Optical and Mechanical Properties of Thin Film Metallic Glasses

金屬玻璃鍍膜之光學與機械性質

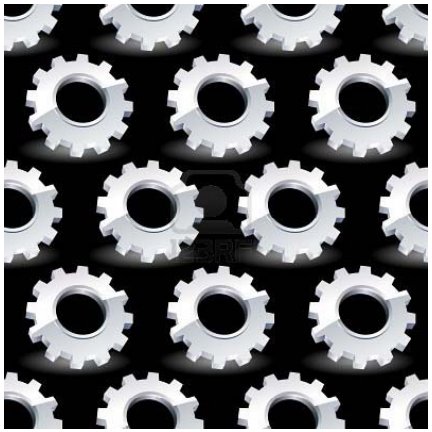
Student: Tina Hu
Advisor: Prof. J. C. Huang

Department of Materials and Optoelectronic Science,
National Sun Yat-Sen University

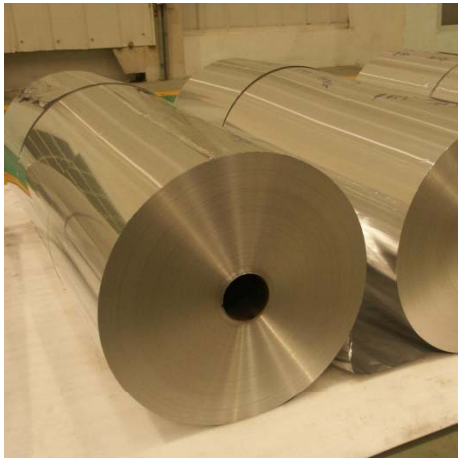
Aluminum applications

wheel

building

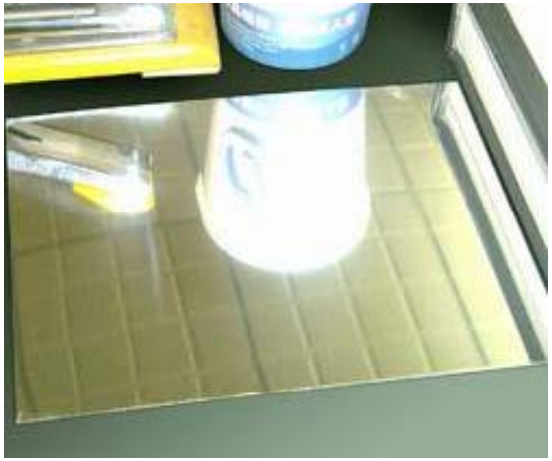


gear



foil

beverage can



high reflection sheet

High reflection Aluminum sheets

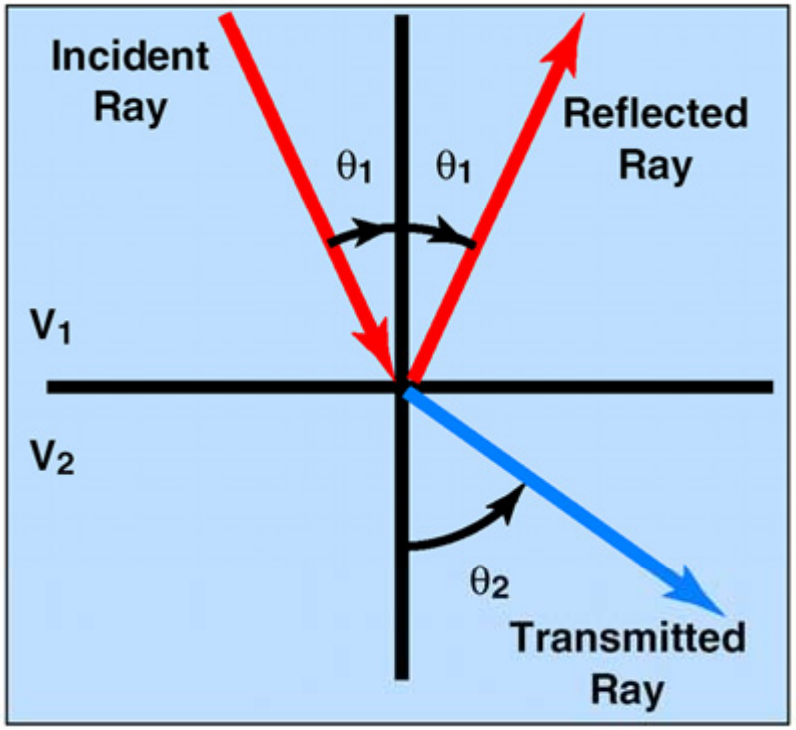
- **Polishing process**

  The difficulties in polishing to mirror level still need to be overcome.

- **Sputtering process**

  Due to the weakness of corrosion resistance, the additional process such as anodic treatment has to be done for protecting the surface.

The rule of reflection and the Snell's law

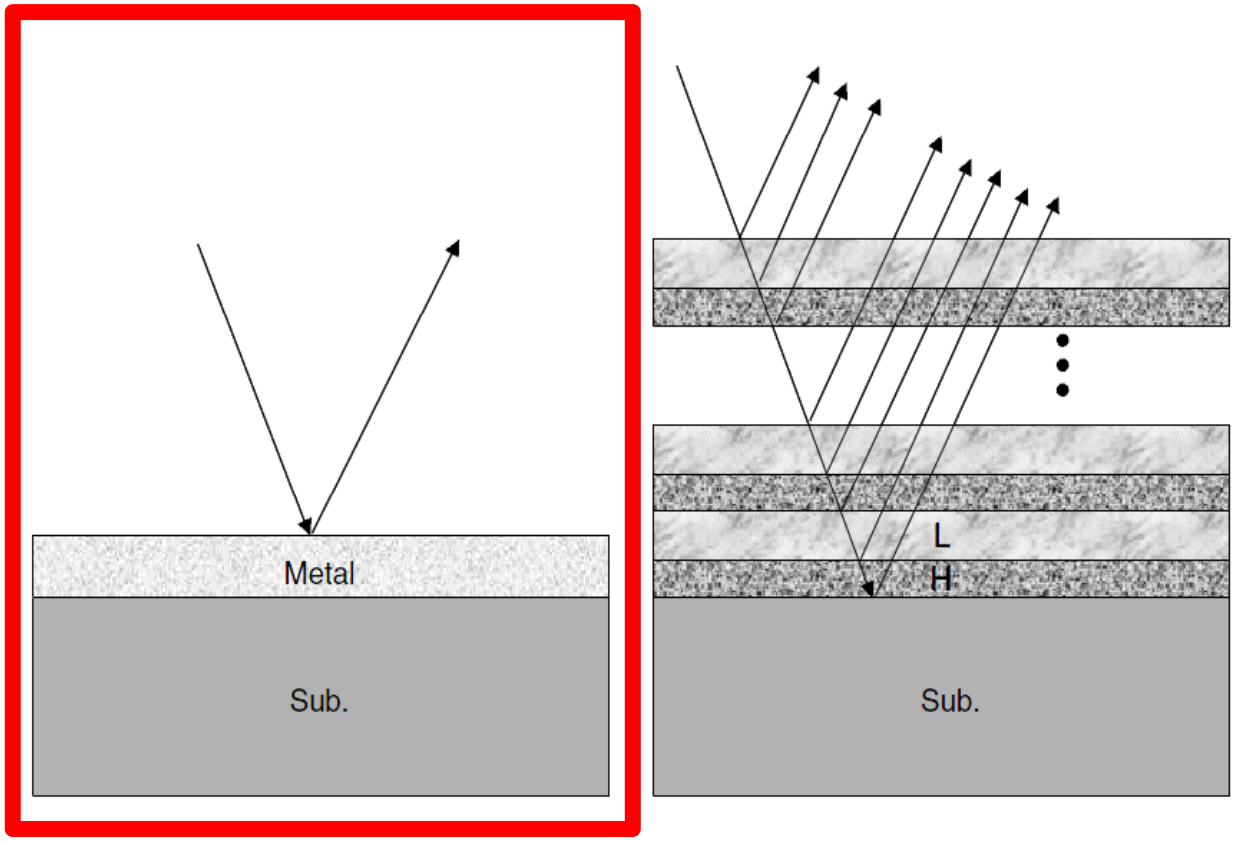


$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

θ: the angle between light and the normal
***v*: speed of light in medium**
n: refractive index

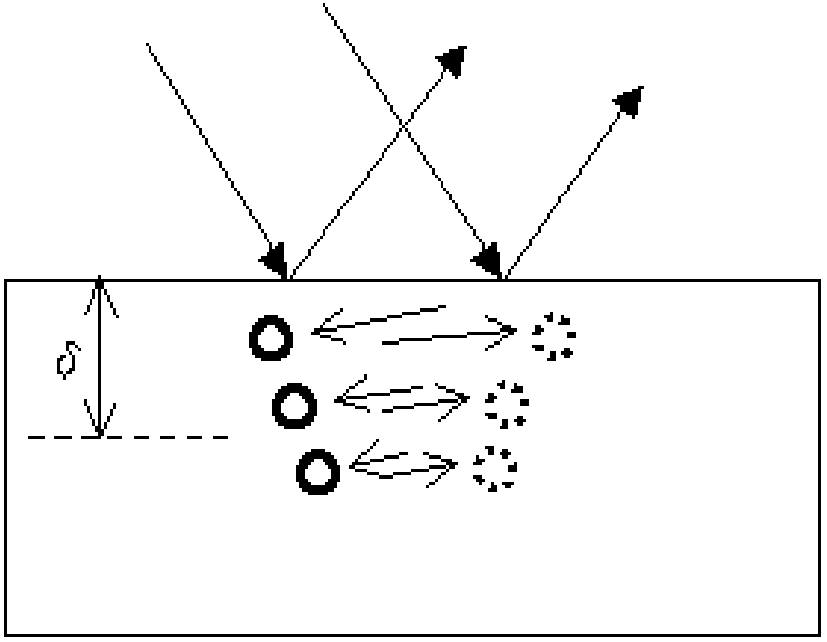
D.J. Struik, Snell, Willebrord, American Council of Learned Societies, New York, (1975).

High reflection coating



M. Yang, A. Gatto, N. Kaiser, J. Opt. A: Pure Appl. Opt., 8 (2006) 327-332.

Skin effect



$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$

ρ: electrical resistivity
ω: angular frequency
μ: permeability

A.K. Azad, W. Zhang, Optics Letters, 30 (2005) 2945-2947.

