Lawrence Livermore National Laboratory

Materials Characterization of Tantalum for High Energy Density Targets

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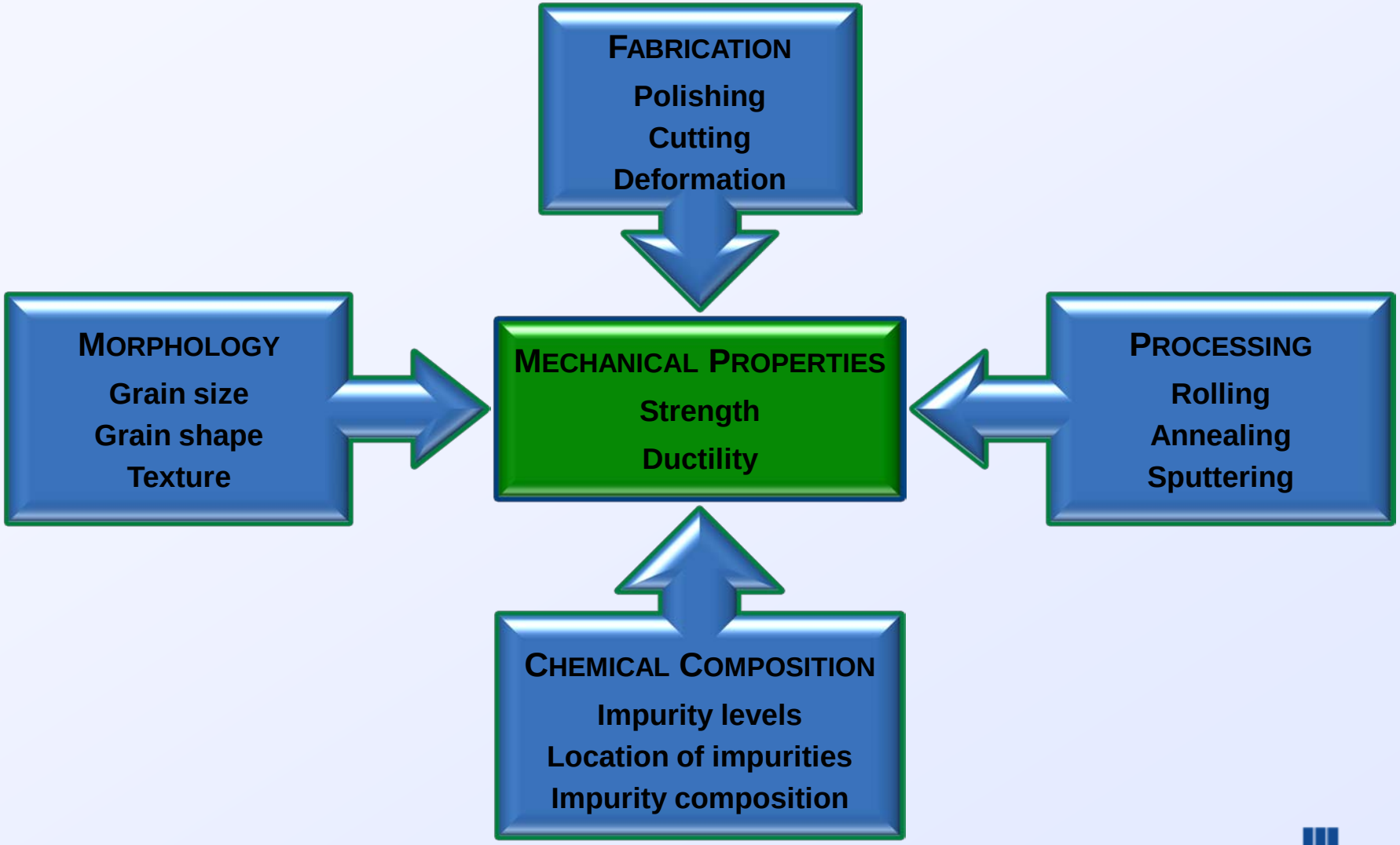
LLNL-PRES-501632

The morphology, processing, and preparation of a target material can be as important as its chemical composition



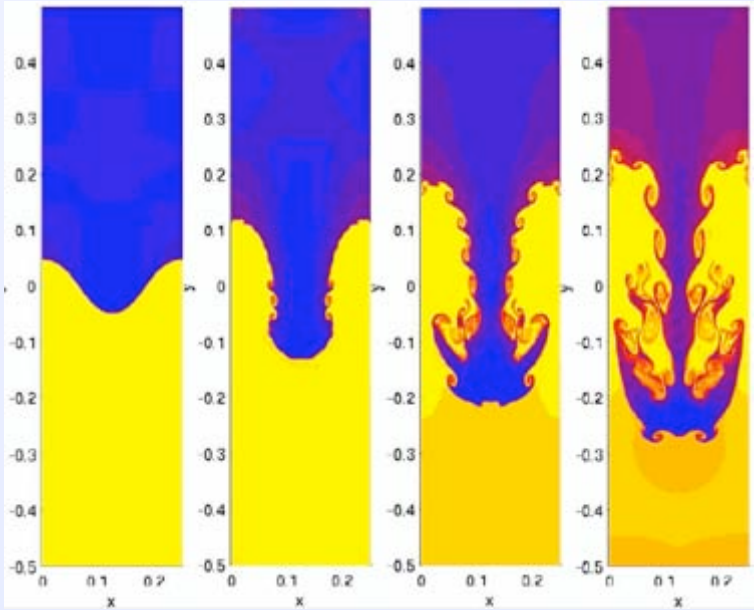
OMEGA and NIF experiments are designed to study mechanical properties of materials at high pressures and high strain rates

- Rayleigh-Taylor experiments for validation of strength models
  - RT instability develops when a less dense fluid pushes a more dense fluid
  - Strength of the material slows growth
  - Instability growth measured with VISAR

High density liquid on top of a lower density liquid

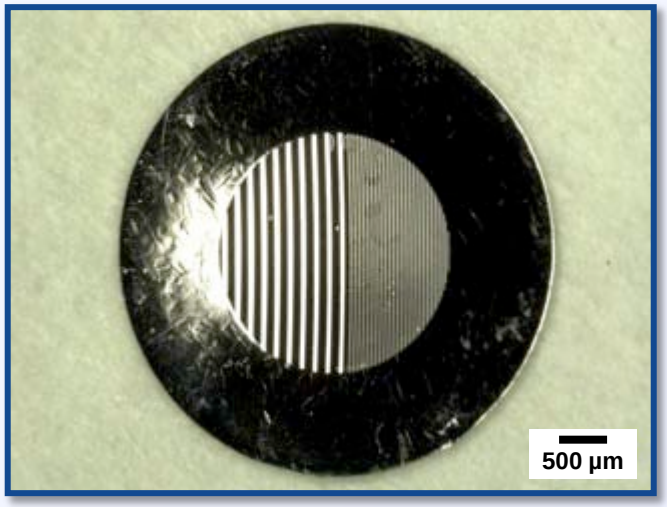
http://www.physicscentral.com/explore/pictures/cup.cfm

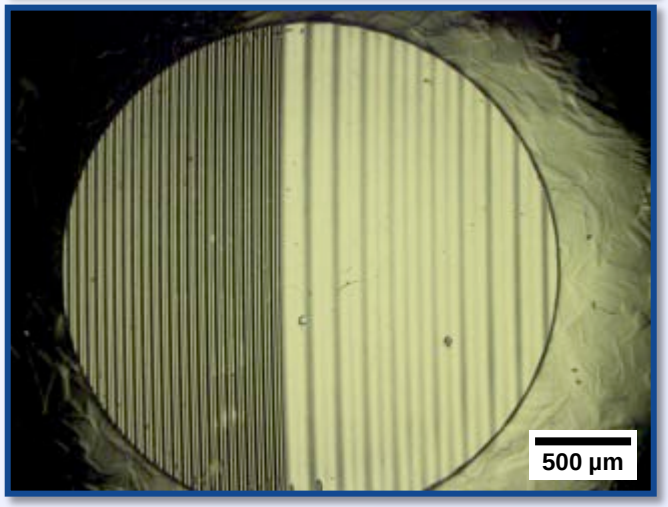
Hydrodynamics simulation of RT growth



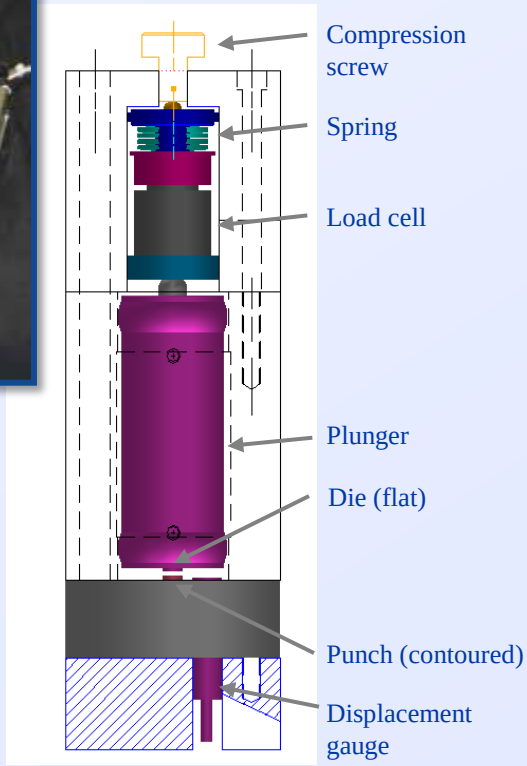
Shengtai Li & Hui Li, "Parallel AMR Code for Compressible MHD or HD Equations," LANL Report LA-UR-03-8926

Rayleigh-Taylor instabilities are seeded with sine-wave ripples on tantlum in OMEGA and NIF targets





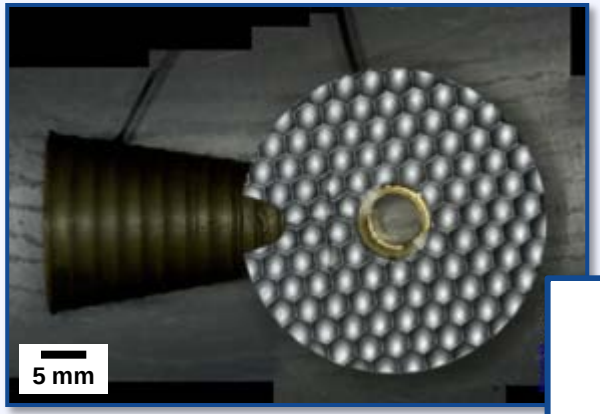
Press for coining sine-wave pattern



Ripple Dimensions

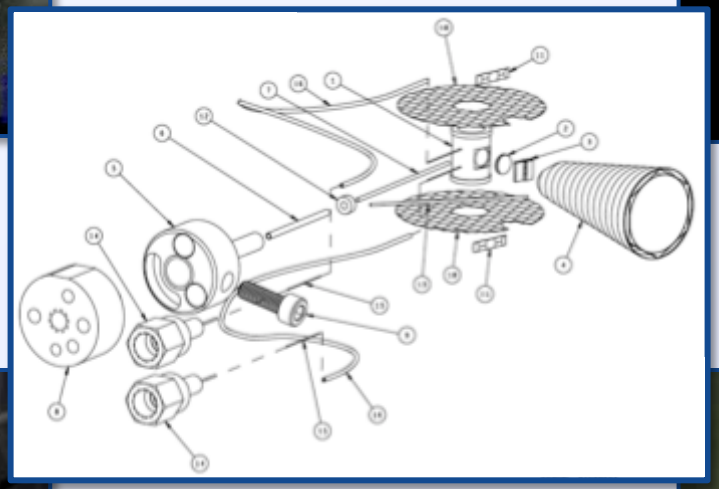
- Peak-to-valley amplitude: 1 – 7 µm
- Wavelength: ~50 µm

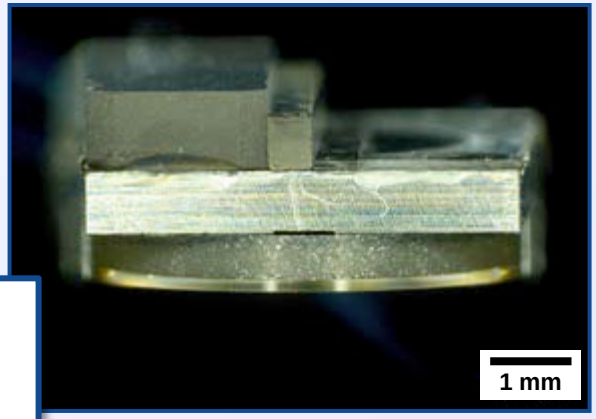
A 5 Mbar drive for Ta Rayleigh-Taylor experiments was demonstrated at NIF in March 2011



Fully assembled target with VISAR and unconverted light shields

Assembly drawing

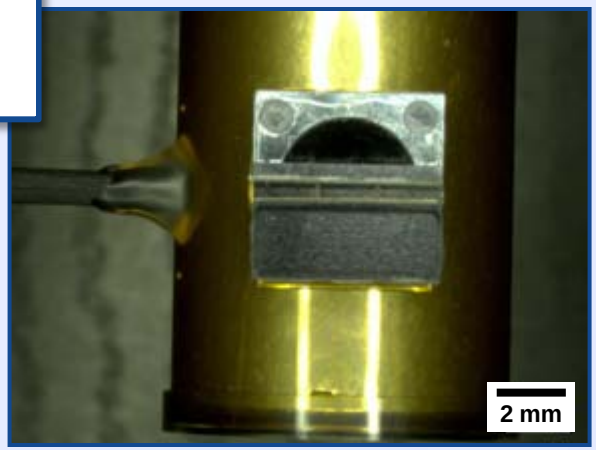




Side view of the target package (LiF & quartz windows, Ta foil, Al spacer, foam reservoir encased in epoxy)

