LA-UR-12-23668

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Title:	Bulk Nanolayered Composites: Interfacial Influence on Microstructural Evolution at Large Plastic Strains
Author(s):	Mara, Nathan A. Carpenter, John S. Han, Weizhong Zheng, Shijian McCabe, Rodney J. Wang, Jian Beyerlein, Irene J.
Intended for:	Microscopy and Microanalysis 2012, 2012-07-29/2012-08-01 (Phoenix, Arizona, United States) Invited Talk

Bulk nanolayered composites: Interfacial influence on microstructural evolution at large plastic strains

N.A. Mara

Center for Integrated Nanotechnologies

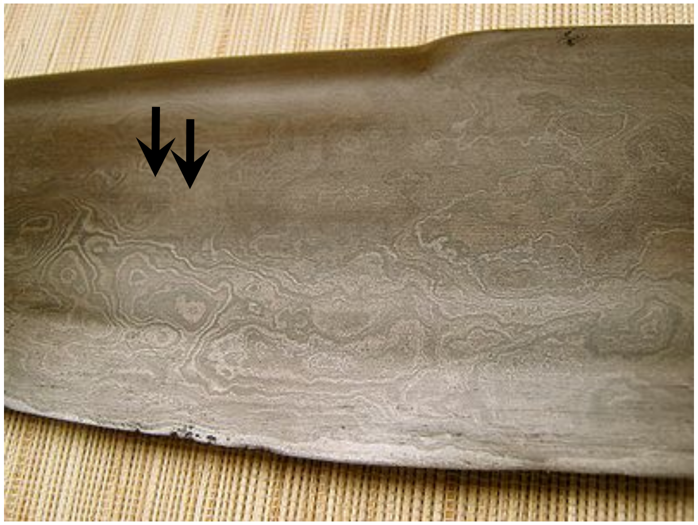
Los Alamos National Laboratory

Co-Authors:
J. Carpenter, W.Z. Han, S. Zheng, R. McCabe, J. Wang, I.J. Beyerlein

Layered composites: Improving mechanical properties since Egyptian times

Plywood—found in Egyptian tombs dating to 3500 BC

--courtesy Amazon.com

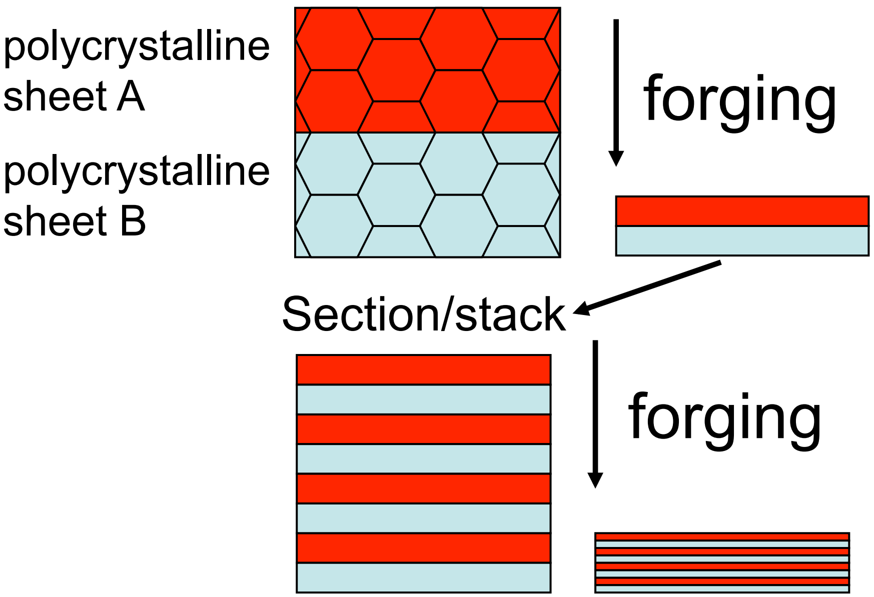


Damascus steel production began ~300BC

Moro barung from Philippines—courtesy Wikipedia

Metallic lamellar composites: Damascus steel

Two different types of steel repeatedly forge-welded together—high strength and toughness combined

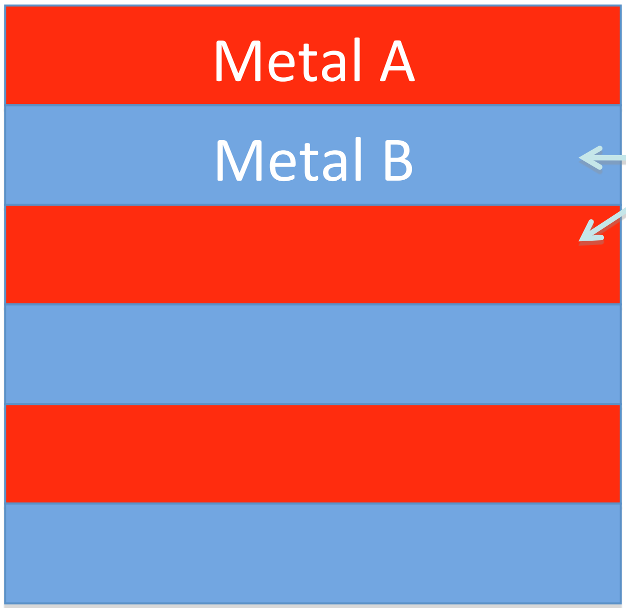


Moro barung from Philippines—courtesy Wikipedia

Defects and Interfaces: Interface-driven material behavior

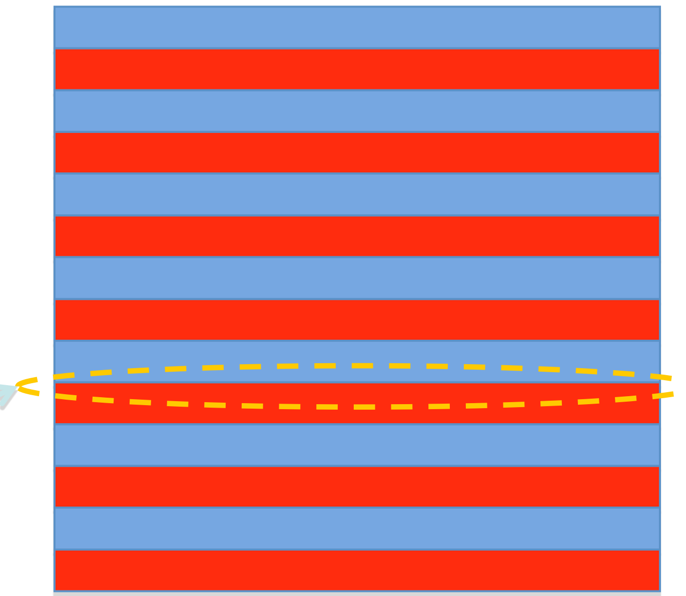
Constituent-dominated behavior

Interface-dominated behavior



Phases
Nucleation
Storage
Recovery
Blocking

Interface
Nucleation
Storage
Recovery
Blocking

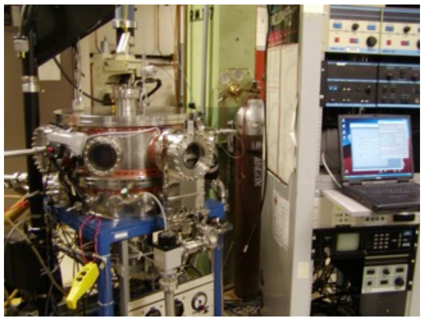


Low density of interfaces

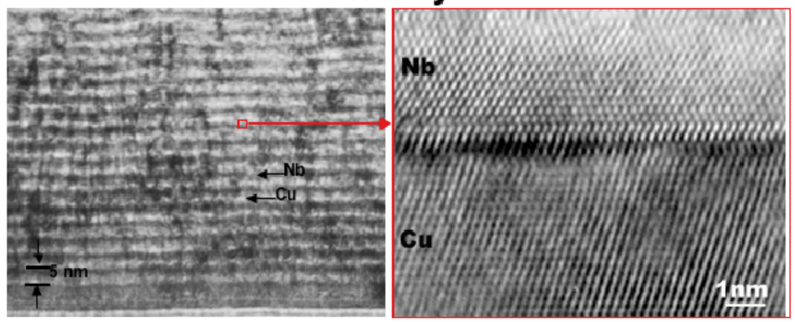
High density of interfaces

Extraordinary behavior of Physical Vapor Deposited (PVD) multilayers

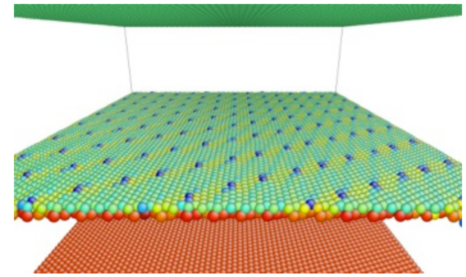
PVD multilayer fab



Cu-Nb 2.5 nm layers



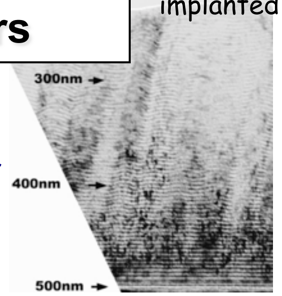
Cu-Nb atomic interface



He implantation: resistance to He bubble formation.[1]

5 nm layers

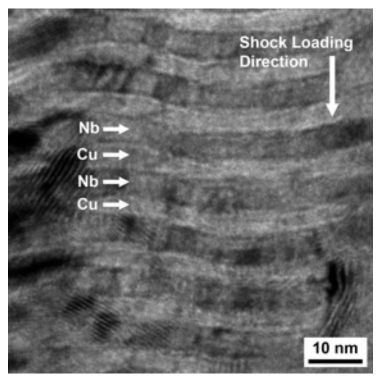
No bubbles in He-implanted Cu-Nb



No amorphization or defect clusters after $10^{17}/cm^2$ 150keV He implantation

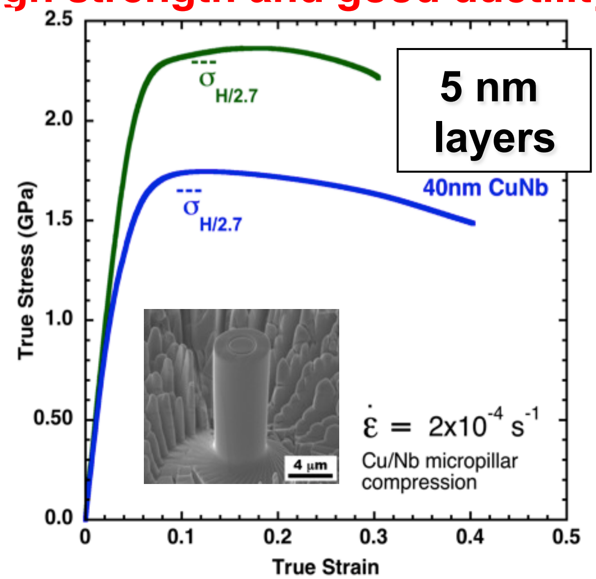
He solubility: ~8%at.

