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*Title:* Role of interfaces in shock-induced plasticity in Cu/Nb nanolaminates

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# Shock compression of Cu/Nb nanolaminates and coarse-grained pure Cu and Nb

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(February 11, 2011)

We investigate deformation of Cu/Nb nanolaminates (synthesized via physical vapor deposition) and coarse-grained pure Cu and Nb induced by flyer plate impact. The peak pressure is about 6 GPa and the targets are soft-recovered with proper momentum traps. For the Cu/Nb nanolaminates, shock loading is applied normal or parallel to the layer interface to reveal possible anisotropy in deformation. The recovered samples are examined with transmission electron microscopy. For the shocked Cu/Nb nanolaminates, abundant deformation twins are found in the Cu layers, and only a small amount of stacking faults, in the Nb layers. For the shocked pure Cu and Nb, dislocations are widely observed besides deformation twins (in particular in Cu), and ultra-fine microstructures are induced in some regions likely due to shear localization. The shock deformation behaviors of Cu/Nb multilayers, pure Cu and Nb are compared, and possible mechanisms, discussed.

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# Role of interfaces in shock-induced plasticity in Cu/Nb nanolaminates

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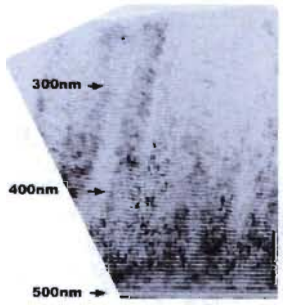
## Background—*Extraordinary properties of Cu/Nb multilayers*

### Radiation resistance[1]

No bubbles in He-implanted Cu-Nb



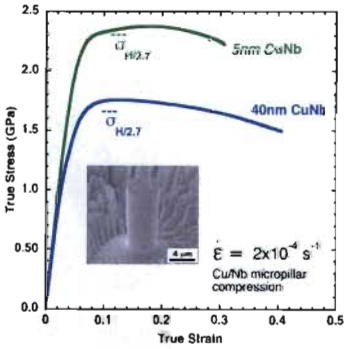

No amorphization or defect clusters after $10^{17}/cm^2$ 150keV He implantation

He solubility: ~8%at.

*[1]D. Bhattacharyya et al, unpublished*

### High strength and good ductility[2]

Nanopillar compression test




*[2]N. A. Mara et al, ARL,92:231901 (2008)*

**Interfaces play a critical role!!!**

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## Motivation—*explore the role of interface under extreme loading*

***Extensively investigation on the shock response of solids at micron or submicro scales. In contrast, few shock studies on nanocrystalline metals in general and on nanolaminates in particular.***

1. **Explore the stability of heterogeneous phase interfaces under extreme loading conditions;**
2. **Investigate the role of interfaces on the plastic deformation mechanism of Cu/Nb multilayers under extreme loading conditions.**

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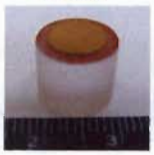
## Experimental design—gas gun shock experiment

**Gas gun setup**

**Sabot**



**Sample holder**

**Materials**

*PVD Cu/Nb nanolaminate*
*30 nm layer thickness; 60 μm total thickness*
*Pure Cu and Nb for comparison*

**Shock condition**

*In plane shock and normal plane shock*
*Maximum shock pressure ~6 GPa*
*Samples were shock recovered*

**Microstructure characterization**

*SEM, EBSD, TEM, HRTEM*

*Shocked flyer plate*

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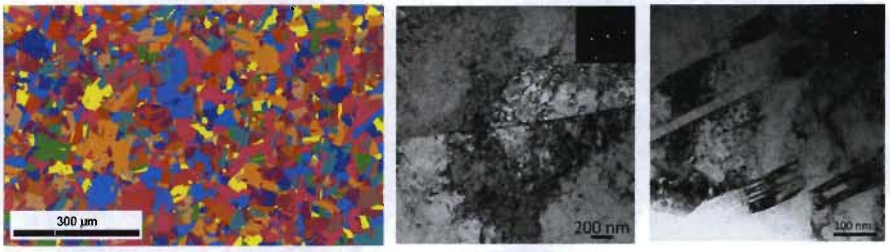
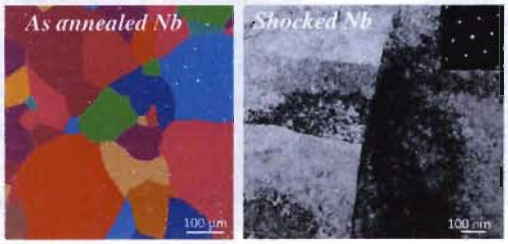
## Results and discussion--shocked pure Cu and Nb