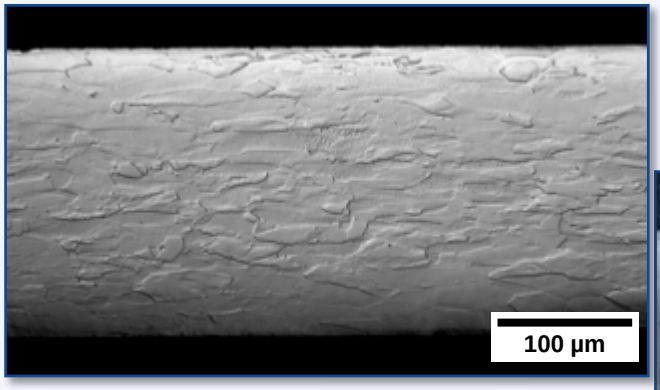
View of the target package, looking down the VISAR shield

Face-on view of the target package mounted on the outside of a hohlraum

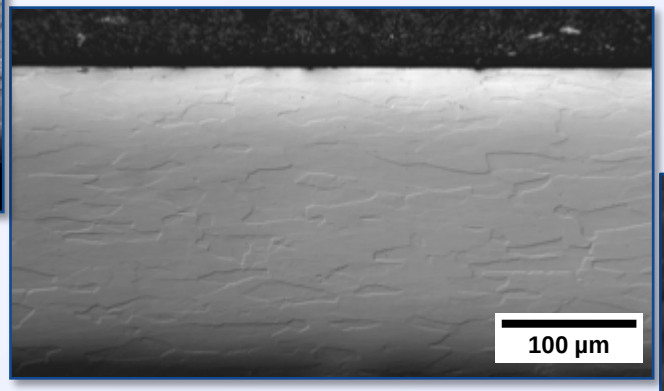


RT experiments measure material properties; it is important to select, process, and characterize tantalum carefully

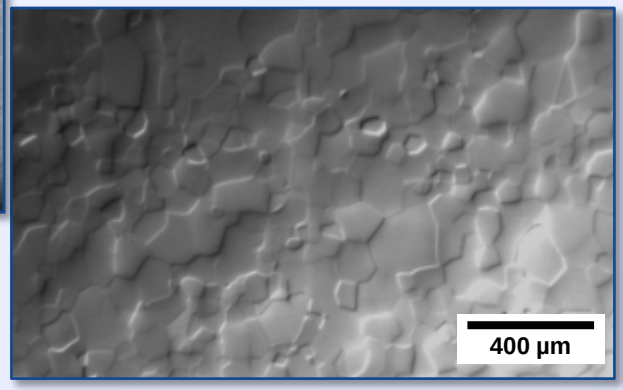
Not all high-purity tantalum is the same!



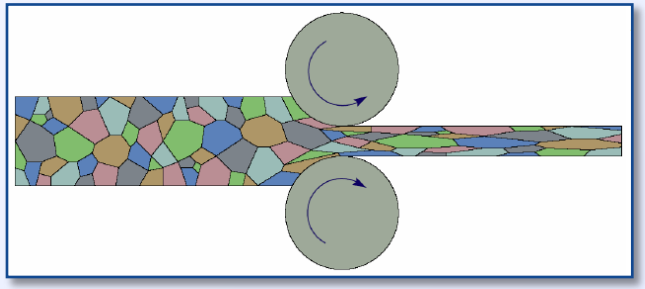
Microstructure of rolled Ta
(pancaked grains)



Rolled and annealed



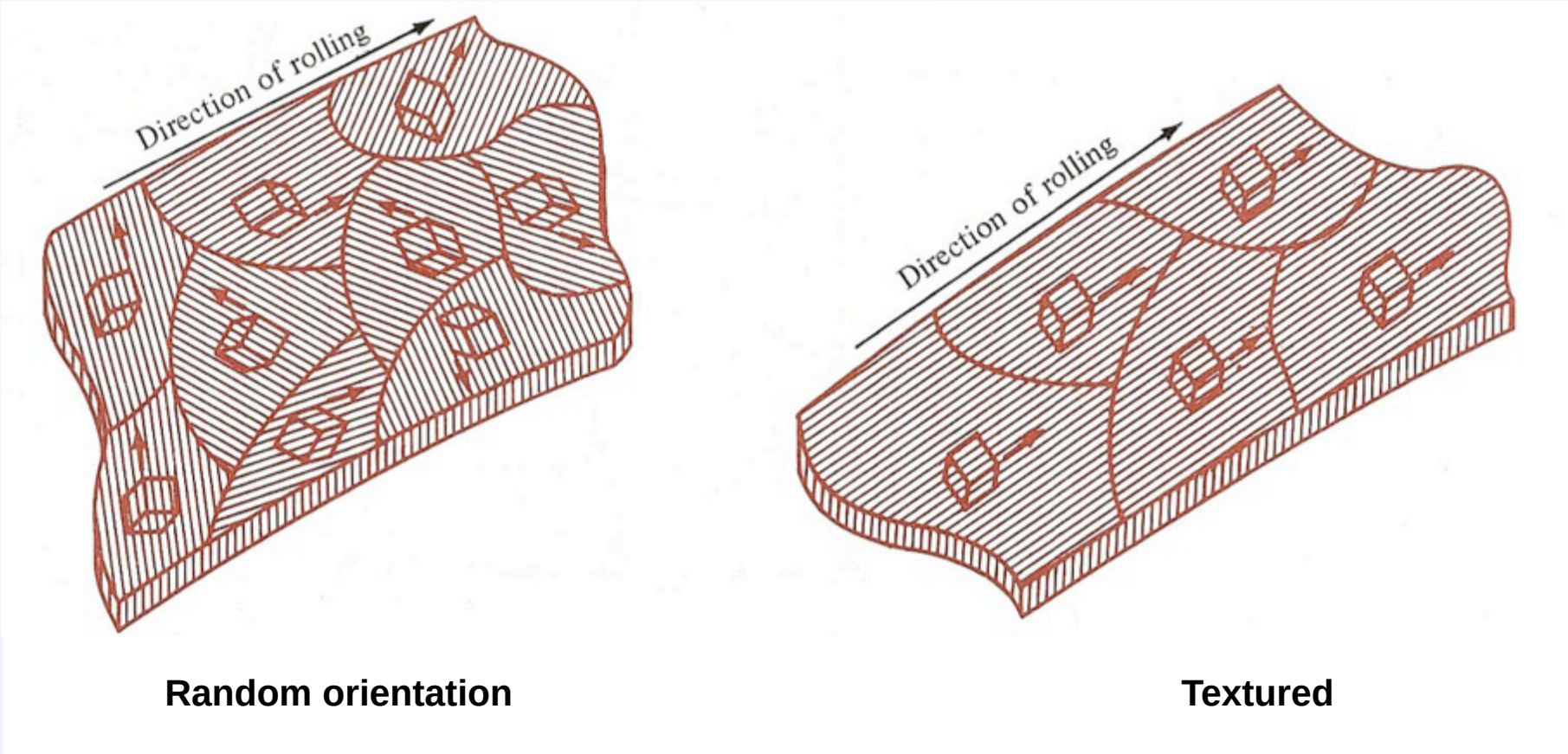
Equiaxed grains



Rolling produces non-equiaxed grains

Most commercially available foils are rolled

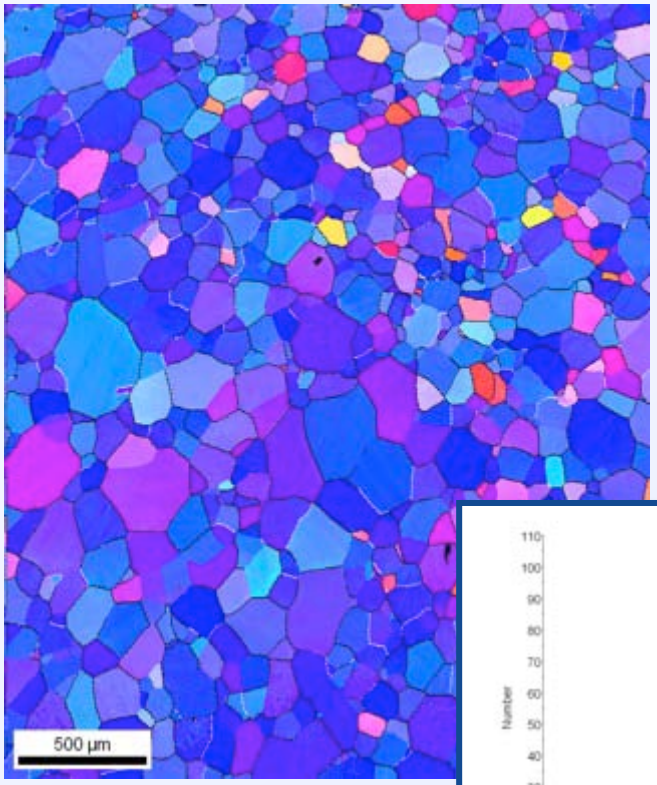
In a “textured” material, the grains have a preferred crystallographic orientation



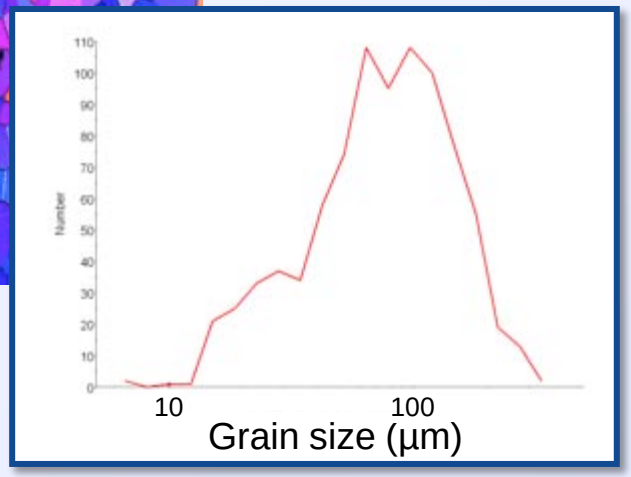
From J.F. Schackelford, Introduction to Materials Science for Engineers, 1988.

We use electron backscatter diffraction (EBSD) to measure texture and grain size

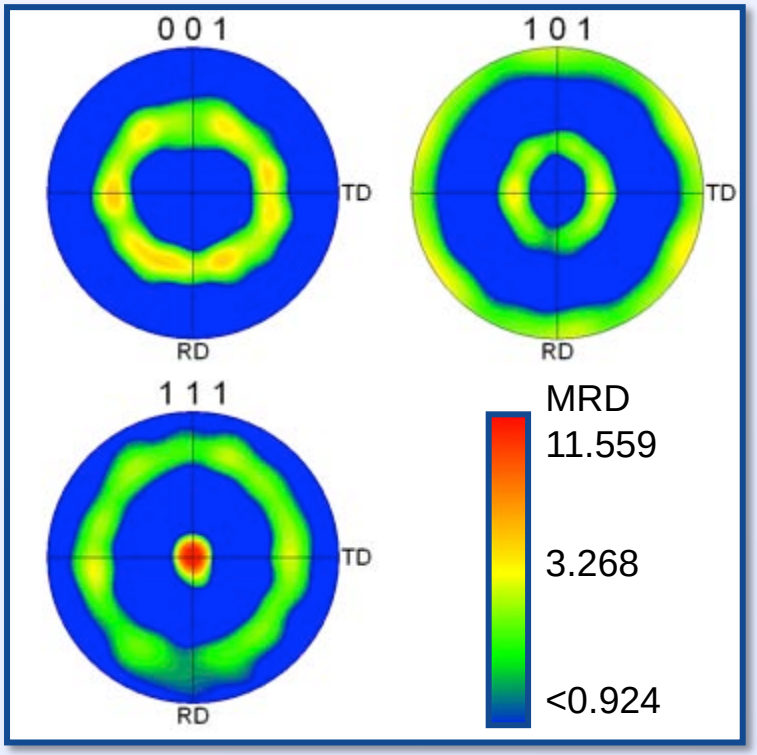
Orientation map



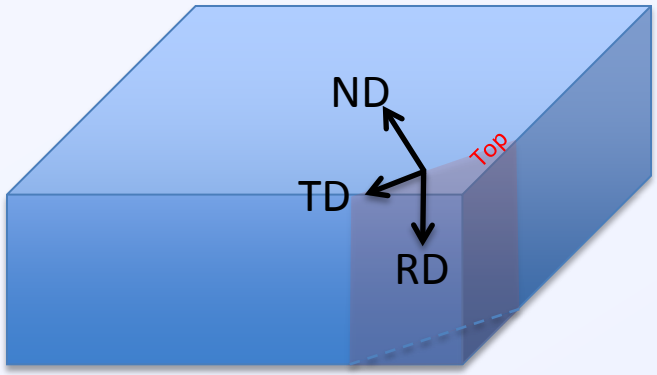
Grain size distribution



Pole figures

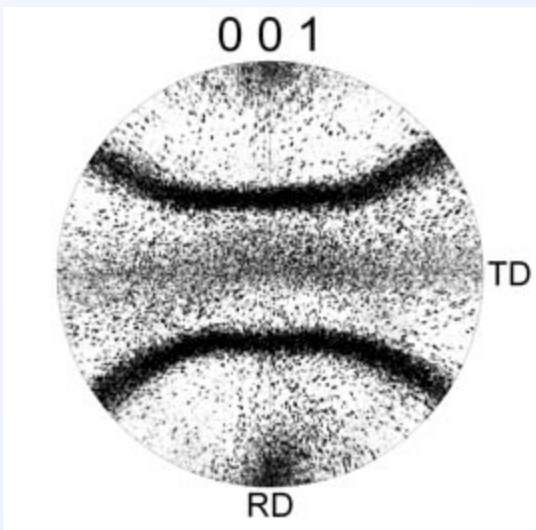


A piece of material can have a preferred orientation in one direction, while randomly oriented in others

