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Assessing the Mechanical and Electrical Performance of Wear Tested Au-ZnO Nanocomposites for Electrical Contact Applications

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Strengthening Attempts for Increased Wear-resistance

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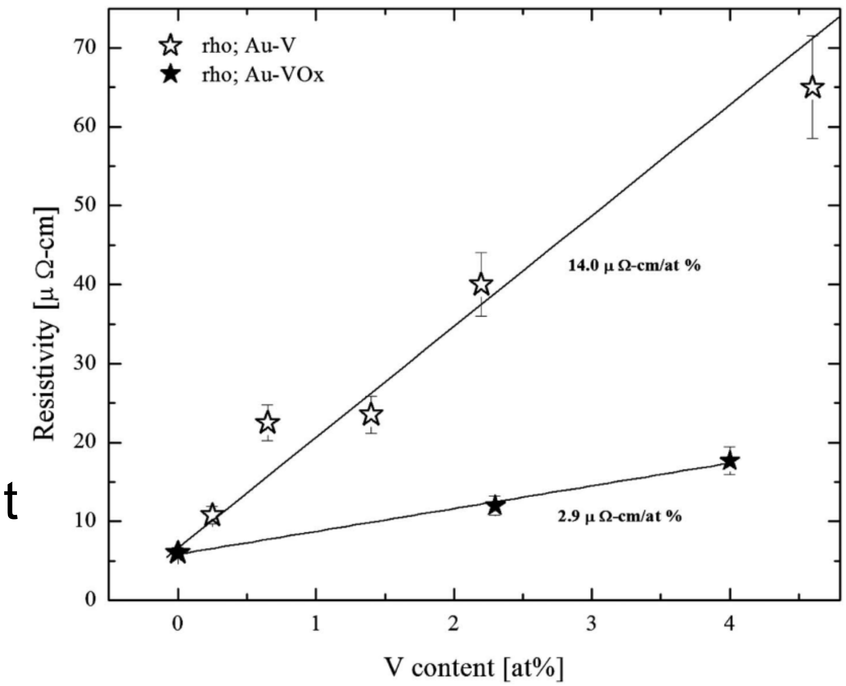
• Bannuru *et al* J. Appl. Phys. 2008

Explored solid solution strengthening (Au-V) and oxide dispersion strengthening (Au-V2O5) to increase hardness

Au-V2O5 films showed a greater amount of strengthening coupled with a lower resistivity than the Au-V films



• Mulloni *et al*: Material Science and Engineering B 2009
Multilayer strengthening of Cr-Au in varying geometries/thicknesses

Motivation

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Reliable Material for Contact Surfaces

- Gold is the material of choice for **low resistance contacts** for long term **environmental stability** and **low resistivity**
- Cyclic contacts can cause mechanical wear
- High currents may lead to micro-welding and added deformation when breaking contacts

GOAL:

- Determine if nanocomposite films show **increased wear resistance with no significant loss in electrical behavior** vs. pure gold.

Purpose

Determine properties of evaporation deposited Au and Au-ZnO films

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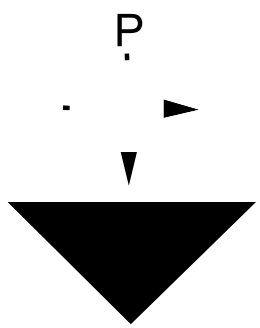
Materials

E-beam evaporation of Au and Au-ZnO films onto silicon wafers

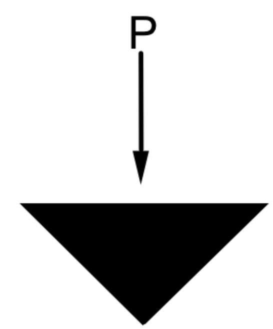
Wear Resistance



Nanoscratch tests using conical diamond tips were used to create wear patterns.

Mechanical Properties

Nanoindentation was used to measure modulus and hardness of the material under the wear patterns.



Sample Preparation and Resulting Structure

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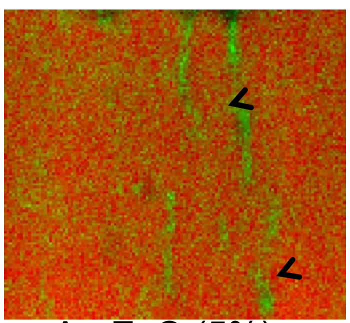
Film Deposition

Dual source e-beam evaporation

Adhesion layer:

