Wyoming NSF/EPSCoR Undergraduate Research Fellowship

Nanoindentation of Polymers

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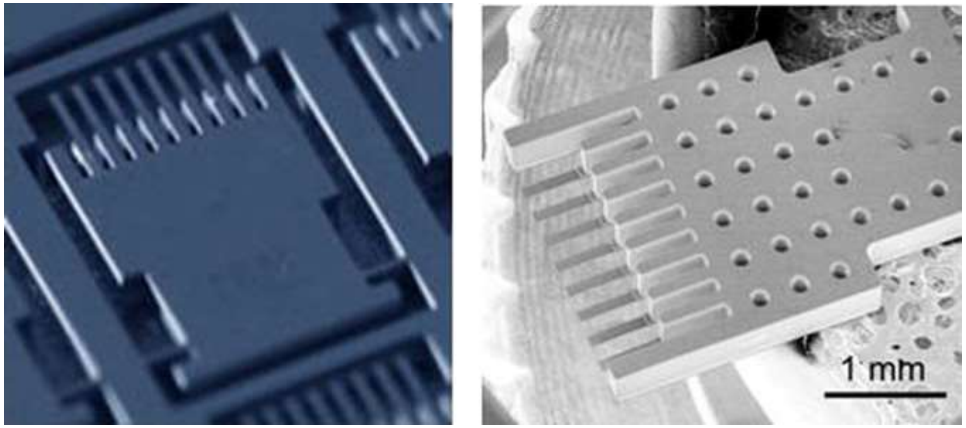
Small-scale polymers

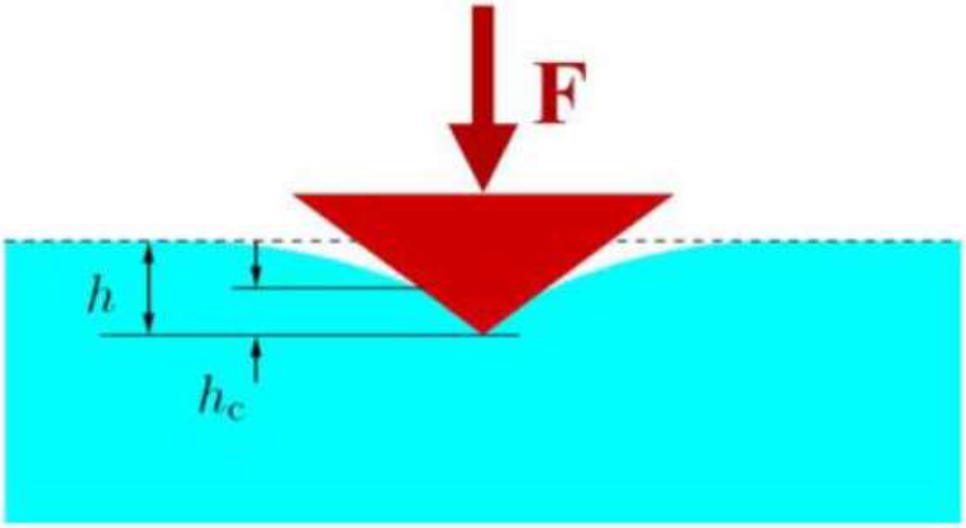
- Coatings and adhesives
- Micromechanical devices
- Biomedical microdevices
- Composites



Boisen, A. et al. (2011). [Figure 8] "Cantilever-like micromechanical sensors," *Reports on Progress in Physics*, 74.

- Engineers use mechanical properties to safely predict the behavior of objects under applied loads.
- It is important to understand the properties of polymers at very small scales.

Hardness: the resistance of a material to permanent penetration by another significantly harder material



On the macroscale, material properties like hardness are constant.

