Nanoindentation of NbTa/Nb_3Sn wires

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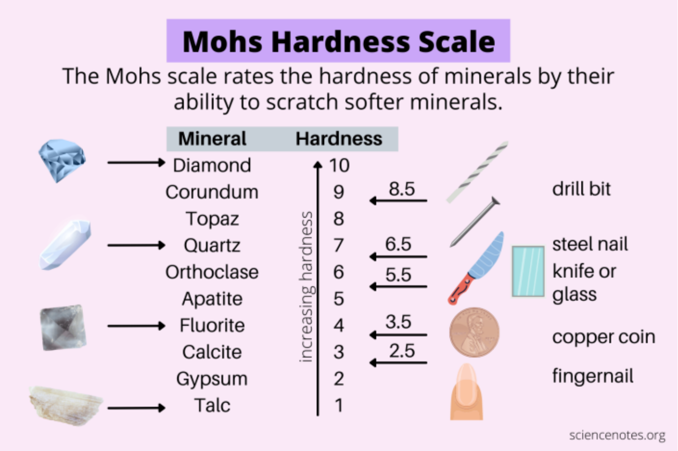
Indentation test: a hard tip with known mechanical properties is pressed into a material with unknown mechanical properties

Hardness – resistance to indentation

19th century

Mohs Hardness Scale



1900s

First static indentation experiments

Load F is selected, indent size d is measured under microscope after unloading (Brinell)

1908

Meyer's Hardness

$$H = \frac{F}{Ap}$$

1983

Depth – sensing indentation

F ≈ μN
h ≈ nm

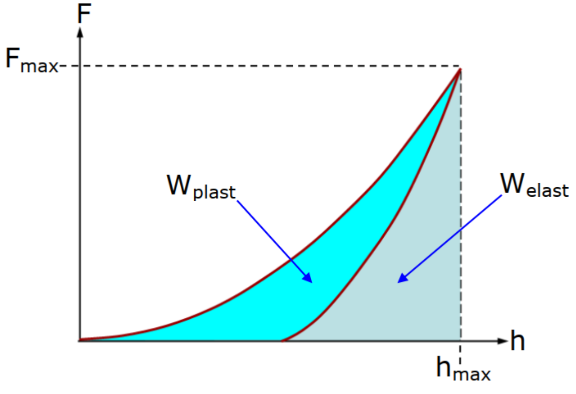
Three quantities are measured – loading force, penetration depth and time.

↓

Mechanical behaviour of materials at the micro- and nanoscales.

Introduction to nanoindentation

- Capacity of applying ultralow loads – detecting nanometer scale deflections
- Load and displacement curves are measured continuously during the load-unload curve
- Enables evaluating contact stiffness (S), elastic modulus (E) and hardness (H)
- Working in a load and depth control modes
- The analysis of load-displacement curve is done automatically according to the ISO 14577 standard



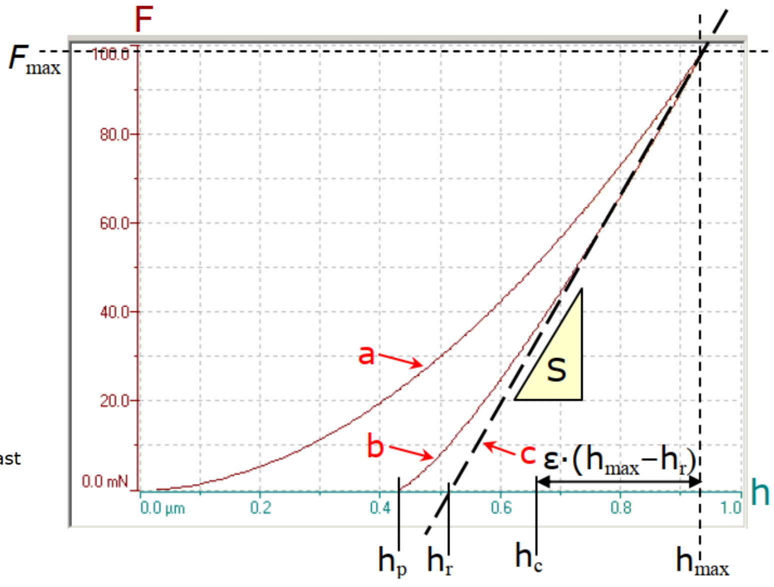
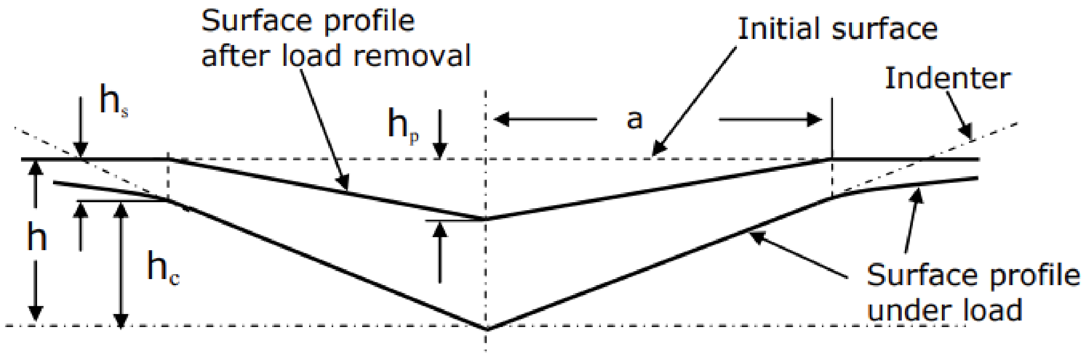


