SHEAR BANDS IN FILMS OF COLLOIDAL DISPERSIONS

Bin Yang

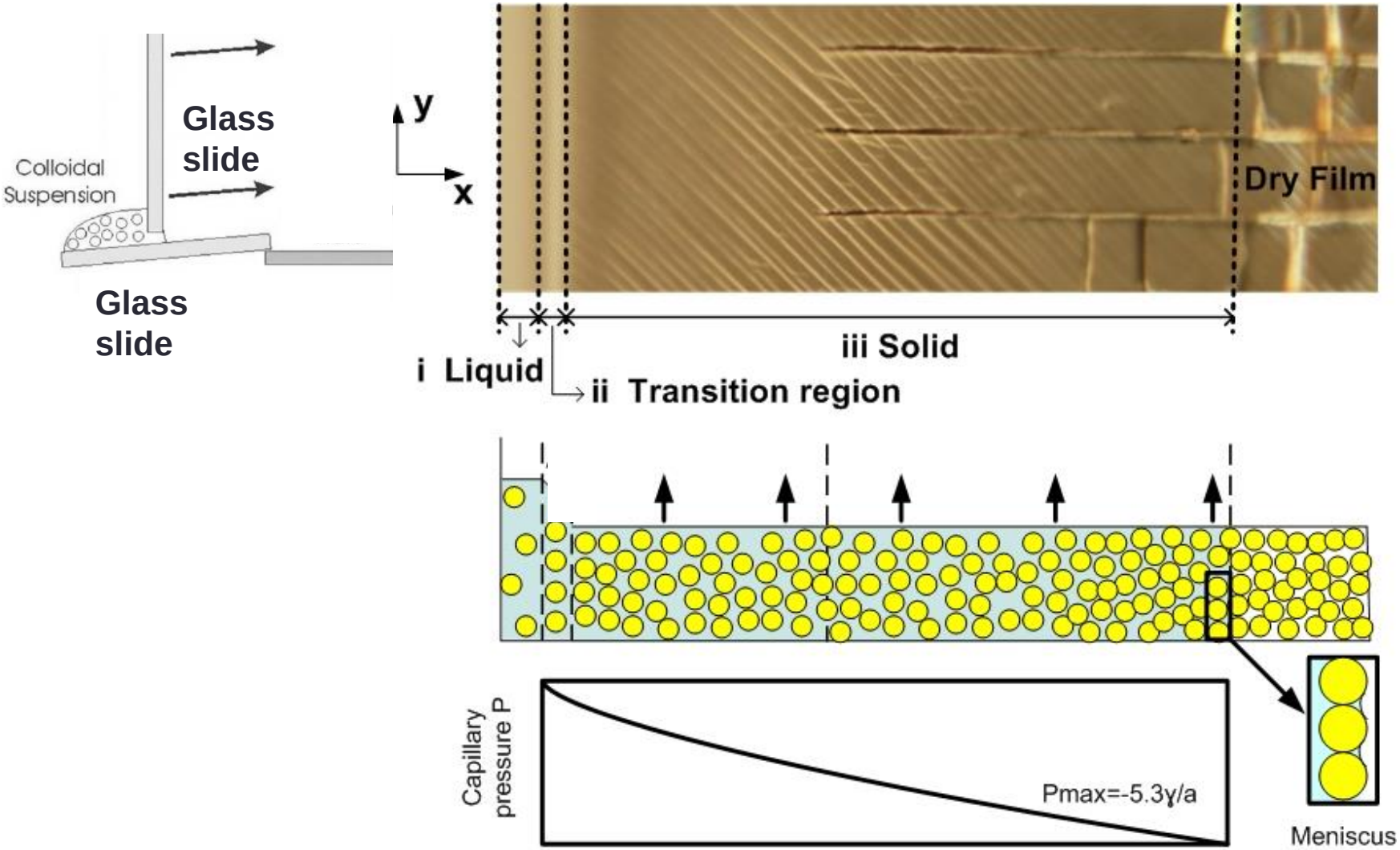
James S. Sharp

Mike I. Smith

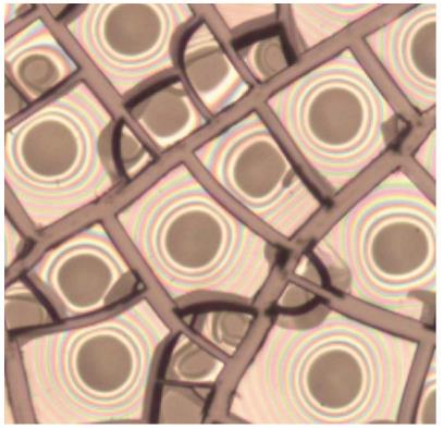
The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

