LA-UR- 11-05808

*Approved for public release; distribution is unlimited.*

| | |
|---|---|
| *Title:* | Interface structures dependent deformation twinning in Cu/Nb multilayers |
| *Author(s):* | W. Z. Han, N. A. Mara, A. Misra, J. Wang, I.J. Beyerlein and S. N. Luo |
| *Intended for:* | MS & T 2011 meeting in Columbus, Ohio, USA, October 16-20, 2011 |

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (7/06)

## Interface structure dependent deformation twinning in Cu/Nb multilayers

W.Z. Han, N. A. Mara, A. Misra, J. Wang, I.J. Beyerlein, and S.N. Luo

Los Alamos National Lab, Los Alamos, New Mexico 87544, USA

We investigate deformation of Cu/Nb nanolaminates (synthesized via physical vapor deposition) induced by flyer plate impact. The peak shock pressure is about 6 GPa and the targets are soft-recovered with proper momentum traps. The as-deposited and shock-recovered samples are examined with high resolution transmission electron microscopy for comparison. Abundant deformation twins are found in the Cu layers, and only dislocations and a small amount of stacking faults, in Nb layers after shock. Most of the deformation twins in Cu layers are at certain angles with the Cu/Nb interface plane. Our results demonstrate that most deformation twins nucleate at the sites of interface dislocations induced by the distinct atomic structure and properties of Cu and Nb, a particular effect of the hetero-phase interfaces on plastic deformation. Interface-driven twinning as revealed by this study shows promise in tuning the plastic deformation mechanisms through the design of hetero-phase interface structures.

U.S. DEPARTMENT OF ENERGY
Office of Science

UNCLASSIFIED

MS&T 2011 Columbus

CMIME
Center for Material at Irradiation and Mechanical Extremes

# Interface-structure-dependent deformation twinning in Cu/Nb multilayers

Weizhong Han

S. N. Luo, A. Misra, N. A. Mara, J. Wang, I.J. Beyerlein

Los Alamos National Laboratory

**Acknowledgement**

This work is sponsored by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Energy Frontier Research Center (EFRC) under Award No. 2008LANL1026.

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

Slide

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

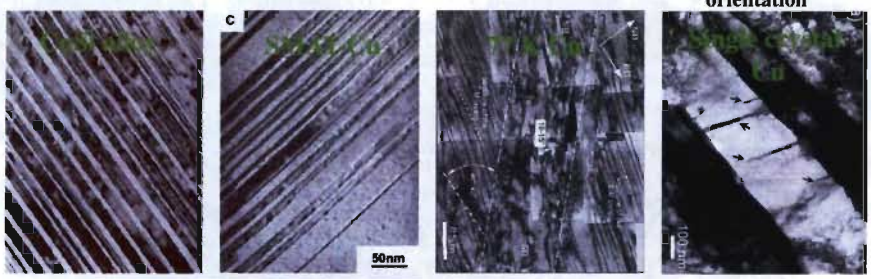
NNSA

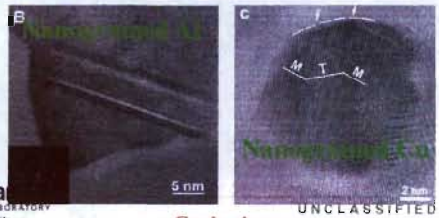
UNCLASSIFIED

## Background—*Key factors for deformation twinning*

### Key factors for twinning in metals

Stacking fault energy | High strain rate | Low temperature | Crystallographic orientation




Grain size

*H. Paul et al. MMT-A 2004-35-3775*
*K. Wang et al.Acta Mater-2006-54-5281*
*W.Z. Han et al. Philos Mag 2008-88-3011*
*W.Z. Han et al. Appl. Phys. Lett. 2008-92-221909*
*M.W. Chen et al. Science. 2003-300-1275*
*X.L. Wu et al. Phys. Rev. Lett. 2008-100-095701*

Los Ala NATIONAL LABORATORY

UNCLASSIFIED

Slide 2

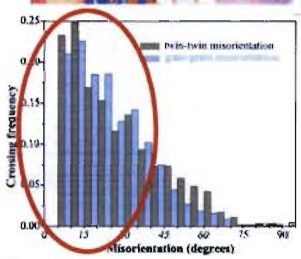
Operated by the Los Alamos National Security, LI

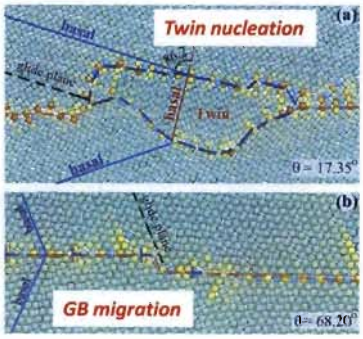
NNSA

UNCLASSIFIED

## Background—*grain boundaries characteristics VS twinning*

**Twinning nucleation depends on GB misorientation angle and GB defects**




Adjoined twin pair at GB;
Twins prefer at low misorientation angle;
GB dislocations play important role.