Fig.75 Indentation test

$$E_r = \frac{\sqrt{\pi} \cdot S}{2 \cdot \beta \cdot \sqrt{A_p(h_c)}}$$

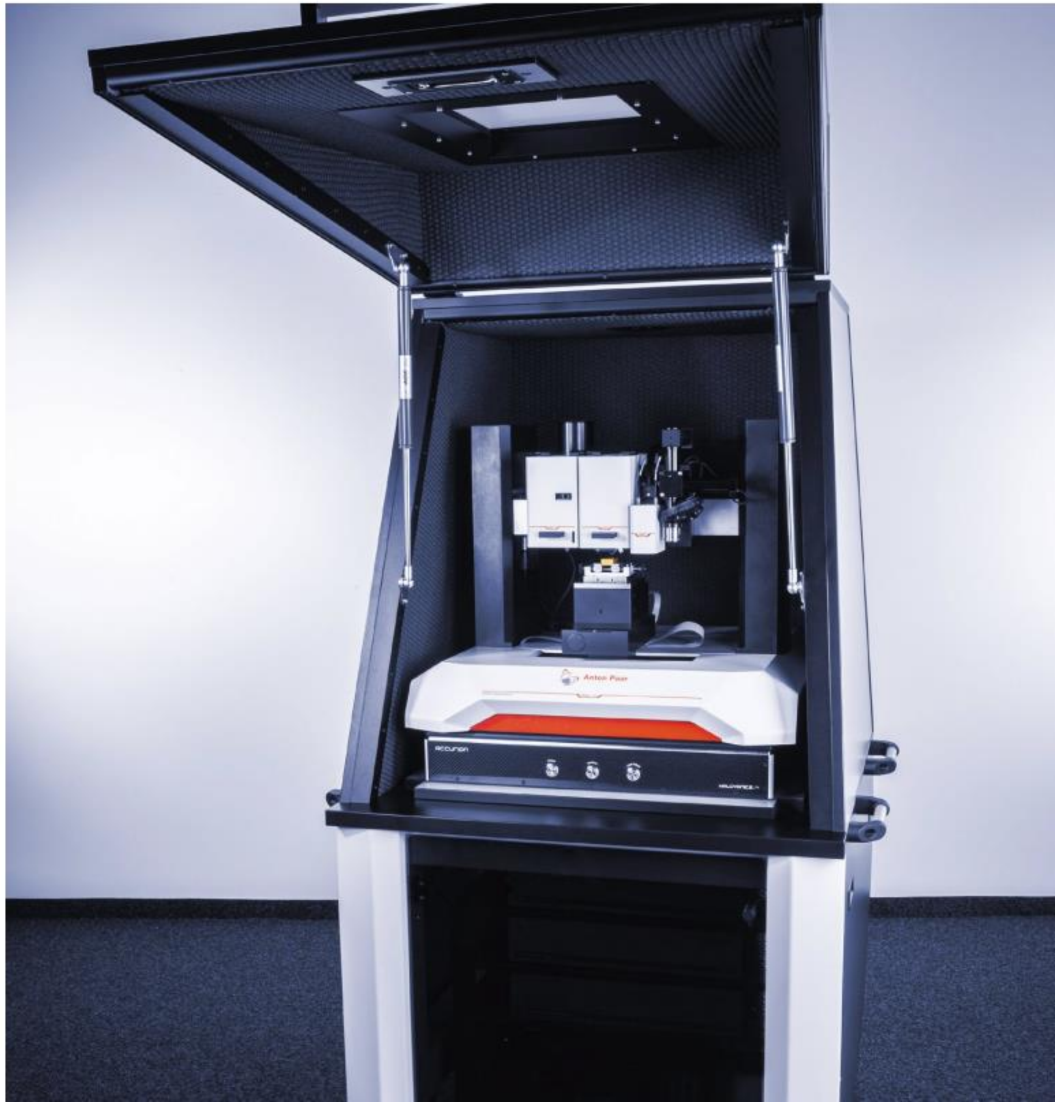
$$H_{IT} = \frac{F_{max}}{A_p}$$



Our equipment

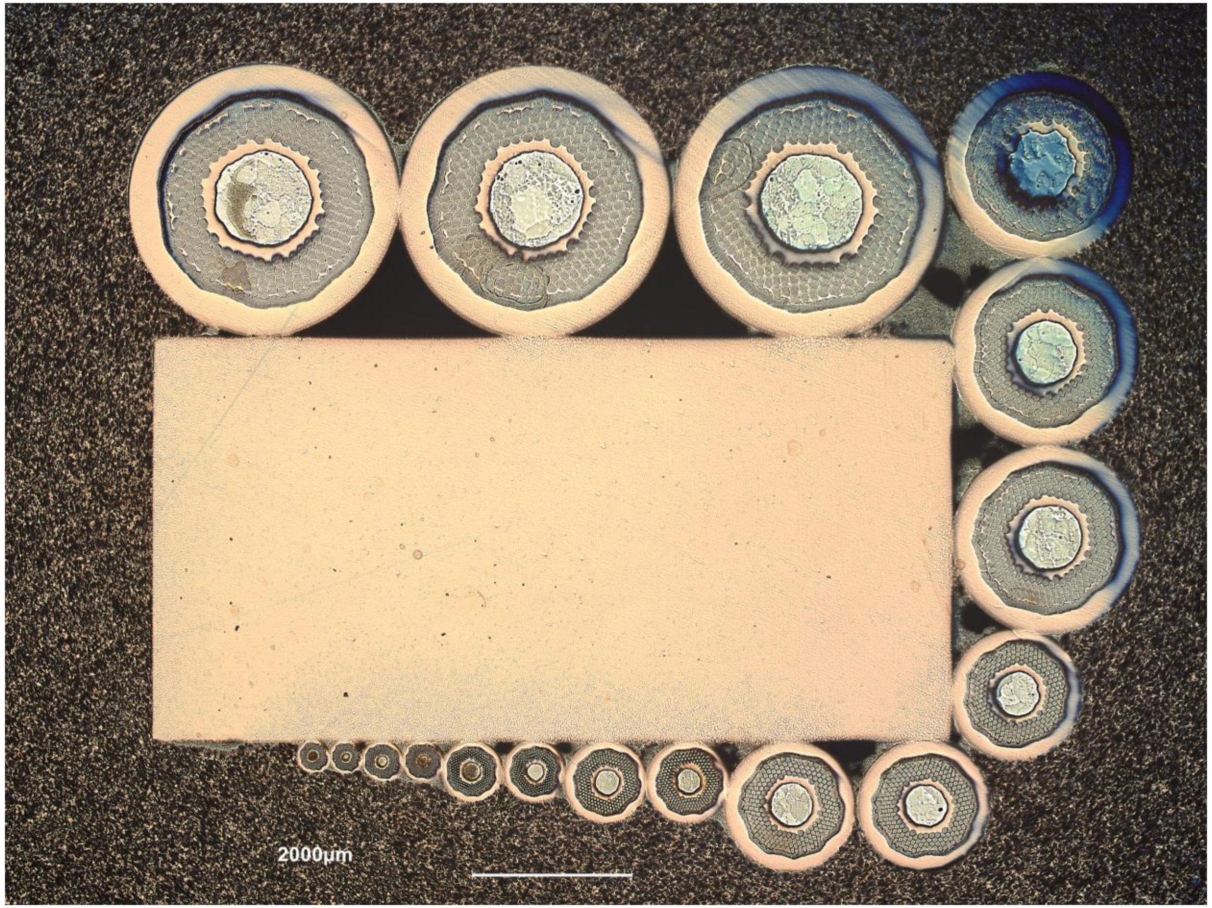
Basic information about the device:

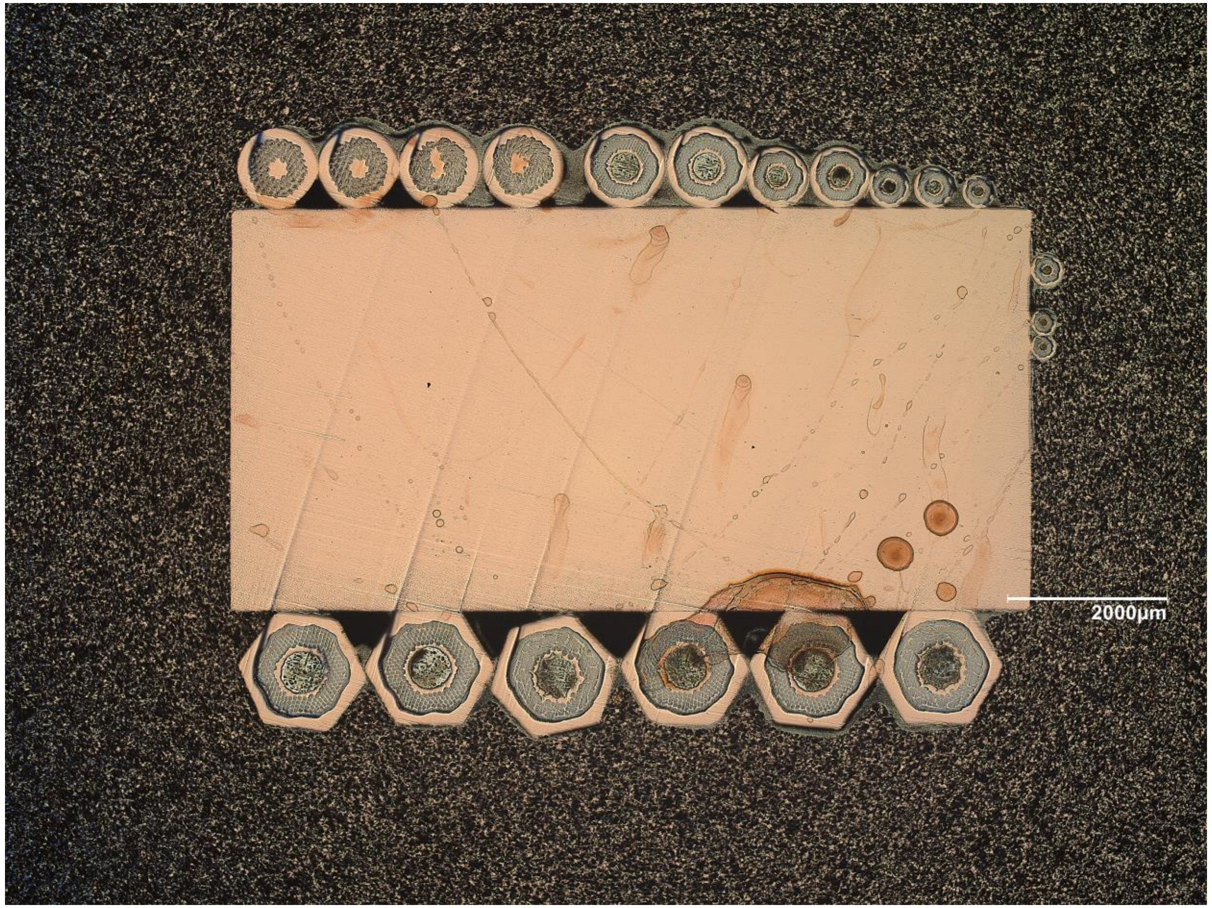
- Anton Paar UNHT^3 nanoindentor with Berkovich tip
- **Indentation testing:** analysis of mechanical properties of material at the nanoscale (hardness, elastic modulus, plastic and elastic energies of deformation, creep)
- **Atomic Force Microscope (AFM)** – analysis of indents, thin films, etc.
- **Scratch testing (MCT^3):** to measure adhesion and scratch resistance of coatings
- Max. **nanoindentation** load: 100 mN
- Resolution:
    - Depth: 0.003 nm
    - Load: 0.003 µN



Tested specimens

1st group: NbTa subelements at various diameters – preliminary study for internal oxidation of wires (without added oxygen sources)





