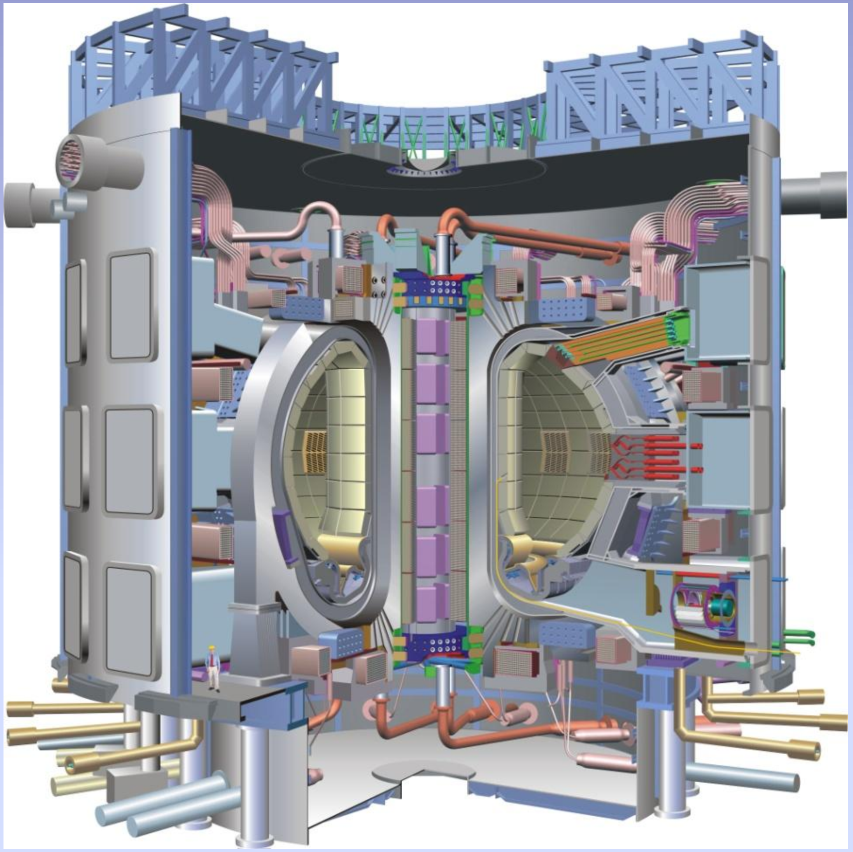
Nanoindentation of Tungsten for Nuclear Fusion Applications

David E.J. Armstrong
Xiaoou Yi
Angus J. Wilkinson
Steve G. Roberts

FEMaS1&PMFMC13

Materials issues for fusion power

- First Wall
- Breeder blanket
- Structural materials
- Divertor
  - Key component for removal of He “ash”
  - 14MeV neutrons – 20-50dpa/year
  - Helium -10-15appm/dpa
  - Hydrogen - 40-50appm/dpa
  - Temperature – 775-3475K
  - Tungsten has potential for both plasma facing and structural roles

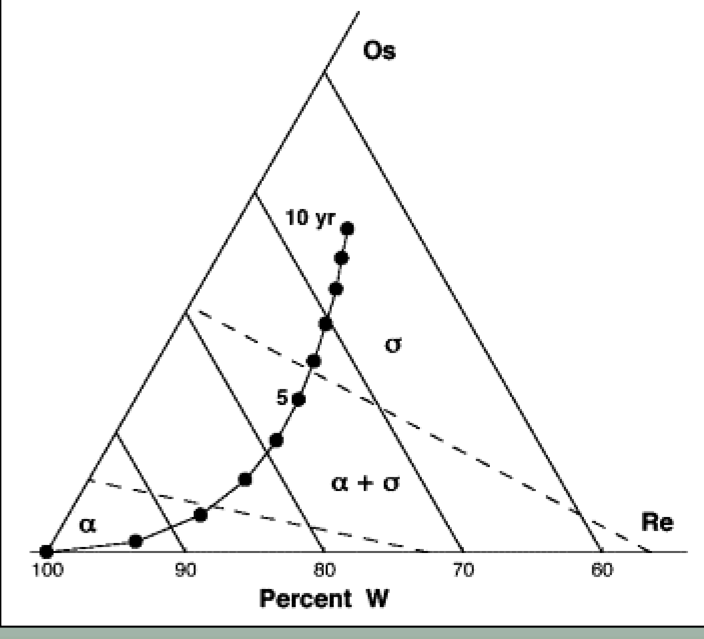


Why tungsten alloys?

- **Neutron damage causes chemical and microstructural changes**
- **Brittle σ–phases can be formed**
- **W-Re-Os alloys are highly expensive - bulk samples not available**

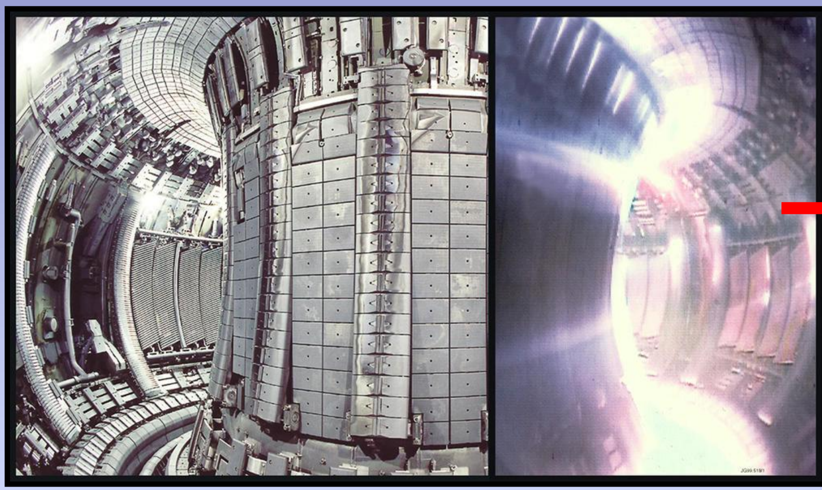
Element	W	Re	Os
	At%		
0 years	100	0	0
2.5 Years	95.4	1.7	0.5
5 years	91	5.1	3.9

- **Tungsten is brittle at RT**
- **Formability is a problem**
- **Re alloying additions can improve ductility**
- **Can other elements?**



Data from Cottrell, Journal of Nuclear Materials, 334, pg 166, 2004

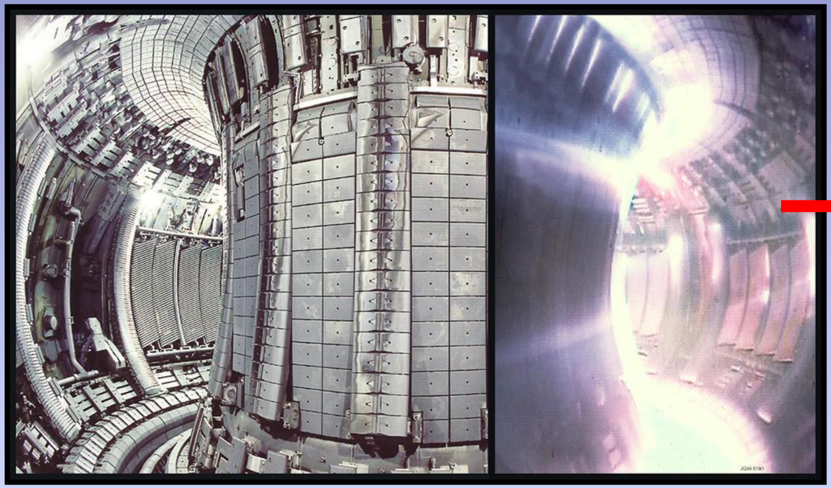
Neutron damage



1-100 displacements per atom
100’s ppm helium
Transmutation radioactivity
Large penetration depths