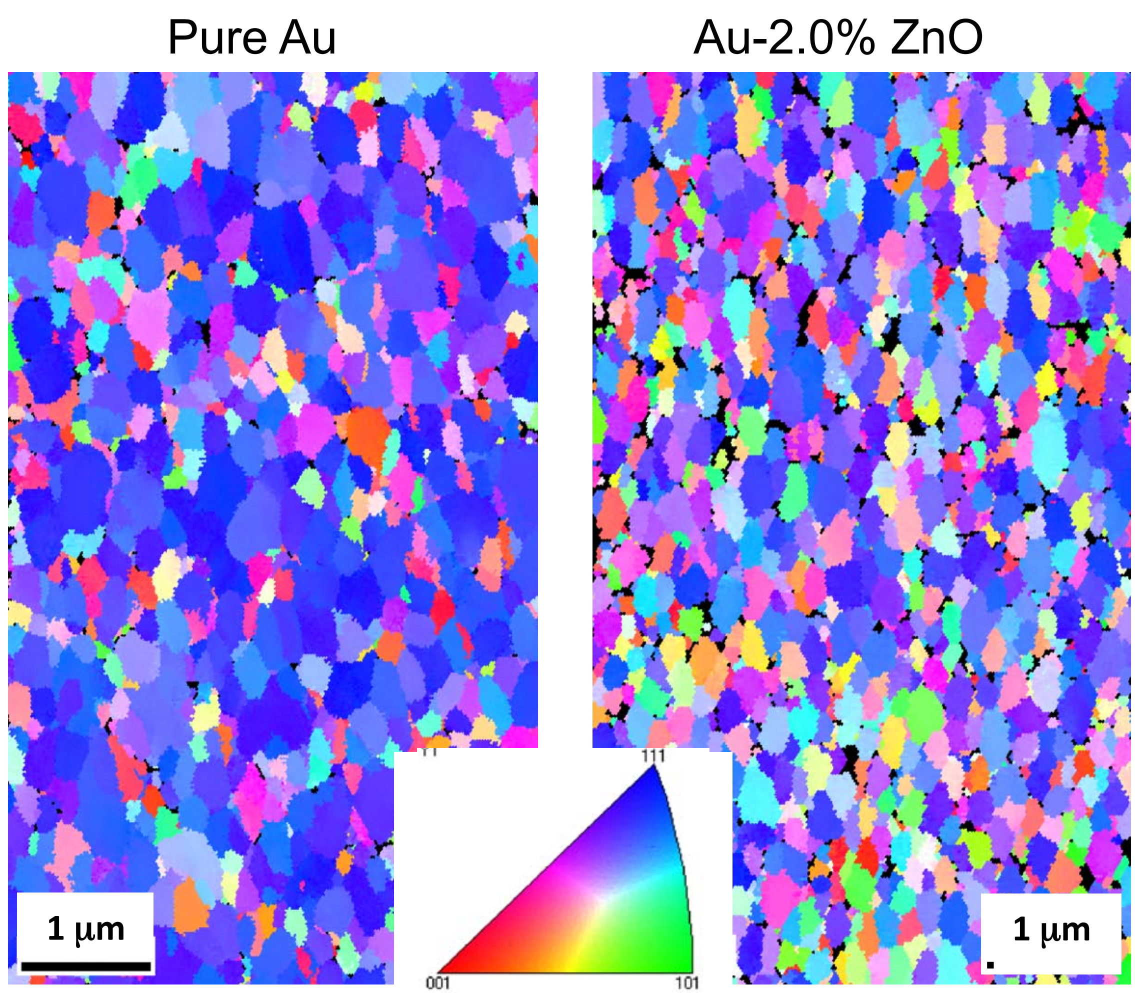
2500Å Ti / 2500Å Pt

Energy Dispersive X-Ray Spectroscopy (EDS) FIB Section



Au-ZnO (5%)

Somuri Prasad, Ron Goeke, Nicolas Argibay, Paul Kotula, Joe Michael, ICMCTF *April 23-27, 2012*



Sample Preparation and Resulting Structure

Film Deposition

Pure Au

Au-2.0% ZnO

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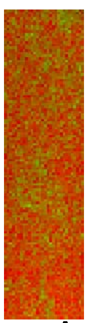
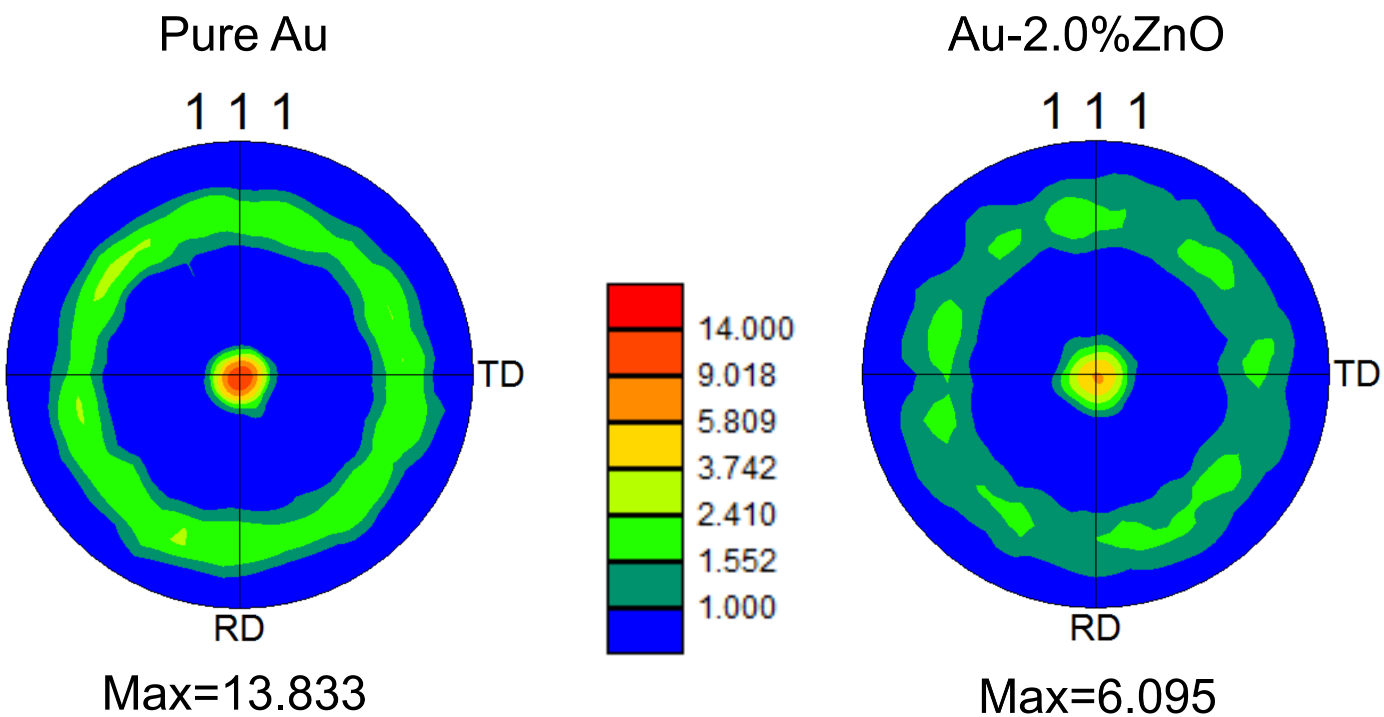
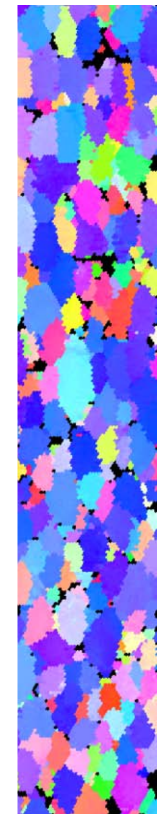
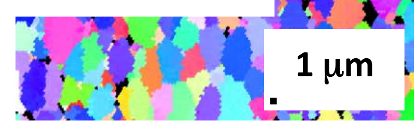


Au-ZnO (5%)

