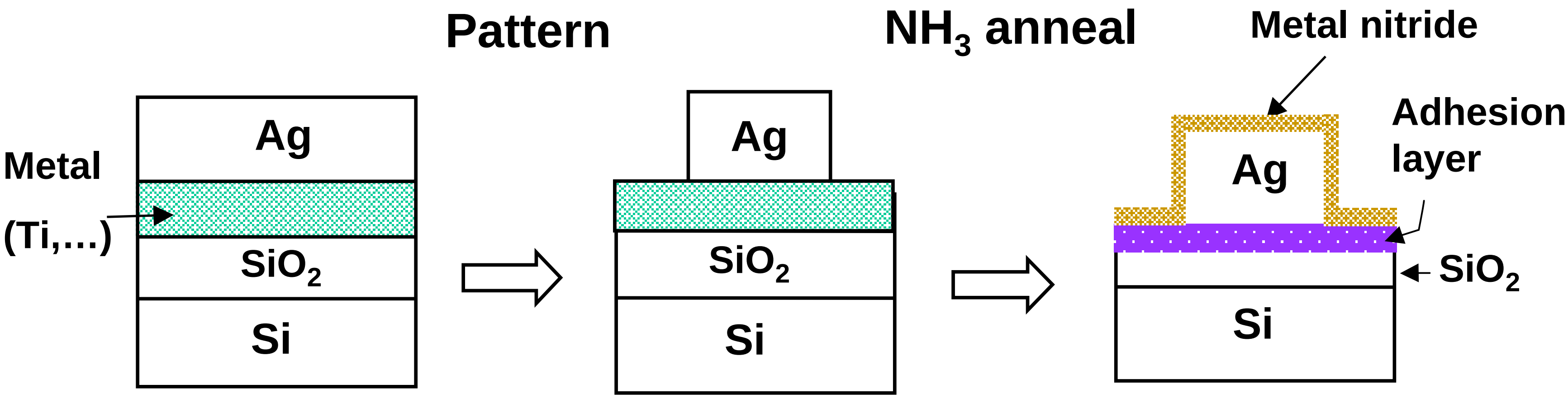
PHASE II: Patterned Ag Structures

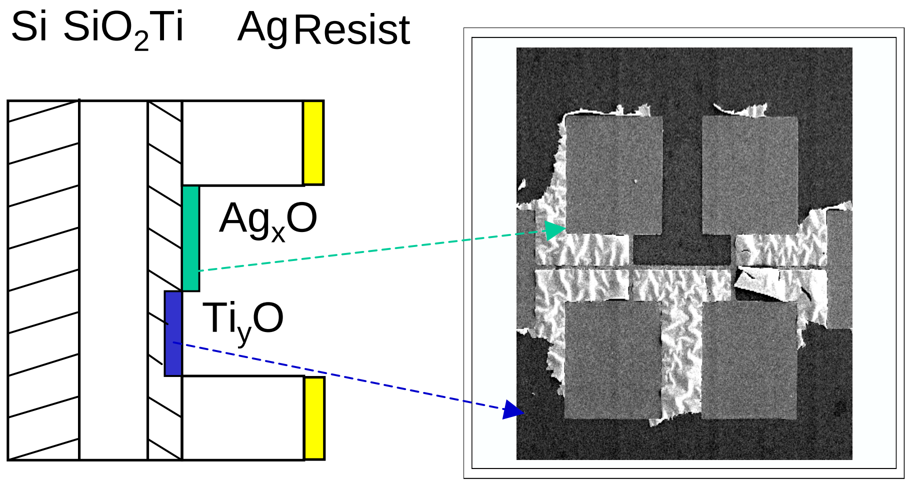


Dry etch

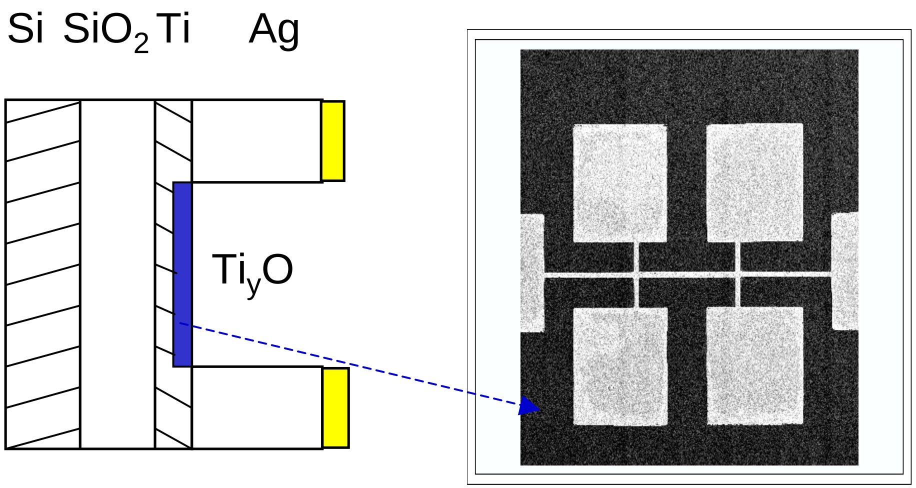
Electromigration testing

Microstructure characterization

Ag Etch in O_2

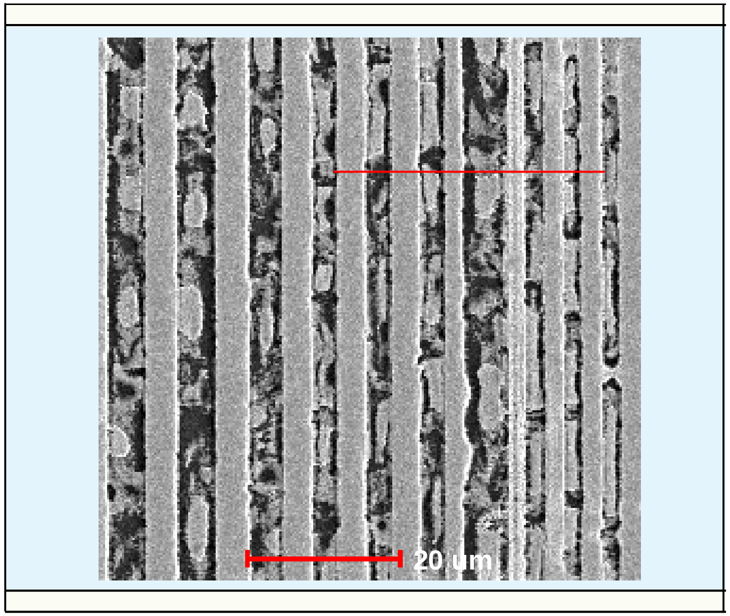


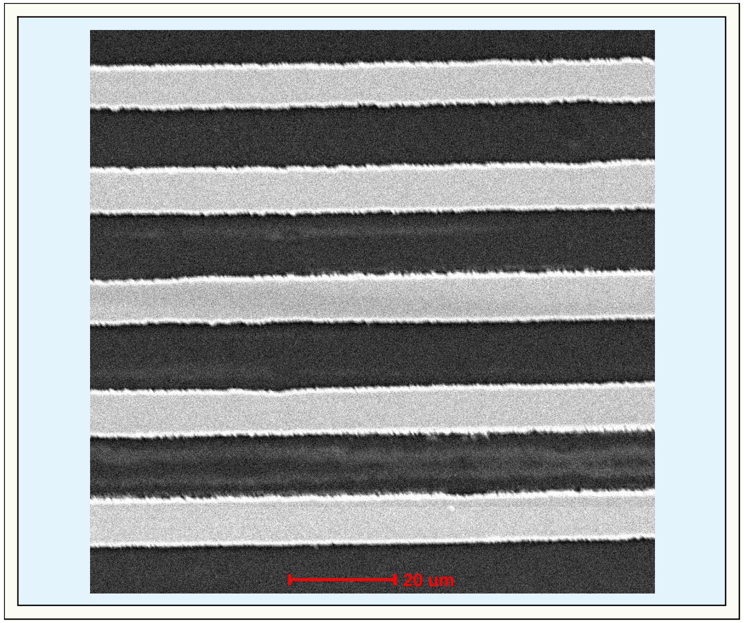
50 watt, 100 mTorr, 4 min



50 watt, 100 mTorr, 5 min

Comparison of O_2 and O_2/Cl_2 Chemistries

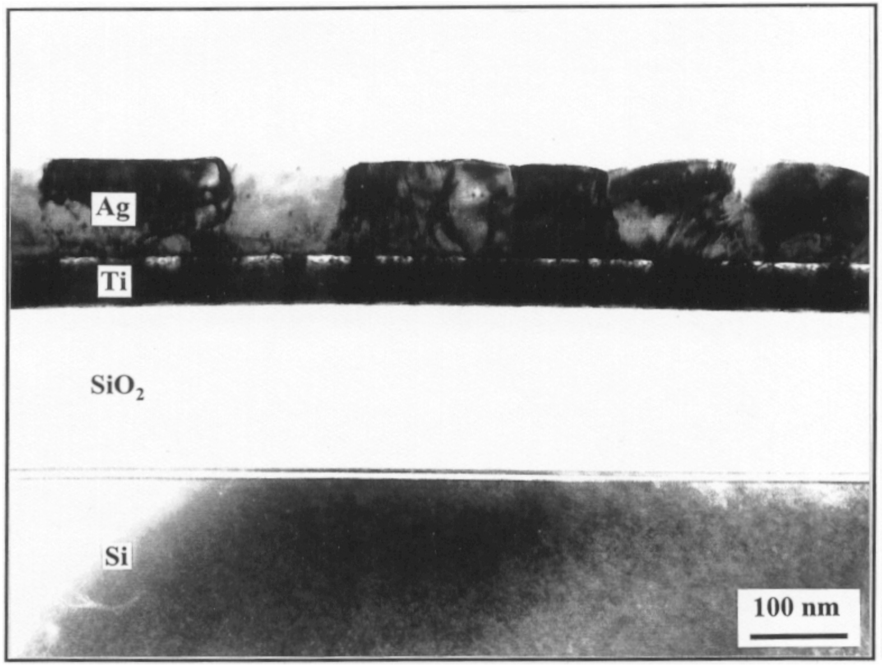




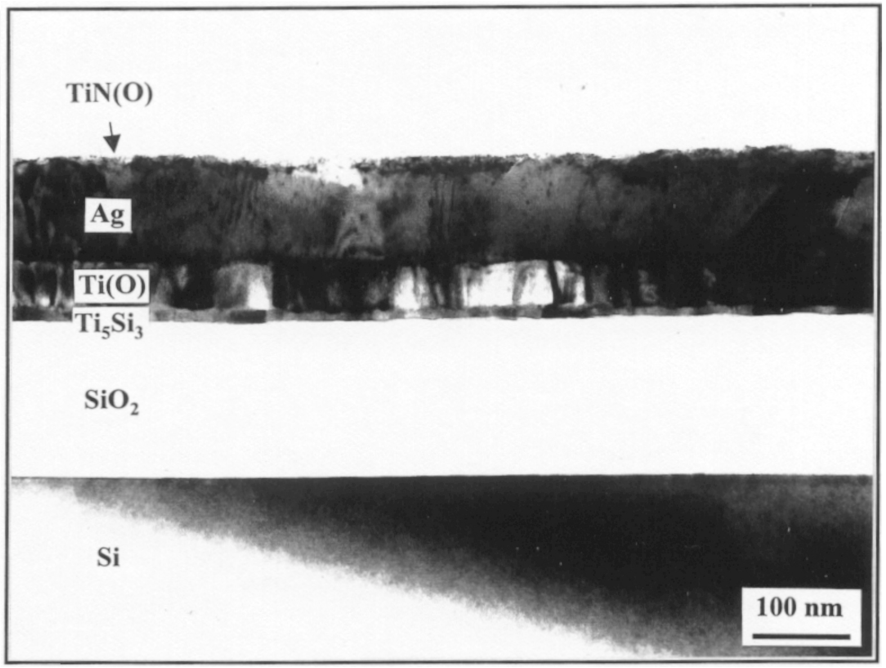
RF Power: 100 W
Pressure: 100 mtorr
O_2: 25 sccm

RF Power: 100 W
Pressure: 100 mtorr
O_2: 17 sccm
Cl_2: 8 sccm

Encapsulation of Ag Patterns



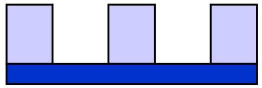
Before **encapsulation**



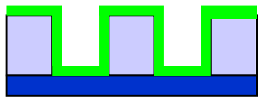
After **encapsulation**

- **Cross-sectional TEM micrographs of 10-μm-wide Ag lines**
