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Experimental Study of Crackling Noise as Micro-mechanics of Flow

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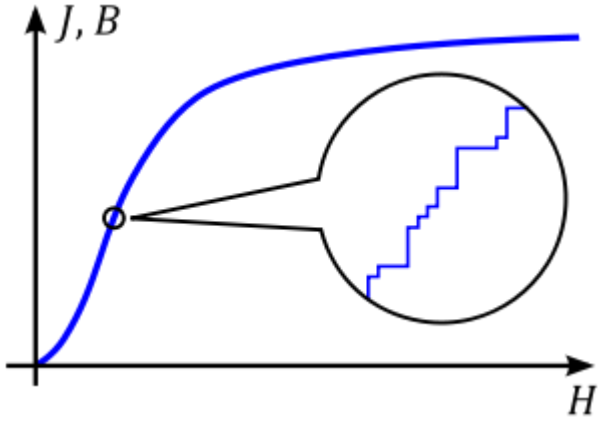
Part of the LIGO SURF programme 2015
California Institute of Technology

Motivation for Crackling Noise

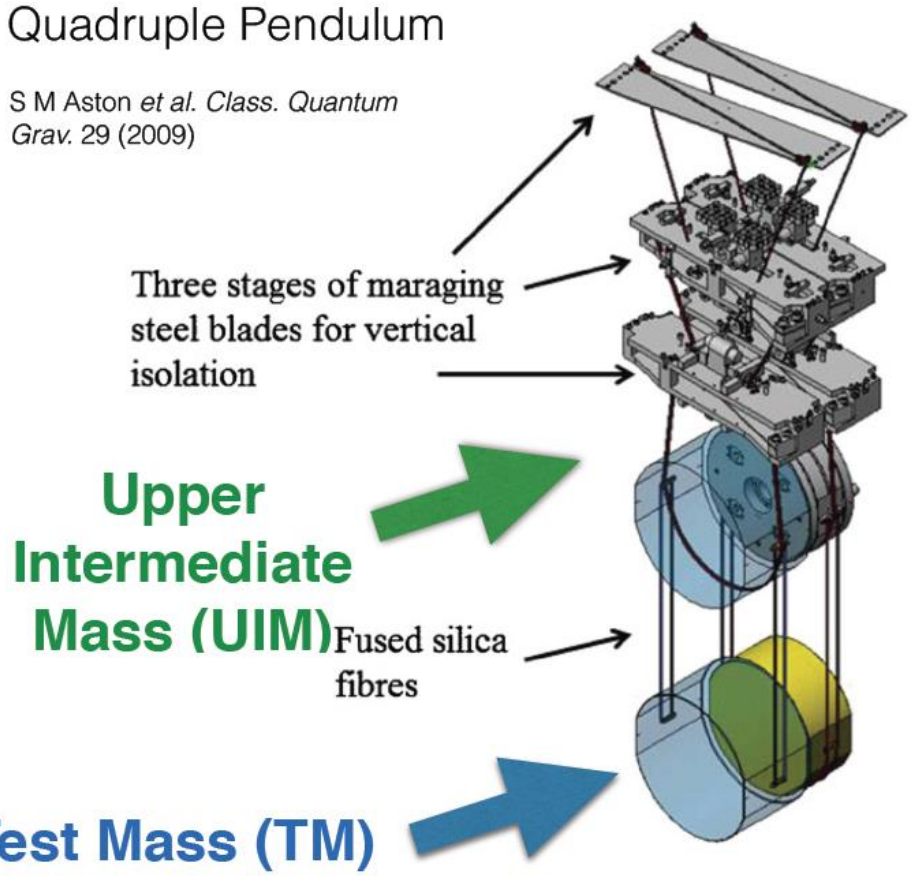
- Barkhausen noise in magnetisation



Wikimedia Commons

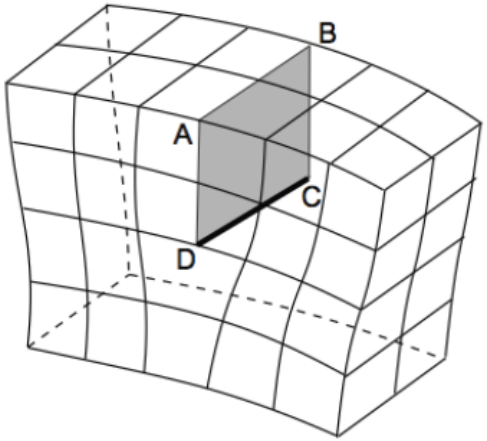
- Stochastic

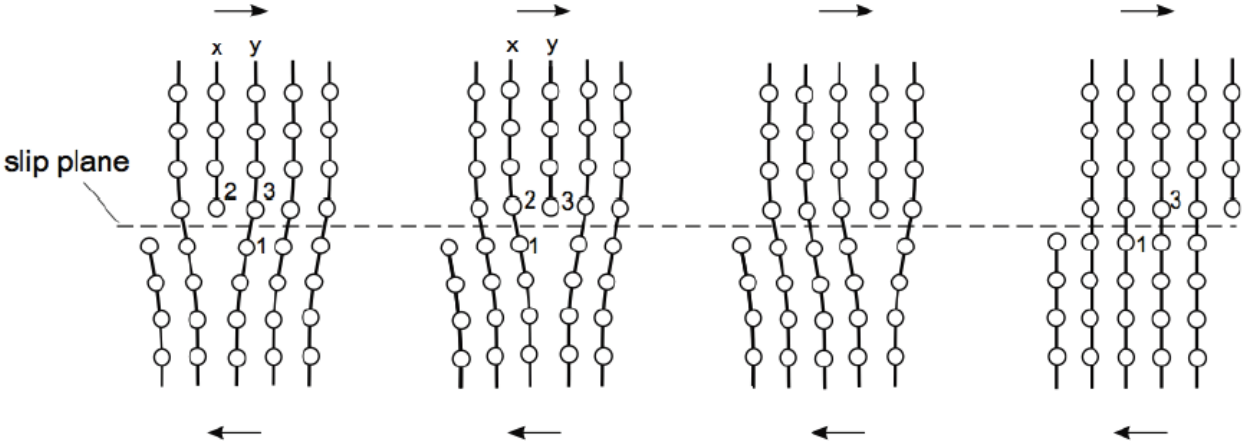
Crackling Noise in aLIGO



Potential Source?

Dislocations are the disjunctions in periodic structure

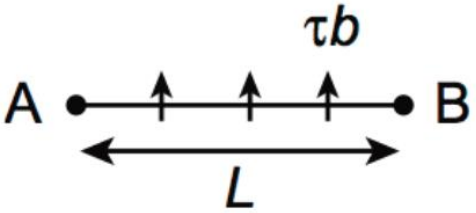


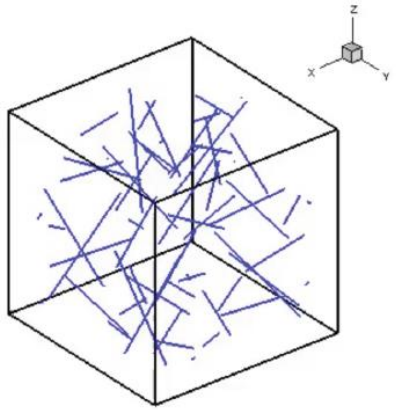


D. Hull, D. J. Bacon, Introduction to Dislocations, 4th ed., Butterworth Heinemann, Oxford (2001)

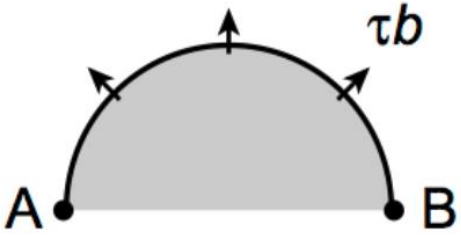
Potential Source?