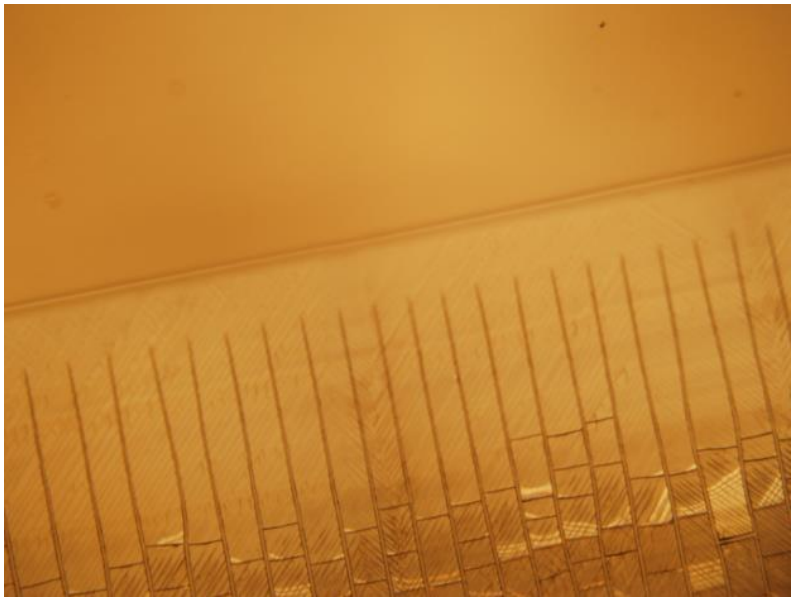
Planar drying of colloidal films



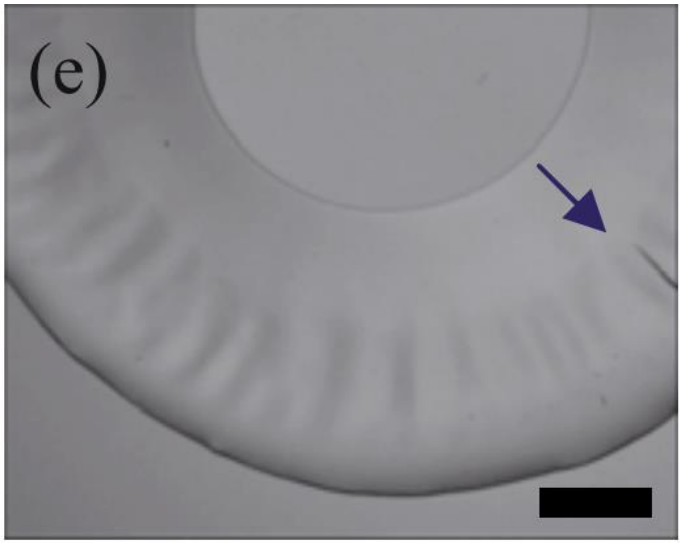
Strain release mechanisms in film formation



