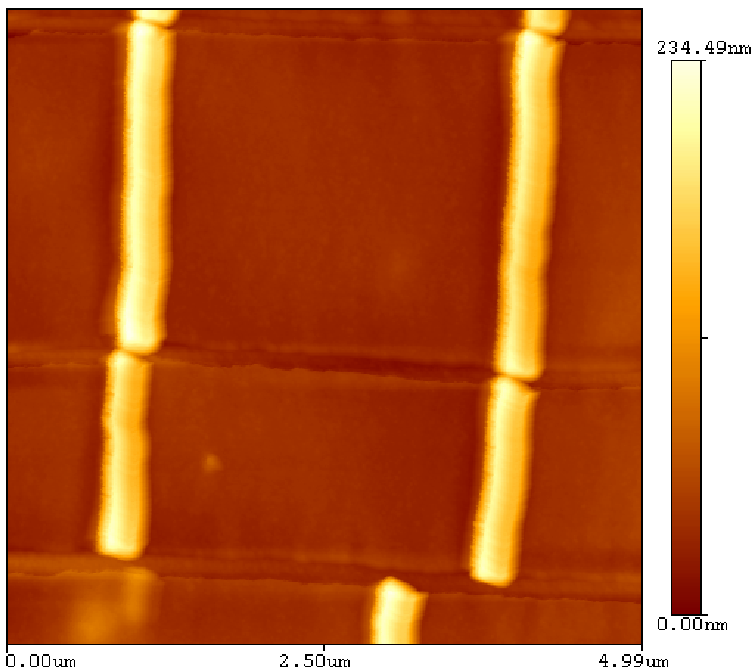
(a) AFM topography image

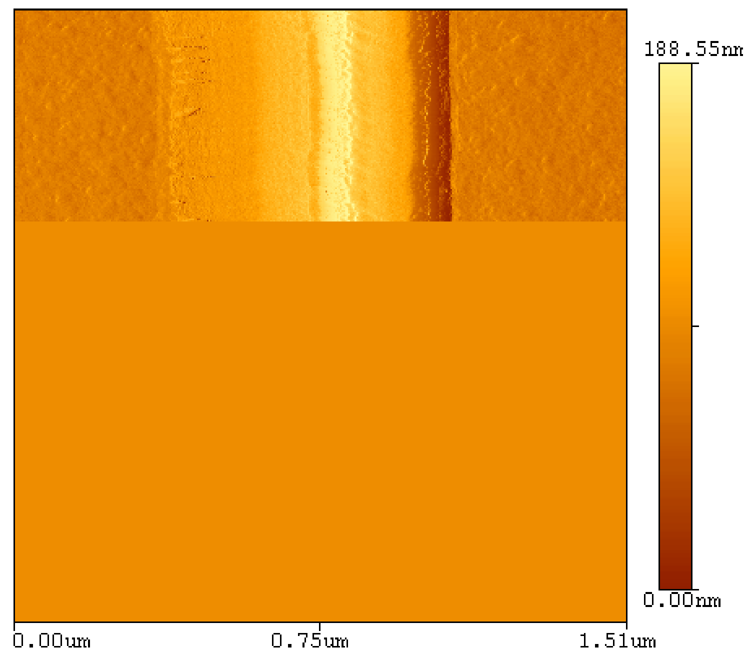


(b) Shaded AFM topography image

Cracking at the Apex of Buckles

AFM image of a buckle on 10 nm Cr film at the global strain of 15%:

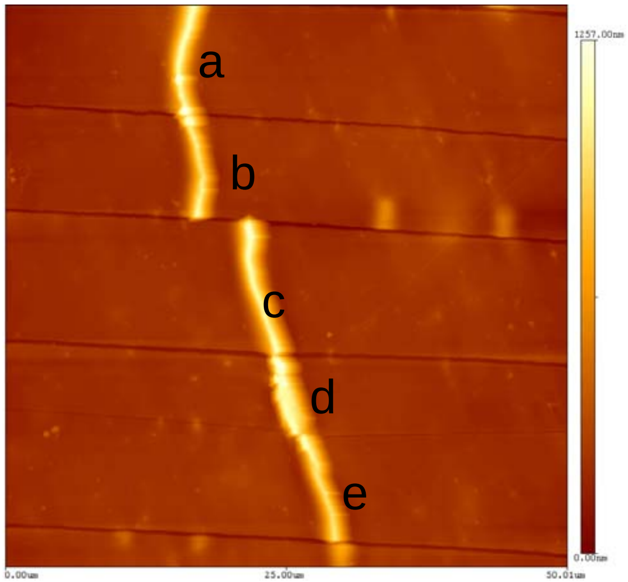




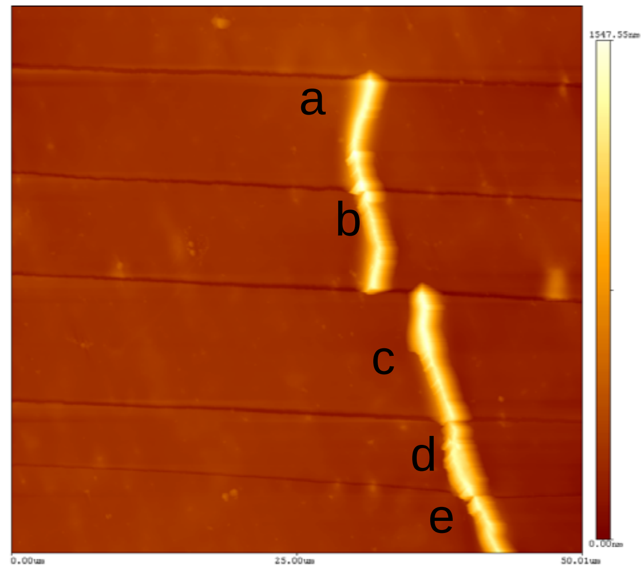
(a) AFM topography image (b) Shaded AFM topography image

In-Situ Measurement of Buckle Growth

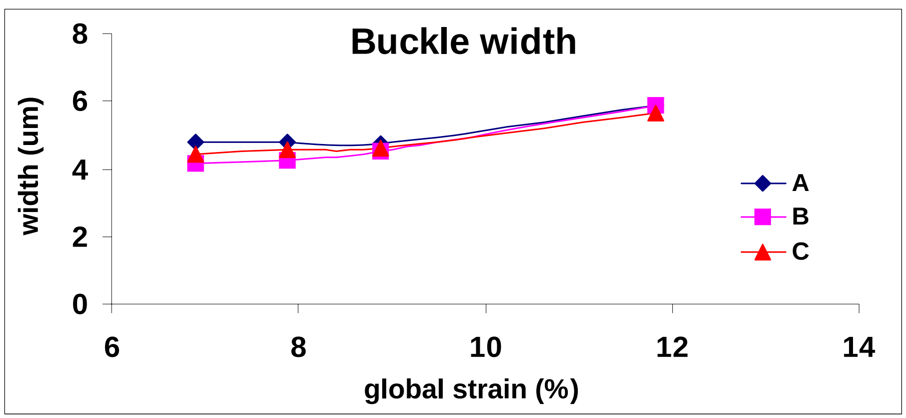
Buckles on 120nm thick films

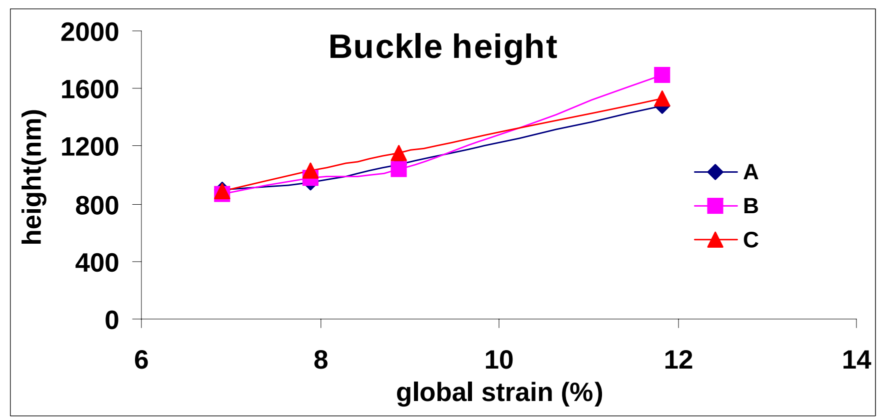


step5



step7





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Summary

- In-situ imaging of optical microscope and AFM were integrated into a microtensile tester to study the cracking and buckling behavior of Cr films on PET substrate;
- The cracks were initiated at small strain of less than 2% in all these three films;
- Crack spacing decreases with the film thickness;
- Maximum shear stress was calculated from the crack information;
- Buckles were initiated at much larger strain of 6.25%~7.0%;
- Buckles grow wider and higher with strain increase for 120nm film. Further systematic study is needed;
- Buckle dimensions were measured from in-situ AFM imaging during stretching.