*I.J. Beyerlein et al. Philos. Mag. 2010-90-2161;*
*J. Wang et al. Scripta Mater. 2010-63-741*

Los Alamos NATIONAL LABORATORY
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

Slide 3

UNCLASSIFIED

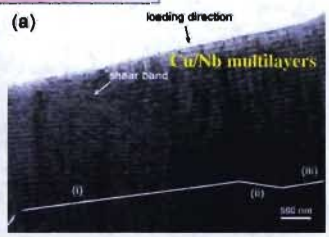
## Motivation—*Phase interfaces VS twinning???*

**Nanolaminates are a type of very important metallic materials**

*The idea sink for the radiation induced interstitials-Good radiation resistance

*The strong barrier for slip transmission-High strength and good ductility

**Deformation mechanism**




**What is the role of heterogeneous phase interface in the deformation of Cu/Nb multilayer? Especially for deformation twinning?**

Los Alamos NATIONAL LABORATORY
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

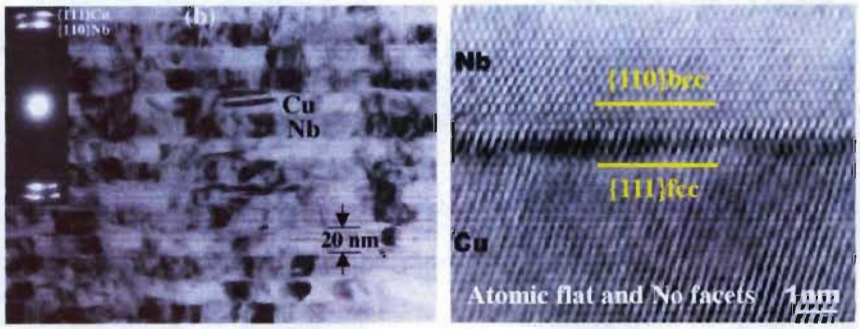
UNCLASSIFIED

Slide 4

UNCLASSIFIED

## PVD Cu/Nb multilayers-Type I (Flat layer structures)

*I. PVD Cu/Nb films with the total thickness of several micrometers*




1. Relative flat layer structures with strong fiber texture along the interface normal;
2. The orientation relationship is predominant with Kurdjumov-Sachs (K-S)
   <011>fcc//<111>bcc and {111}fcc//{110}bcc
   Interface plane with {111}fcc//{110}bcc

Los Alamos NATIONAL LABORATORY

*Misra A, Hirth JP, Hoagland RG. Acta Mater 2005;53:4817*

Slide 5

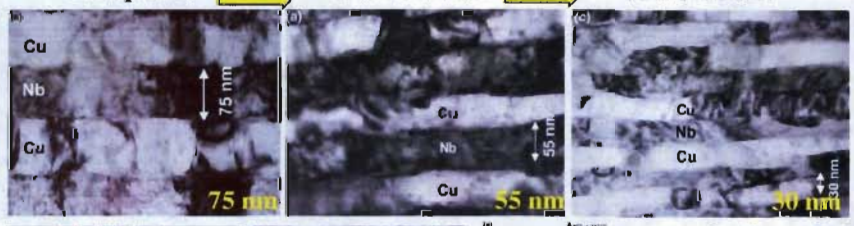
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## PVD Cu/Nb in multlayers-Type I-Rolling

As deposited → Rolling → 40% reduction → Rolling → 60% reduction



Kurdjumov-Sachs

(111)Cu//(110)Nb,
[0-11]Cu//[1-11]Nb

Interface plane type

u//(110)Nb

**Symmetrical slip systems activated and maintain uniform deformation**

Tamakov et al. Nature Mater. 2002;1:45 Zhang K et al., Philos Mag 2008;88:2559

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

Slide 6

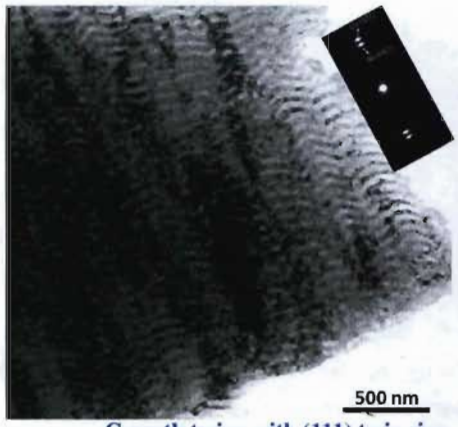
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