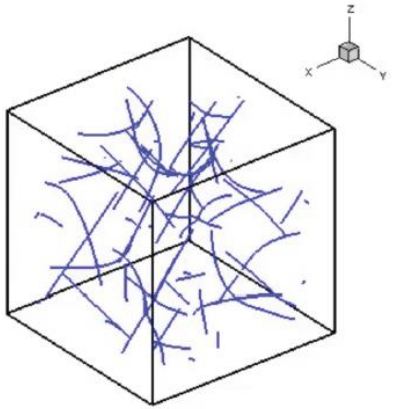
Non-linear collective behaviour of pinned dislocations





Orowan Bowing



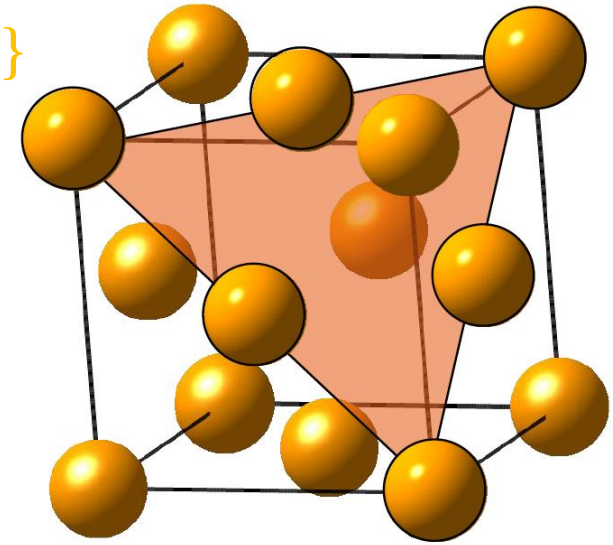


X. Ni ,What is Crackling Noise: a Study of Micro-mechanics of Flow in Metals (2015)

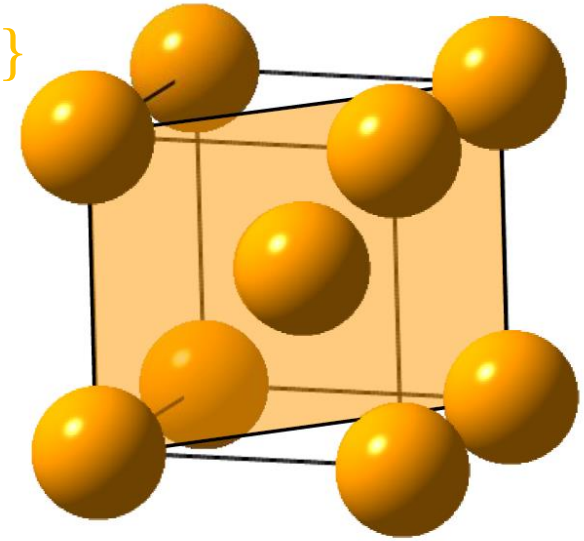
Then, how to study?

- Pure Copper > Maraging Steel
- fcc > bcc
- Well-defined slip planes

{111}



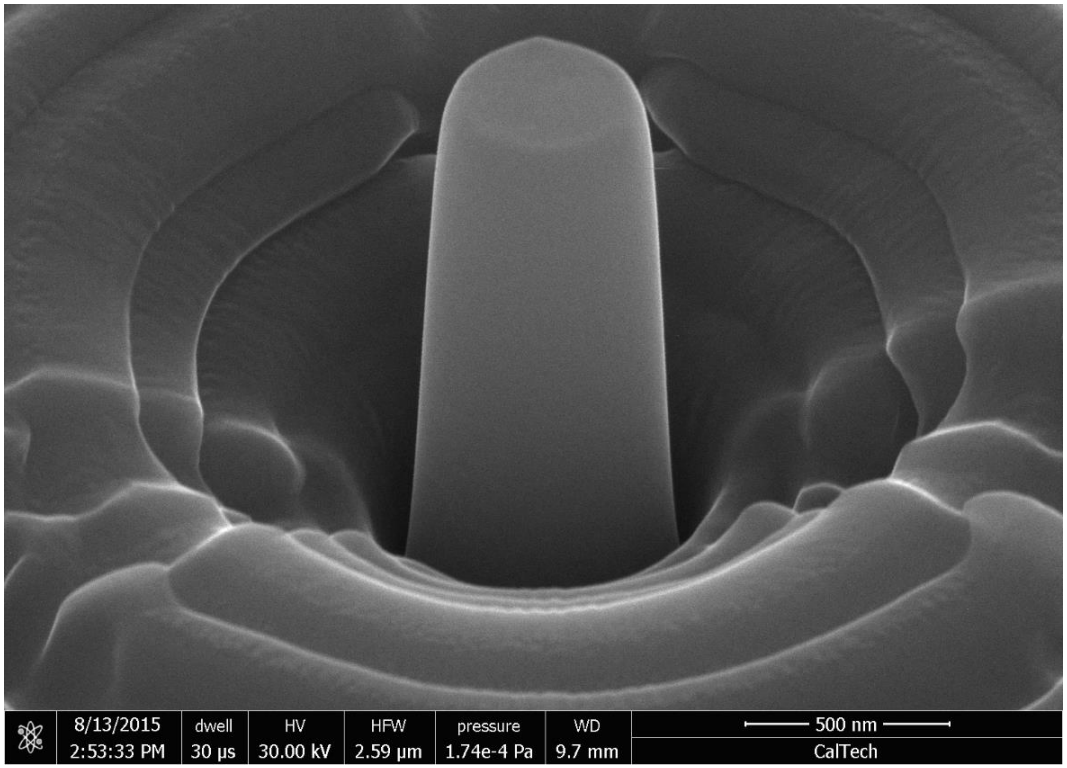
{110}



MSM Part IA Course D Handout, University of Cambridge (2014)

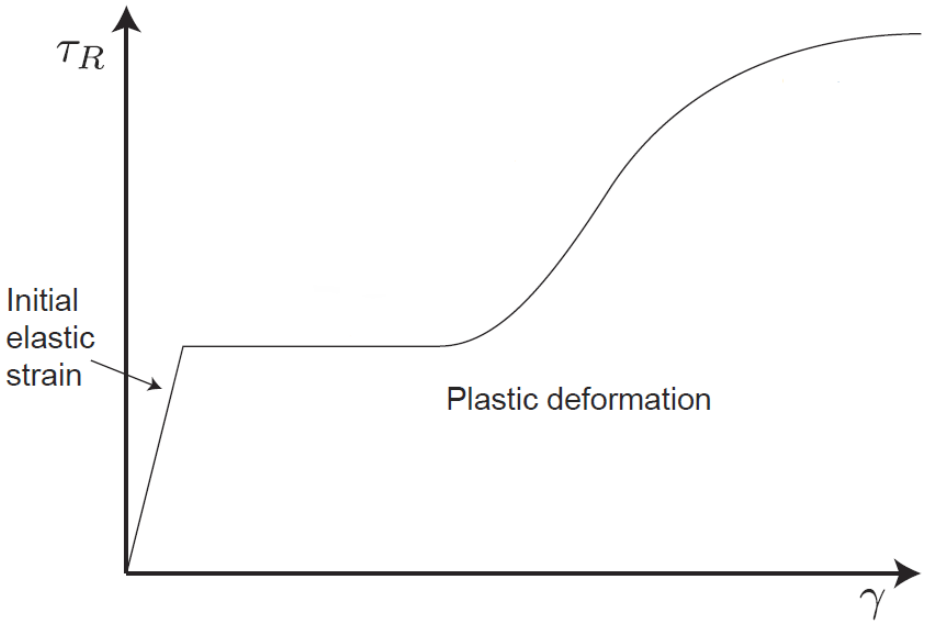
Then, how to study?

