Data Interpretation 4: Mapping

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Grid Indentation

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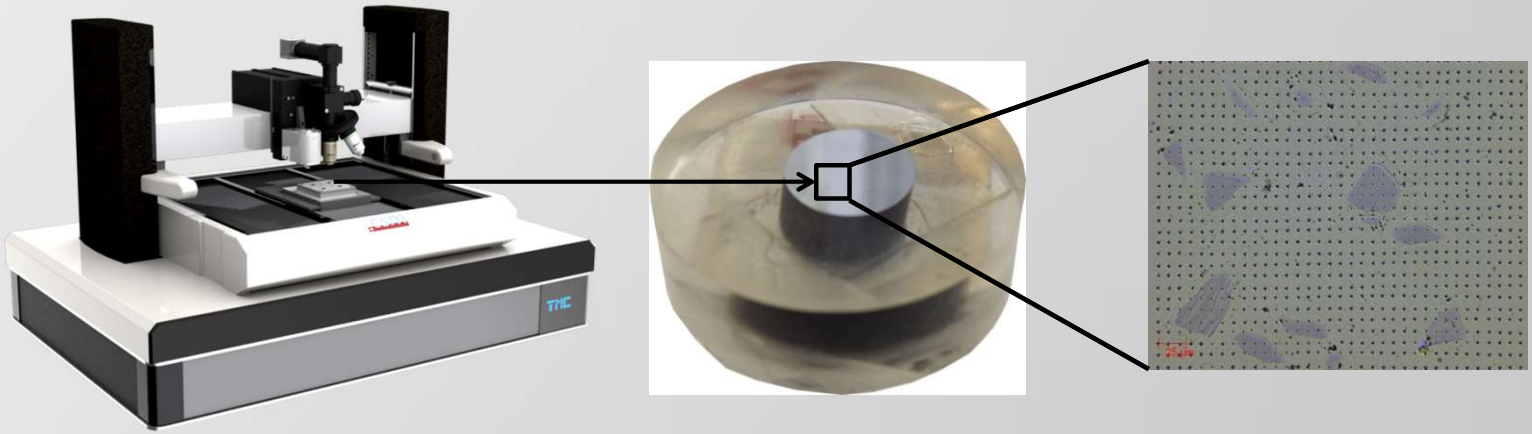
> **Statistical analysis**

- Automated matrix of measurements
- Easy access to average data of Hardness (H_{IT}) & Elastic Modulus (E_{IT})

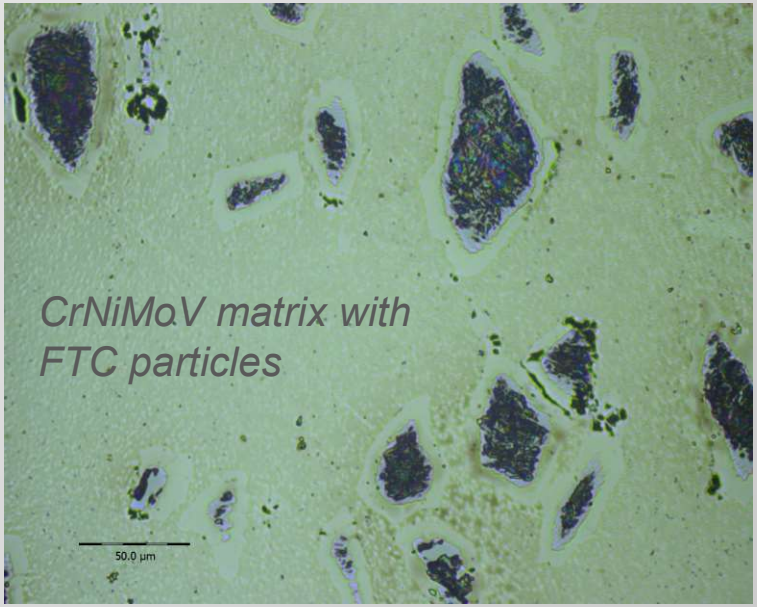
> **Grid indentation technique**

- A two-dimensional mapping tool for examining the properties of constituent phases independently of each other.
- Large arrays of indentations and statistical analysis of the resulting data