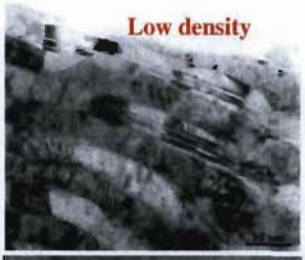
NNSA

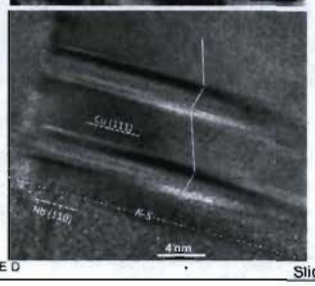
UNCLASSIFIED

## PVD Cu/Nb multilayers-Type II (Curved layer structures)

*2. PVD Cu/Nb films with the total thickness of tens of micrometers*




**Growth twins with (111) twinning plane parallel to the interface; K-S is the dominant OR.**

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

Slide 7

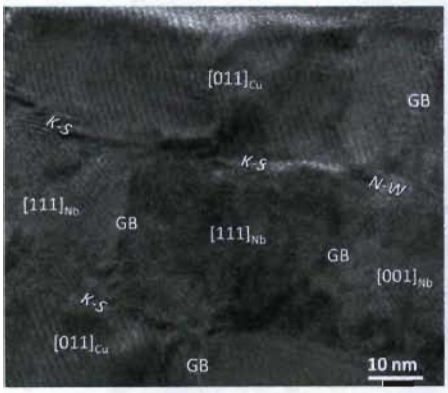
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

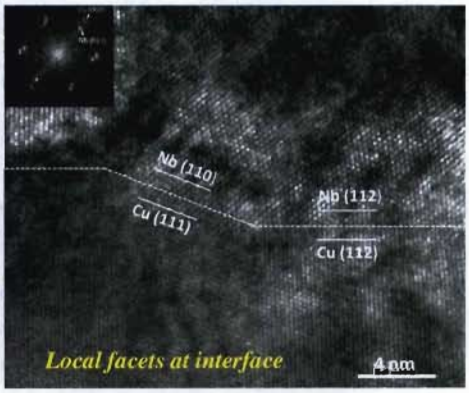
NNSA

UNCLASSIFIED

## PVD Cu/Nb multilayers-Type II (Curved layer structures)

*Local grains and interface structures*




***Local interface structures can be {111}fcc//{110}bcc or {112}//{112} or other types.***

*Han WZ et al., Philos Mag 2011 in press.*

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

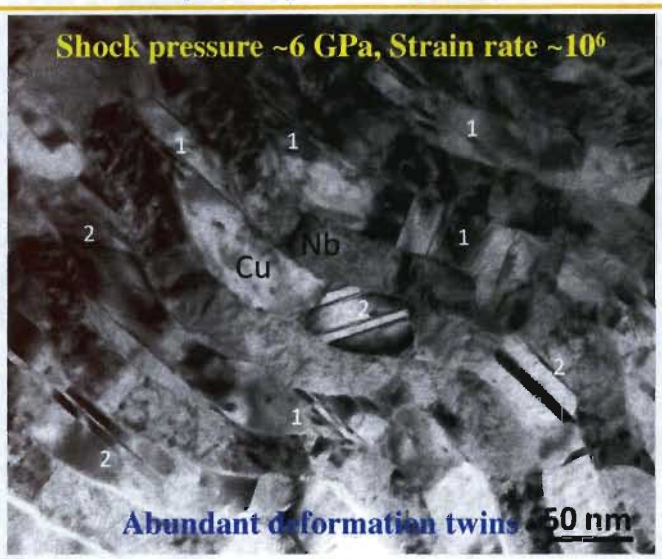
Slide 8

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## PVD Cu/Nb multilayers-Type II-Shocked