Laser Shock resistance



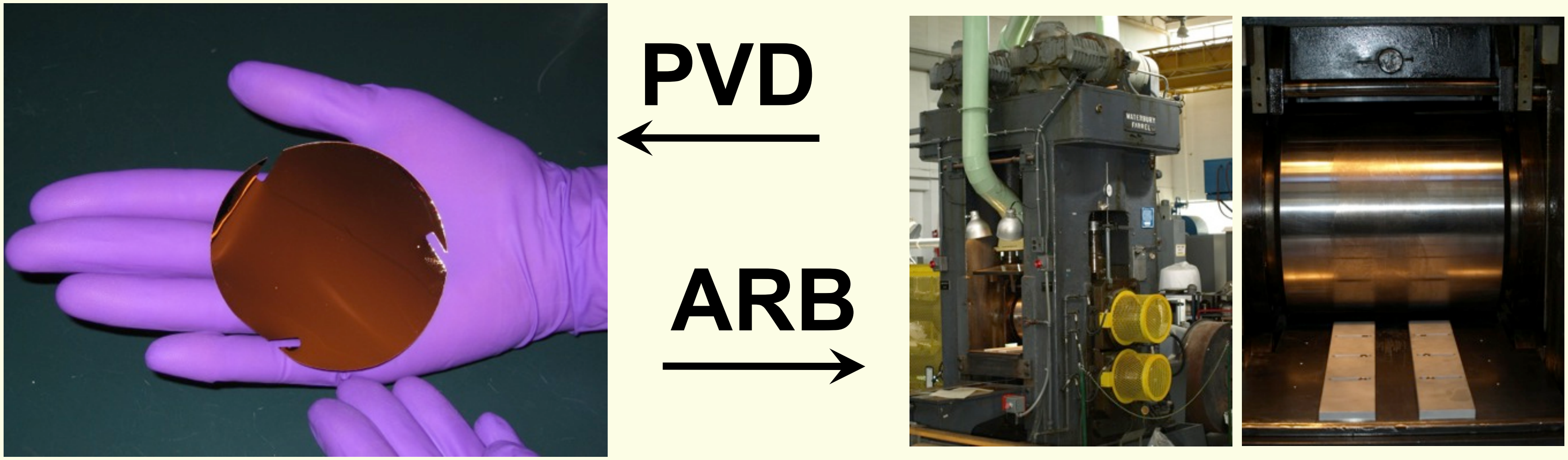
5 nm layers

Micropillar Compression: High strength and good ductility[2]



1. D. Bhattacharyya et al, unpublished 2. N. A. Mara et al, APL,92:231901 (2008) 3. A. Misra, et al, Acta Mater. (2003)

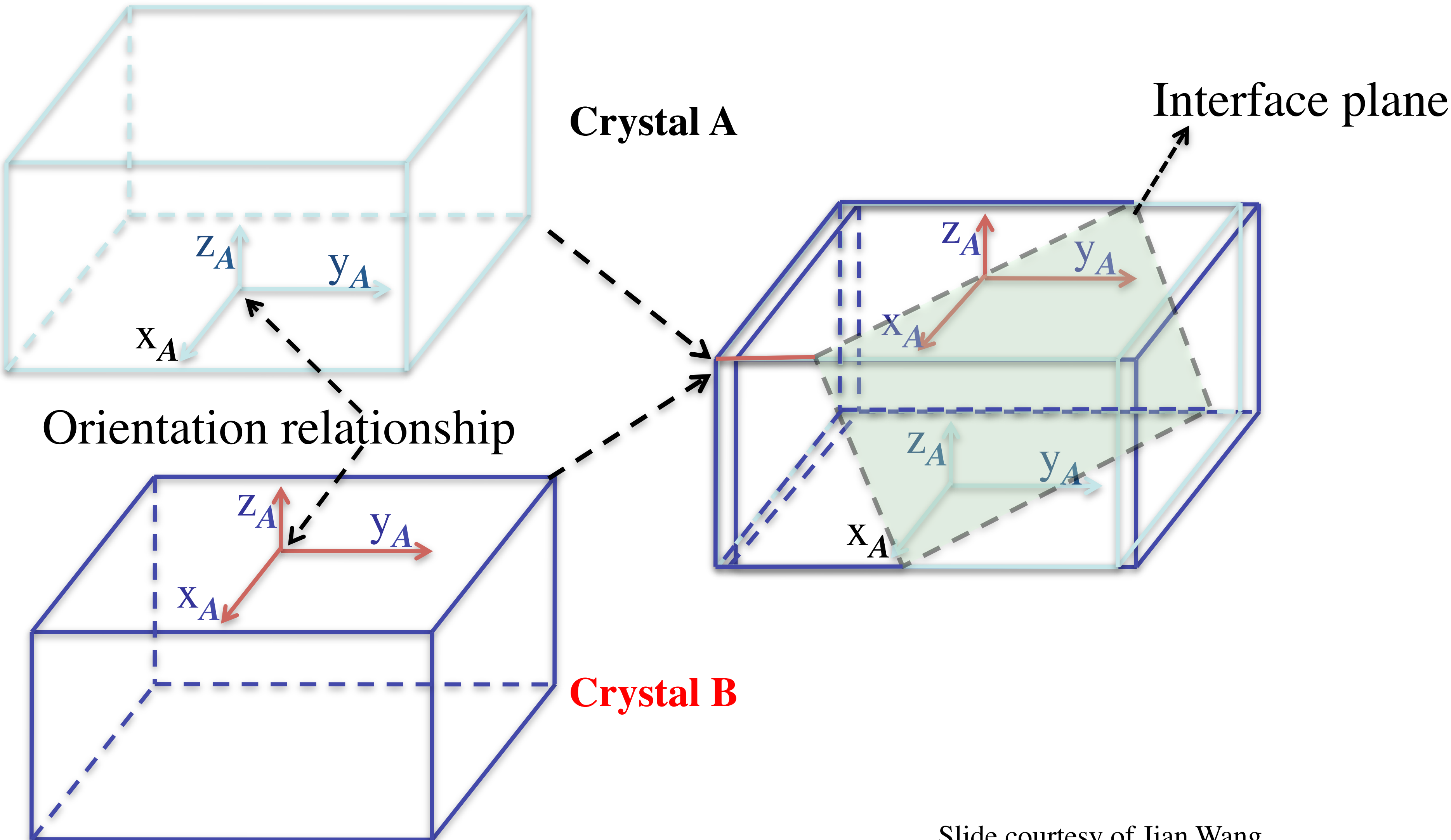
Extraordinary behavior of Physical Vapor Deposited (PVD) multilayers



Hypothesis: The atomic structure of an interface dictates its mechanical response. Interfaces with different atomic structure will exhibit different mechanical behavior. Controlling synthesis routes can give preferred interfacial structures with superior properties.

1. D. Bhattacharyya et al, unpublished 2. N. A. Mara et al, APL,92:231901 (2008) 3. A. Misra, et al, Acta Mater. (2003)

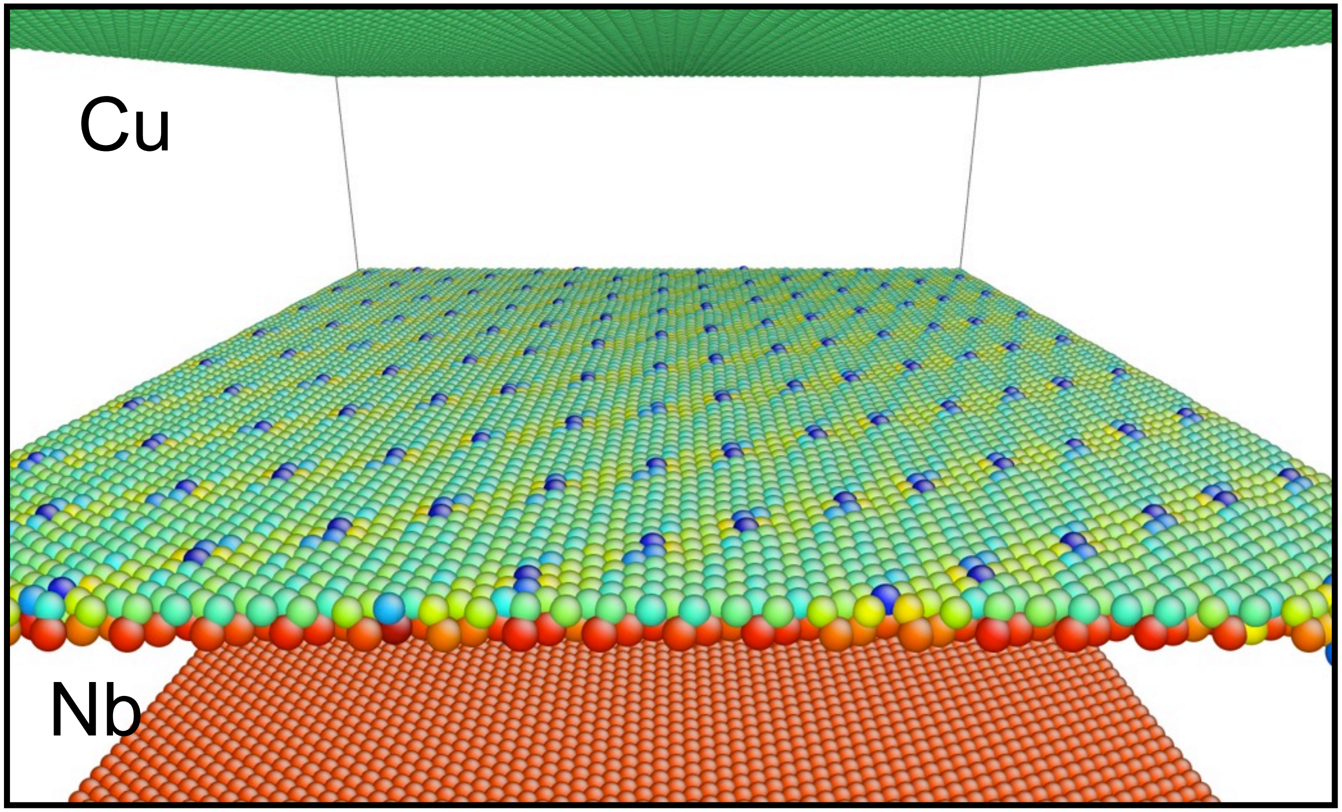
Orientation relationship and interface plane



Slide courtesy of Jian Wang

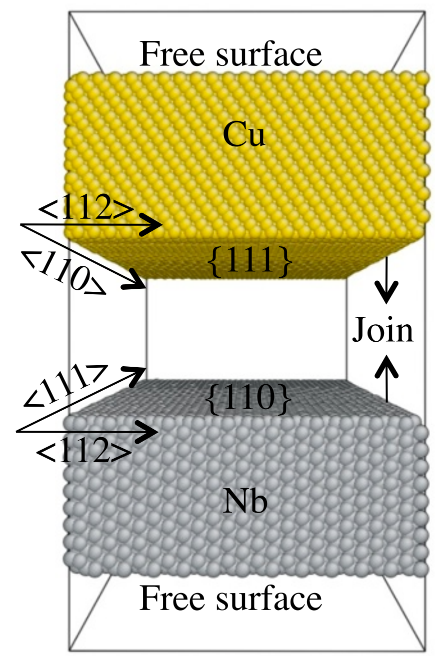
PVD foils: Fine sample dimensions and relatively uniform interfacial properties