Film Delamination



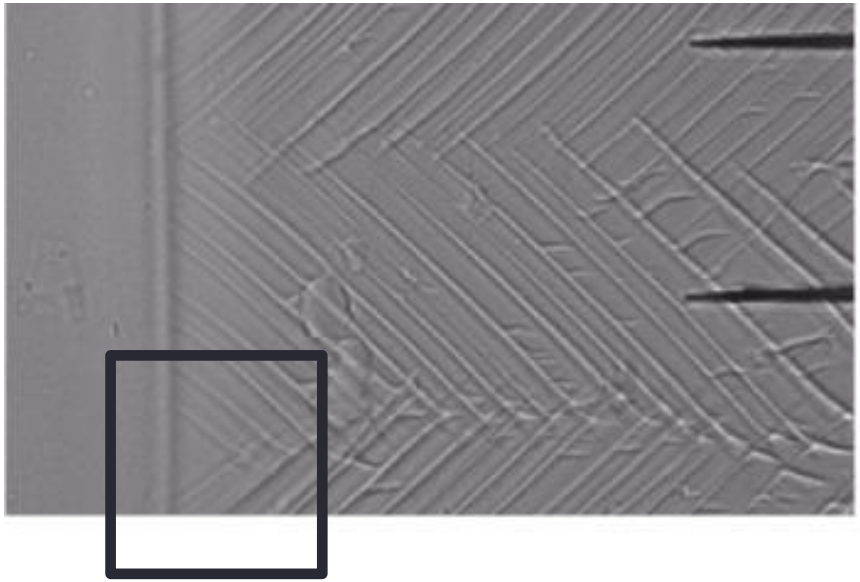
Crack formation

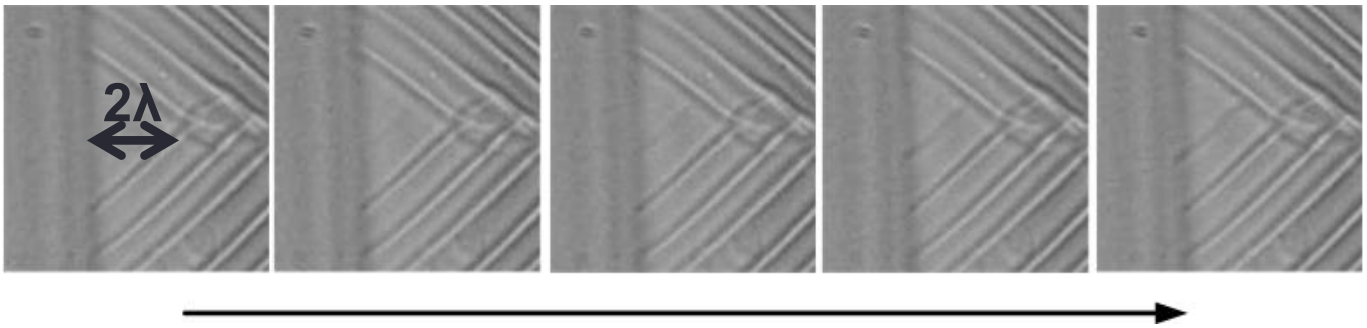


Surface Wrinkling / Buckling

Diagonal Banding

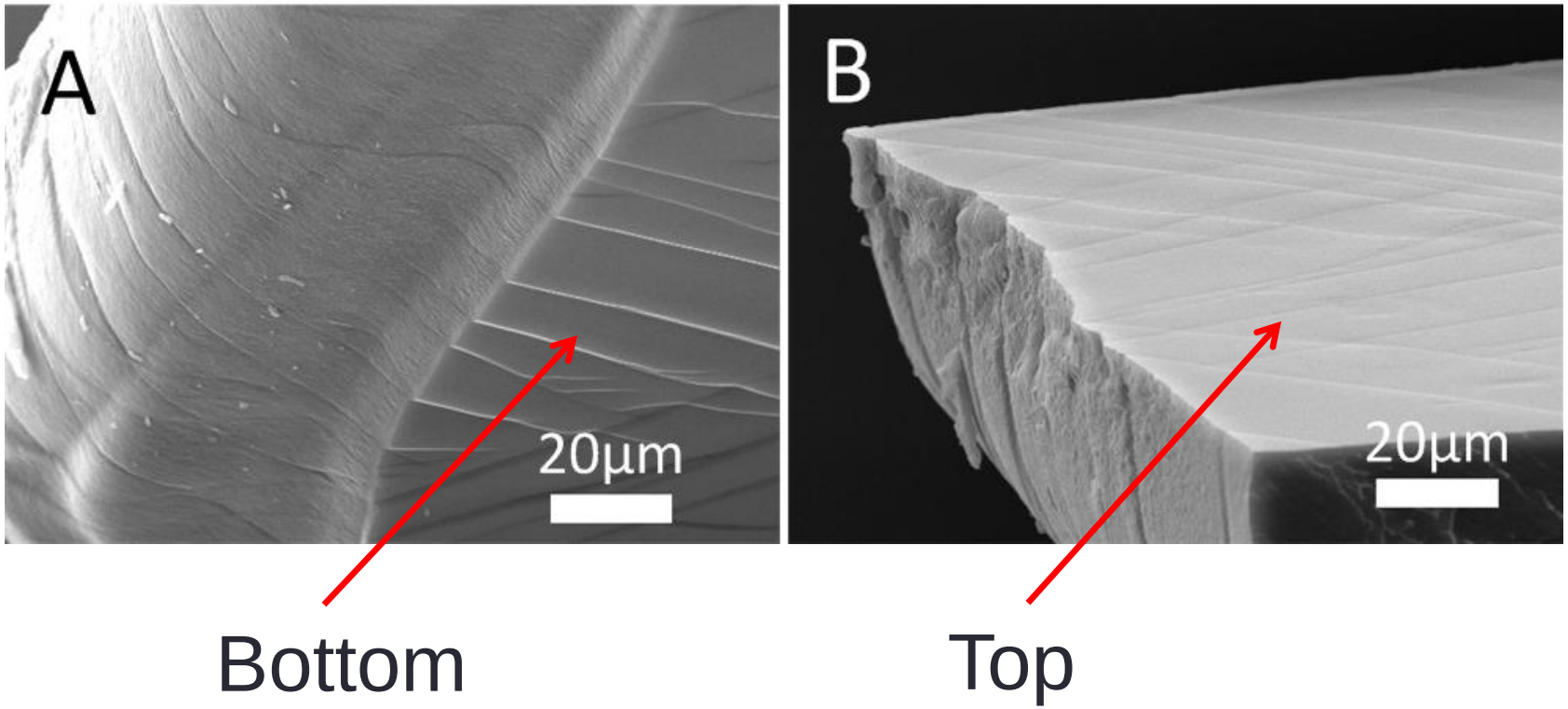
- **Bands form behind transition region**
- **Bands form for 50 & 100nm particles but not 200nm and greater.**