Tested specimens

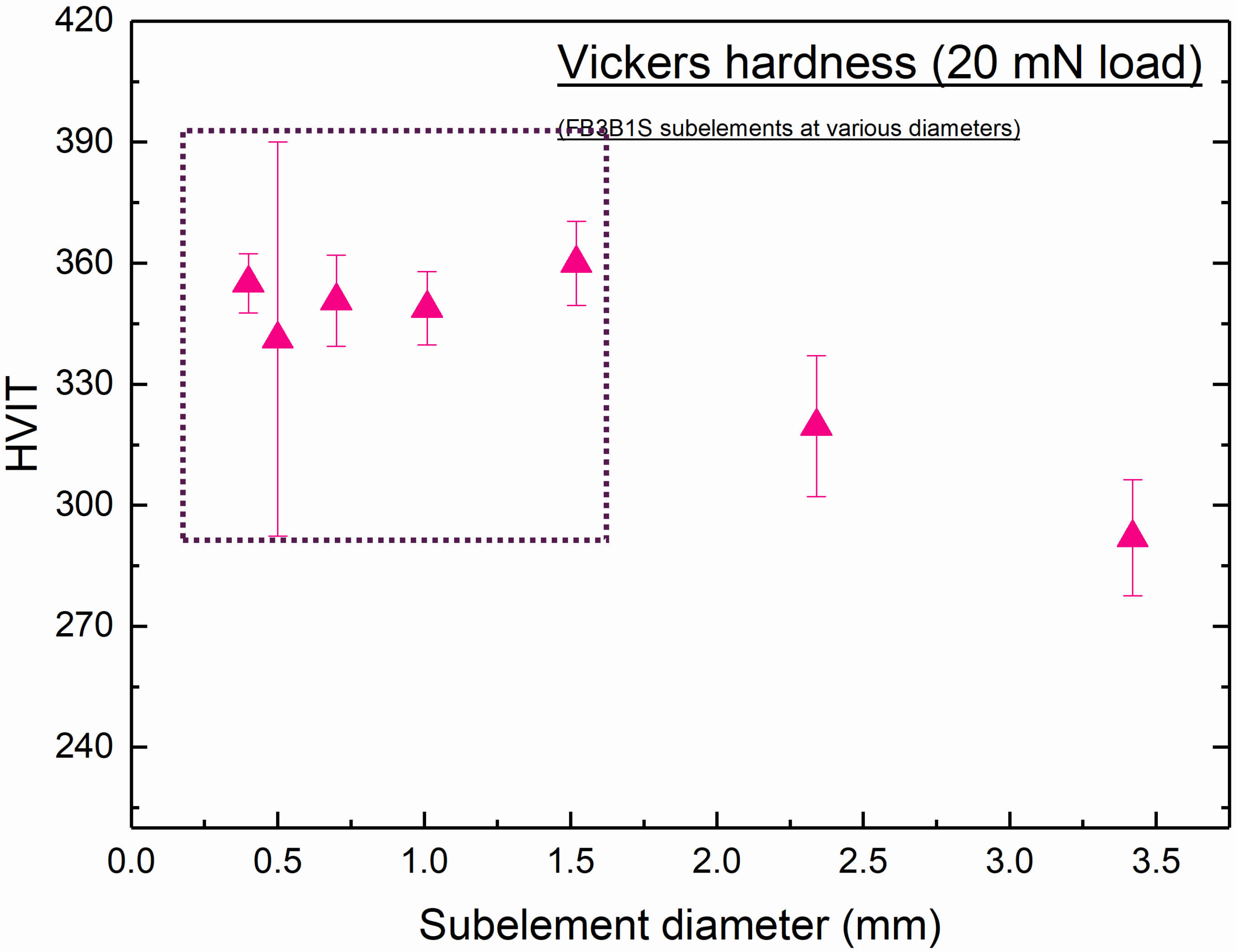
Analysis of Nb-Ta filaments

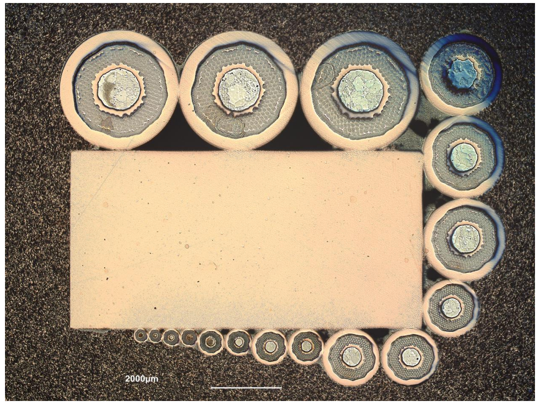
Analysis of Cu

Indents made on the Cu-filaments interface were discarded

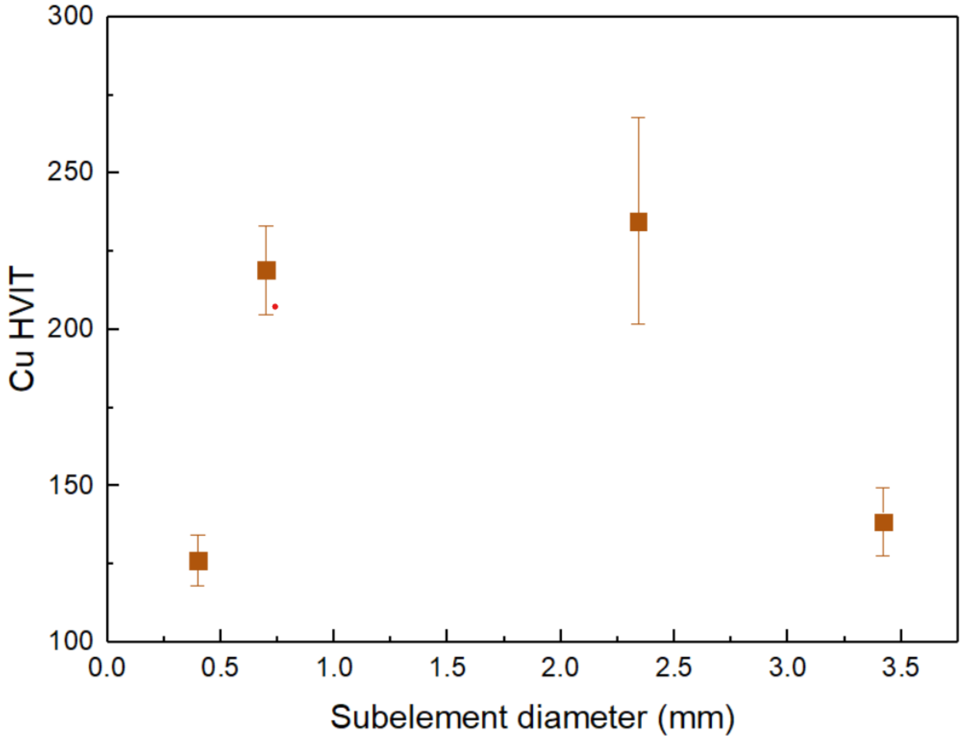
Nanomechanical characterization of NbTa filaments and Cu