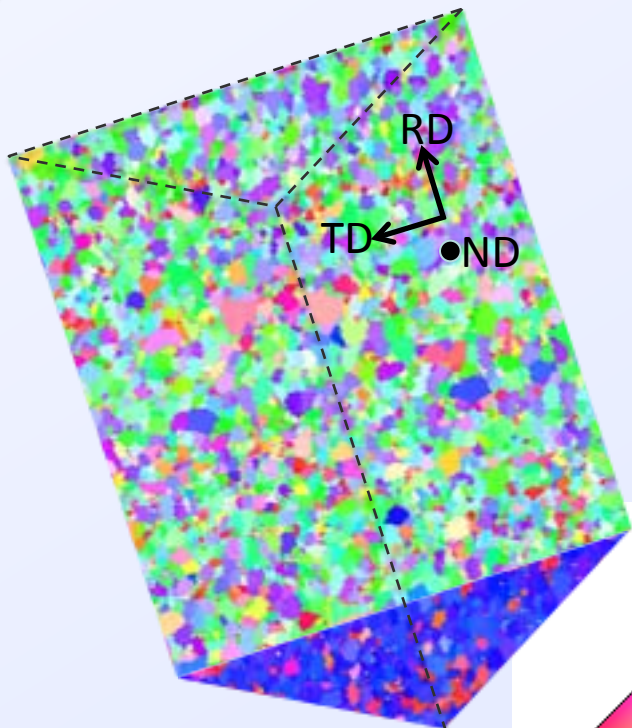


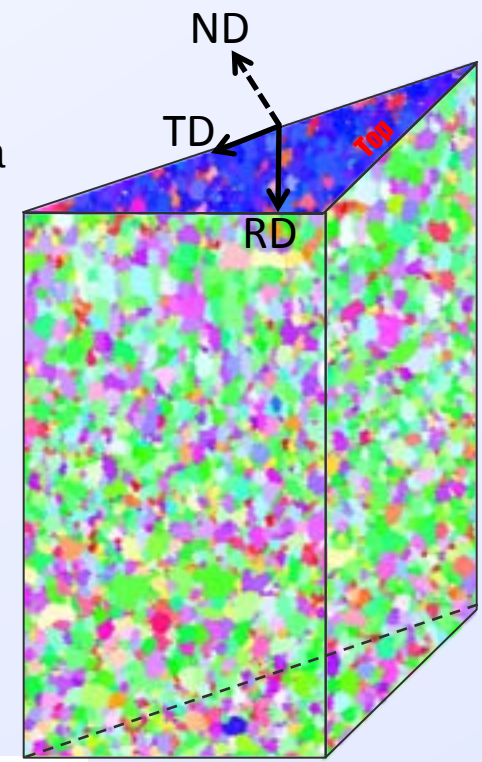
The top face of the block has a preferred 111 orientation

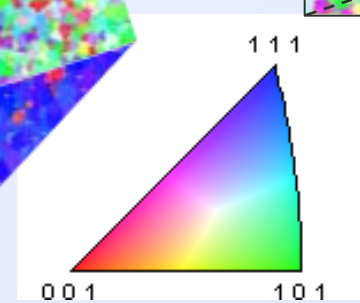
The sides of the block have a preferred 101 orientation



Pole figure for normal direction

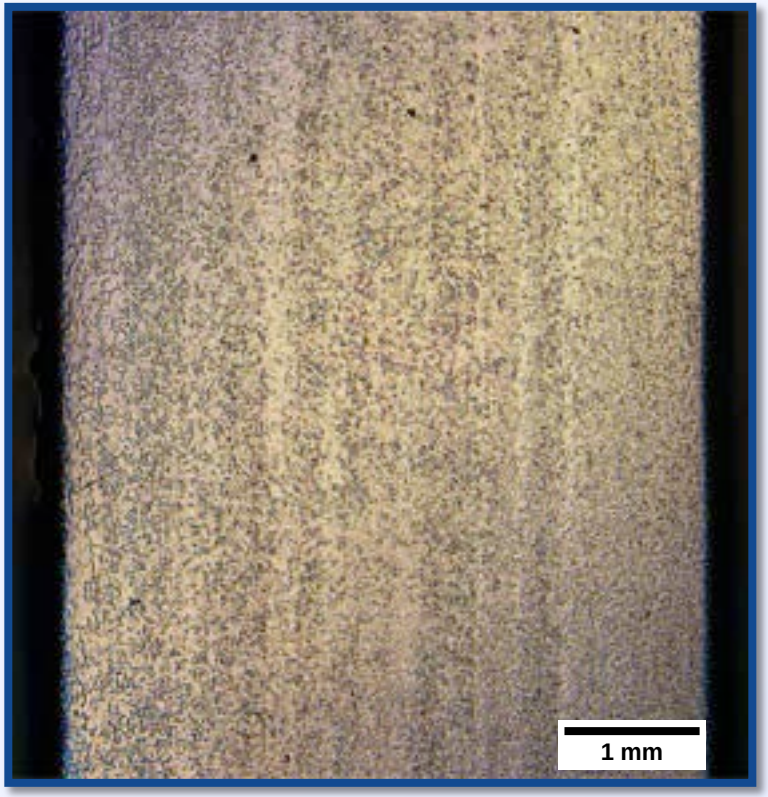


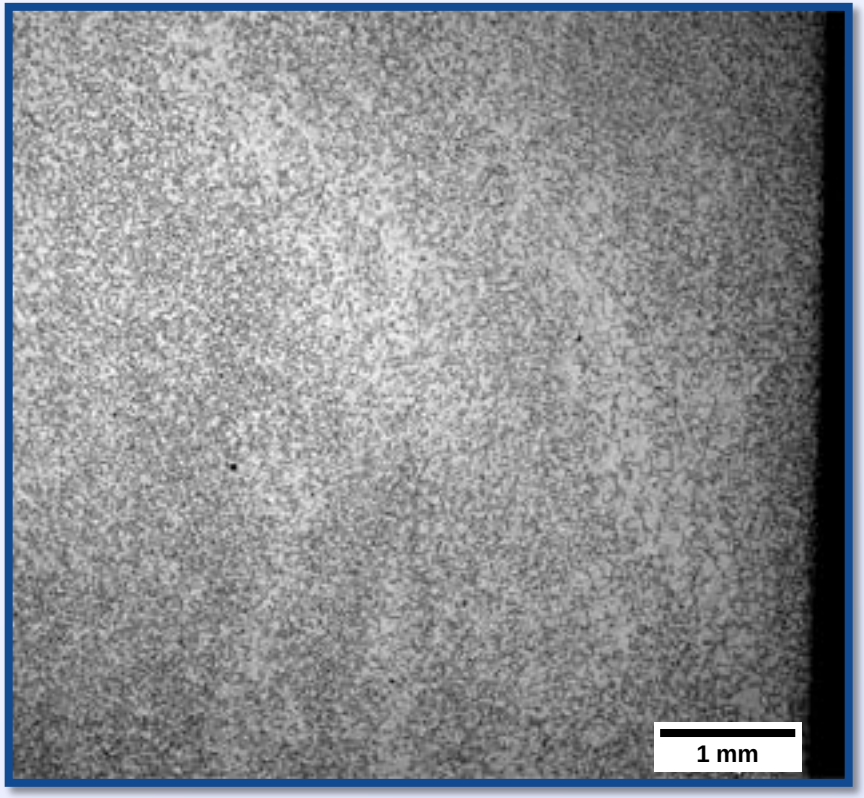




ND = normal direction
TD = transverse direction
RD = rolling direction (note: this is not necessarily the direction in which the sample was rolled

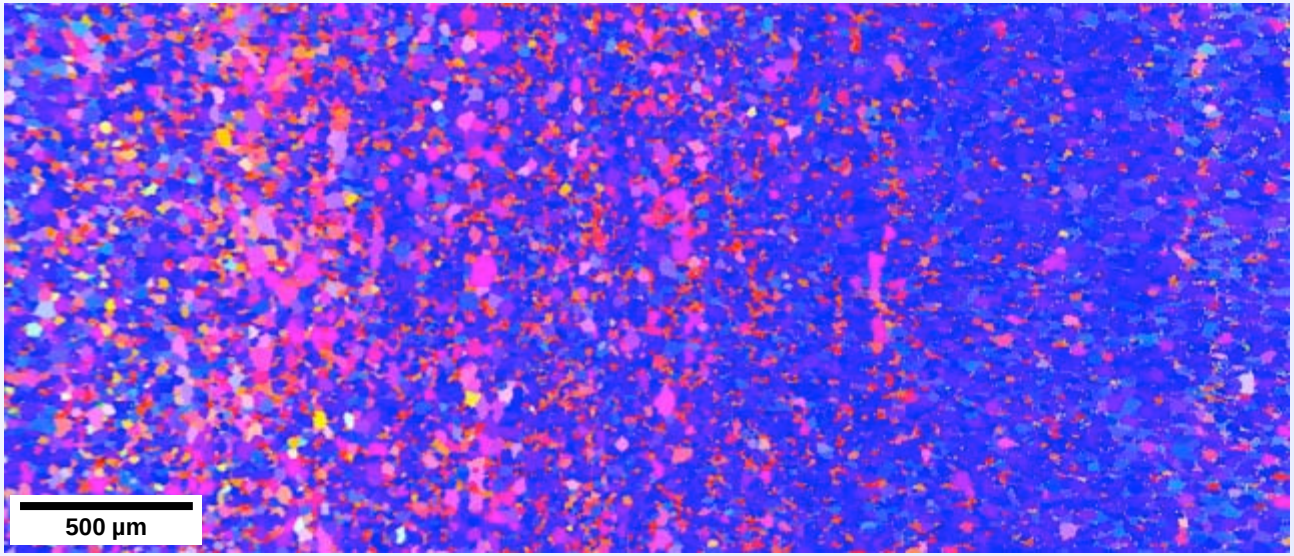
Tantalum is notoriously inhomogeneous with respect to grain size and texture

