Electromigration in Solder Joints and Lines

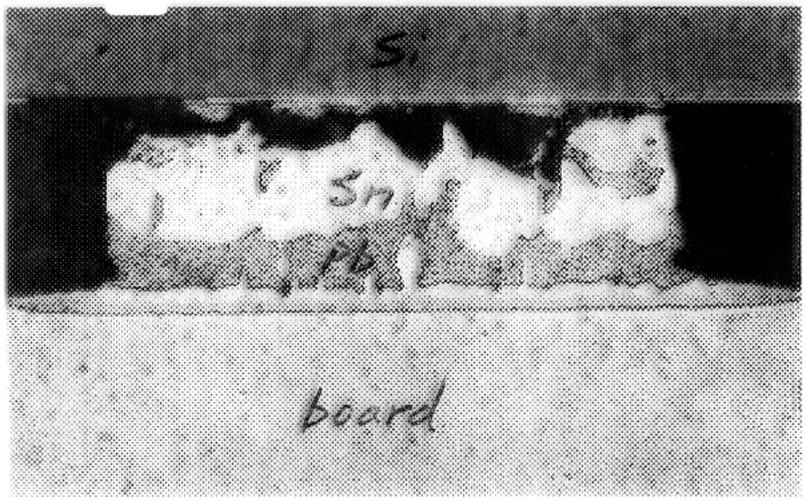
K. N. Tu, Xu Gu, Hua Gan, and W. J. Choi
Dept. of Materials Science &Engineering, UCLA
Los Angeles, CA 90095-1595

1. **Introduction**
2. **Unique behavior or electromigration in solder joints**
3. **Electromigration of flip chip solder joints**
   - SnPb vs. Pb-free (SnAgCu)
4. **Electromigration of solder lines in V-groove**
   - Temperature, composition, and polarity
5. **Summary**

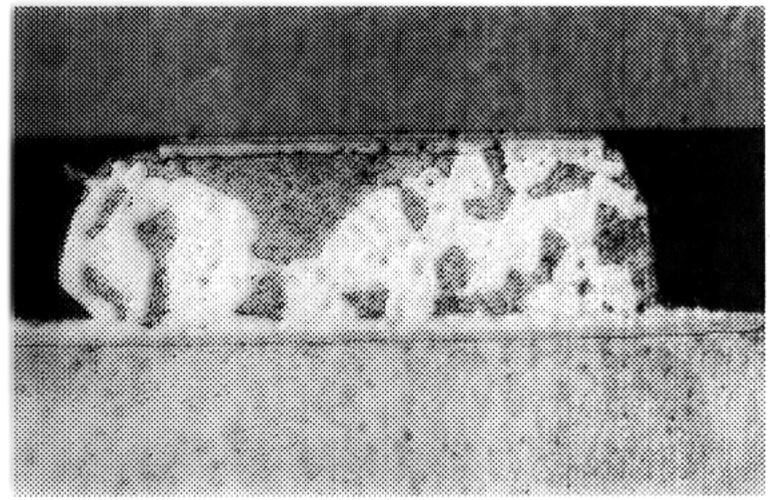
• Supported by NSF,SRC, IBM, Intel, Motorola

Co-workers : Dr. Everett C. Yeh, Intel, Santa Clara, CA
Prof. C. Y. Liu, National Central University, Taiwan
Prof. C. Chen, National Chiao Tung University, Taiwan
Dr. Taek Yeong Lee, Bell Lab. Lucent Technologies
Drs. P. Elenius & H. Balkan, Flip Chip Technologies

63Sn/Pb Electromigration Example



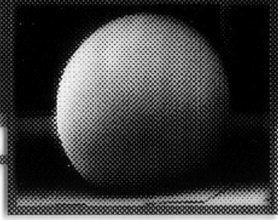
Bump Connected to Positive Terminal on Substrate (bottom)



Bump Connected to Negative Terminal on Substrate (bottom)

Peter Elenius, Flip Chip Technologies, (1999)

Electromigration Model (Black's)