Hardness NbTa filaments



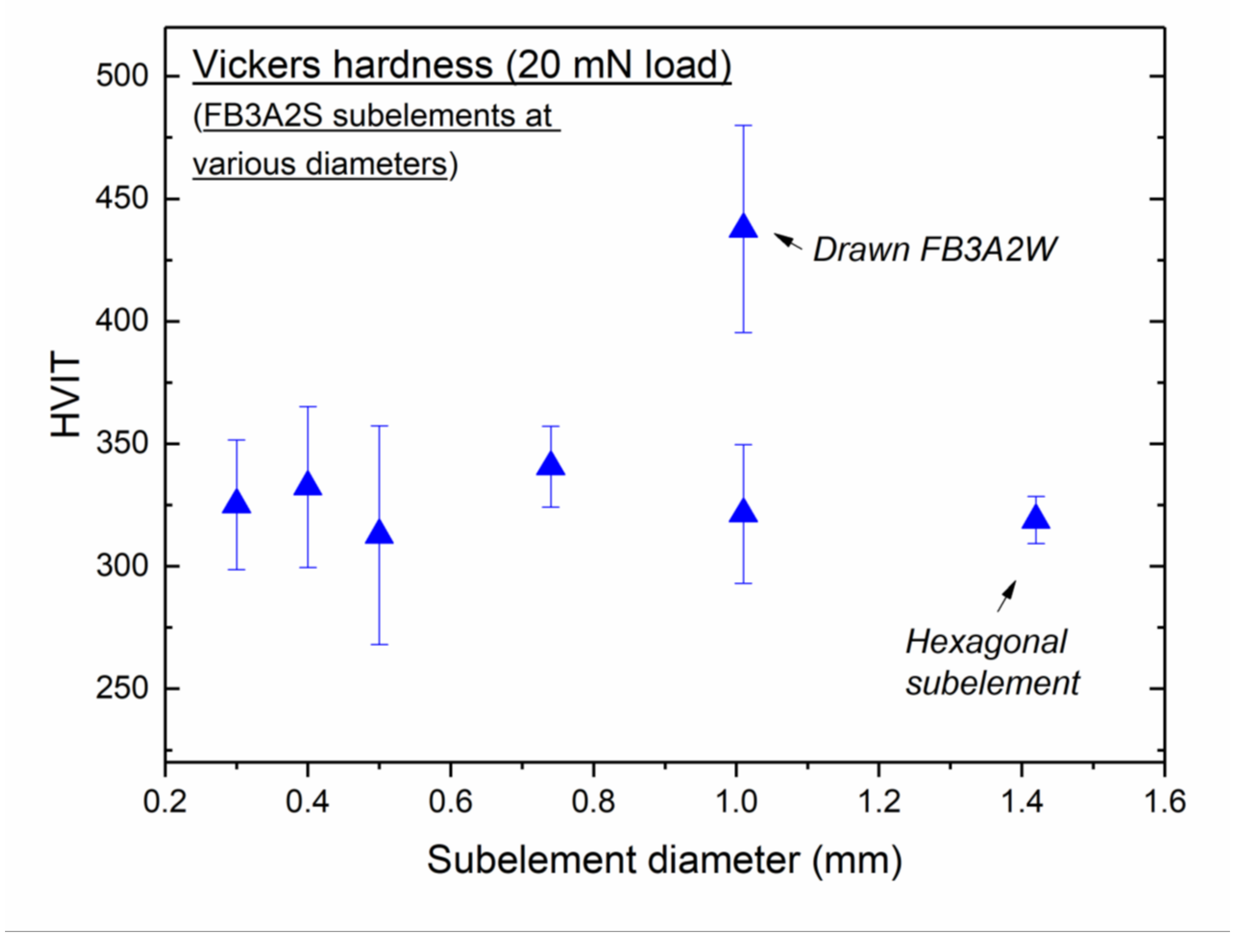


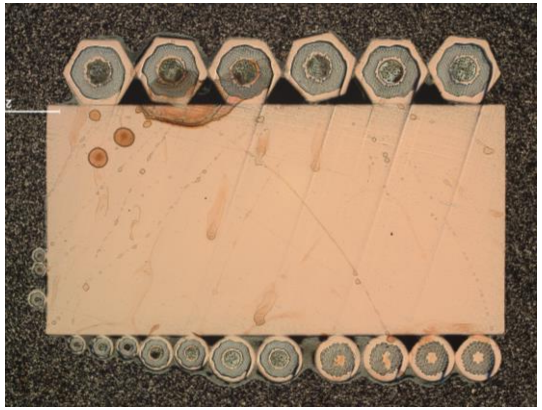
Hardness- Cu



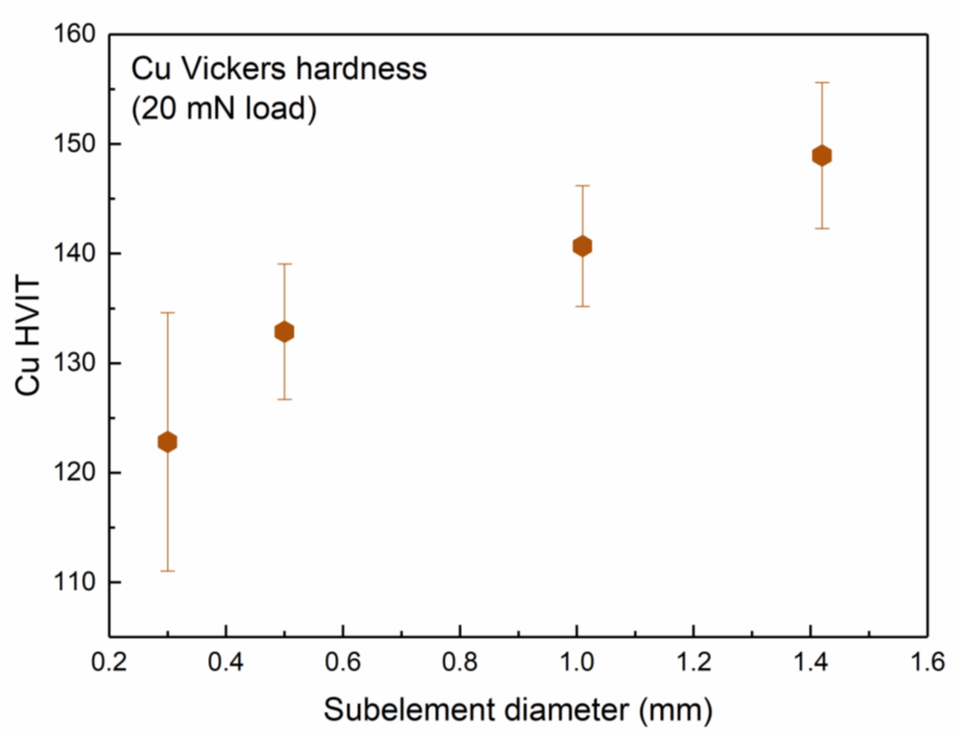
Nanomechanical characterization of NbTa and Cu