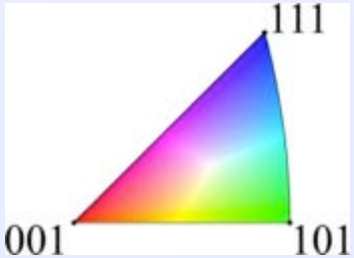


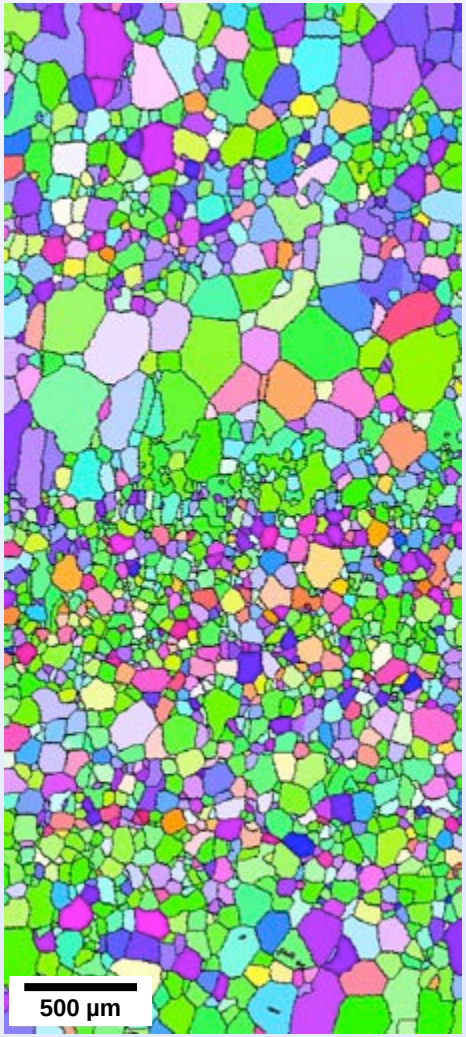


Banding readily occurs, even over small length scales

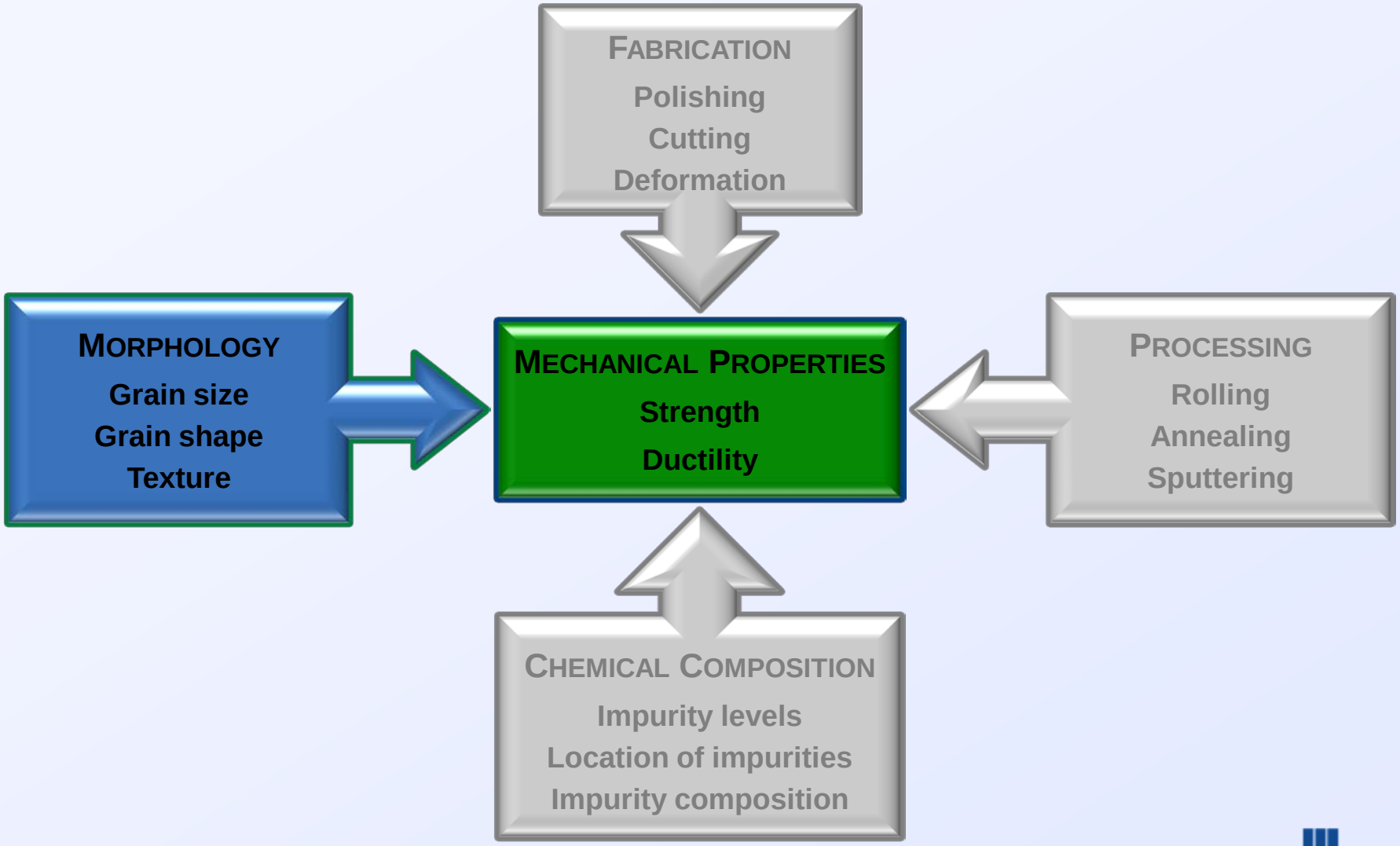
Characterization of tantalum is essential, given its propensity for inhomogeneity







The morphology, processing, and preparation of a target material can be as important as its chemical composition



Grain size affects material strength (Hall-Petch relation)

- Strength is inversely related to grain size (Hall-Petch equation)
- Grain size is typically measured with optical or scanning electron microscopy

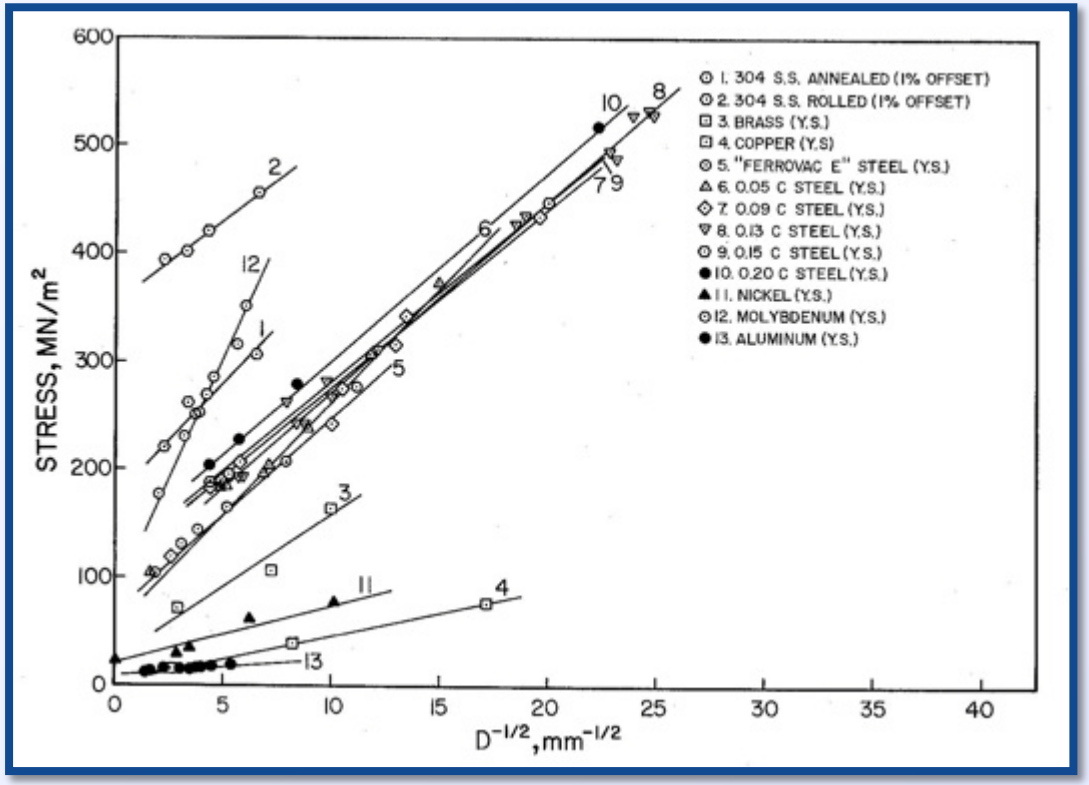
$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{D}}$$

σ_y = yield stress

σ_0 = frictional stress required to move dislocations

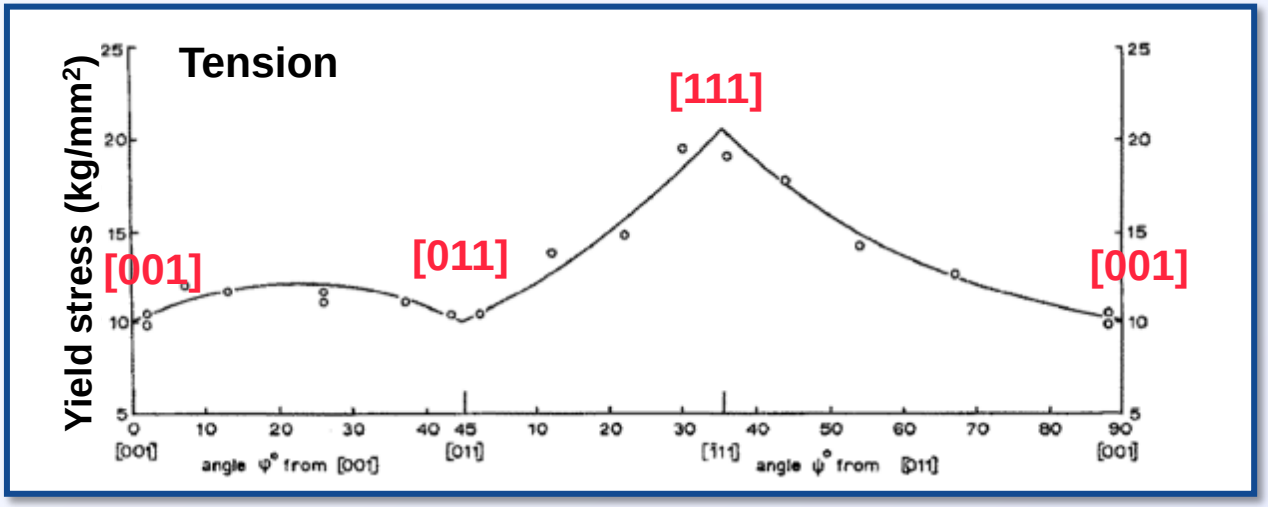
k_y = "locking parameter" (relative hardening contribution of grain boundaries)

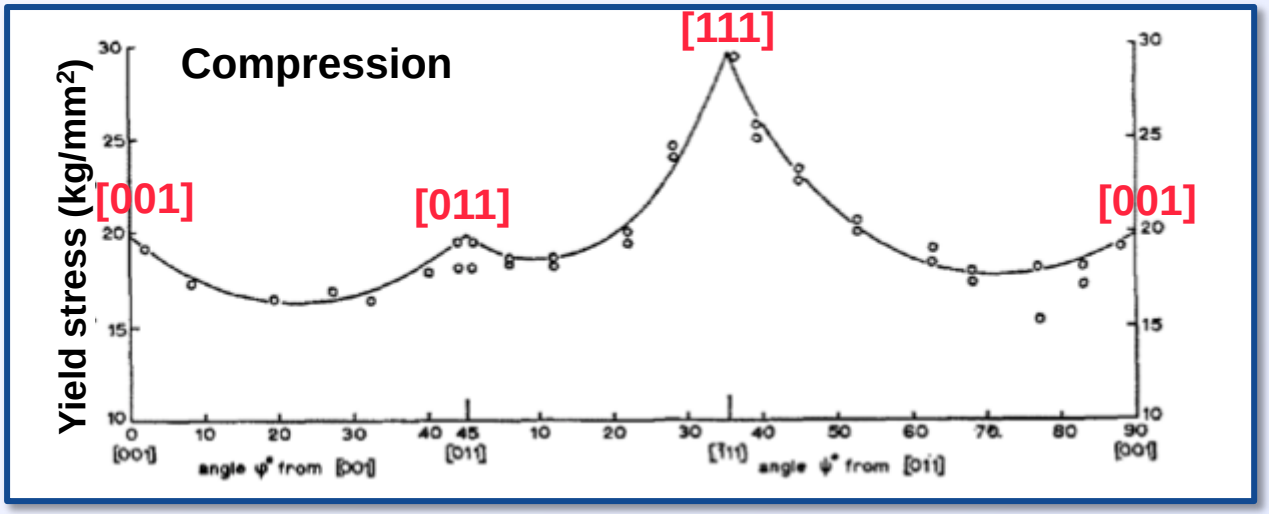
D = grain size



From M.A. Meyers & K.K. Chawla, Mechanical Metallurgy, 1984.

The strength of tantalum is also a strong function of orientation (texture)





Yield strength of oriented single crystals

Strain rate = 4 x 10^{-4}/s

J.F. Byron, Journal of the Less-Common Metals, 1968.