- **Ag lines are encapsulated by TiN(O) layer**

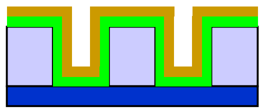
Comparison of Cu and Ag Metallization Processes

1


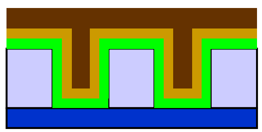
Conventional Lithography

2


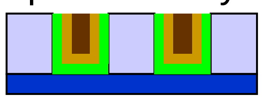
Barrier Deposition

3


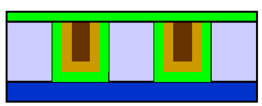
Deposit CVD Cu Seed layer

4


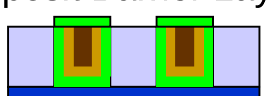
Sputter Cu layer

5


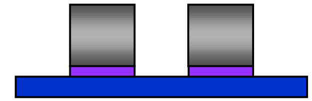
Chemical Mechanical Polish

6


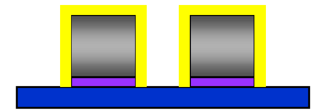
Deposit Barrier Layer

7


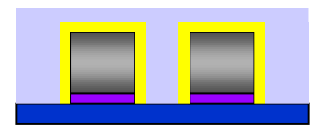
Pattern / Etch Barrier Layer



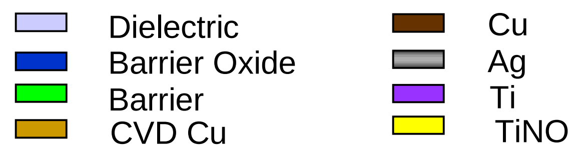
Conventional Lithography



Encapsulation



Conventional Deposition

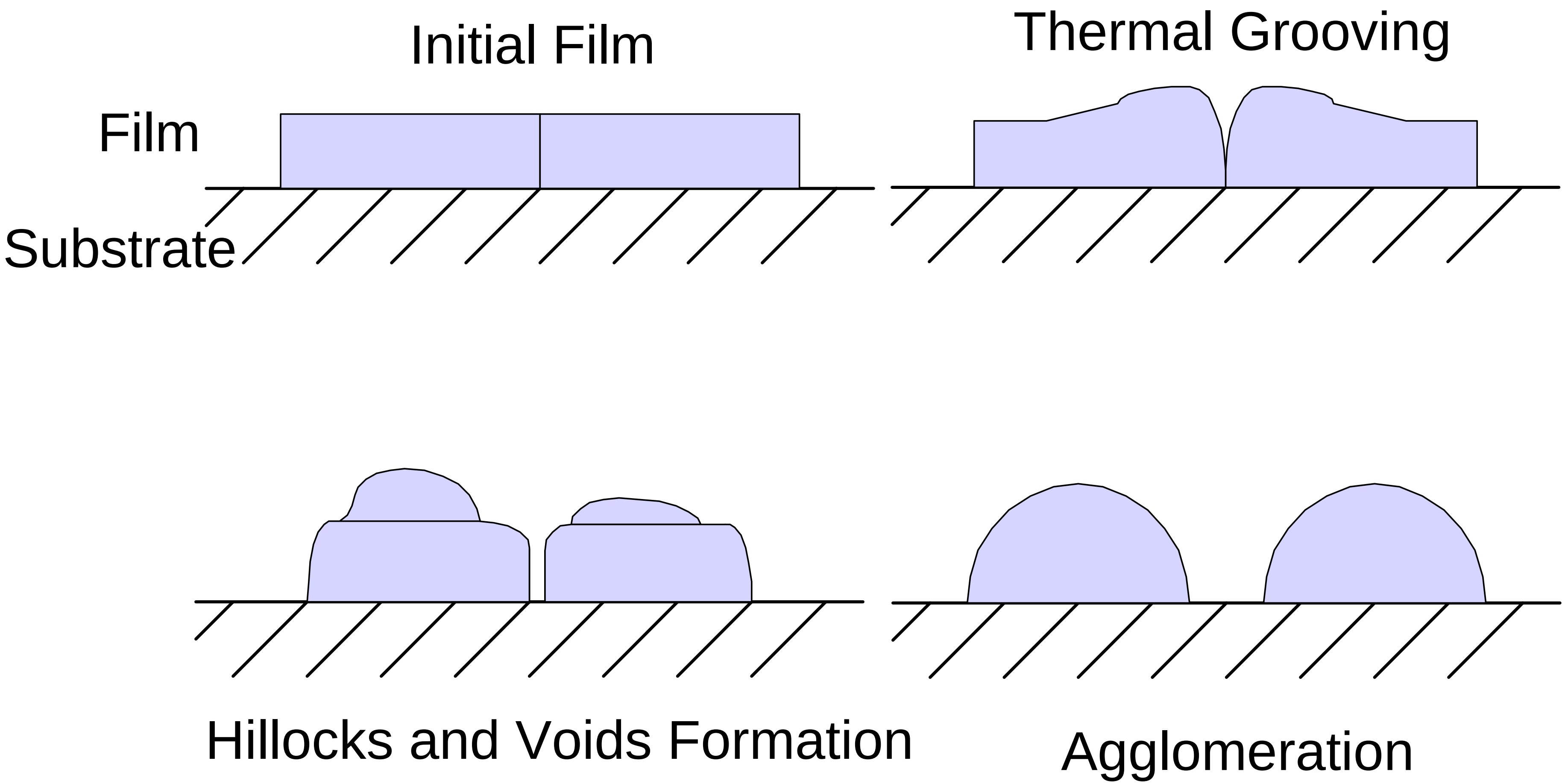


The Ag process is more manufacturable !