Indentation Size Effects (ISE): the apparent increase in material-specific properties at very small scales

Metals

- ISE well documented, well understood

Polymers

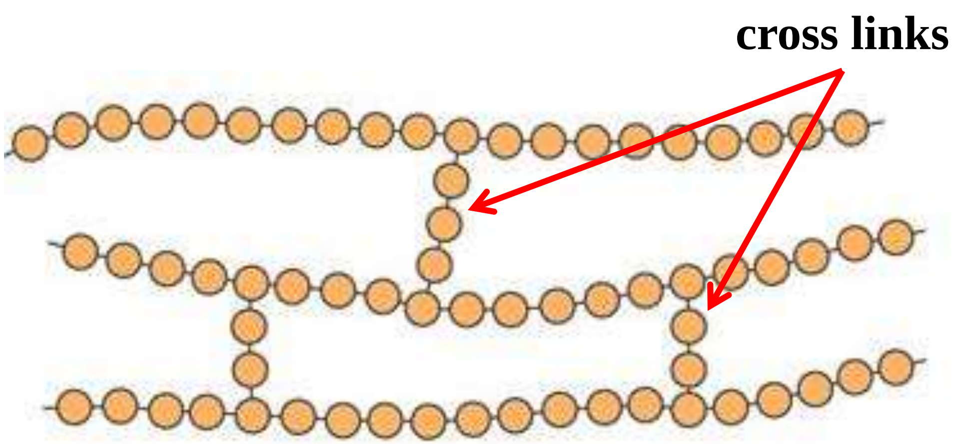
- ISE not well document, not well understood

Research

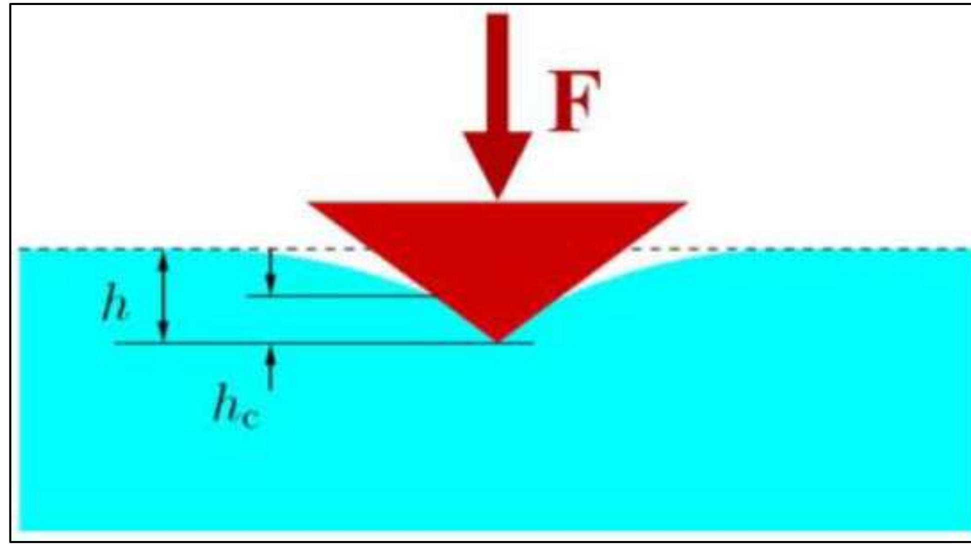
- Study ISE in polymers, using **polydimethylsiloxane (PDMS)**
- Improve the understanding of ISE in polymers
- Help develop physically based theories to model and explain ISE in polymers