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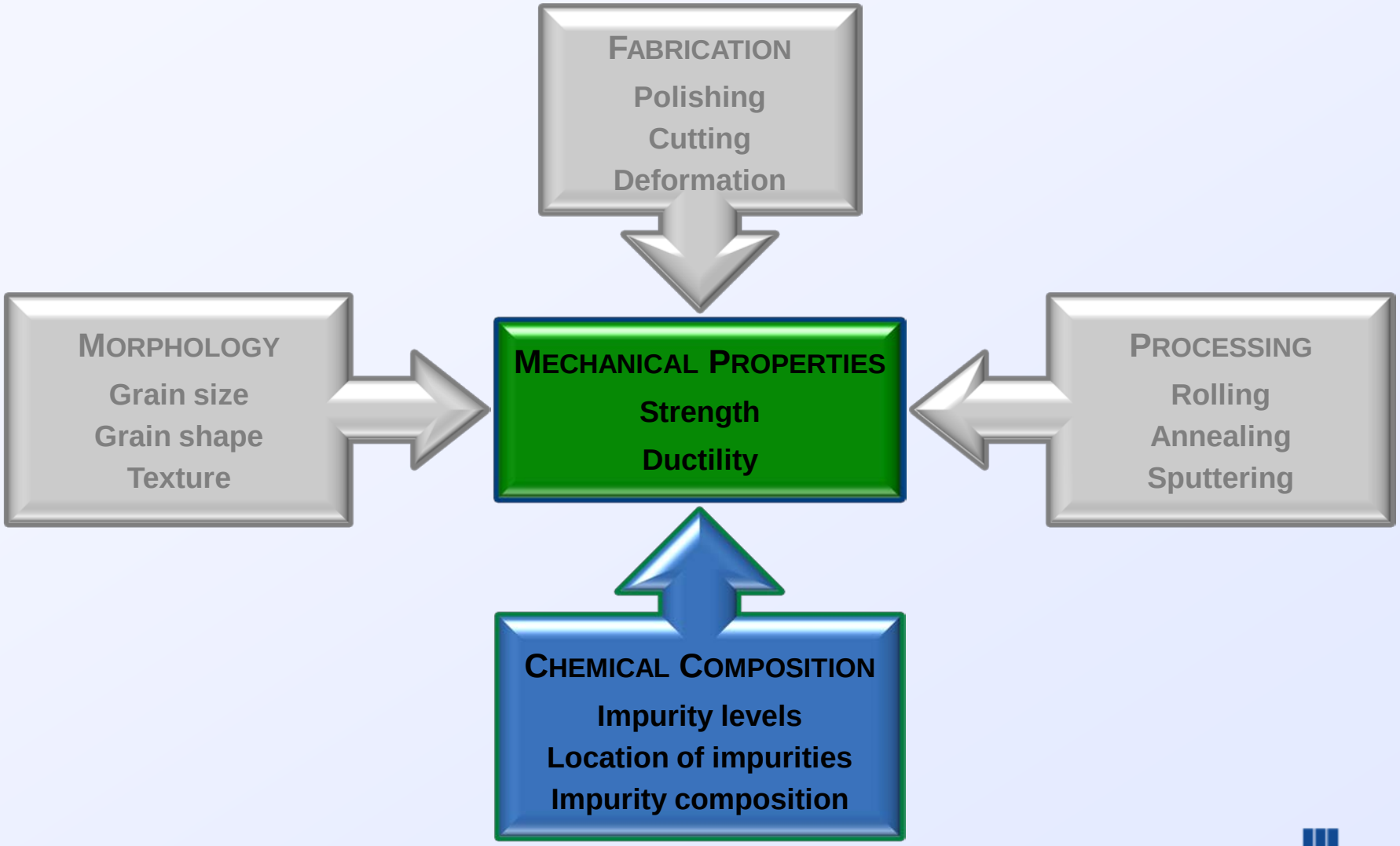
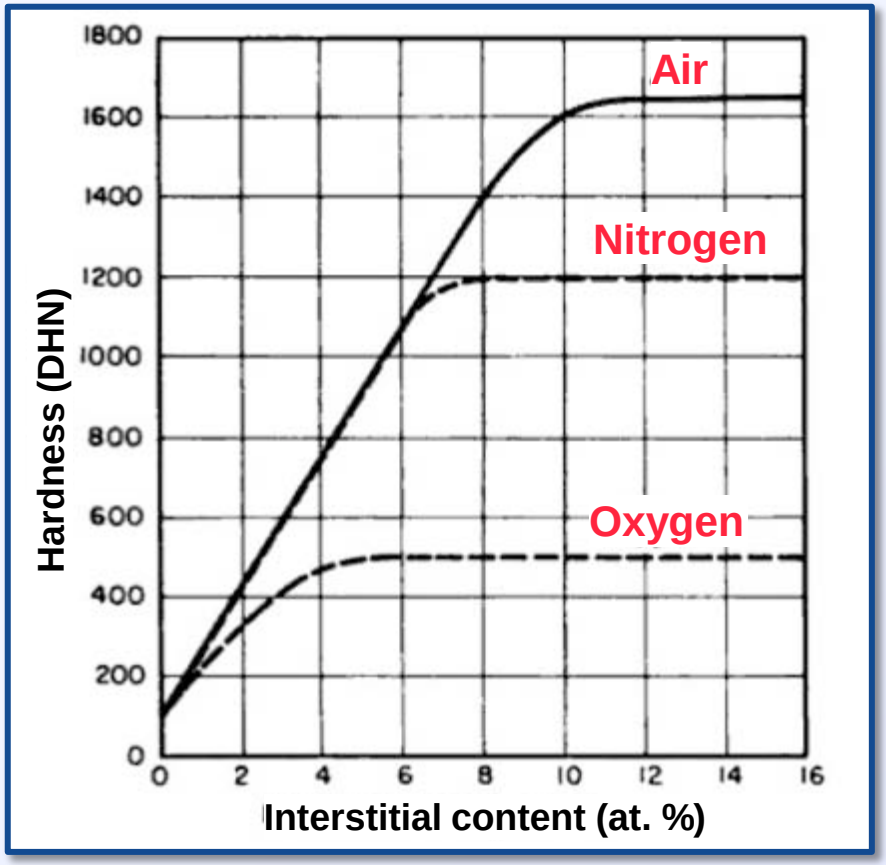
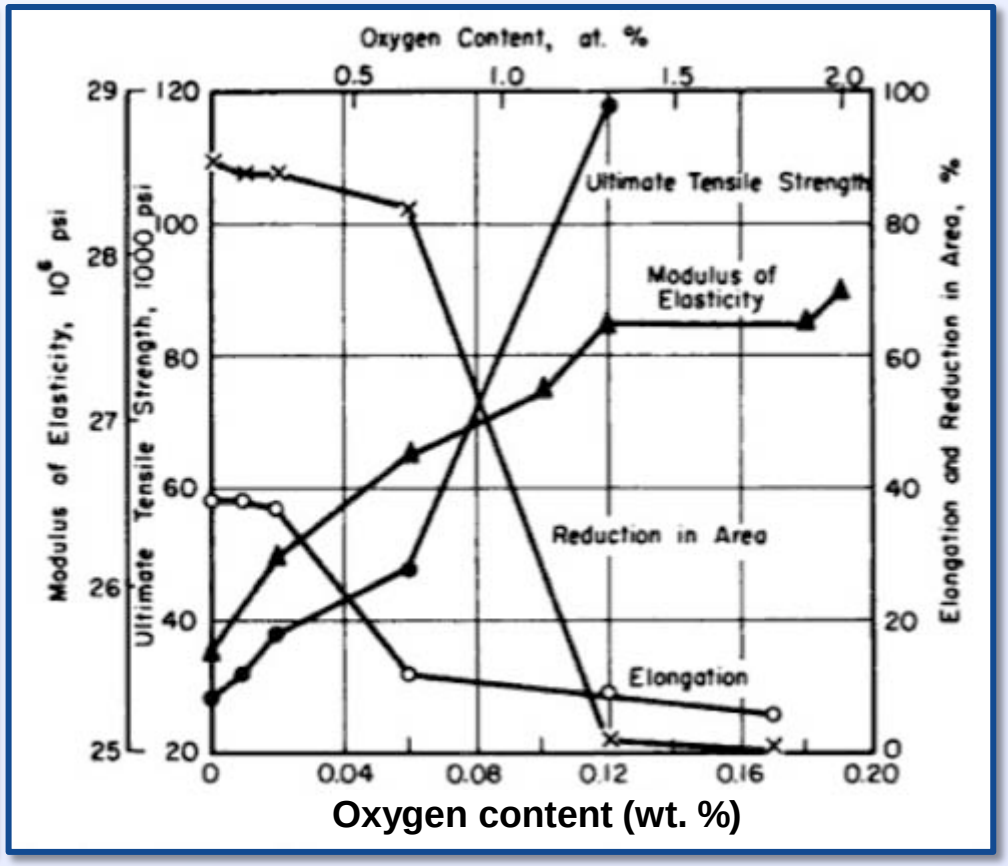


Small amounts of impurities can dramatically affect the strength of tantalum

Interstitial impurities



Oxygen content



T.E. Tietz and J.W. Wilson, Behavior and Properties of Refractory Metals, 1965.

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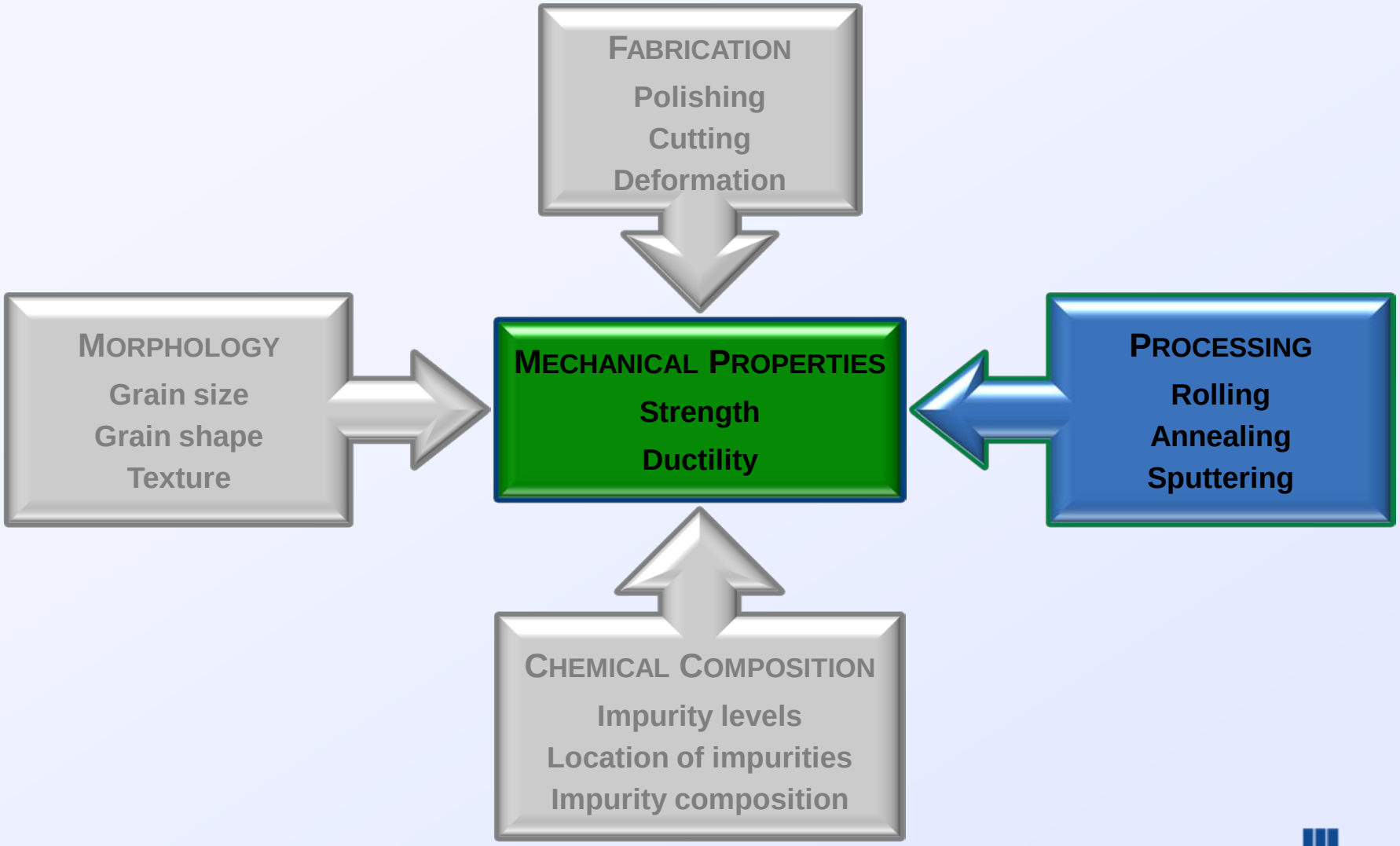
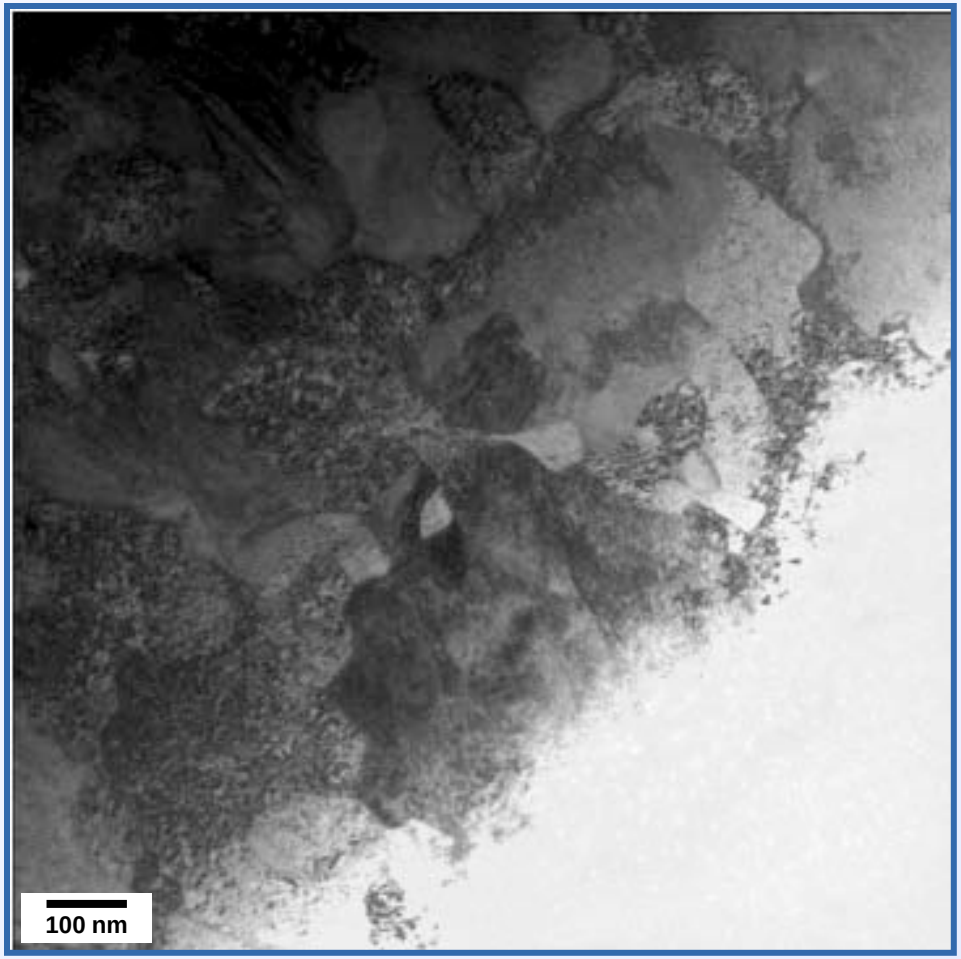
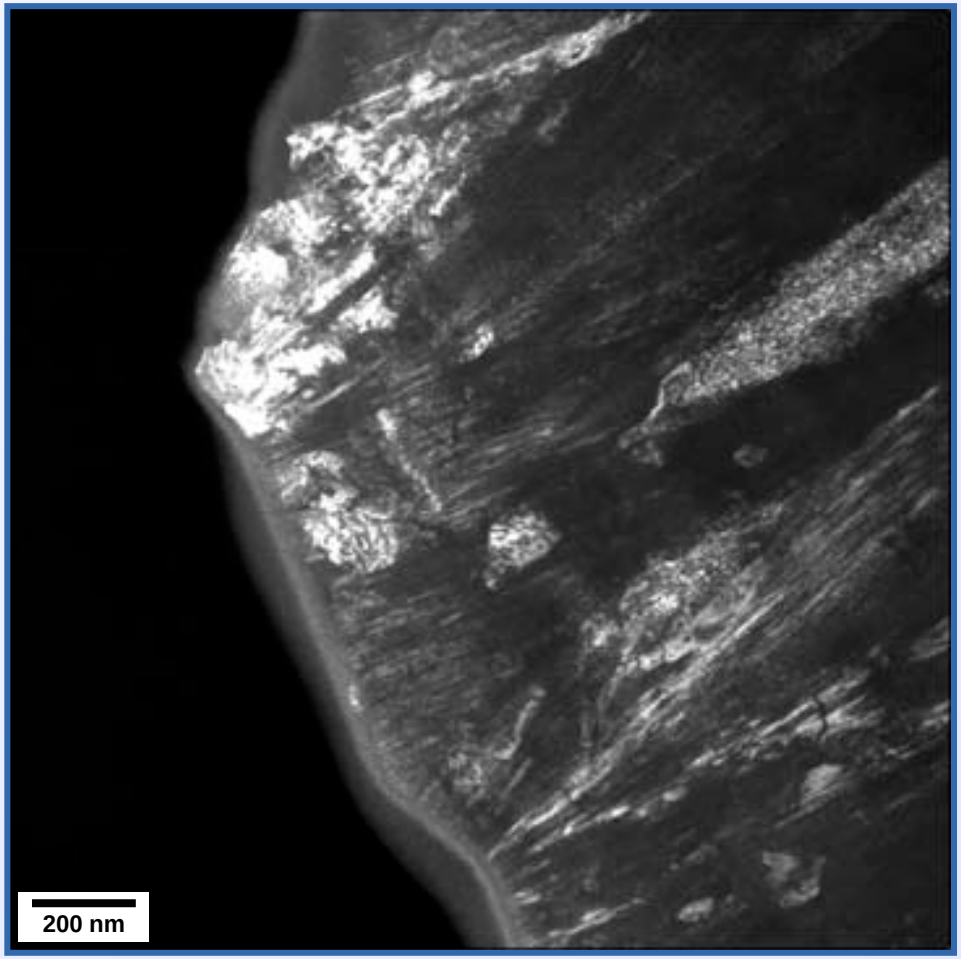