Test Reactor
But...
- Expensive
- Slow
- Radioactive

Simulating neutron damage

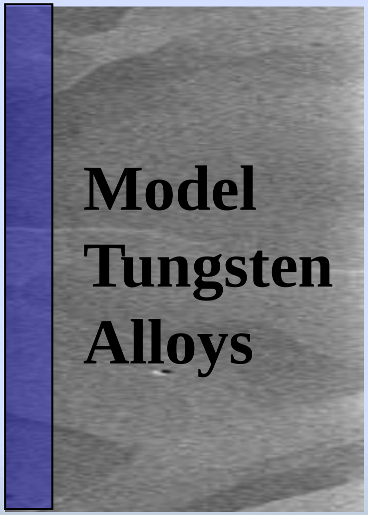


1-100 displacements per atom
100’s ppm helium
Transmutation radioactivity

W^+

2MeV

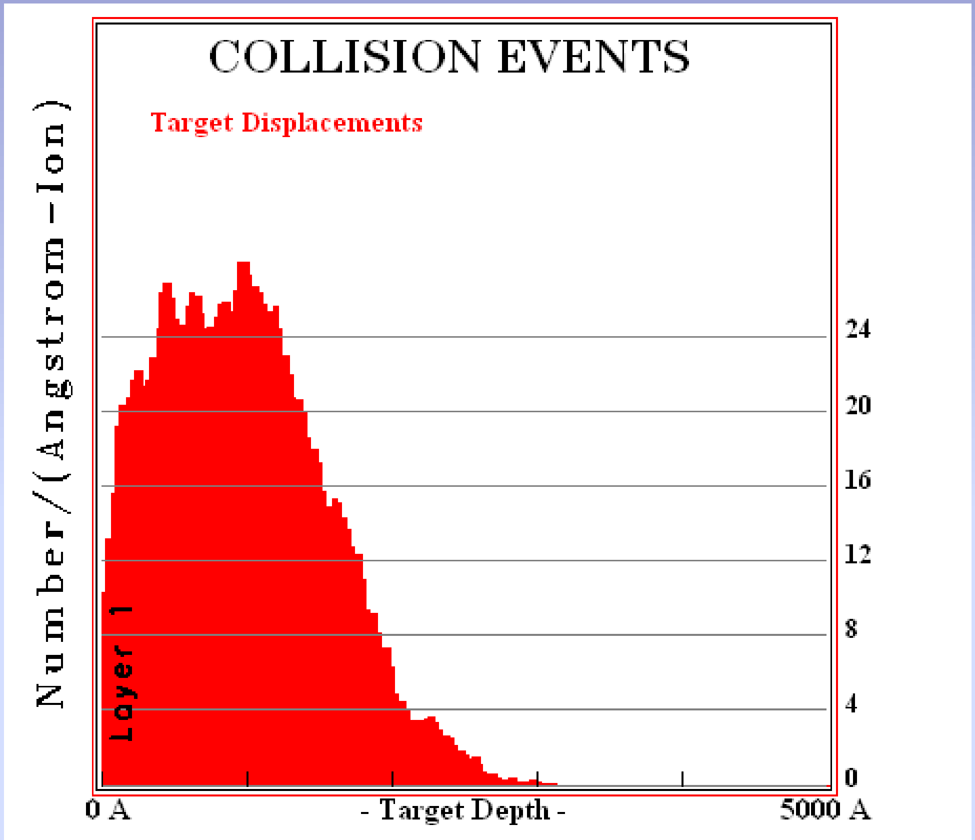
~200-300nm



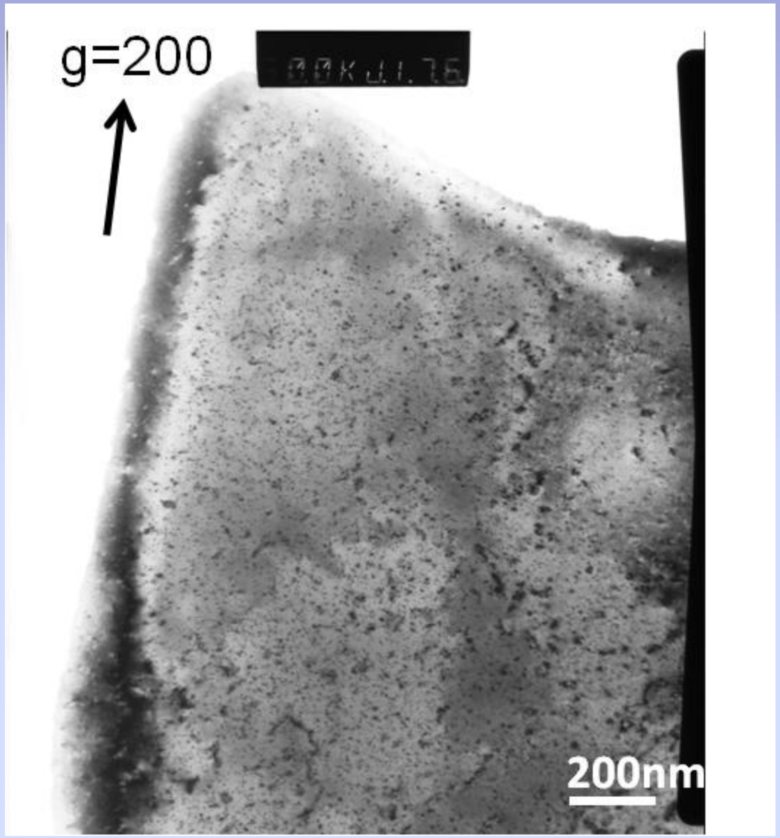
Simulating neutron damage

- Implantations carried out at National Ion Beam Centre, University of Surrey, UK
- Temperature 400°C
- Single energy @ 2MeV
- Doses: (rate≈3dpa/hour)

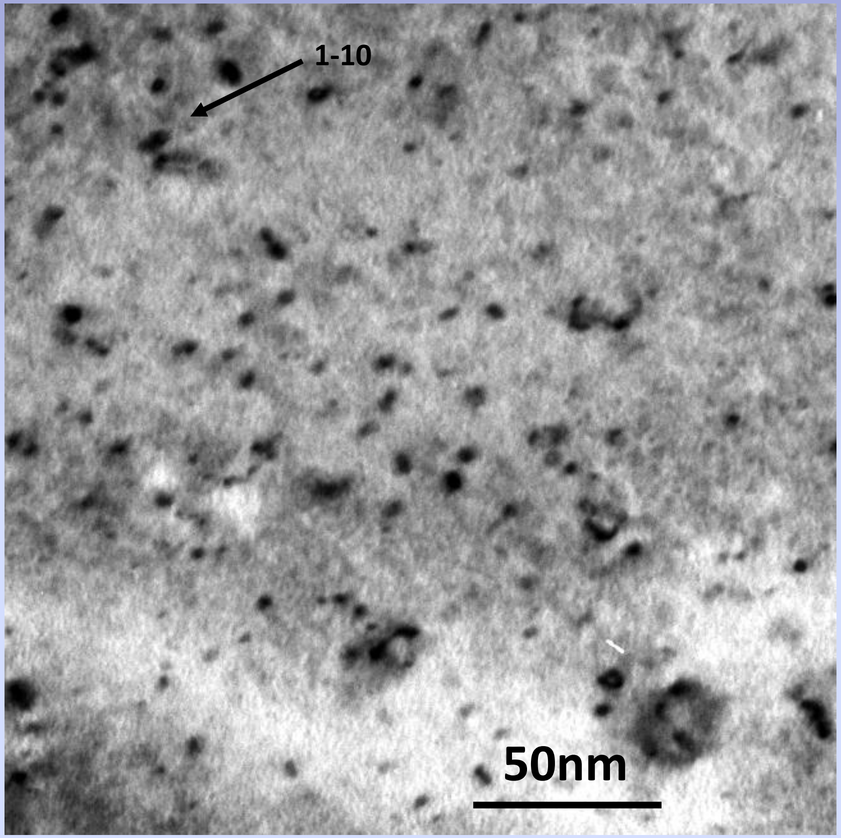
Dose (Ion/cm^2)	DPA	Temp °C
$5.5x10^{12}$	0.07	400
$3.3x10^{13}$	0.4	400
$1.05x10^{14}$	1.2	400
$1.0x10^{15}$	13	400
$2.5x10^{15}$	33	400