1. **ISE can be observed in PDMS.**

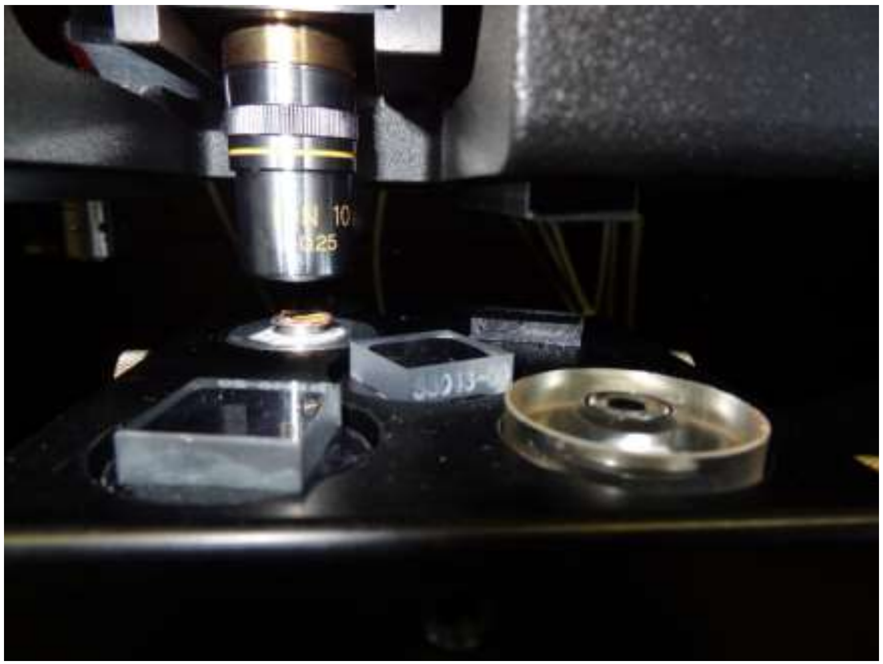
2. **These ISE vary with different cross-link densities.**



Callister, W. (2010). [Figure 14.7] “Materials Science and Engineering: An Introduction, 8th ed.”

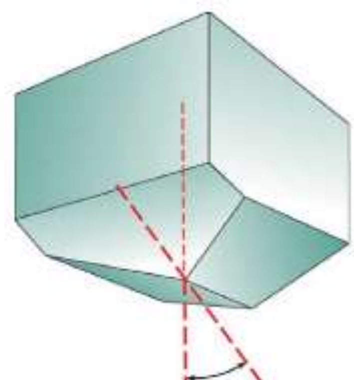


Nanoindenter tip under a load, *F*, displacing a material to an indentation depth, *h*