Cu-Nb 2.5 nm layers



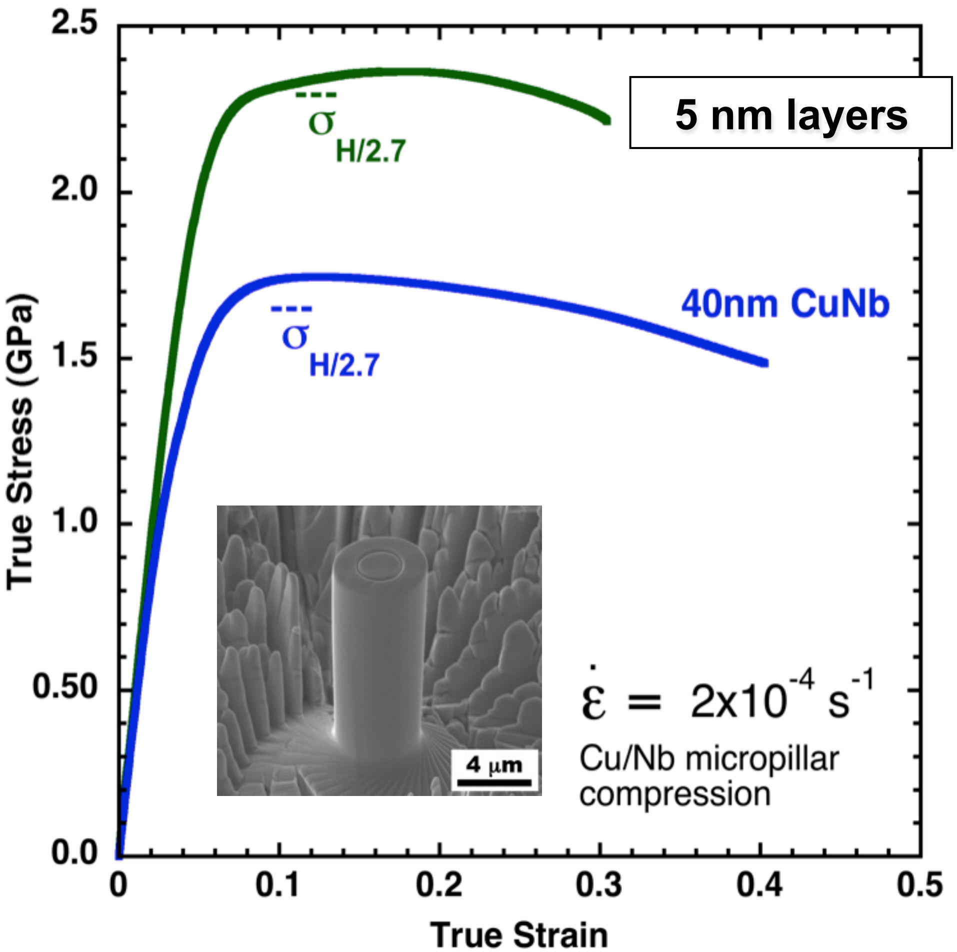
Characteristic interface in PVD foils

Interface planes:
$\{111\}_{Cu} \parallel \{110\}_{Nb}$



Extraordinary behavior of Physical Vapor Deposited (PVD) multilayers

Micropillar Compression: High strength and good ductility

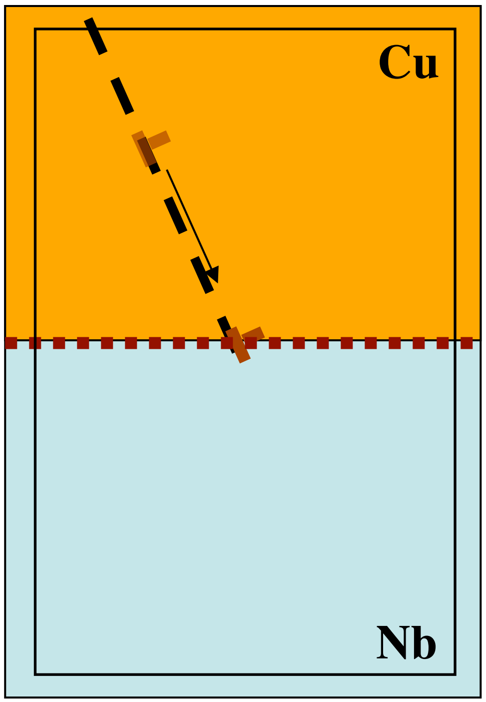


One distinguishing feature makes this material different from pure Cu or Nb

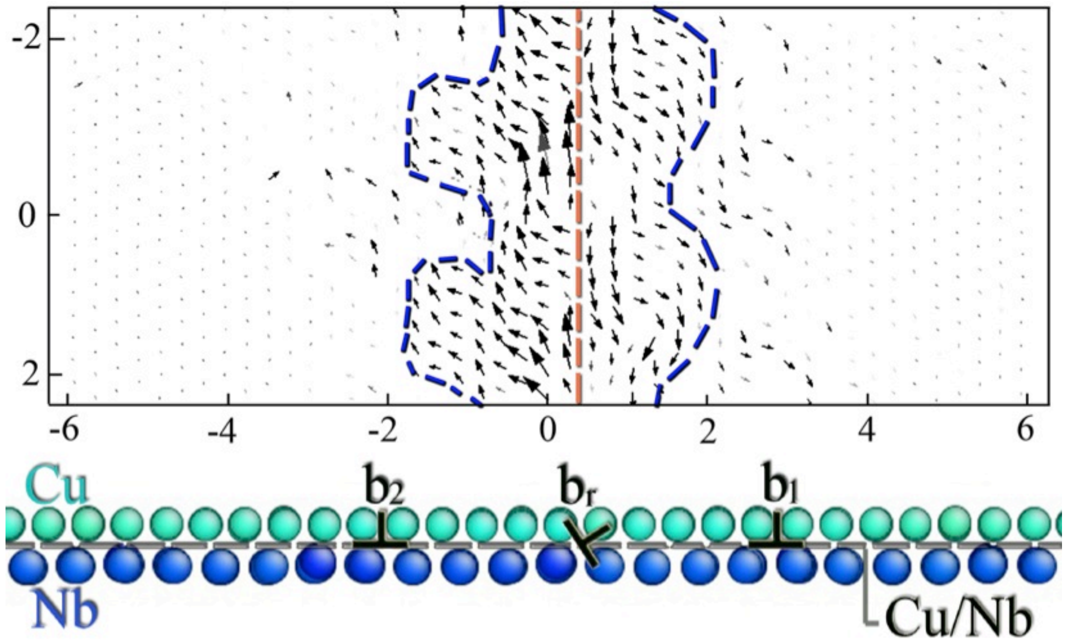
High interfacial content

N.A. Mara et al., APL, **92** (2008) 213901.
N.A. Mara et al., APL, **97** (2010) 021909.

Glide dislocations are trapped by weak interfaces that shear in response to dislocation stress field



Core spreading of an edge Shockley partial dislocation within interface



Dashed lines indicate the position while the glide dislocation entering interface.
Blue dashed curves outline the region of core spreading within interface.

J. Wang, R.G. Hoagland, J.P. Hirth and A. Misra, Acta Materialia (2008).

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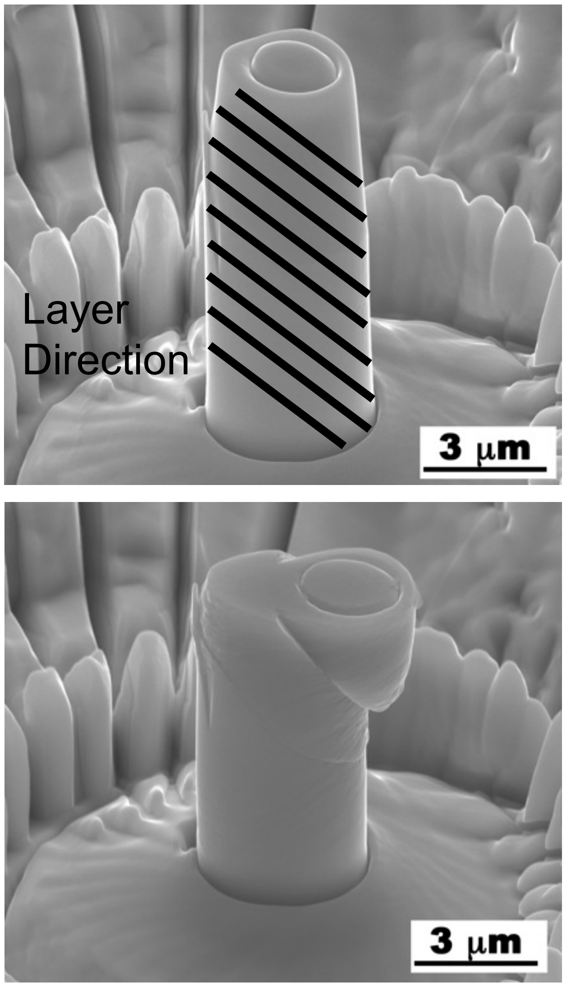
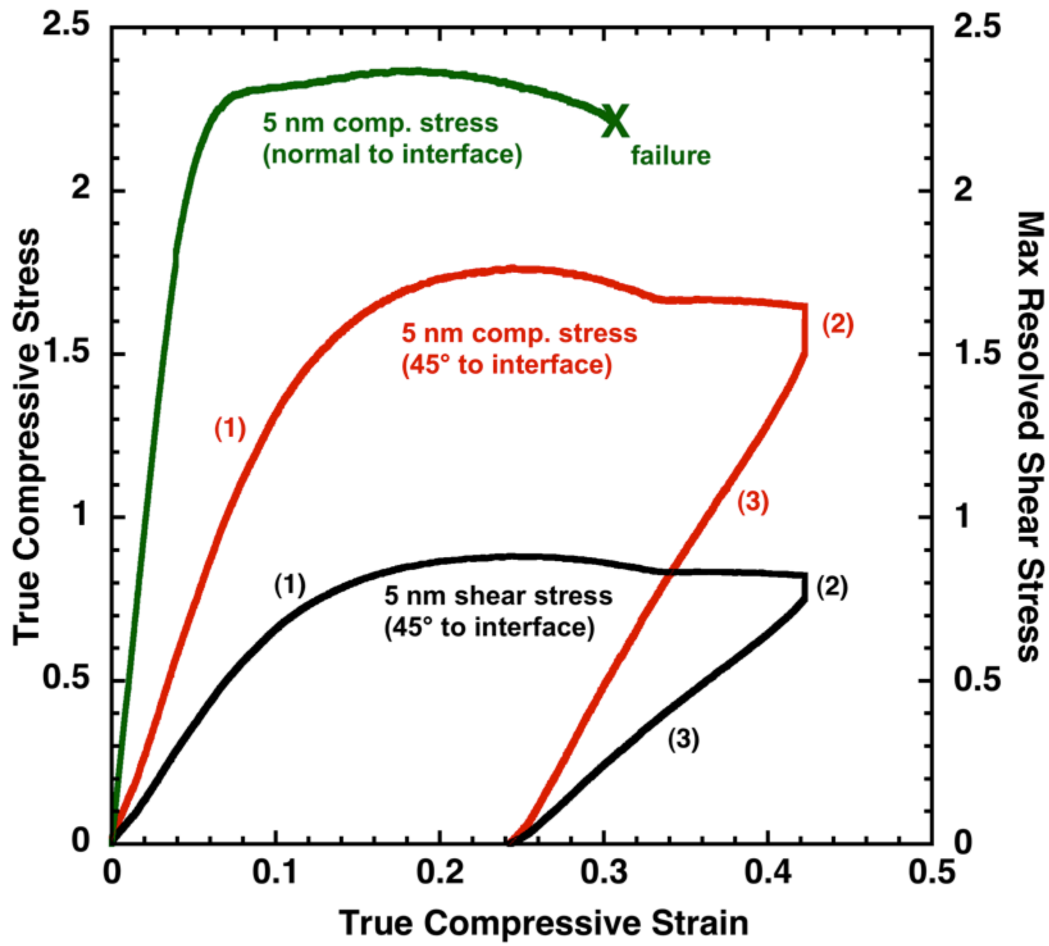
5 nm CuNb multilayers: layer interface oriented 45° w/r to compression axis





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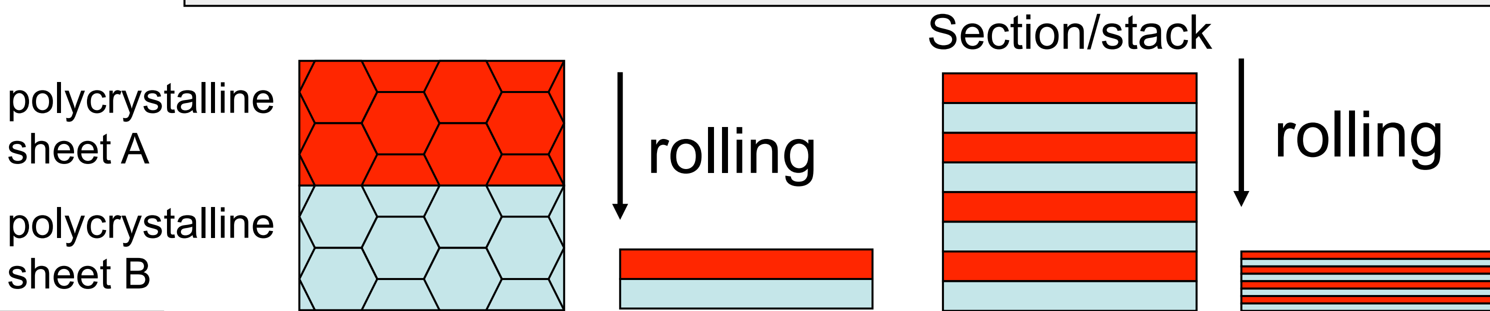
Physical Vapor Deposited Cu/Nb--Conclusions