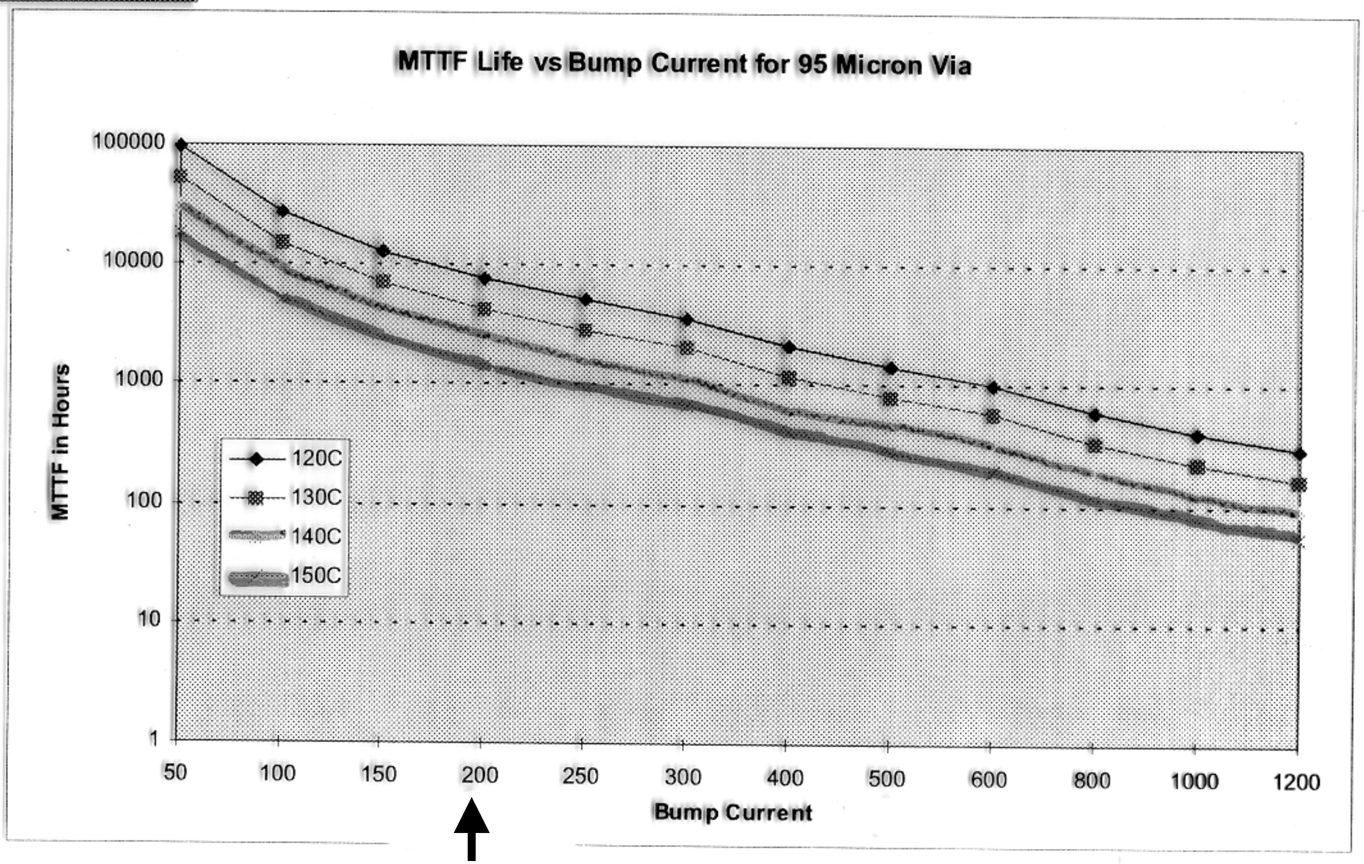


$$\mathrm{MTTF}(J,T) = \left(\frac{A}{J^{n}}\right)\cdot \exp\left(\frac{Ea}{k\cdot T}\right)$$