Sputter-deposited Ta has a highly defected, columnar morphology, which affects mechanical properties



Plan view



Cross-section

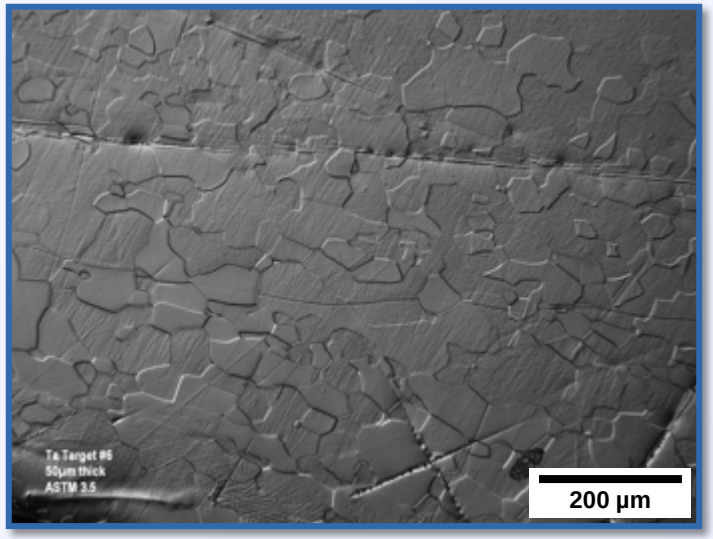
Compared to a commercially available Ta foil, sputter-deposited Ta is significantly harder

Commercially available foil

Vickers Hardness = 137.7

Sputter-deposited foil

Vickers Hardness = 208



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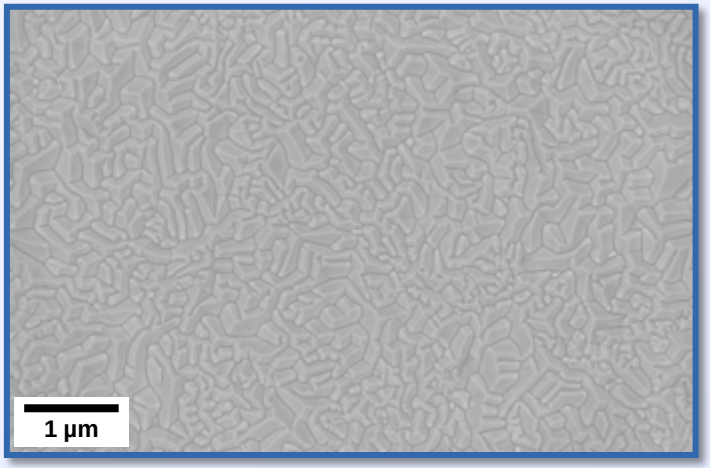

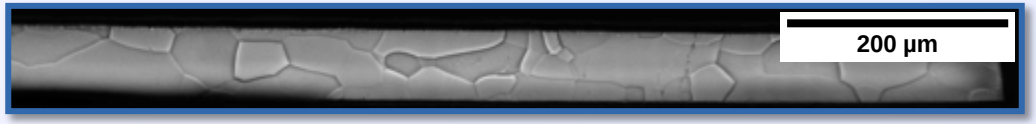

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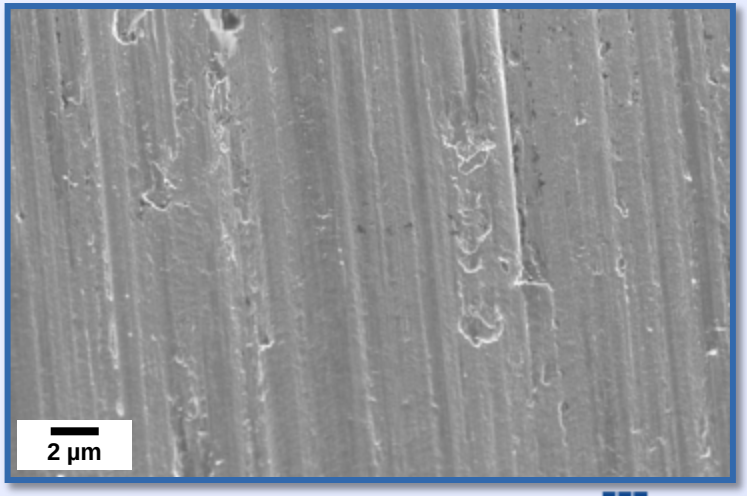

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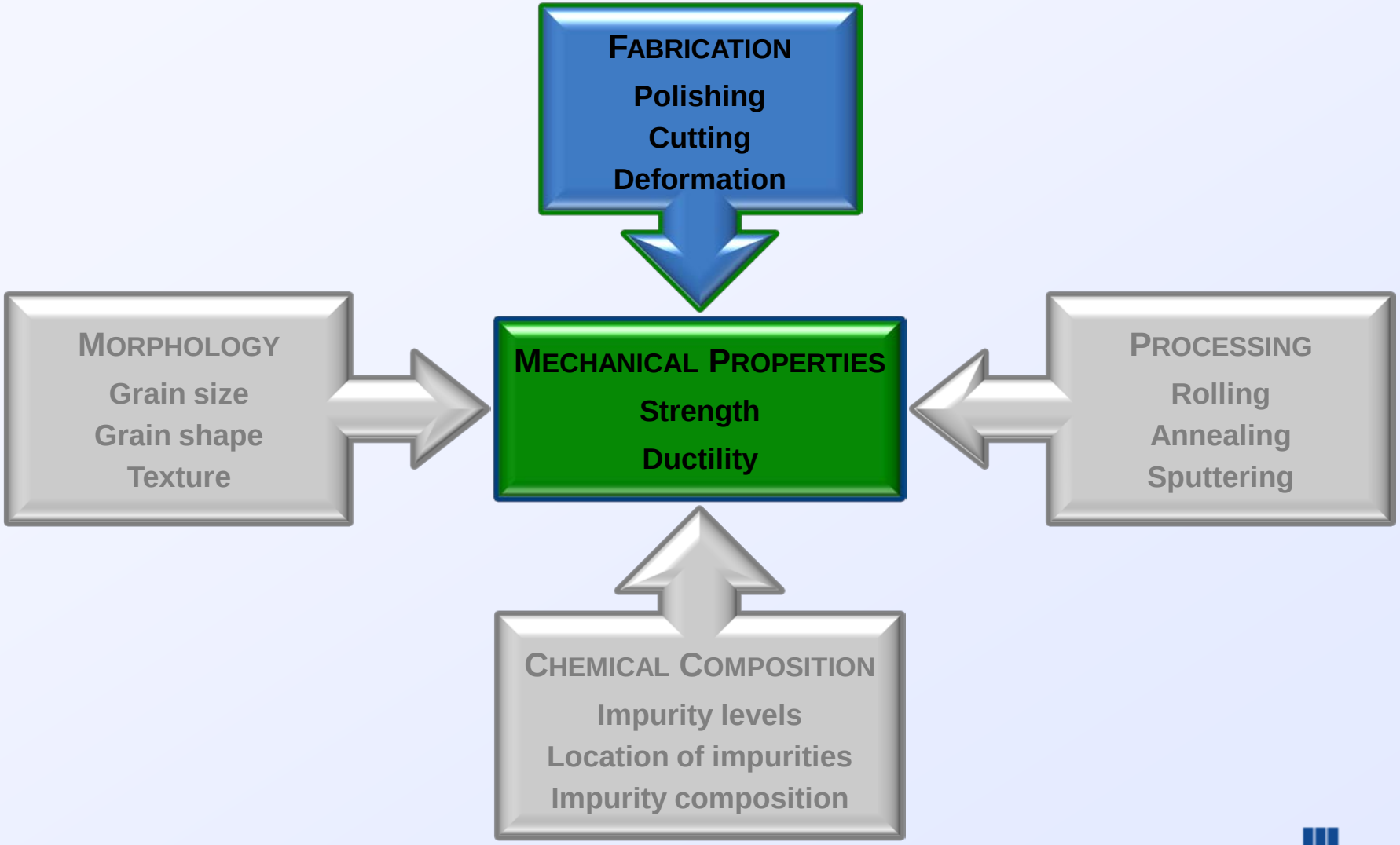
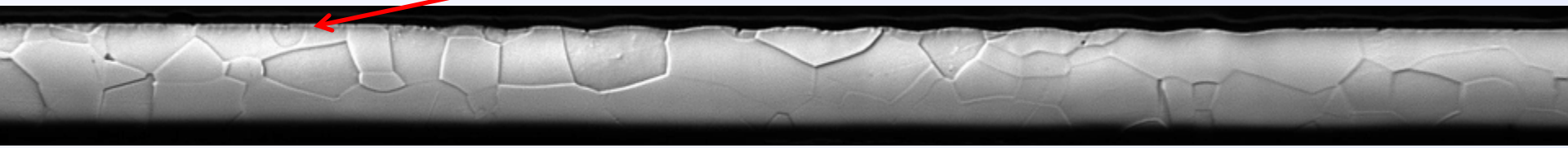
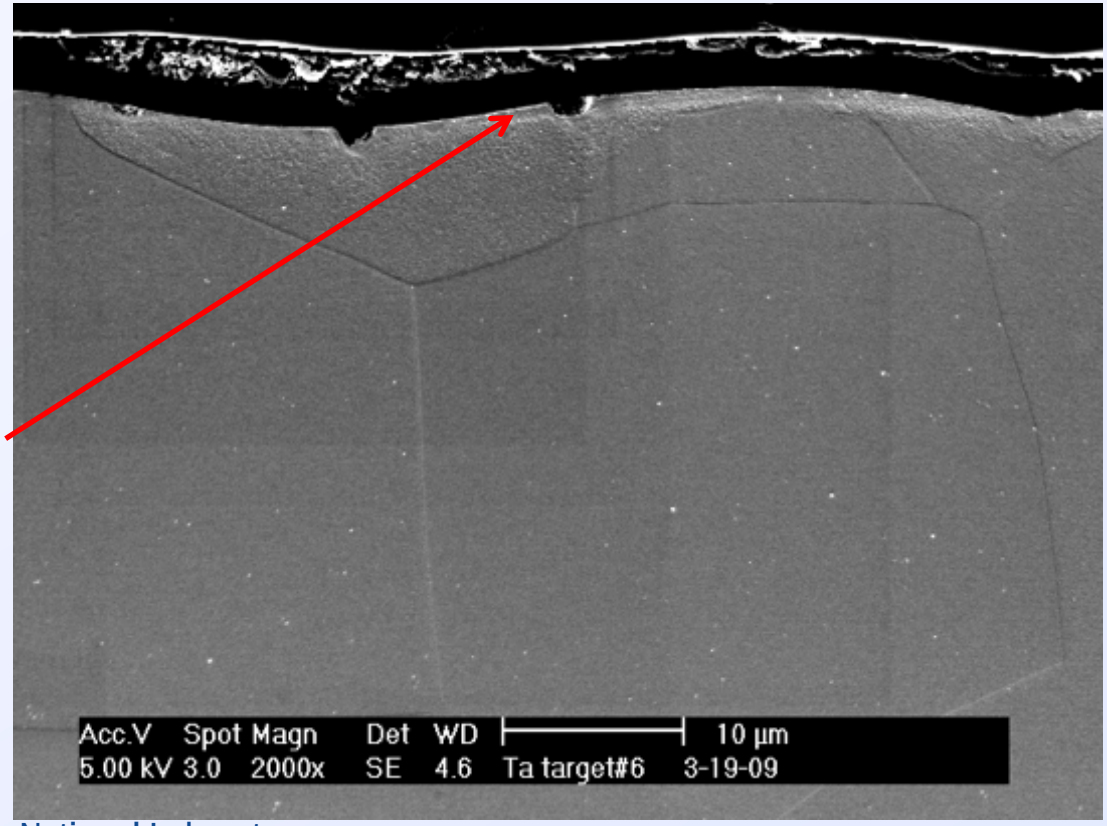