- Atomic structure of the PVD Kurdjumov-Sachs {111}Cu// {110}Nb interface dictates its mechanical behavior
  - Interface is relatively weak in shear
  - Dislocation core spreading in the interface due to low shear strength makes transmission difficult
  - No deformation twinning evident, even after large strains

- Questions:
  - How will interfaces with differing atomic structure behave under mechanical loading?
  - Effects of:
    - Crystal geometry
    - Misfit dislocation structure
    - Synthesis pathway

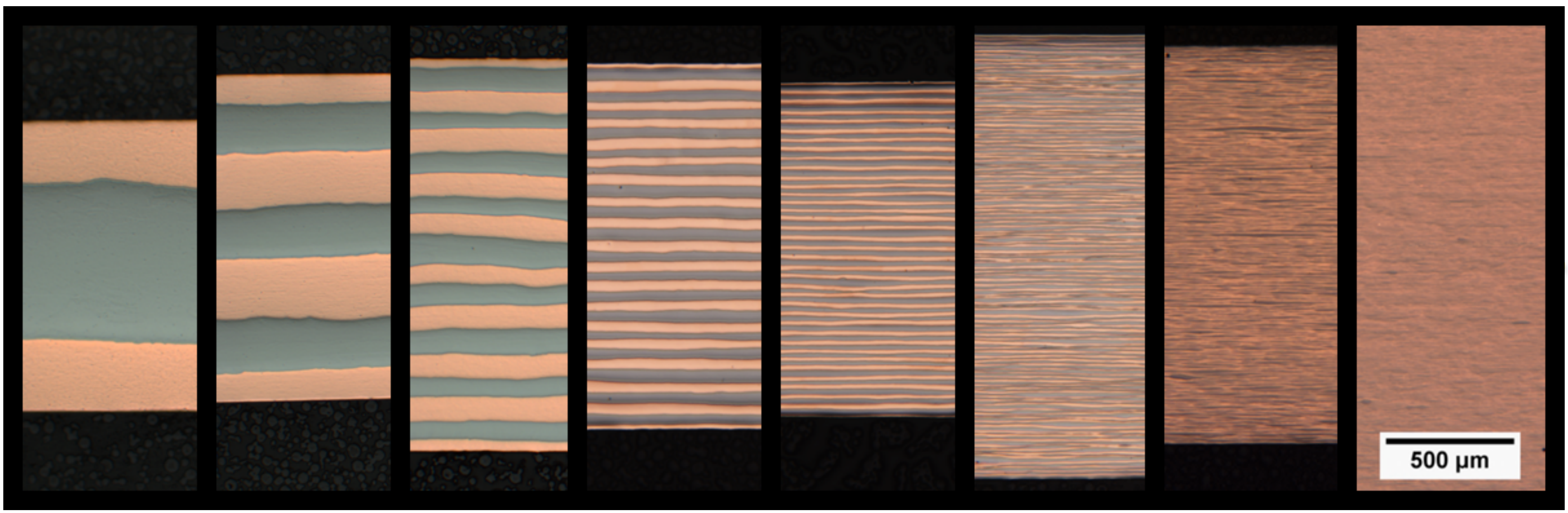
Synthesis of bulk multi-layered nano composite materials chemically identical to PVD

Accumulative Roll Bonding (ARB): Sheet

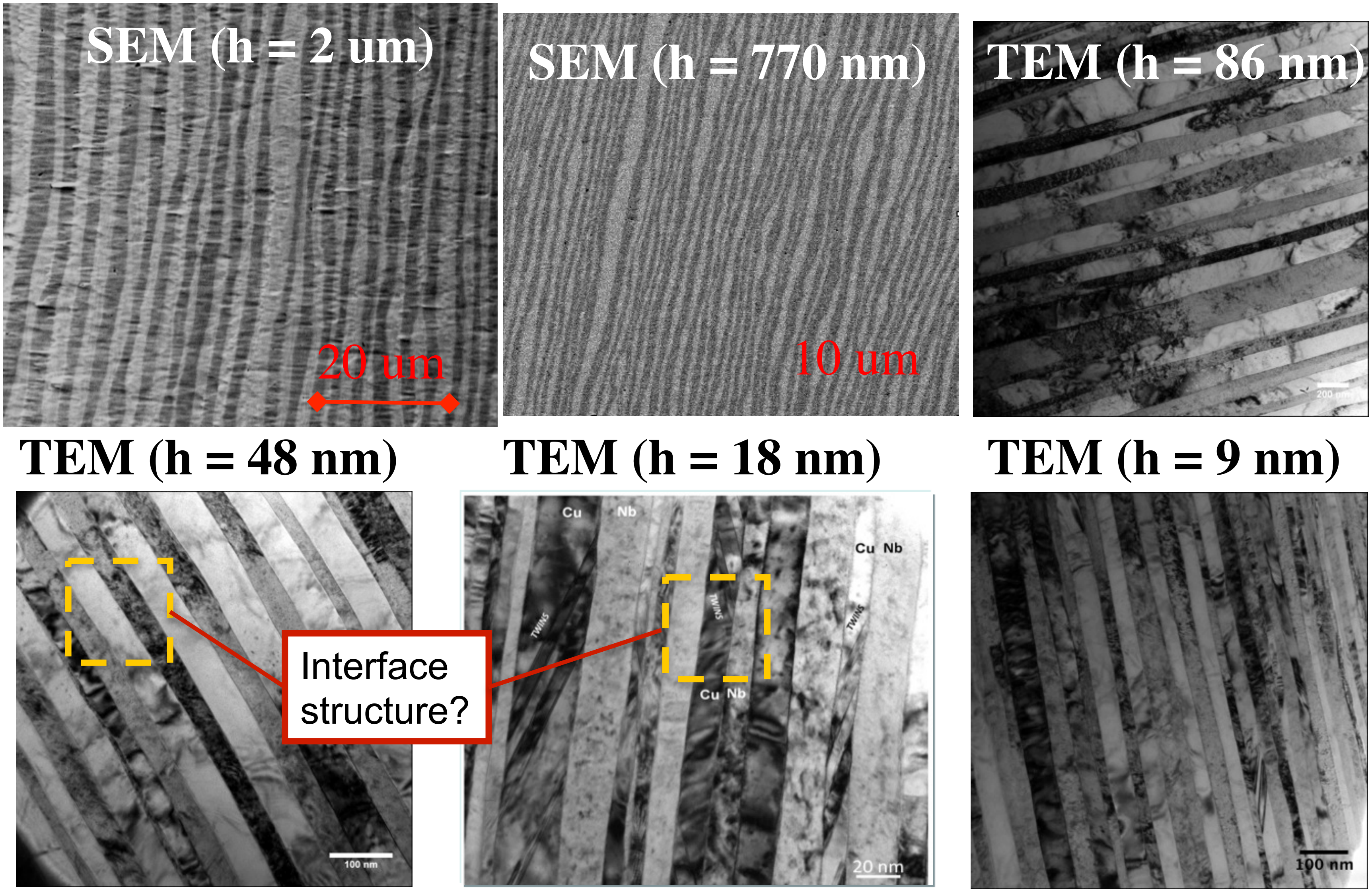


1-2 mm

~0.5 μm

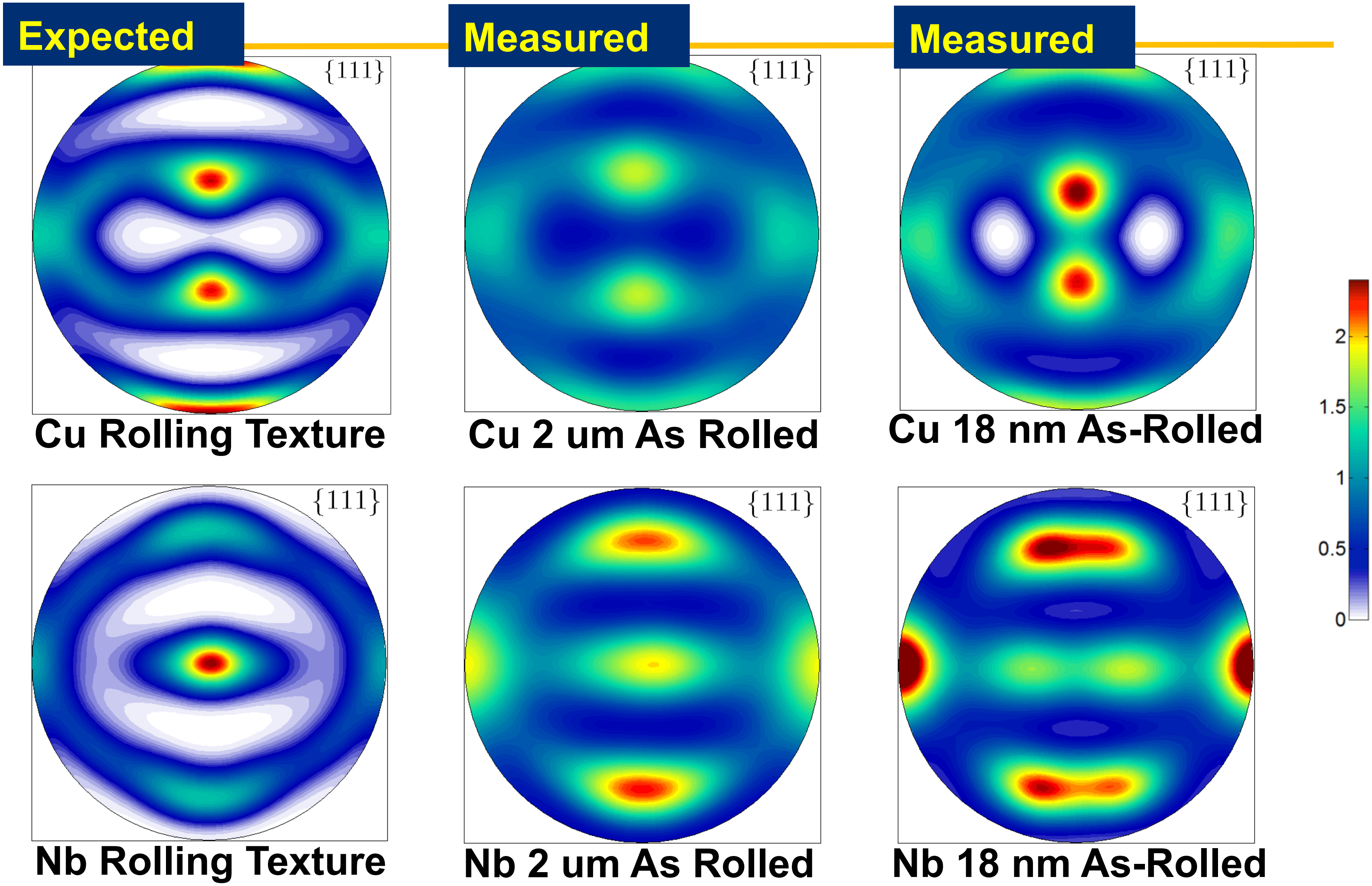


ARB Cu/Nb composites with controllable layer thickness



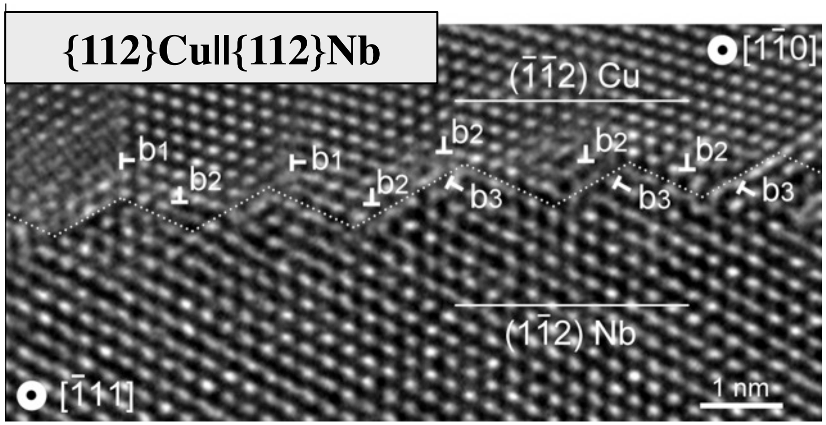
Carpenter et al. 2012, Acta Mater.