MTTF = Mean Time to Failure (hours)
J = Current Density (amp/cm2)
T = Average Bump Temperature (K)
K = Boltzman Constant (8.616 X 10-5 eV/K)
Ea = Activation Energy (0.8 eV)
n = model parameter for Current Density (1.82)
A = Constant (0.80)

Peter Elenius, Flip Chip Technologies, (1999)

MTTF vs Bump Current for 95μm Via



Peter Elenius, Flip Chip Technologies, (1999)

Unique Features of Electromigration in Solder Joints

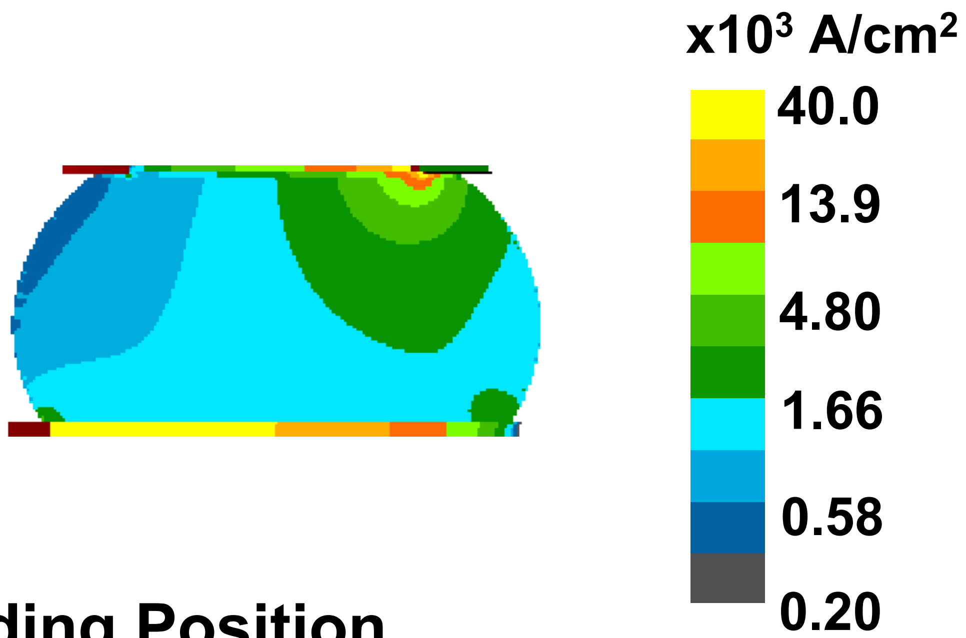
1. Geometry (Line-to-bump)
   - Current crowding and local Joule heating

2. Eutectic Composition
   - No chemical potential gradient as a function of composition
   - It can lead to a large composition gradient or redistribution

3. UBM dissolution
   - Fast diffusion of noble and near-noble elements in solder

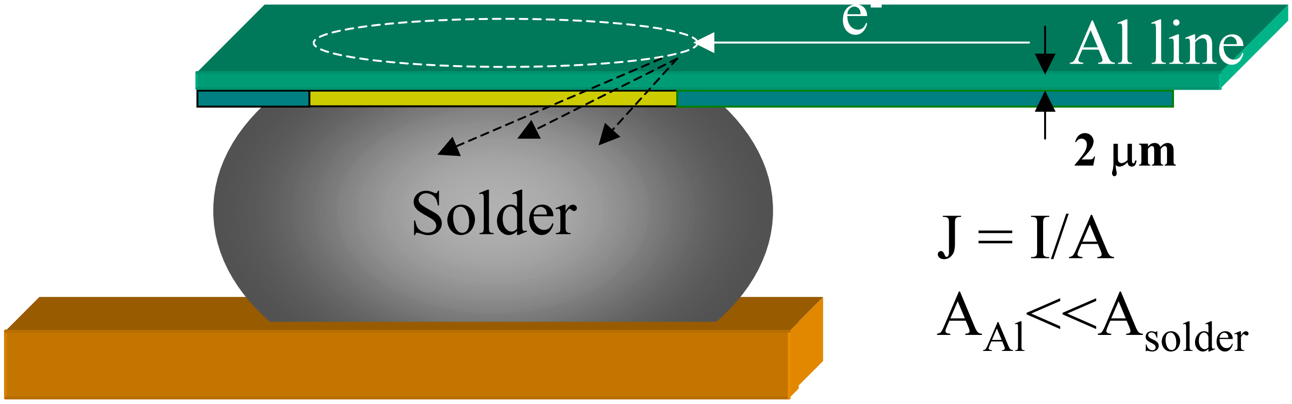
4. Multiple driving forces
   - Thermo-mechanical,chemical, electrical