TEM of Implantation Damage



1.2 dpa W5Re

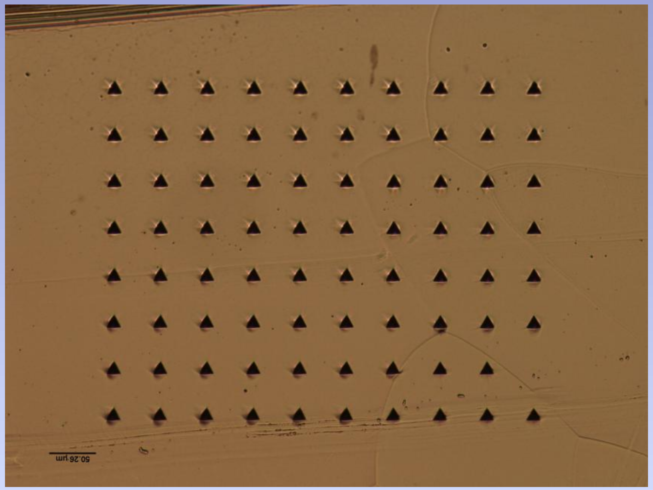


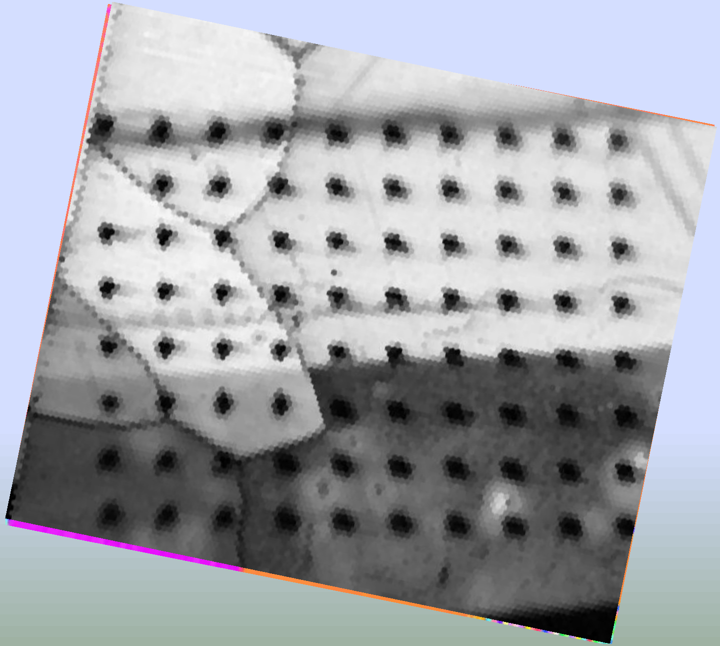
33 dpa UHP W

TEM analysis X. Yi Oxford Materials Poster 55B

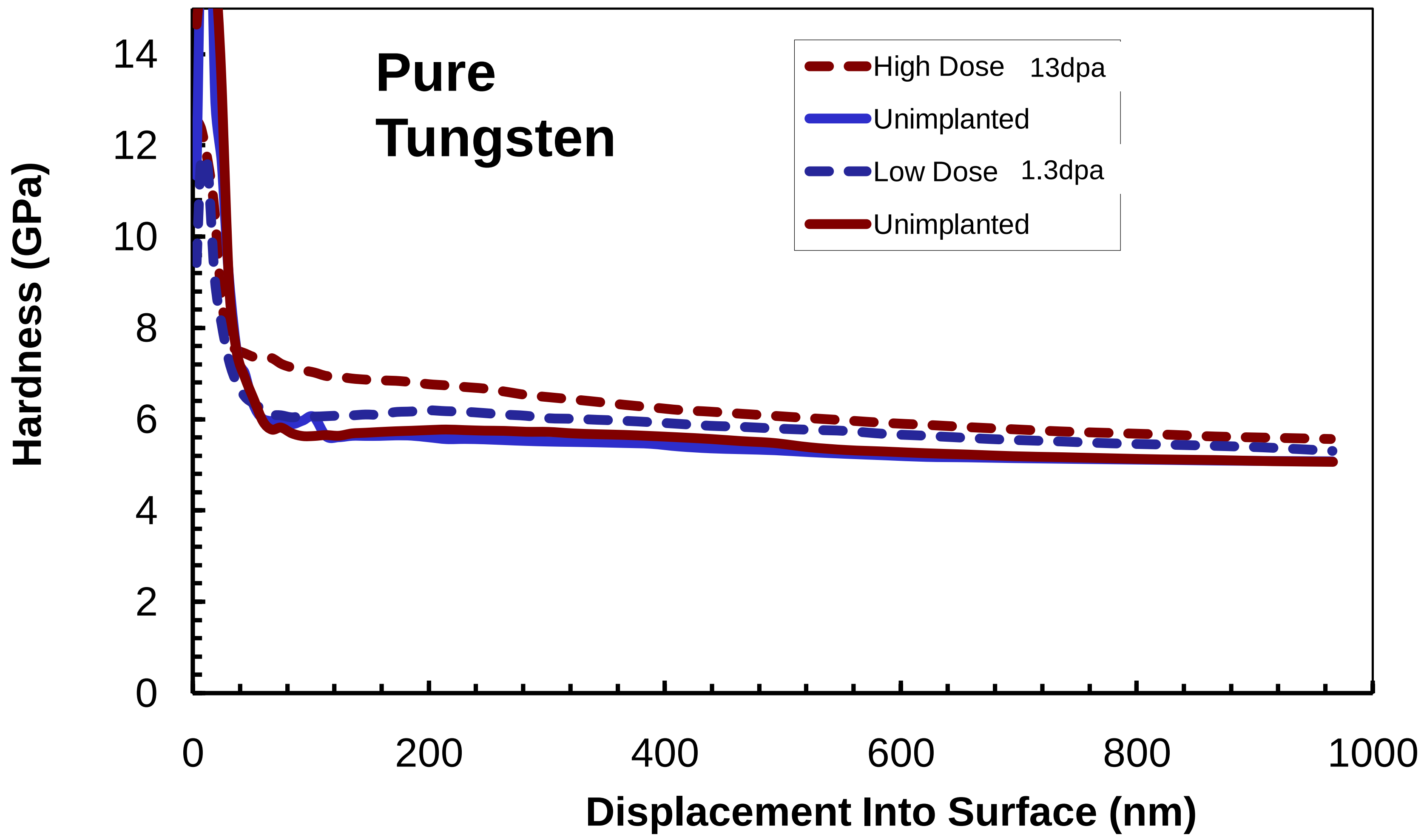
Nanoindentation

- Basic nanoindentation carried out on implanted samples
- Modulus and hardness calculated as a function of depth
- Poorly defined strain field makes interpreting results difficult
- EBSD used to find implanted region
- Implanted materials include, pure tungsten and W5Re and W5Ta alloys