Deviations from theoretical rolling texture as the layer thickness reduces to nanoscale



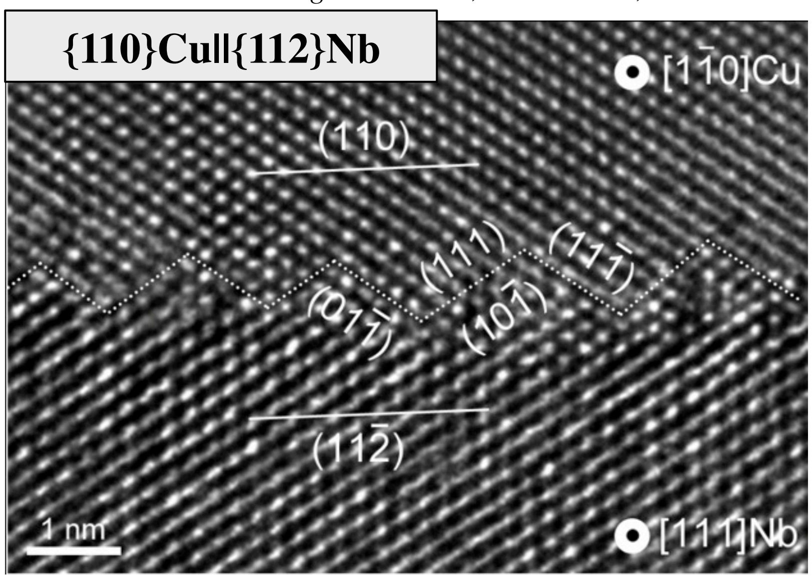
Two interfaces with same KS orientation relationship but different interface planes

{112}Cu||{112}Nb



S. J. Zheng et al. 2012, Acta Mater., In Press

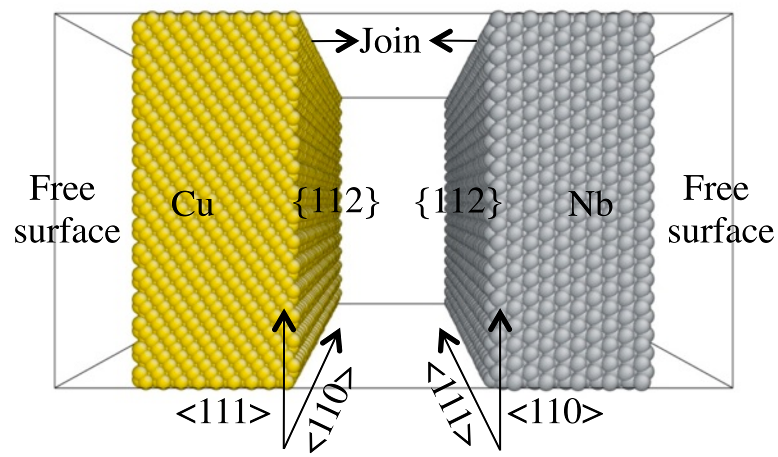
{110}Cu||{112}Nb

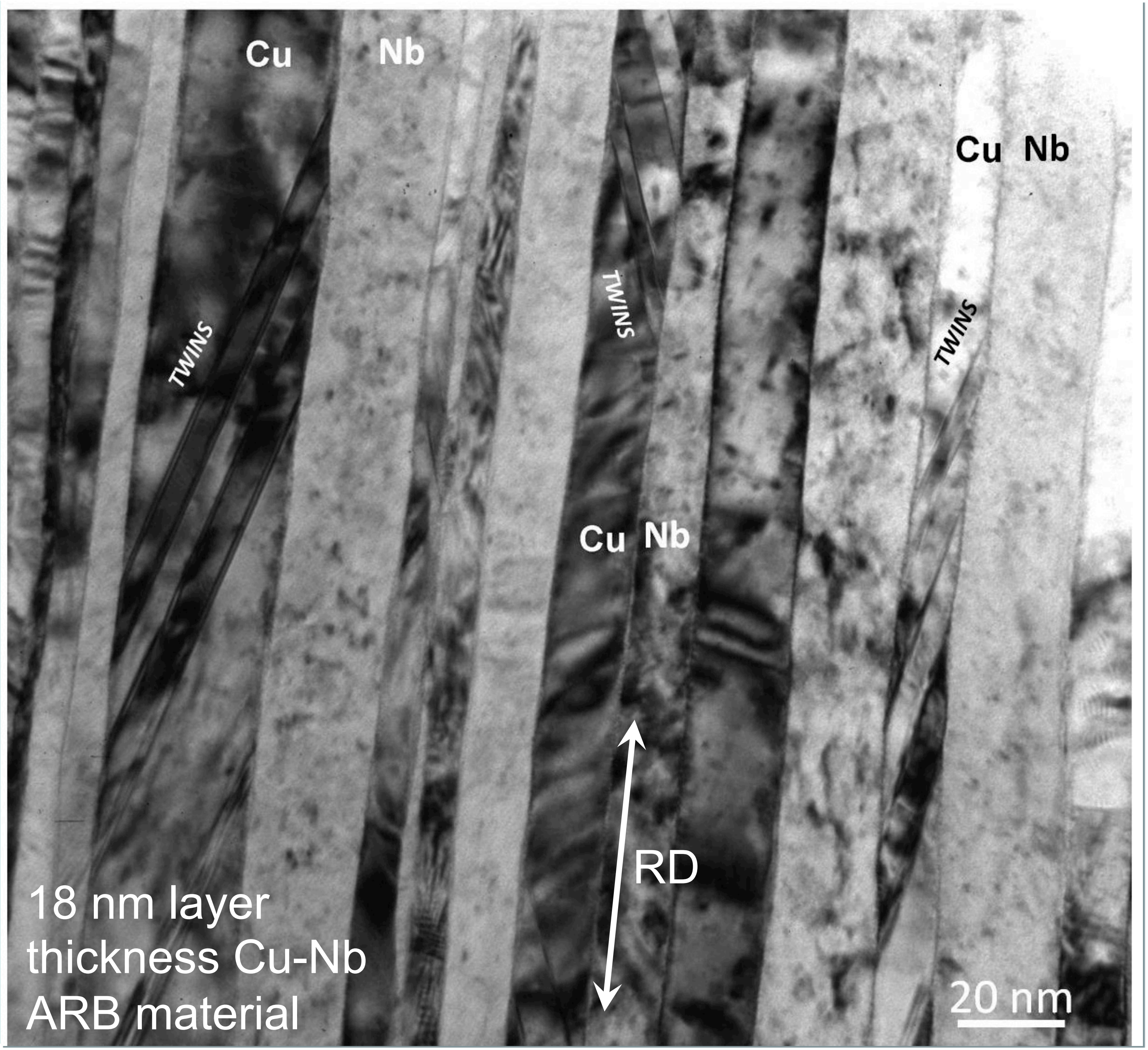


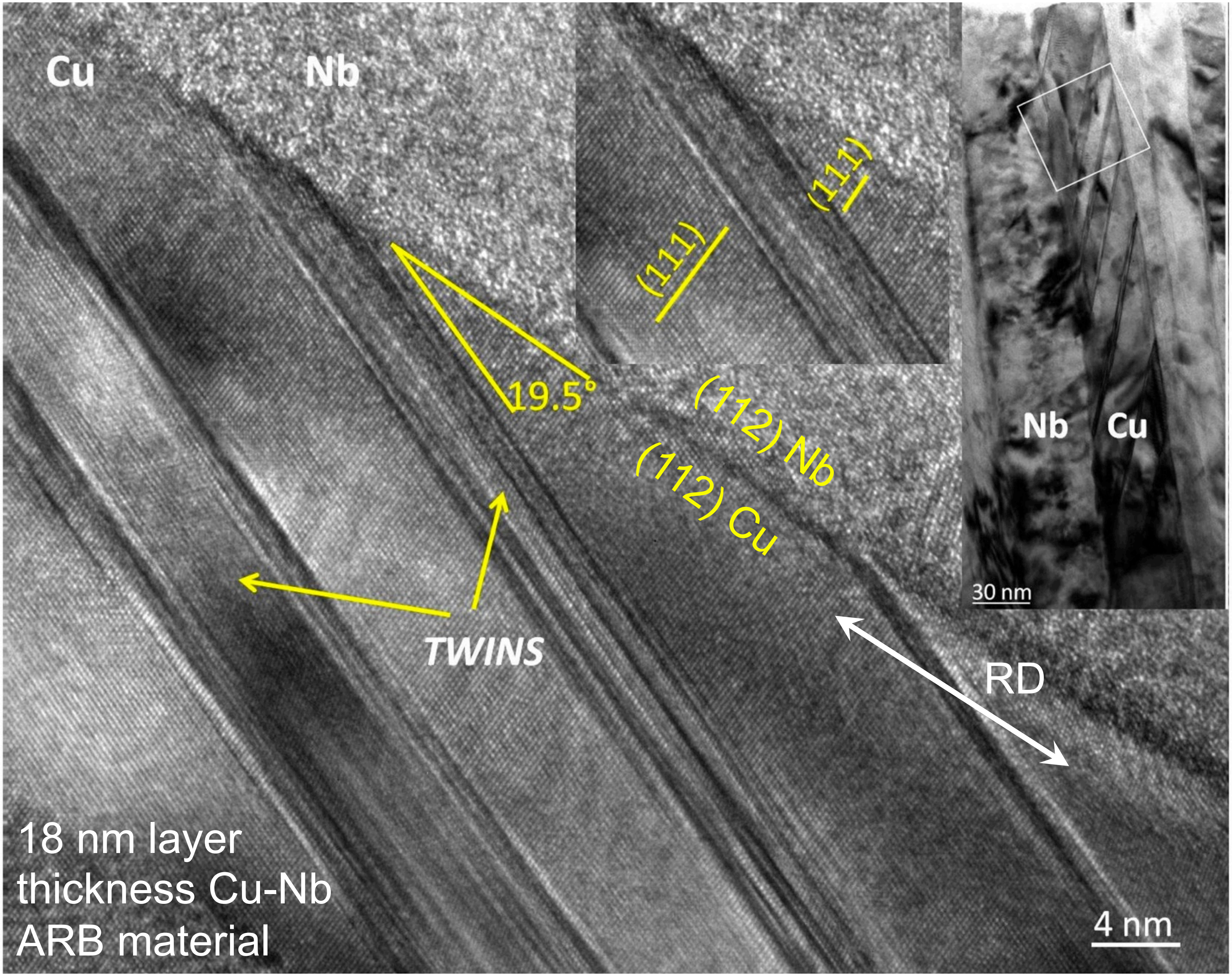
TD|| <110>Cu||<111>Nb

Characteristic interface in fine ARB samples

Interface planes:
$\{112\}_{Cu} \parallel \{112\}_{Nb}$




Cu
Nb
Cu Nb
TWINS
TWINS
TWINS
Cu Nb
RD
18 nm layer
thickness Cu-Nb
ARB material
20 nm


Cu
Nb
(111)
(111)
19.5°
(112) Nb
(112) Cu
TWINS
RD
Nb
Cu
30 nm
18 nm layer
thickness Cu-Nb
ARB material
4 nm