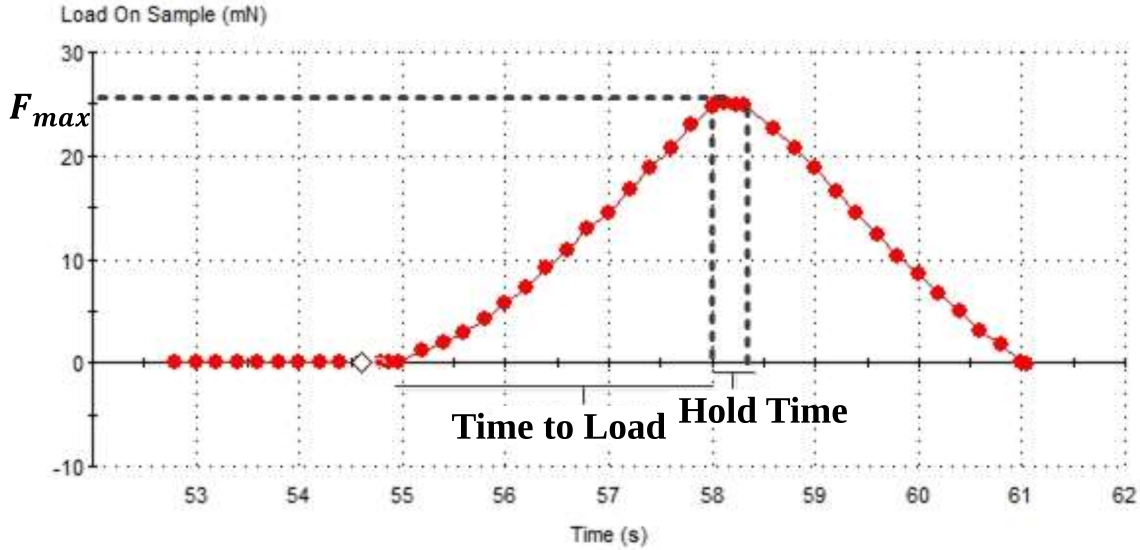


G200 Nano Indenter™

Agilent Technologies

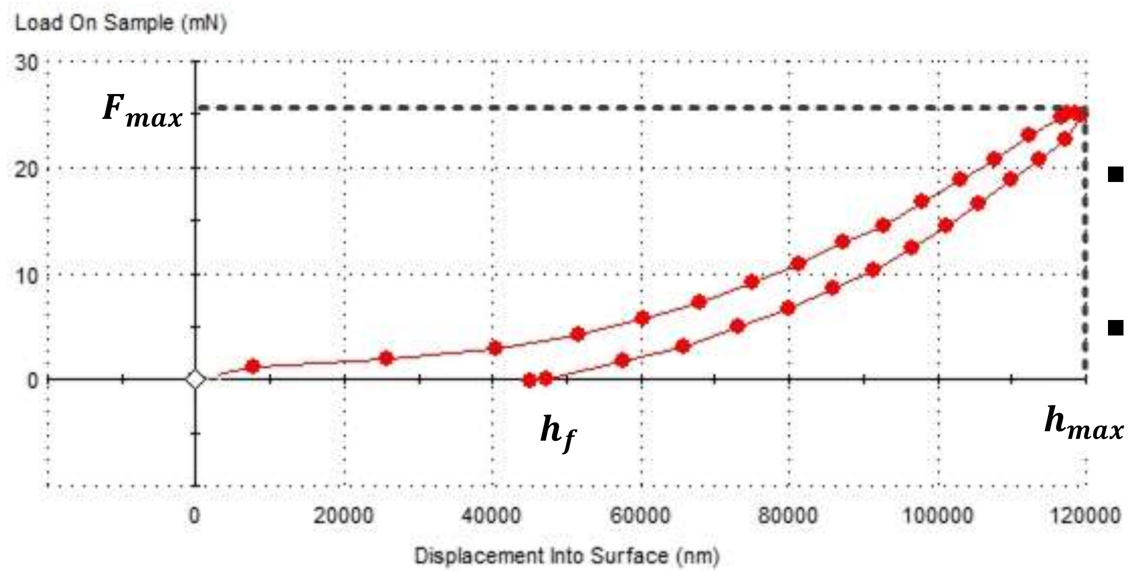


Berkovich indenter tip



Parameters

- Surface Approach Sensitivity, K_{tol}
- Time to Load
- Hold Time
- Maximum Load, F_{max}



Results

- Maximum Indentation Depth, h_{max}
- Permanent Indentation Depth, h_f

Cross-Link Densities

- **2.5%**
- **5%**
- **10%**

Parameters

- Time to Load: **5 seconds**
- Hold Time: **0 seconds**
- Surface Approach Sensitivity, K_{tol}: **50 N/m**
- Maximum Load, F_{max}: **0.3 mN to 45 mN**

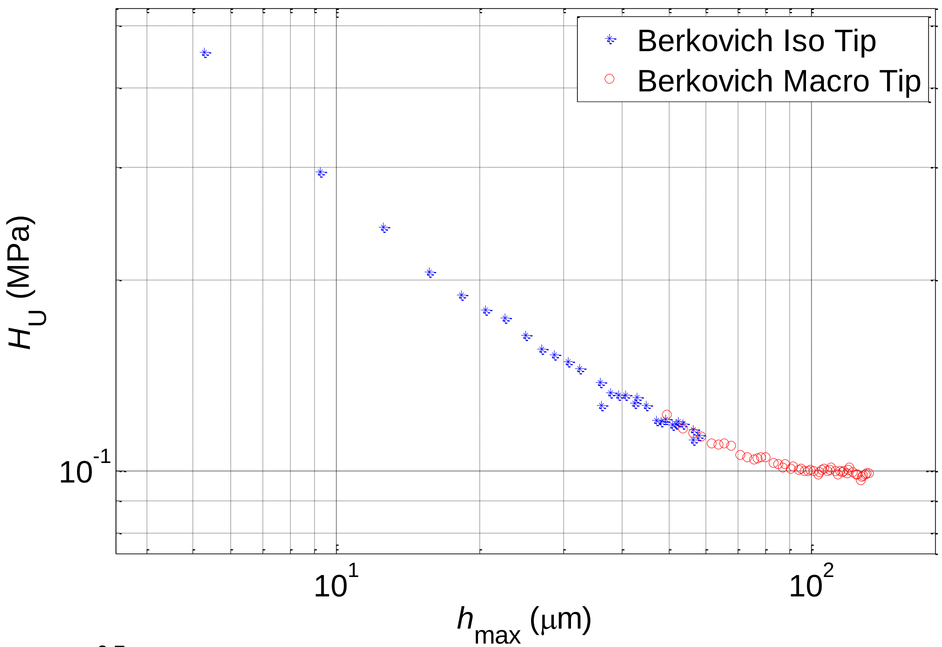
Berkovich Tip Sizes

- 0.3 mN to 10 mN: “Berkovich ISO Tip”
- 8 mN to 45 mN: “Berkovich MACRO Tip”