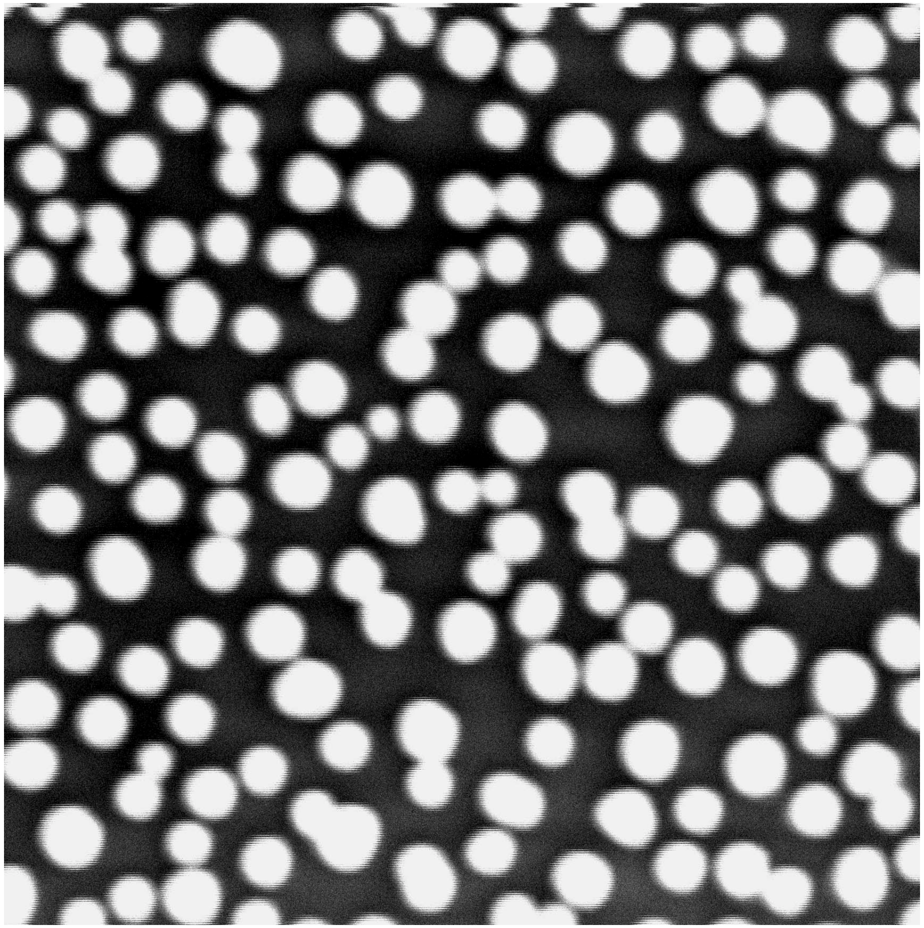
Thermal Stability

- **Thermal Stability Study**
  - **In-situ four-point probe to detect the onset temperature during annealing process**
    - **Onset temperature dependent on ramp rate**
  - **Calculate the activation energy for each film thickness, ambient, and its corresponding substrate - based on sheet resistance differences between measured values and linearity**
  - **Ramp rate only shifts the Arrhenius plot but does not change the slope**

Schematic of Films Evolution During Annealing



Demonstration of a Complete Agglomerated Ag/SiO_2 Annealed in Air



Arrhenius Relation

- Activation energies based on film thickness and onset temperature as follow:

$$\lambda^3 = C \exp\left(-\frac{E_a}{kT_i}\right)$$

λ - Film thickness

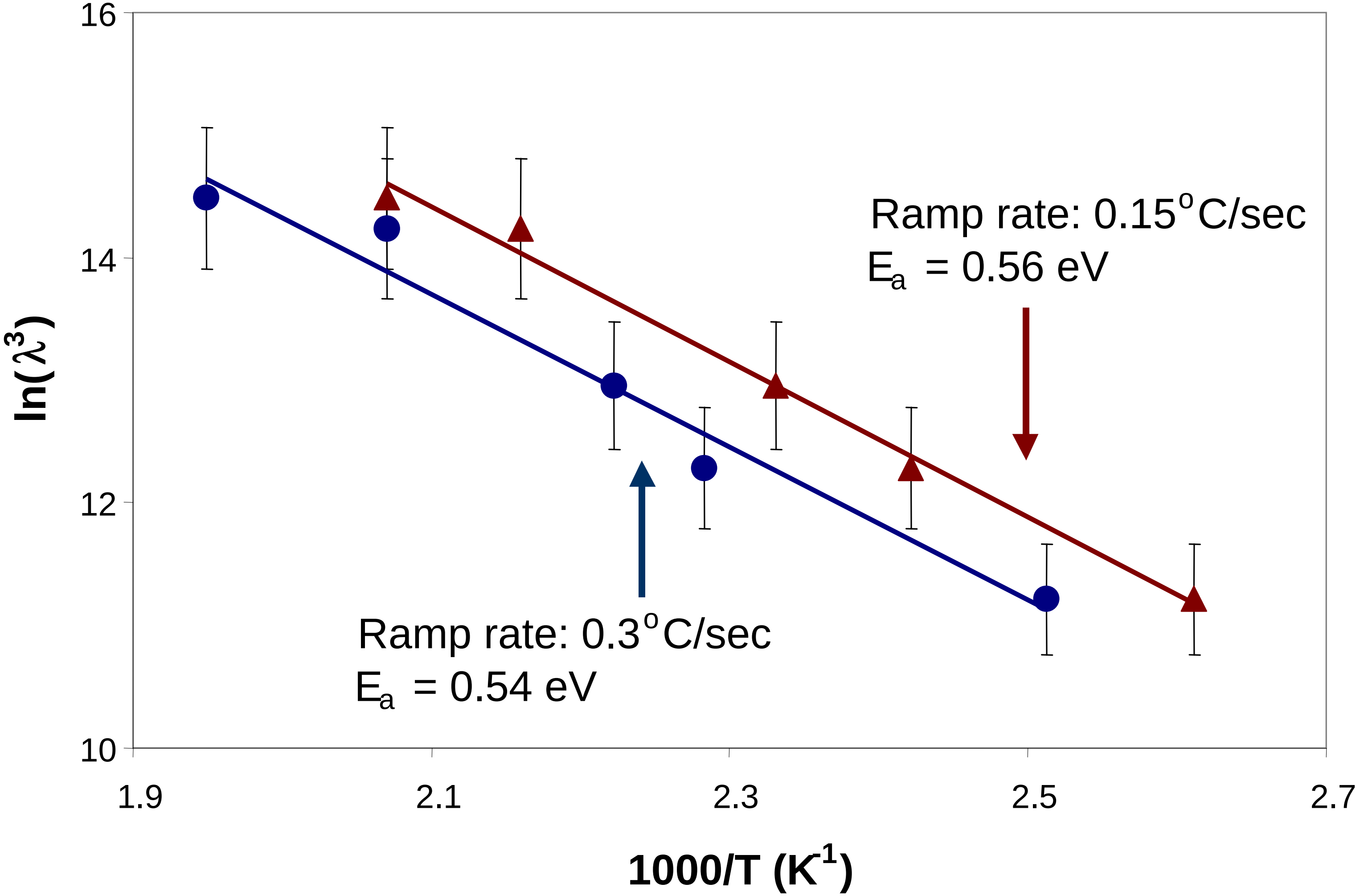
E_a - Activation energy

T_i - Onset temperature for void nucleation

k - Boltzman constant

C - Pre-exponent factor

Arrhenius plot of various Ag thicknesses (on SiO_2 annealed in air, at 0.15 and 0.3 ^oC/sec) vs.onset temperature



Calculation Formulation

- The Arrhenius dependence of each film thickness, its associated substrate, and ambient - based on the sheet resistance differences