- Monocrystalline Cu nanopillars: 500x1500 nm (1:3)

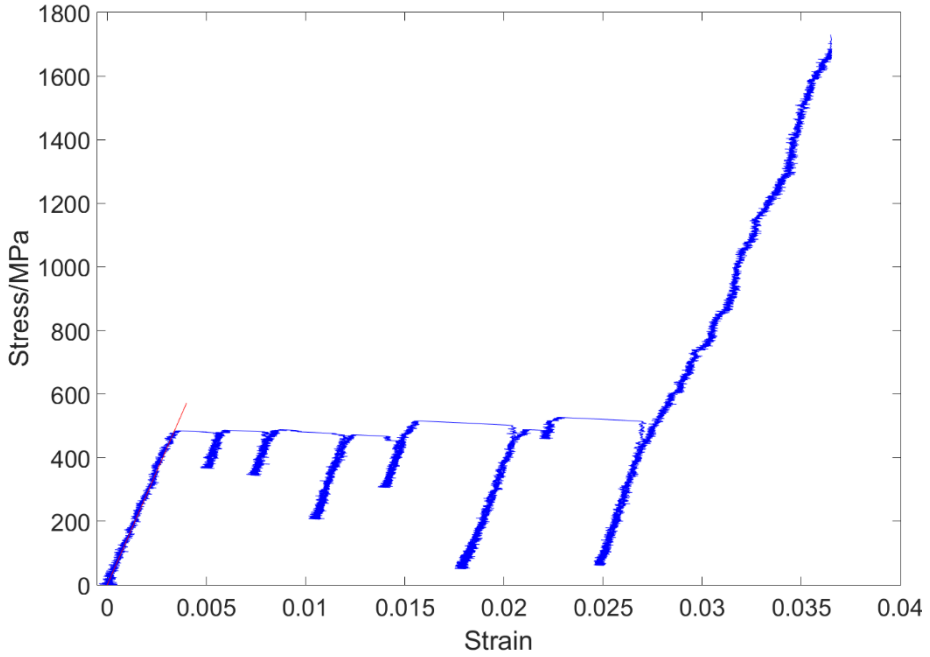


Why Nanopillars?

Bulk

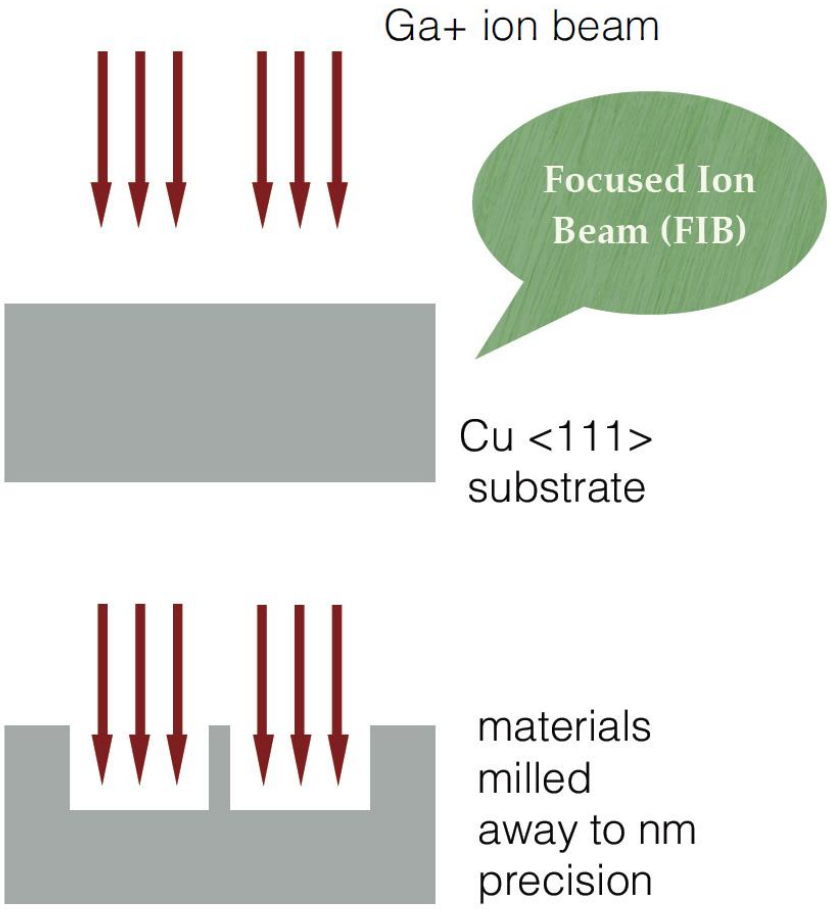


Nanopillar



MSM Part IA Course D Handout,
University of Cambridge (2014)

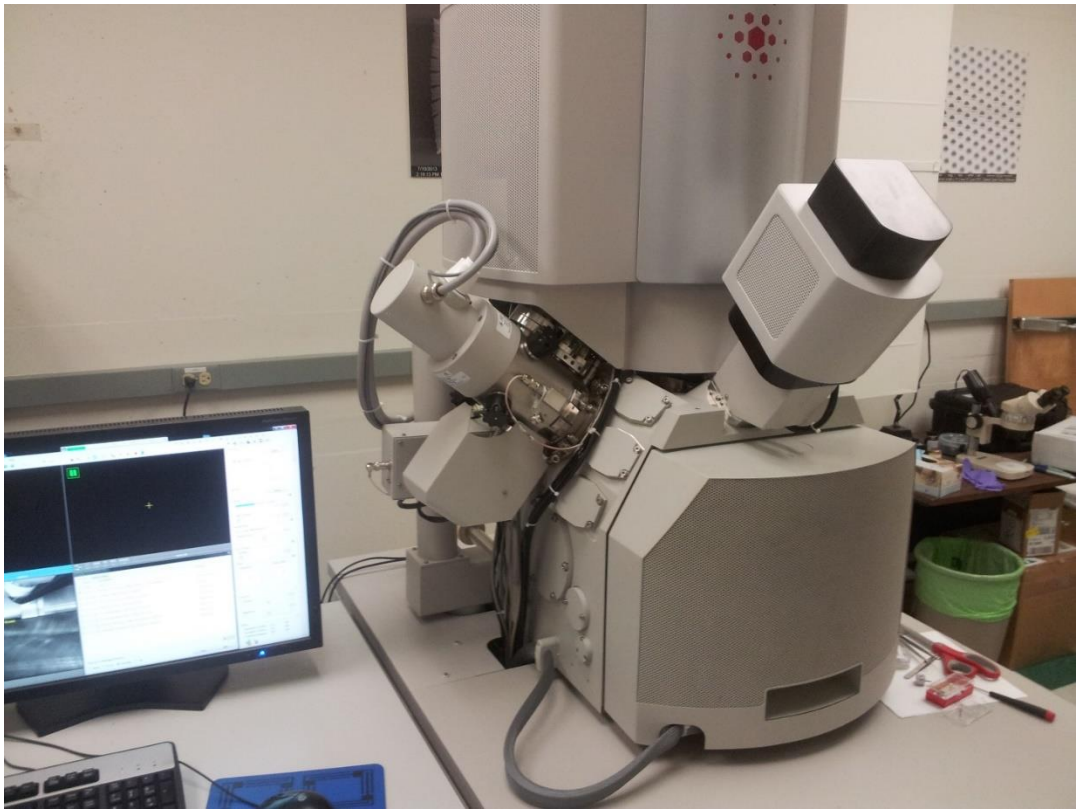
Focused Ion Beam (FIB)