Hardness NbTa filaments



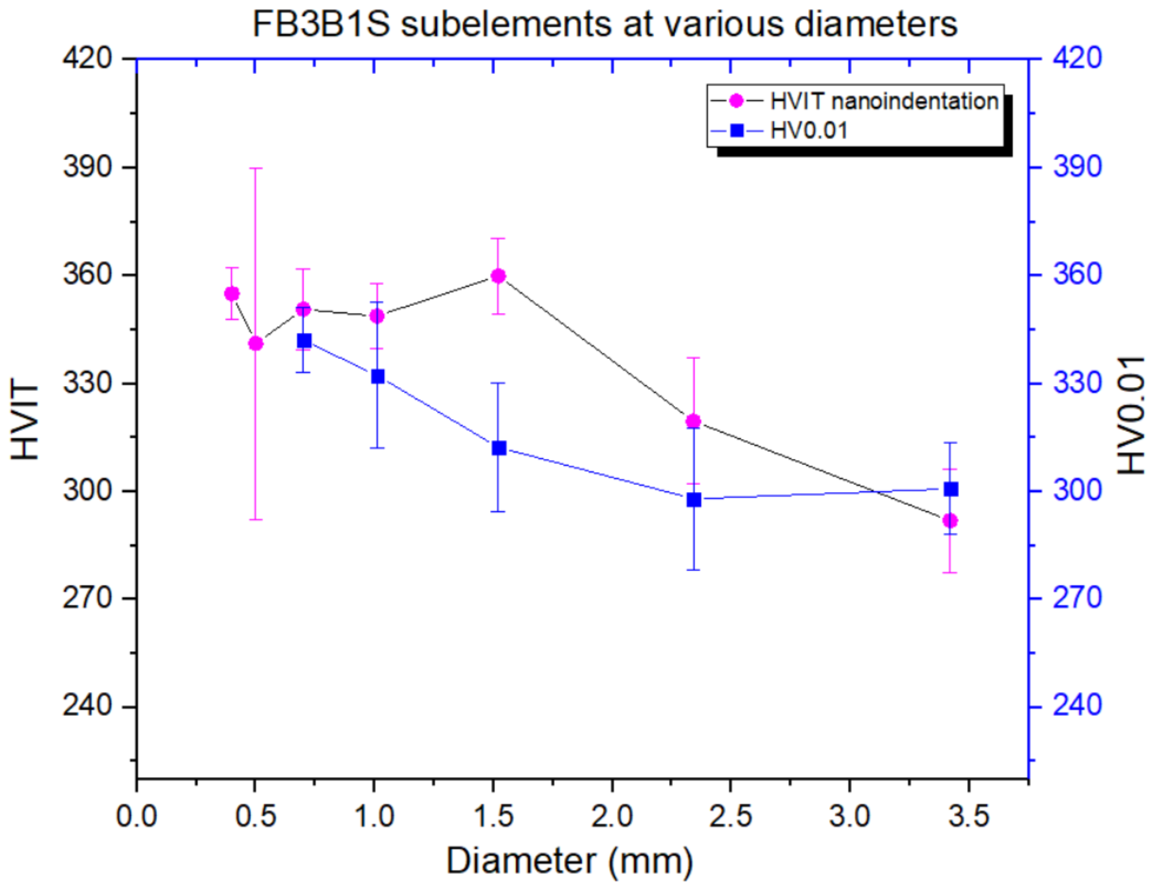


Hardness Cu

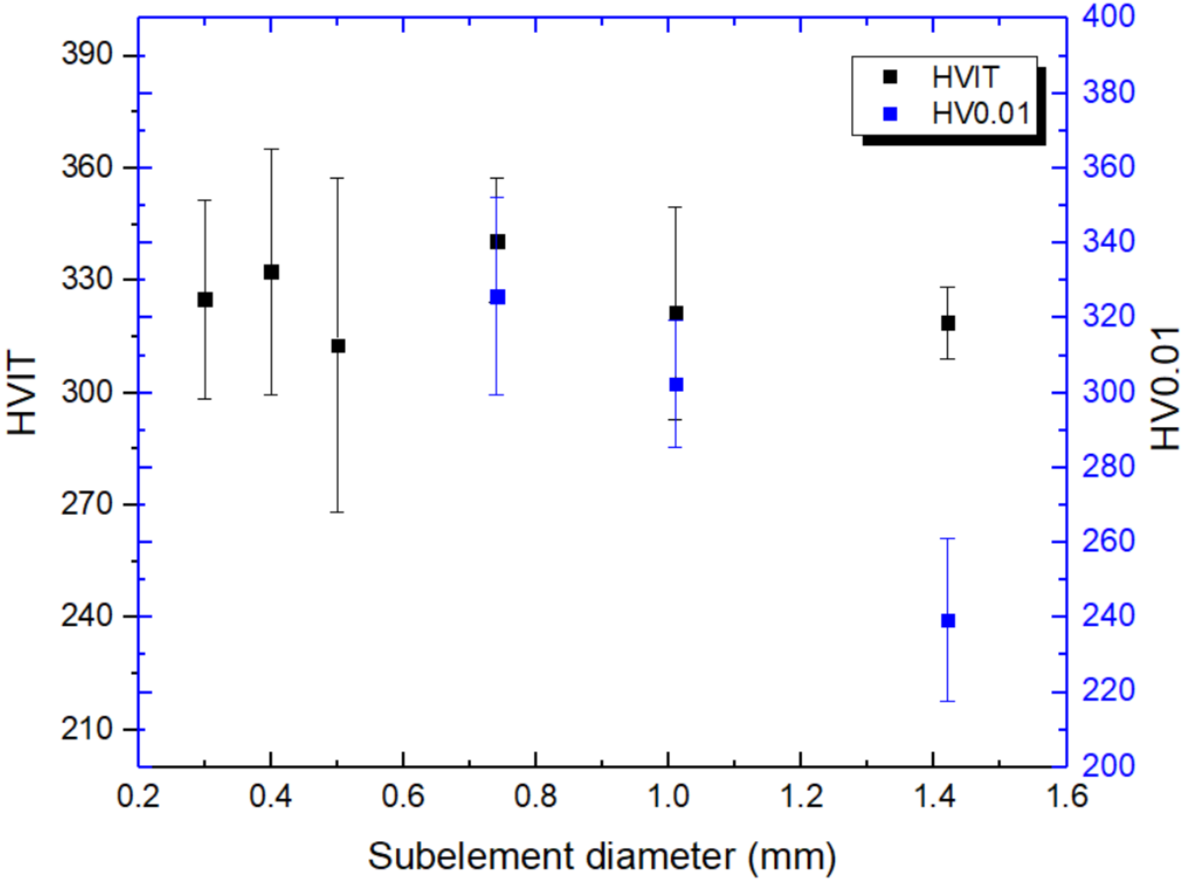


Microhardness vs. nanoindentation

Hardness NbTa filaments



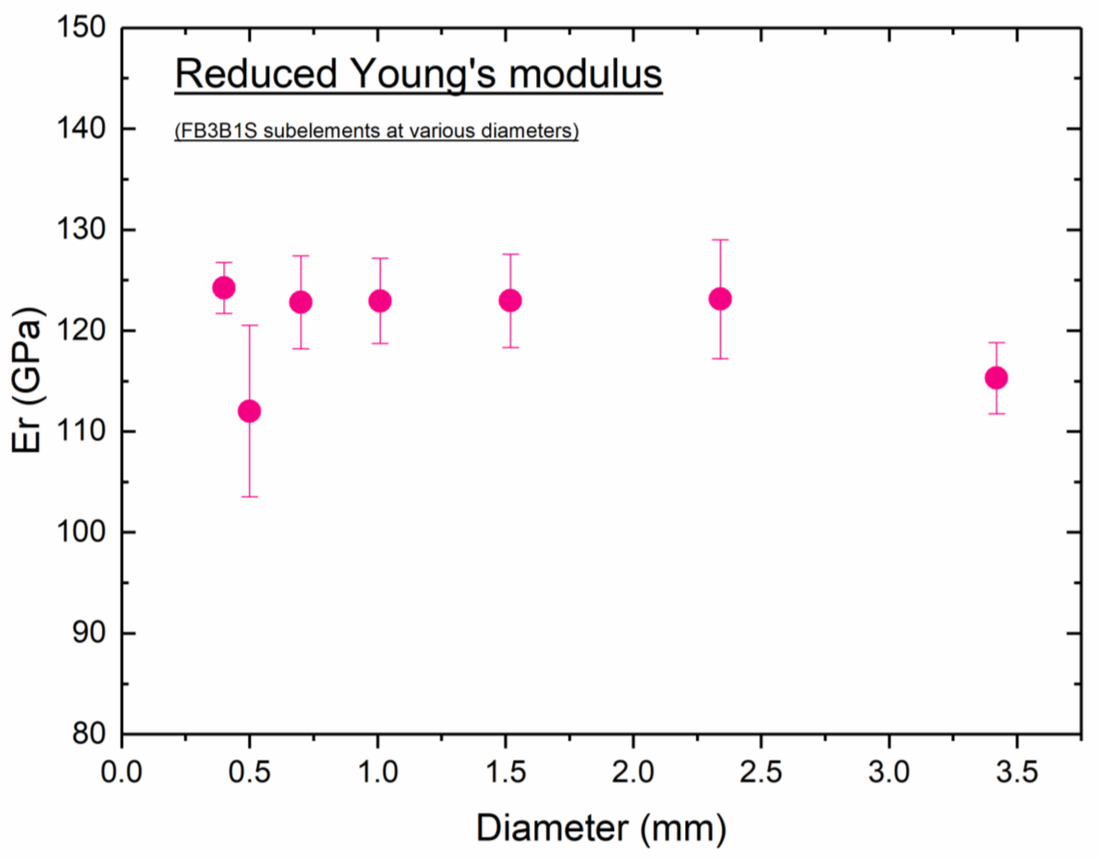
Hardness NbTa filaments



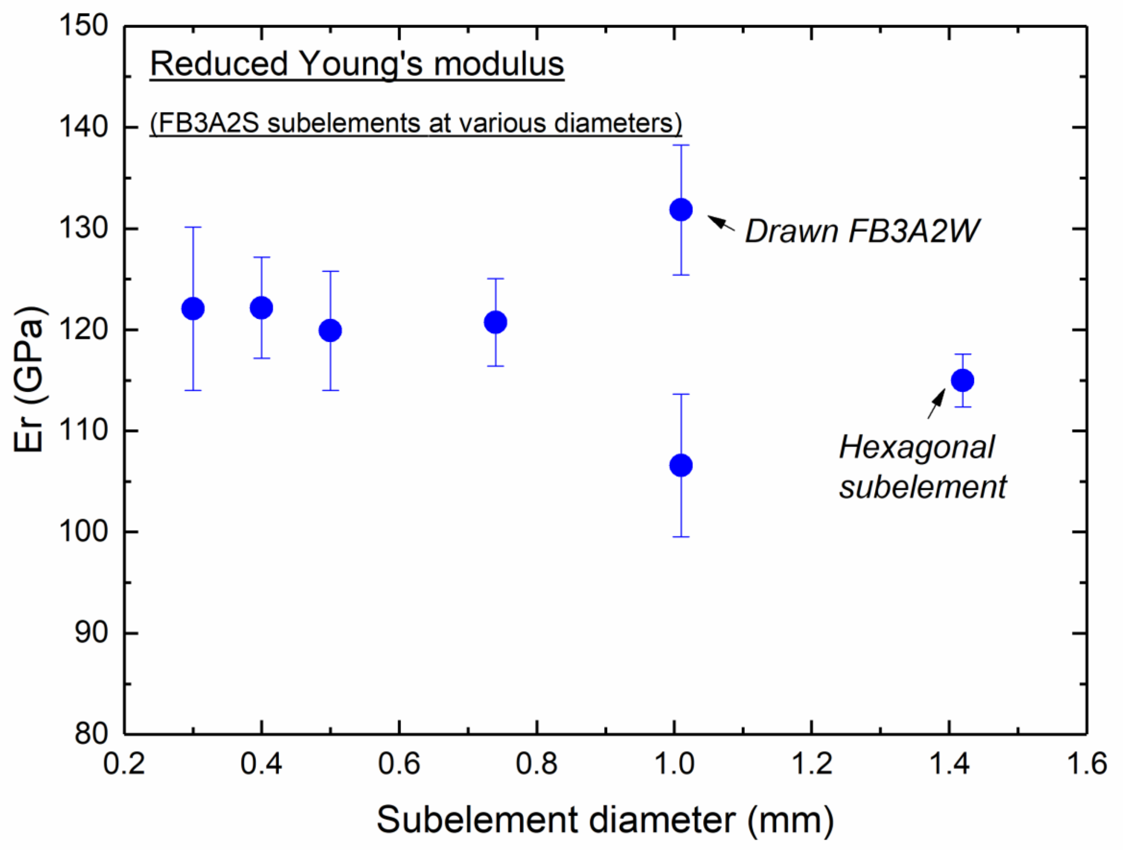
Additional measurements performed at 100 mN load using microhardness tester

Evaluation of reduced Young's modulus

Er NbTa filaments



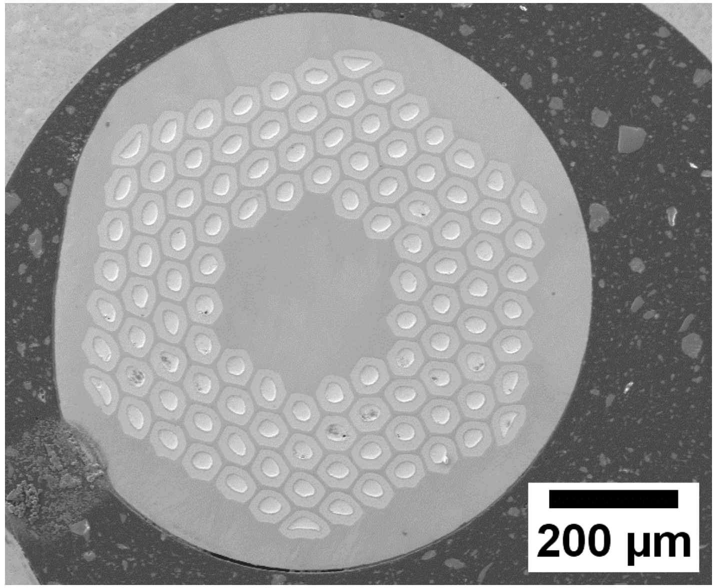
Er NbTa filaments



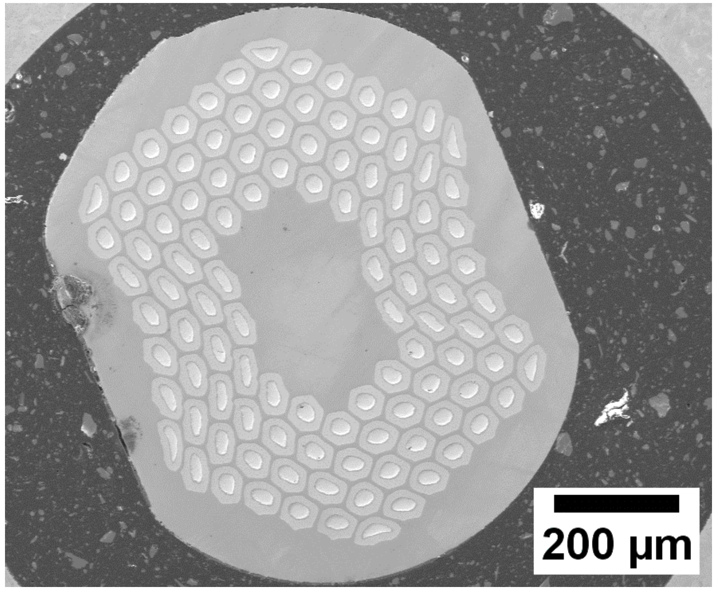
Tested specimens: MQXF wires

- <u>4 states: </u>**unreacted** (rolled and non-rolled) and **reacted** (rolled and unrolled)
- **Nanoindentation parameters:** Nb/Nb_3Sn subelements (**20 mN**), Cu (**100 mN**)