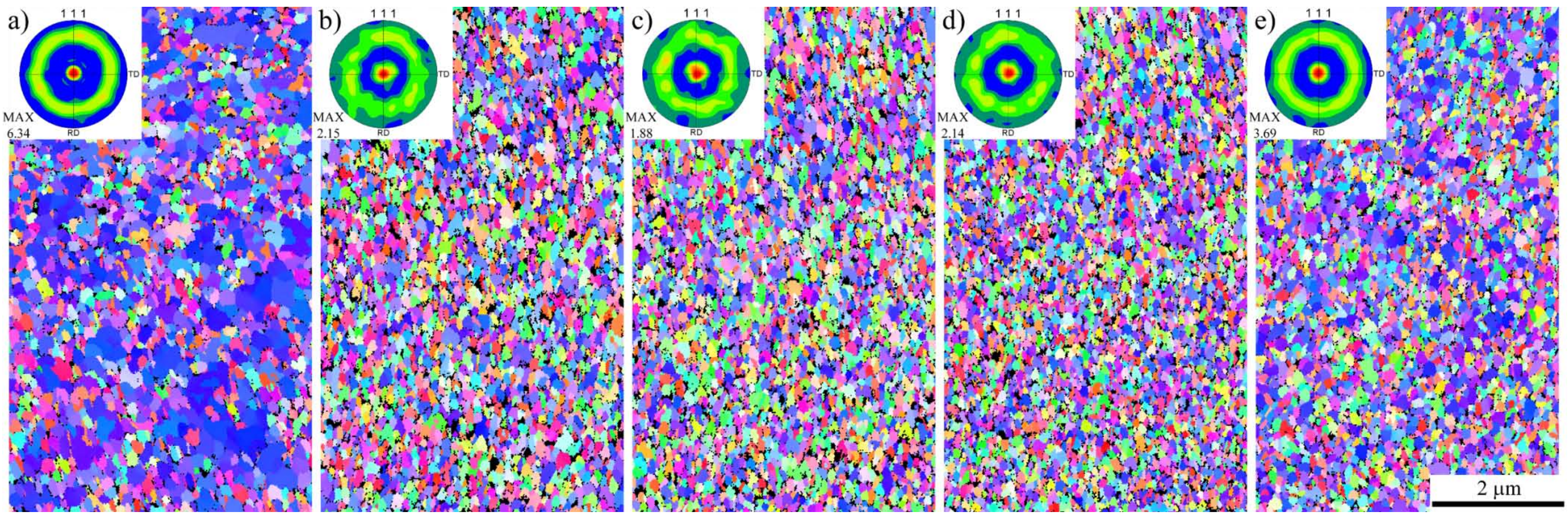






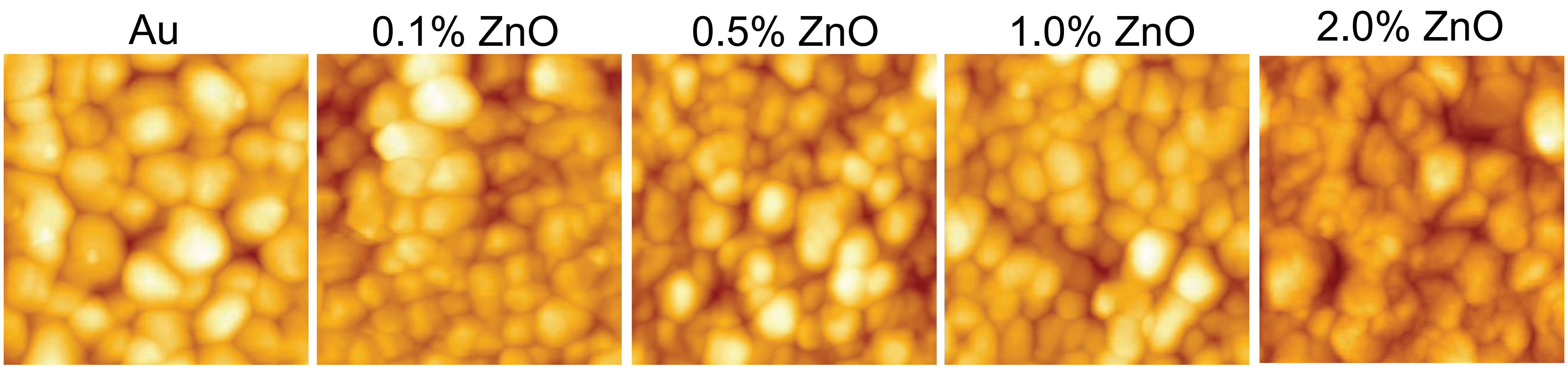
Somuri Prasad, Ron Goeke, Nicolas Argibay,
Paul Kotula, Joe Michael, ICMCTF *April 23-27, 2012*

Structure and Strength of Au-ZnO Films



All films are nanograined. The addition of ZnO particles effectively reduced the grain size. They also led to a weakening of the (111) texture

Refinement in Grain Size of As Deposited Films



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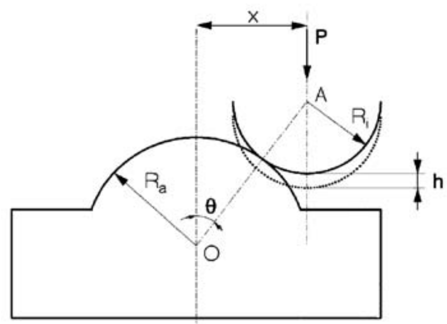
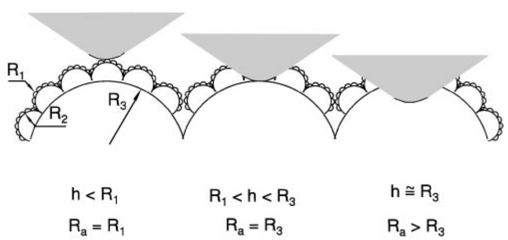
Hardness can vary with asperity geometry and property gradients.



Single Asperity



Multiple Asperities

Near surface variations in hardness can be attributed to:

- surface chemical effects
- indentation size effects
- property variations with depth
- surface roughness

Surface roughness results from large strains and local strain rate responses during wear pattern generation

Asperities created during wear are high stress and strain energy structures

Probing properties introduces additional factors.

(Bobji and Biswas, 1999)

Experimentally we can separate geometric and material through contact area to a first order correction.

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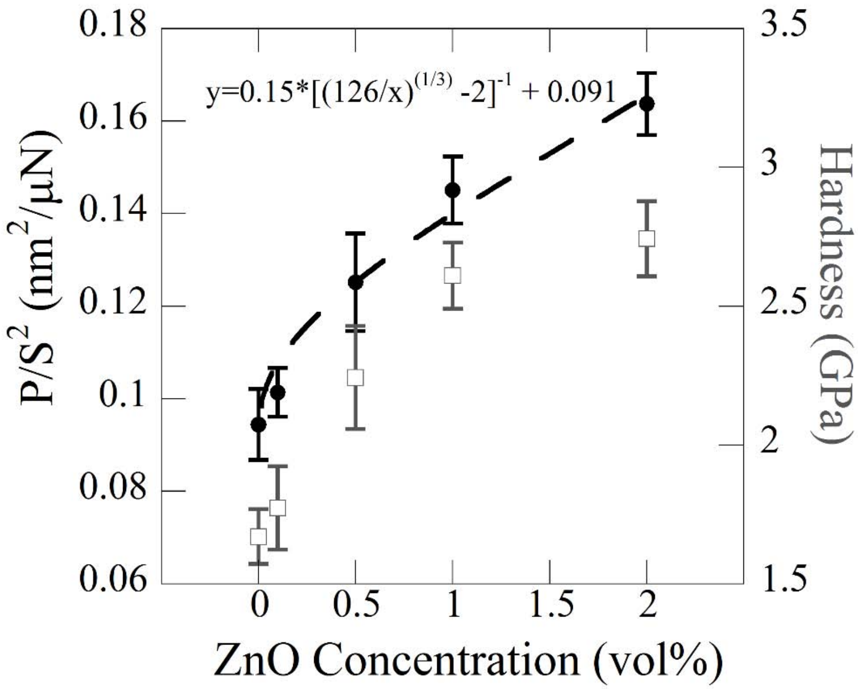
Experimentally these terms are separated using a P/S^2 approach assuming a constant elastic modulus