Los Alamos NATIONAL LABORATORY EST. 1943

UNCLASSIFIED

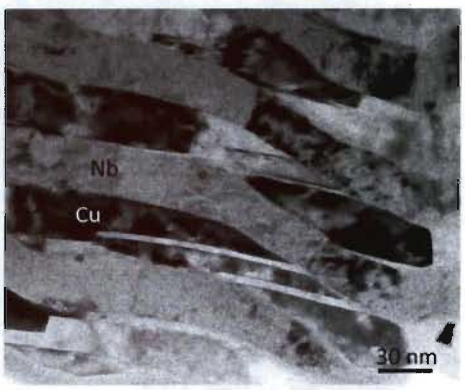
Slide 9

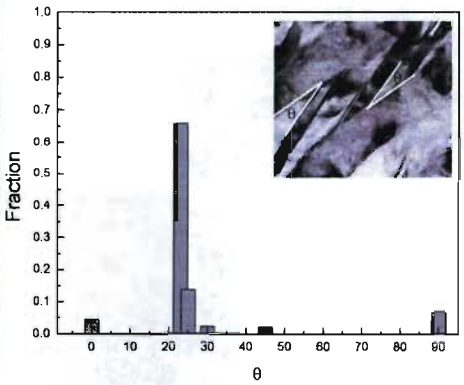
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## PVD Cu/Nb multilayer-Type II-Shocked




1. Deformation twins tend to have an angle with respect to the interface plane;
2. Deformation twinning is the main deformation model in Cu layer, while no deformation twins were found in Nb layer under shock loading.

Los Alamos NATIONAL LABORATORY EST. 1943

UNCLASSIFIED

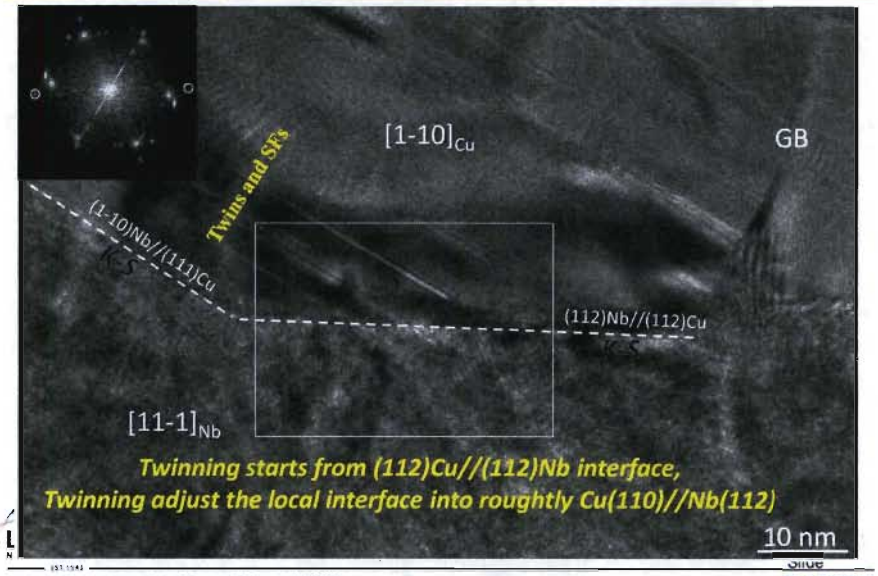
Slide 10

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## PVD Cu/Nb multilayer-Type II-Shocked