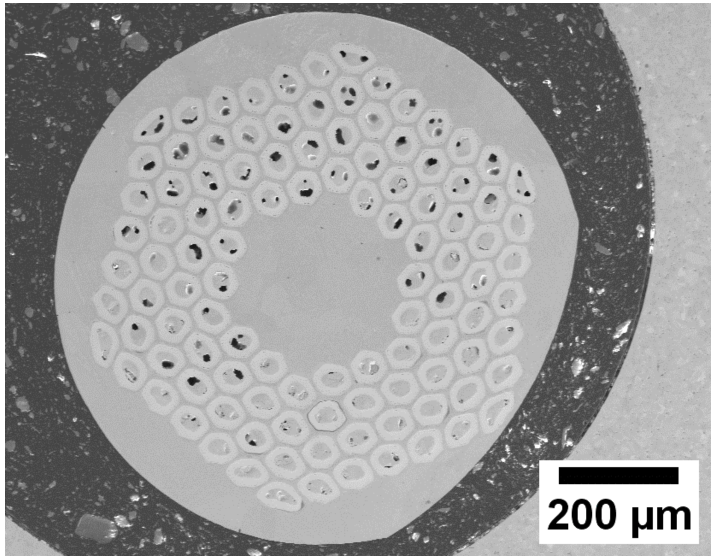
Unreacted



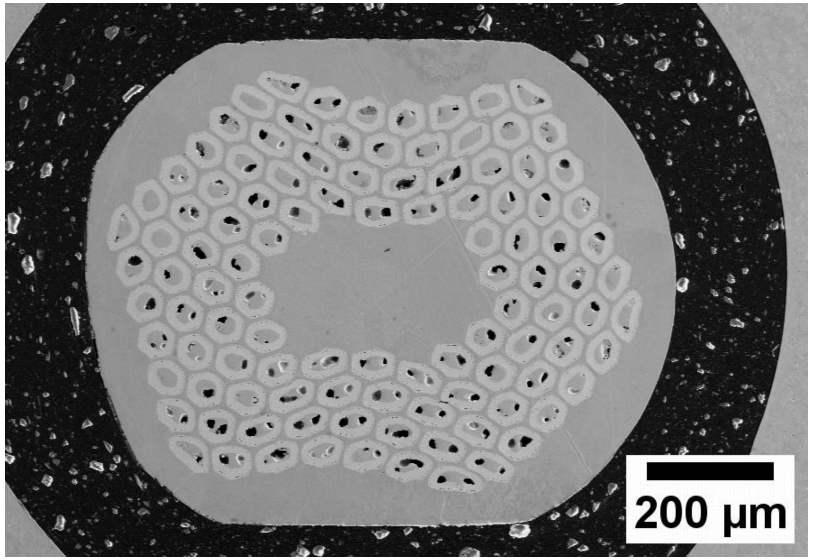
Rolled unreacted



Reacted



Rolled reacted

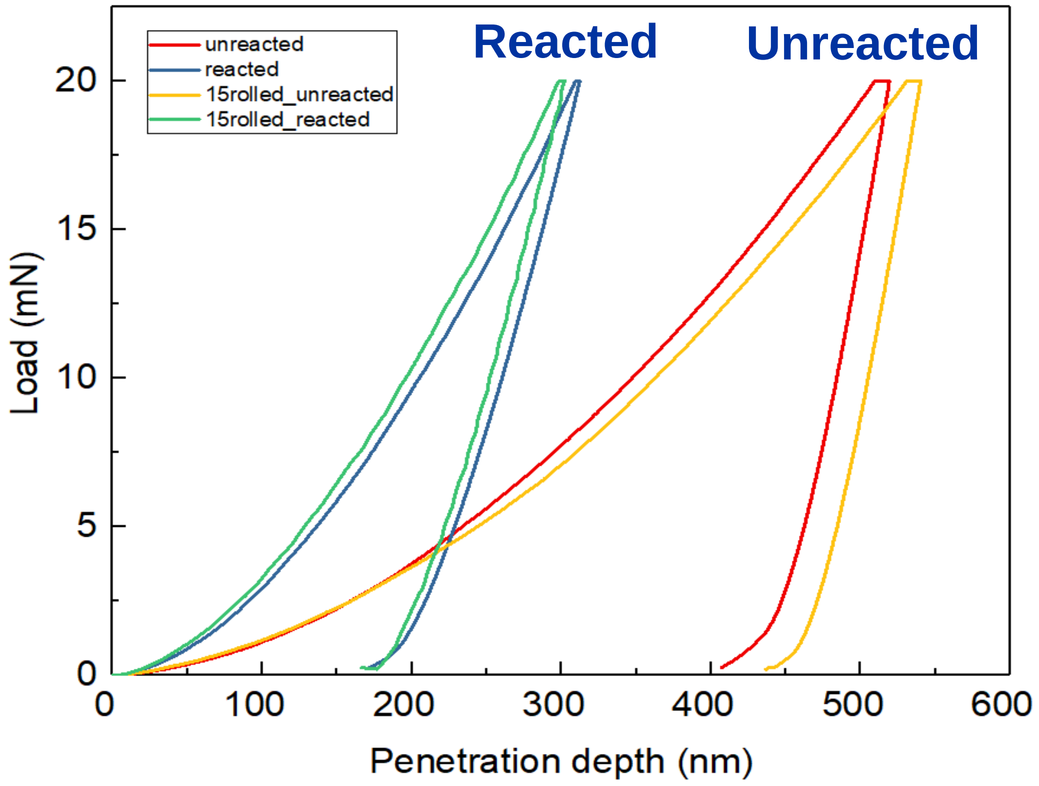


Evaluation of nanomechanical properties of MQXF wires (Nb/Nb_3Sn)

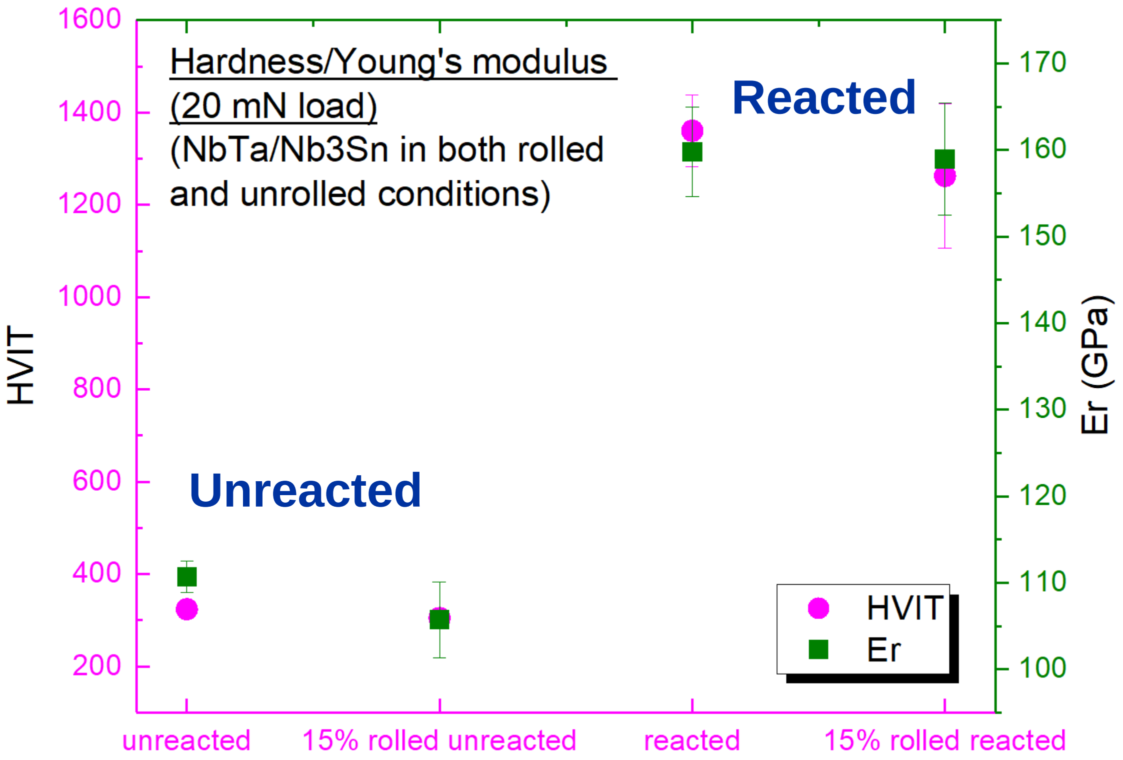
- No significant differences between rolled and unrolled conditions for Nb and Nb_3Sn
- Significant increase in H and E_r in reacted samples