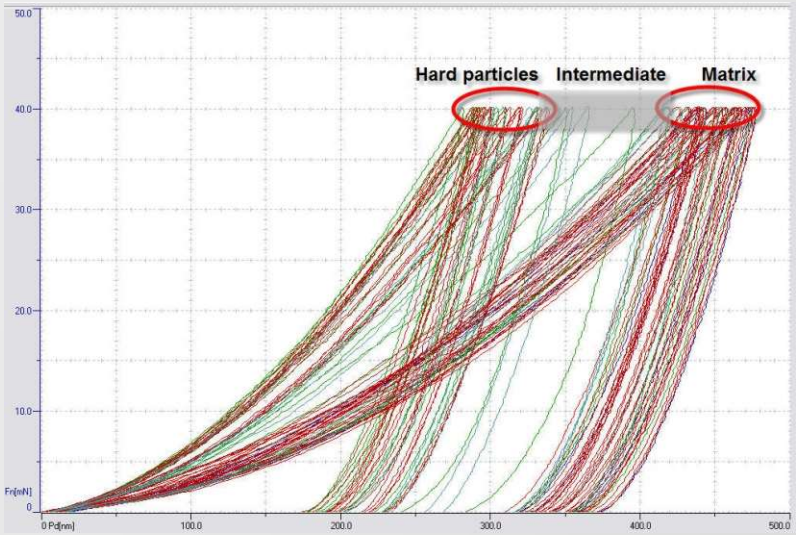


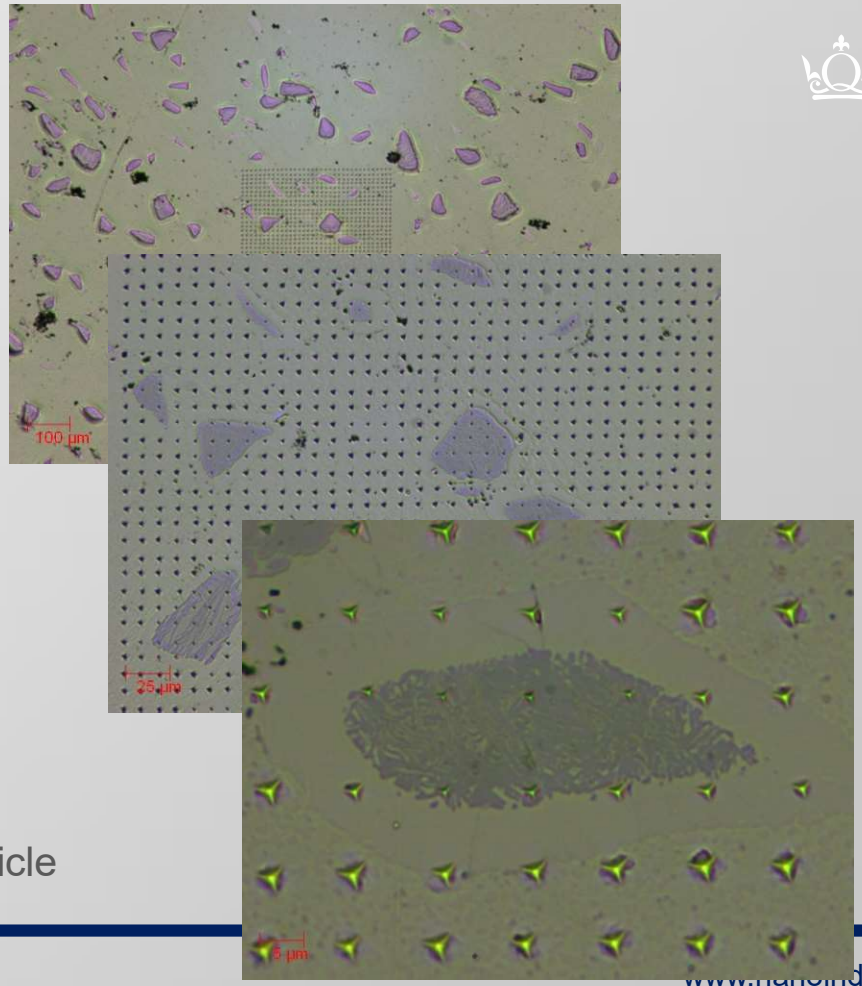
Co-W alloy

Simple Matrix
20 x 20indents
Applied load 20 mN
Loading rate 40 mN/min.
Pause 15 s
Approach and Retract speeds 5000 nm/min.
Separation: 7 µm



Co-W alloy





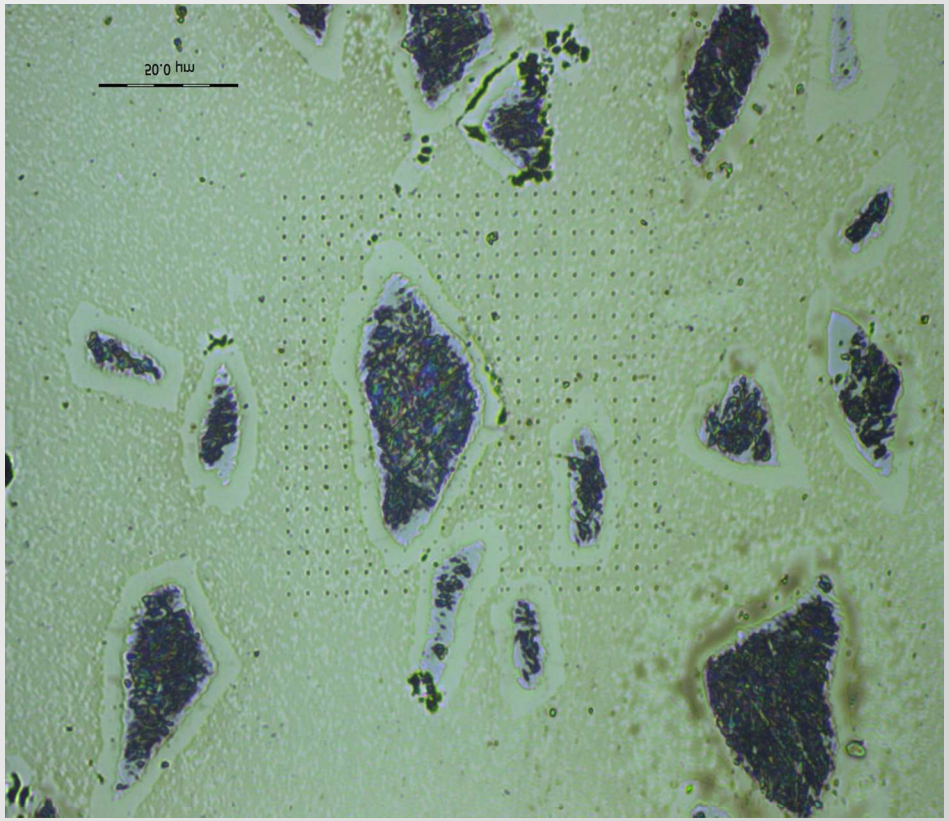
Three types of position of the indentation:

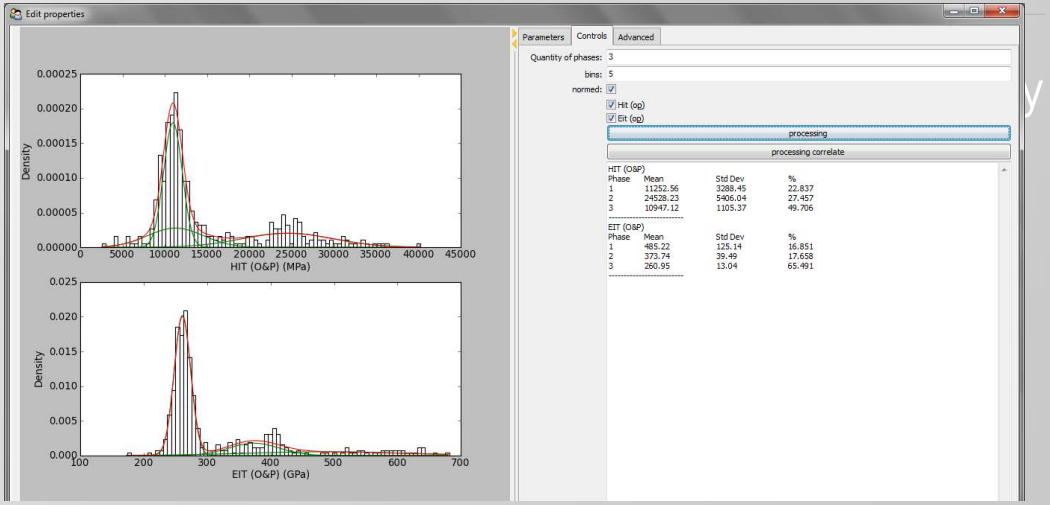
1 – in the matrix

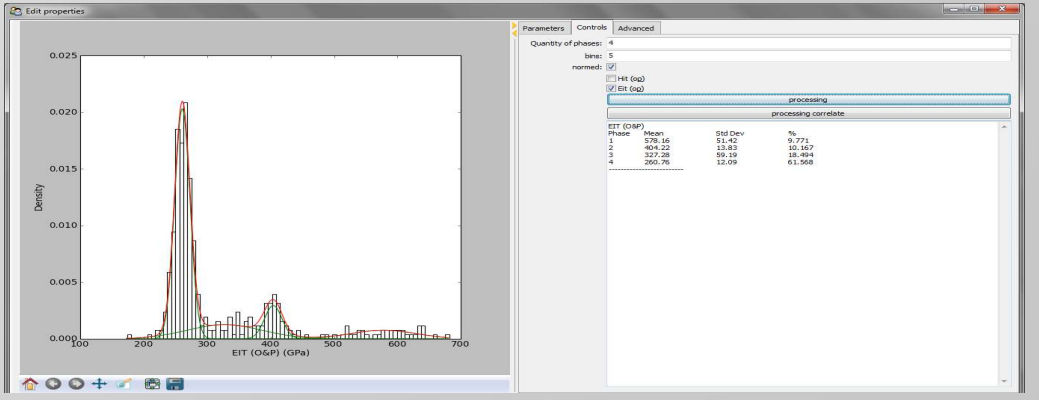
2 – in the particle

3 – on the interface of the matrix and the particle

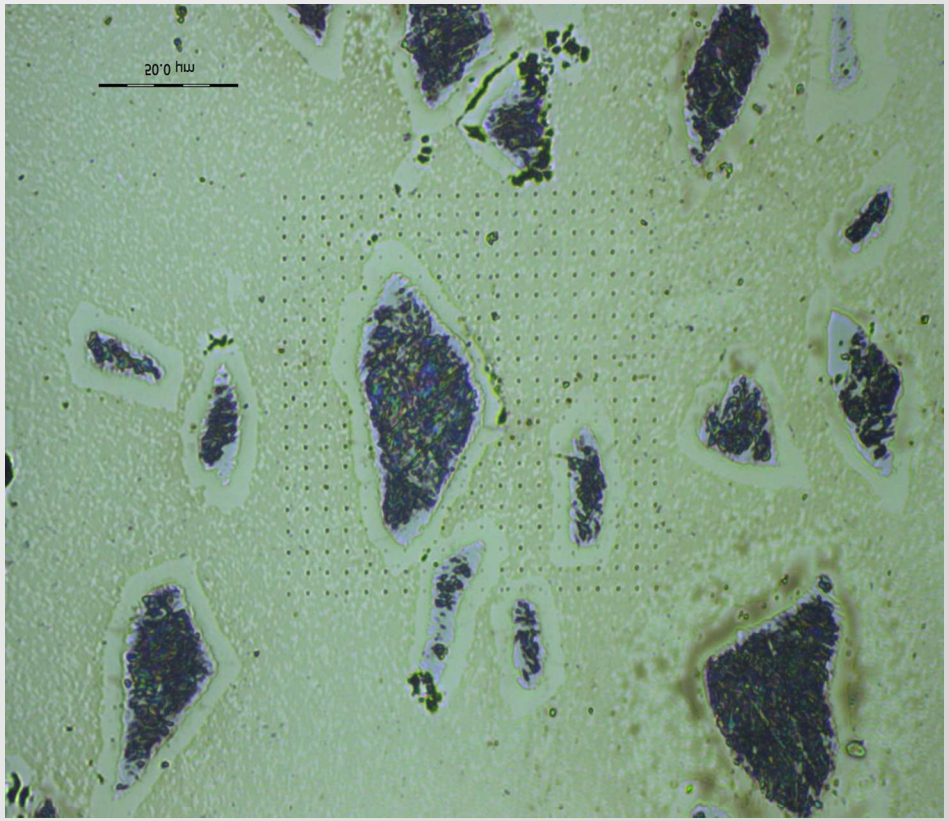
Co-W alloy

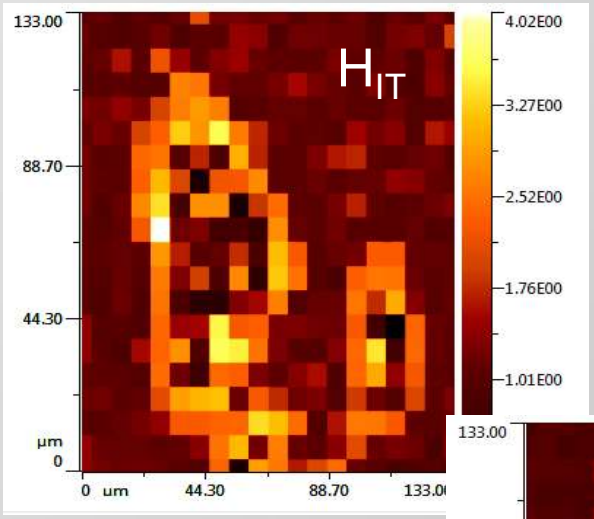

20.0 µm

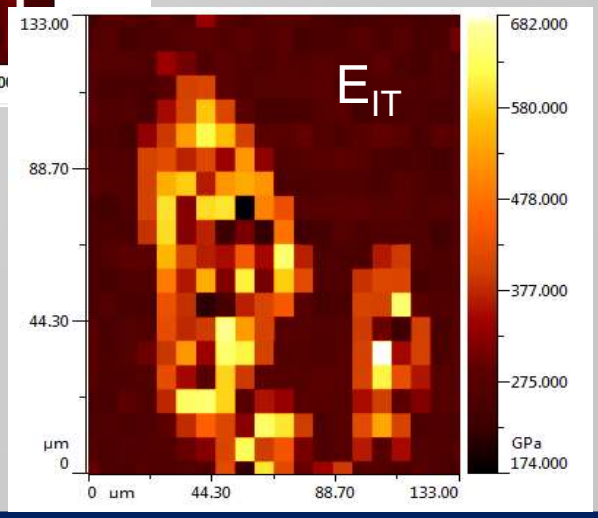

Edit properties
Parameters
Controls
Advanced
Quantity of phases: 3
bins: 5
normed:
Hit (op)
Eit (op)
processing
processing correlate
HIT (O&P)
Phase Mean Std Dev %
1 11252.56 3288.45 22.837
2 24528.23 5406.04 27.457
3 10947.12 1105.37 49.706
EIT (O&P)
Phase Mean Std Dev %
1 485.22 125.14 16.851
2 373.74 39.49 17.658
3 260.95 13.04 65.491
Density
HIT (O&P) (MPa)