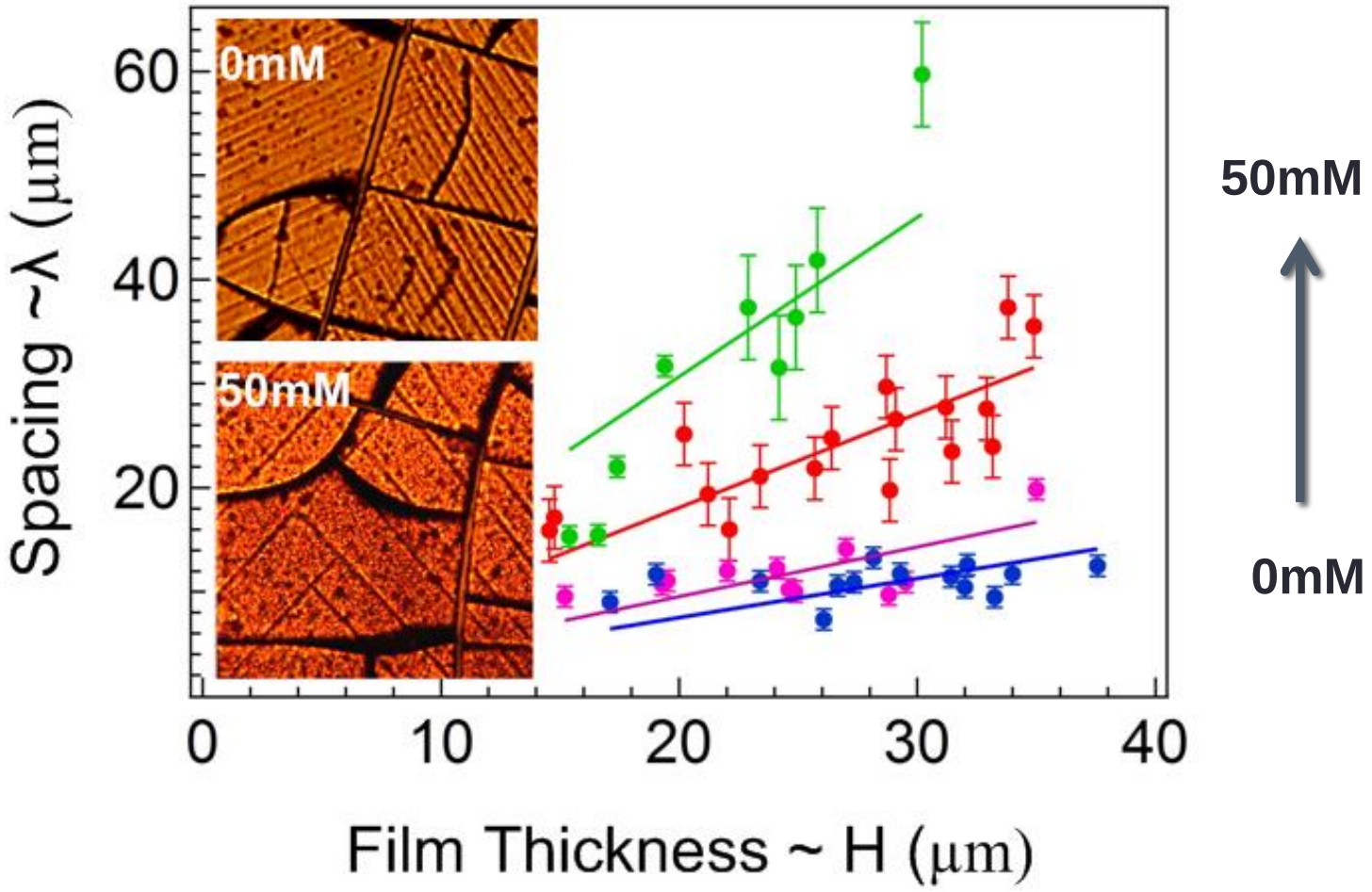


0s **0.17s**

SEM of the band morphology



Band Spacing



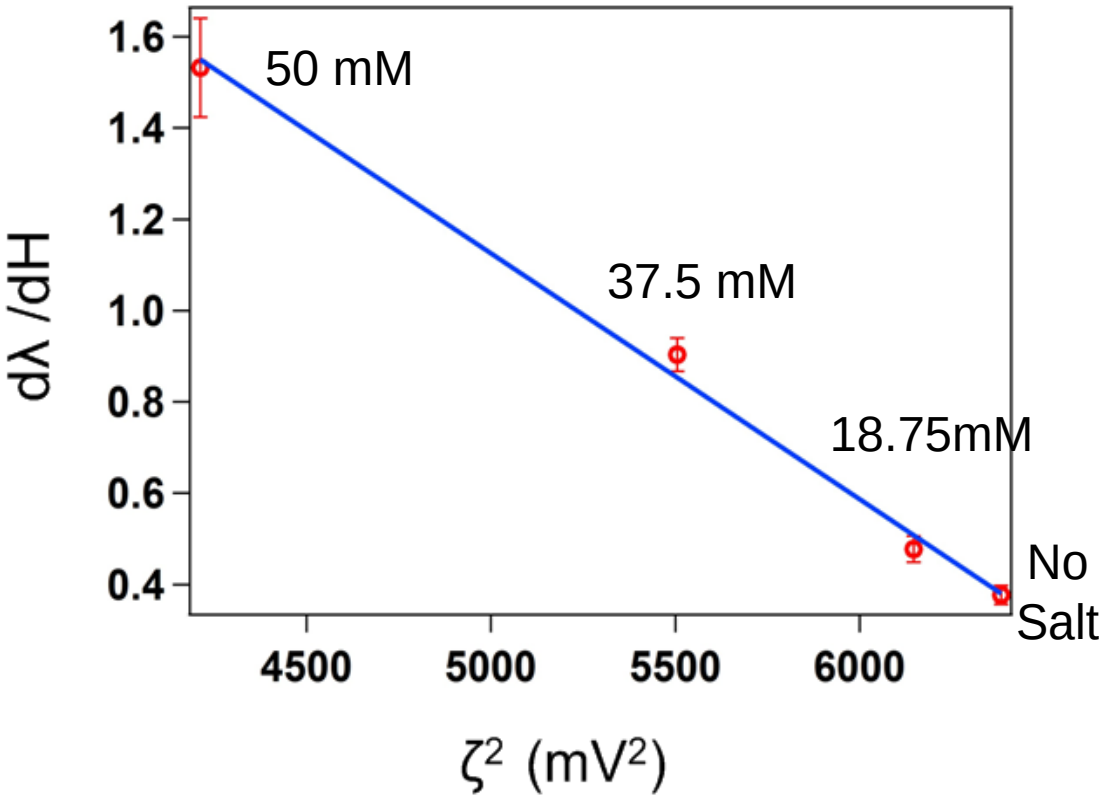
The role of yield stress

A shear band should occur when the stress applied to the film exceeds the film yield stress,

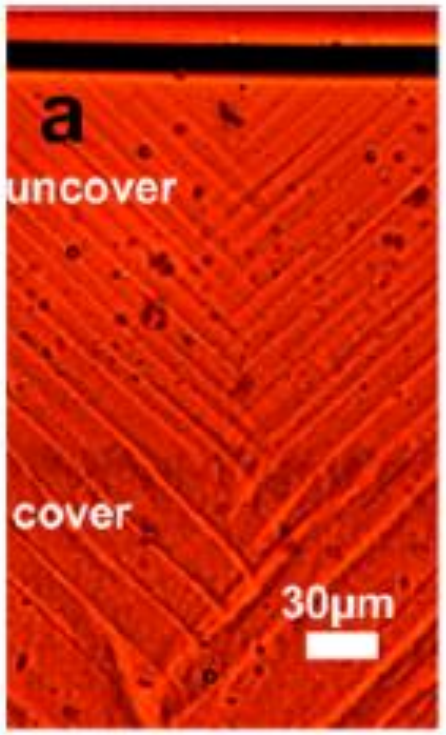