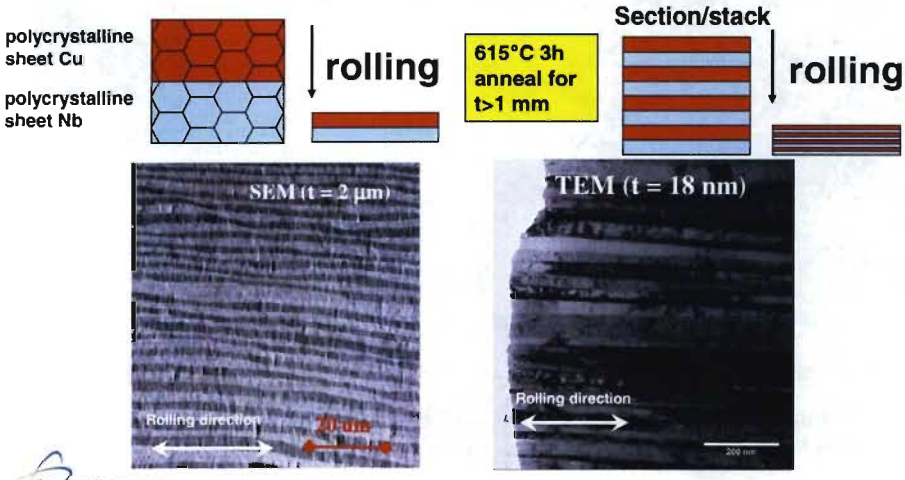



Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

## ARB Cu/Nb multilayer-SPD method prepared

*Accumulative rolling bonding (ARB) prepared Cu/Nb multilayers*




Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

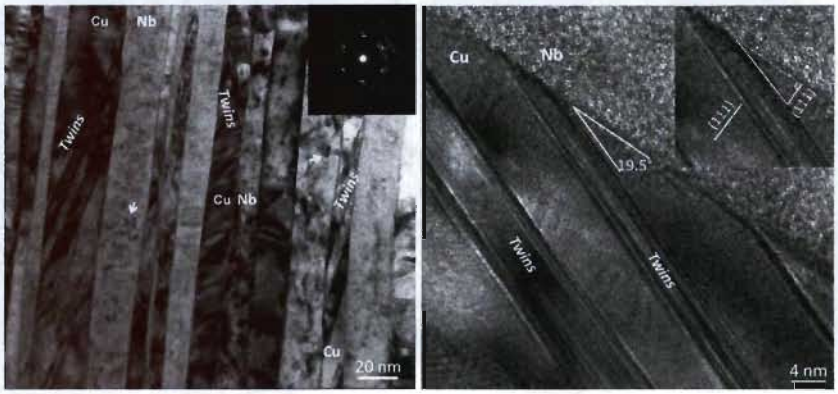
Slide 12

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

UNCLASSIFIED

## ARB Cu/Nb multilayer-Deformation twins

Once layer thickness down to <50 nm, deformation twins appear.




1. Deformation twins can be readily found in Cu layers;
2. The interface plane at Cu layer side is ~{112} plane.

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

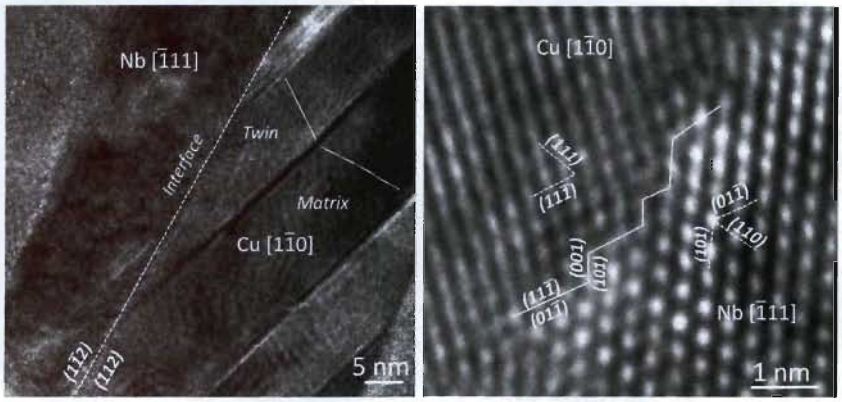
Slide 13

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## ARB Cu/Nb multilayer-Interface structures




1. Deformation twins initiate from Cu{112}//Nb{112} interface;
2. The initial interface structures has a facet feature with two to three atomic layer thick.

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

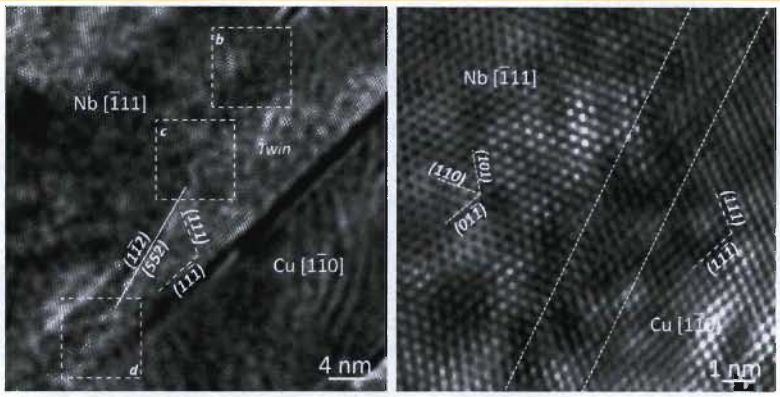
Slide 14

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## ARB Cu/Nb multilayer-Interface structures after twinning




Interface altered from Cu(112)//Nb(1-12) to Cu (552)//Nb(1-12)