X. Ni, What is Crackling Noise: a Study of Micro-mechanics of Flow in Metals (2015)

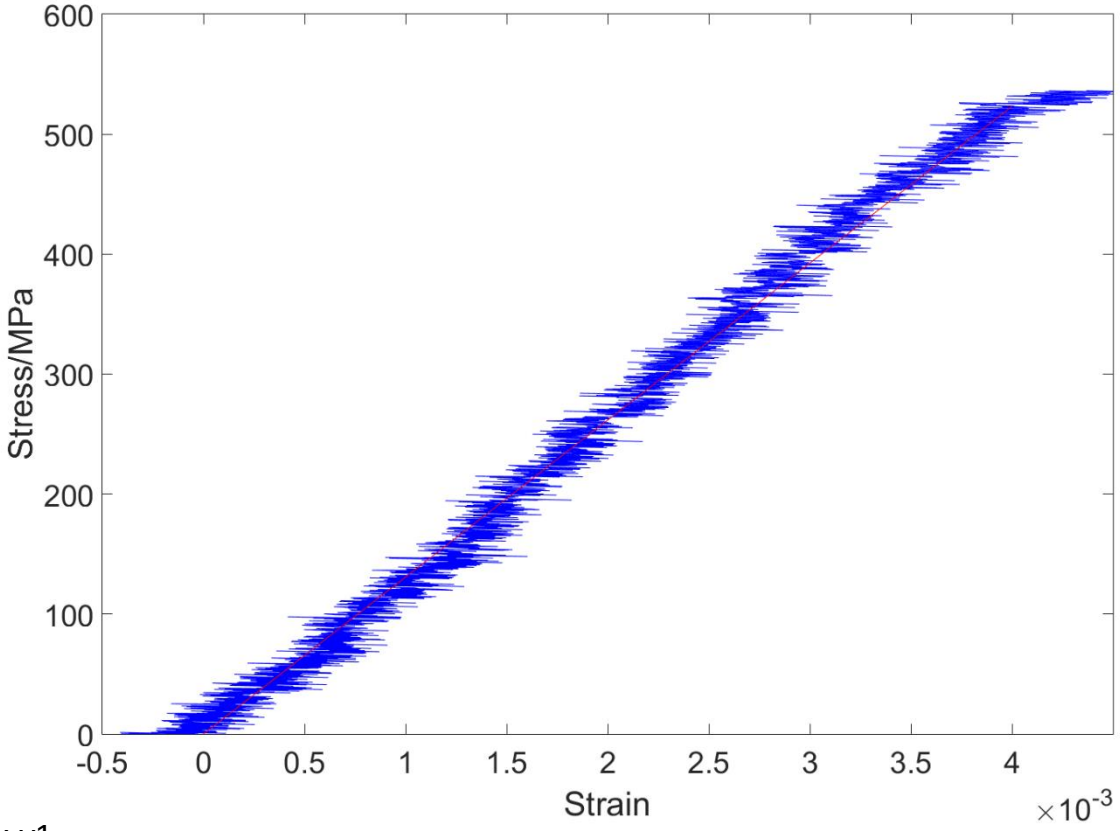
Focused Ion Beam (FIB)

FEI® Versa 3D



Well, what's the problem?

- Too much noise



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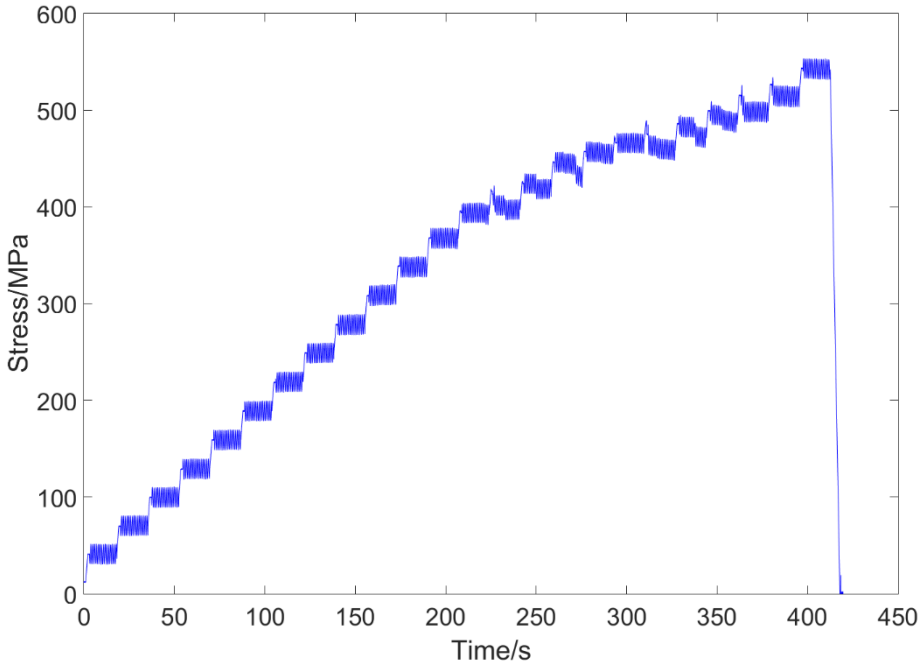
Alternative approach?

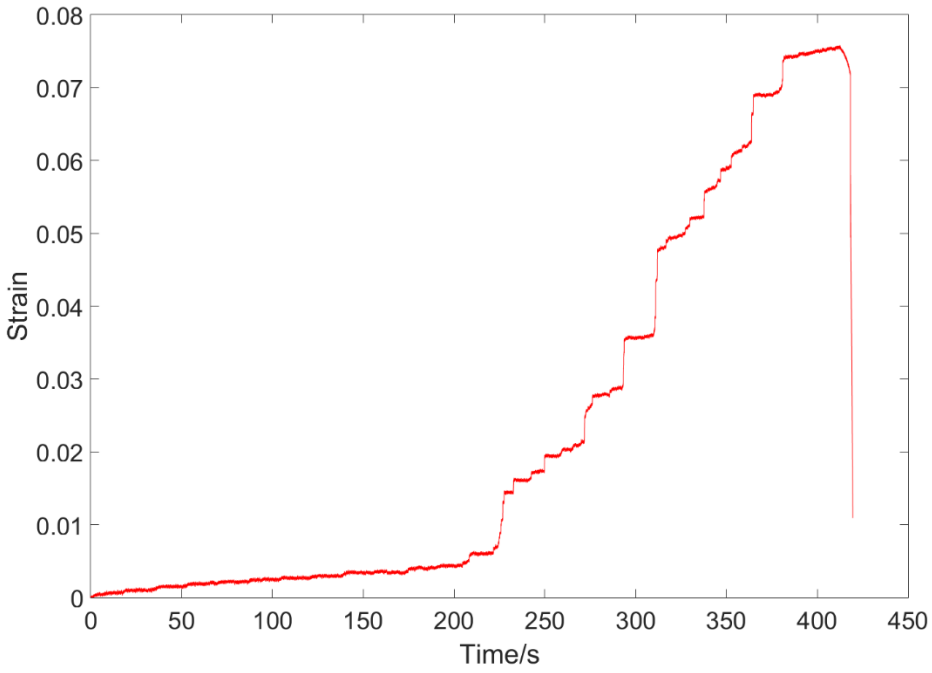
- Energy dissipation
- *Dynamic Mechanical Analysis (DMA)*

Dynamic Mechanical Analysis (DMA)