$$S = \frac{2}{\sqrt{\pi}} E^* \sqrt{A} \; : \; H = \frac{P}{A}$$

with

$$\frac{1}{E^*} = \left[\frac{\left(1 - \nu_i^2\right)}{E_i} + \frac{\left(1 - \nu_s^2\right)}{E_s} \right]$$

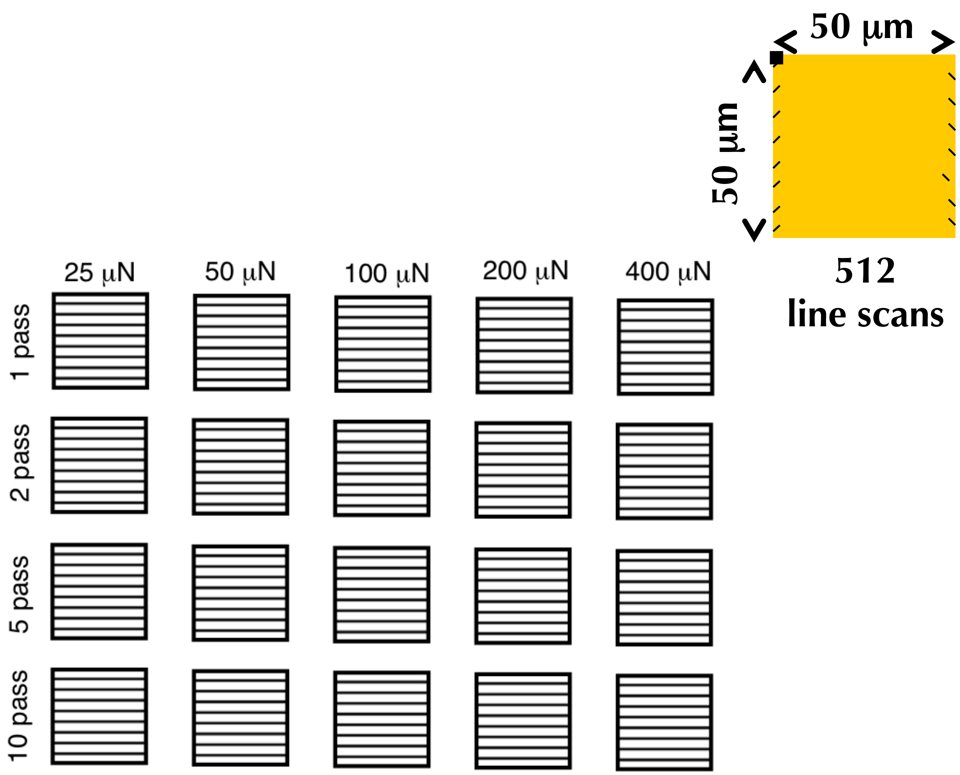
$$\frac{P}{S^2} = \frac{\pi P}{4AE^*} = \frac{\pi H}{4E^*}$$



(Page, Pharr, Hay, Oliver, Lucas, Herbert, Riester, 1998)

- Hardness values exhibit a well-defined increase with ZnO concentration

Nanoscratch tests were used to create wear patterns as a function of applied load and number of scratch passes.



The wear patterns were generated on a Hysitron Triboindenter

- 1 μm 90º conical tip
- Loads from 25 mN to 400 mN
- 1, 2, 5 and 10 passes
- Sliding speed of 20 μm/s

Low load high resolution nanoindentation was used to measure material properties within each wear pattern.

Topography of Wear-tested 2 mm Au

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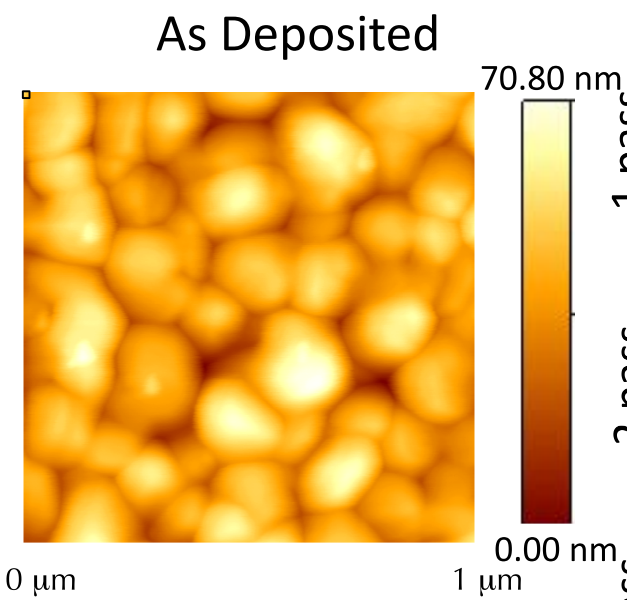