$$\sigma_y = A - B\zeta^2$$

$$d\lambda/dH = a - b\zeta^2$$

Spacing of bands depends on yield stress of film



Shear rate dependence – Lever rule

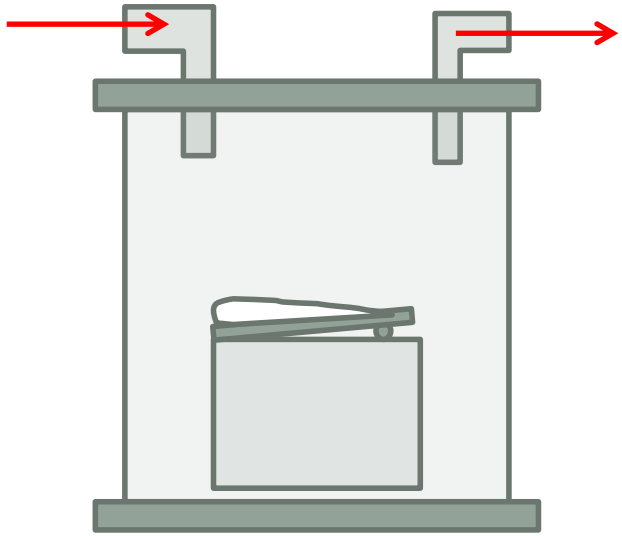


Shear banding in yield stress fluids is known to obey a Lever Rule → Rate dependence