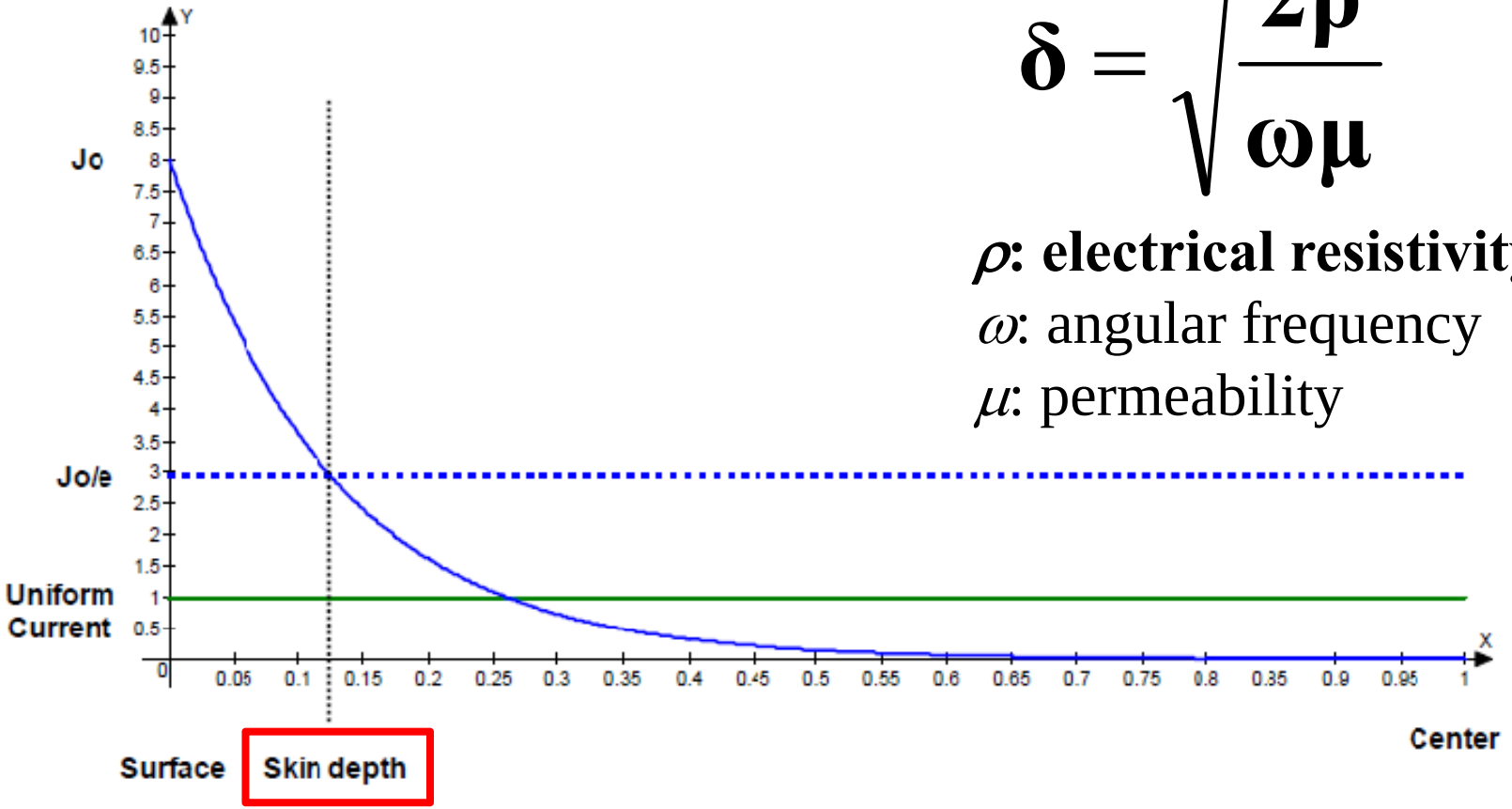
Skin depth

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}$$

ρ: electrical resistivity

ω: angular frequency

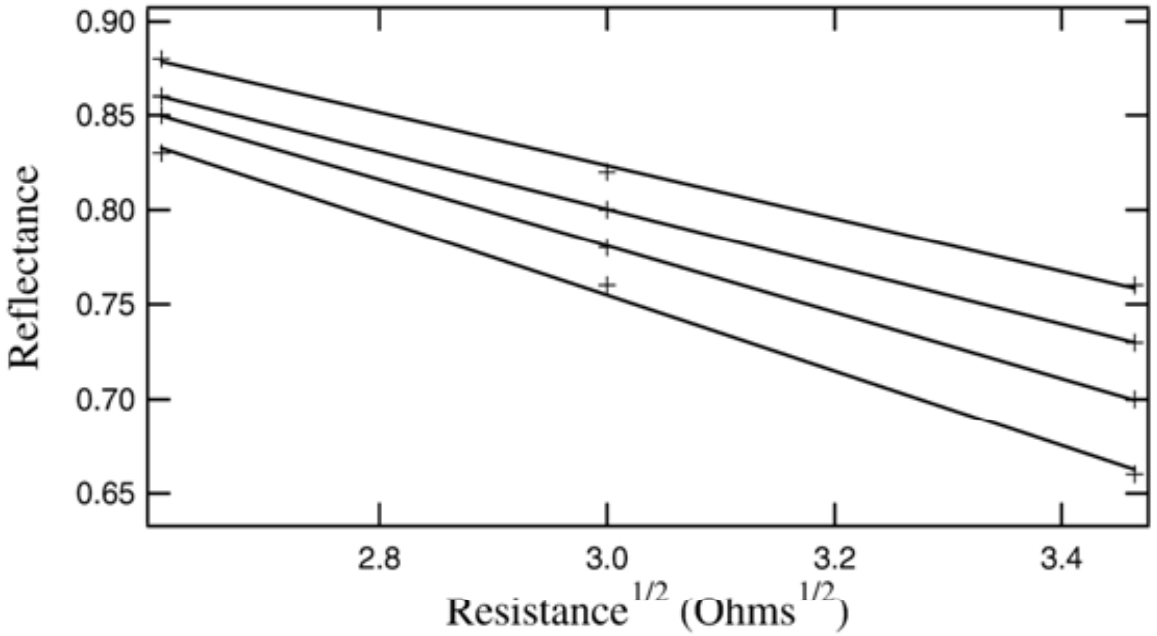
μ: permeability



D. Brooks, Ultracad Design, Inc. (2009).

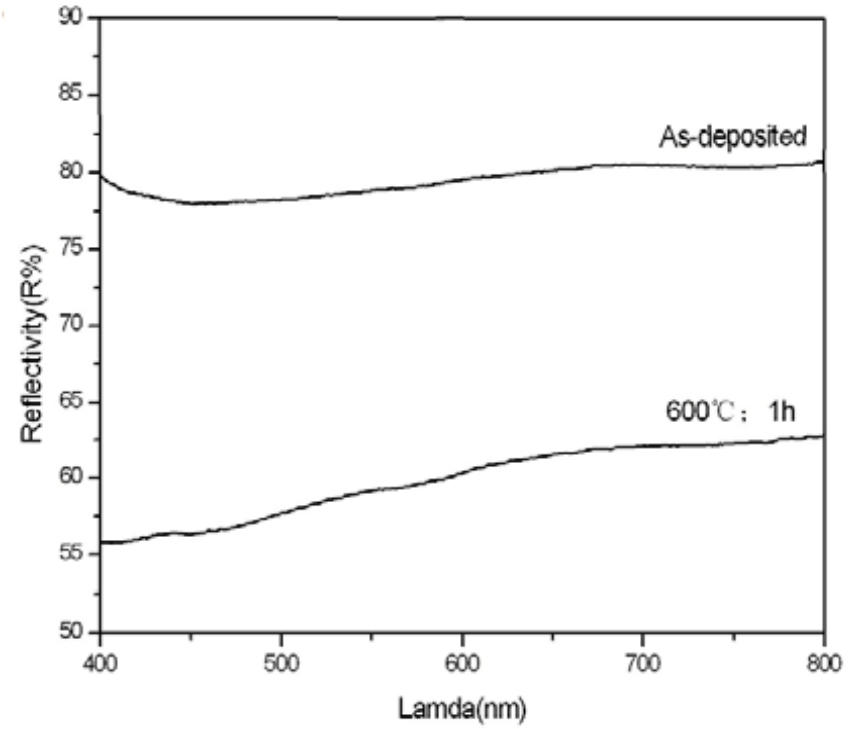
Correlation between reflectance and resistance

$$R \propto \frac{1}{\delta} \propto \frac{1}{\sqrt{\rho}}$$

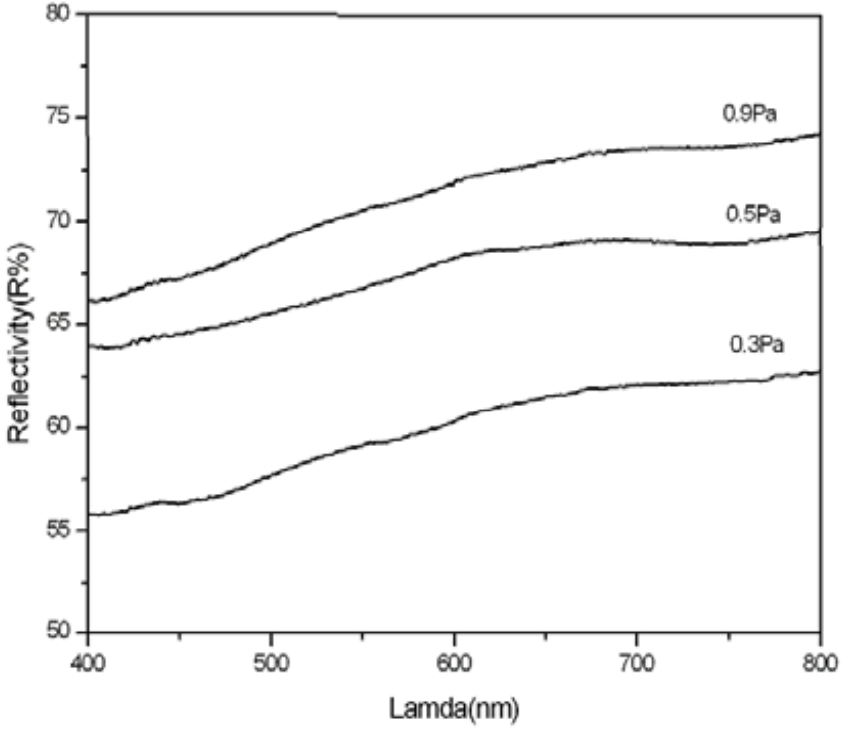


H.B. Scott, F. Stefan, Journal of Alloys and Compounds, 338 (2002) 73-79.

Reflectivity vs. temperature

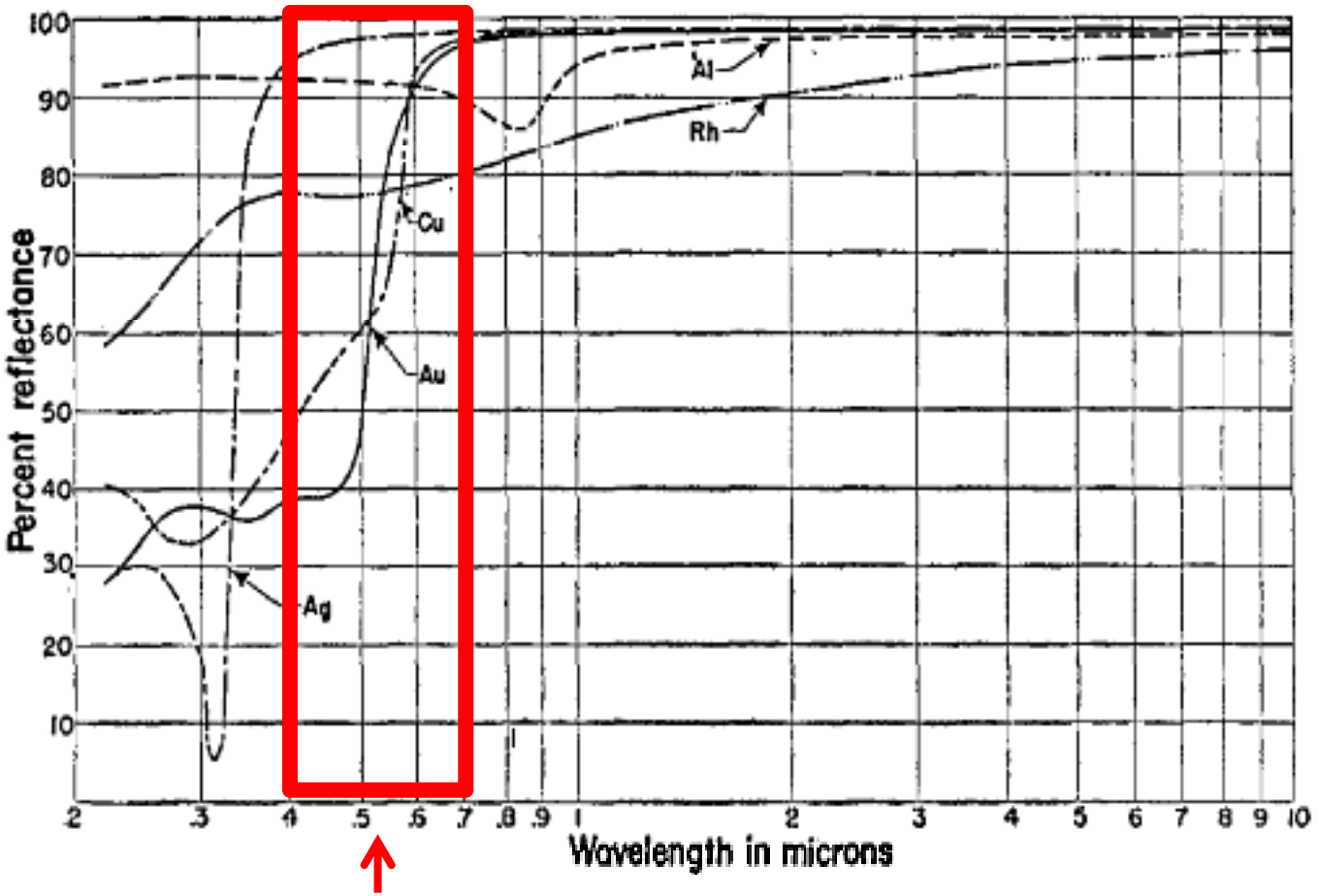


Reflectivity vs. sputtering pressure (working pressure)



W. Chao, H.E. Cuiqun, M. Xiangshui, http://www.paper.edu.cn, (2011).

Reflectance vs. wavelength



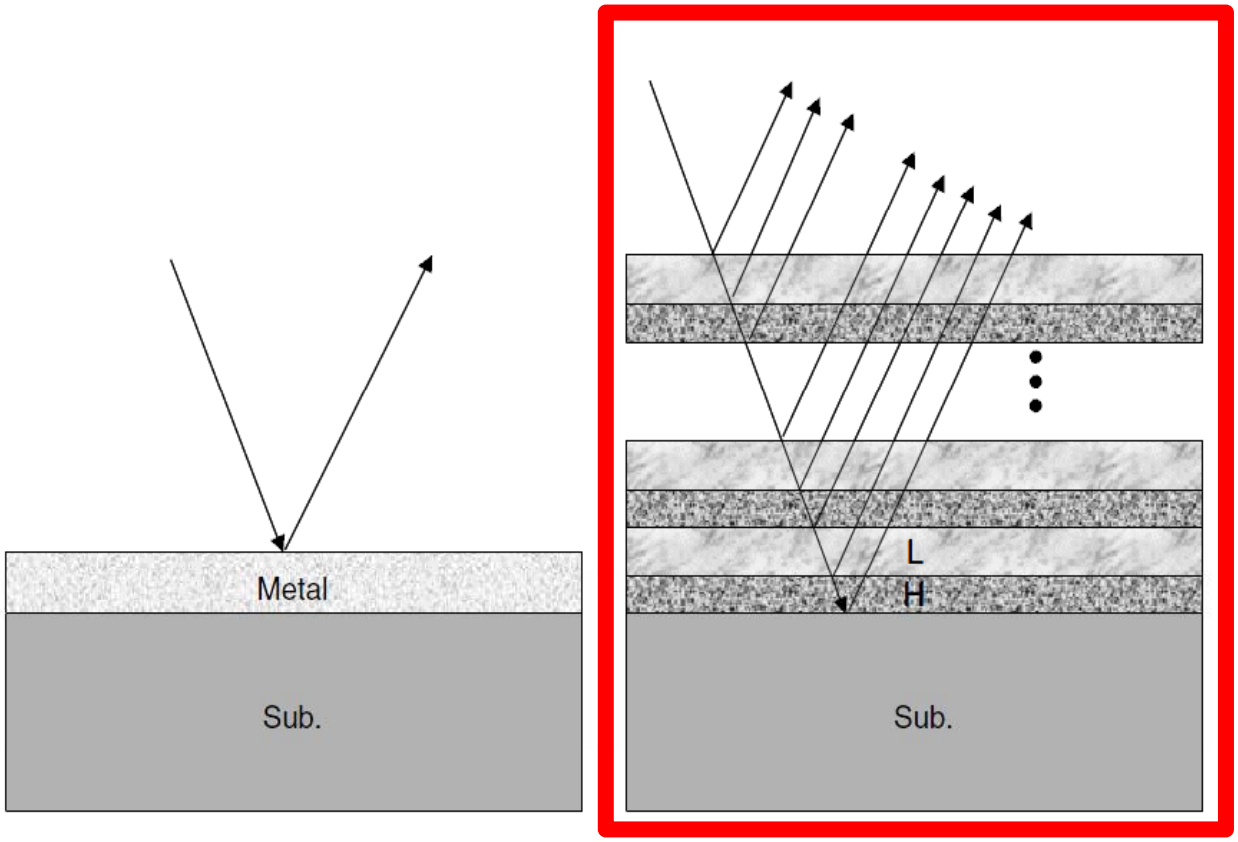
Visible spectrum

G. Hass, Journal of the Optical Society of America, 45 (1955) 945-952.

Metals	700 nm reflectivity	550 nm reflectivity	400 nm reflectivity
Al	0.90	0.92	0.93
Ag	0.97	0.96	0.97
Au	0.96	0.84	0.39
Cu	0.95	0.64	0.51

http://refractiveindex.info/

High reflection coating



H: high refractive index

L: low refractive index

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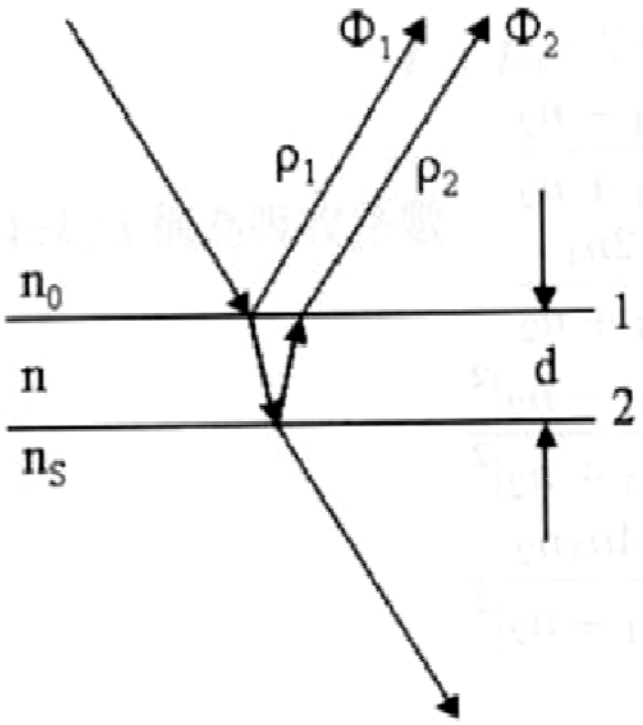
Interference



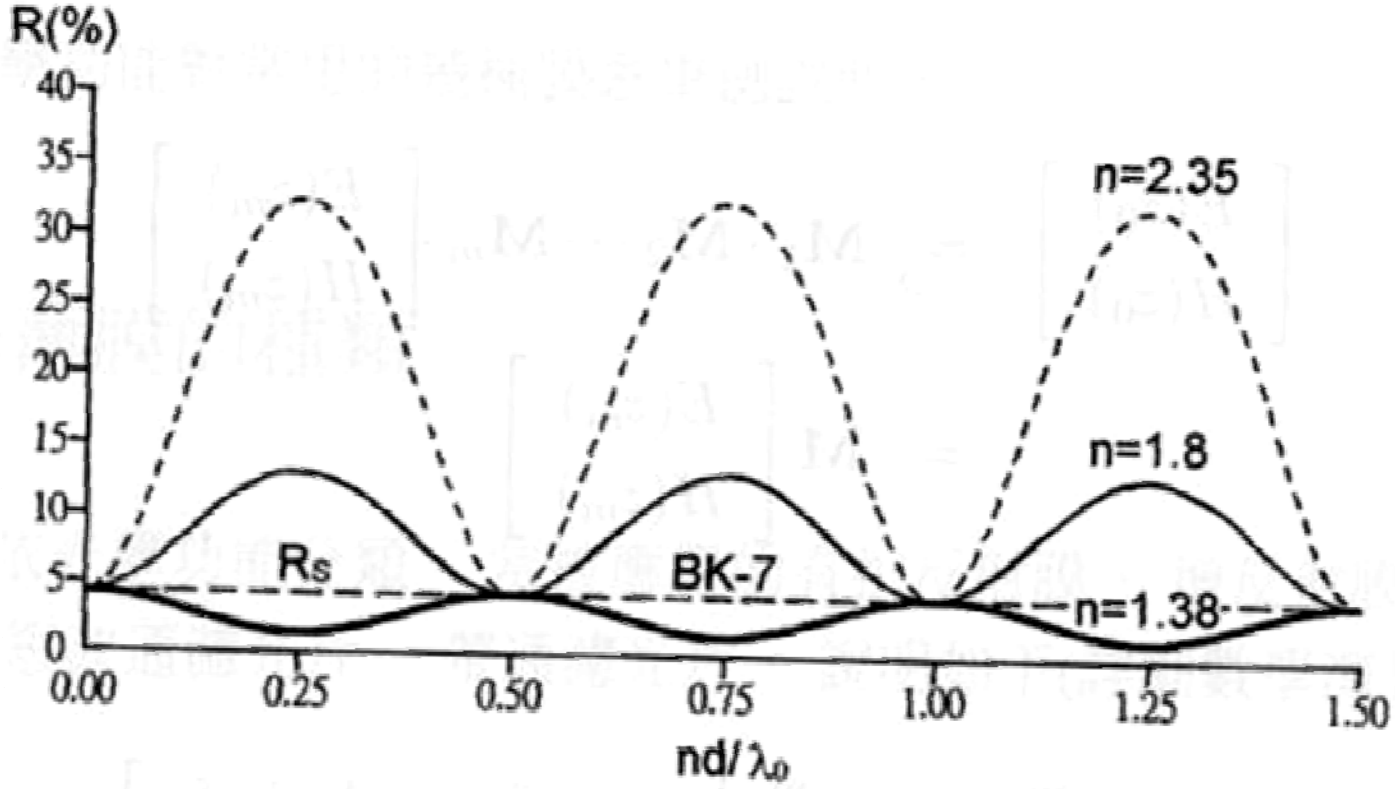
$$nd = \frac{\lambda}{4}$$

Constructive interference

λ: wavelength
n: refractive index
d: film thickness

李正中， 薄膜光學與鍍膜技術， 藝軒， 台北, (2006).

Interference



$n_{BK-7} = 1.52$

$n > n_s$: constructive interference → improving reflection

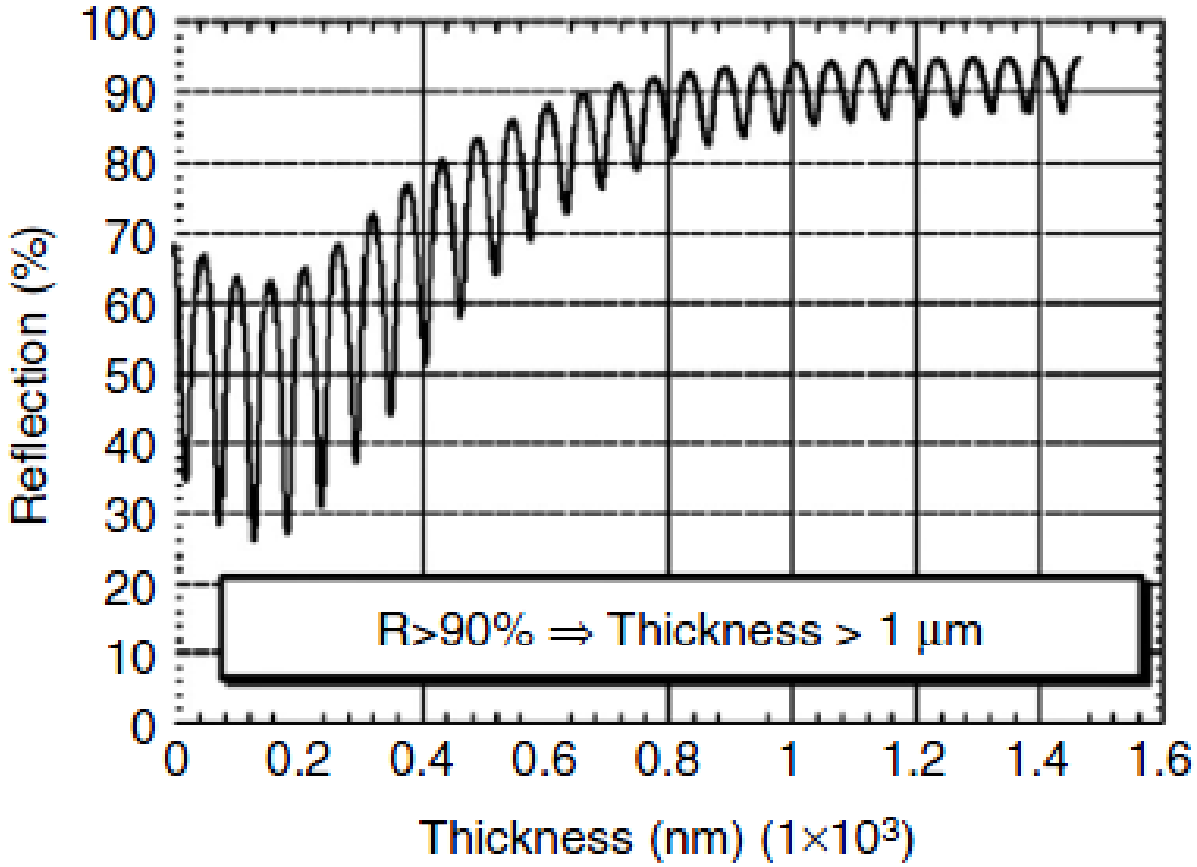
$n < n_s$: destructive interference → anti-reflection

李正中，薄膜光學與鍍膜技術，藝軒，台北, (2006).

Dielectric films	700 nm refractive index	650 nm refractive index	500 nm refractive index
TiO_2	2.4907	2.4929	2.5045
Al_2O_3	1.7630	1.7655	1.7747
SiO_2	1.5404	1.5421	1.5488
MgF_2	1.3759	1.3767	1.3798

http://refractiveindex.info/

Dielectric multilayered system



M. Yang, A. Gatto, N. Kaiser, J. Opt. A: Pure Appl. Opt., 8 (2006) 327-332.

Motivation

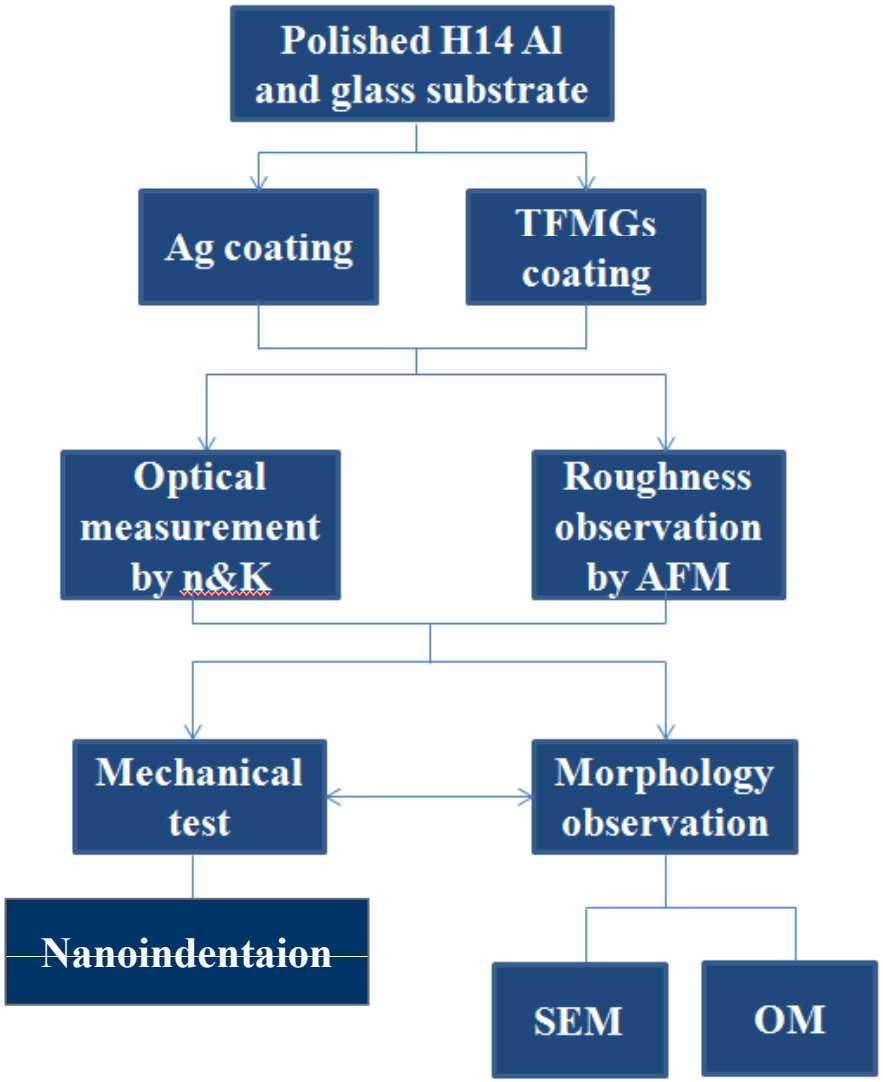
- **The treatment of Al sheet**

  The various thin film systems will be deposited on the surface of Al sheet to improve the optical and mechanical properties.

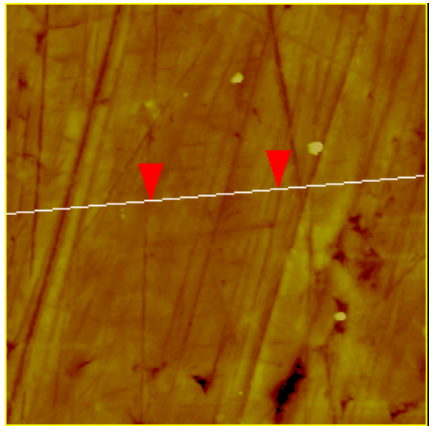
- **The enhancement of reflectivity by sputtering thin film metallic glasses (TFMGs)**

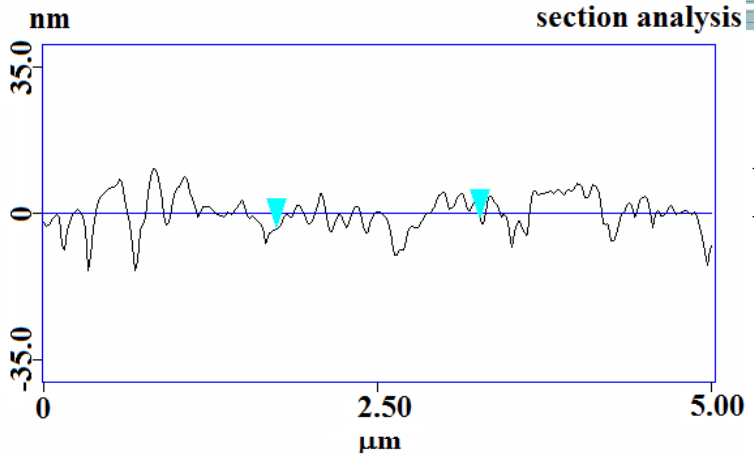
  The probability of TFMGs applied in optical field will be investigated in this study.

Flow chart


Polished H14 Al and glass substrate
Ag coating
TFMGs coating
Optical measurement by n&K
Roughness observation by AFM
Mechanical test
Morphology observation
Nanoindentaion
SEM
OM

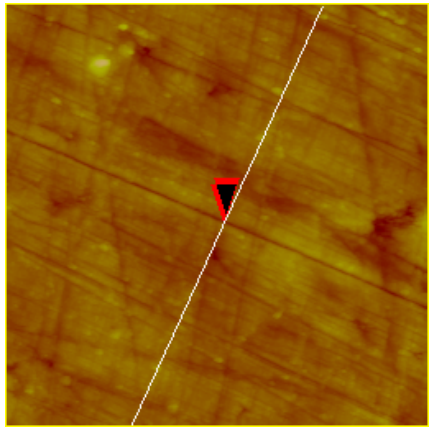
Ra: average roughness

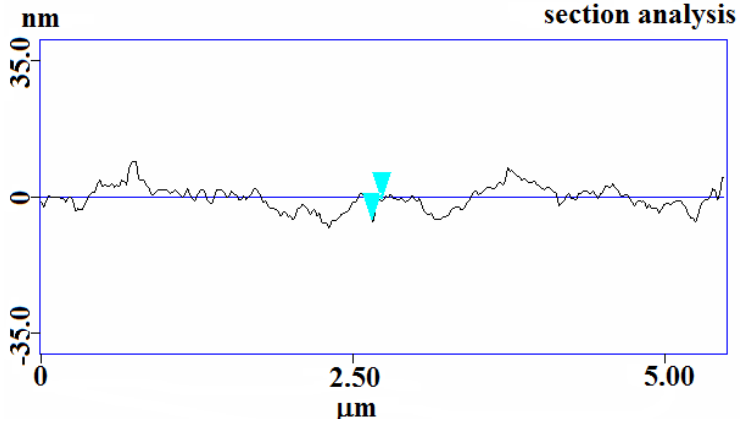




Rough polishing

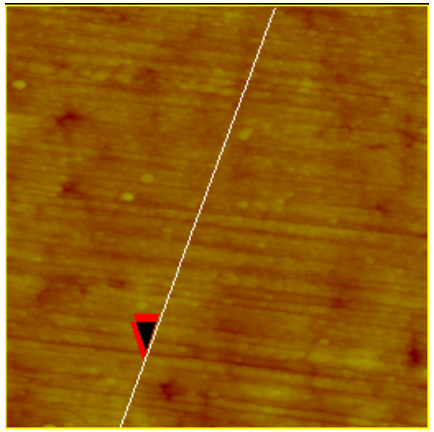
Ra = 2.5 nm

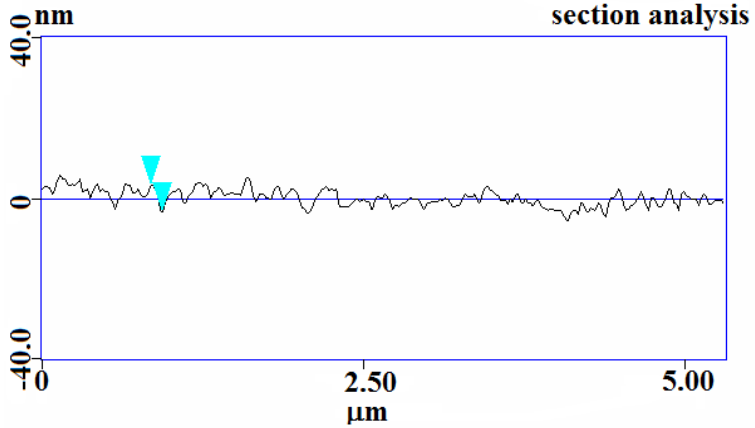




Fine polishing

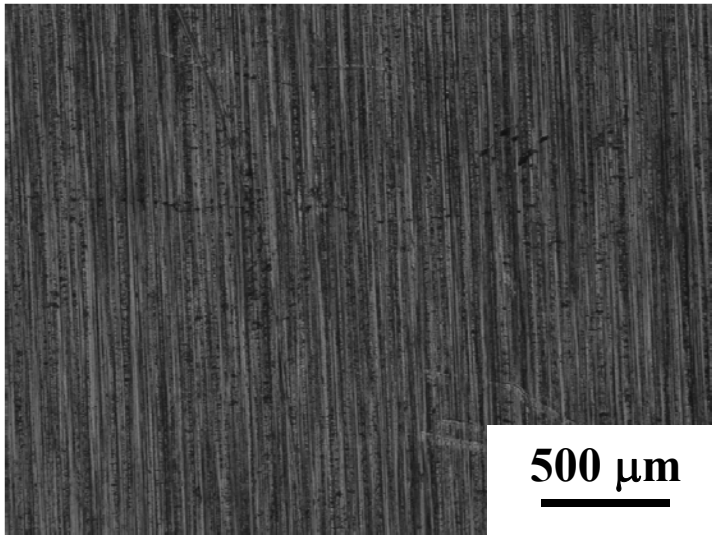
Ra = 0.9 nm



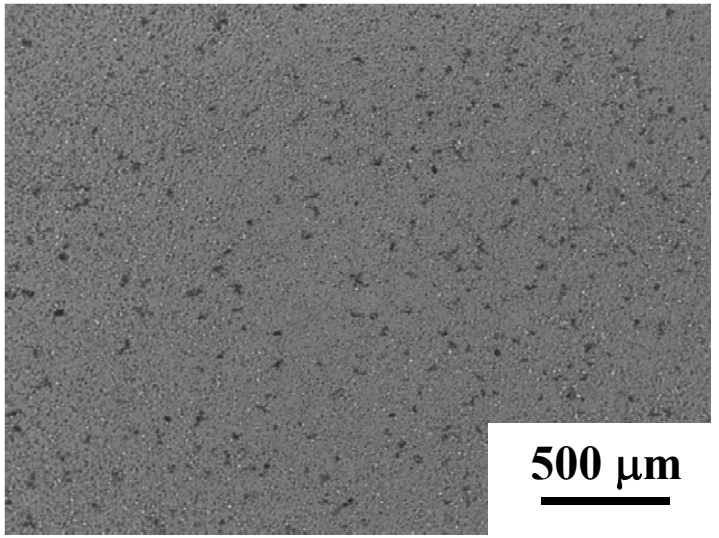


After Ag coating

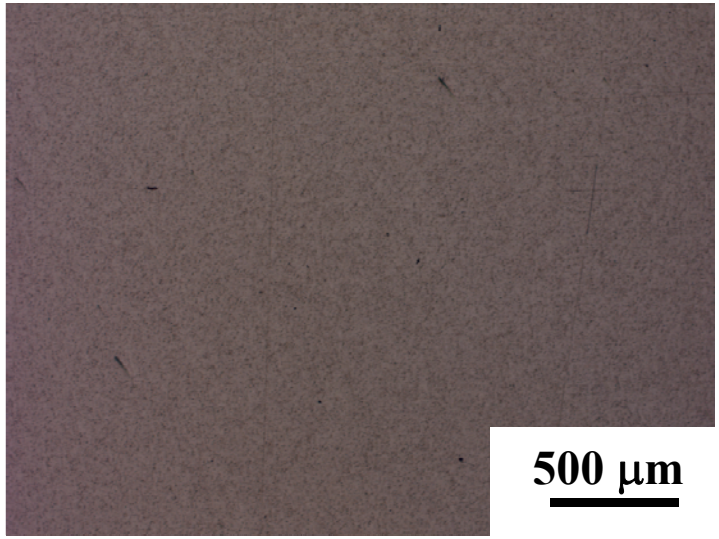
Ra = 0.7 nm



As-cast Al sheet

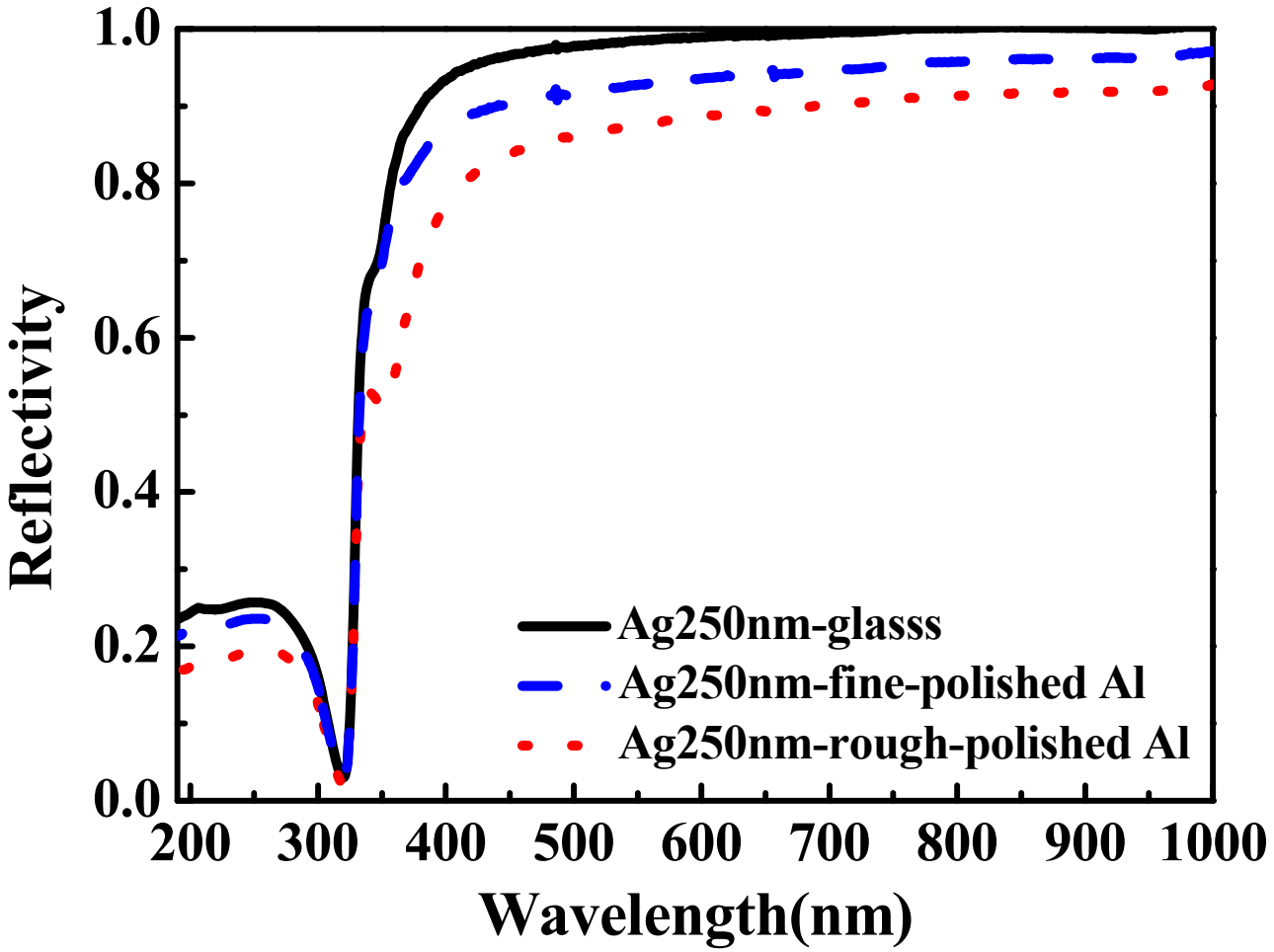


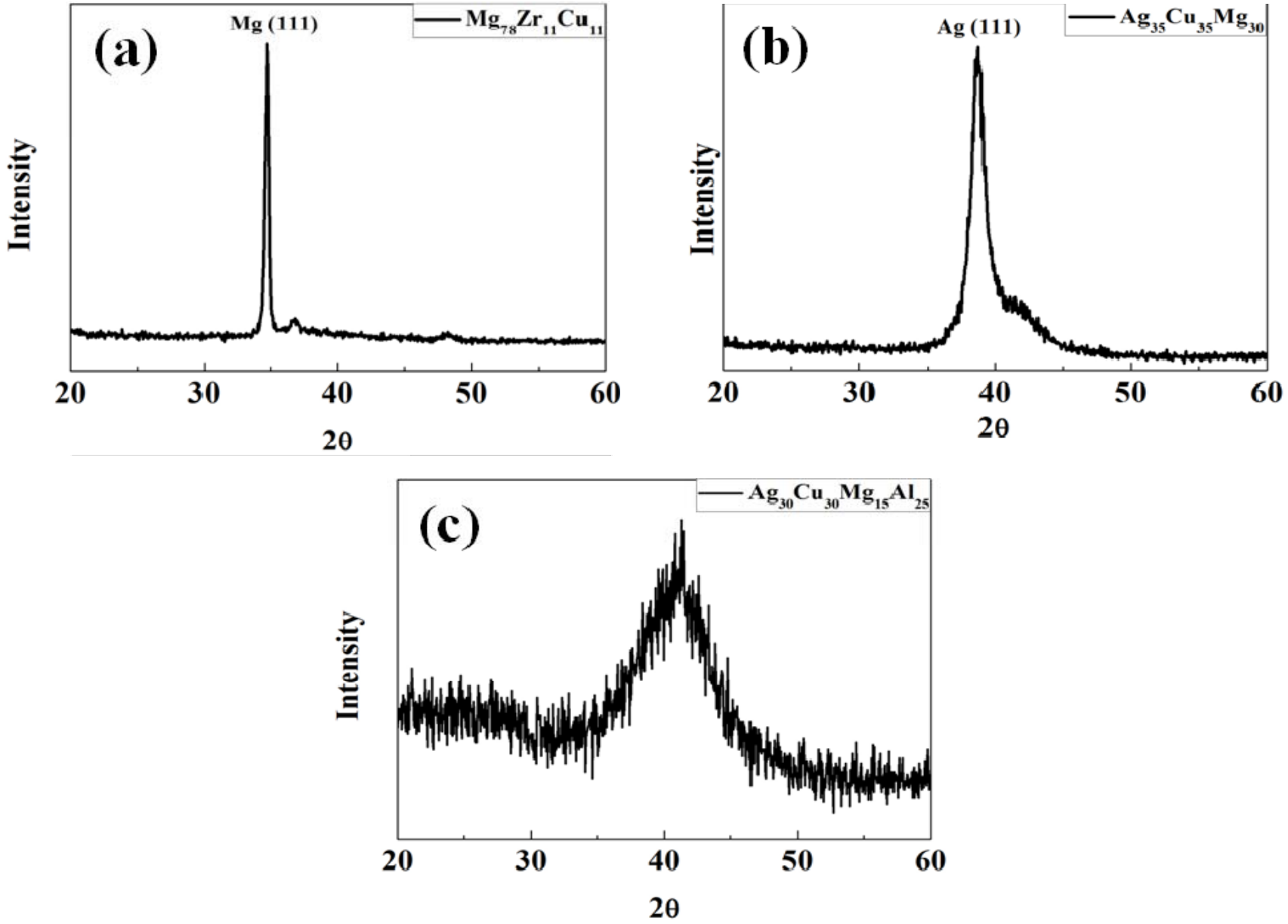
Rough-polished Al sheet

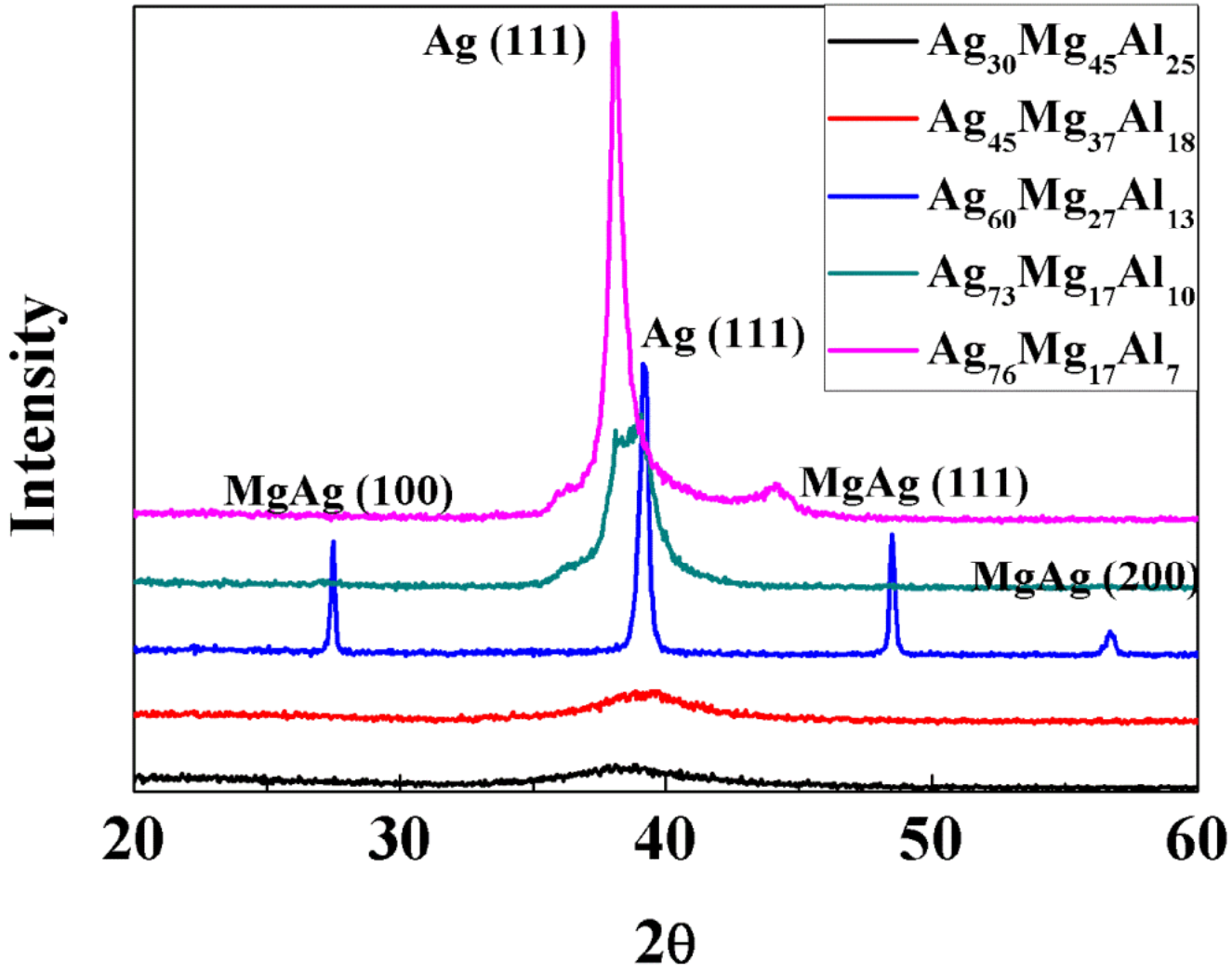


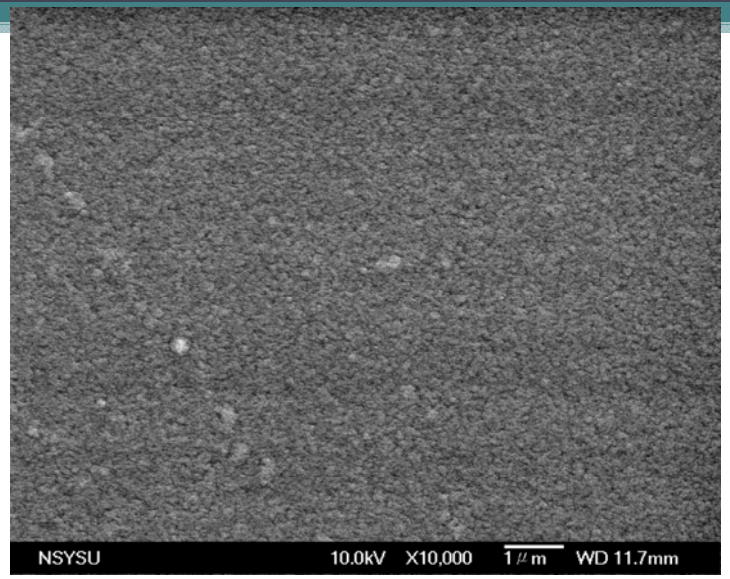
Fine-polished Al sheet

n&K results

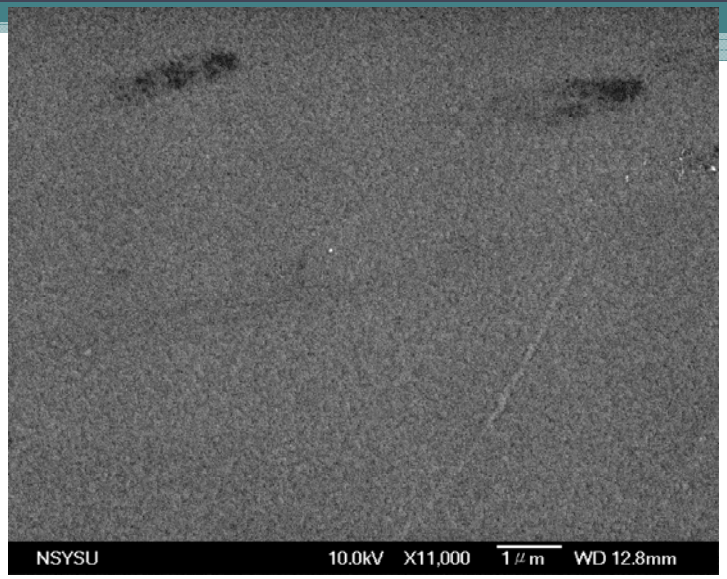

1.0
0.8
0.6
0.4
0.2
0.0
Reflectivity
200
300
400
500
600
700
800
900
1000
Wavelength(nm)
Ag250nm-glasss
Ag250nm-fine-polished Al
Ag250nm-rough-polished Al


(a)
Mg (111)
$Mg_{78}Zr_{11}Cu_{11}$
Intensity
20
30
40
50
60
2θ
(b)
Ag (111)
$Ag_{35}Cu_{35}Mg_{30}$
Intensity
20
30
40
50
60
2θ
(c)
$Ag_{30}Cu_{30}Mg_{15}Al_{25}$
Intensity
20
30
40
50
60
2θ

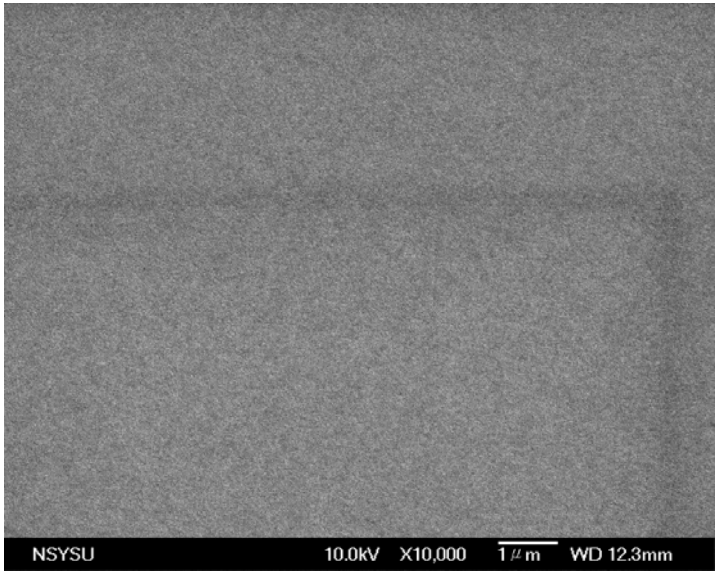

Ag (111)
Ag (111)
MgAg (100)
MgAg (111)
MgAg (200)
Ag30Mg45Al25
Ag45Mg37Al18
Ag60Mg27Al13
Ag73Mg17Al10
Ag76Mg17Al7
Intensity
20
30
40
50
60
2θ



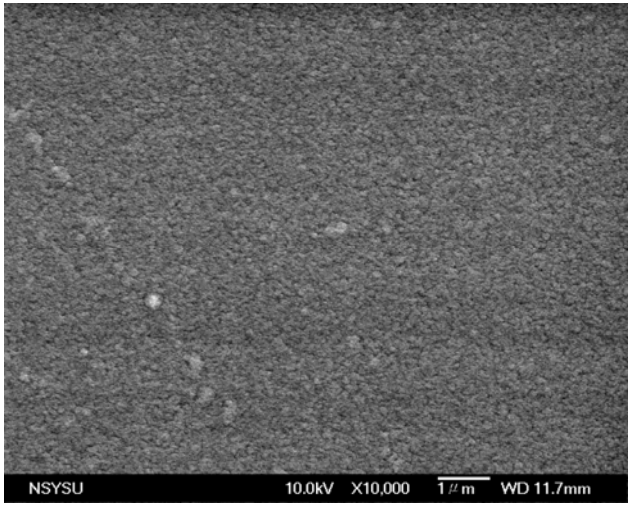
$Ag_{30}Mg_{45}Al_{25}$



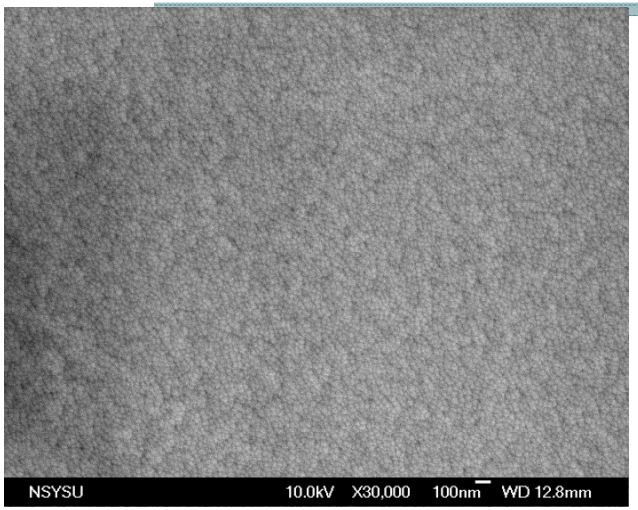
$Ag_{45}Mg_{30}Al_{25}$



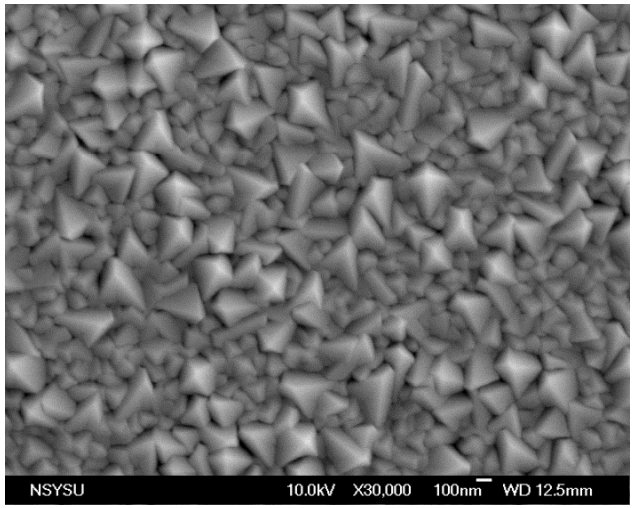
$Ag_{30}Cu_{30}Mg_{15}Al_{25}$



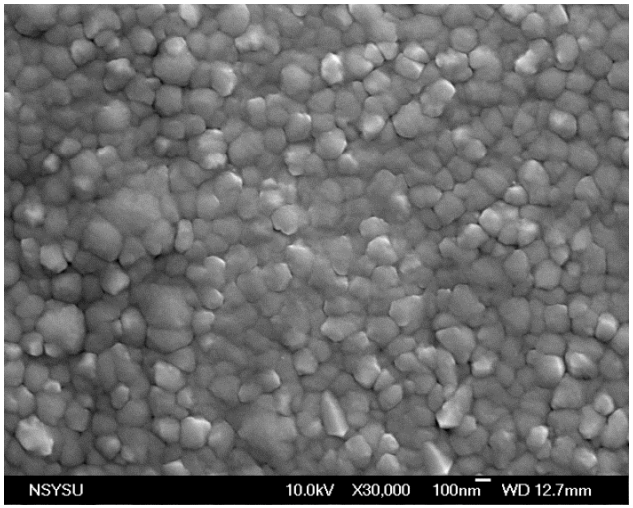
$Ag_{30}Mg_{45}Al_{25}$



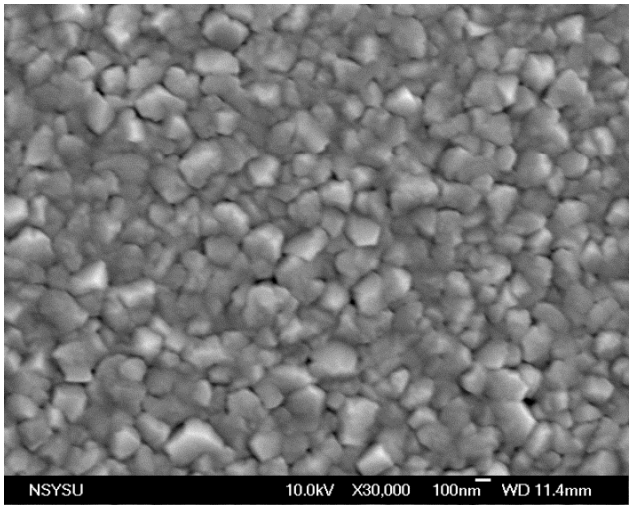
$Ag_{45}Mg_{30}Al_{25}$



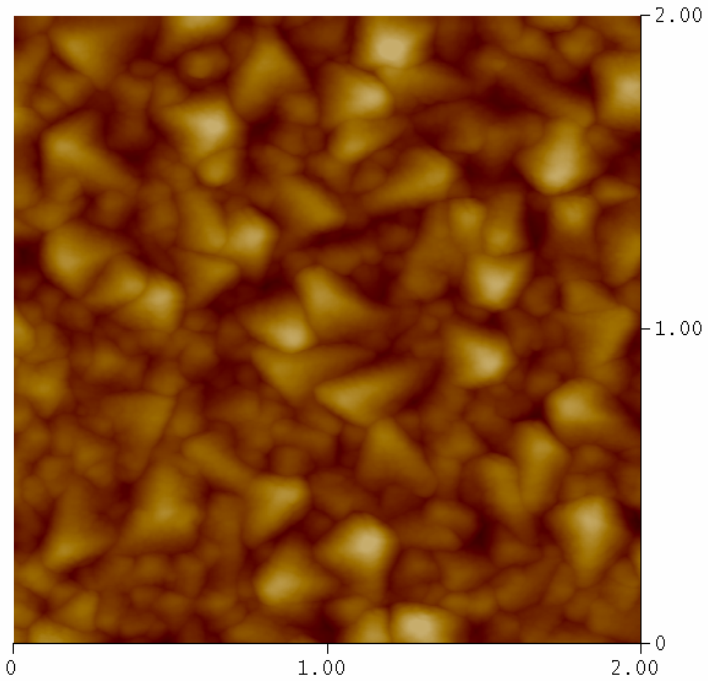
$Ag_{60}Mg_{27}Al_{13}$



$Ag_{73}Mg_{17}Al_{10}$



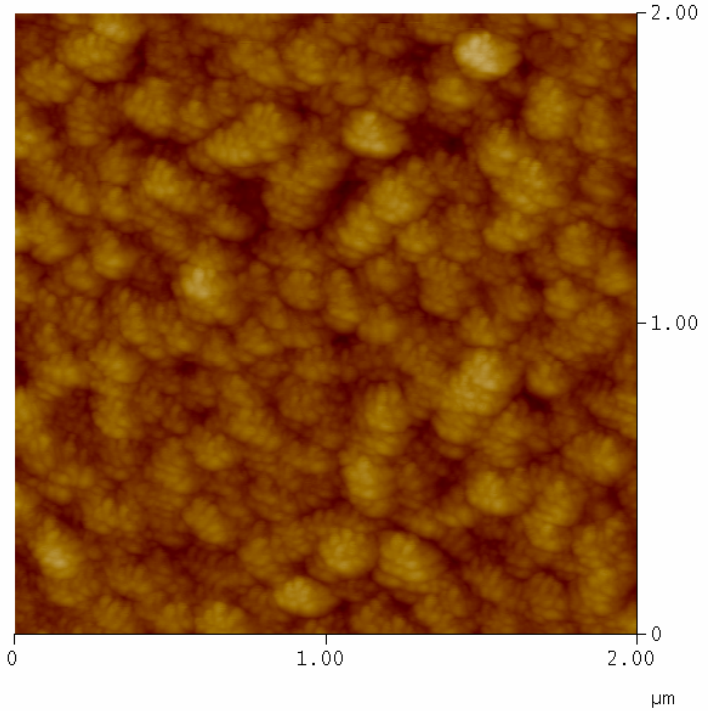
$Ag_{76}Mg_{17}Al_{7}$



Digital Instruments NanoScope
Scan size 2.000 µm
Scan rate 0.2001 Hz
Number of samples 512
Image Data Height
Data scale 250.0 nm

$Ag_{60}Mg_{27}Al_{13}$

Ra:26.49 nm

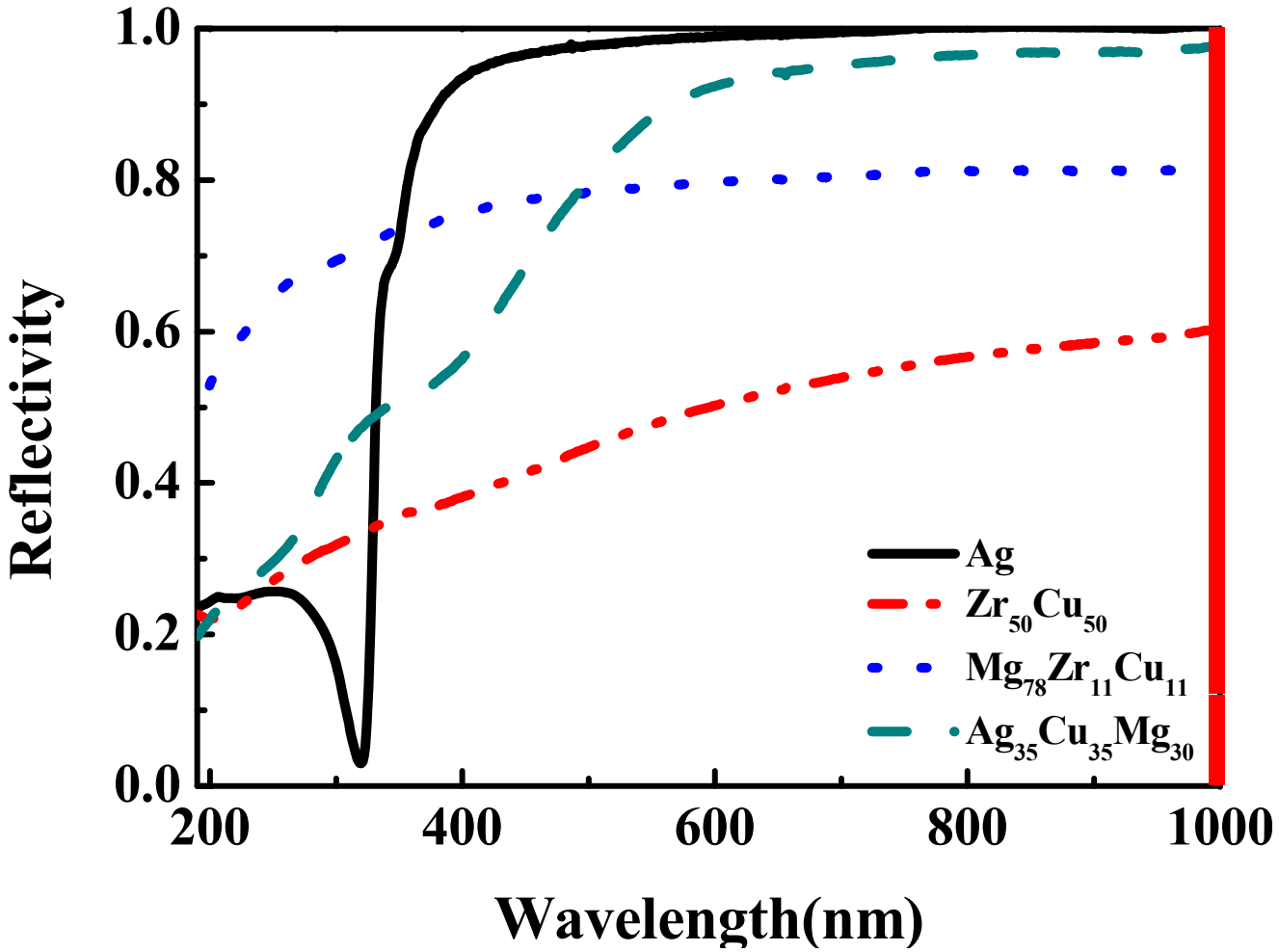


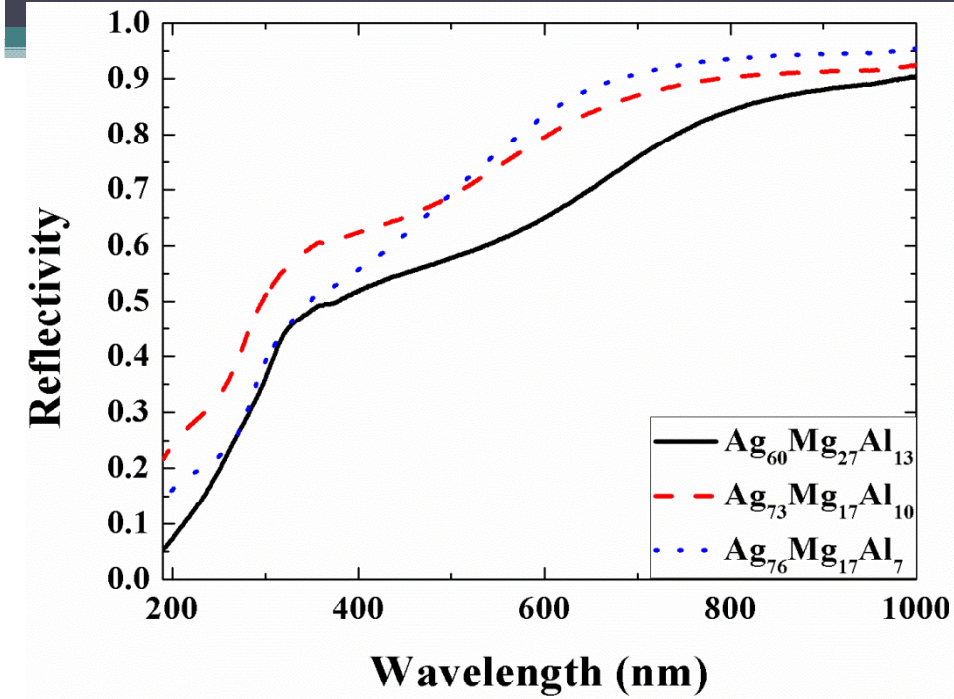
Digital Instruments NanoScope
Scan size 2.000 µm
Scan rate 0.2001 Hz
Number of samples 512
Image Data Height
Data scale 50.00 nm

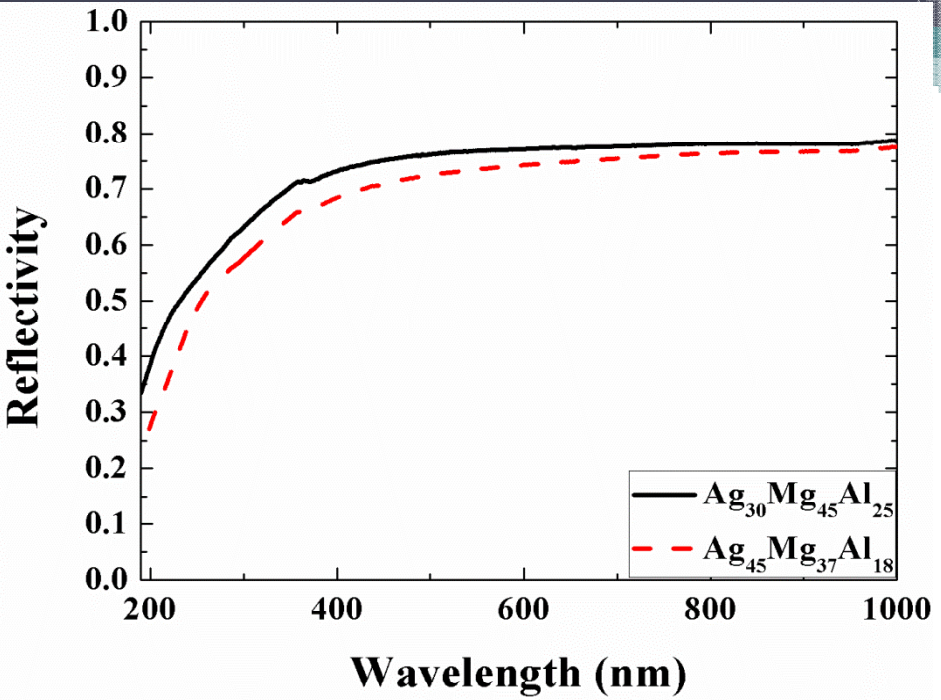
$Ag_{45}Mg_{30}Al_{25}$

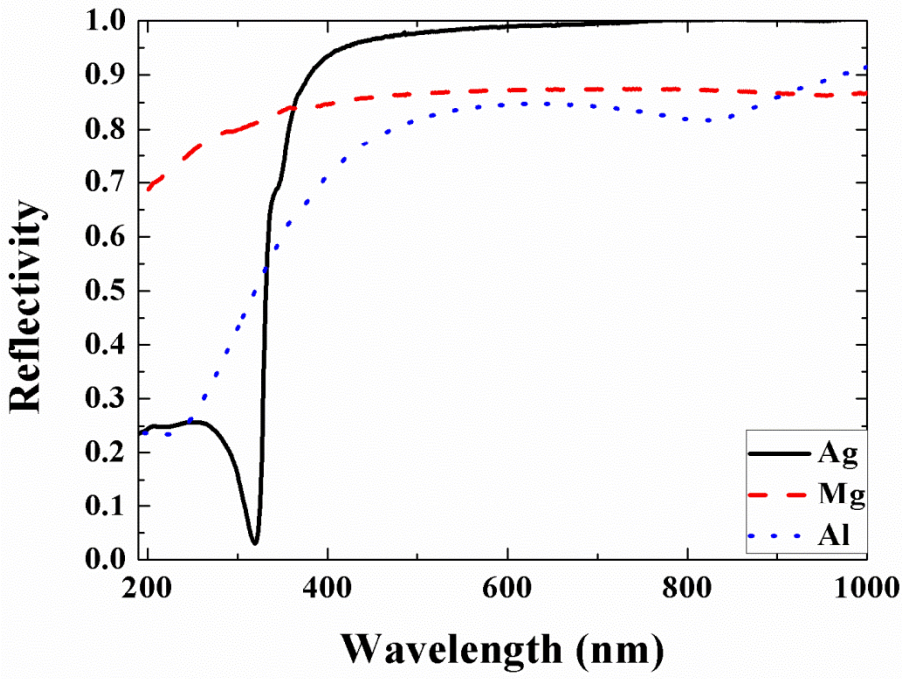
Ra:4.35 nm

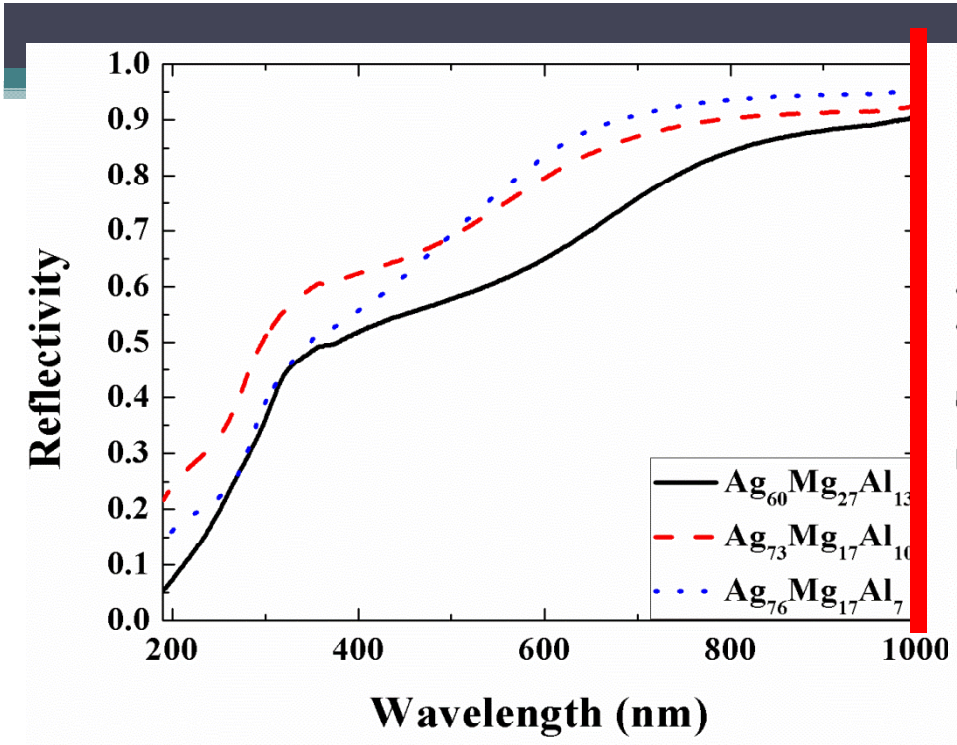
n&K results

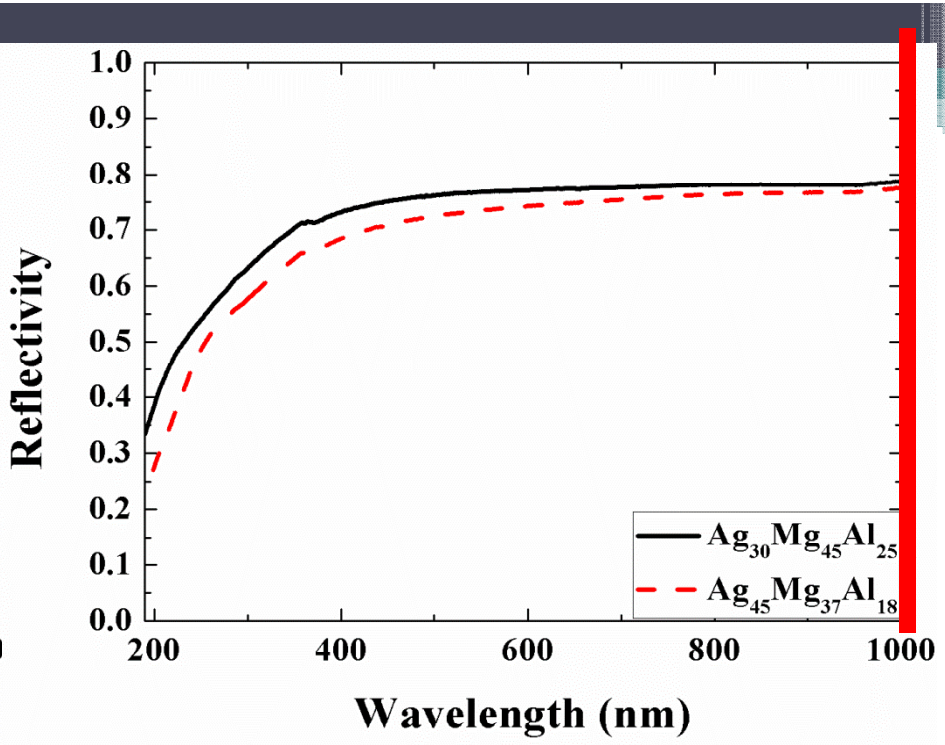

1.0
0.8
0.6
0.4
0.2
0.0
Reflectivity
200
400
600
800
1000
Wavelength(nm)
Ag
Zr50Cu50
Mg78Zr11Cu11
Ag35Cu35Mg30


Reflectivity
Wavelength (nm)
$Ag_{60}Mg_{27}Al_{13}$
$Ag_{73}Mg_{17}Al_{10}$
$Ag_{76}Mg_{17}Al_{7}$


Reflectivity
Wavelength (nm)
$Ag_{30}Mg_{45}Al_{25}$
$Ag_{45}Mg_{37}Al_{18}$


Reflectivity
Wavelength (nm)
Ag
Mg
Al


Reflectivity
Wavelength (nm)
Ag60Mg27Al13
Ag73Mg17Al10
Ag76Mg17Al7


Reflectivity
Wavelength (nm)
Ag30Mg45Al25
Ag45Mg37Al18

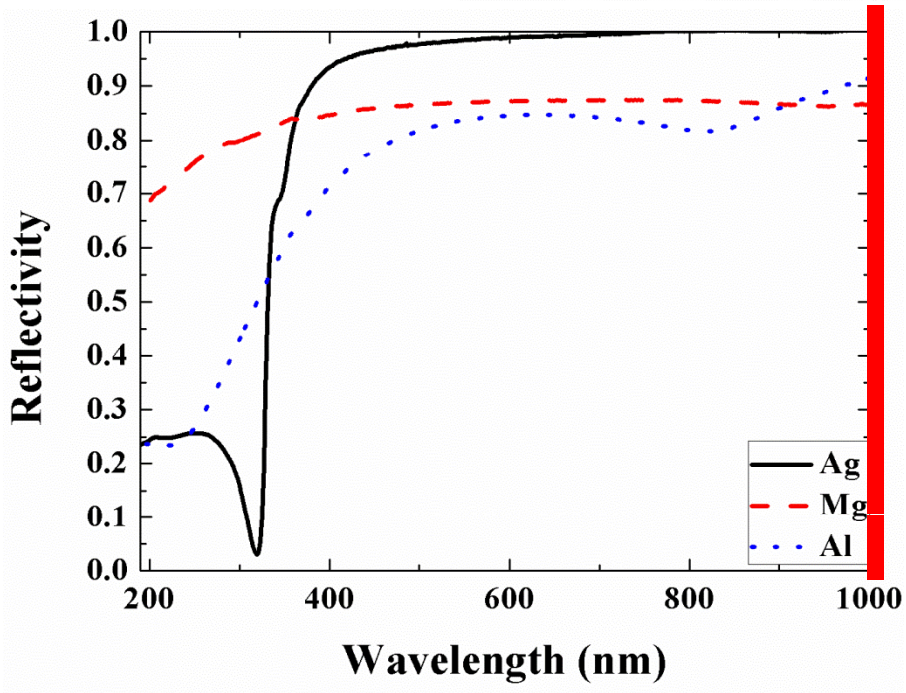

Reflectivity
Wavelength (nm)
Ag
Mg
Al

Table 1 Comparison of the electrical resistivity and light reflectivity

	Electric resistivity ρ, $n\Omega m^{1/2}$	Light reflectivity R, at 1000nm
Ag	18	0.98
Cu	22	0.97
Al	31	0.94
Mg	45	0.92
$Ag_{35}Cu_{35}Mg_{30}$ (crystalline)	189	0.98
$Ag_{76}Mg_{17}Al_{7}$ (crystalline)	230	0.95
$Ag_{73}Mg_{17}Al_{10}$ (crystalline)	286	0.92
$Ag_{60}Mg_{27}Al_{13}$ (crystalline)	304	0.91
$Ag_{45}Mg_{37}Al_{18}$ (amorphous)	1178	0.77
$Ag_{30}Mg_{45}Al_{25}$ (amorphous)	1032	0.79
$Ag_{30}Cu_{30}Mg_{15}Al_{25}$ (amorphous)	1120	0.77
$Zr_{50}Cu_{50}$ (amorphous)	2975	0.60

http://refractiveindex.info/

Light reflection vs. Electrical resistance