*As annealed Cu* | *Shocked Cu*




**Dense dislocation activities in both shock pure Cu and Nb**

**Few deformation twin in shocked Cu due to low shock pressure**

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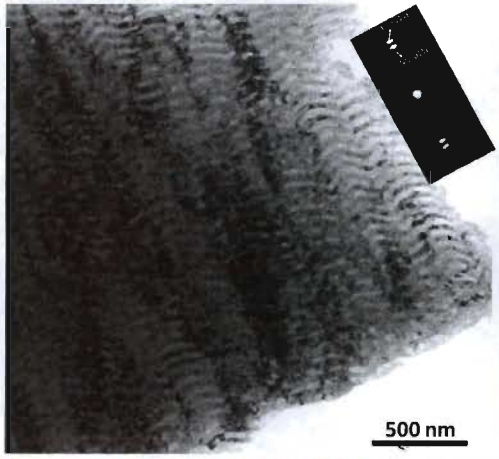
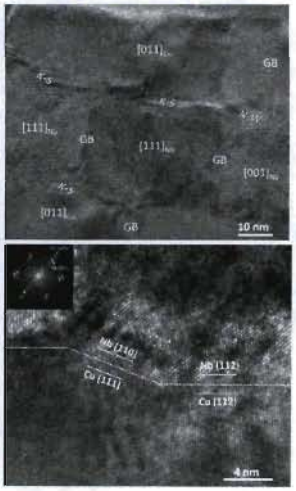
## Results and discussion--as deposited Cu/Nb nanolaminates

**As deposited Cu/Nb nanolaminate**




***Kurdjumov-Sachs is the dominant one***




**Interface plane (111)Cu//(110)Nb or (112)Cu//(112)Nb or Other types**

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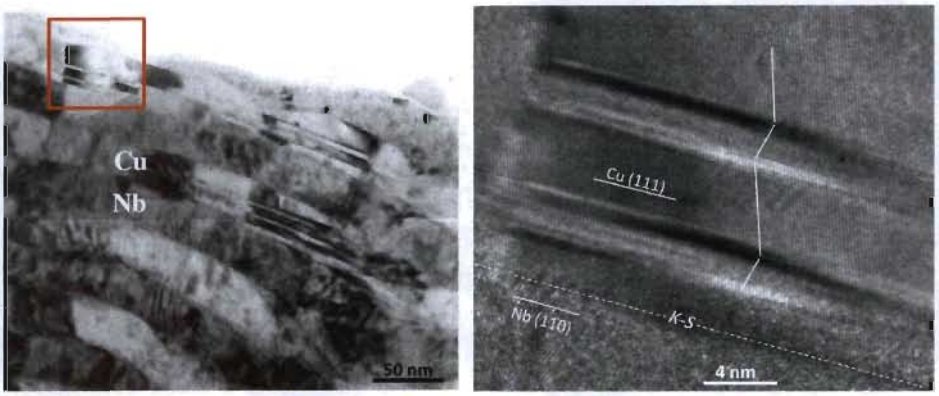
## Results and discussion--as deposited Cu/Nb nanolaminates

*Few growth twins can be found in random locations*




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

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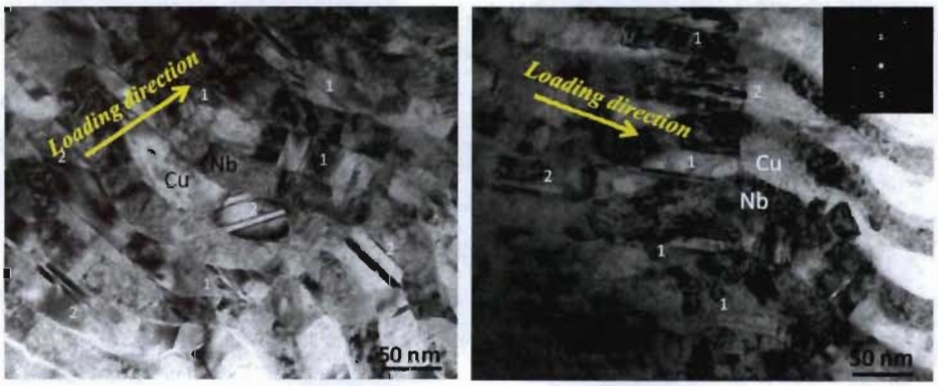
## Results and discussion--shocked Cu/Nb nanolaminates