$$\frac{\delta}{\lambda} \sim \frac{\dot{\gamma}}{\dot{\gamma}_c}$$

$\dot{\gamma}_c$ **is a material dependent parameter**

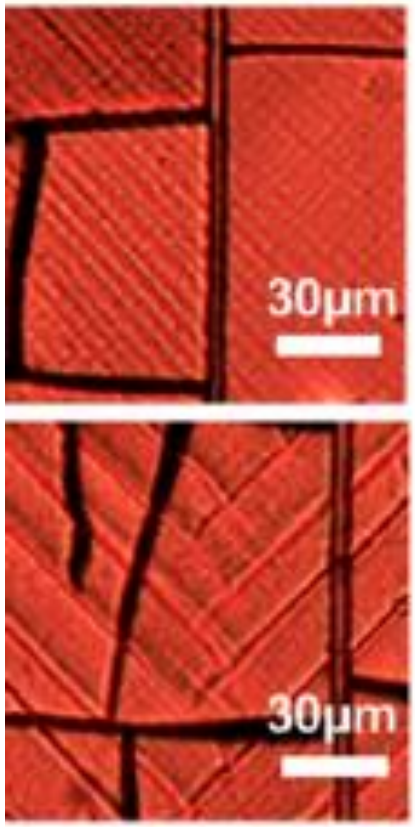
Controlled Humidity Air



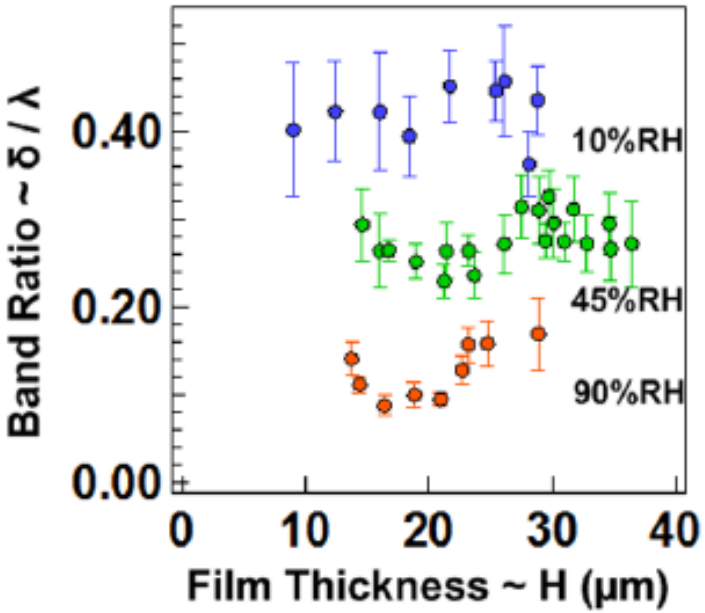
Controlling the evaporation rate alters the band spacing.

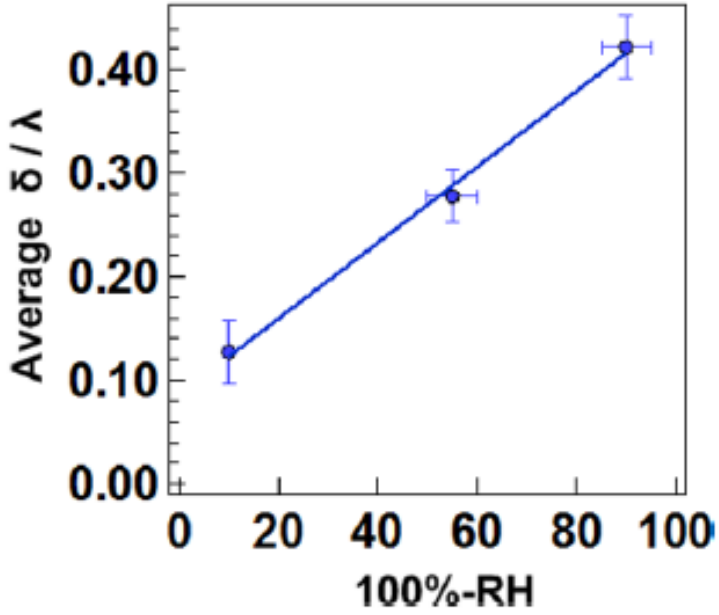
Fast

Slow



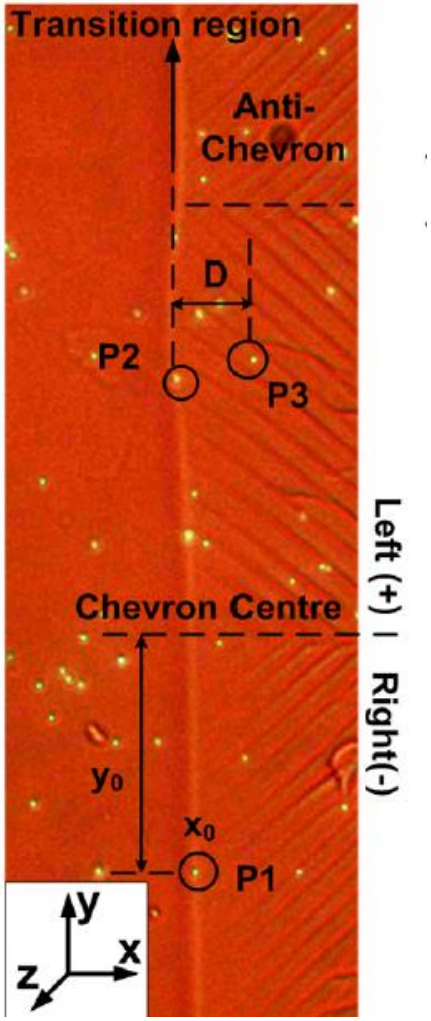
$$\frac{\delta}{\lambda} \sim \frac{\dot{E}_{dry}}{\dot{E}_c} \sim \frac{(100 - RH)}{\dot{E}_c}$$