Interface region disordered after twinning

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

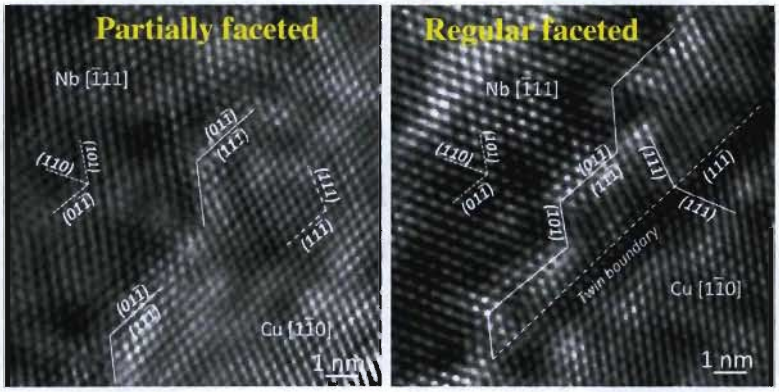
Slide 15

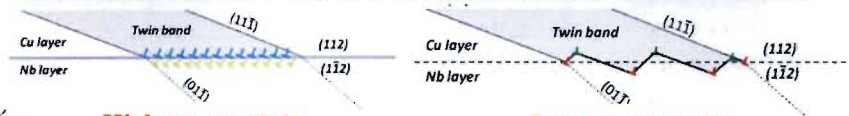
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA

UNCLASSIFIED

## ARB Cu/Nb multilayer-Interface structures after twinning




High energy state

Low energy state

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

Slide 16

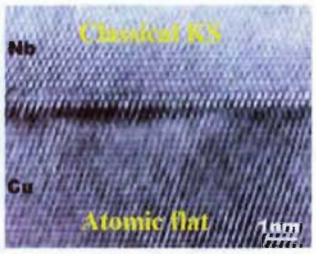
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

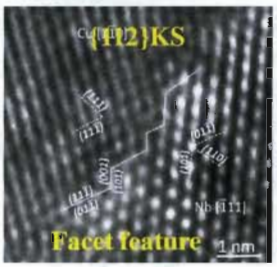
NNSA

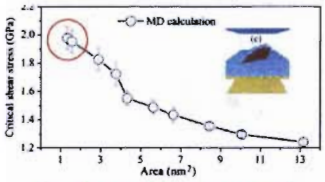
UNCLASSIFIED

## Why {112} K-S interface?

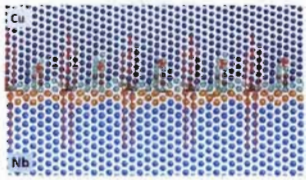
Local interface structures




Nucleation stress for partials




Interface dislocations

Los Alamos NATIONAL LABORATORY

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

R.F. Zhang et al. Scripta Mater-2011

Slide 17

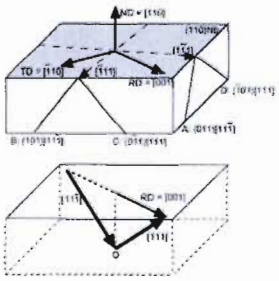
NNSA

UNCLASSIFIED

## Why {112} K-S interface?

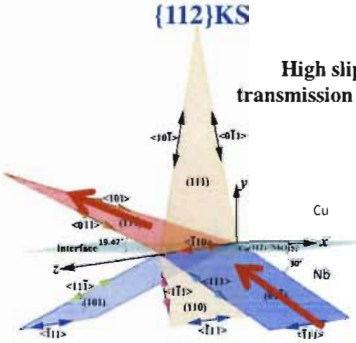
Special OR facilitate slip transmission

**Classical KS**




**{112}KS**

High slip transmission factor




**Symmetrical slip**
**Uniform deformation**

**Slip transmission**
**Shear localization**

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

Slide 18

NNSA

U.S. DEPARTMENT OF ENERGY
Office of Science

UNCLASSIFIED

## Summary

CMIME
Center for Material at Irradiation and Mechanical Extremes

1. Cu(112)//Nb(112) type interfaces are the favorite sites for nucleating deformation twins, instead of the classical KS orientation relationship interface Cu(111)//Nb(110);

2. Twinning can modify the interface plane and forming new local facet features via the evolution of residual dislocation configuration;

3. Both the interface local structures and the OR play a role in the deformation twinning process in Cu/Nb multilayers.

***Thanks for your attention!***

Los Alamos NATIONAL LABORATORY

UNCLASSIFIED

Slide 19

Operated by the Los Alamos National Security, LLC for the DOE/NNSA

NNSA