EIT (O&P) (GPa)


Edit properties
Parameters
Controls
Advanced
Quantity of phases: 4
bins: 5
normed:
Hit (op)
Eit (op)
processing
processing correlate
EIT (O&P)
Phase Mean Std Dev %
1 578.16 51.42 9.771
2 404.22 13.83 10.167
3 327.28 59.19 18.494
4 260.76 12.09 61.568
Density
EIT (O&P) (GPa)

Co-W alloy

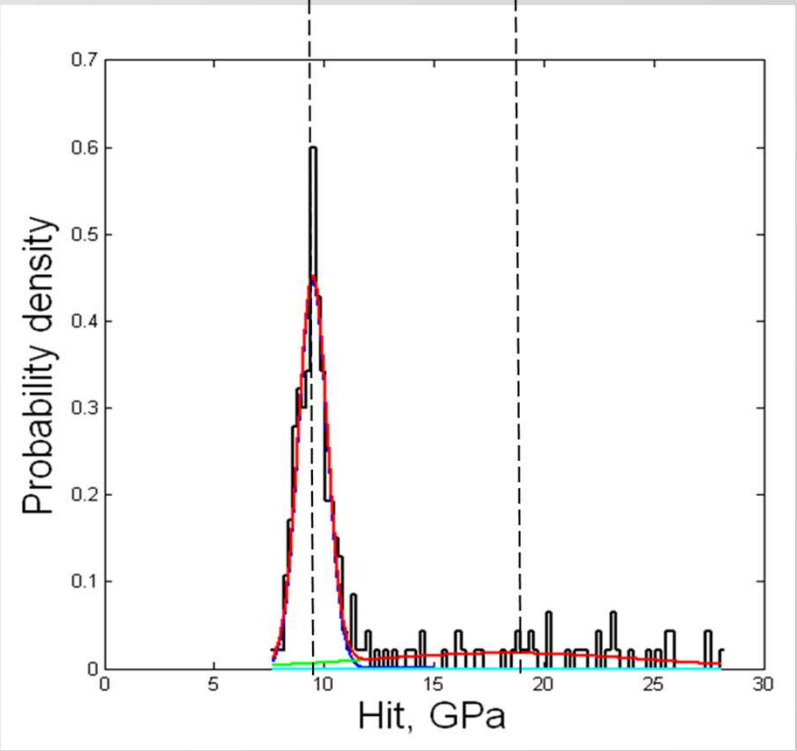



H_{IT}
133.00
88.70
44.30
µm
0
0 µm
44.30
88.70
4.02E00
3.27E00
2.52E00
1.76E00
1.01E00


E_{IT}
133.00
88.70
44.30
µm
0
0 µm
44.30
88.70
133.00
682.000
580.000
478.000
377.000
275.000
GPa
174.000

Co-W alloy

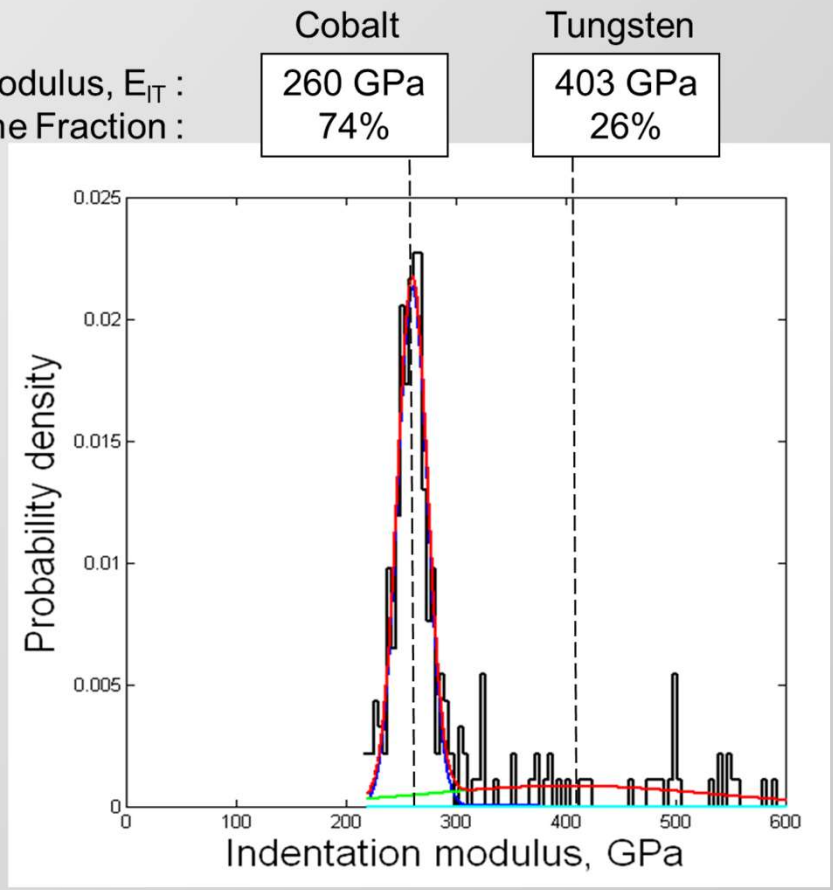
	Cobalt	Tungsten
Hardness, H_{IT} :	9.5 GPa	18.4 GPa
Volume Fraction :	74%	26%