$$\Delta\rho_s = \rho_o \exp\left(-\frac{E_a}{kT}\right)$$

$$\rho_{sm} = \rho_c + \alpha T + \rho_o \exp\left(-\frac{E_a}{kT}\right)$$

$$\Delta\rho_s = \rho_{sm} - (\rho_c + \alpha T)$$

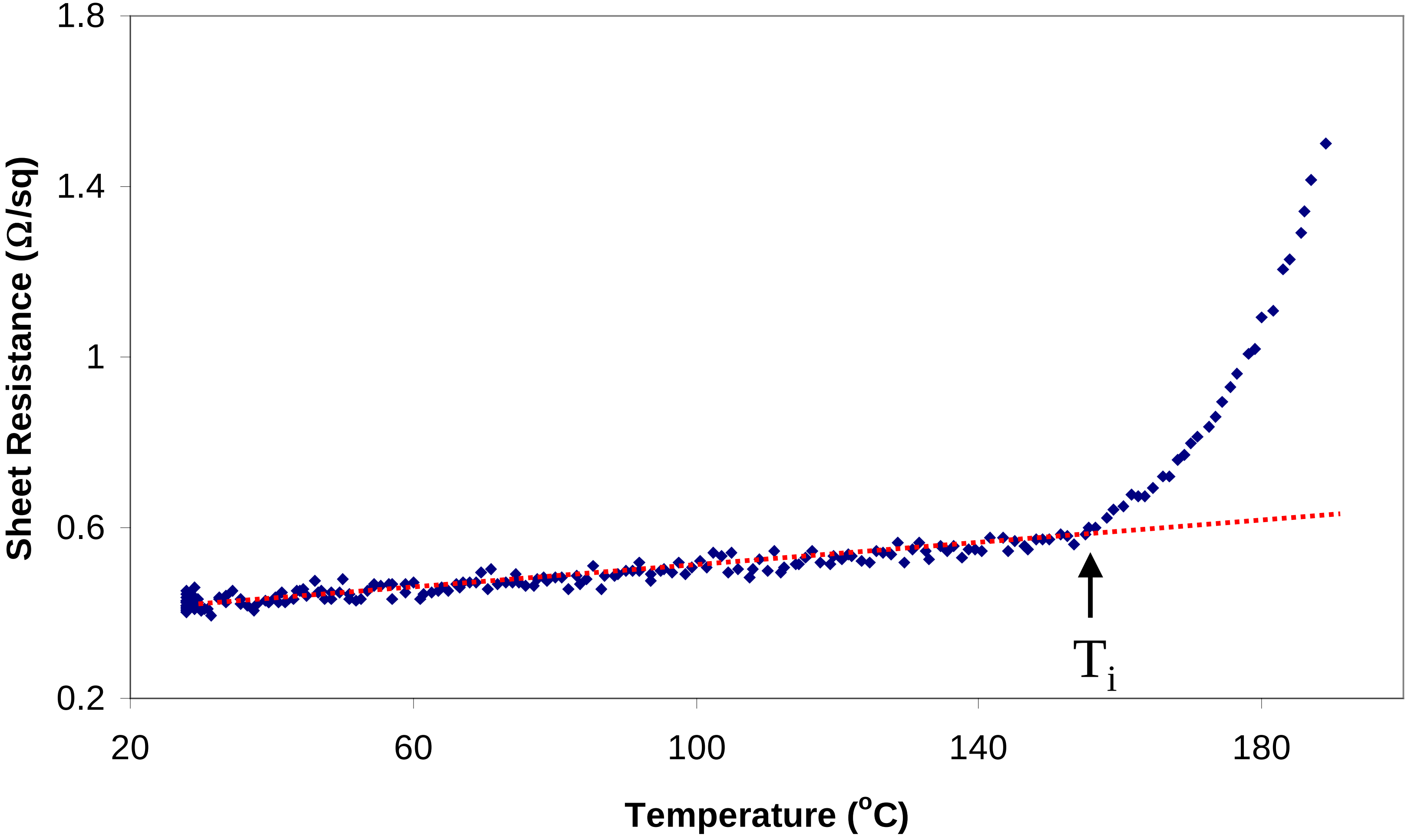
T - Temperature (K)

ρ_o - pre-exponential factor constant

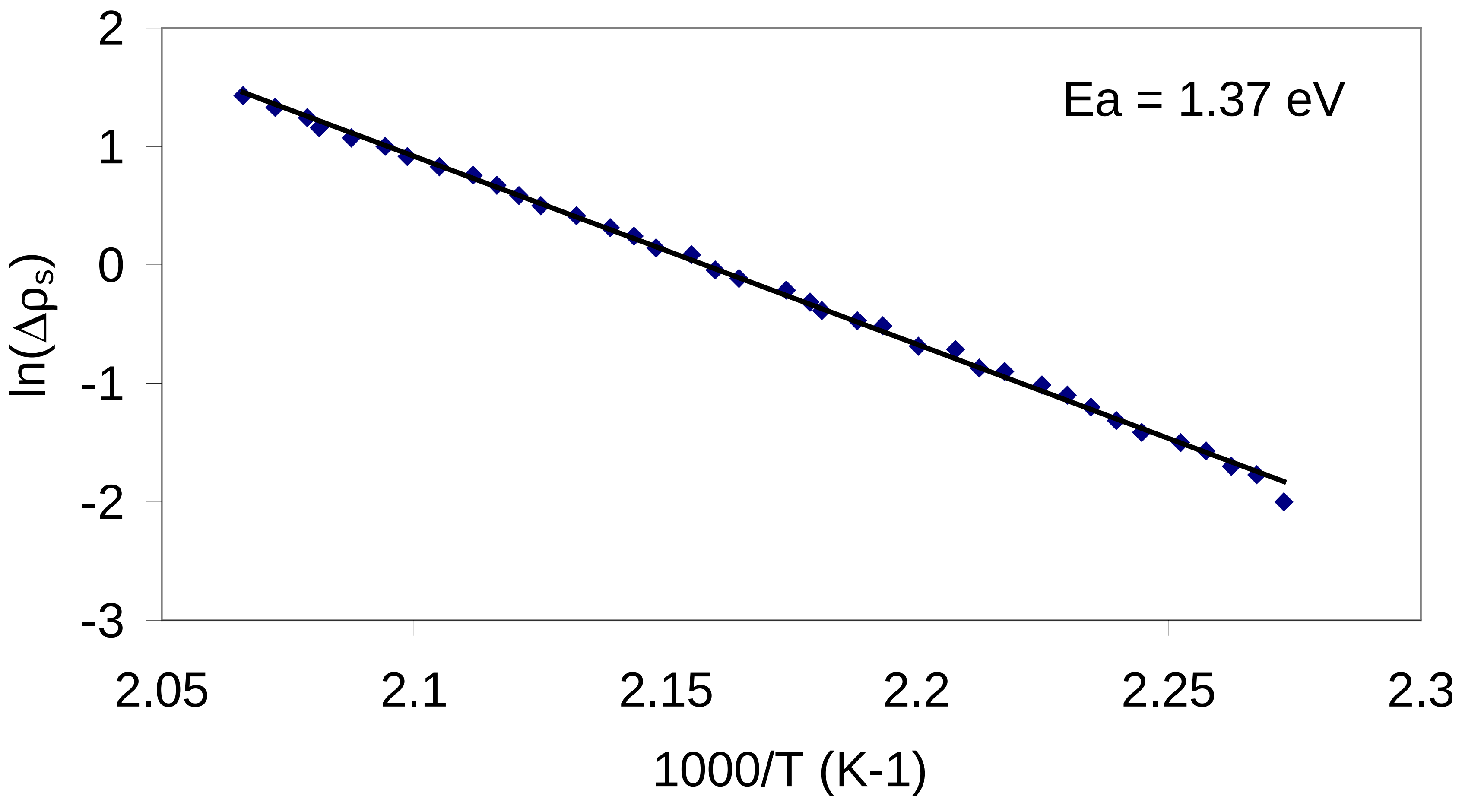
ρ_{sm} - measured sheet resistance

$\rho_c + \alpha T$ - sheet resistance change due to phonon scattering

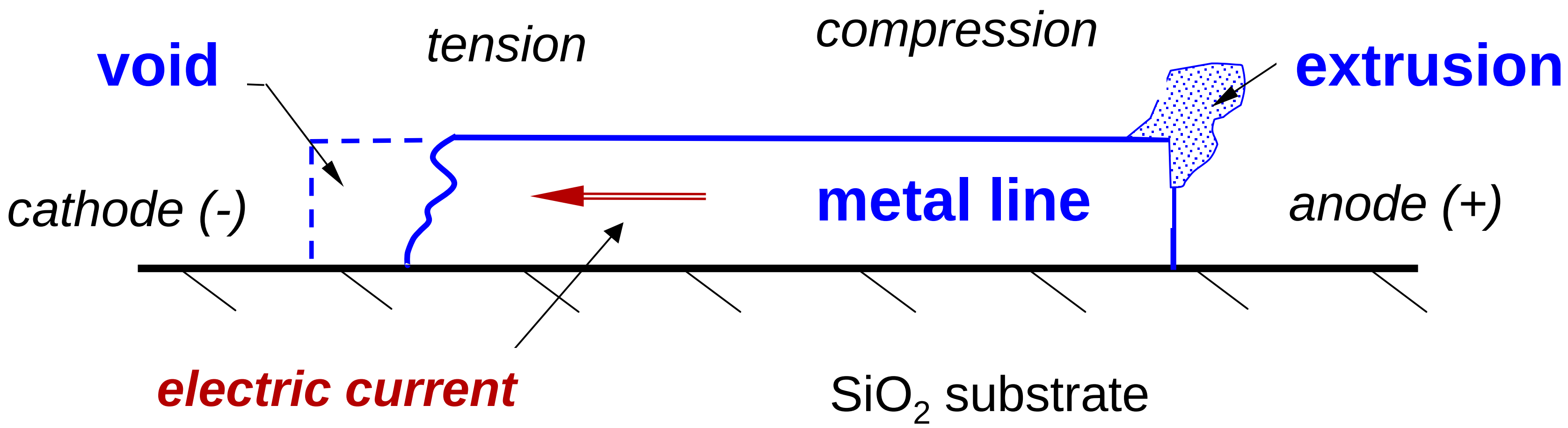
Sheet Resistance (SiO_2/Ag 60 nm, air, and 0.15 °C/sec) vs. Temperature.