$$\sigma(t) = \sigma_0 \sin(\omega t)$$

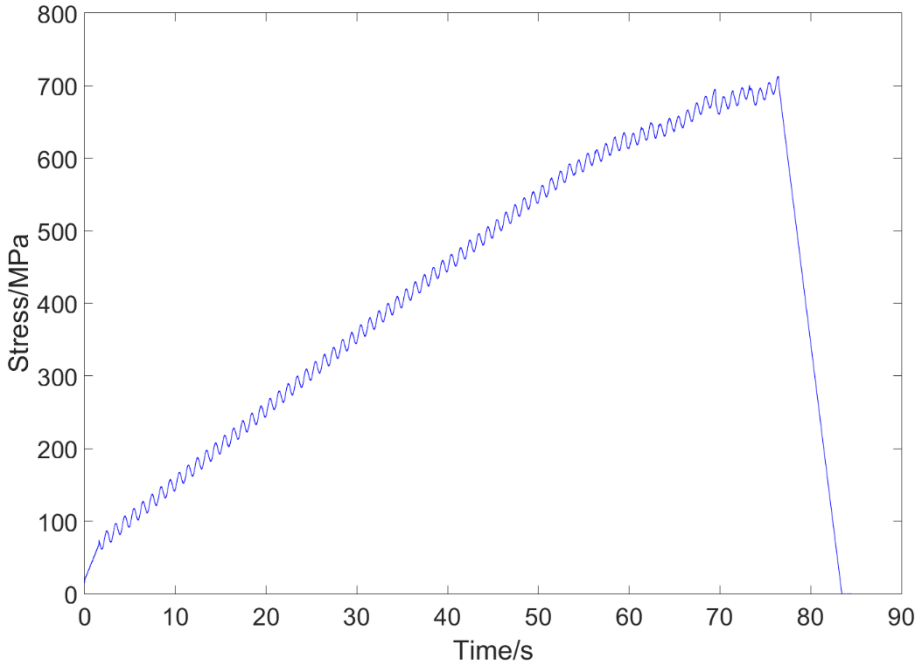


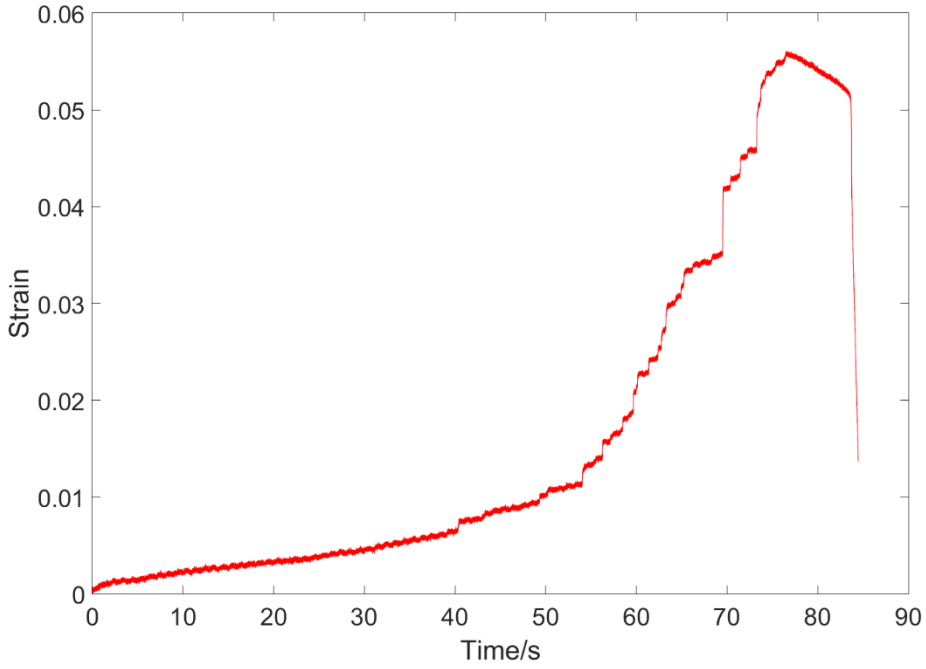
$$\varepsilon(t) = \varepsilon_0 \sin(\omega t - \phi)$$



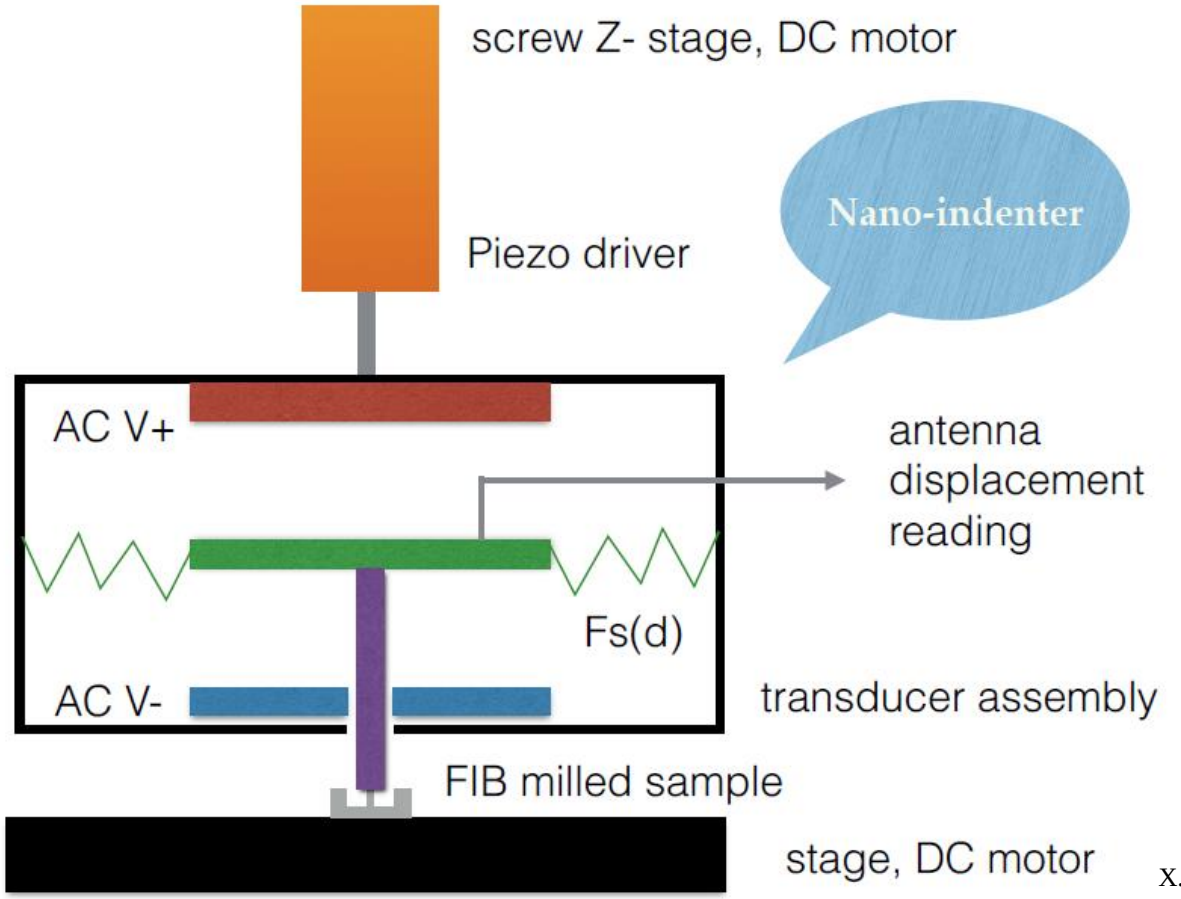
Dynamic Mechanical Analysis (DMA)

Continuous DMA





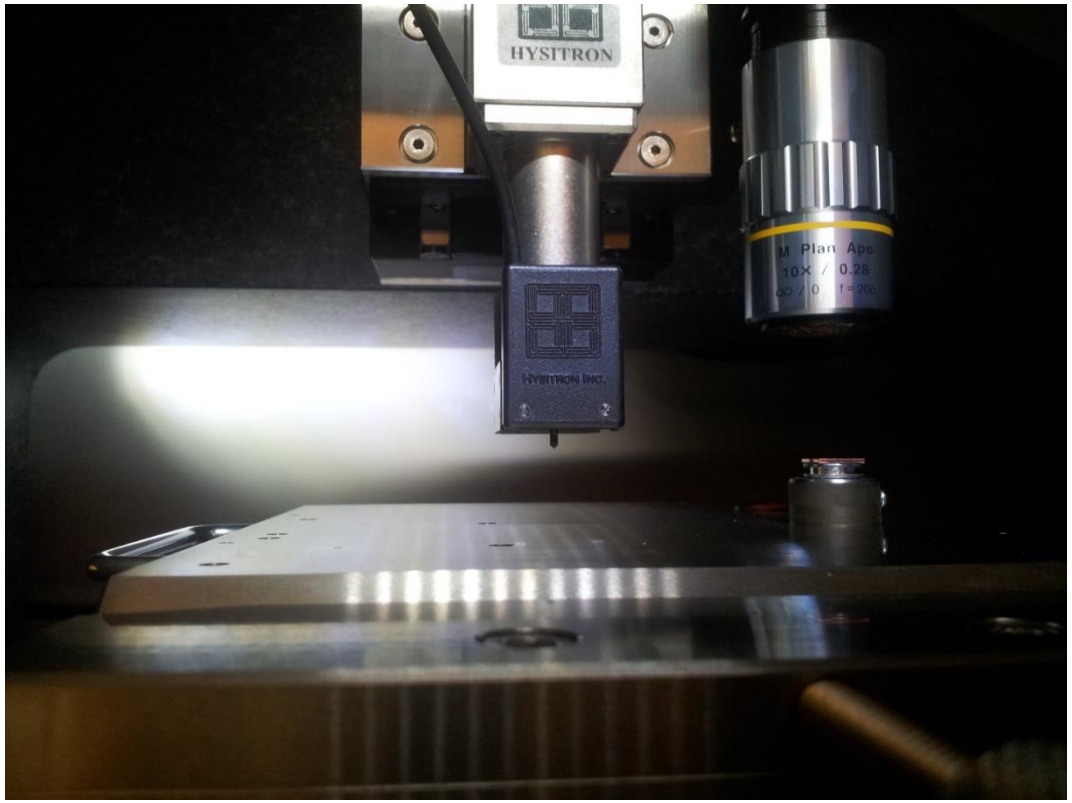
Dynamic Mechanical Analysis (DMA)