*Normal shock* | *In plane shock*




**No obvious microstructure differences were found for normal shock and in plane shock**

**Profuse deformation twin—shocked multilayer *VS* few deformation twins–shocked Cu**

**interface splay critical role**

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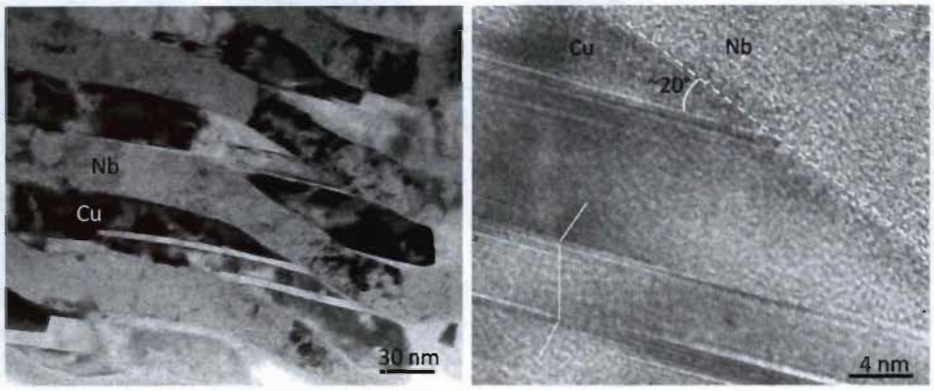
## Results and discussion--deformation twinning

**Twinning plane VS the interface plane**




The interacting angle between <111> and <112> could be ~20°.

About 70% of deformation twins interacting 20° with respect to the interface plane

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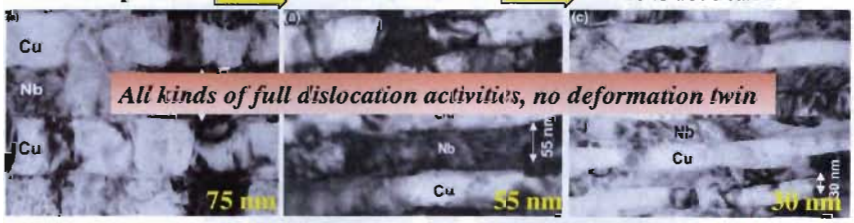
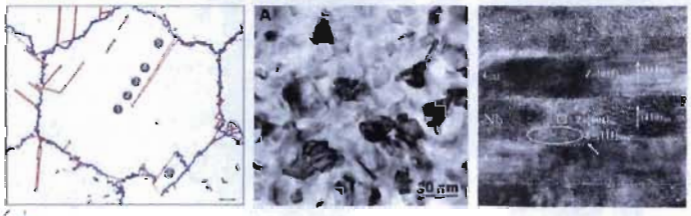
## Results and discussion--deformation in PVD Cu/Nb nanolaminates

*Deformation mechanism of PVD Cu/Nb under rolling, nanoindentation, compression test etc.*

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




*All kinds of full dislocation activities, no deformation twin*




Kurdjumov-Sachs

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

Interface plane type

(111)Cu//(110)Nb

*Misra A et al.Acta Mater-2004-52-2387*
*Yamakov et al. Nature Mater. 2002-1-65*
*Chen MW et al. Science-2003-300-1275*
*Zhang K et al., Philoso Mag 2008-88-2559*

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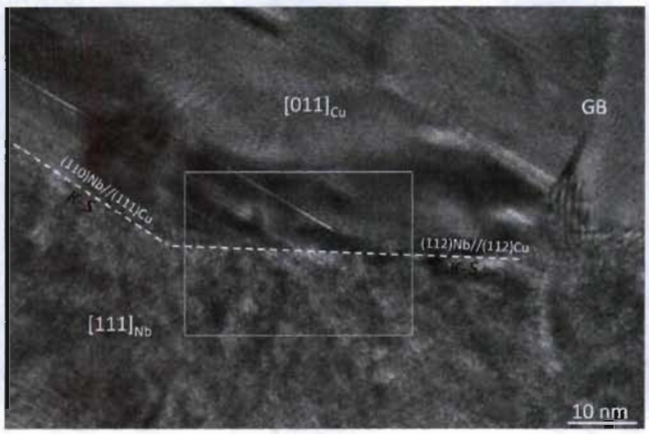
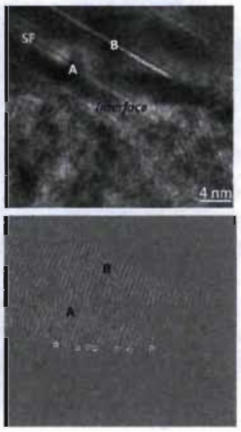
## Results and discussion—interface structures

*HRTEM of the PVD Cu/Nb interface*




*Interface defects*




Twinning starts from (112)Cu//(112)Nb interface, and alter the interface from (112)Cu//(112)Nb to roughly (110)Cu//(112)Nb

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## Summary

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1. Comparison study on the shocked pure Cu, pure Nb and Cu/Nb nanolaminates demonstrate that interfaces plays a critical role on the plastic deformation mechanism of the multilayer;

2. Cu(112)//Nb(112) type interfaces are the favorite sites for deformation twins nucleation, in contrast to the classical KS orientation relationship interface Cu(111)//Nb(110). In addition, the high strain rate of the shock loading also promote the twinning nucleation in Cu and Cu/Nb multilayer

***Thanks for your attention!***

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