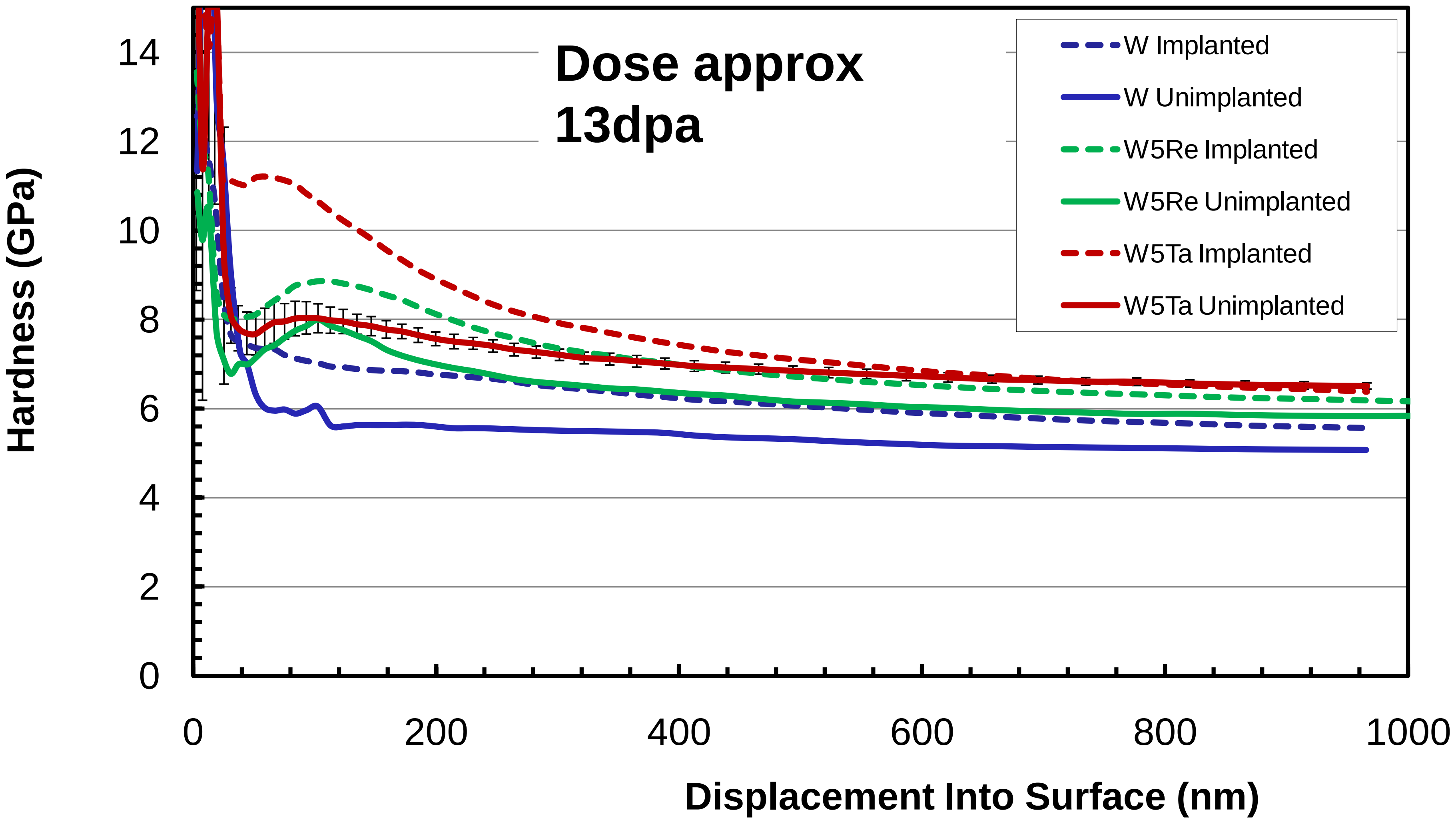




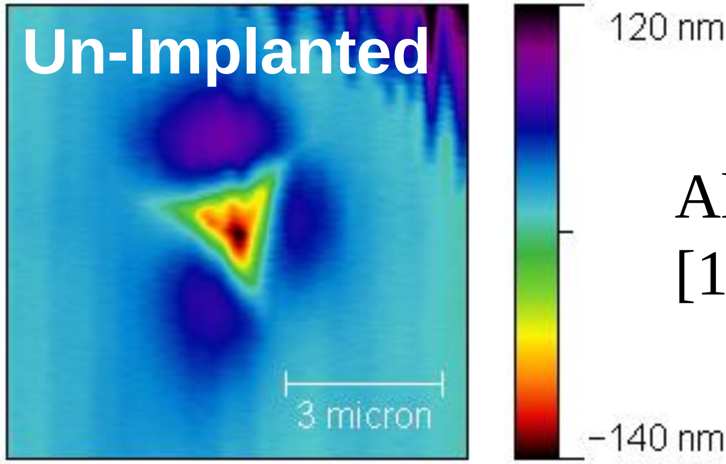
Nanoindentation results -W



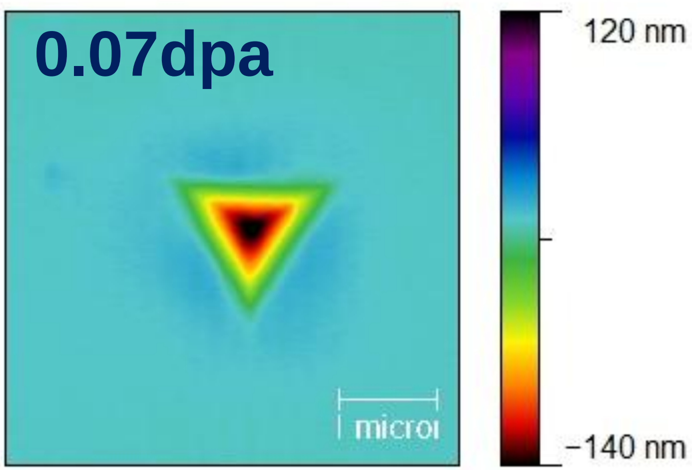
Nanoindentation results - WX

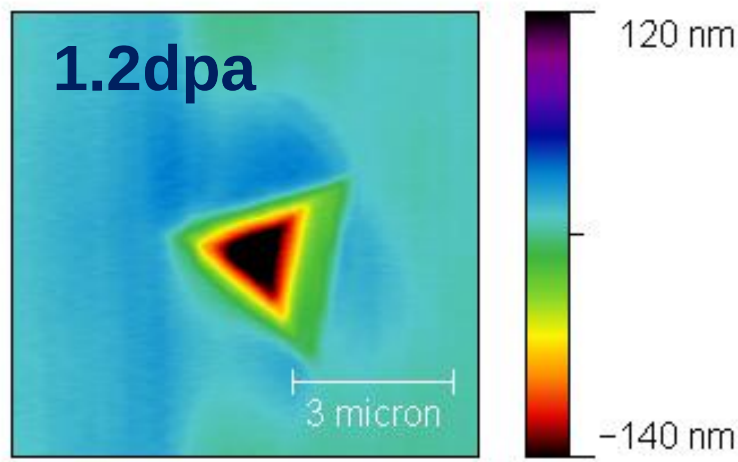


AFM Scans 200nm indents - W



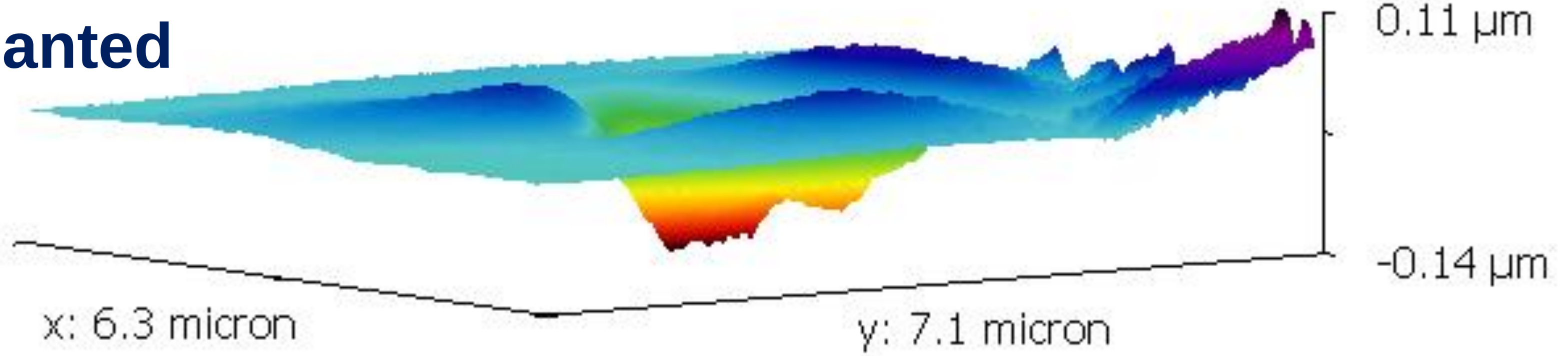
All grains close to [111] surface normal