Current Density Distribution



<u>2 μm UBM</u>

Current Crowding Position

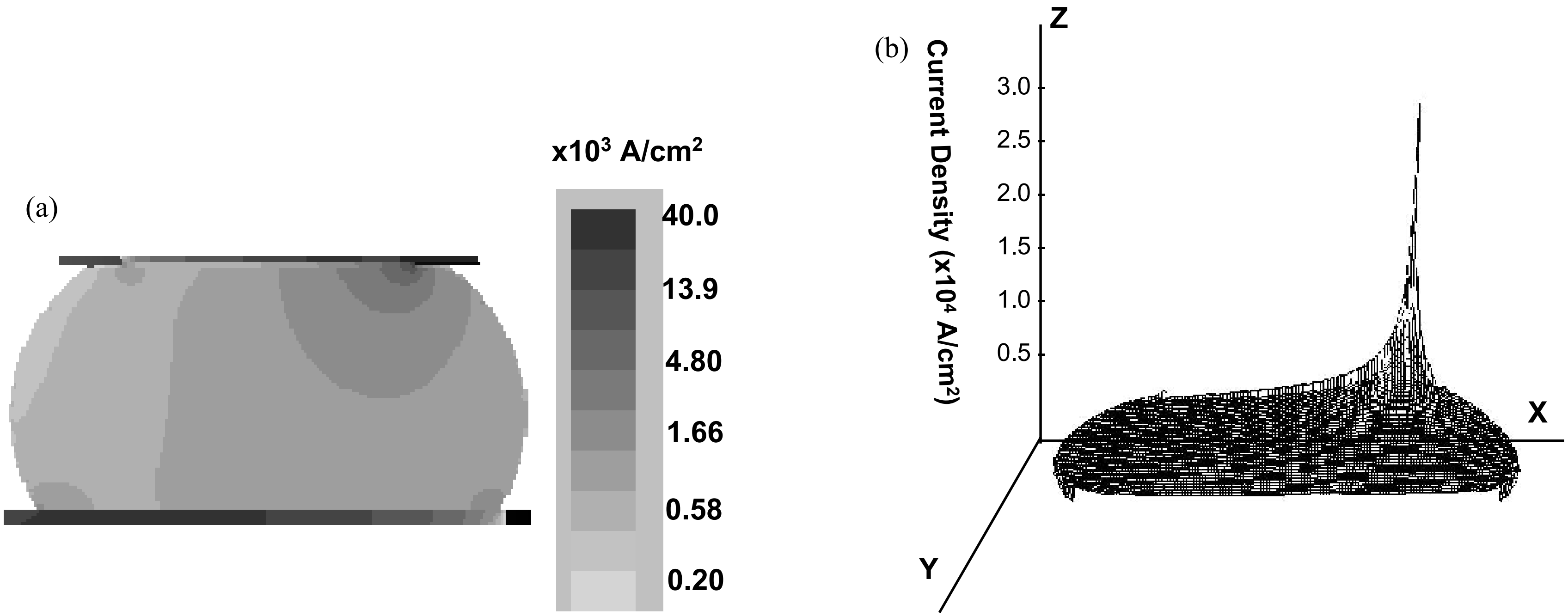


$J = I/A$

$A_{Al} << A_{solder}$

Simulation of current crowding in the solder bump

- Current carried by solder bump : 0.2 Amps
- Thickness of Al interconnection : 2 μm
- Contact window (opening) : 100 × 100 μm²