Artifacts can be introduced during target fabrication

- Cutting/thinning operations
  - Polishing can leave surface damage
  - Electro-discharge machining can introduce impurities
- Coining
  - Results in increased hardness

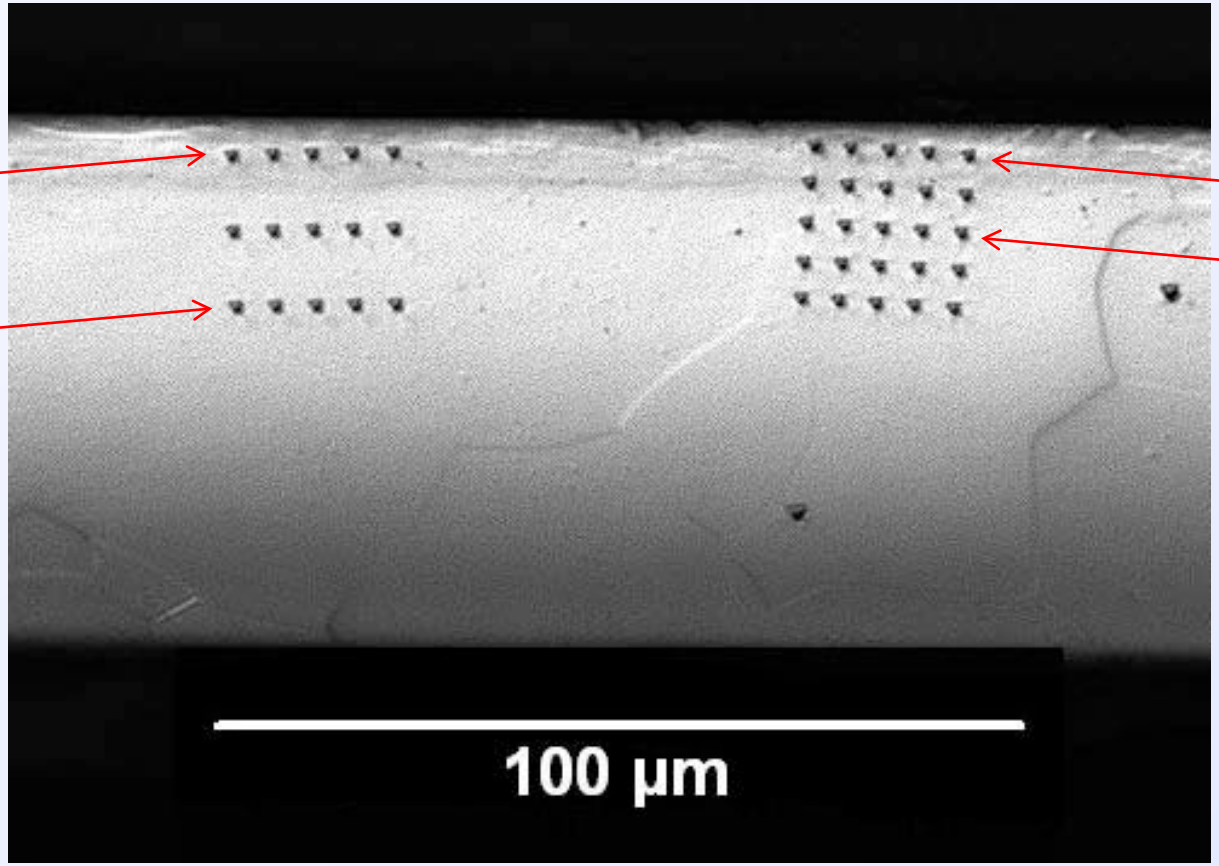
Aggressive polishing can leave a layer of deformed material on the surface of the target



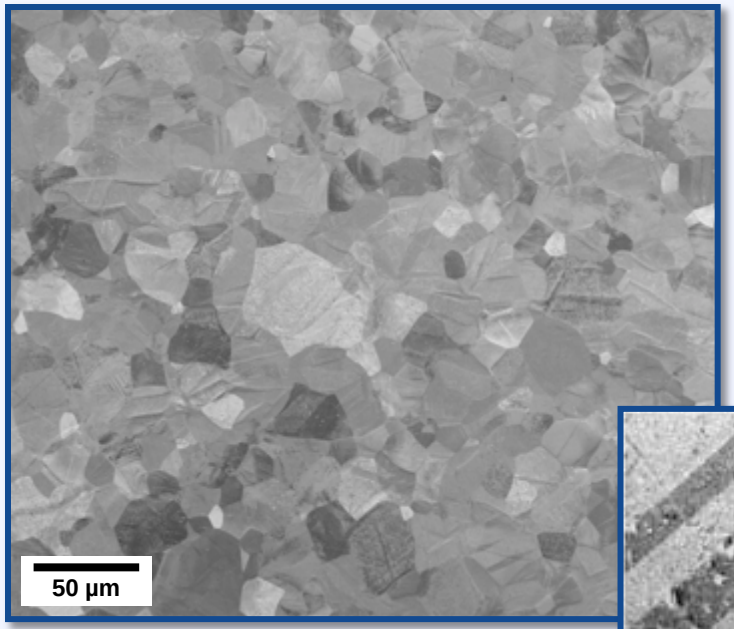


The surface layer damaged by polishing is harder than the underlying material

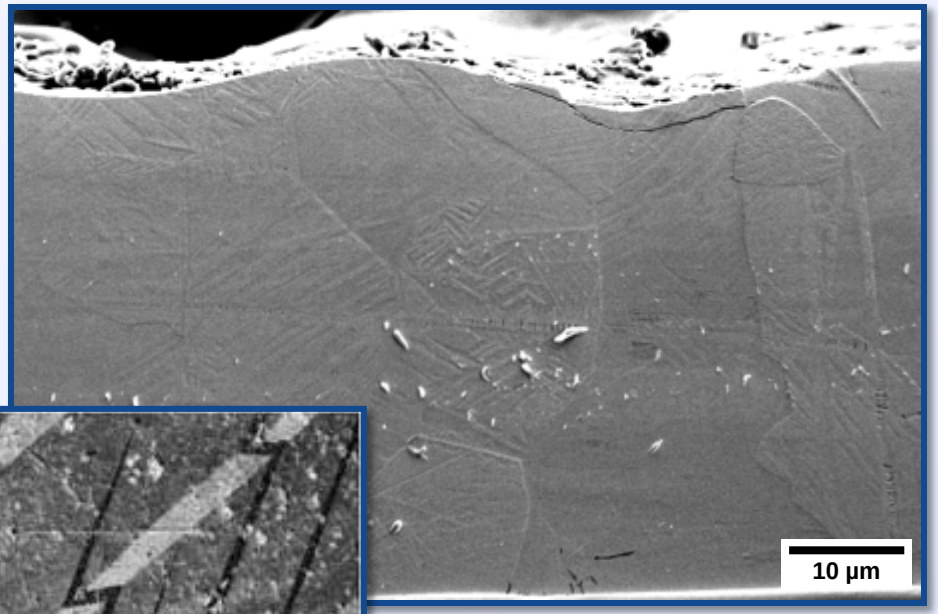
Hardness values obtained from nanoindentation



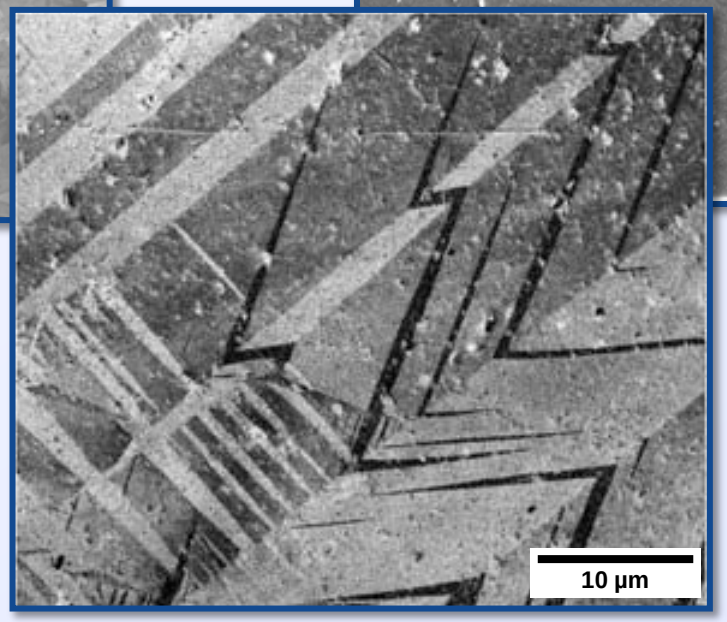
In tantalum, we discovered that polishing to approximately 50 µm thick results in deformation banding



Plan view SEM



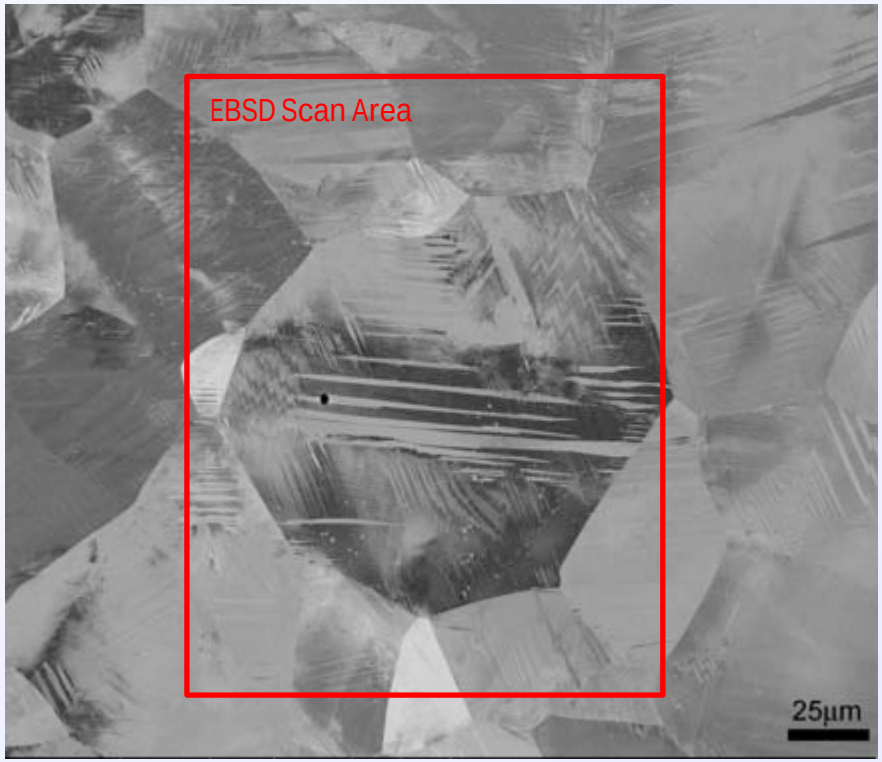
Cross-sectional SEM



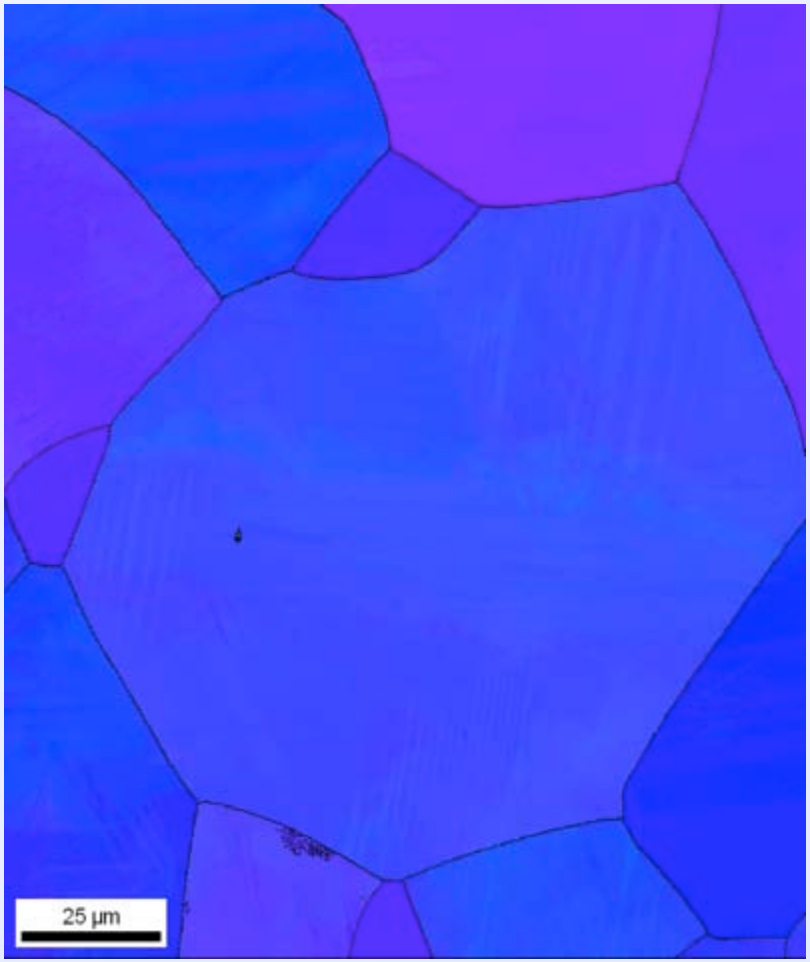
Plan view SEM

Deformation bands in thin tantalum foils are small angle misorientations—*not twins*