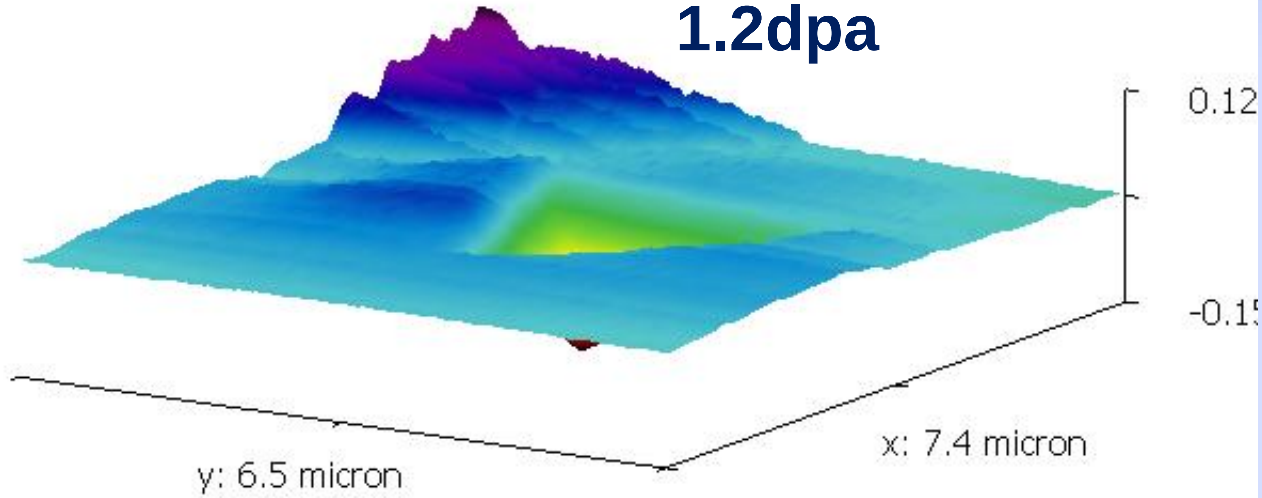


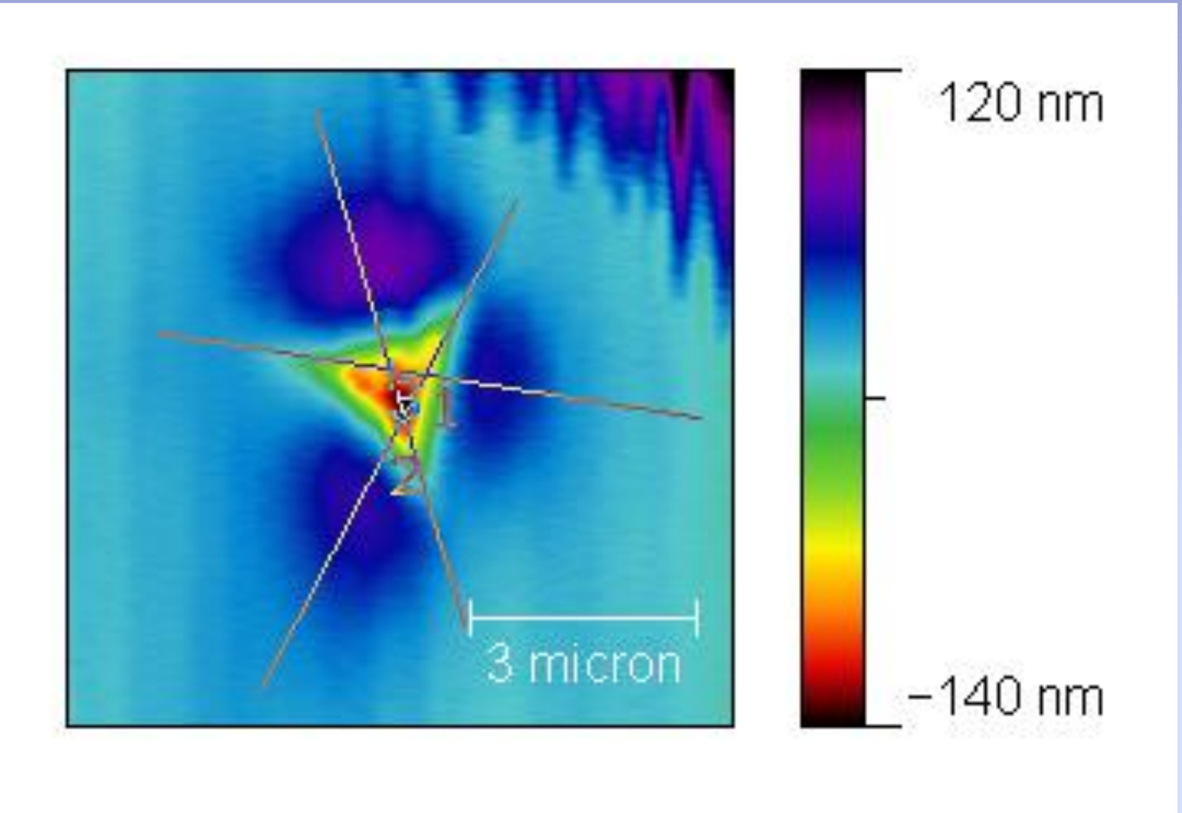
AFM Scans- W x dpa

Unimplanted



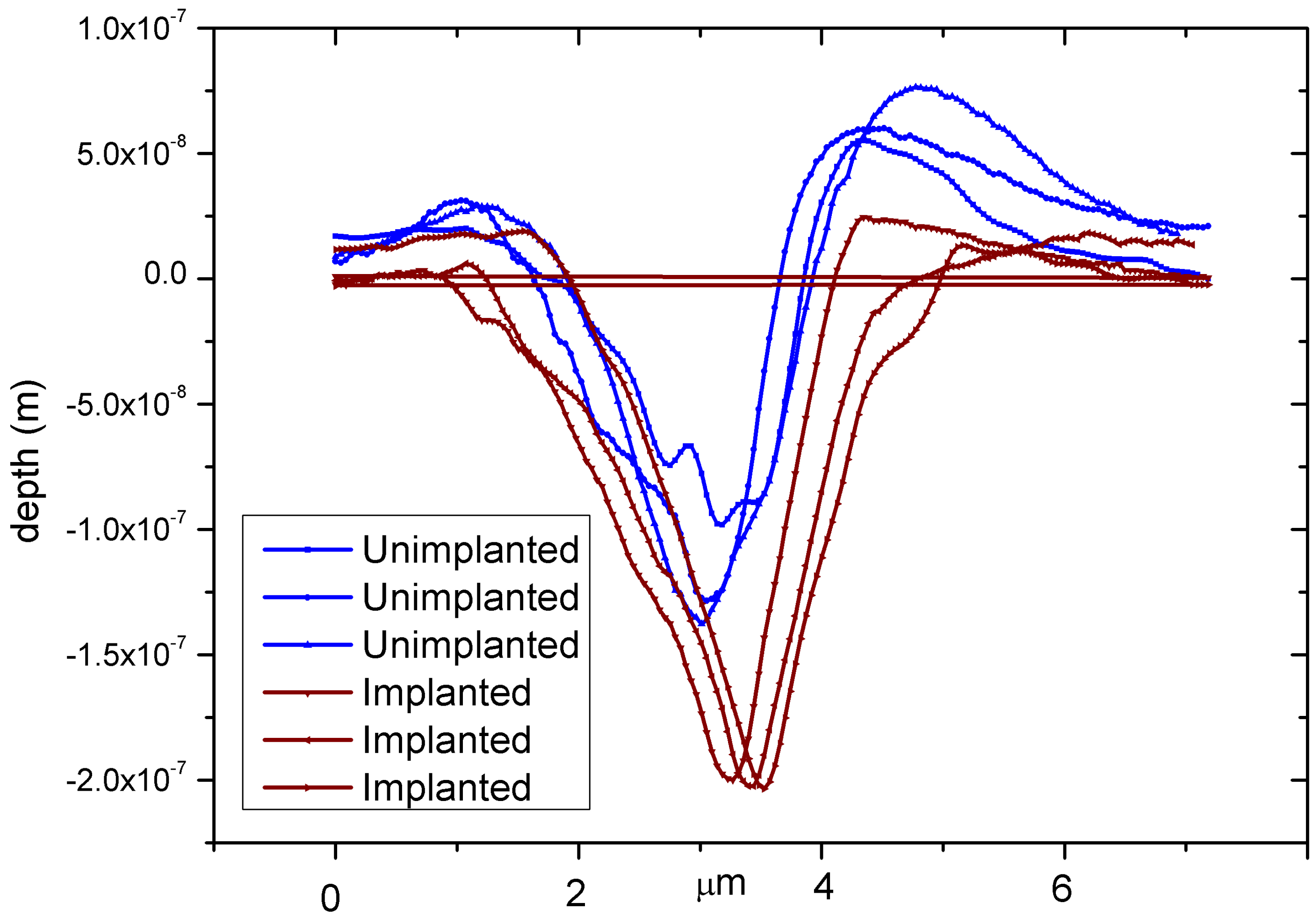