Results for 5% cross-link density

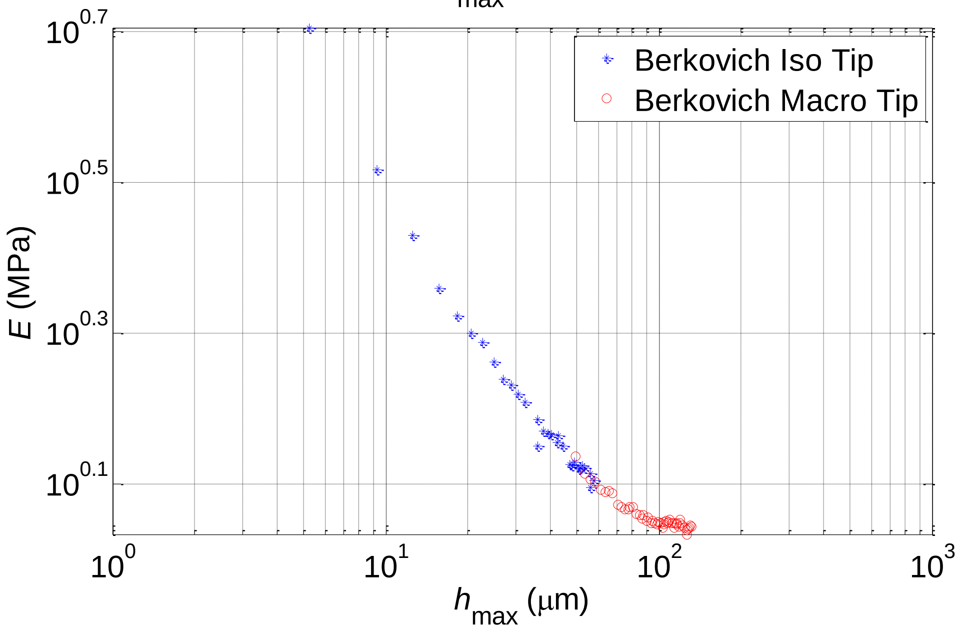
- **Universal Hardness, H_U**

$$H_U = \frac{F}{26.43h^2}$$ [1]