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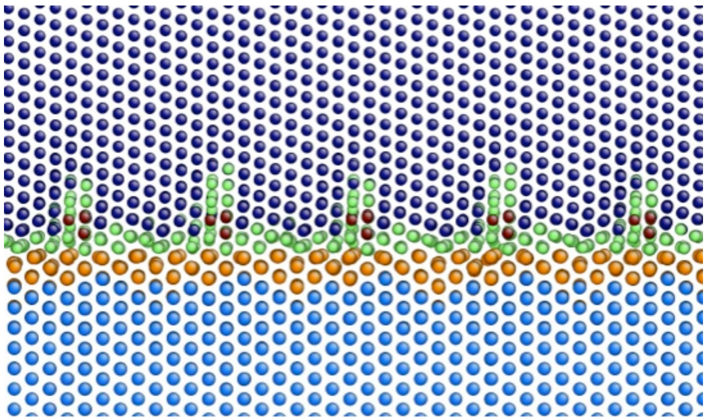
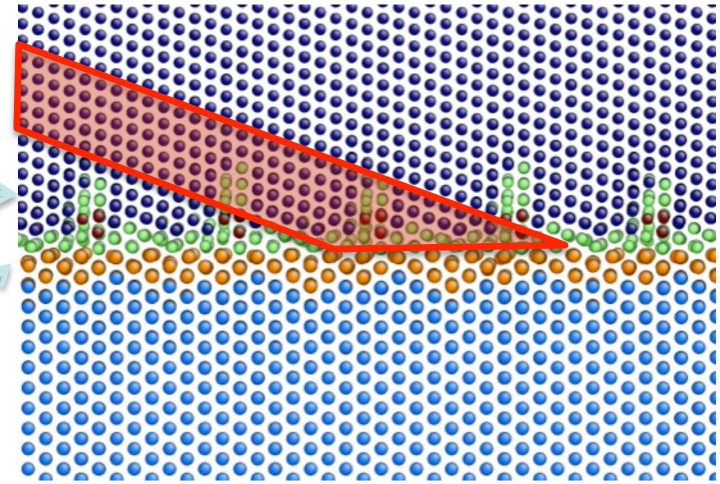
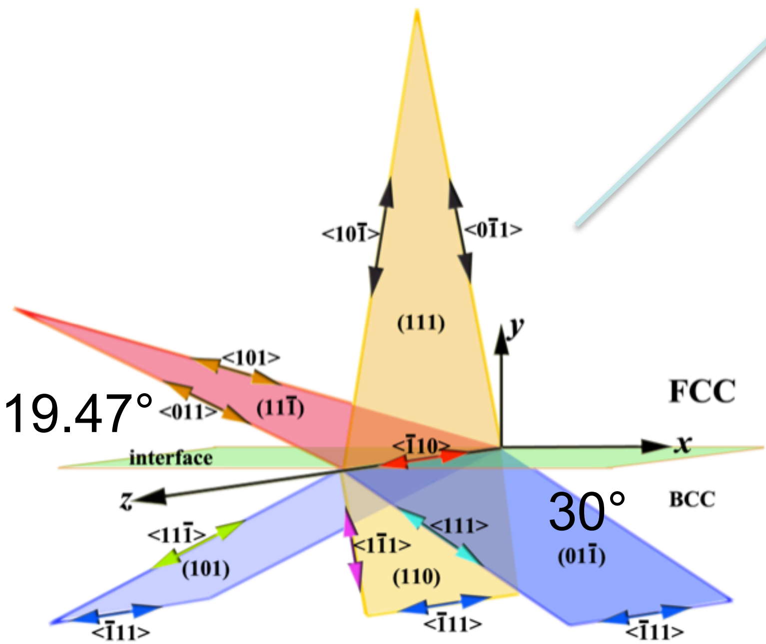
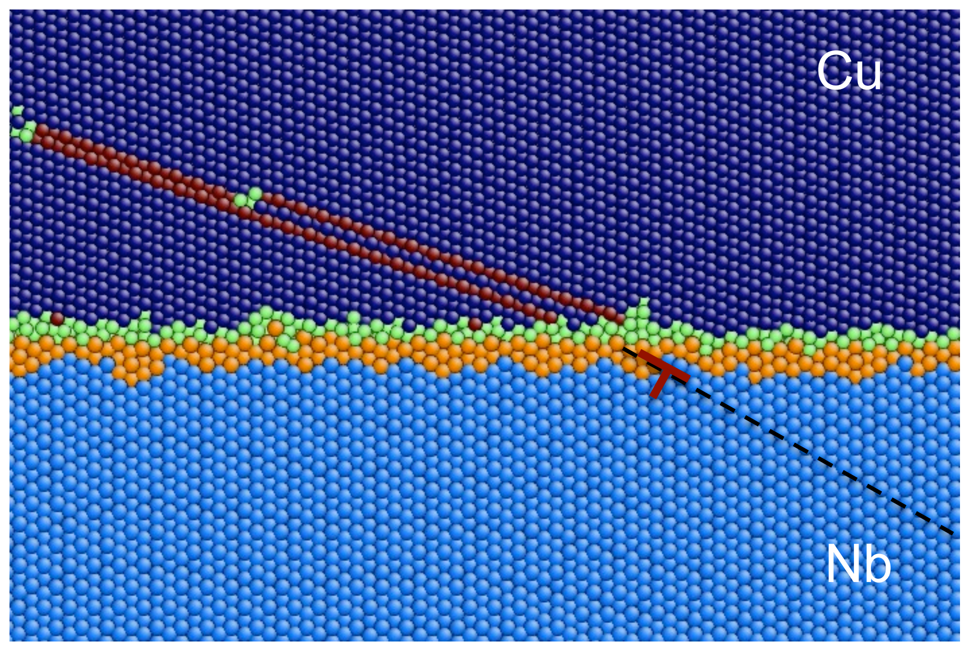
{112}Cu//{112}Nb KS: Twinning is preferred on the (11-1) slip plane





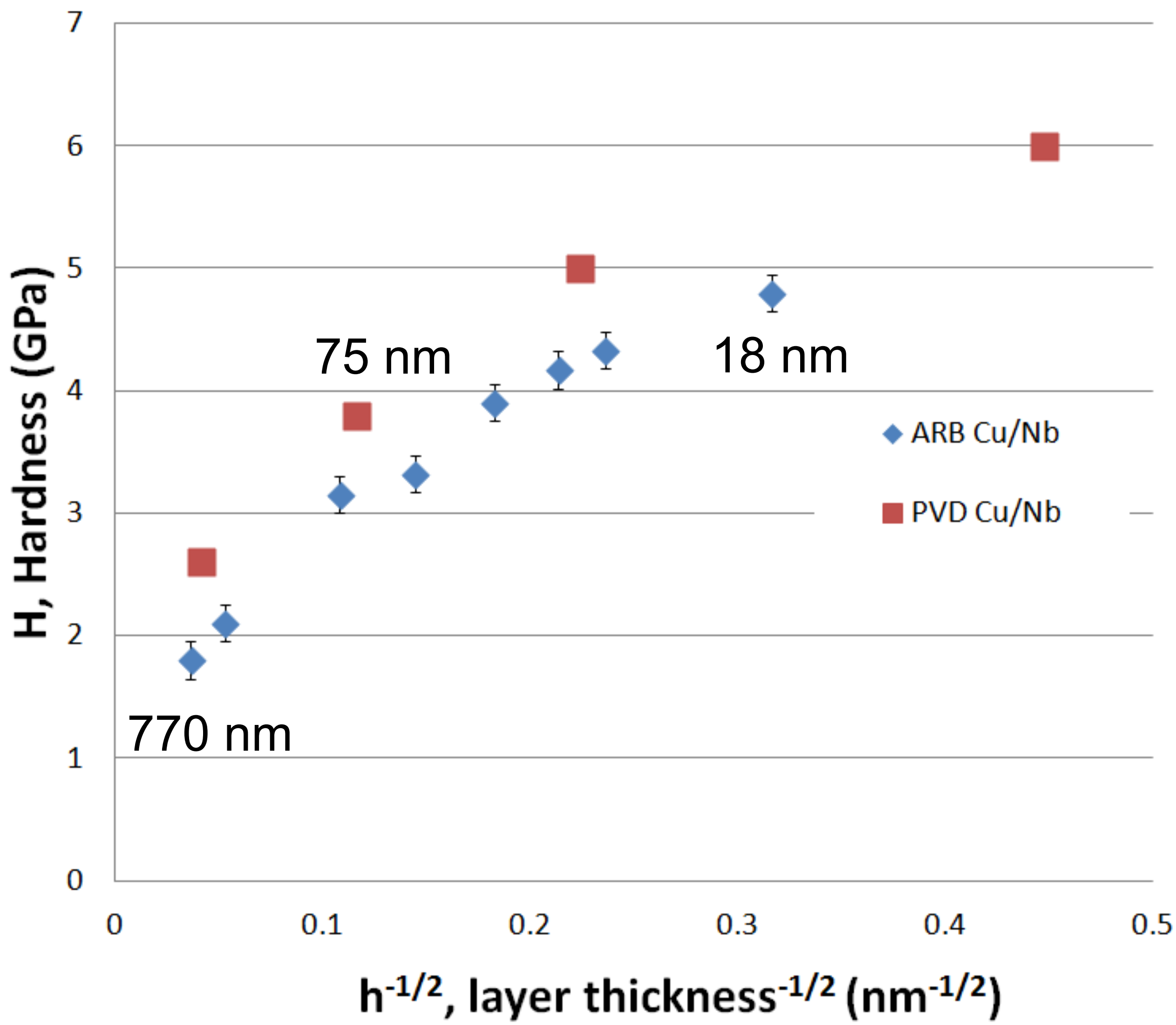




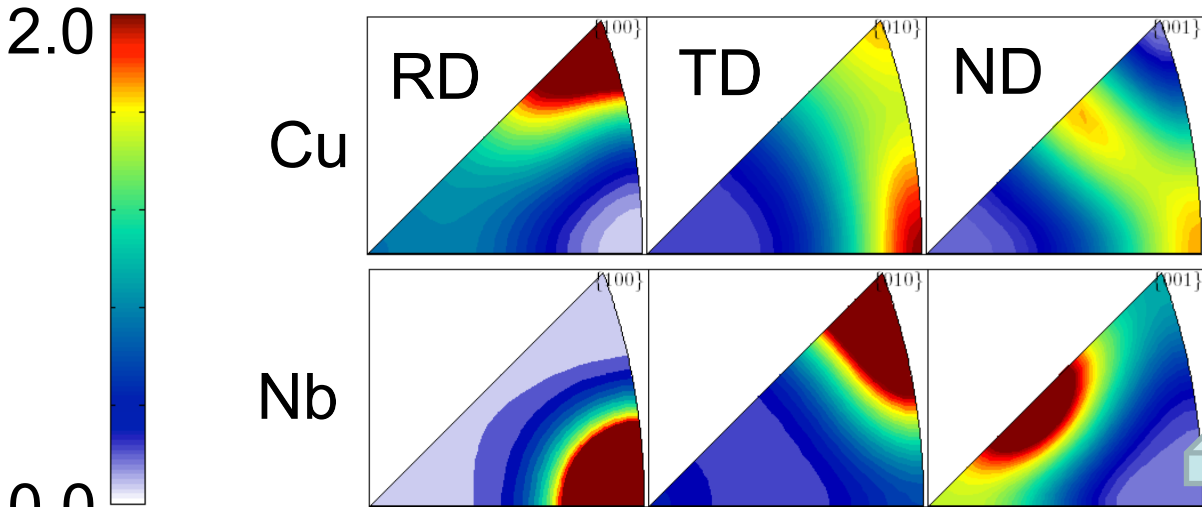
ARB Material Presents Lower Strength as compared to PVD material

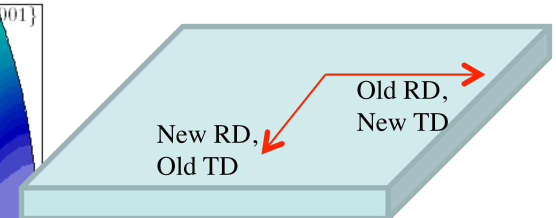
Is the ARB interface a less effective barrier to slip than the PVD interface?