Nb/Nb_3Sn

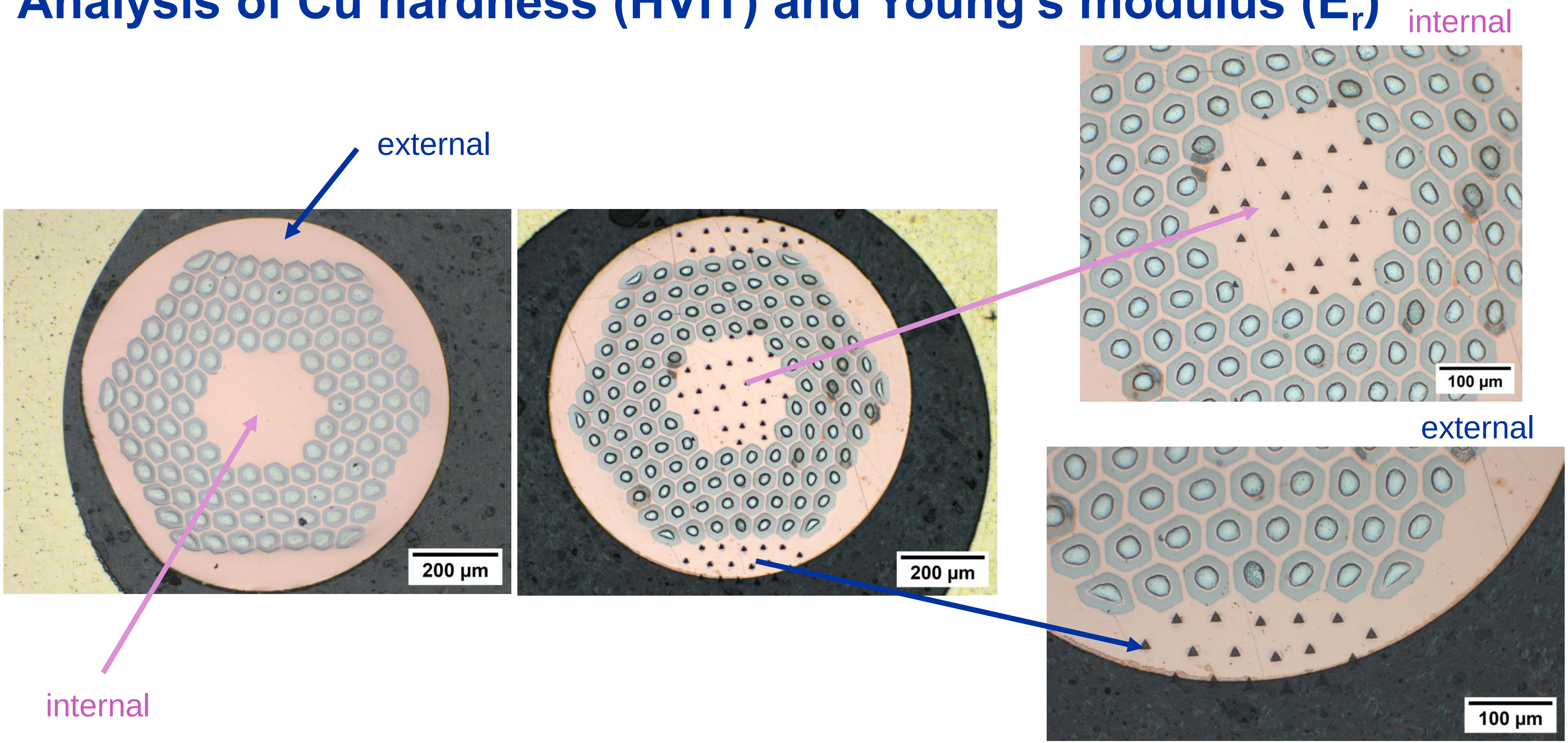
Indentation load-displacement curve



HVIT/E_r for Nb/Nb_3Sn



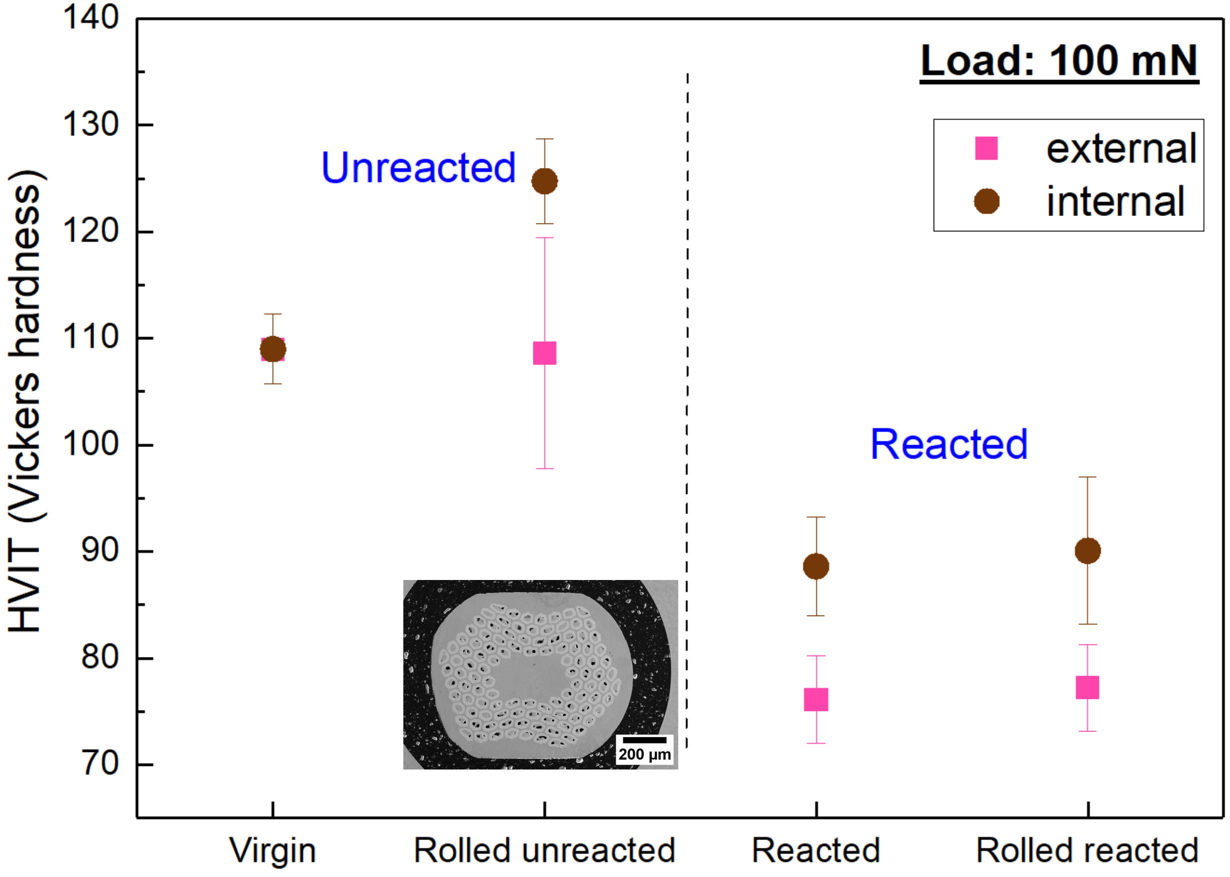
Analysis of Cu hardness (HVIT) and Young's modulus (E_r)