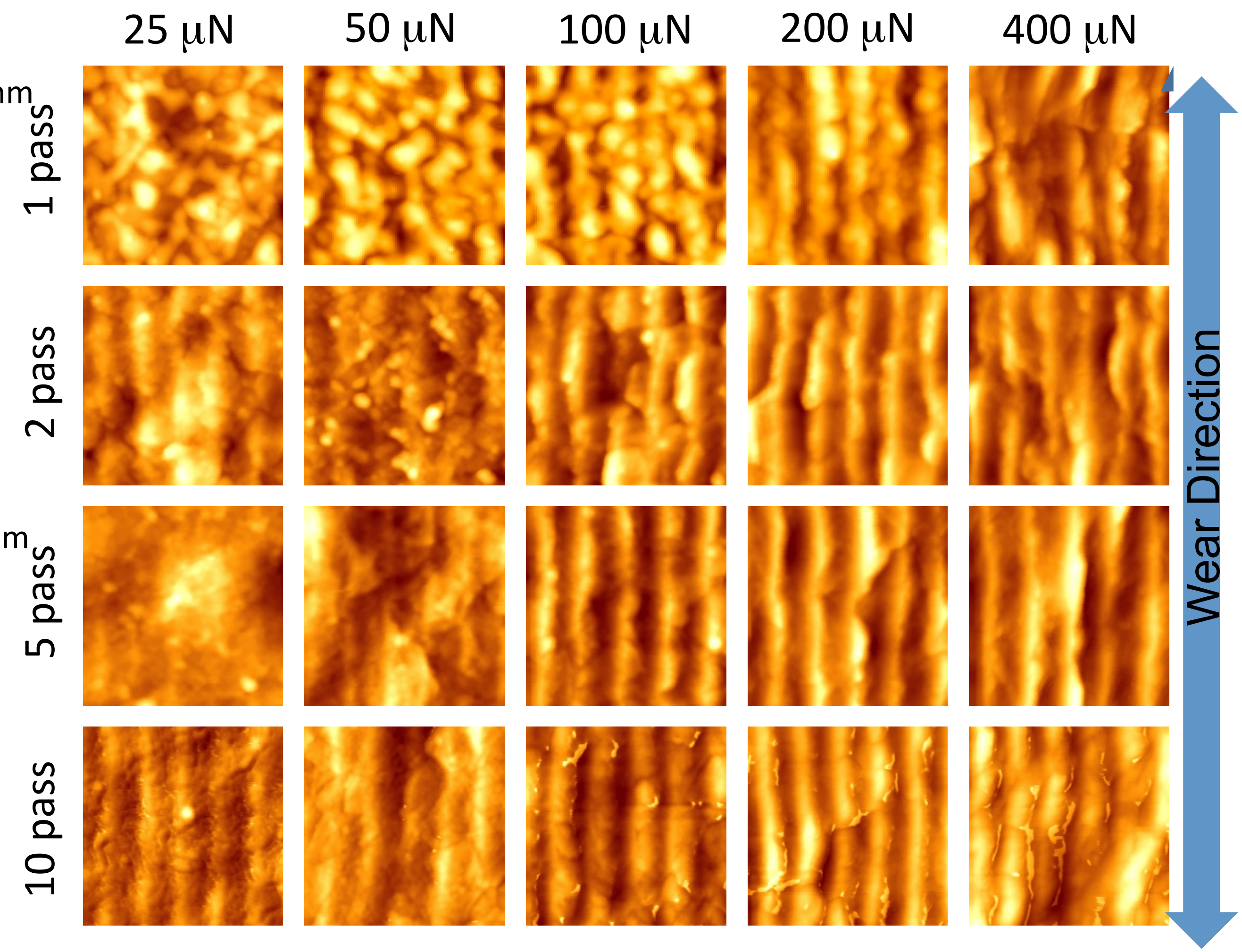

- Evidence of grain coalescence starting at lowest wear condition.
- Obvious wear track formation at low loads

Topography of Wear-tested Au-2.0% ZnO

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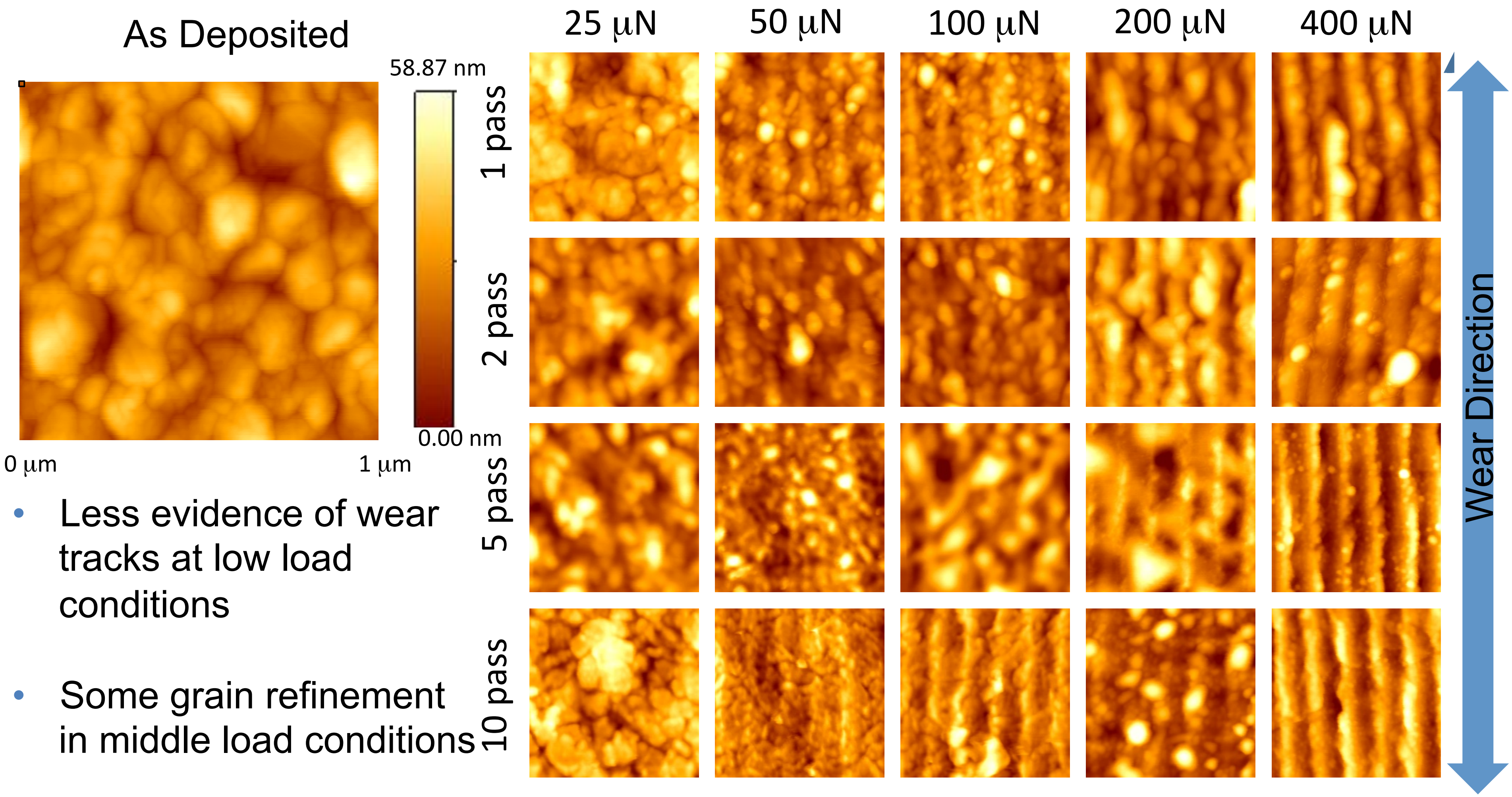