1.2dpa



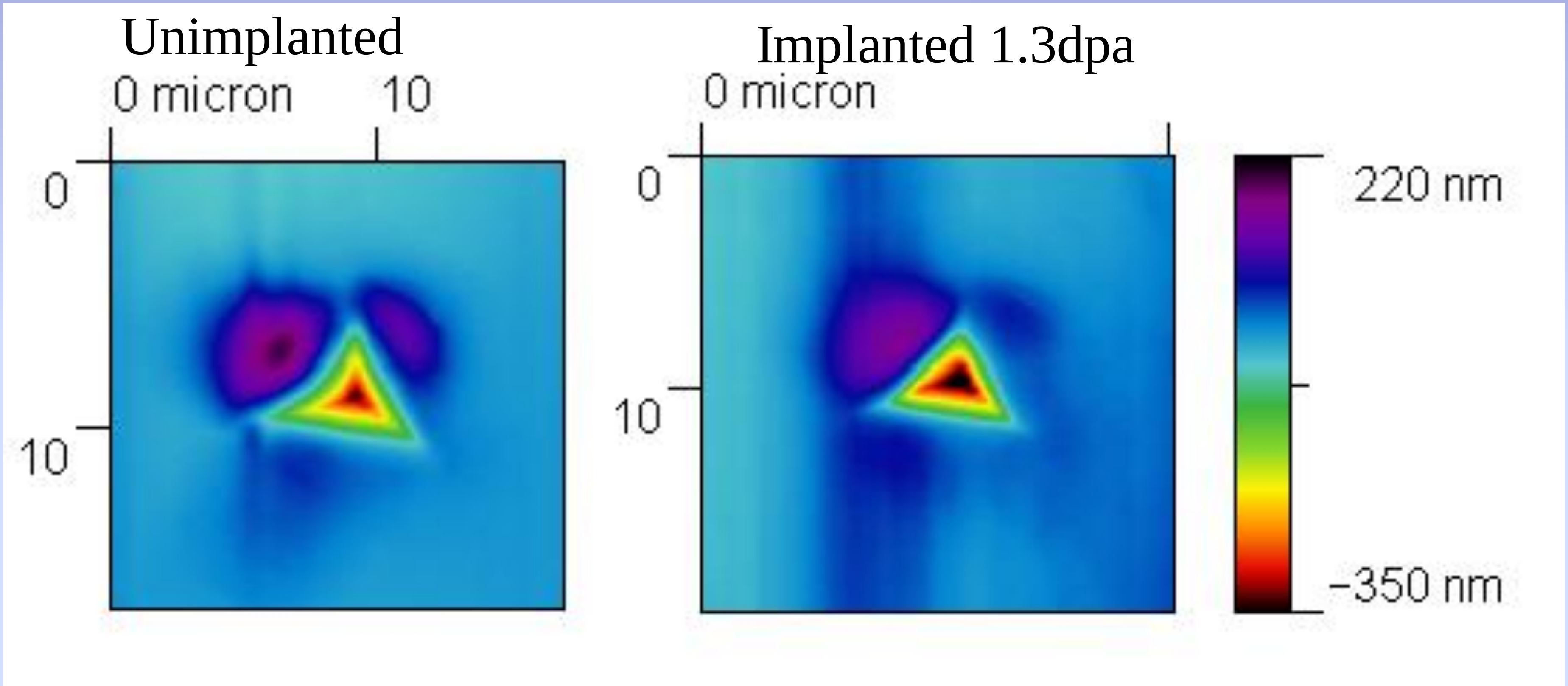


120 nm
−140 nm
3 micron

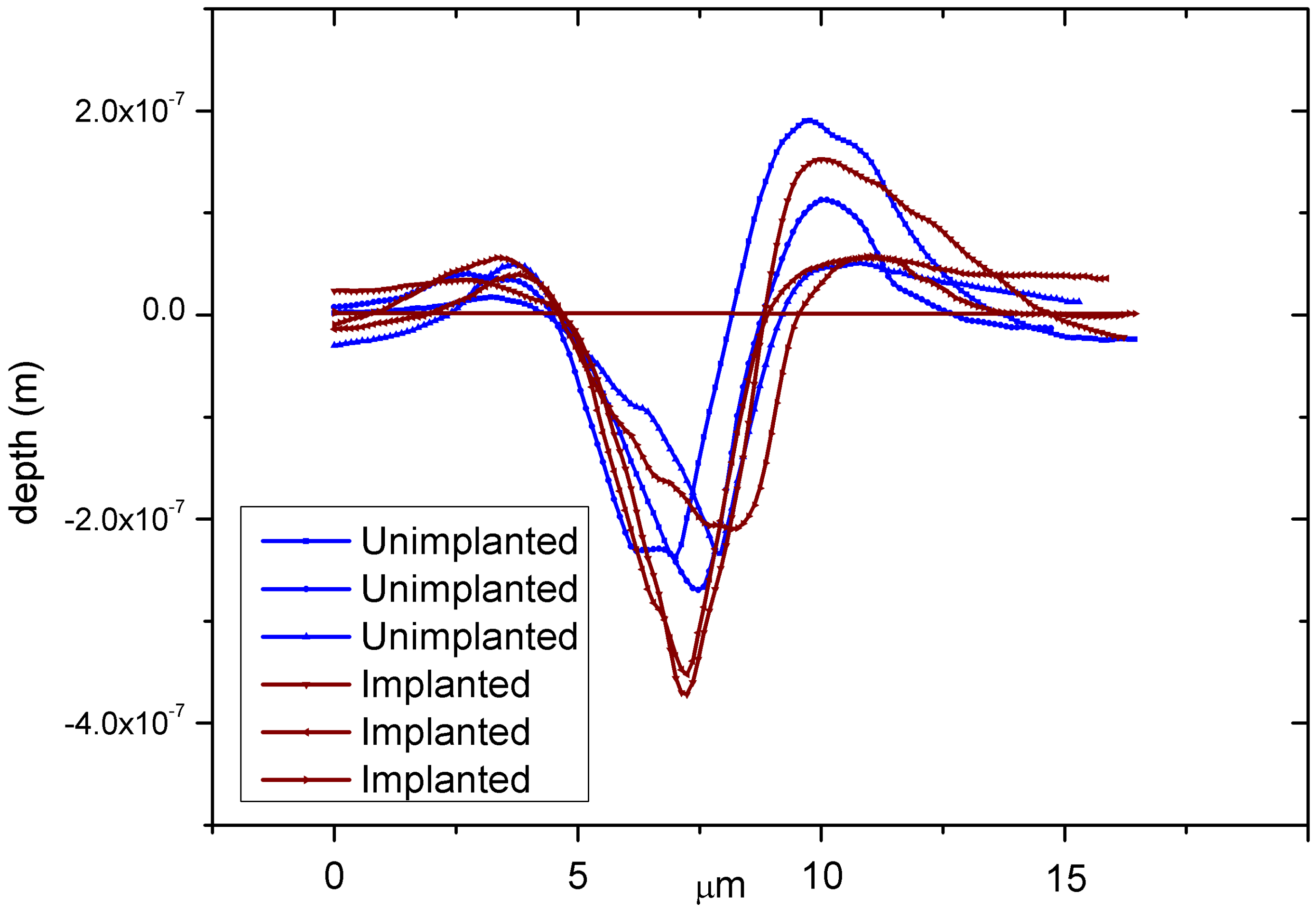
Nanoindentation results 200nm indents - W