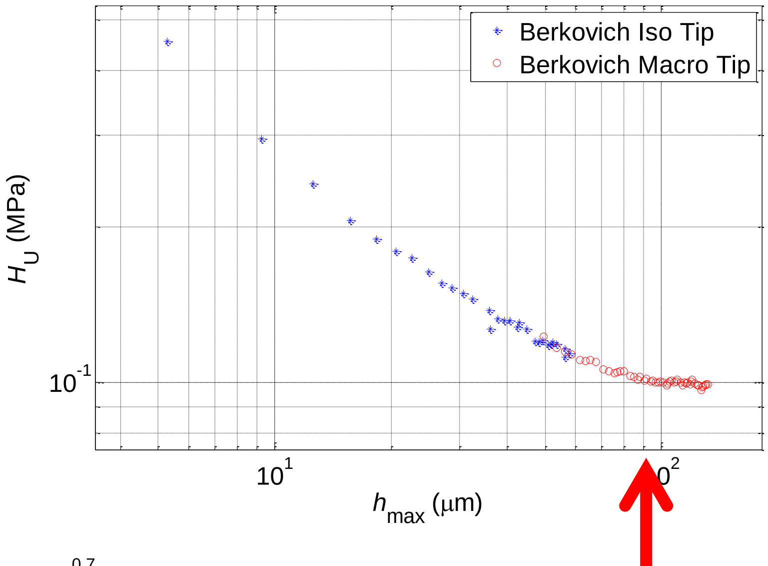


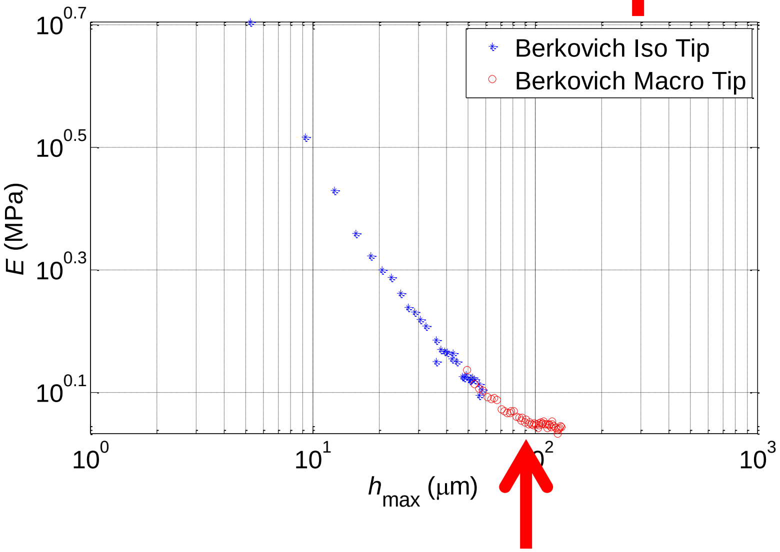
- **Elastic Modulus, E**

$$F = \frac{2E\tan\alpha}{\pi(1-v^2)}h^2$$ [2]



1. ISO 14577-1 Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 1: test method. *International Organization for Standardization* (2002).
2. Sneddon, I. "The relation between load and penetration in the axisymmetric boussinesq problem for a punch of arbitrary profile." *Int. J. Eng. Sci.* 3. (1965): 47-57.