- Cobalt has very distinct peak
- Tungsten is spread. Why?
- When indenting a hard phase embedded in a softer phase, difficult to have no influence of soft material
- Grain size here is 50 μm and indent depth is 500 nm, so 2 orders of magnitude smaller but there is still influence of the Cobalt…

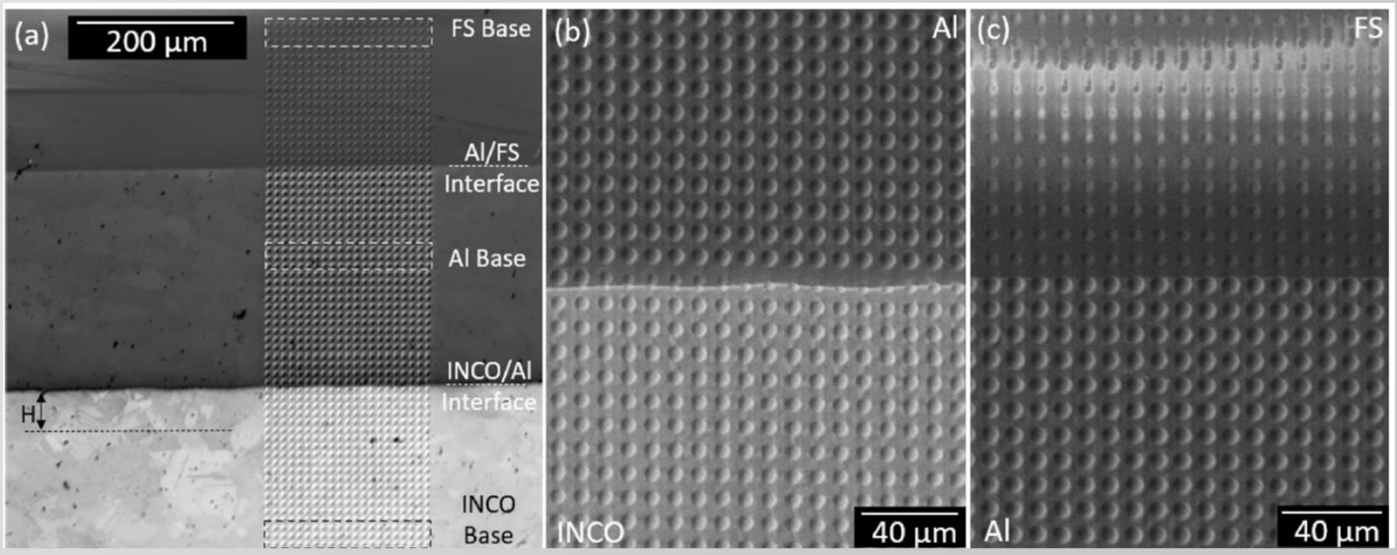
Co-W alloy

(Macro) E_{IT} = 288 GPa



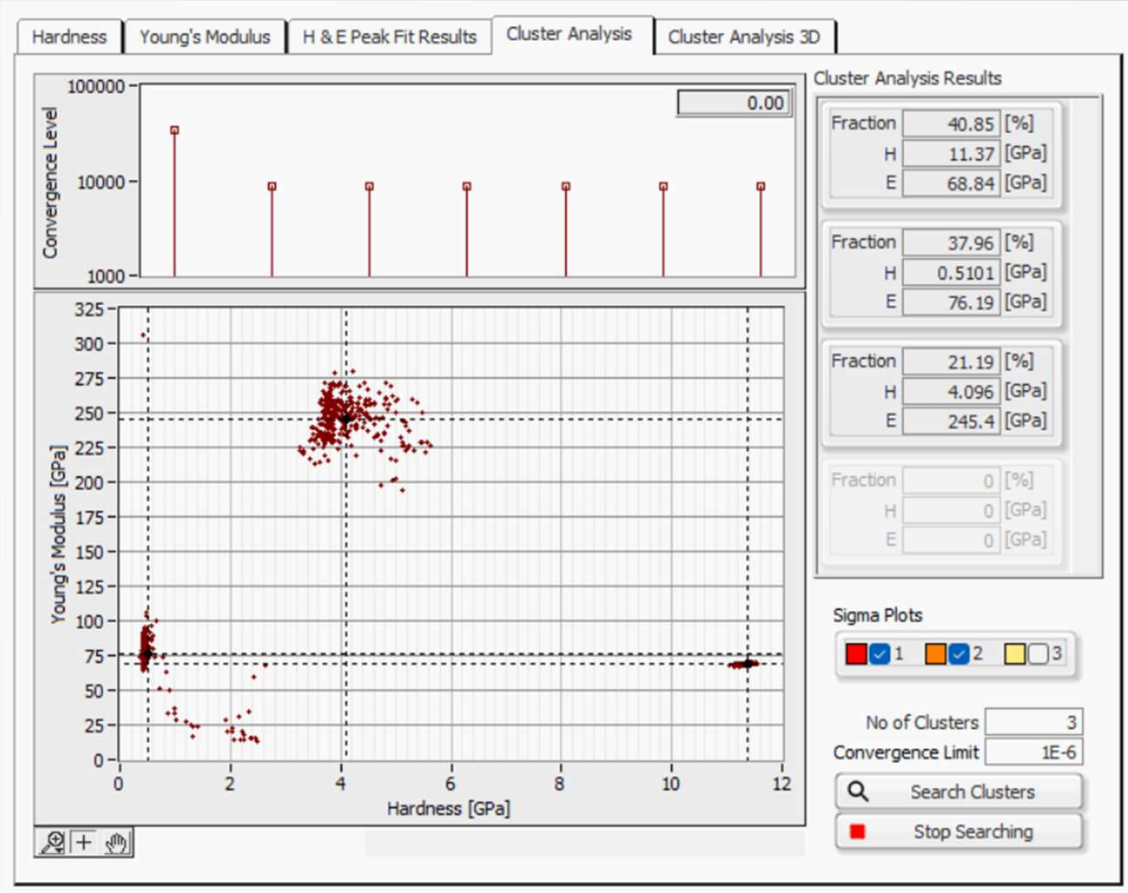
Inconel/Al/Fused Si Diffusion Bonded Joint