Backscatter SEM micrograph of area scanned at high resolution



$[001]_S$ Inverse Pole Figure Map of scan area



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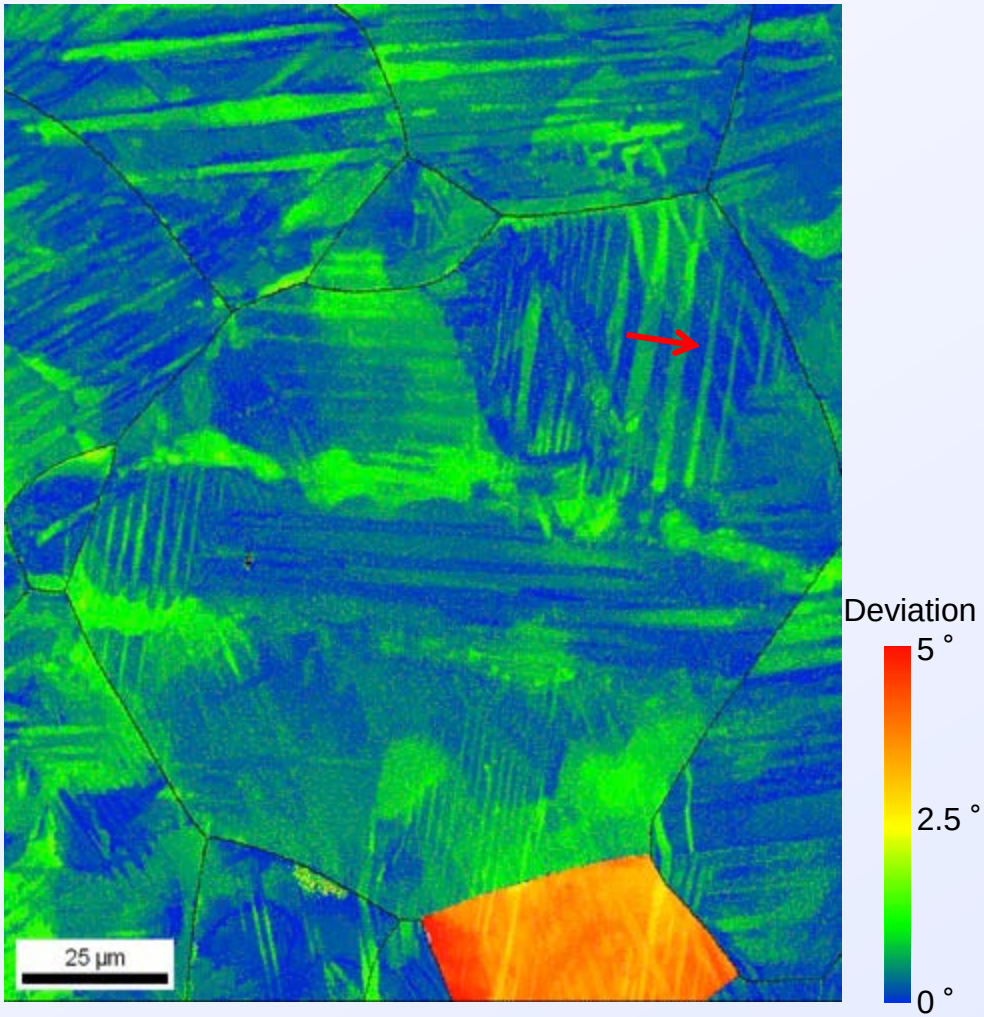
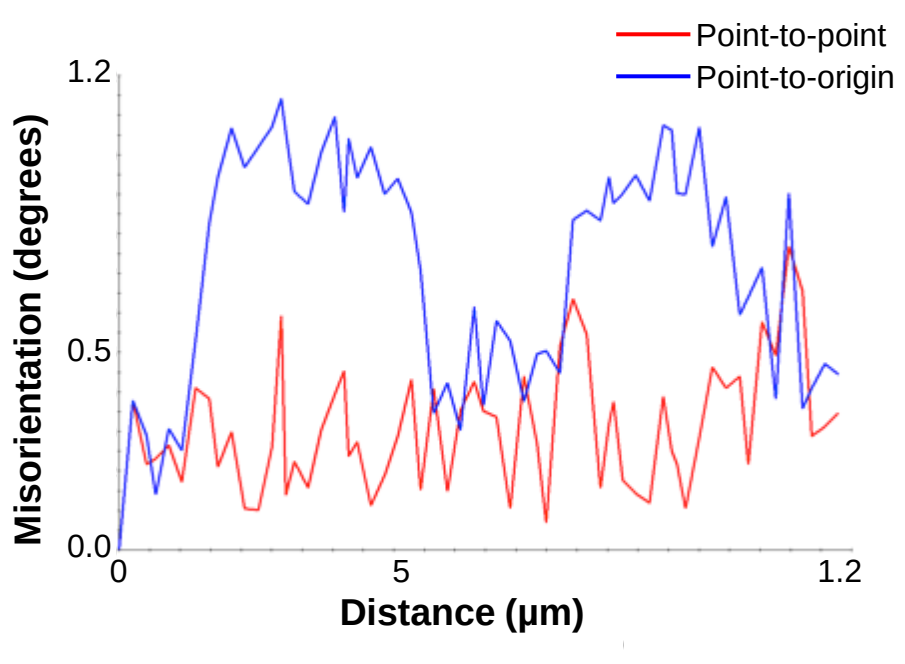
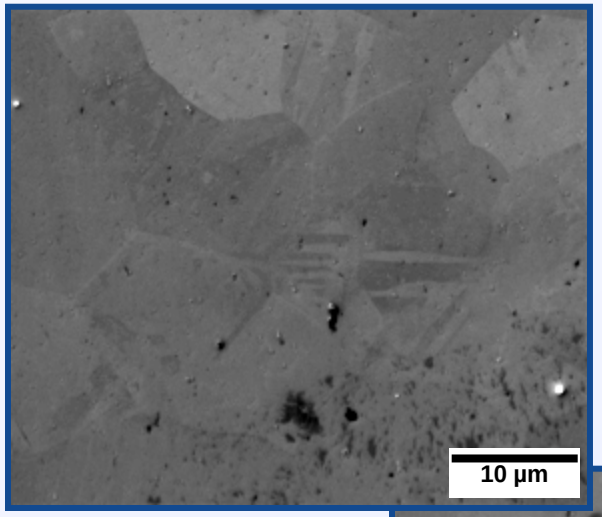


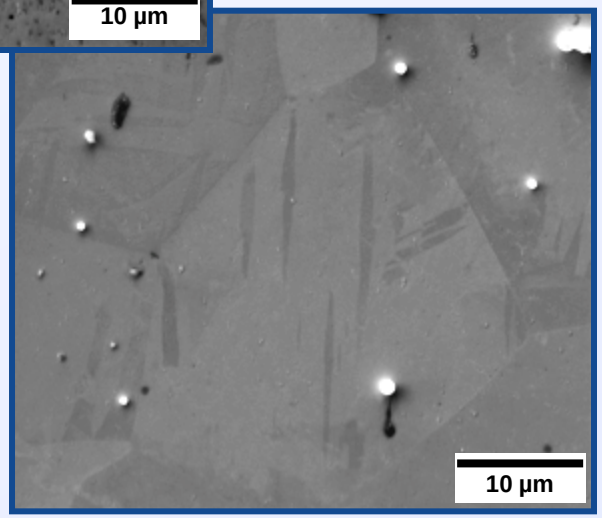
Twins would have a misorientation angle of 60°



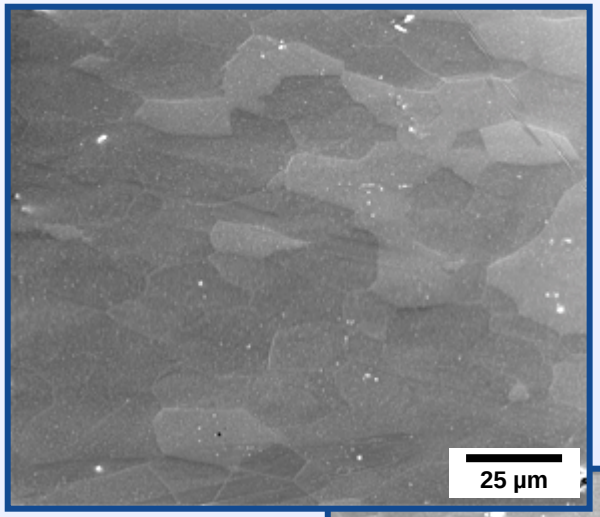
Annealing appears to remove most of the deformation banding

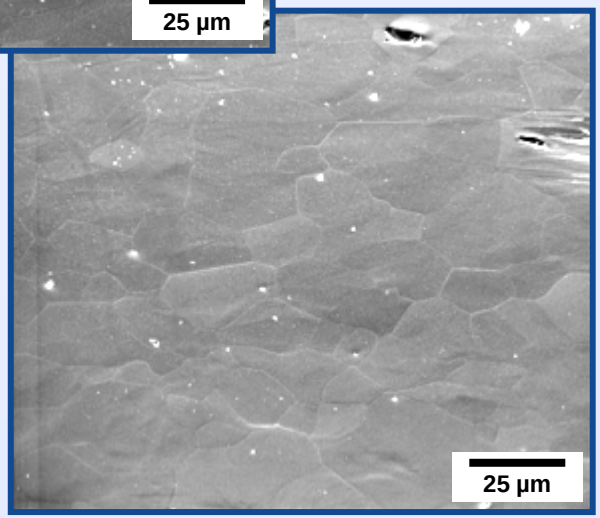
Pre-annealing

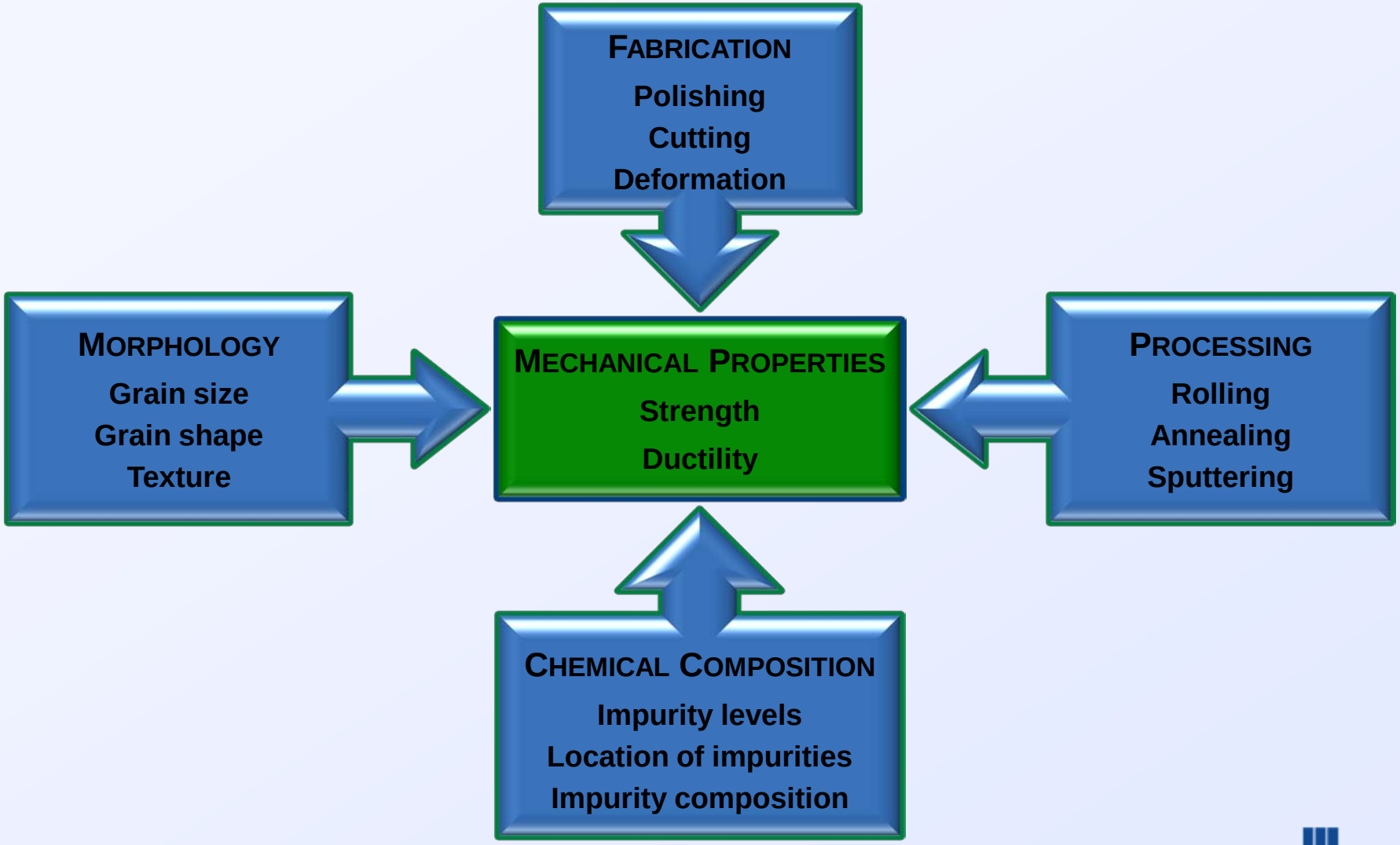




Annealed at 980°C for 30 minutes (UHV)





Debris is due to laser cutting and previous mounting medium

The morphology, processing, and preparation of a target material can be as important as its chemical composition