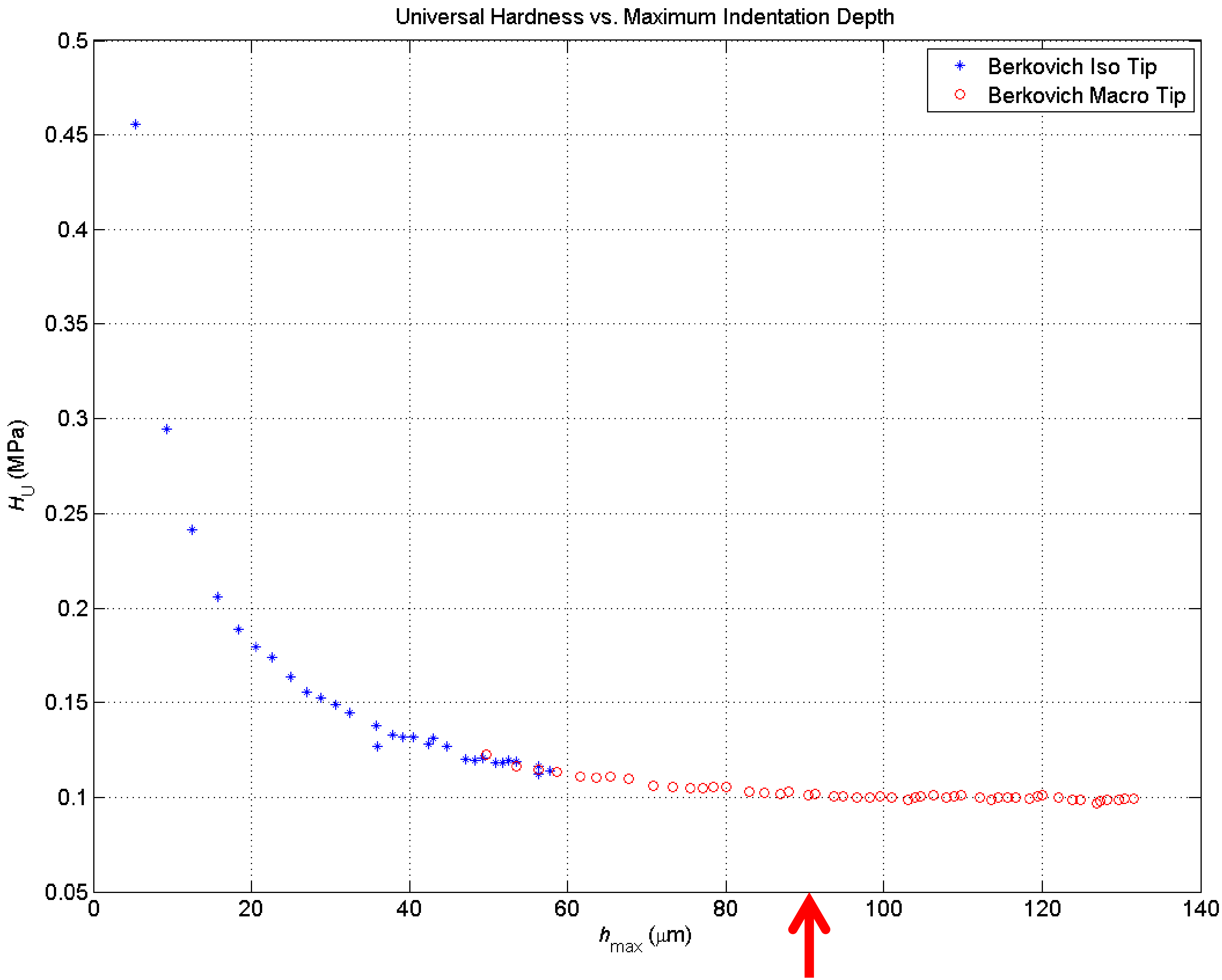


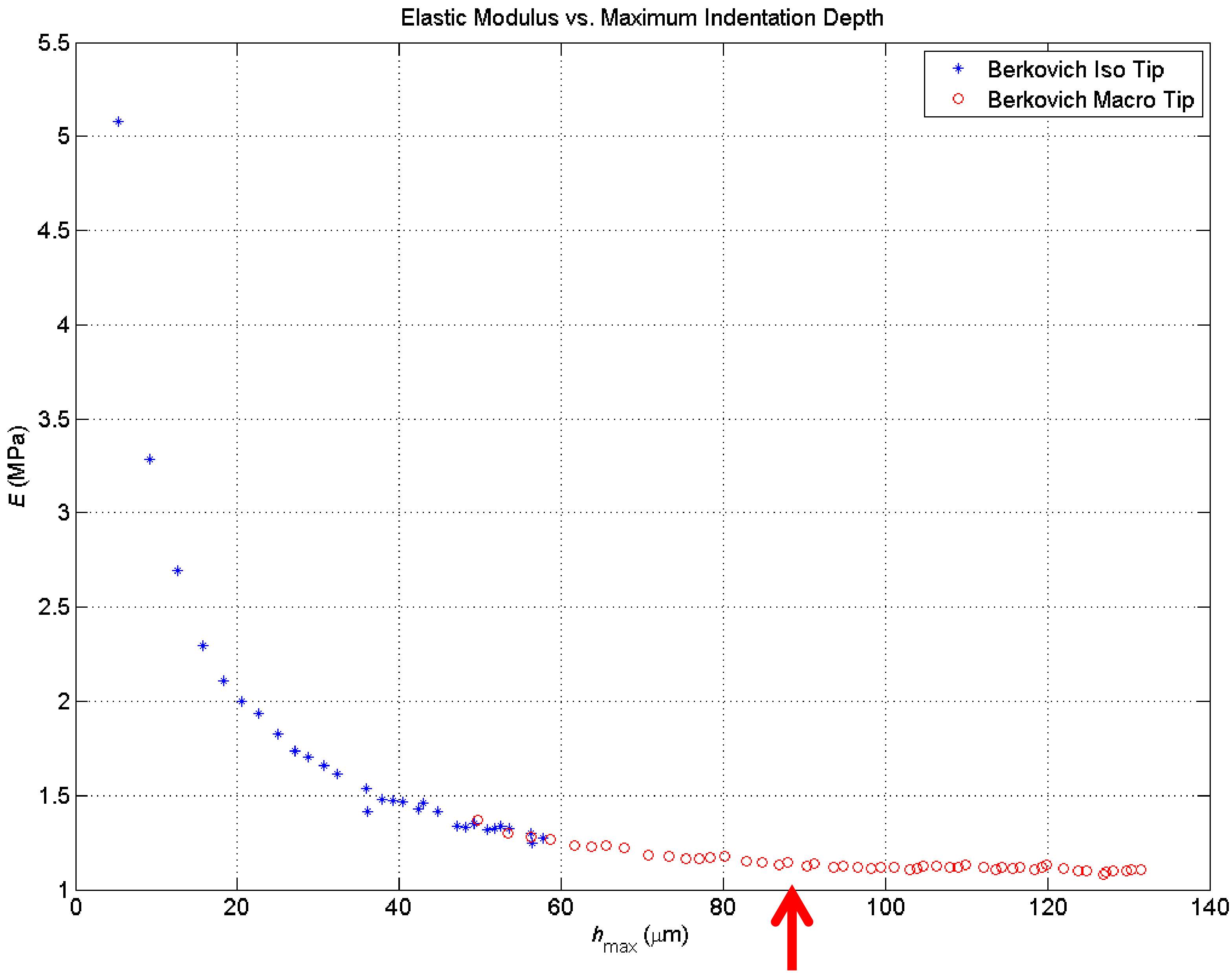
Two important characteristics:

1. Drastic increase with decreasing indentation depths below 90 μm

2. Reach transient quantity as indentation depths increase above 90 μm

Indentation Size Effects

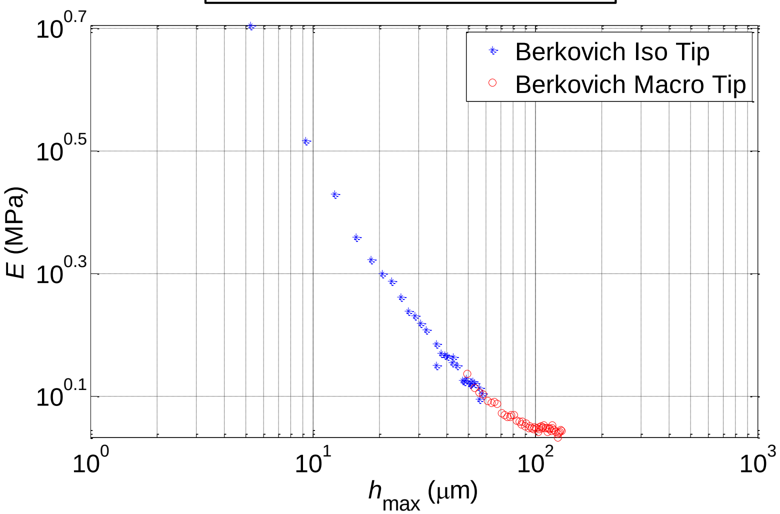

Universal Hardness vs. Maximum Indentation Depth
Berkovich Iso Tip
Berkovich Macro Tip
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
20
40
60
80
100
120
140
H_U (MPa)
h_max (μm)


Elastic Modulus vs. Maximum Indentation Depth
Berkovich Iso Tip
Berkovich Macro Tip
E (MPa)
h max (μm)
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0
20
40
60
80
100
120
140

Elastic Modulus

- The material property, elastic modulus, does not actually increase.
- Has been shown to be constant by lab member, Seyed Hamid Reza Sanei.
- The problem is how the test results are used to calculate elastic modulus.
- Classical continuum theories do not account for strain gradients.

$$F = \frac{2E\tan\alpha}{\pi(1 - v^2)}h^2$$



spherical indenter tip

➢ This research will help shed light on the shortcomings of classical continuum theory.

Unanswered Question: How does ISE vary with cross-link density?

Current Project Goals:

1. Determine appropriate surface approach sensitivity criteria, K_{tol}.

2. Repeat testing for 2.5%, 5%, and 10% with new K_{tol}.

3. Repeat experimental procedure for epoxy.

4. Interpret for a manuscript to be submitted for publication in an international scientific journal.

Thank you for your attention.

Special Thanks to Dr. Han and EPSCoR.

Questions?