Mechanical Properties of Nanolayered Al/Pd Thin Films Using Nanoindentation

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Motivation and Goal

- Synthetic nanolayered materials are known to exhibit enhanced mechanical properties compared to those of individual constituent monolayer films, but the exact mechanism(s) of strengthening at the smallest length scale are not yet fully understood.
- Knowledge of the exact strengthening mechanism(s) may play a vital role in designing future smart materials with desired mechanical properties.
- In the present work, in an attempt to understand the strengthening mechanism(s), we are trying to establish a relationship between the mechanical properties and the parameters associated with nanolayered **Aluminium/Palladium (Al/Pd)** thin films.
- The objective of our work is to enhance the mechanical properties of Al-based light-metal alloys.

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

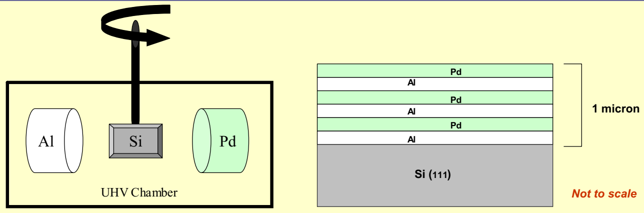
  (**Al**: c_{11} = 114.0, c_{12} = 65.3, c_{44} = 28.5 GPa)

  (**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



- Thin film specimens consisting of alternate nano-layers of Al and Pd on Si(111) wafer substrate were deposited at room temperature by magnetron sputtering in Ultra-High-Vacuum (UHV) condition
- Alternate layers of Al and Pd were deposited by rotating substrate to face the Al and Pd targets sequentially
- Individual layer thickness was controlled by controlling magnetron power and deposition time
- Total film thickness for all the samples was ~ 1 micron

Samples Specification

- **Multilayer films:**

  Set 1: Al layer thickness = Pd layer thickness

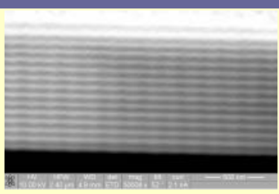
  Al layer = Pd layer = 1 nm to 40 nm

  (Bilayer thickness* = 2 nm to 80 nm)

  Set 2: Al layer thickness » Pd layer thickness

  Al layer = 27 ± 2 nm; Pd layer = 2 nm to 10 nm

  (Bilayer thickness* = 33 ± 2 nm)



FIB[#] cross-sectioned micrograph of nanolayered Al/Pd (Al Layer = Pd Layer = 40 nm; No. of Bilayers = 15)

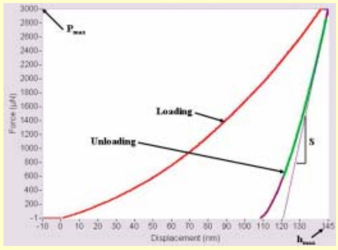
Total number of bilayers were varied to achieve the total film thickness of ~ 1 μm

- **Monolayer films:** Al ~ 1μm and Pd ~ 1μm

* Bilayer thickness = Al layer thickness + Pd layer thickness

[#] Focussed Ion Beam (FIB)

Nanoindentation with a Berkovich Indenter



A typical Force-Displacement plot from nanoindentation experiment

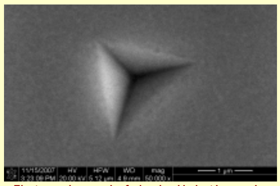
Modulus (E) and Hardness (H) measurement by nanoindentation using "Oliver and Pharr" method[b]:

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

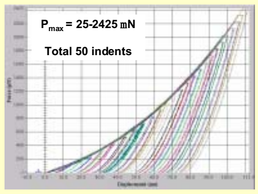
$$H = \frac{P_{max}}{A(h_c)}$$

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

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



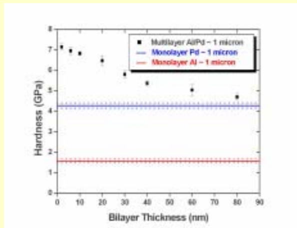
Electron micrograph of a low load indent impression



A typical set of Force-Displacement plots from nanoindentation experiment

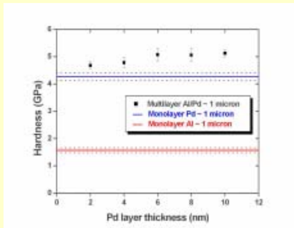
[b] W. C. Oliver and G. M. Pharr: J. Mater. Res., Vol. 7, No. 6, 1992, 1564-1583

Hardness: Multilayer Vs Monolayer



Set 1: Al layer thickness = Pd layer thickness

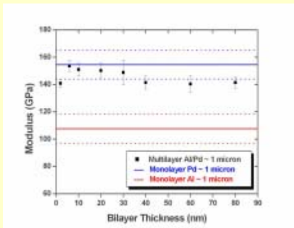
By combining 50% (v/v) Pd with Al, hardness can be increased by ~350% compare to hardness of pure Al film



Set 2: Al layer thickness » Pd layer thickness

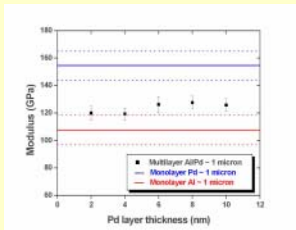
By combining just 6.5% (v/v) Pd with Al, hardness can be increased by ~200% compare to hardness of pure Al film

Modulus : Multilayer Vs Monolayer



Set 1: Al layer thickness = Pd layer thickness

Modulus enhancement observed



Set 2: Al layer thickness » Pd layer thickness

No modulus enhancement observed

Al/Pd Vs Other Al-based Multilayer Systems

Al-based multilayer systems	Maximum hardness achieved so far (GPa)	References
Al/Al_3Sc	2.95 ± 0.23	c
Al/SiC	2.4 ± 0.3	d
Al/Pd	**7.14 ± 0.16**	**Present work**

[c] M. A. Phillips *et al.*, Acta Mat., 51 (2003), 3171-3184
[d] Xin Deng *et. al.*, Adv. Eng. Mat., 7, No. 12, (2005), 1099-1108

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