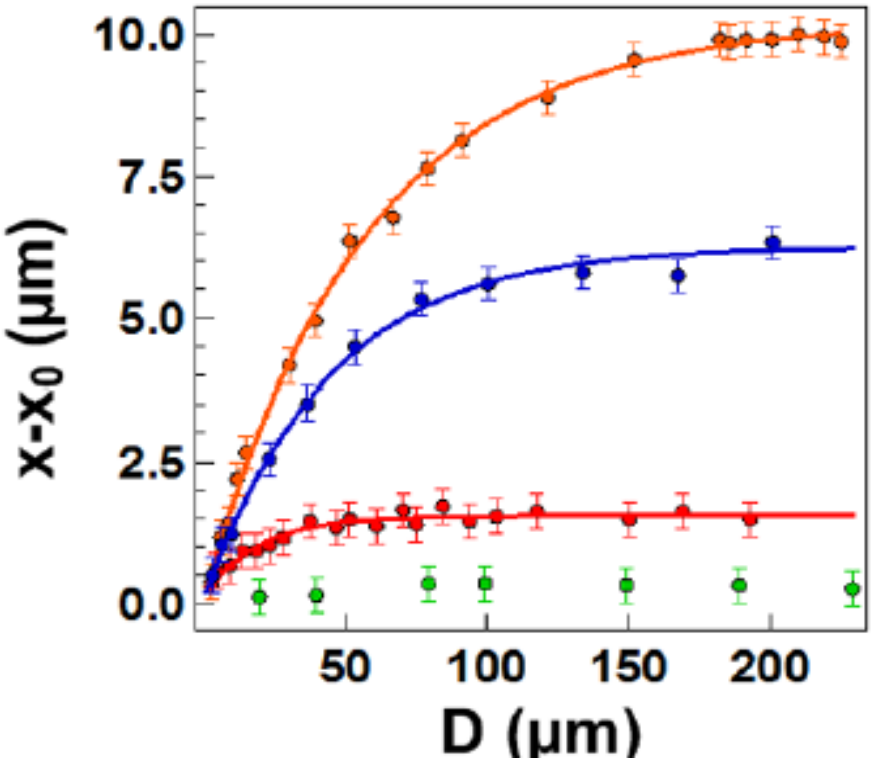
What causes shear band formation?

Measuring the film deformation



- Fluorescent tracer particles added to suspension
- Once particles become trapped at the transition region we track their x and y coordinates
- The small subsequent movements enable us to quantify film deformation

Compaction



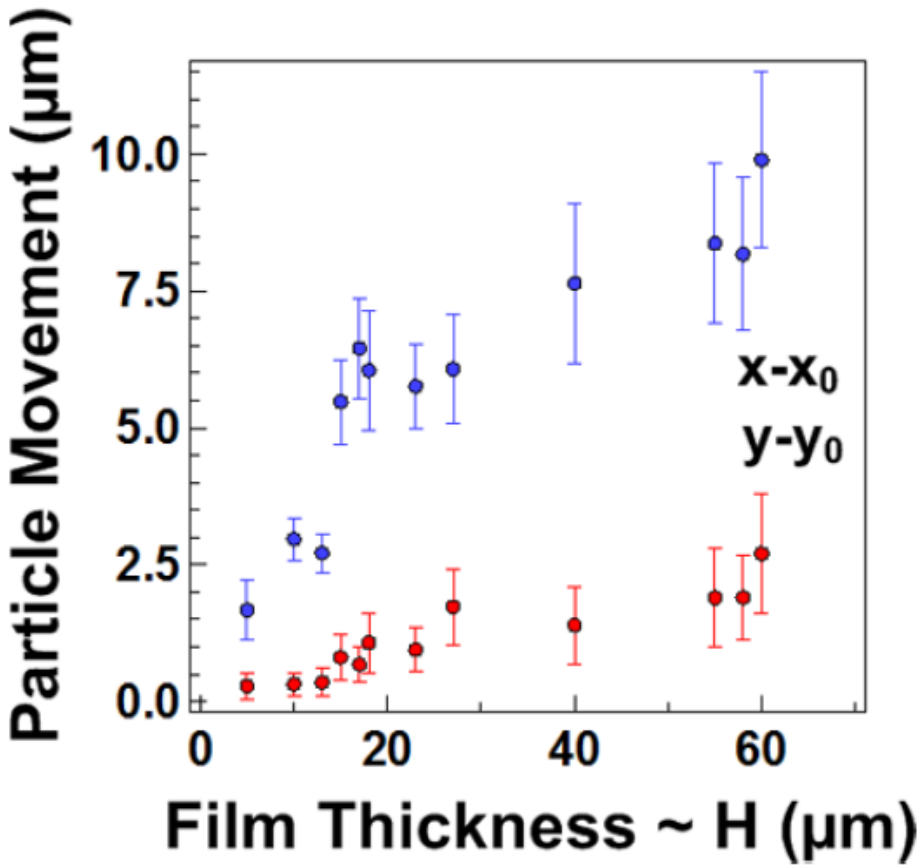
- Stress in the drying film produces compaction beyond transition region.
- Compaction is too small to measure for 200nm particles → no banding

$$dx = dx_{max}[1-\exp(-D/\lambda_{fit})]$$

- λ_{fit} closely matches the spacing between shear bands.