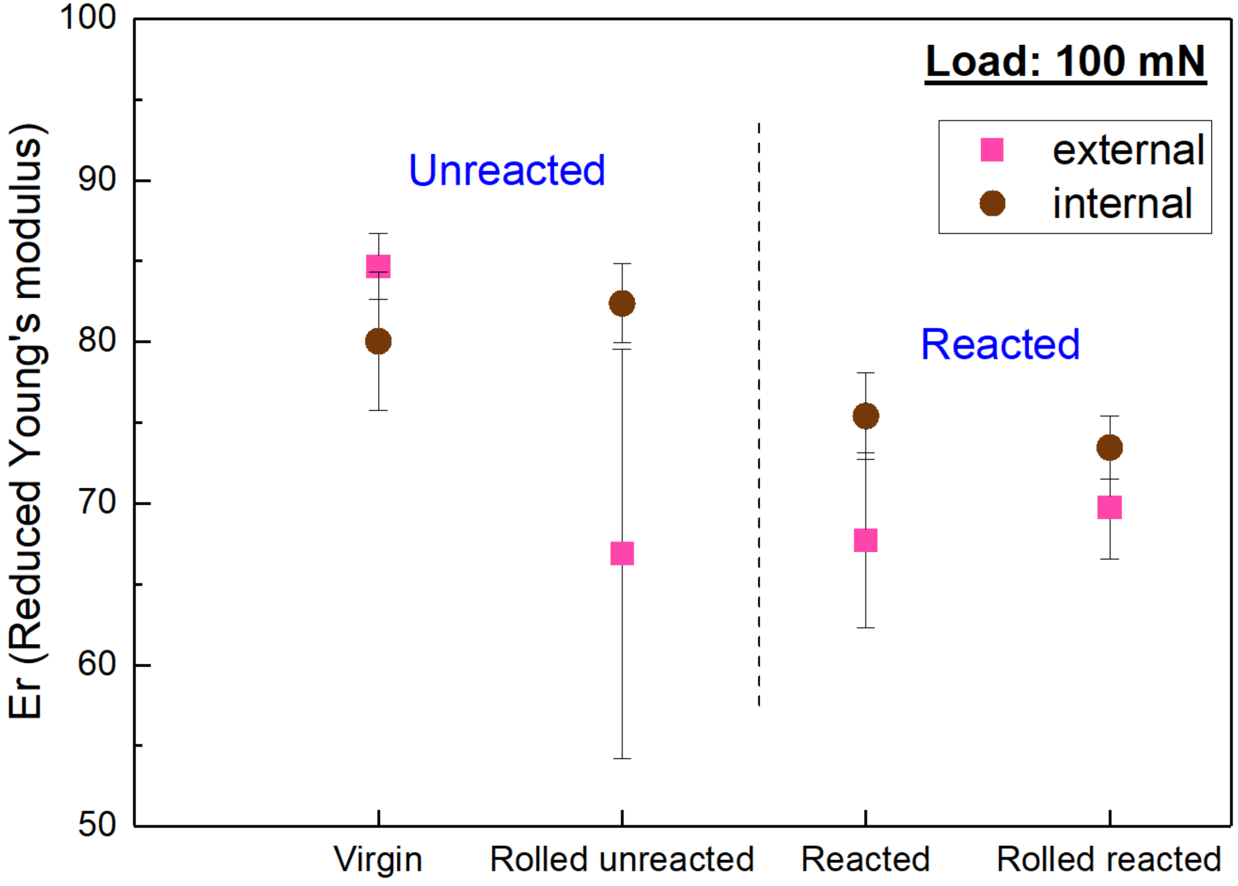


Analysis of Cu/CuSn hardness

Load: 100 mN to decrease indentation size effect

Cu/CuSn





HVIT decreases after HT

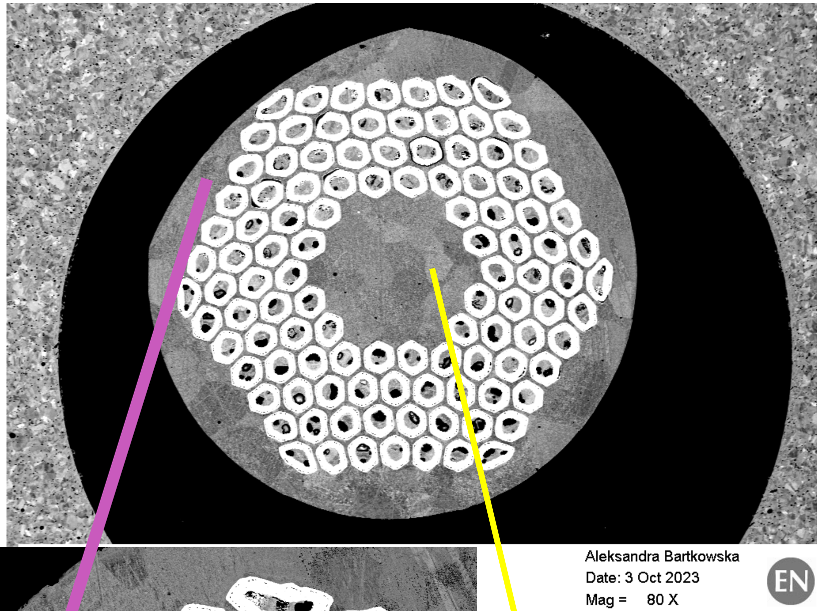
Low Er – pile up effect

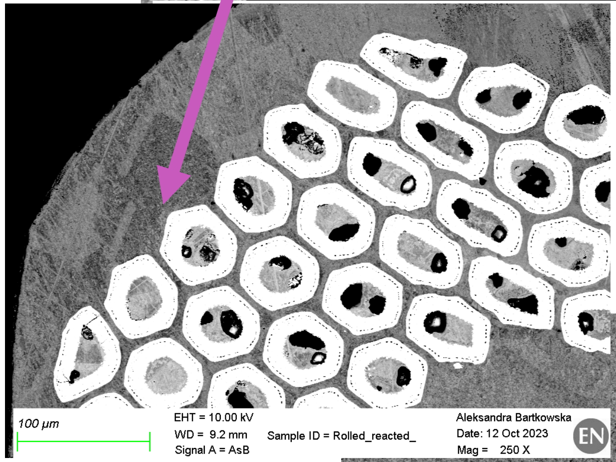
$$E_r = \frac{\sqrt{\pi} \cdot S}{2 \cdot \beta \cdot \sqrt{A_p(h_c)}}$$

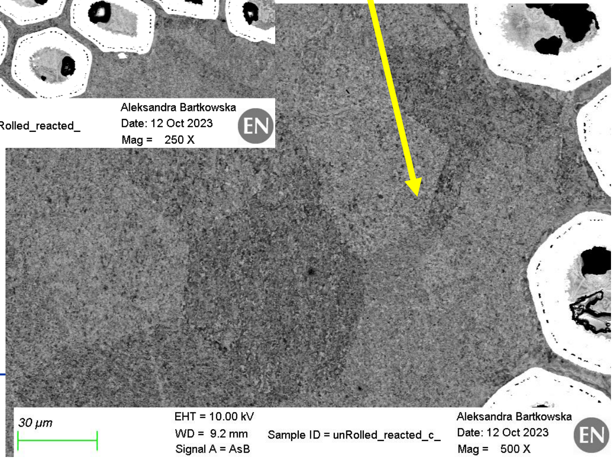
Analysis of Cu/CuSn hardness

Unreacted wire – refined Cu grains
Reacted wire – larger grains with subgrains

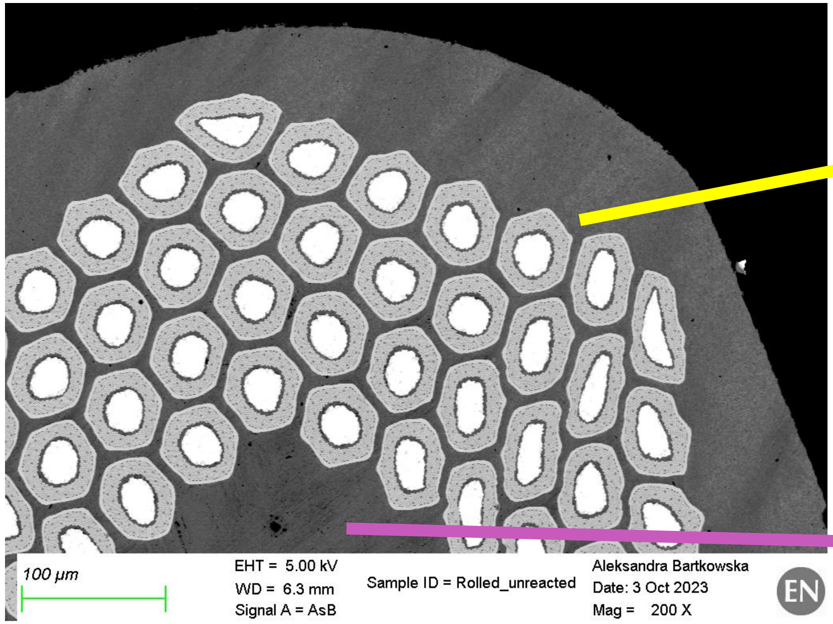
Reacted wire

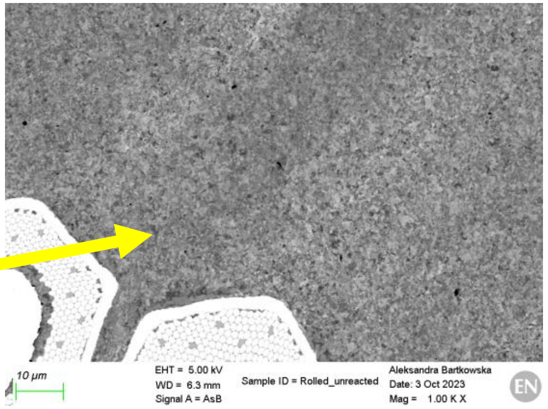


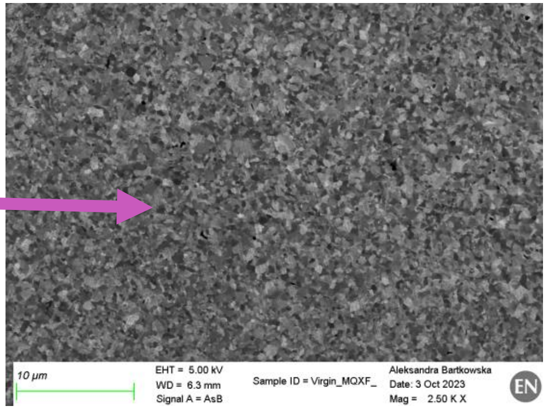




Unreacted wire







Comparison with literature

Sample	Measured E_r	Lit. value
Nb	105-110	92-110
Nb_3Sn	160	124-179
Cu (external)	67-84	80-125