X. Ni , What is Crackling Noise: a Study of Micro-mechanics of Flow in Metals (2015)

Dynamic Mechanical Analysis (DMA)

Hysitron® Triboindenter



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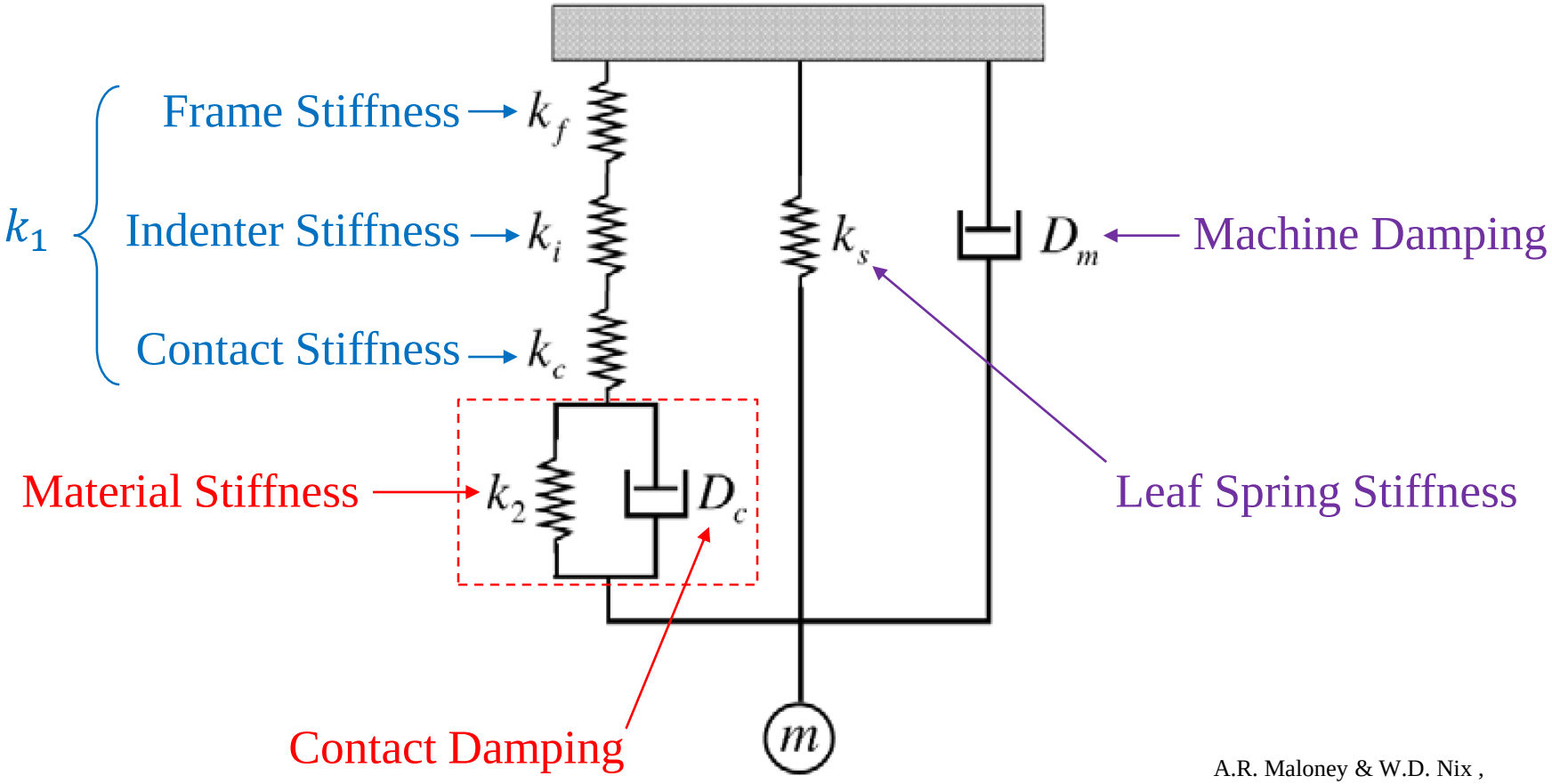
Dynamic Moduli

$$E = E_{storage} + iE_{loss}$$

$$E \equiv \frac{\sigma_0}{\varepsilon_0}(\cos\phi + i\sin\phi)$$

Standard Linear Model of Solids

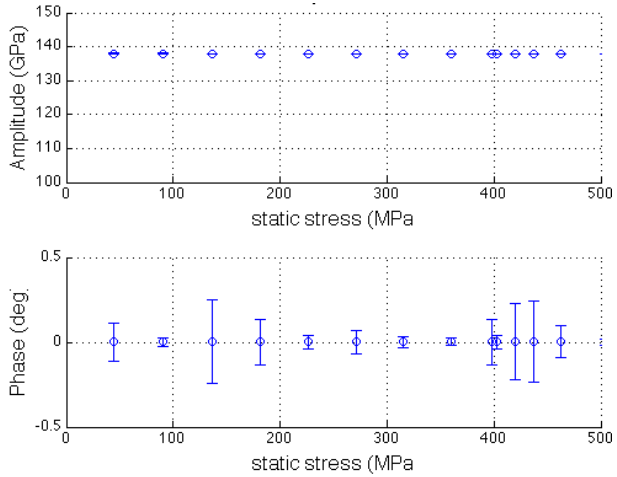


A.R. Maloney & W.D. Nix ,
An Improved Analysis for Viscoelastic Damping in Dynamic Nanoindentation (2007)

