Microstructure and mechanical properties of multilayered Al/Pd thin films

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Motivation and Goal

- Nanolayered materials composed of dissimilar metals are known to exhibit enhanced mechanical properties compared to those of constituent metals, but the exact mechanism(s) of strengthening are not yet fully understood.
- Knowledge of the exact strengthening mechanism(s) may play a vital role in designing future smart composite materials with desired mechanical properties.
- Here, in an attempt to study the possibility of mechanical properties enhancement of Al-based multilayered composites, the hardness and elastic modulus of nanolayered **aluminium/palladium (Al/Pd)** thin films were investigated using **nanoindentation**.
- To understand the strengthening mechanism(s) Al/Pd samples were further examined using q-**2**q **X-ray diffraction (XRD) and cross-sectional transmission electron microscopy (XTEM)** techniques.

Why Nanolayered Al and Pd?

According to Koehler[a], epitaxial multilayers of two different metals A and B can show very high strength if:

- Their lattice parameters, at the operating temperature, are nearly equal

  (Both **Al** and **Pd** possess face-centered cubic (fcc) crystal structure with lattice parameters of 4.0496 Å and 3.8818 Å, respectively, at room temperature)
- Their elastic constants differ by as much as possible

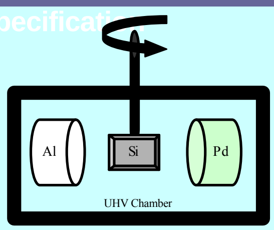
  (**Al**: c_{11} = 114.0, c_{12} = 65.3, c_{44} = 28.5 GPa)

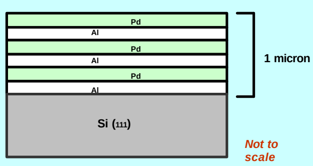
  (**Pd**: c_{11} = 227.1, c_{12} = 176.04, c_{44} = 71.73 GPa)
- The thickness of the A and B layers are of the order of 100 atomic layers or less

  (This suggests that **Al** and **Pd** layers should be 40 nm thick or less)

[a] J. S. Koehler: Phy. Rev. B, Vol. 2, No. 2, 1970, 547-551

Material Fabrication and Samples Specification





Not to scale

- Thin film specimens consisting of alternate nano-layers of Al and Pd on Si(111) wafer substrate were deposited at room temperature by DC magnetron sputtering in Ultra-High-Vacuum (UHV) condition.
- **Multilayer films-Set I: Al layer thickness = Pd layer thickness**

  Al layer = Pd layer = 1 nm to 40 nm (Bilayer thickness* = 2 nm to 80 nm)

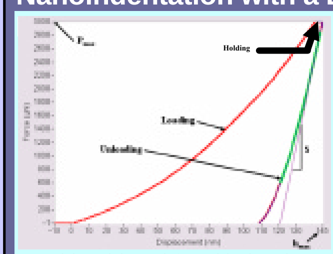
  Multilayer films-Set II: Al layer thickness » Pd layer thickness

  Al layer = 27 ± 2 nm; Pd layer = 2 nm to 10 nm (Bilayer thickness* = 33 ± 2 nm)

  Monolayer films: Al ~ 1mm and Pd ~ 1mm

* Bilayer thickness = Al layer thickness + Pd layer thickness

Nanoindentation with a Berkovich



A typical Force-Displacement plot from nanoindentation experiment

Modulus (E) and Hardness (H) measurement by nanoindentation using "Oliver and Pharr" method[b]:

$$h_c = h_{max} - 0.75\frac{P_{max}}{S}$$

$$H = \frac{P_{max}}{A(h_c)}$$

$$E = \frac{\sqrt{p}}{2\sqrt{A(h_c)}}S$$

h_c = Contact depth
S = Stiffness
$A(h_c)$ = Tip area function

[b] W. C. Oliver and G. M. Pharr: J. Mater. Res., Vol. 7, No. 6, 1992, 1564-1583

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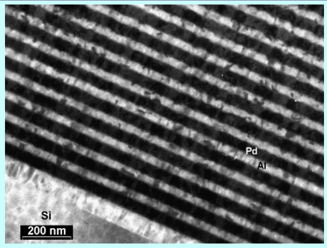
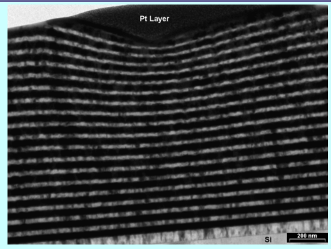
XTEM Results

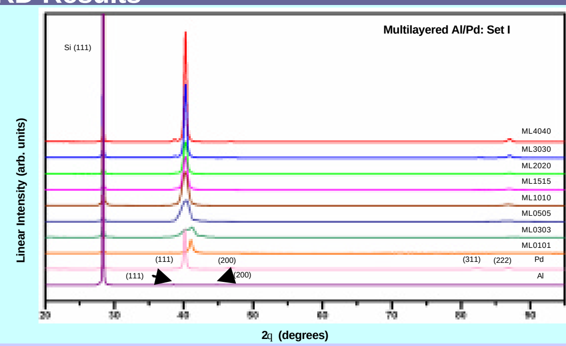


XTEM image of a nanolayered Al/Pd sample from Set I with individual layer thickness of 40 nm showing sharp Al-Pd interfaces

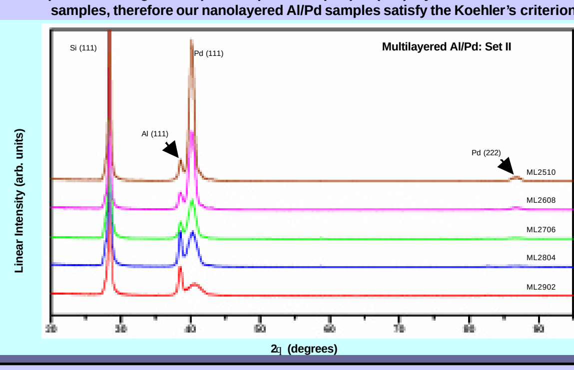


XTEM image of an indent showing bending of layers (Al = Pd = 30 nm); No sign of shearing or fracture of layers was observed

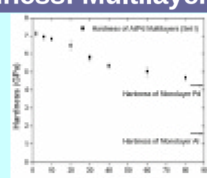
XRD Results



XRD spectra showing almost perfect epitaxial Al(111)/Pd(111) crystal structure for both sets of samples, therefore our nanolayered Al/Pd samples satisfy the Koehler's criterion

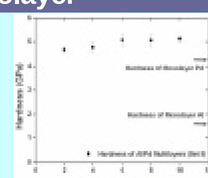


Hardness: Multilayer Vs Monolayer



Set I: Al layer thickness = Pd layer thickness

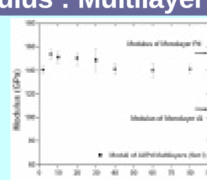
By combining 50% (v/v) Pd with Al, hardness can be increased by ~350% compare to hardness of pure Al film



Set II: Al layer thickness » Pd layer thickness

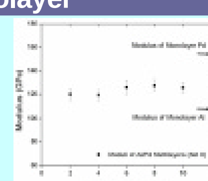
By combining just 6.5% (v/v) Pd with Al, hardness can be increased by ~200% compare to hardness of pure Al film

Modulus : Multilayer Vs Monolayer



Set I: Al layer thickness = Pd layer thickness

Modulus enhancement observed



Set II: Al layer thickness » Pd layer thickness

Less modulus enhancement observed