Example of a spherical nanoindentation map (1500 indents)



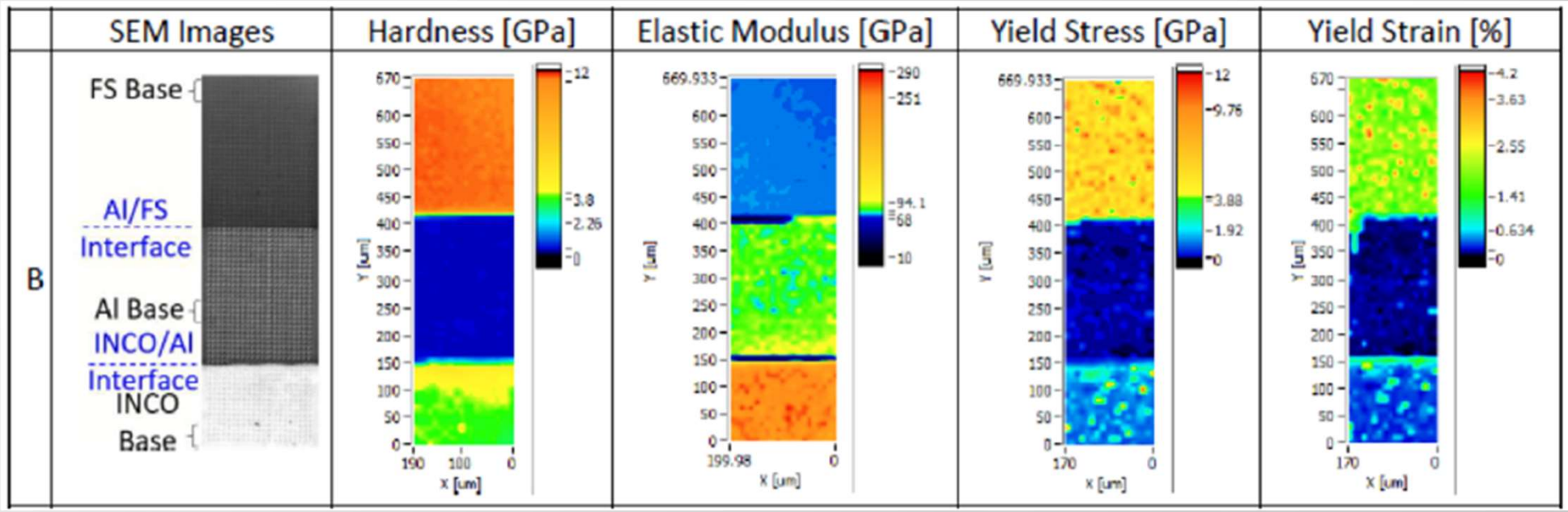
Inconel/Al/Fused Si Diffusion Bonded Joint

Cluster Analysis:



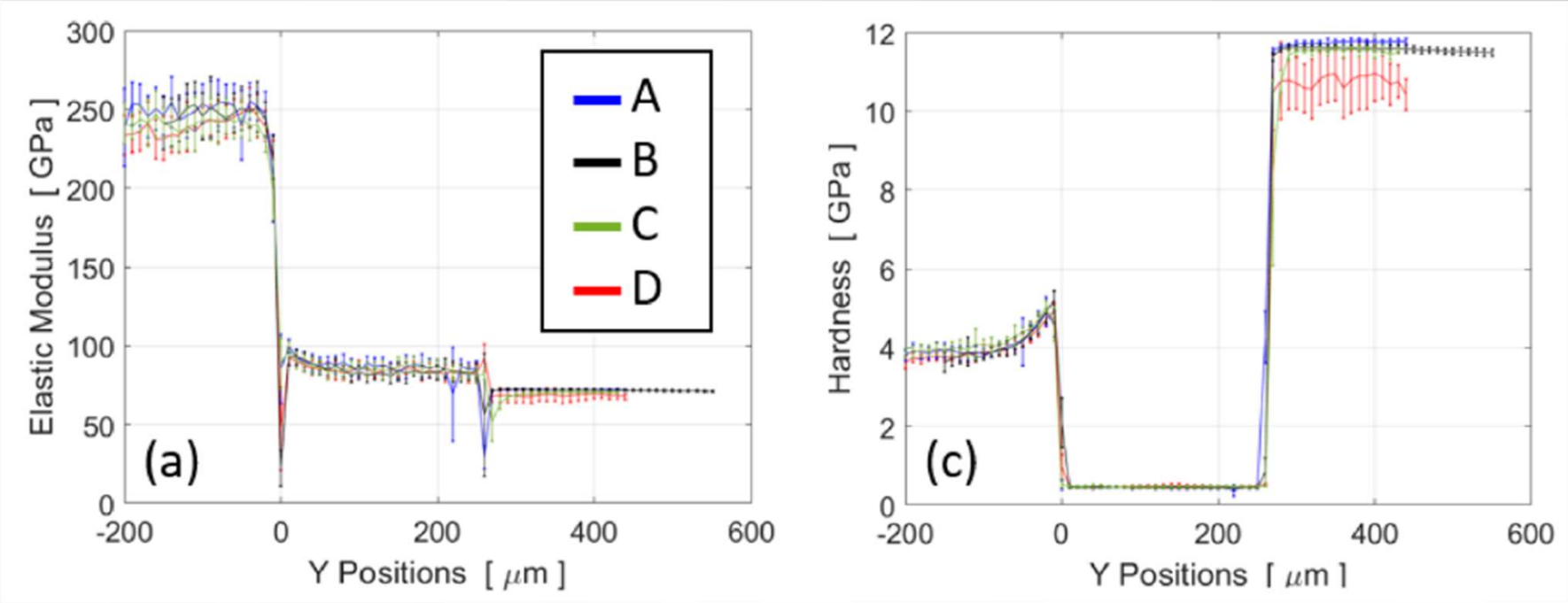
Inconel/Al/Fused Si Diffusion Bonded Joint