Arrhenius plot of the sample shown in the previous slide

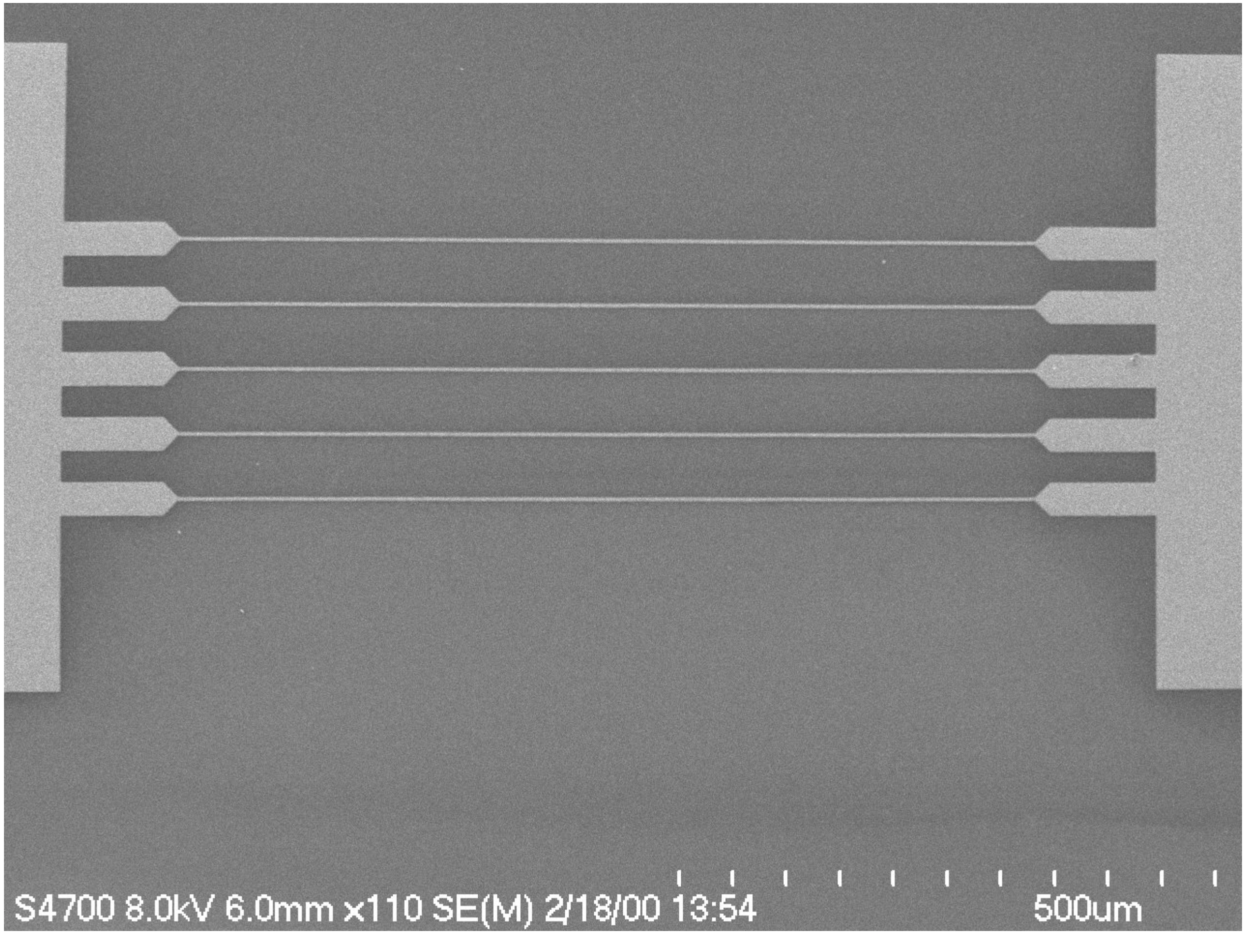


electromigration

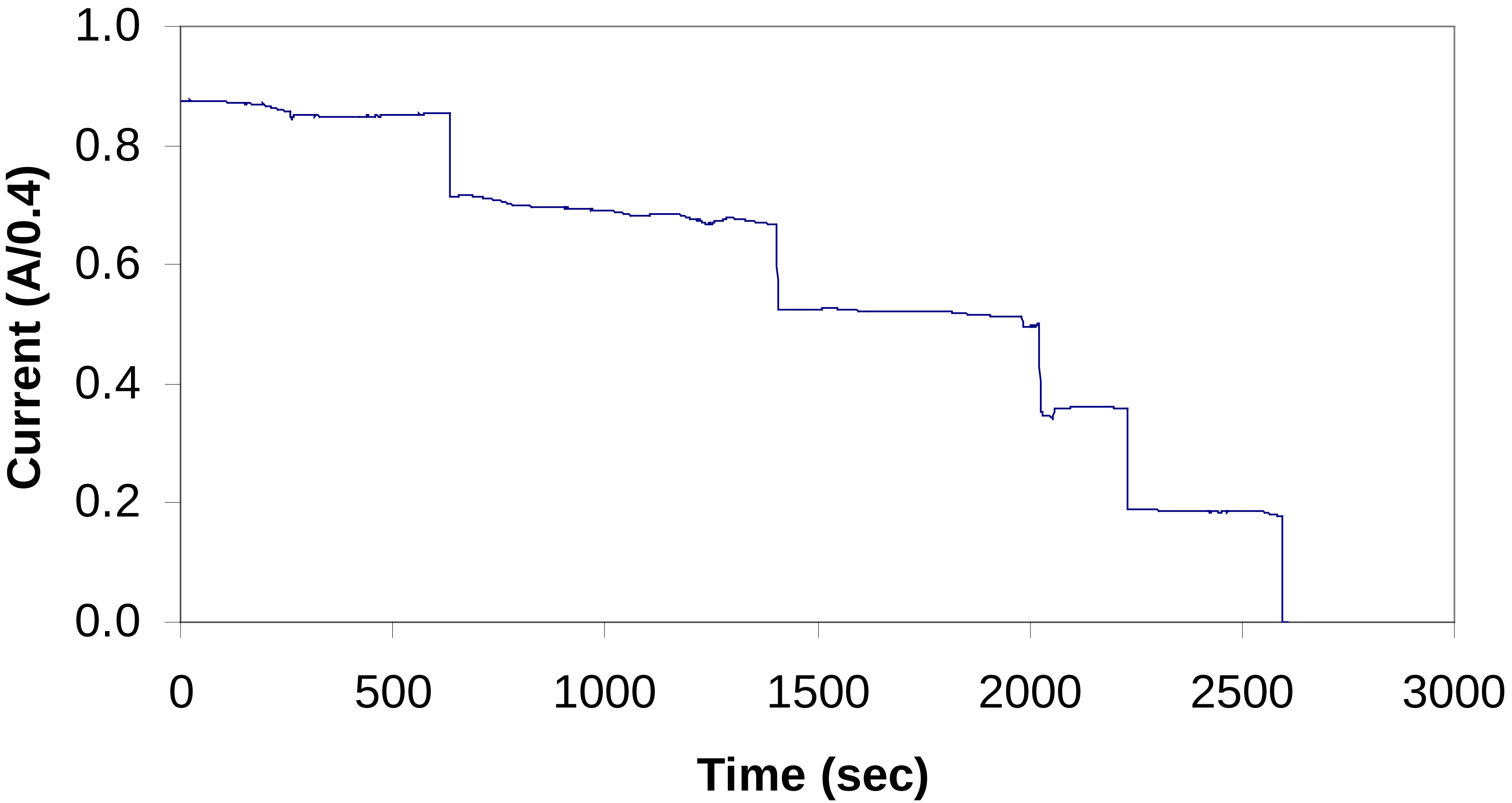


- ***mass transport at high current levels***
- ***critical failure mechanism***

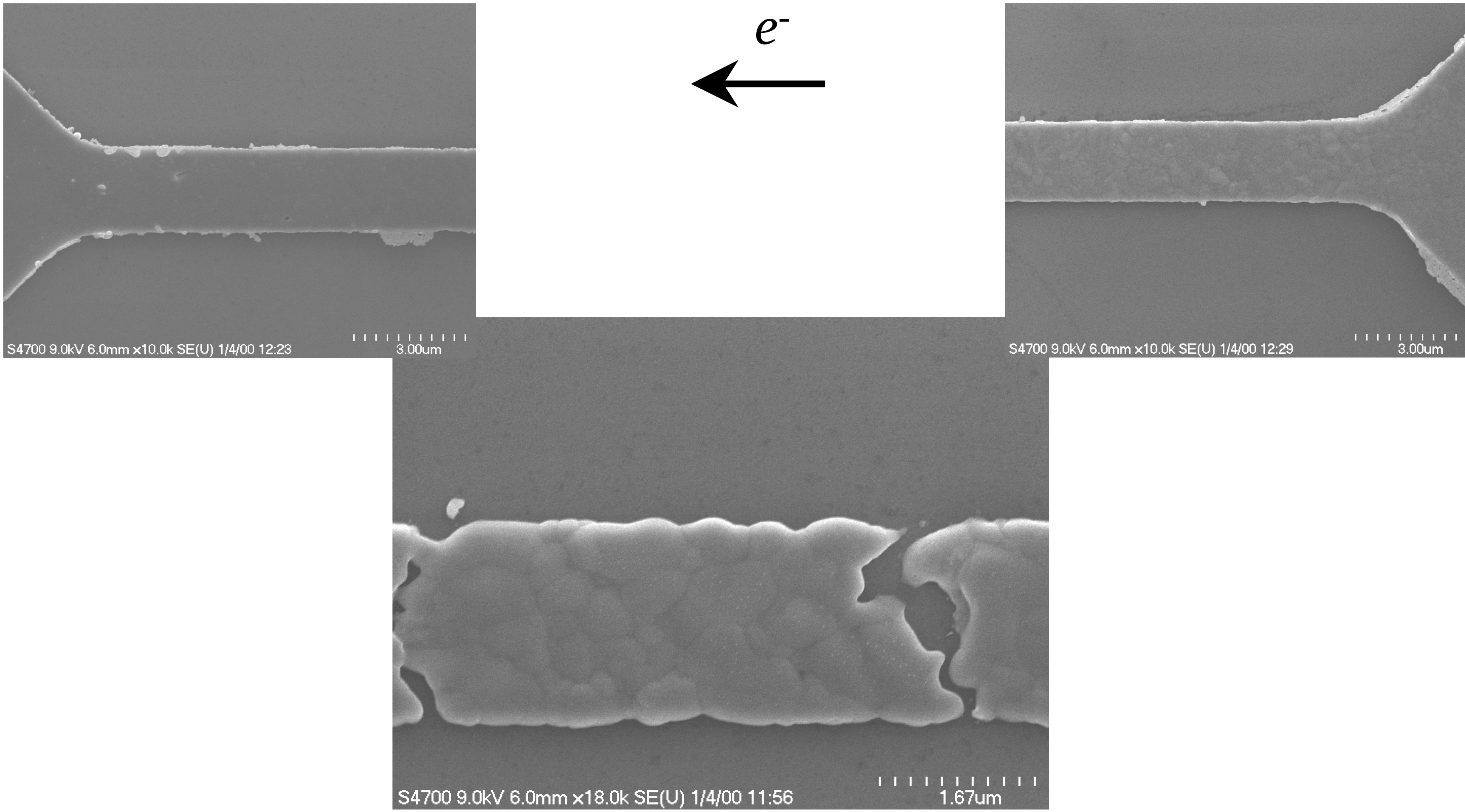
An EM Test Structure



Actual Current Measurements during EM test
200 nm Ag/SiO_2, J ~ 17.5 MA/cm^2, T ~ 160 ^oC