- Less evidence of wear tracks at low load conditions
- Some grain refinement in middle load conditions

Comparison of Wear Response Between Different Films

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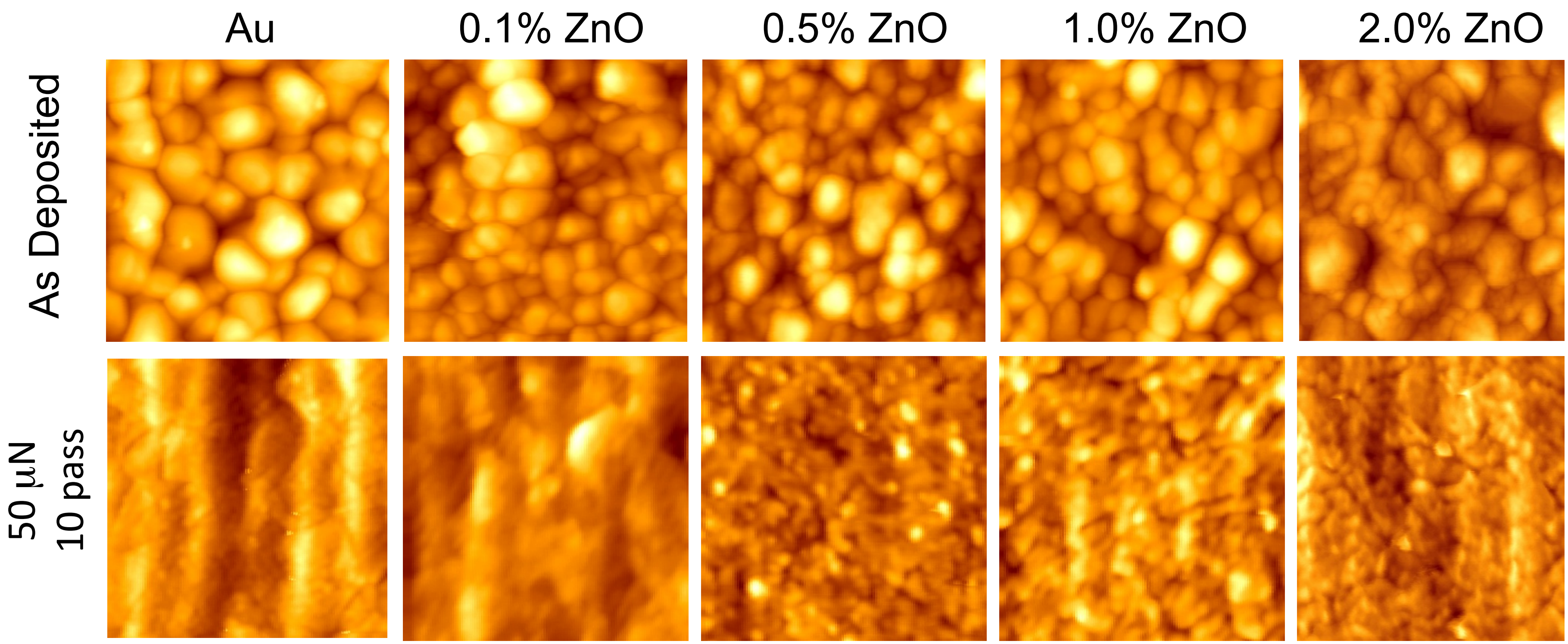
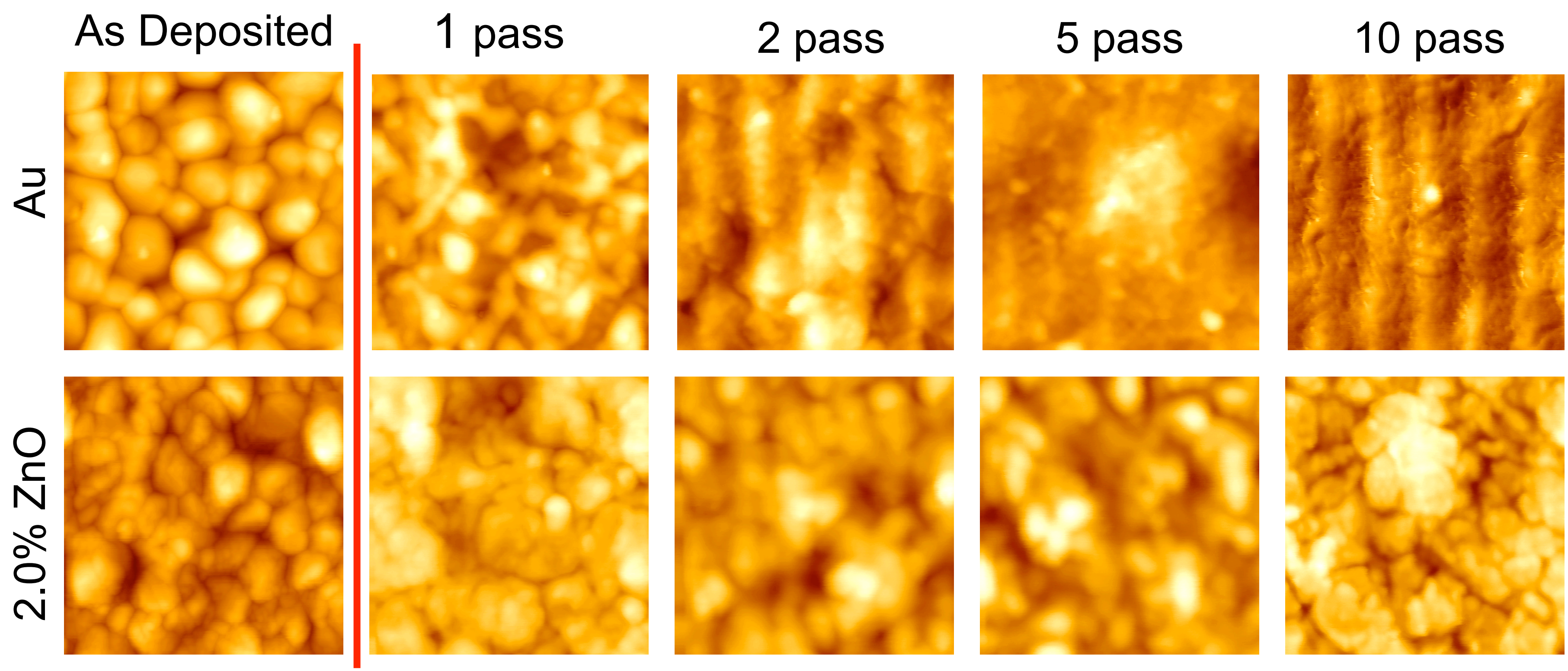