Is the ARB material, with its texture produced via rolling, simply softer in certain directions due to this texture?



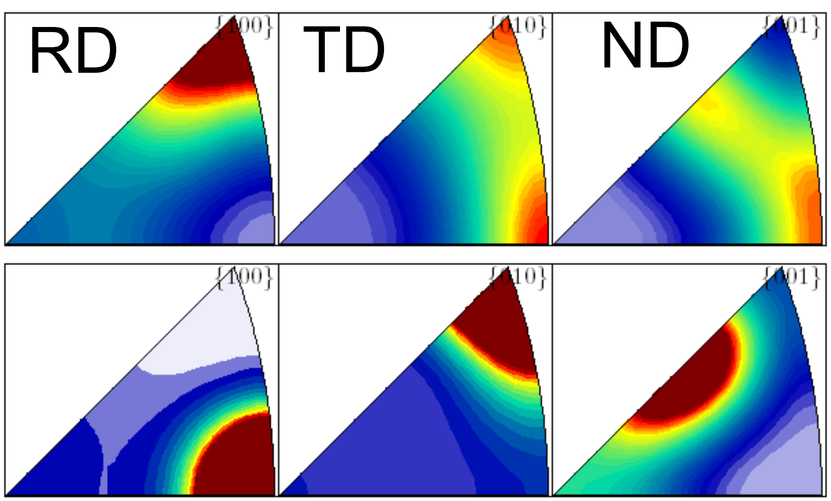
90° Strain path change: 56 nm to 30 nm

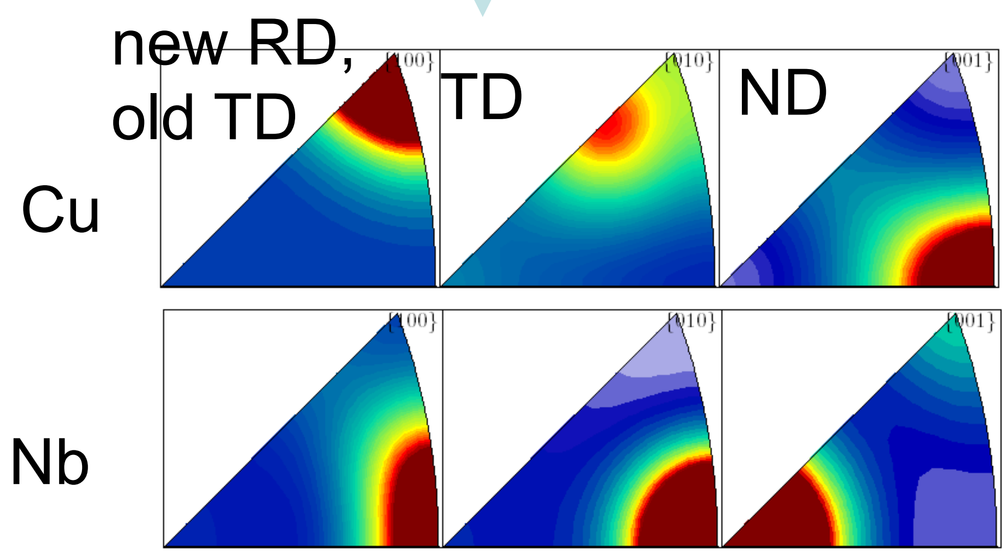




Perform single 90° rotation
follow with further rolling

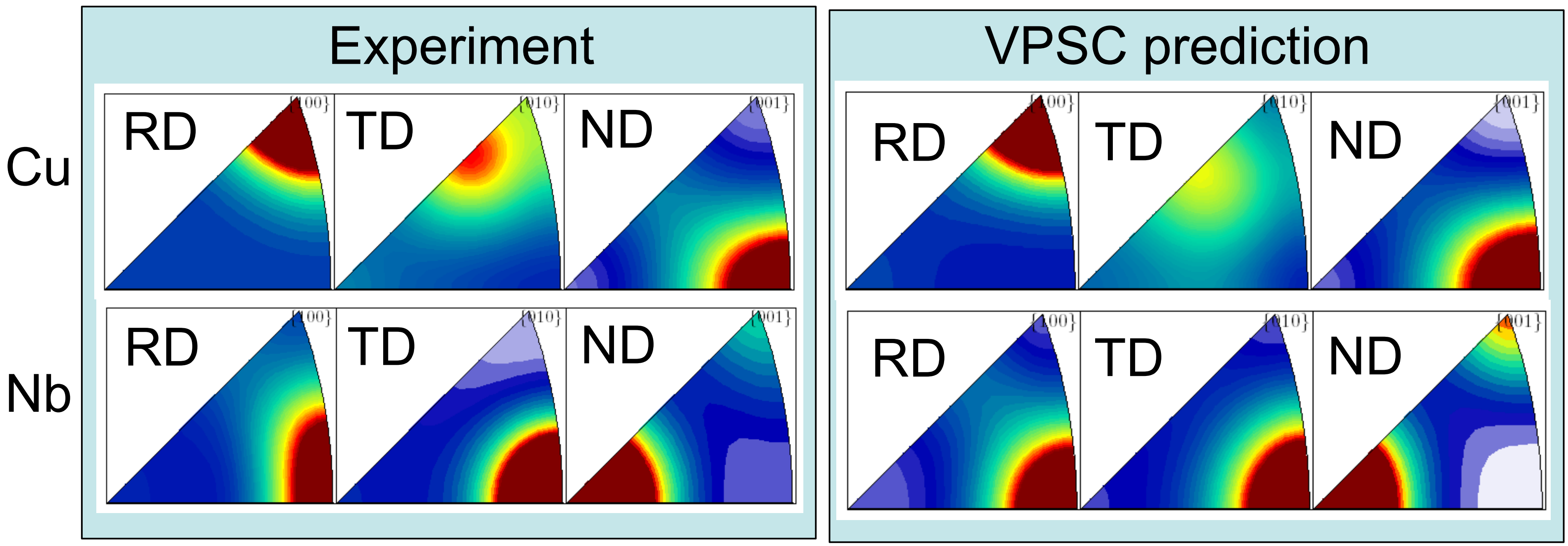
Maintained consistent rolling direction



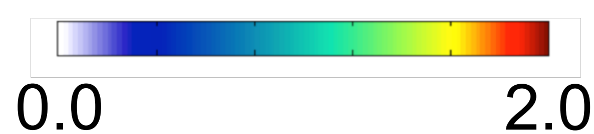


90° Strain path change: 56 nm to 30 nm

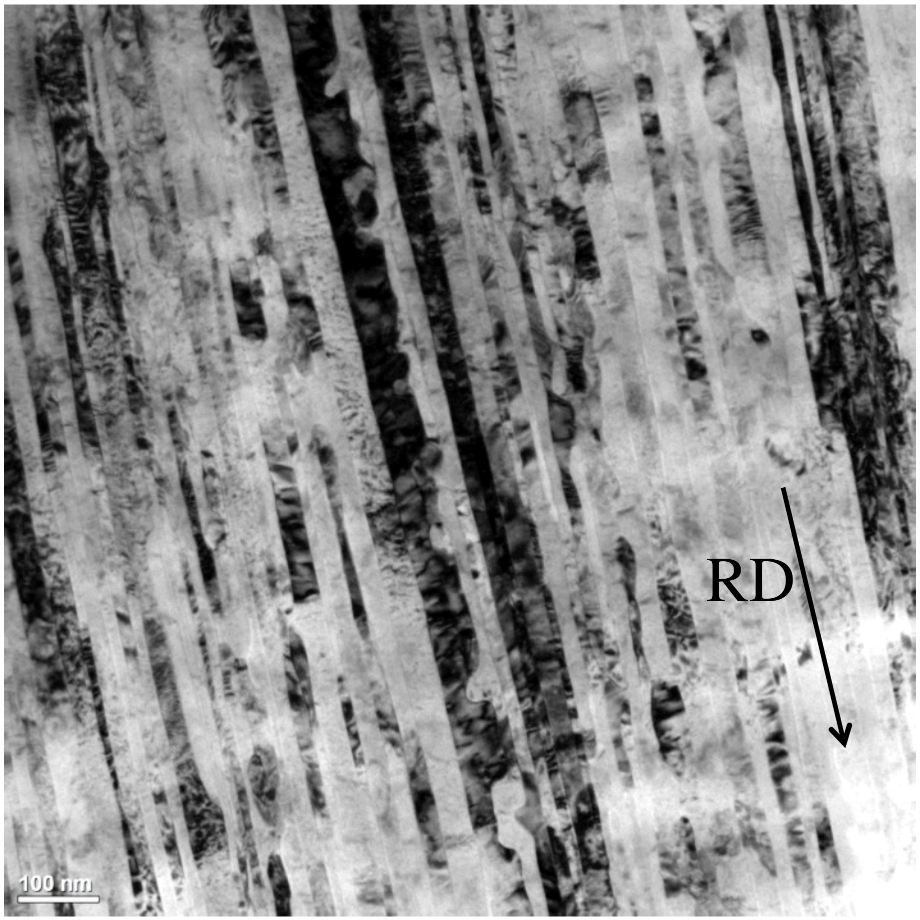
Inverse Pole Figures after Strain Path Change



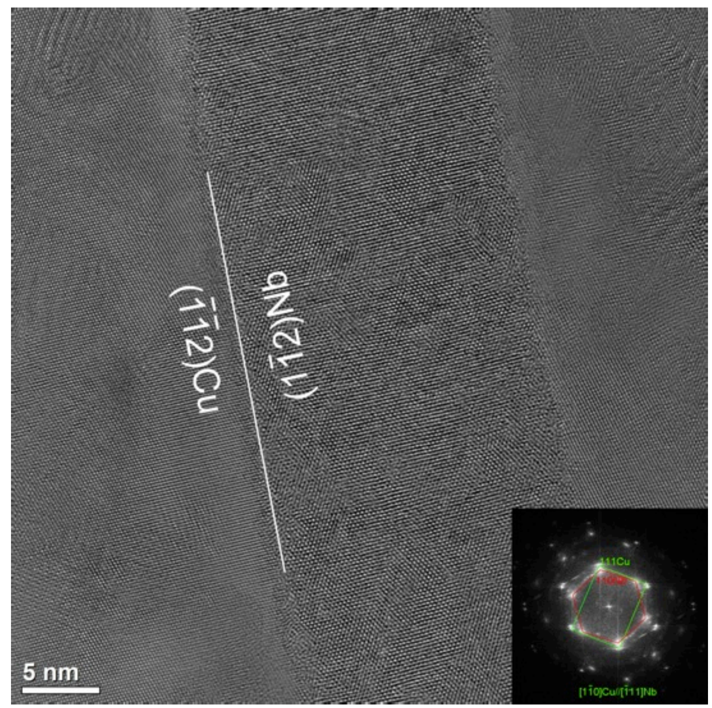
VPSC can predict textures, and can aid in predicting new interface OR/IP