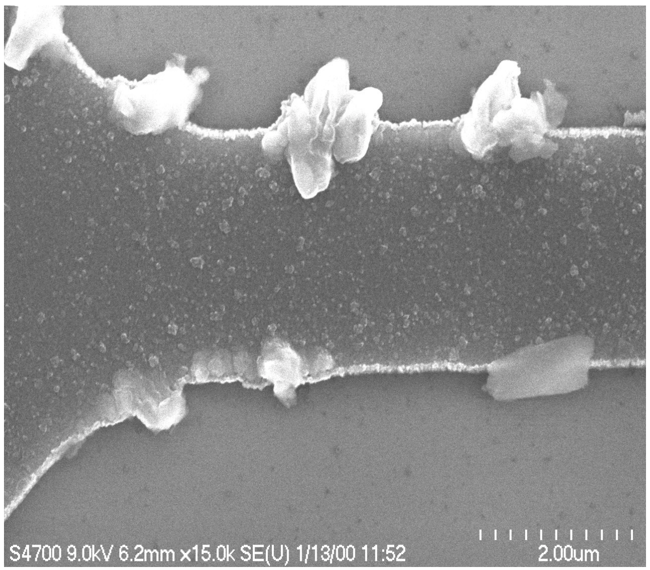
Ag/SiO_2, J ~ 22.5 MA/cm^2, T = 160 ^oC

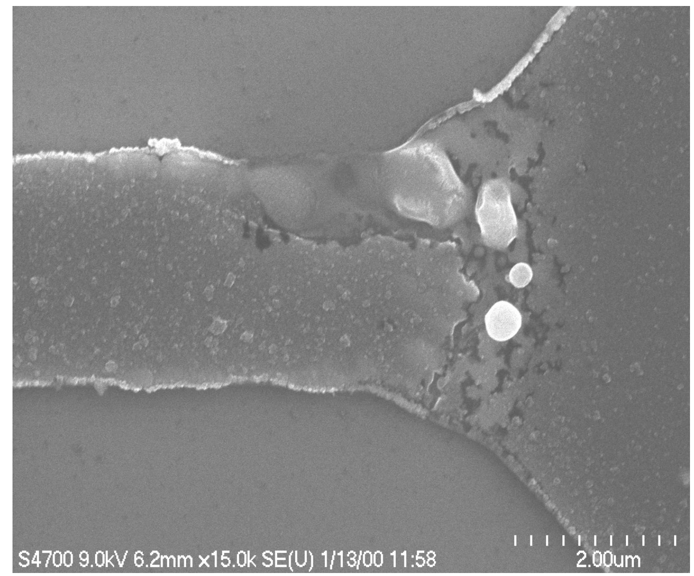


Al/SiO_2, J ~ 9 MA/cm^2, T = 160 ^oC

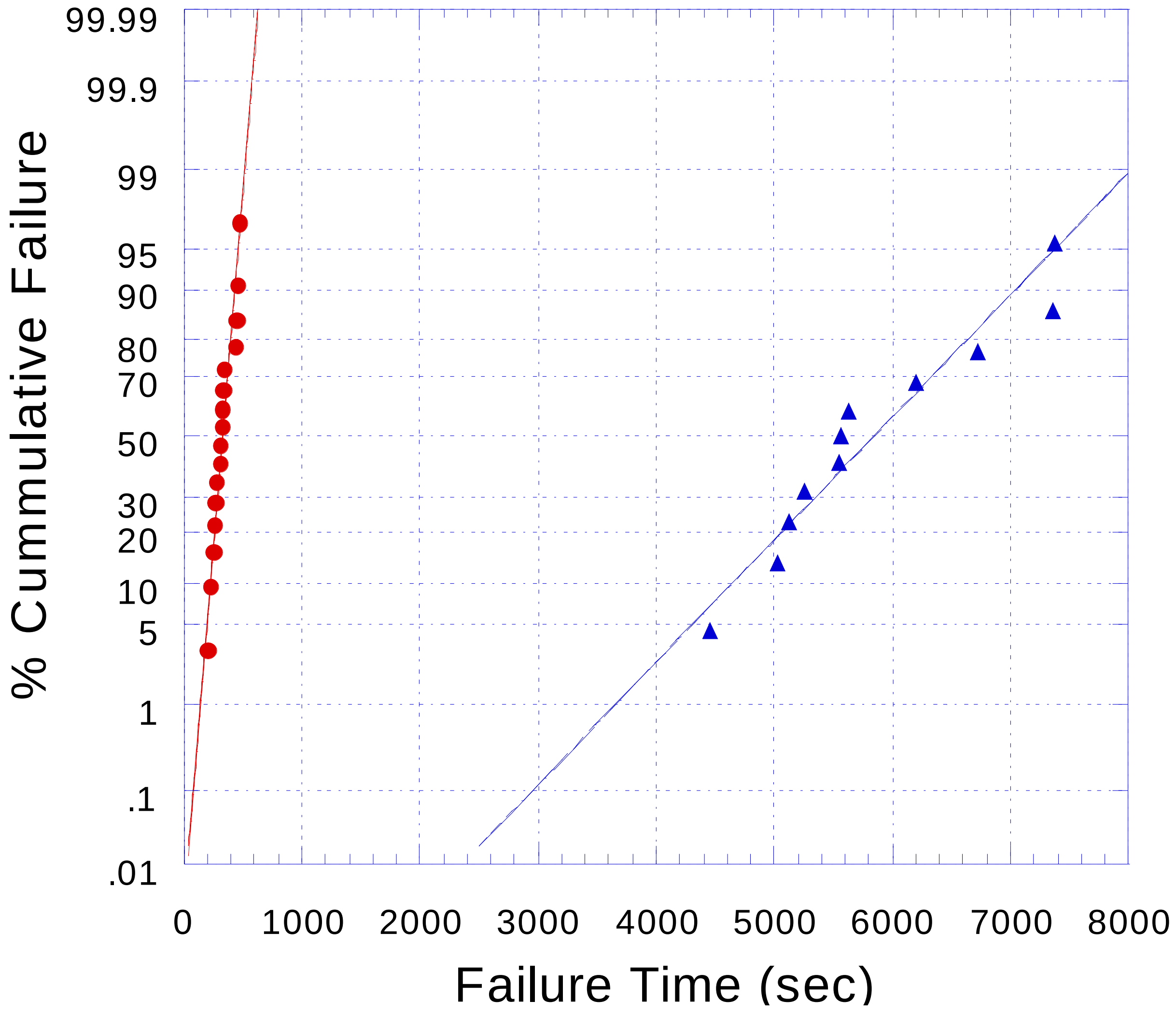
e^-

←



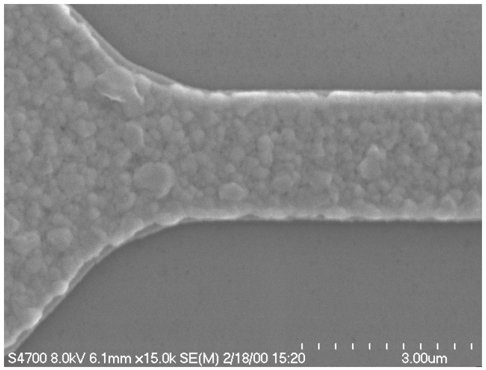


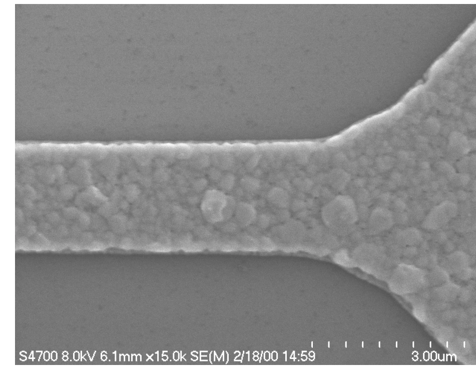
Ag/SiO_2 and Al/SiO_2, J ~ 9 MA/cm^2 T ~ 160°C

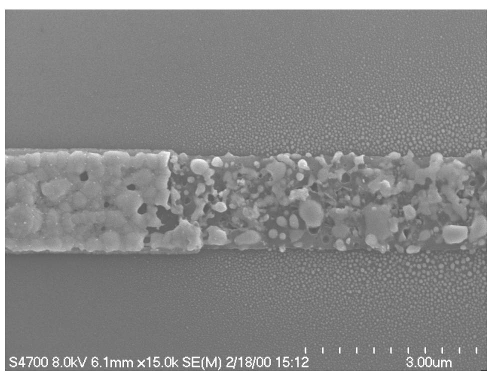


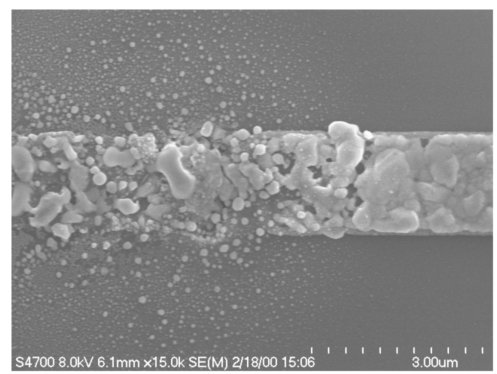
Ag/Ti/SiO_2, J ~ 18 MA/cm^2, T = 290 ^{o}C

e^- ←

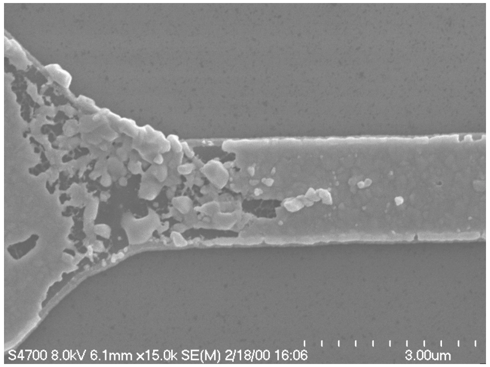


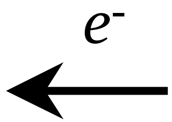


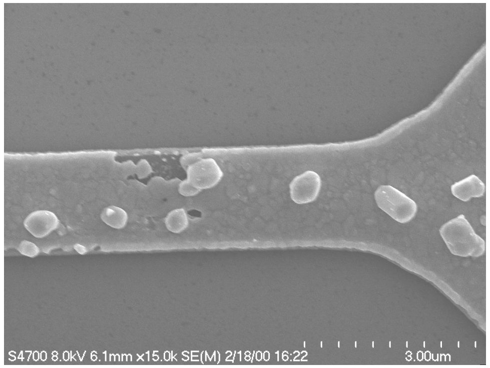


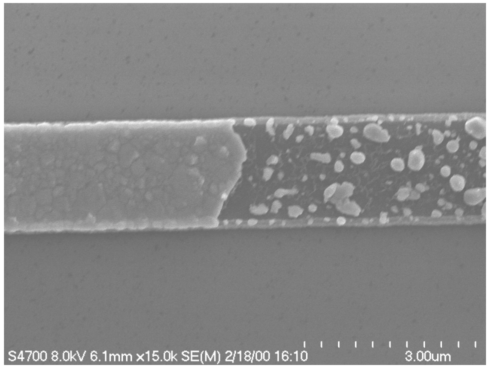


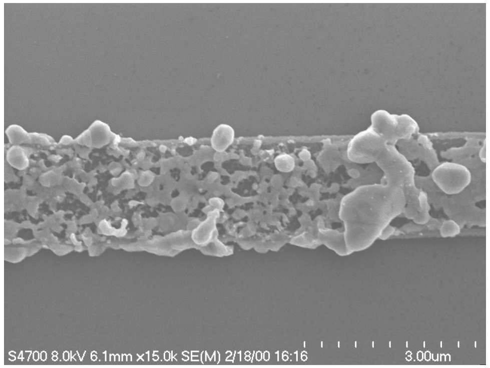
$TiON_x/Ag/SiO_2$, J ~ 18 MA/cm^2, T = 290 ^oC