Indentation property maps:



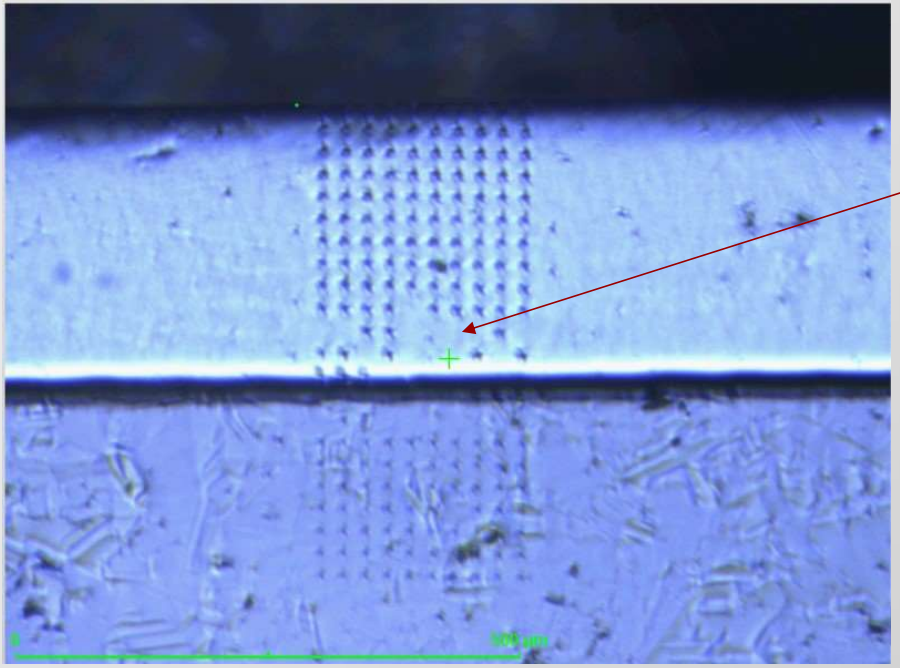
Inconel/Al/Fused Si Diffusion Bonded Joint

H and E typical profiles:

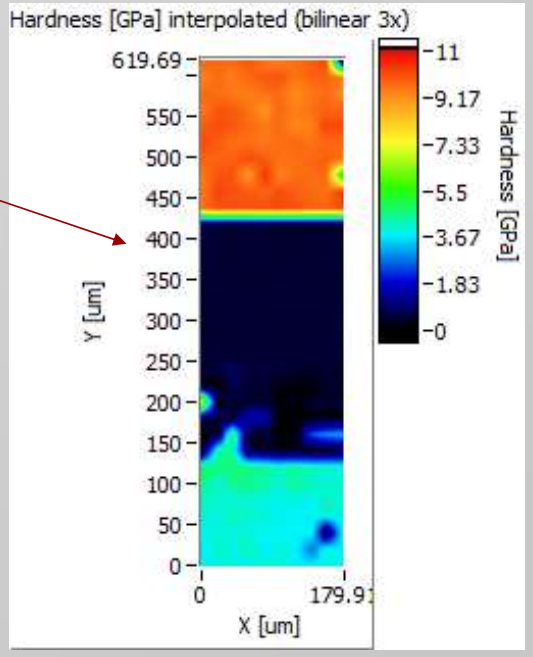


Inconel/Al/Fused Si Diffusion Bonded Joint

Maps do not always go according to plan…! From a previous course..

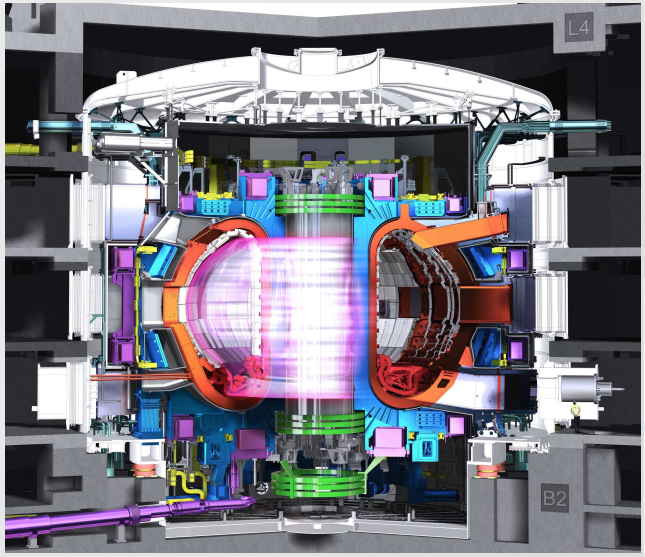


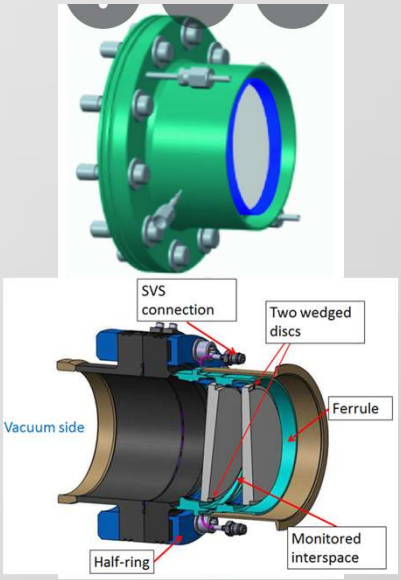
If nanoindentation mapping protocols are not properly designed, some indents may be missing (e.g. typical in noisy environments)