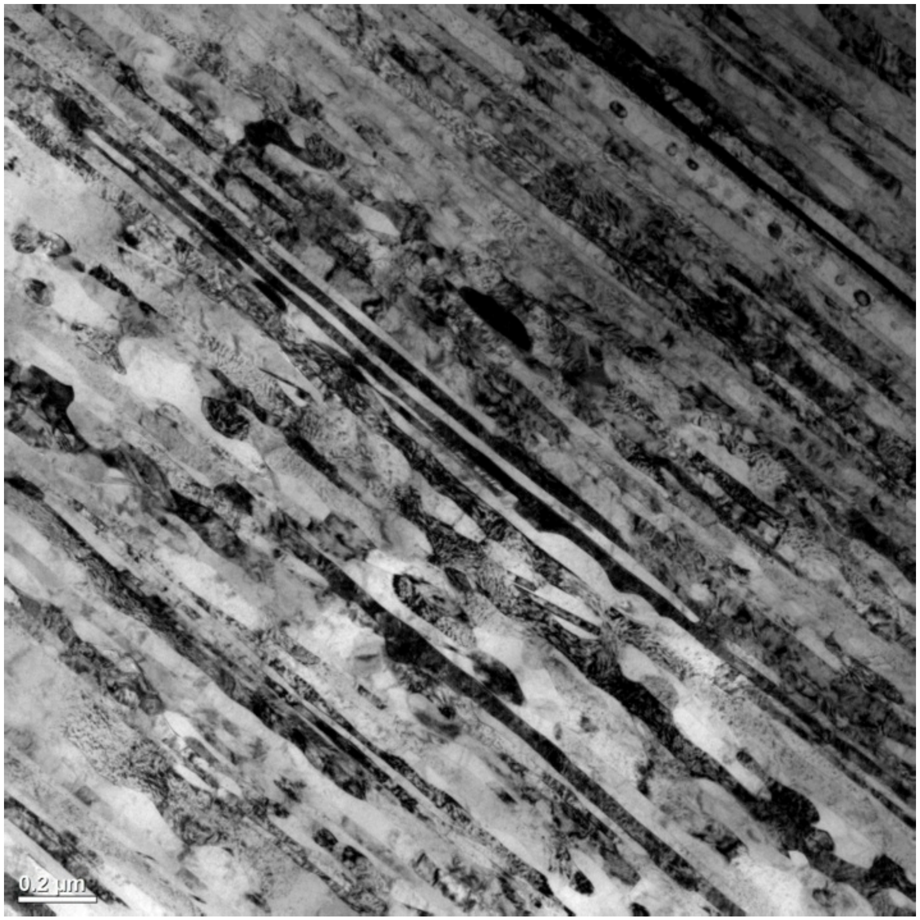
18 nm Cu/Nb Annealed at 500°C



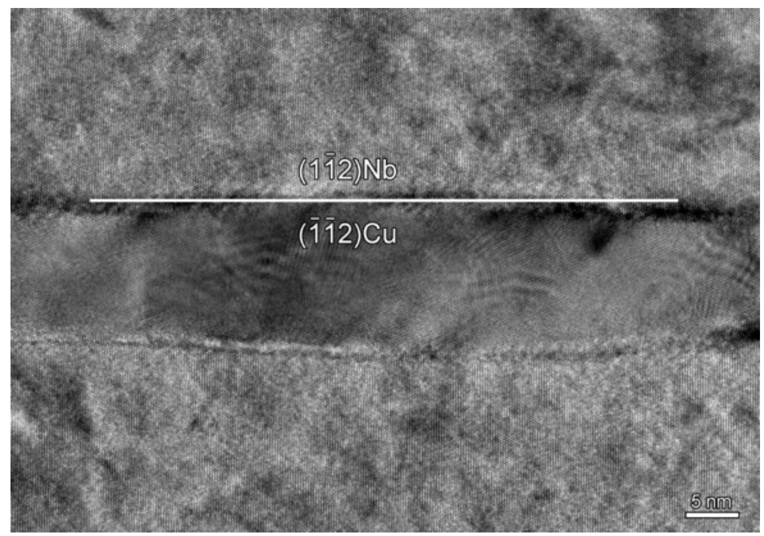
- Layers maintain ~ 18 nm layer thickness
- Interfaces are still largely planar
- Locations do show initial stages of instability, but not at (112)||(112) interfaces



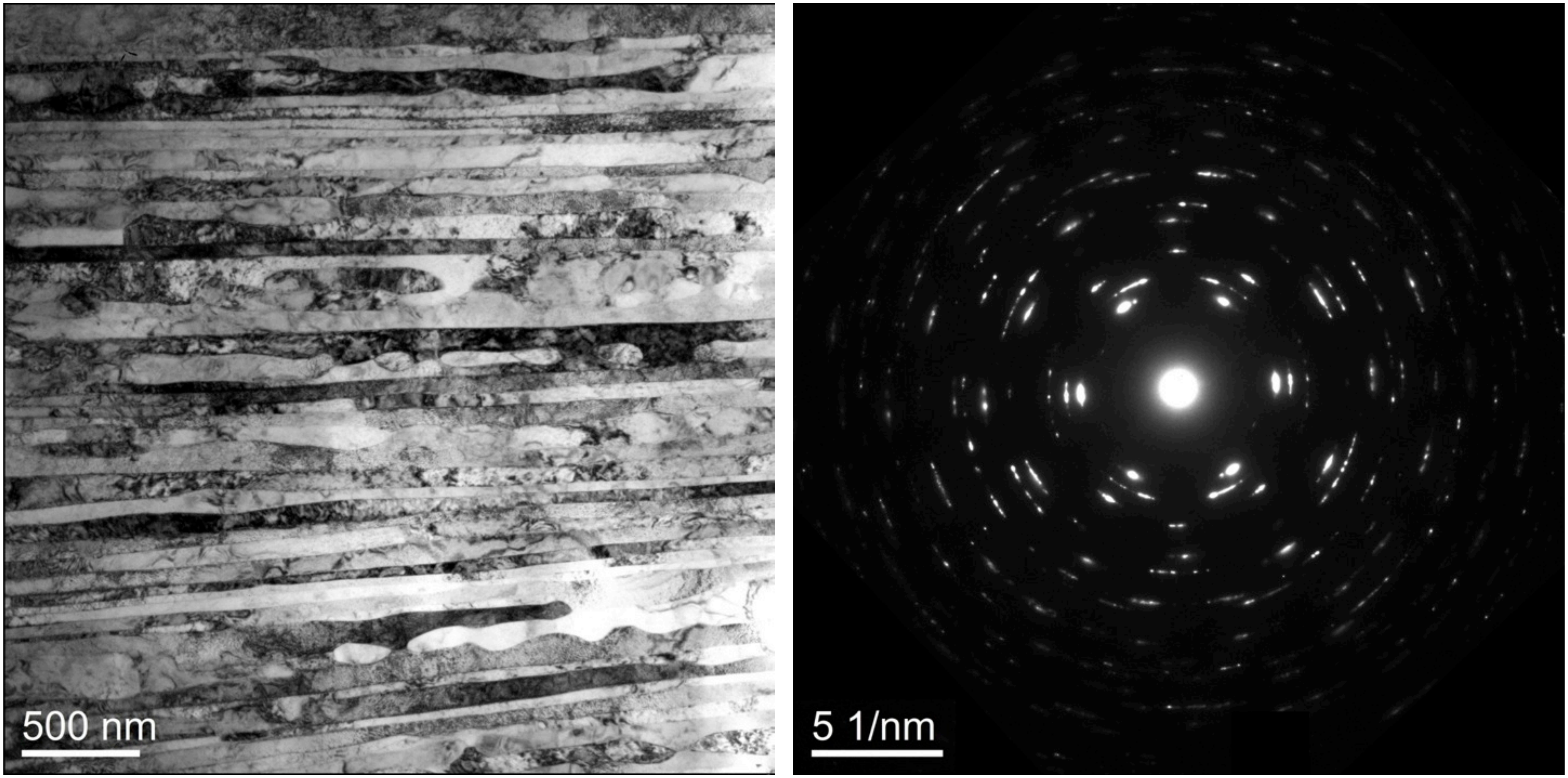
18 nm Cu/Nb Annealed at 600°C



- Layers are becoming noticeably thicker ~ 50 nm in thickness
- Interfaces are still largely planar
- More instability noted, but not at (112)|| (112) interfaces

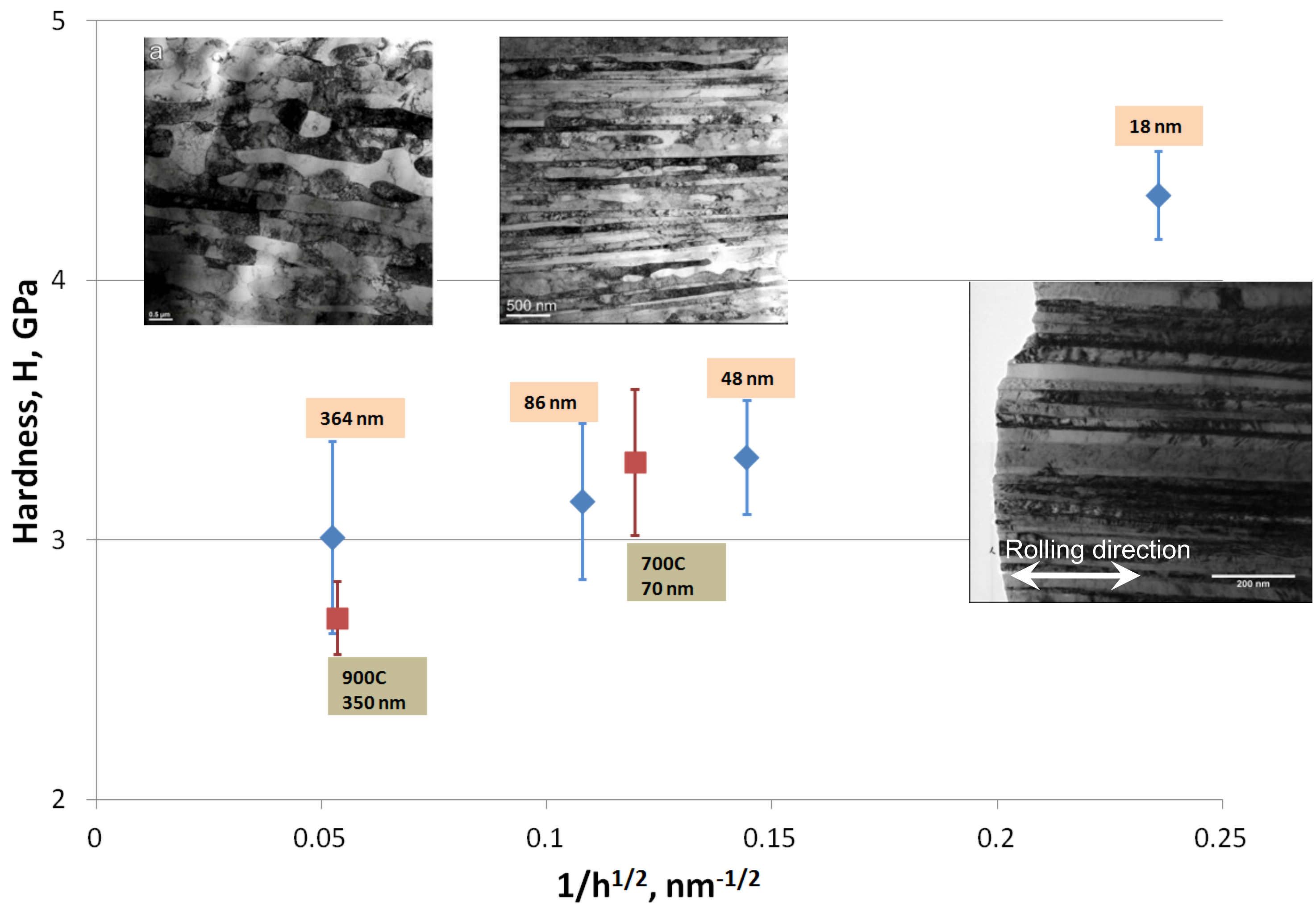


18 nm Cu/Nb Annealed at 700°C



Strong texture and lamellar structure is maintained

Mechanical Behavior – 700C Maintains Strength Trend



Lamellar structure is important in maintaining trend in hardness

Conclusions

- As-processed ARB material has similar morphology, chemistry as PVD, but different interfacial structure
- Density of interfaces <u>AND</u> interfacial structure play a role in determining hardness
  - Example: twinning in Cu at the {112}Cu//{112}Nb interface
  - Higher strength, no twinning in Cu in the {111}Cu//{110}Nb interface
- Need to understand effects of processing history to predict the effects on the interfaces we produce:
  - Amount of strain
  - Strain Path
  - Annealing