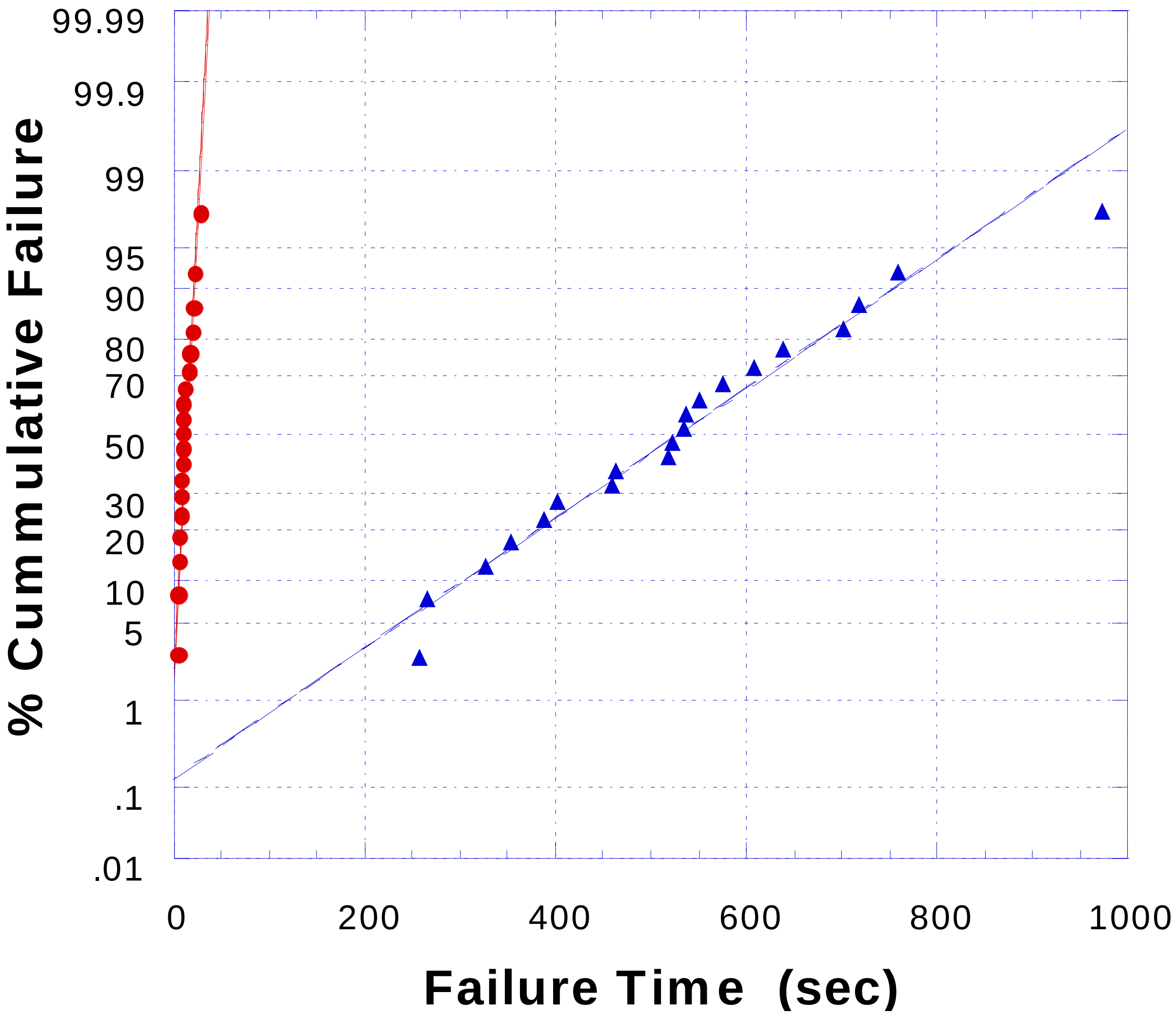




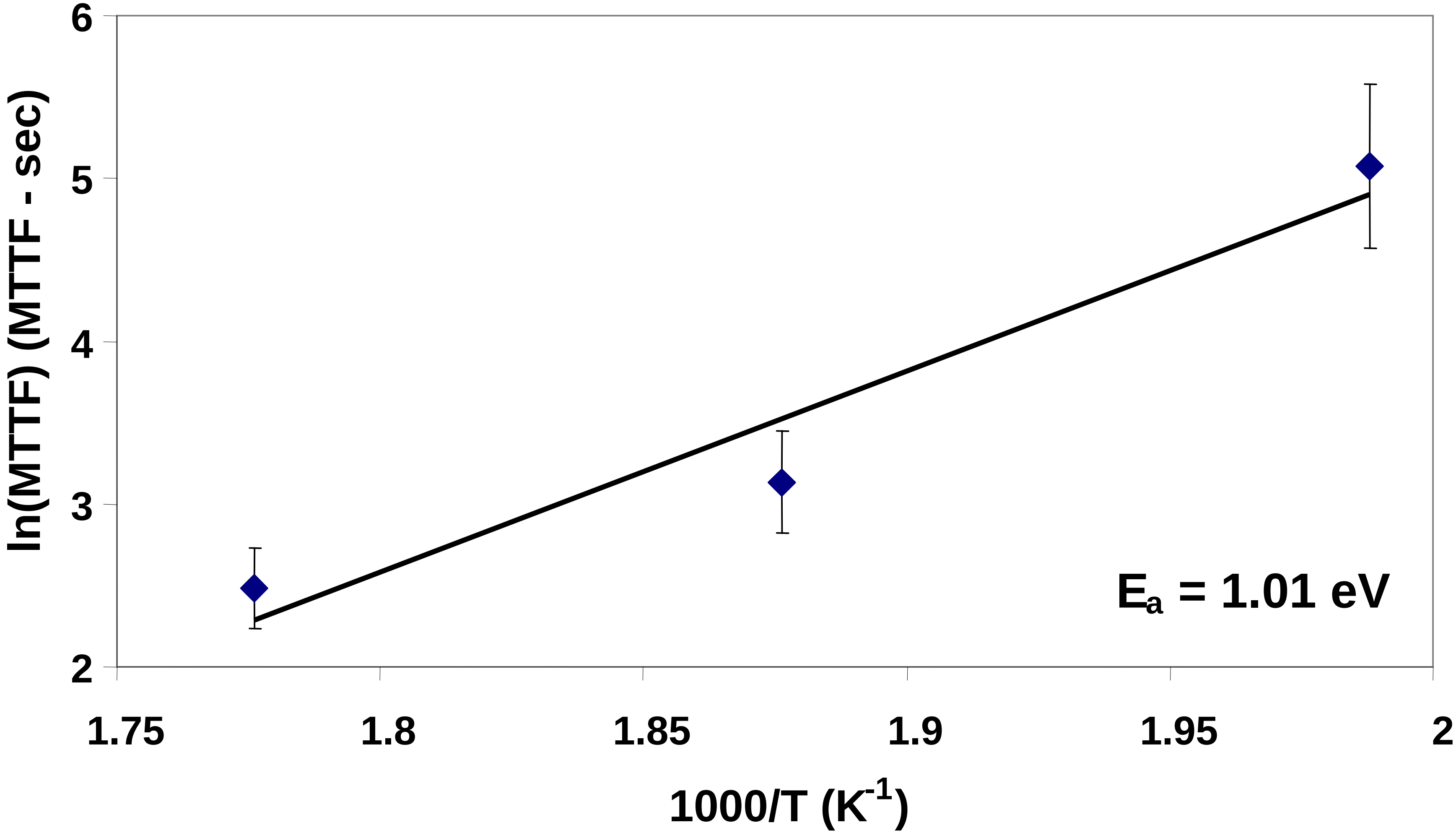


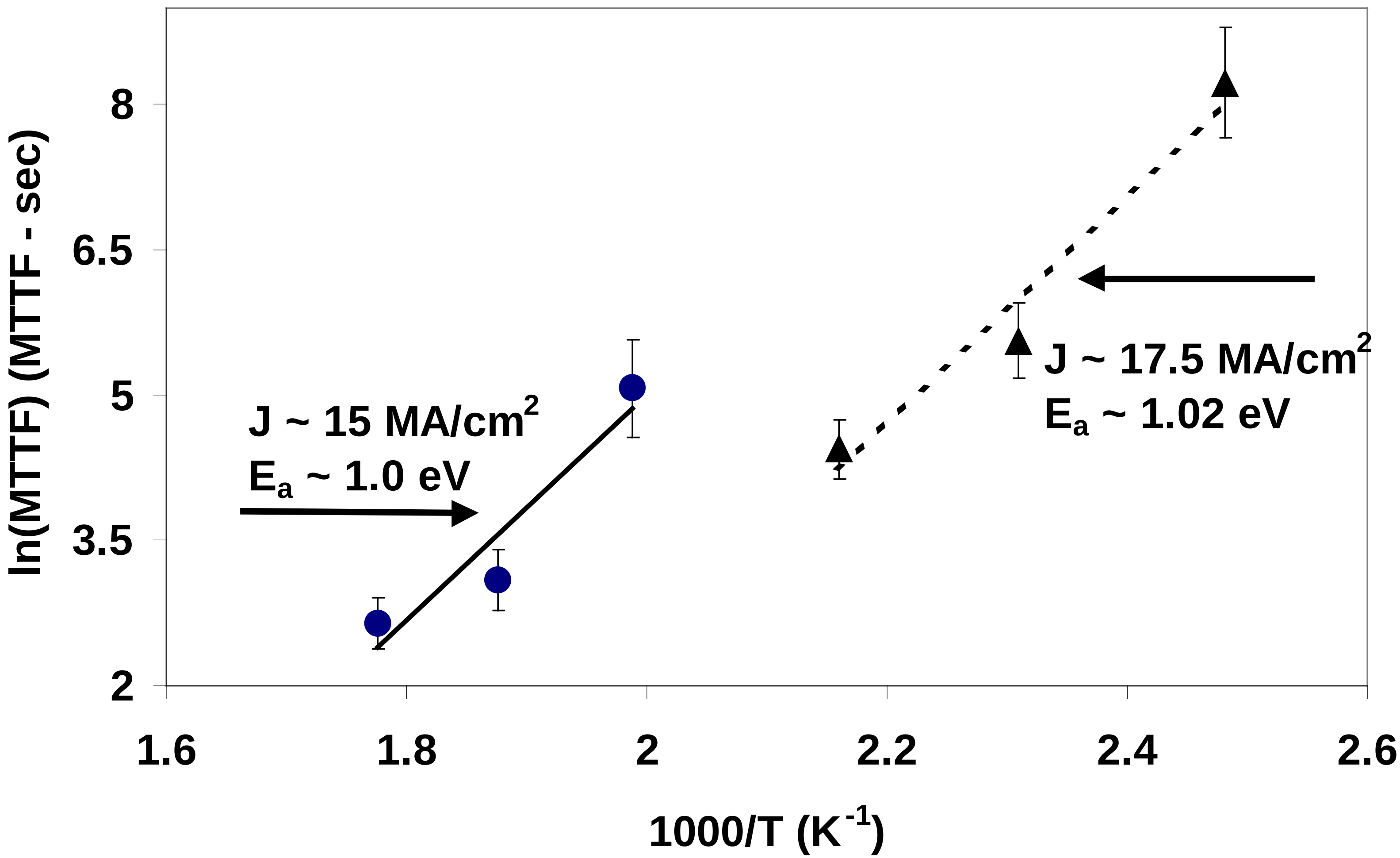


Ag/Ti and $TiON_x$/Ag/Ti, J~ 18 MA/cm^2, T ~ 290^{o}C



100 nm Ag/Ti/SiO_2 , J ~ 18 MA/cm^2 , 230 - 290 °C





ln(MTTF) (MTTF - sec)
8
6.5
5
3.5
2
1.6
1.8
2
2.2
2.4
2.6
1000/T (K-1)
J ~ 15 MA/cm2
Ea ~ 1.0 eV
J ~ 17.5 MA/cm2
Ea ~ 1.02 eV

EM Summary

- EM test at temperatures < T_i and at low current density:
  - Direction of transport is the same as that of electron flow
  - Voids form near to the cathode
  - More hillocks and less void from near the anode

- EM failure when tested at high current density show that open line is caused by slit-like formation

- EM activation energies (E_a) depend on current densities
  - E_a ~ 0.6 eV for J < 5 MA/cm^2
  - E_a ~ 1.0 eV for J >15 MA/cm^2

Silver Metallization

- **Lower ρ than Al and Cu** → ***Reduced RC Time Delay***
- **Higher Z and melting point**
- **Encapsulation process** → ***Improved Reliability***
- **Textured microstructure**
- **Dry etch capability** → ***Lower Fabrication Cost***