Nanoindentation results 1000nm indents - W

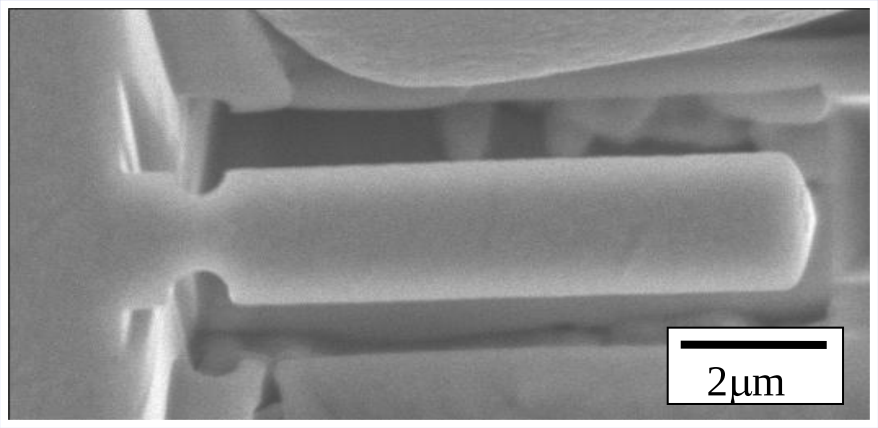


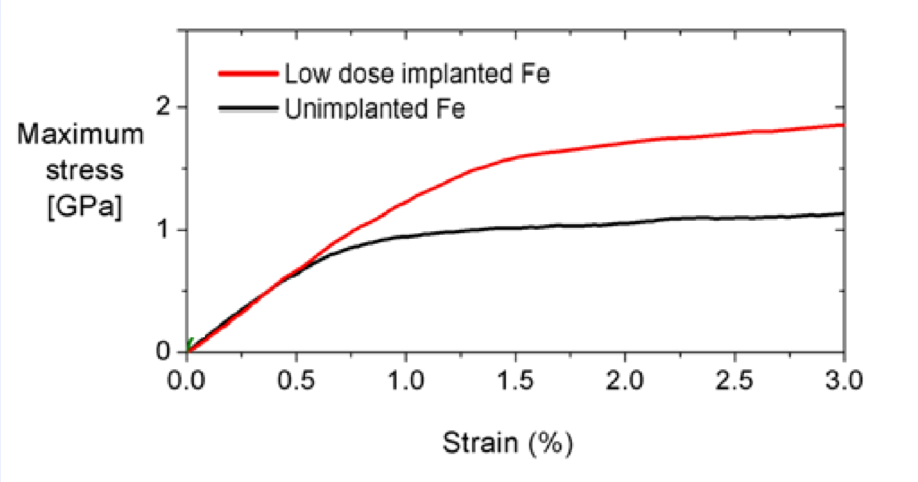
Nanoindentation results 1000nm indents - W



"Nano" cantilevers?

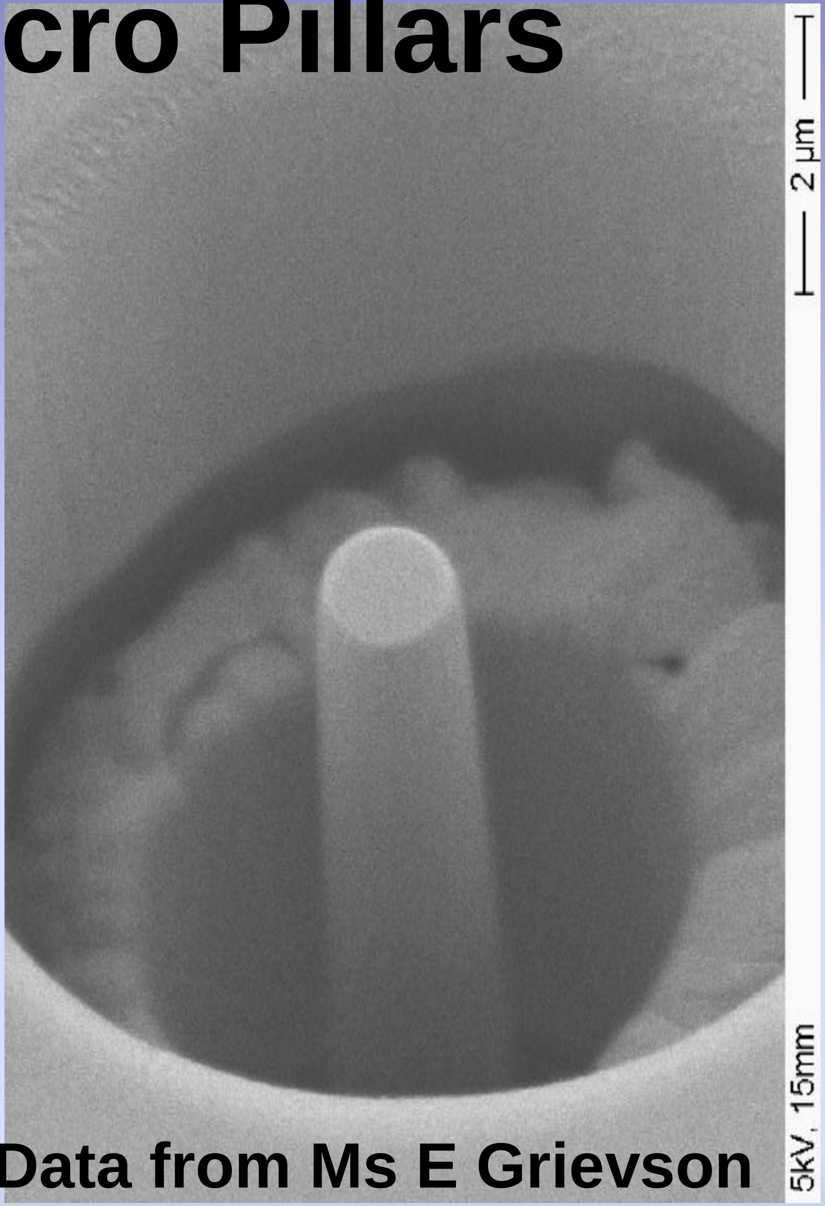
- Can we machine cantilevers into the implanted layer?
- Work in progress……
- Some success in FeCr alloys
- Deeper implantation depths soon