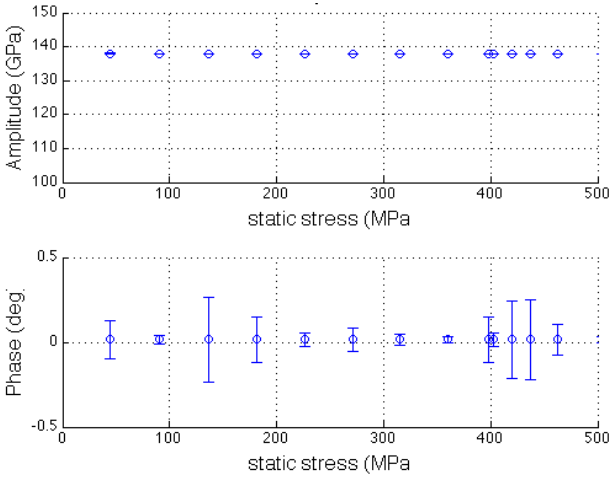
Results for Cu 500nm

Theoretical results

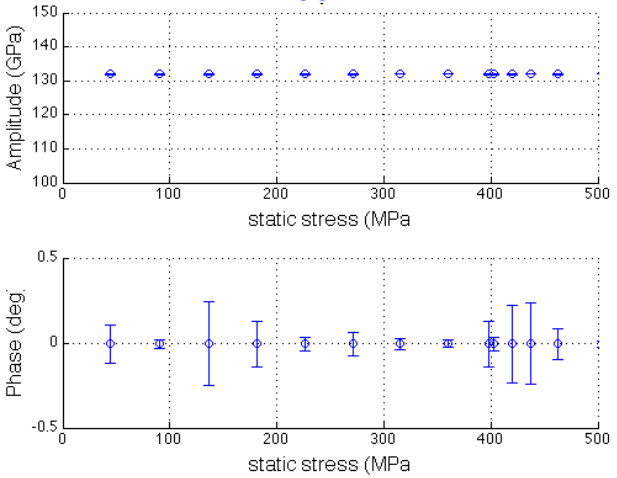
1 Hz



10 Hz

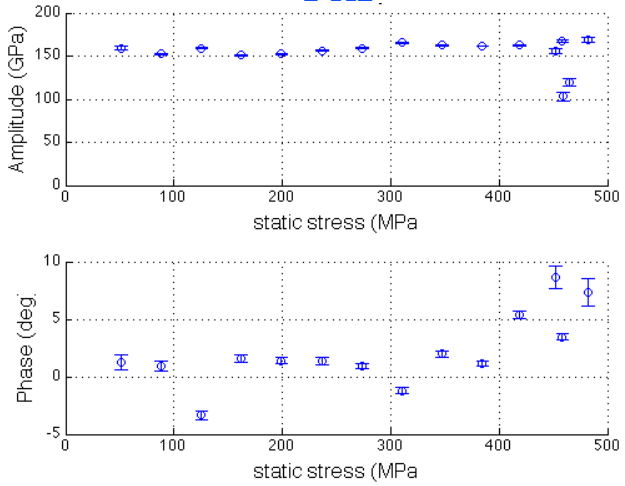


200 Hz

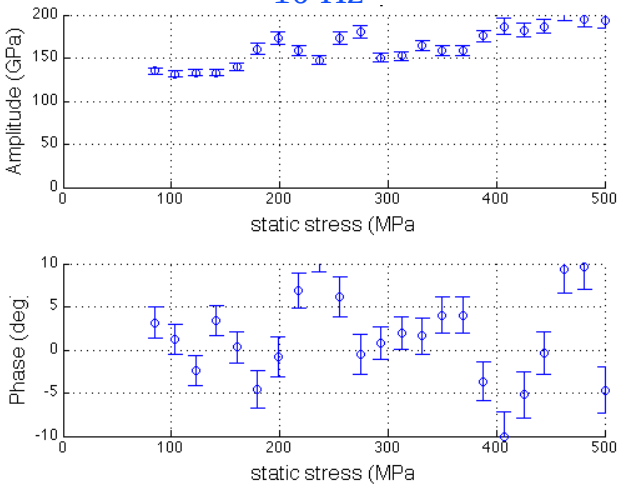


Experimental results

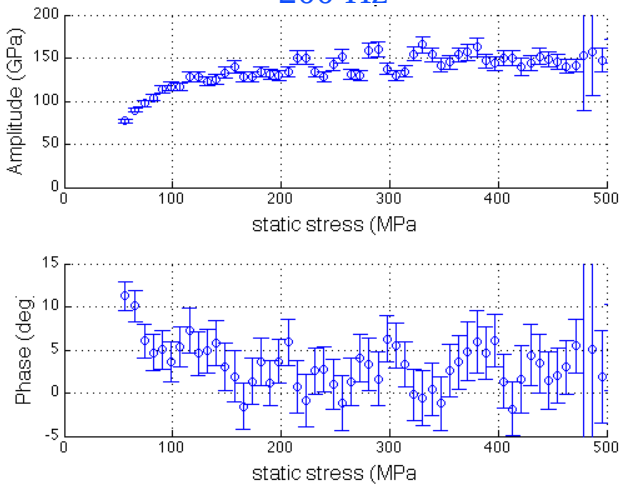
1 Hz



10 Hz



200 Hz



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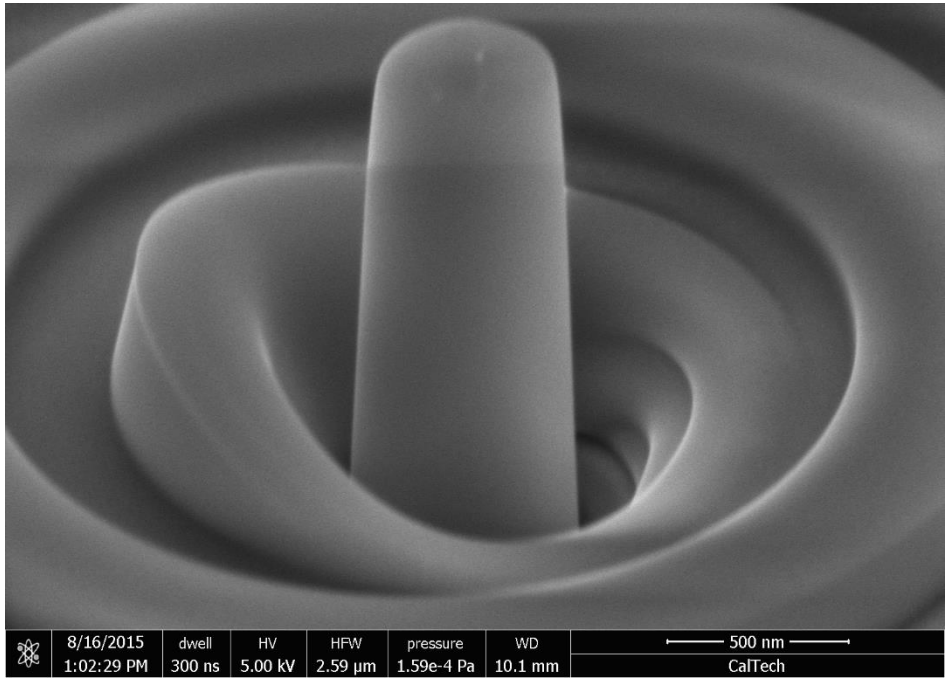
But…how can we be sure?

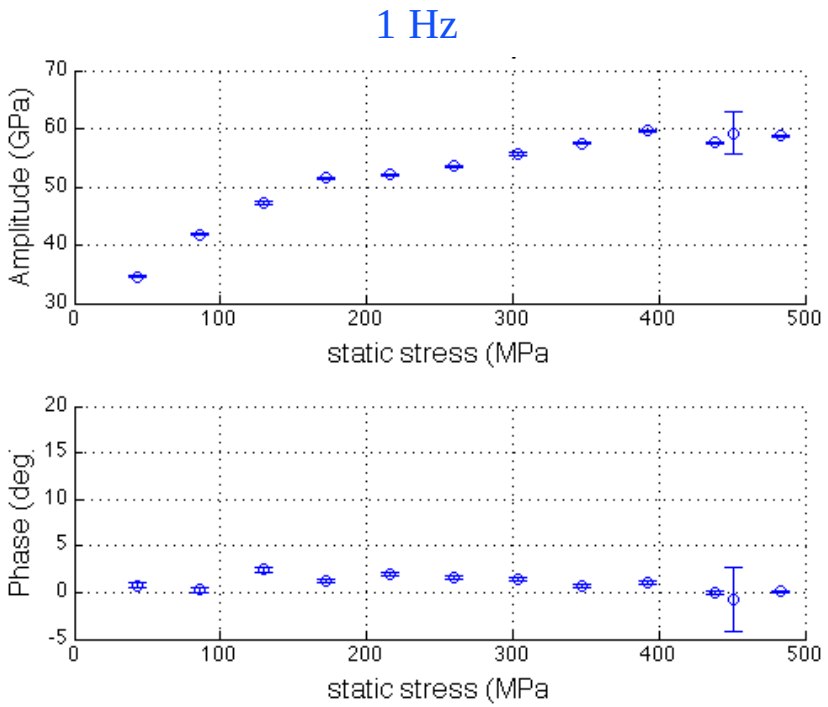
- Machine artefacts: thermal drift?
- Calibration?
- Are machine parameters actually constant?