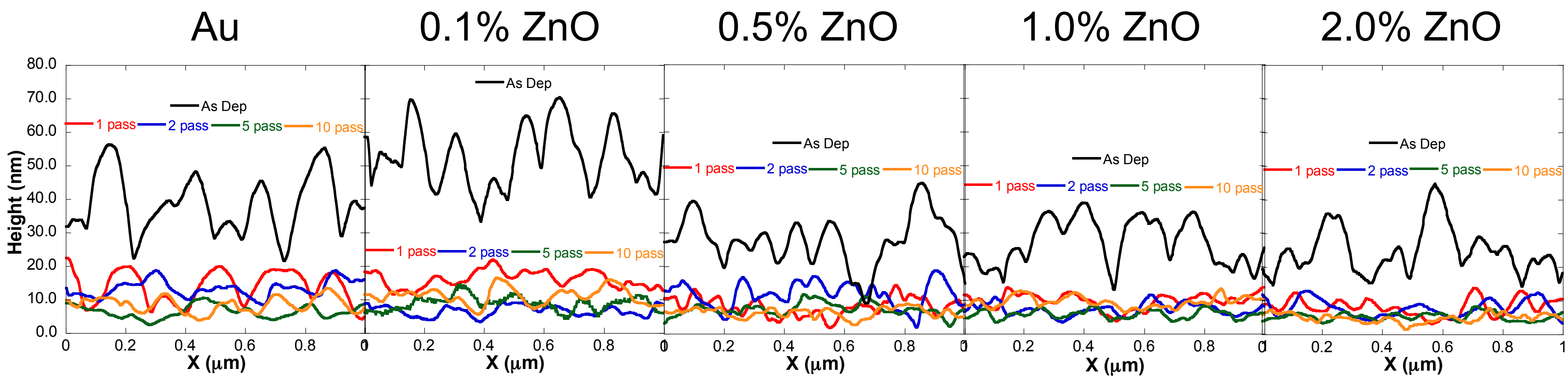
- Both the pure Au and 0.1% ZnO show significant wear track formation at 50 mN 10 pass condition.
- 0.5%, 1.0% and 2.0% films show likely grain refinement instead.

Comparison of 25 mN Wear Response



- Pure Au starts showing grain coalescence at lowest wear condition, followed by wear track formation in consecutive passes.
- 2.0% film shows little to no change in structure due to different wear conditions.

Evolution of Roughness Dependence on ZnO Concentration at 50 mN



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? ???????????????		?1?	sGM??? ?	sCM??? ?	zGM??? ?	eGM??? ?
?O? ???OA???		m2t u?	i o25 5?	m23o?	325t ?	321 3?
uo?μ?	i ???O O?	t 233?	t 2s C?	n2oo?	n2hu?	t 21 o?
	n???O O?	n2ou?	i 233?	t 2oo?	i 2Cu?	n23C?
	u???O O?	n2n3?	t 21 u?	i 2C5?	i 23s?	i 2t t ?
	i o???O O?	n21 3?	n2Cu?	i 2t i ?	i 2o5?	i 2os?

The effect of wear on film hardness

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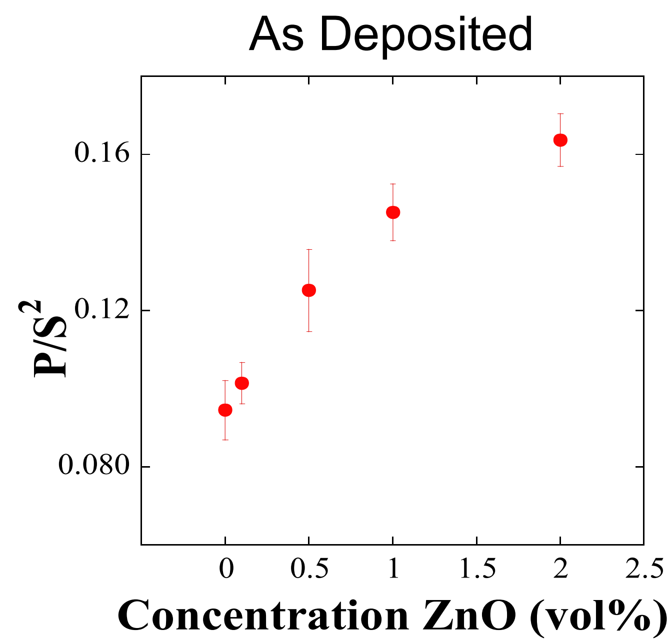
Indentation tests:

Peak load- 1250 mN

Loading rate- 200 mN/s

Hold segment- 30s

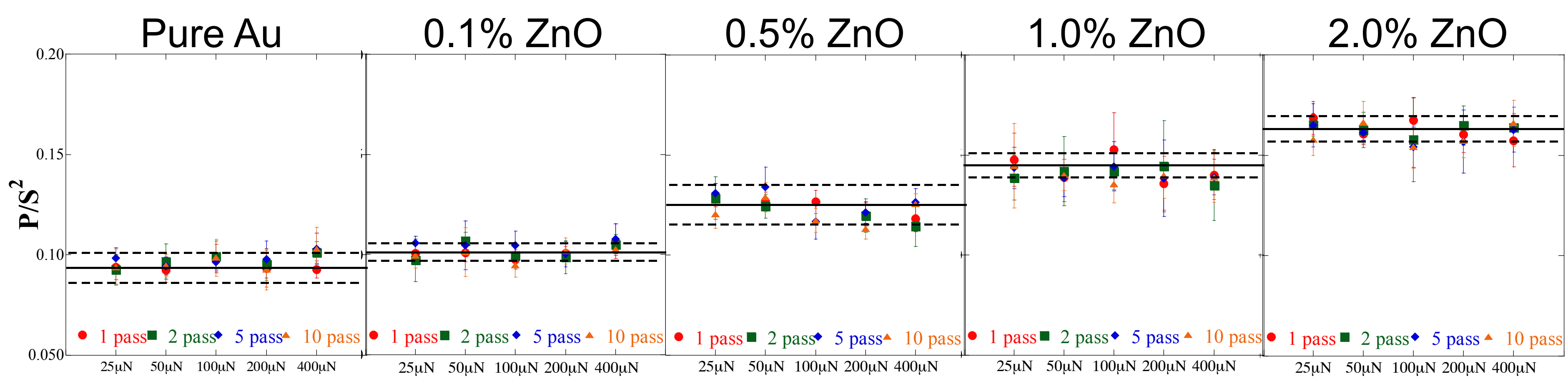
Depths < 15% of film thickness



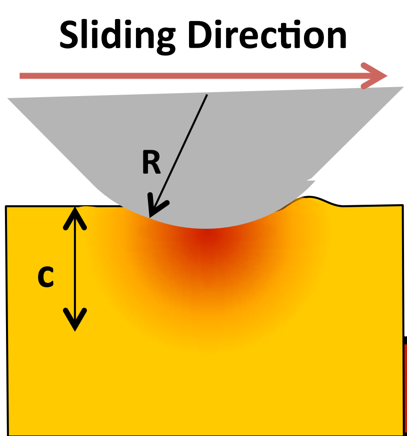
- Corrected hardness values for roughness and pile-up effects on contact area approximation

$$H \propto \frac{P}{S^2}$$

(nm²/µN)