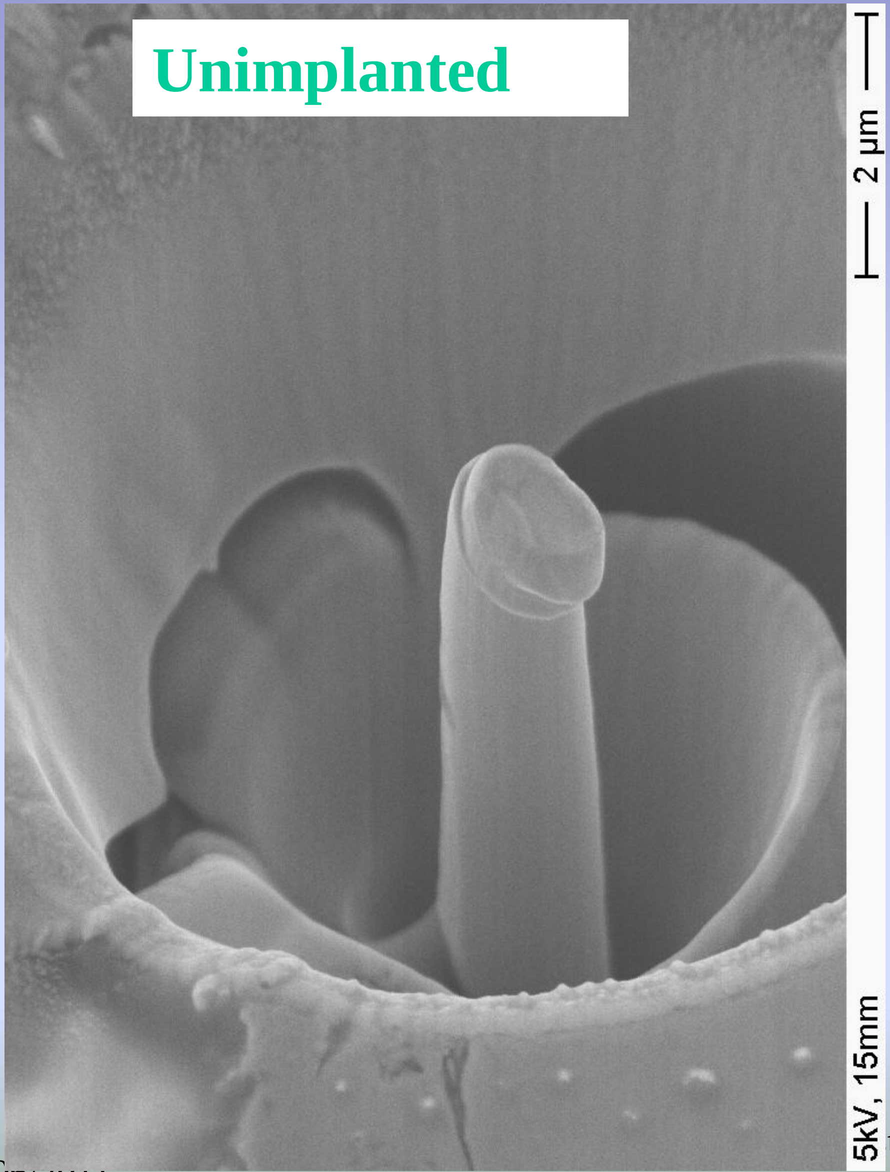
FeCr Micro Pillars

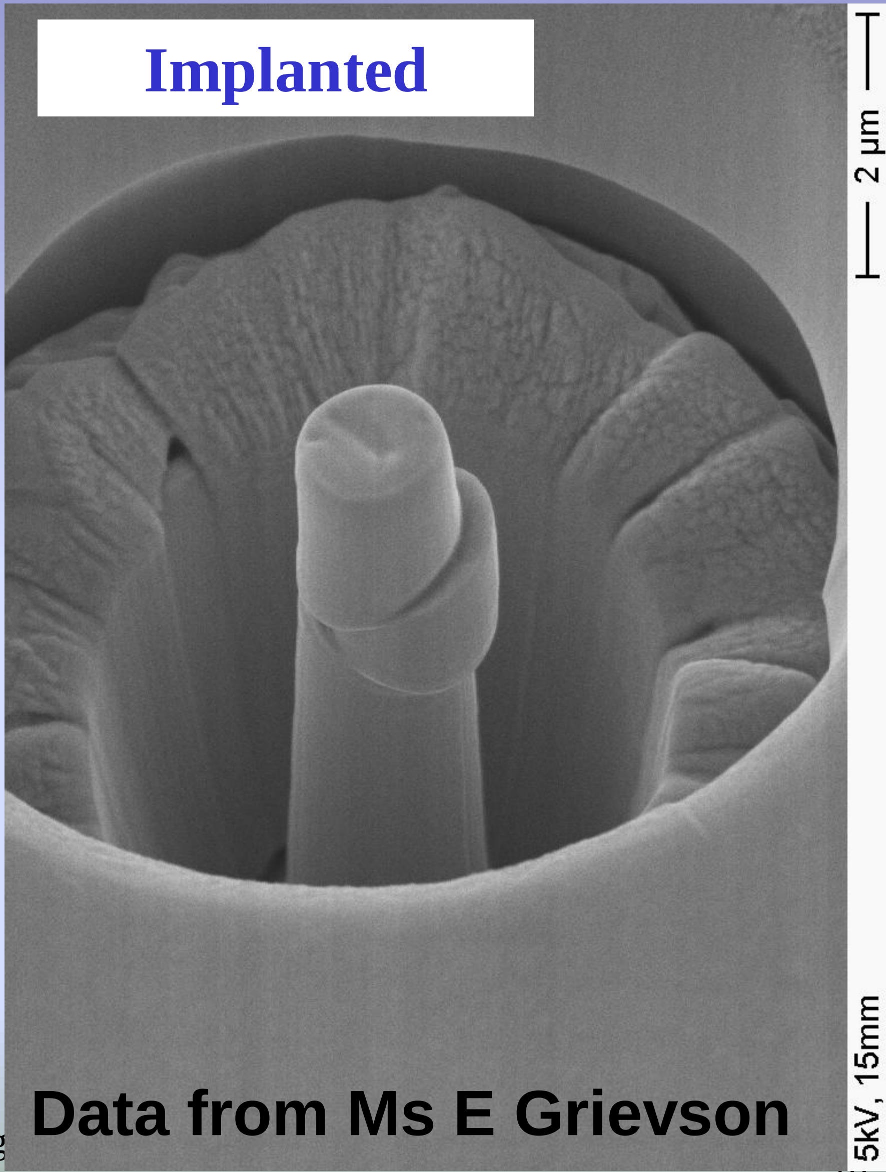
- **Pillars machined into the ion implanted layers, using multi stage approach**
- **Width approx 500nm**
- **Height 3μm**
- **Flat Punch type nanoindenter tip used to compress the pillars**



Data from Ms E Grievson

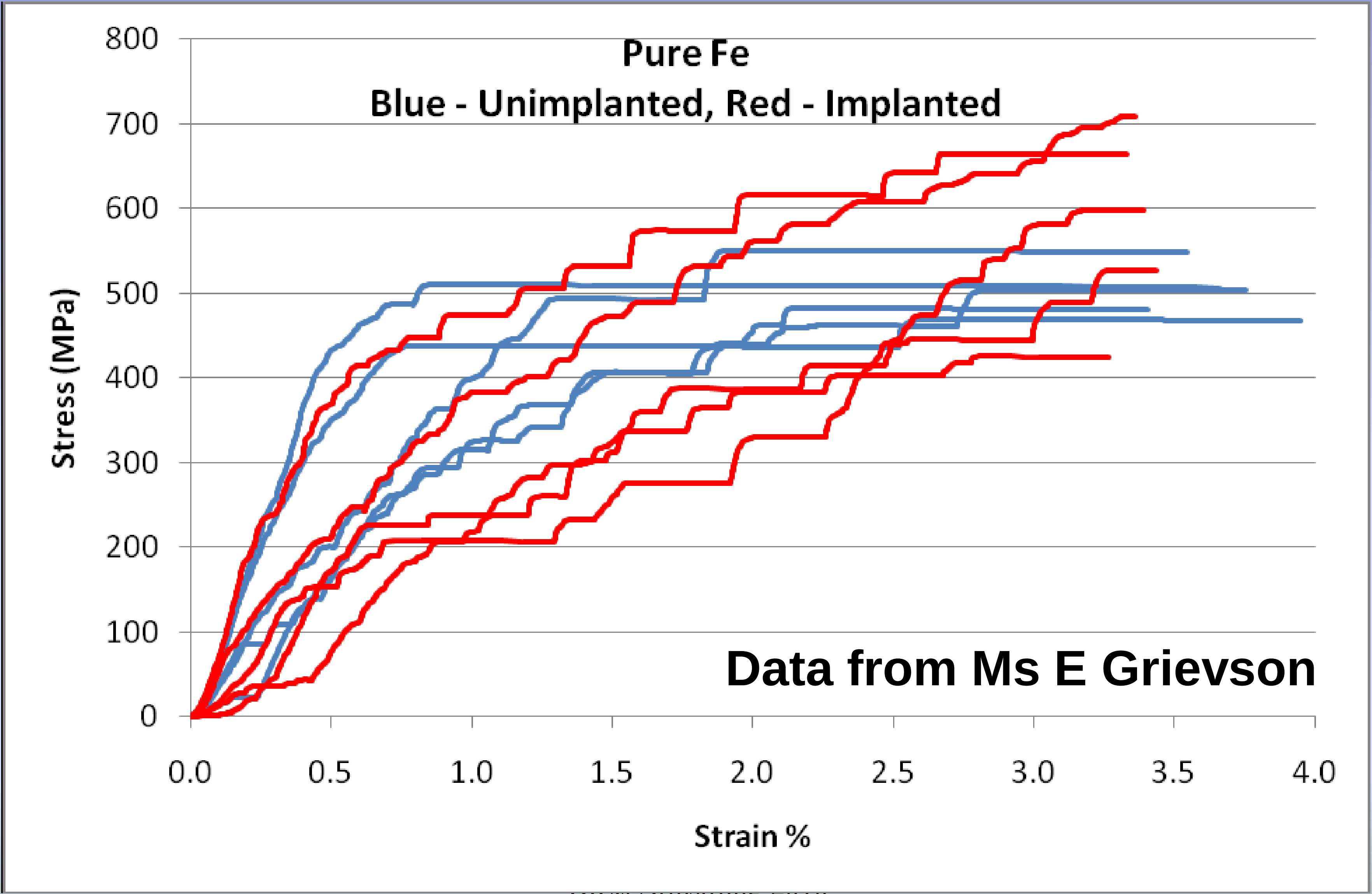
FeCr Micro Pillars





Data from Ms E Grievson

FeCr Micro Pillars



Summary and Future Work

- Nanoindentation alloys differences in hardness measured
- Only small volumes of materials needed for many results
- Doesn’t tell us about yield stress, work hardening rates
- Substrate effects need explaining

2011 and Beyond

- Nanoindentation alloys differences in hardness measured
- Only small volumes of materials needed for many results
- Doesn’t tell us about yield stress, work hardening rates
- Substrate effects need explaining

- Problems in working in such small specimens
- Are the results representative of bulk samples?
- Contact area problems
- Modelling and experimental work is ongoing to further understand these results
- High temperature tests now being developed

Thanks to

- CCFE for Fellowship Funding
- National Ion Beam Facility for Access
- Andy Bushby, Sergei Dudarev Michael Rieth, Emmanuelle Marquis and Reinhard Pippan for useful discussions