Fused Silica Nanopillars

- Amorphous
- No dislocation



Result for Fused Silica



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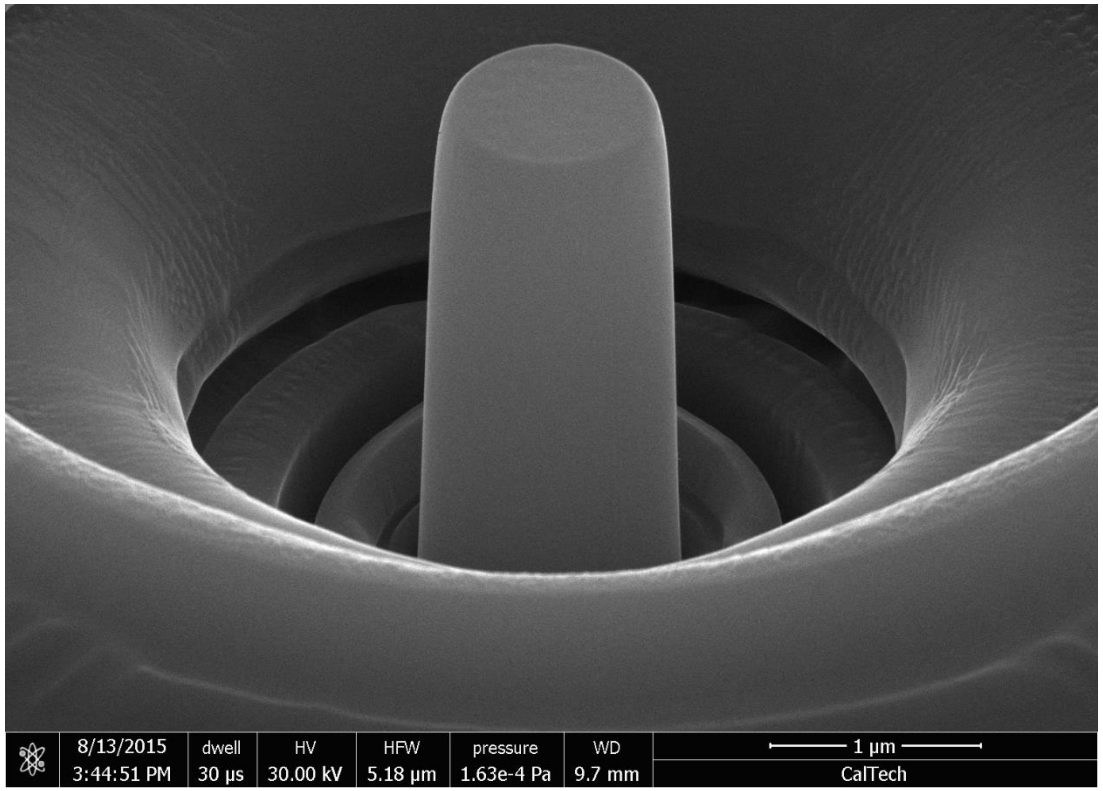
Size Effect

- Cu 1 µm nanopillars



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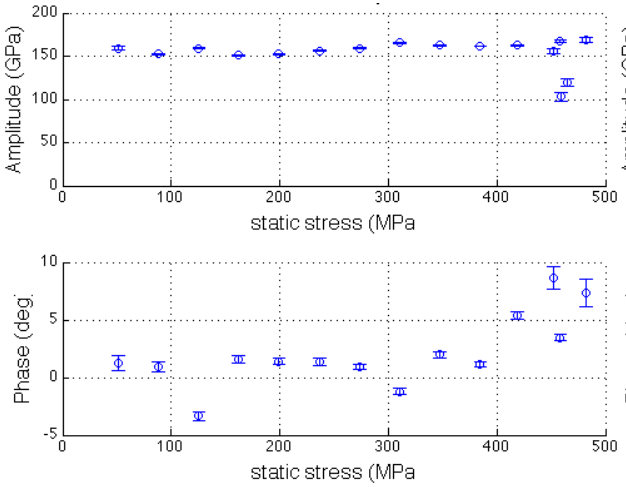
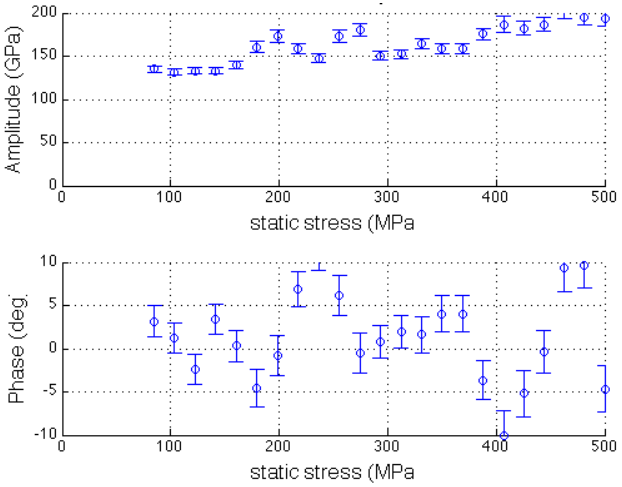
Comparing Results

500 nm

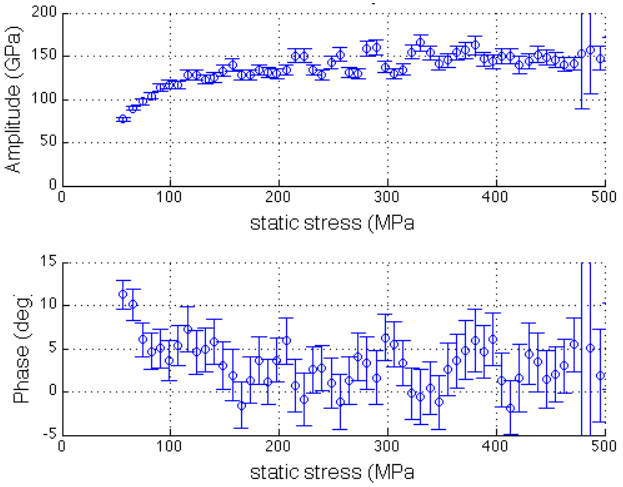
1 Hz



10 Hz

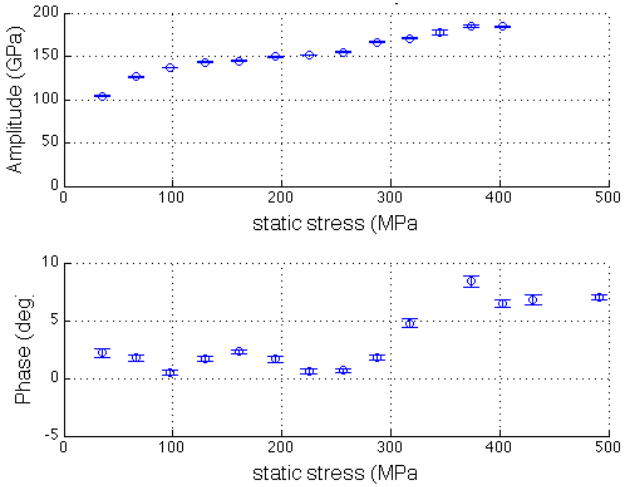


200 Hz

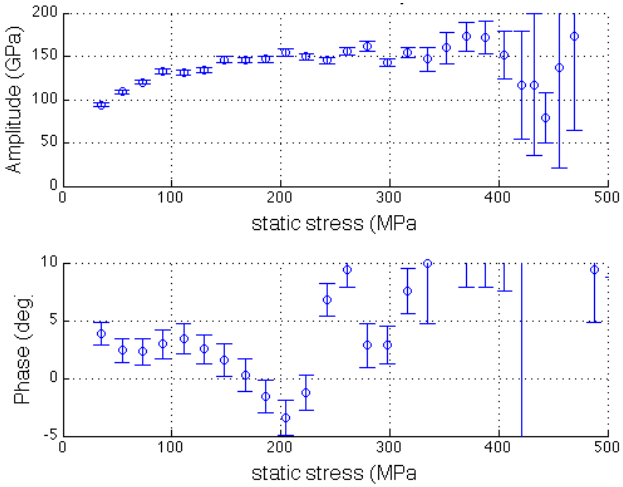


1 µm

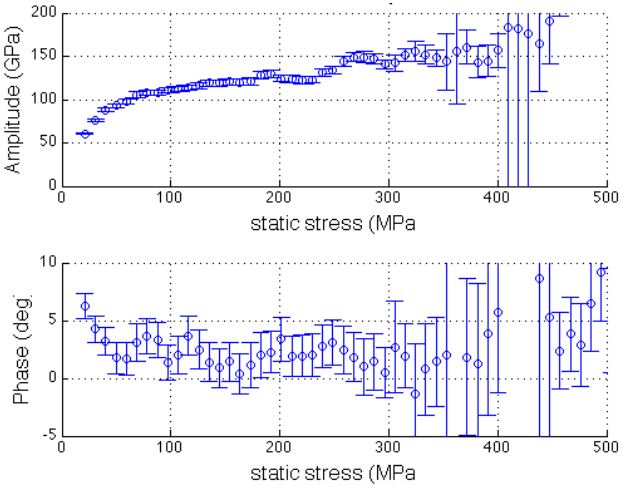
1 Hz



10 Hz



200 Hz



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Conclusion

- Non-constant loss moduli in the elastic regime
- Not from machine artefacts
- Non-trivial microstructure evolution
- Existence of crackling noise?
- Need a theoretical model to confirm
- Further experiments