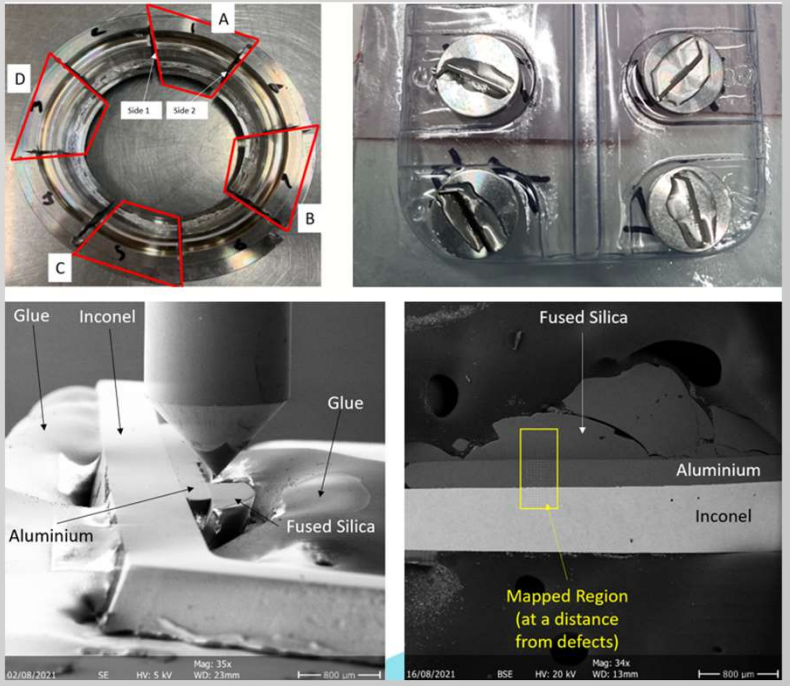
Inconel/Al/Fused Si Diffusion Bonded Joint

The sample you tested is from the ITER Nuclear Fusion Tokamak reactor…





The ITER tokamak will be the world's largest tokamak, with a plasma radius (R) of 6.2 m and a plasma volume of 840 m³, operating at 150 Million°C and producing 500 MW https://www.iter.org/mach



Pero, R., Randall, N., Frey, D., Widmer, R. N., Darby, T., Aucott, L., ... & Bushby, A. (**2023**). Stress-strain curve mapping by nanoindentation–a technique to qualify diffusion-bonded window assemblies for ITER. Fusion Engineering and Design, 196, 113977. https://doi.org/10.1016/j.fusengdes.2023.113977

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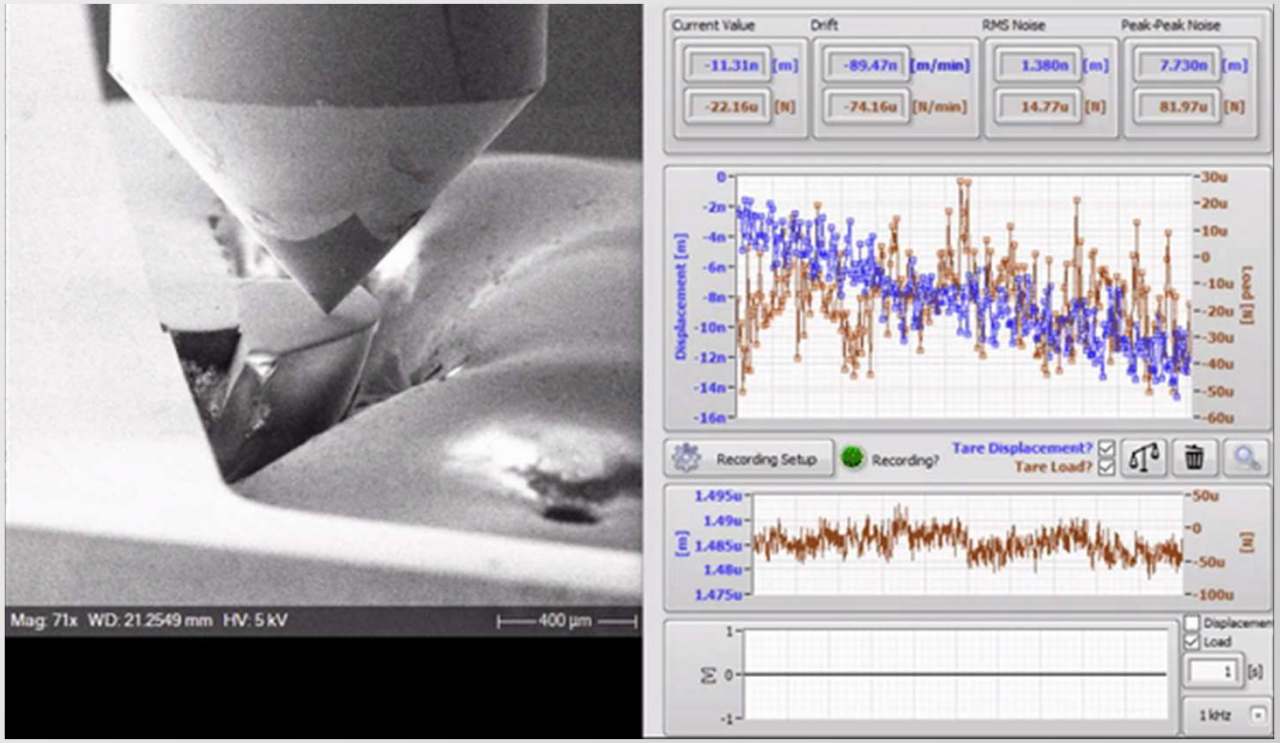

2x30 indentation map across the 2 interfaces
32 µm spacing (large spacing)

Load and Displacement vs. Time

Load and Voltage (applied to the piezostack) vs. Time
At 1 kHz acquisition rate