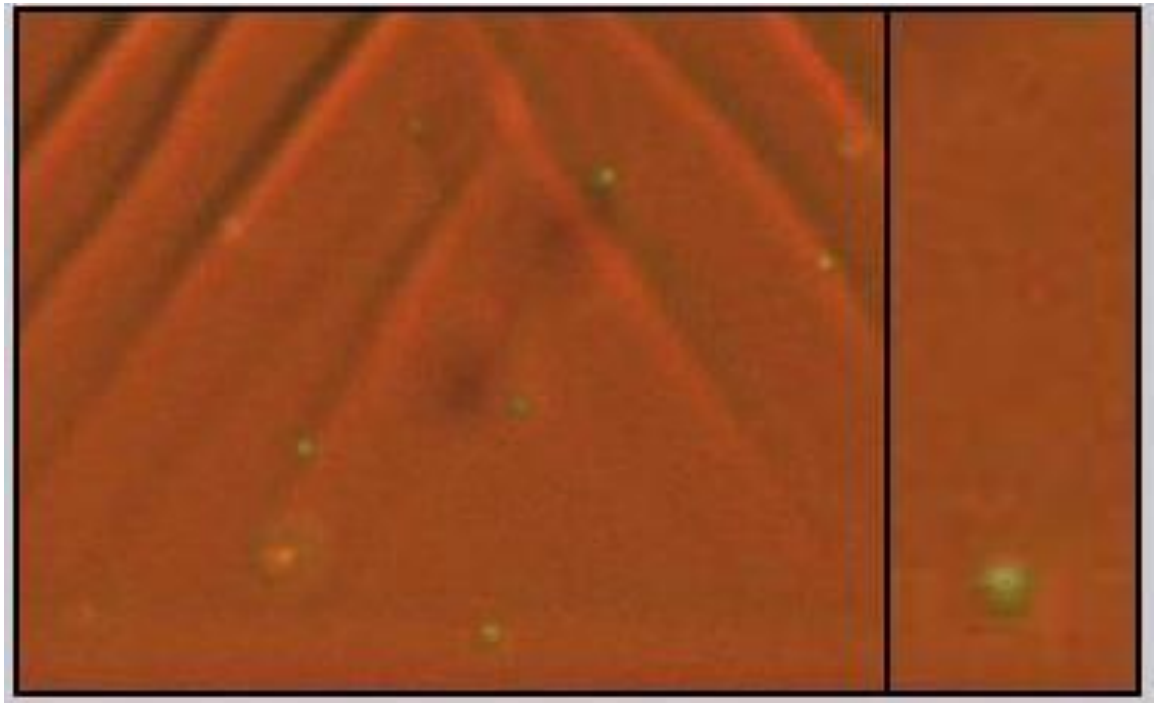
- 50nm, H=60μm
- 50nm, H=27μm
- 100nm, H=25μm
- 200nm, H=38μm

→ Suggests compaction drives shear band formation and sets lengthscale



- Total movement of particles depends on film thickness.
- Consistent movement in the y direction also measurable
- Particles to the left of a chevron move left; particles to the right move right.
- y movement due to shear, x movement compaction + shear

Directly observing compaction and shear banding



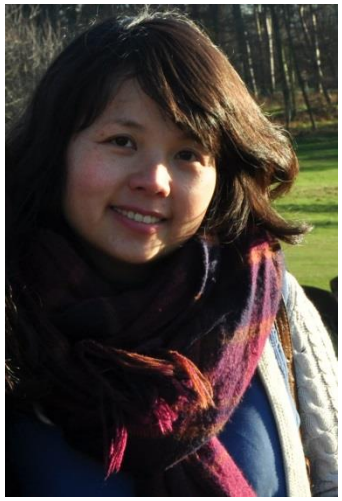
“Shear banding in drying films of colloidal nanoparticles”
B. Yang et al ACS Nano 9, 4077-4084 (2015)

Conclusions

- Diagonal lines observed in drying films are shear bands
- The spacing of bands depends on film yield stress and obeys a simple Lever Rule
- Particle tracking shows that compaction after the transition region provides the driving force for shear band formation.

"Shear banding in drying films of colloidal nanoparticles"
B. Yang et al ACS Nano 9, 4077-4084 (2015)

Acknowledgements



Dr Bin Yang

Dr James Sharp

Funding:

EXCELLENCE IN SCIENCE THE ROYAL SOCIETY

EPSRC Engineering and Physical Sciences Research Council

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA