# SILVER METALLIZATION FOR ULSI APPLICATIONS

**Prof. Terry L. Alford**

*Dept. of Chemical, Bio, and Materials Engineering*
*NSF Center for Low Power Electronics*

# Outline

- ♦ **Introduction**
- ♦ **Results**
  - ***PHASE I*: Blanket Thin Ag Films**
  - ***PHASE II*: Patterned Ag Structures**
- ♦ **Summary**

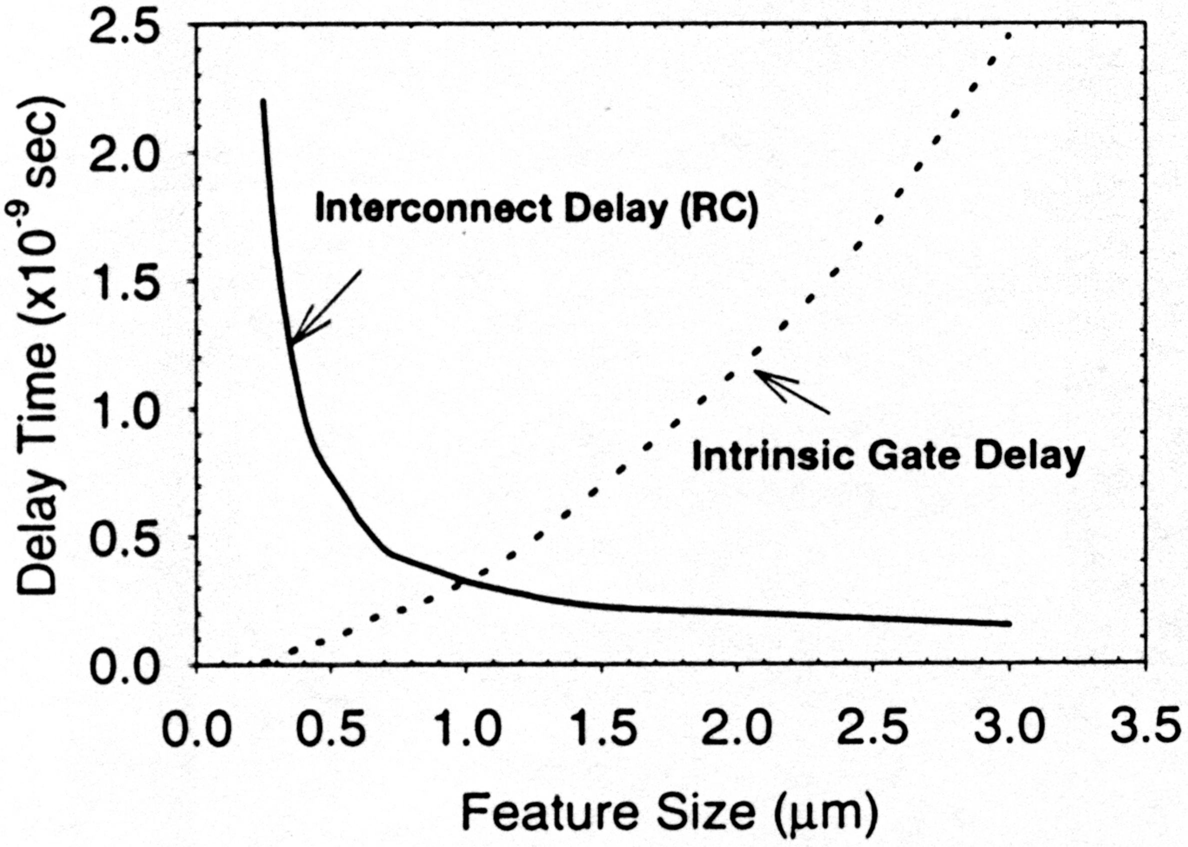
***National Science Foundation (L. Hess)***
***Center for Low Power Electronics and member companies***
***Yuxiao Zeng, Lee Zou, Phucanh Nguyen, Yu Wang, Jason Hason***

# Technology Trend :
# *Continuous Device Scaling*

- **BENEFITS**
  - ***Faster circuit speed***
  - ***Higher functional density***

- **ISSUES**
  - ***Propagation delay***
  - ***Power dissipation***
  - ***Cross talk noise -***

# *Interconnect RC Delay: A Performance-Limiting Factor for Submicron Integrated Circuits*



**(S.-P. Jeng *et al*., *Advanced Metallization for Devices and Circuits – Science, Technology, and Manufacturability*, 1994.)**

# Conventional Al Metallization

- **Relatively high resistivity**
- **Electromigration (EM) failure**

***— Questionable for ULSI***

# *Approach to Reduce Interconnect RC Delay*

♦ **Low-ρ metals to replace Al(Cu)**

| | |
|---|---|
| **Al(Cu)** | **3.1 μΩ·cm** |
| **Au** | **2.4 μΩ·cm** |
| **Cu** | **1.7 μΩ·cm** |
| ***Ag*** | ***1.58 μΩ·cm*** |

♦ **Low-$k$ dielectrics to replace $SiO_2$**

| | |
|---|---|
| **$SiO_2$** | **$k = 4.0\text{-}4.5$** |
| **Low-$k$ dielectrics** | **$k < 3$** |

# Ag Metallization

- **Advantages**
  - *- Lower resistivity than Al and Cu (~ 40% and 5%)*
  - *- Higher EM resistance than Al*

- **Disadvantages**
  - *- Poor adhesion to* $SiO_2$
  - *- Rapid diffusion in Si*
  - *- Corrosion in S or Cl ambient*
  - *- Agglomeration*

# Challenges of Ag Metallization

- **Address issues:**
  - ***Diffusion***
  - ***Corrosion***
  - ***Agglomeration***
  - ***Adhesion***
- **Improve EM resistance**
- **Produce Ag pattern**

## Project Objective:

***Demonstrate Ag as an interconnect material***

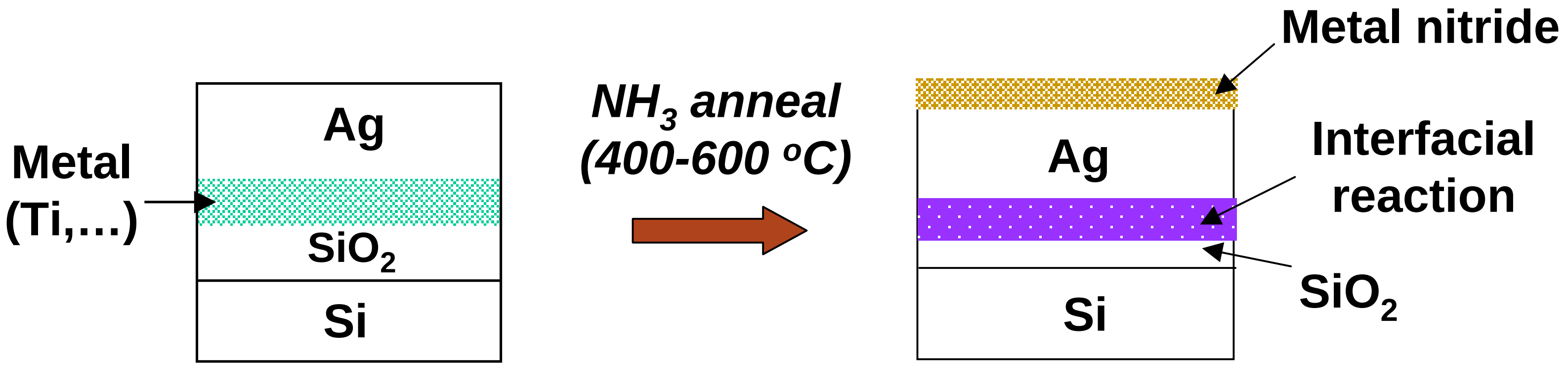
- ***Overcome Ag’s critical issues***
- ***Develop Ag reactive ion etch***
- ***Optimize EM performance***

# ***Strategy - Encapsulation Process***

***PHASE I*: Blanket Thin Ag Films**

***PHASE II*: Patterned Ag Structures**

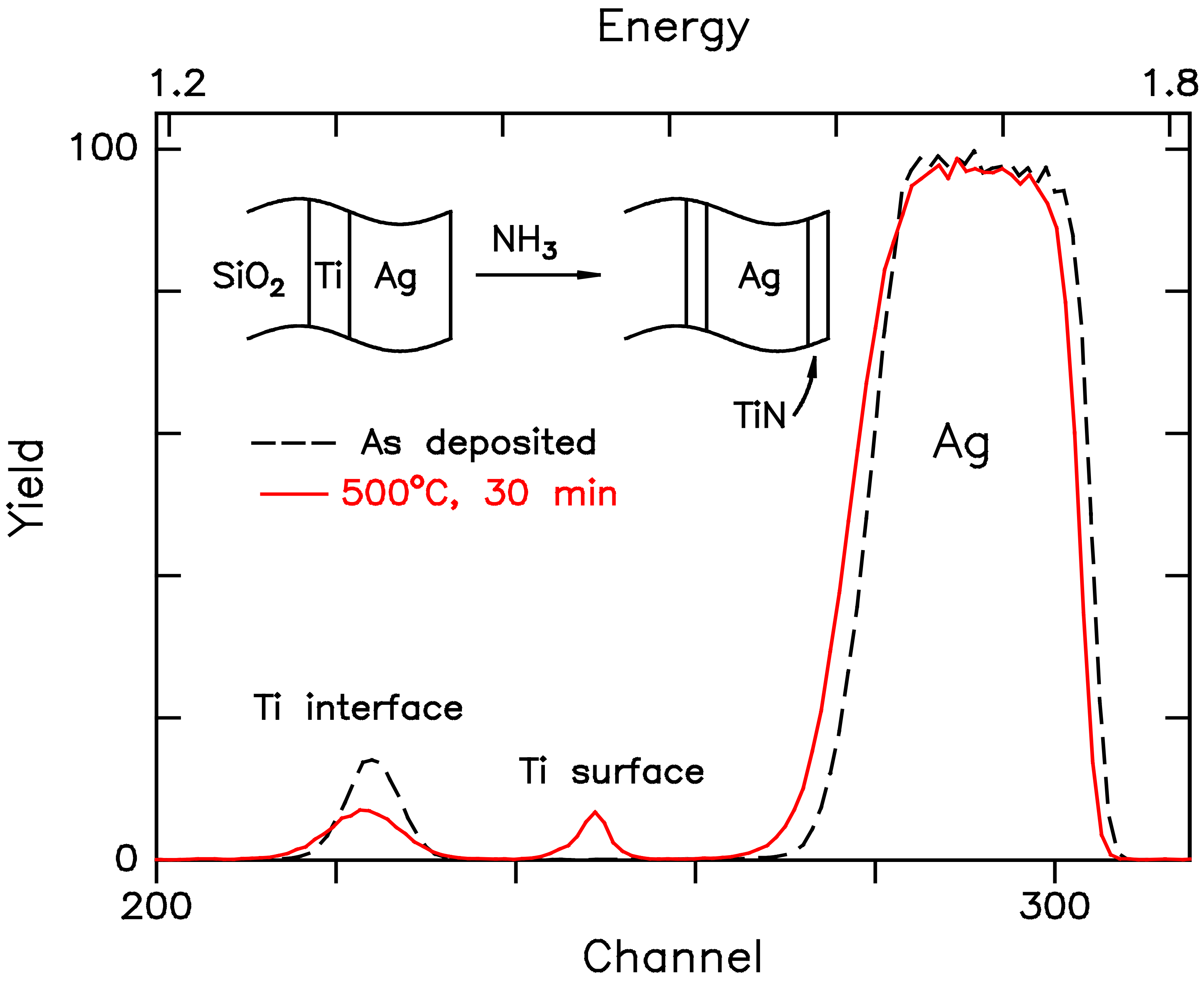
# *PHASE I:* Blanket Thin Ag Films

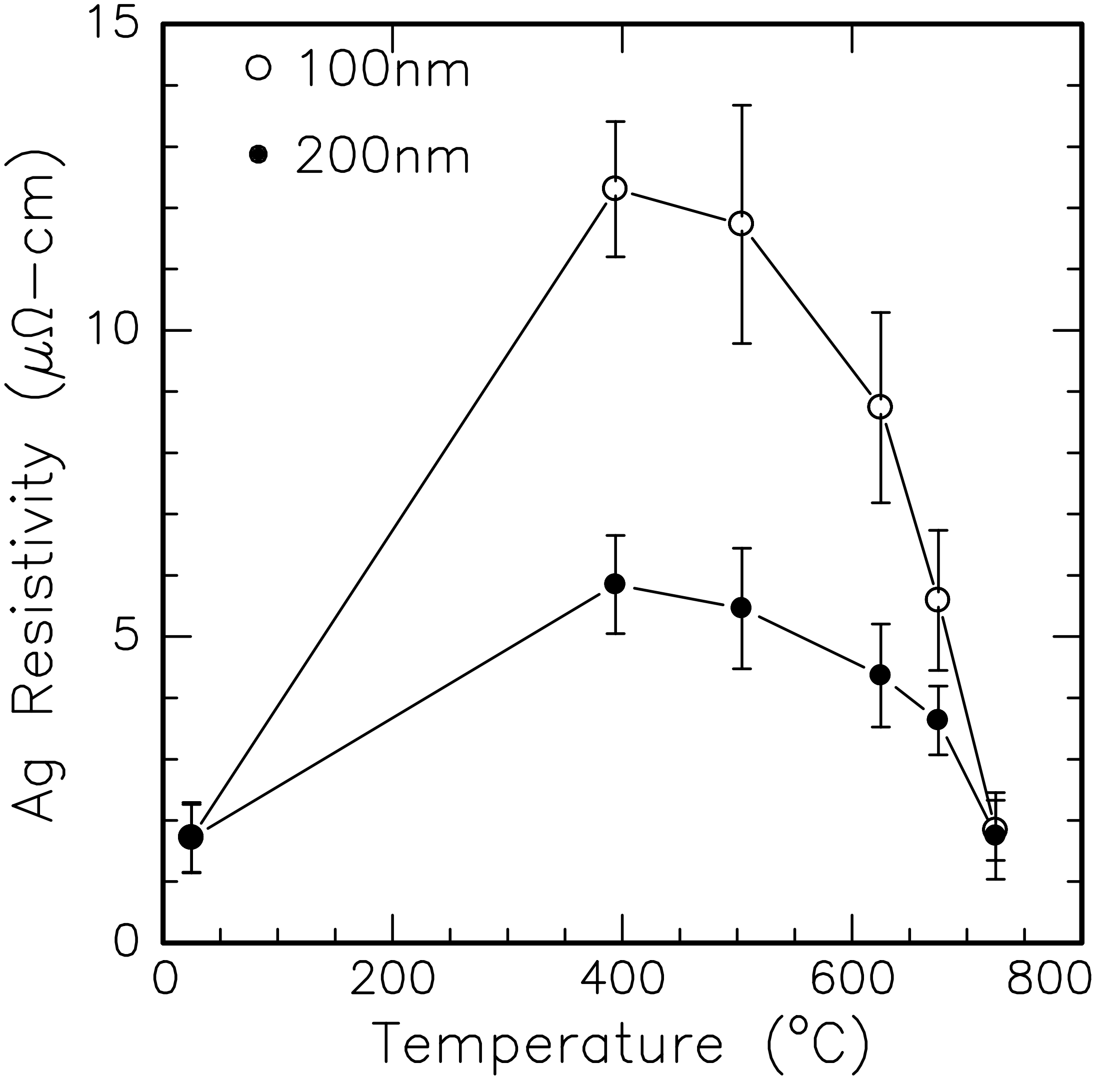


**Encapsulation process**

**Texture and microstructure optimization**

**Resistivity measurement**


Energy
1.2
1.8
100
0
Yield
200
300
Channel
SiO$_2$
Ti
Ag
NH$_3$
Ag
TiN
As deposited
500°C, 30 min
Ag
Ti interface
Ti surface


○ 100nm
● 200nm
Ag Resistivity (μΩ−cm)
Temperature (°C)
0
5
10
15
0
200
400
600
800

$$\rho_{alloy} = \rho_0 + \kappa\, c_i \qquad \kappa = \frac{\Delta\rho}{\Delta c_i}$$

| | $\kappa$ | |
|---|---|---|
| | Experimental | Theoretical[*] |
| Cu (% Ti) | 13 | 16 |
| Ag (% Ti) | 1.8 | *NA* |
| Ag (% Al) | 1.3 | 1.95 |

[*] K. Schroeder, Handbook of Electrical Resistivities of Binary Metallic Alloys, CRC Press,1983.

# Encapsulation Process

- **Ti or Al diffuses through Ag**
- **Metal-N(O) forms on Ag surface**
- **Metal reduces the underlying $SiO_2$**
- **Negligible residual metal in Ag films**

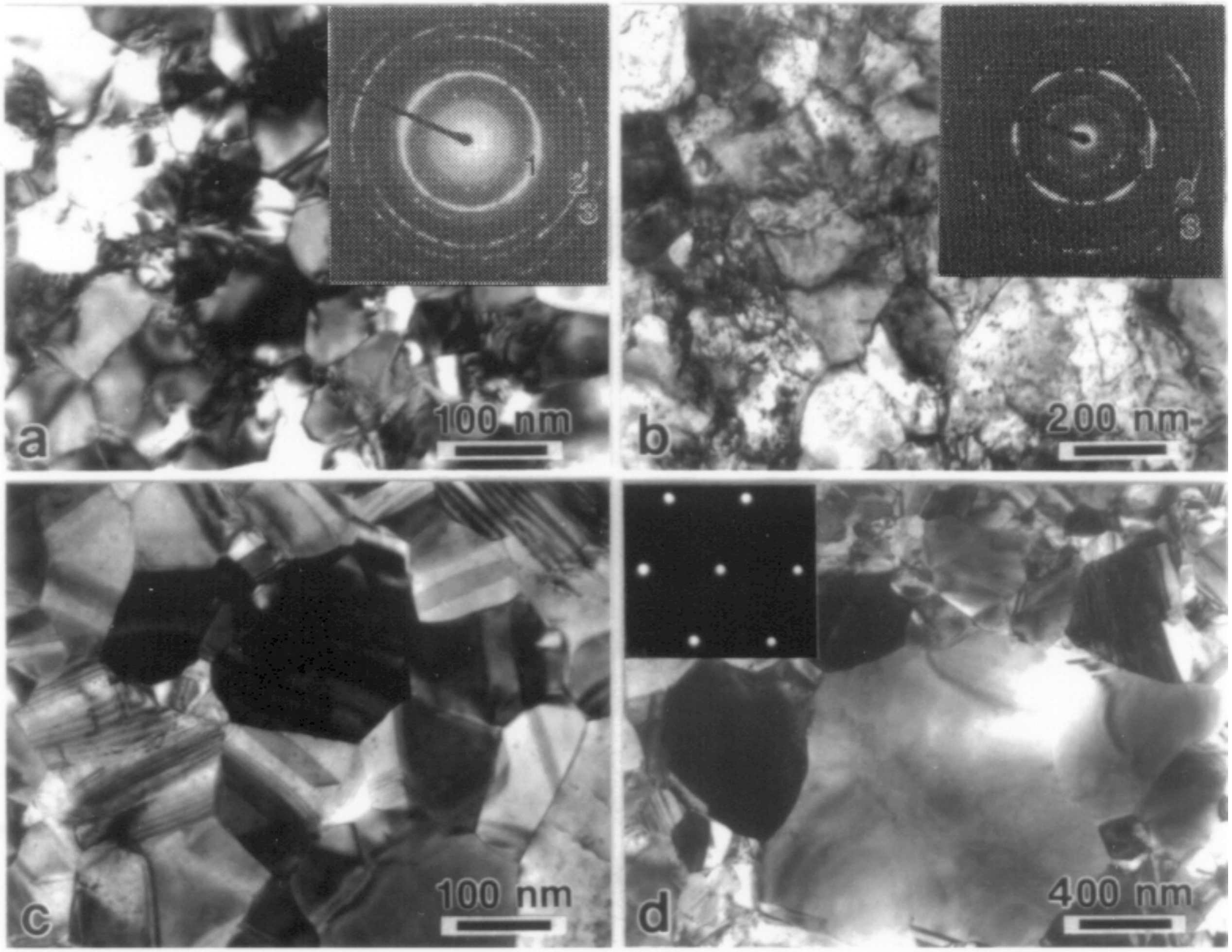
***— Ti and Al are ideal for encapsulation***

# comparison of major texture parameters of Ag, Cu, and Al(Cu) thin films

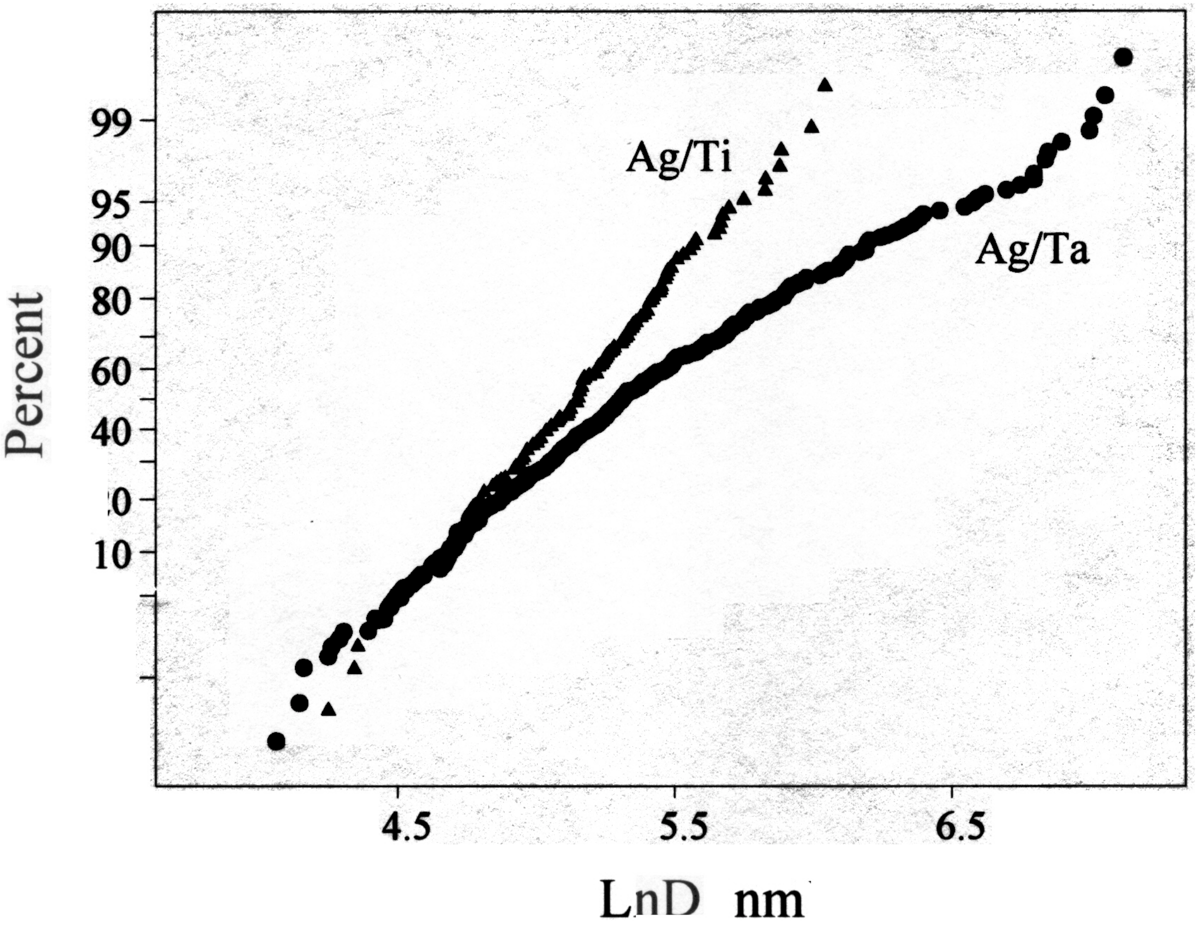
| | Condition | Volume fraction of grains | | FWHM (°) of <111> texture component |
|---|---|---|---|---|
| | | <111> + <511> | Random | |
| Ag | As-deposited | 0.74 + 0.17 | 0.09 | 5.6 |
| | 400 °C 1 hr | 0.93 + 0.05 | 0.02 | 3.0 |

| | Condition | Volume fraction of grains | | | FWHM (°) of <111> texture component |
|---|---|---|---|---|---|
| | | <111> + twin | <200> | random | |
| Cu | As-deposited | 0.63 + 0.13 | 0.10 | 0.14 | 28.4 |
| | 400 °C 1 hr | 0.74 + 0.07 | 0.12 | 0.07 | 21.0 |

| | Condition | Volume fraction of grains | | FWHM (°) of <111> texture component |
|---|---|---|---|---|
| | | <111> | Random | |
| AlCu | As-deposited | 0.89 | 0.11 | 10.2 |
| | 400 °C 1 hr | 0.91 | 0.09 | 6.6 |



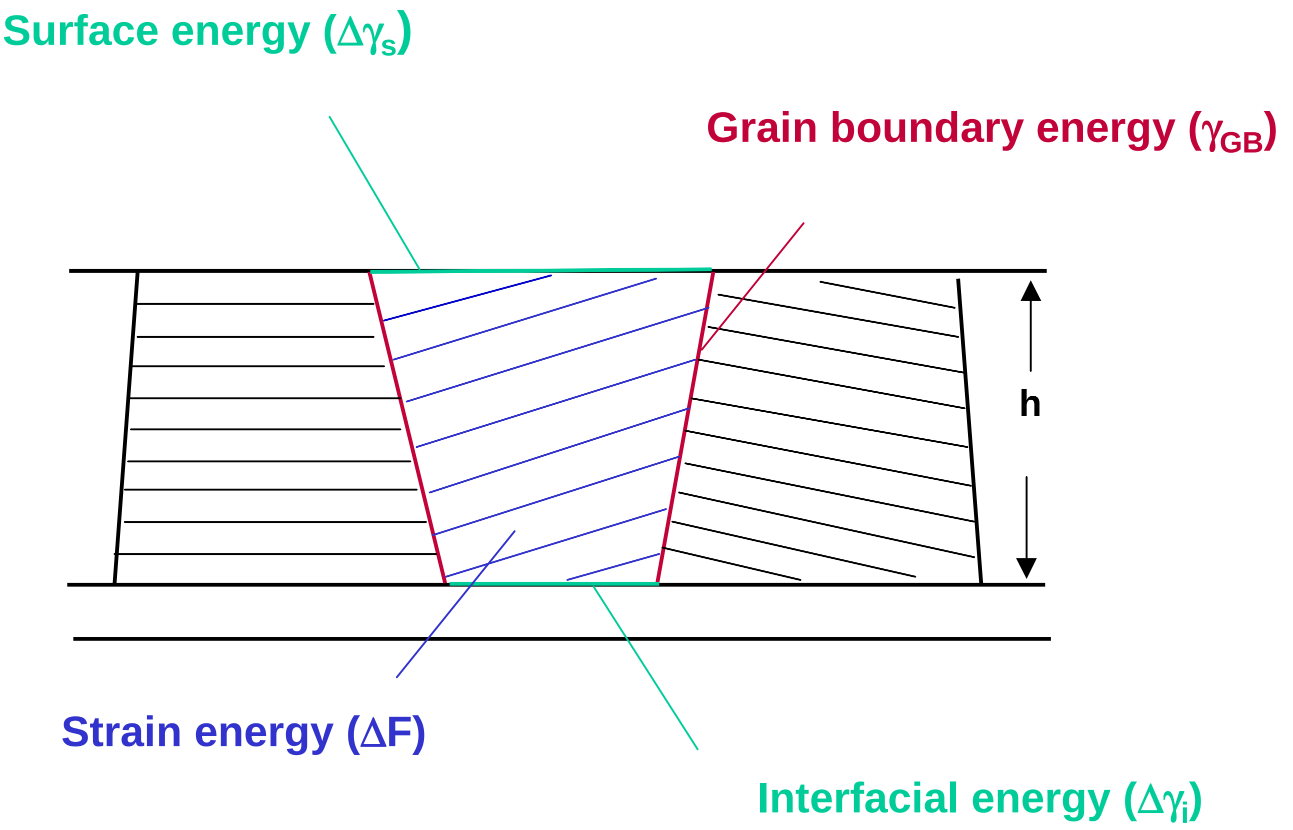
*a)* as-deposited, and *b)* 600 °C 15 min annealed Ag/Ti bilayers,
*c)* as-deposited, and *d)* 600 °C 15 min annealed Ag/Ta bilayers



**Grain size distribution of Ag films in Ag/Ti and Ag/Ta bilayers**

**Ag/Ti: Monomodal Ag/Ta: Bimodal**

# Surface and Strain Energy Controlled Grain Growth



- ♦ ***Driving force:*** **energy minimization**
- ♦ ***Grain growth rate:*** **$v = m[\Delta\gamma/h+\Delta F+\gamma_{GB}(1/r_a-1/r)]$**

# Ag Texture and Microstructure

- **Underlayer Dependence**

  **- Ti:** ***Strong Ag <111> texture, uniform microstructure***

  **- Ta, Cr:** ***Random orientation, abnormal grain growth***

- **Mechanisms**

  **-** ***Lattice match***

  **-** ***Surface-and-strain-energy-controlled grain growth***