Plastic Zone Size from Different Wear Loads



The total depth of plastic deformation is given by

$$c = \sqrt{\frac{3P}{2\pi\sigma_{ys}}} \quad \text{where} \quad \sigma_{ys} = \frac{H}{3}$$

Plastic Zone Size (nm)

Load (μN)	Au	0.1% ZnO	0.5% ZnO	1.0% ZnO	2.0% ZnO
			Hardness (MPa)		
	2362	2449	3159	3773	3865
25	123	121	106	97	96
50	174	171	151	138	136
100	246	242	213	195	193
200	348	342	301	276	272
400	493	484	426	390	385

The plastic zone size from indentation is larger than from wear indicating that material under the wear pattern is influencing results

Electrical Response of Wear-tested Composite Films

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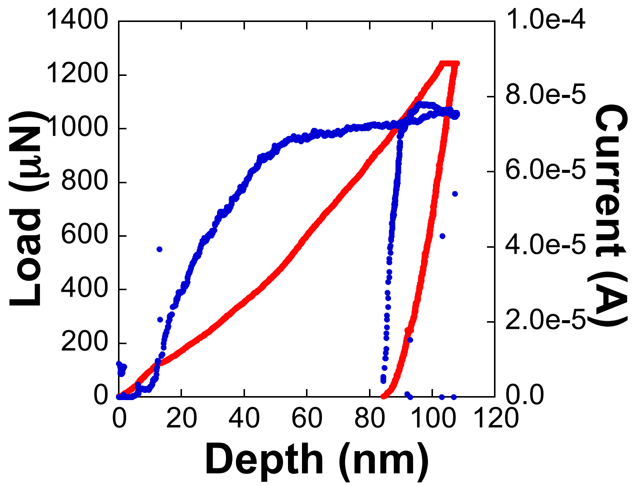
<u>NanoECR</u>



Conducting Indentation:

Peak Load- 1250 mN

Loading Rate- 200 mN/s

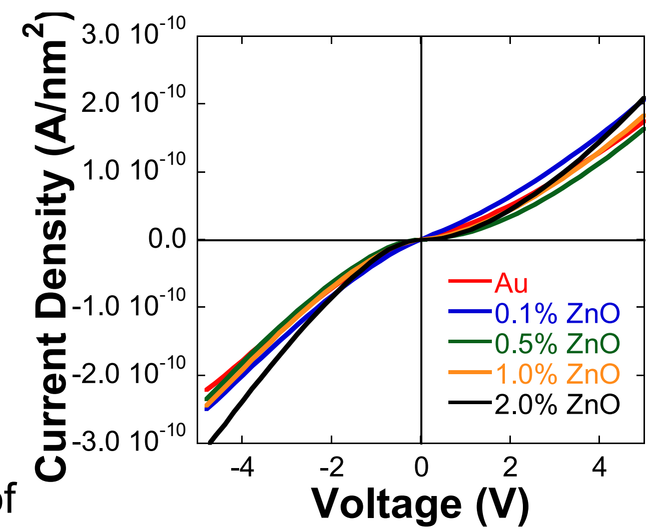
Hold Segment- 30 s

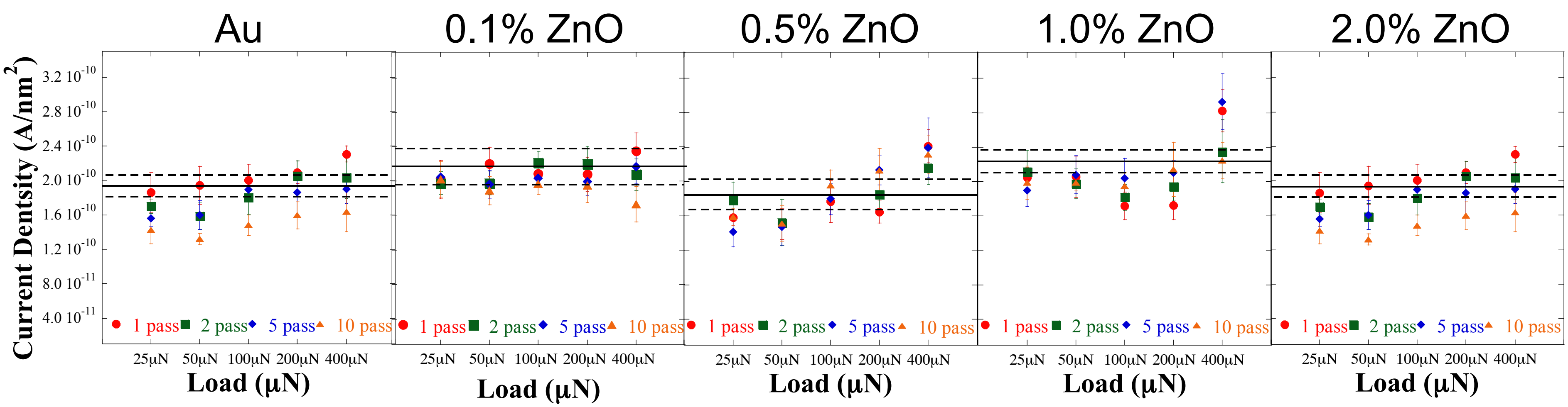
Applied Voltage- 5 V

I-V sweep:

Voltage- -5 V to 5 V

Measured at beginning of unload





Summary

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Structure

- Slight reduction in grain size with addition of ZnO particles.
- Reduction in (111) texture of as deposited films with ZnO particle addition.

Mechanical Properties

- Increased hardness with increasing concentration of ZnO particles.
- Different wear conditions have a negligible effect on the hardness of the films suggesting little dislocation storage.

Topological Observations

- Increasing wear resistance and possible grain refinement as the concentration of ZnO increases above 0.1% ZnO.

Electrical Properties

- No significant degradation is seen due to ZnO concentrations (less than 2.0 vol%) or any of the wear conditions used in this study.