Void Propagation (e-SnPb solder)

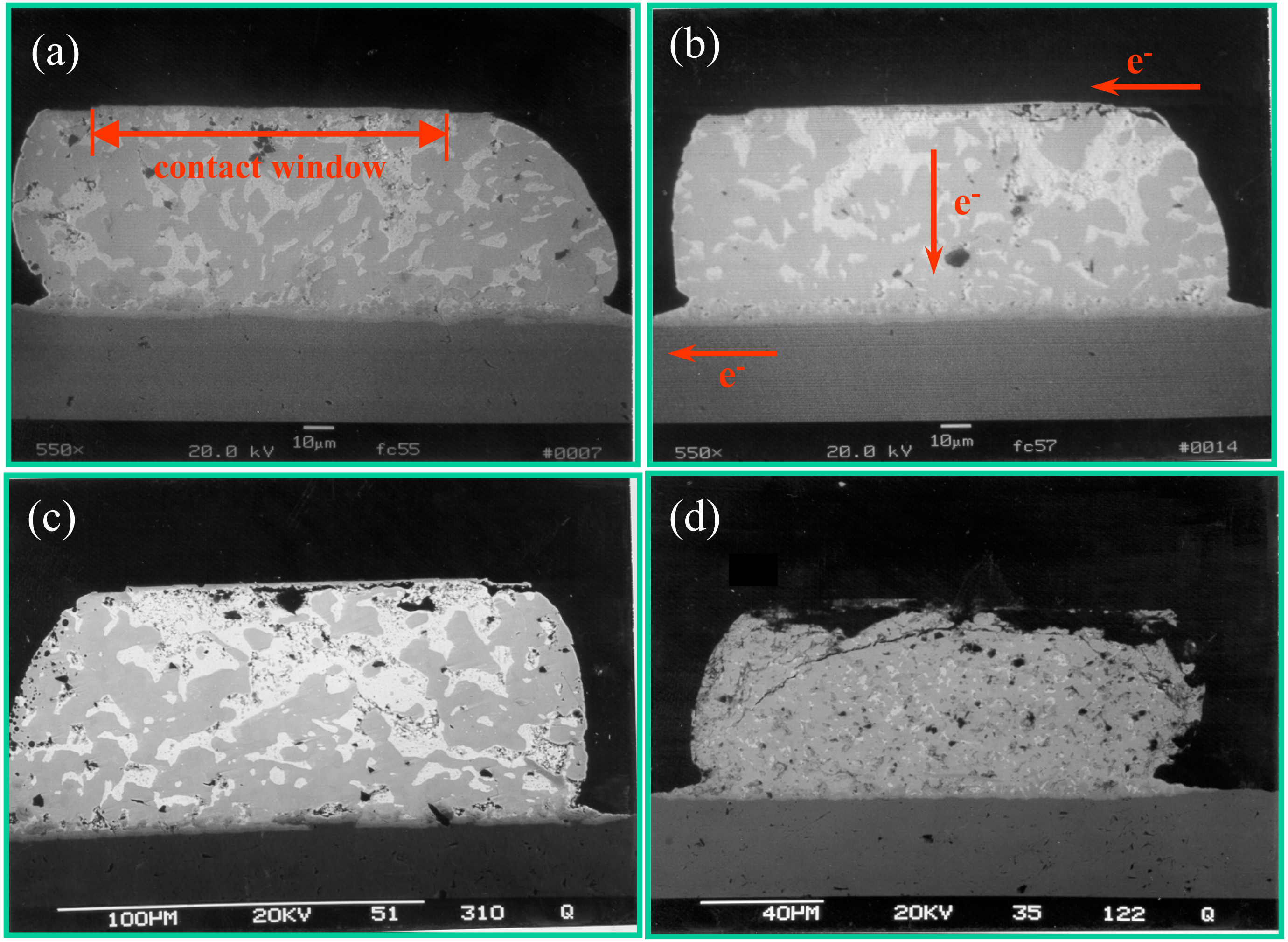
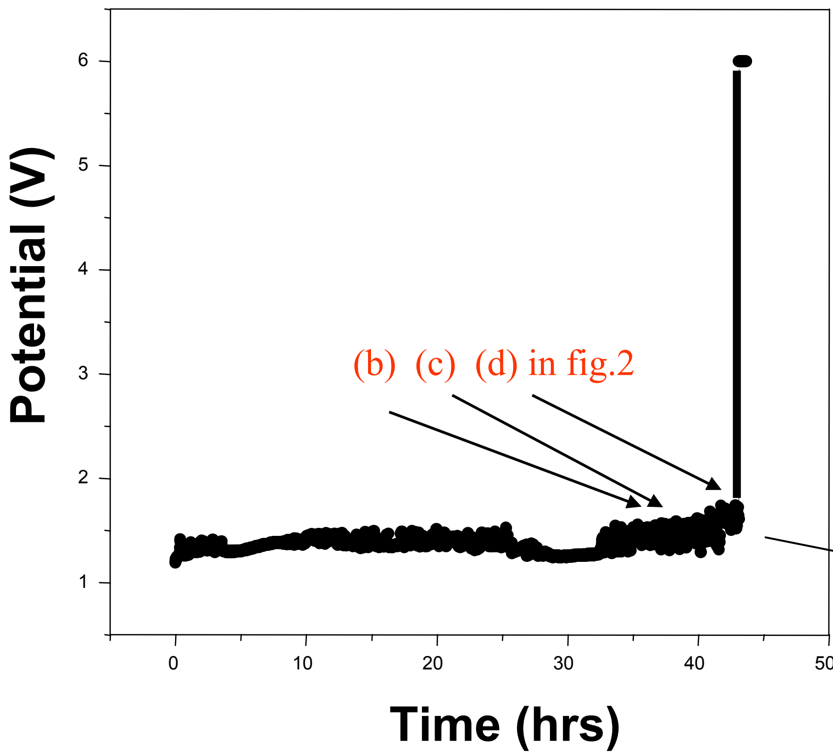
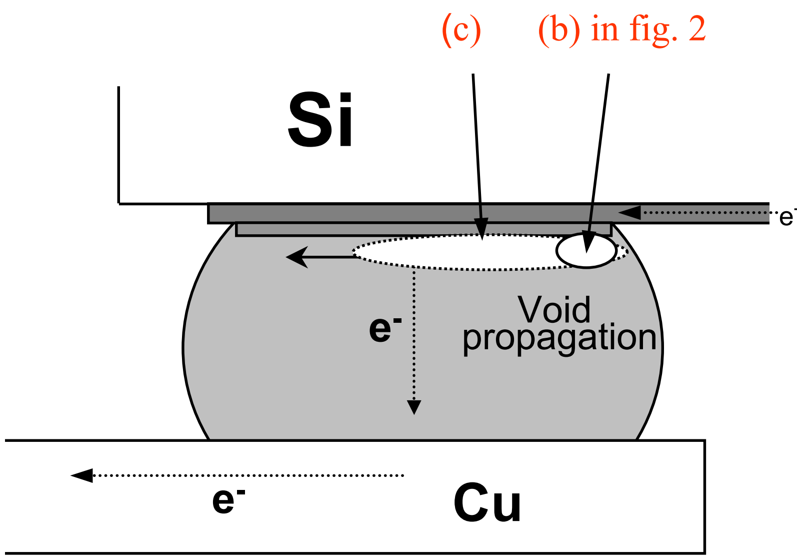


Fig. Sequence of the void propagation at 125 ^oC, and 2.25×10^4 A/cm^2
(a) 37 hrs (b) 38 hrs (c) 40 hrs (d) 43 hrs

Time - Potential Curve





Resistance does not change much

Fig. Potential change of the solder bump due to the electromigration

Mean Time To Failure

$$MTTF = Aj^{-n} exp\left(\frac{Q}{kt}\right)$$

n = 1.8, Q = 0.8 eV
(By Flip Chip Technologies)

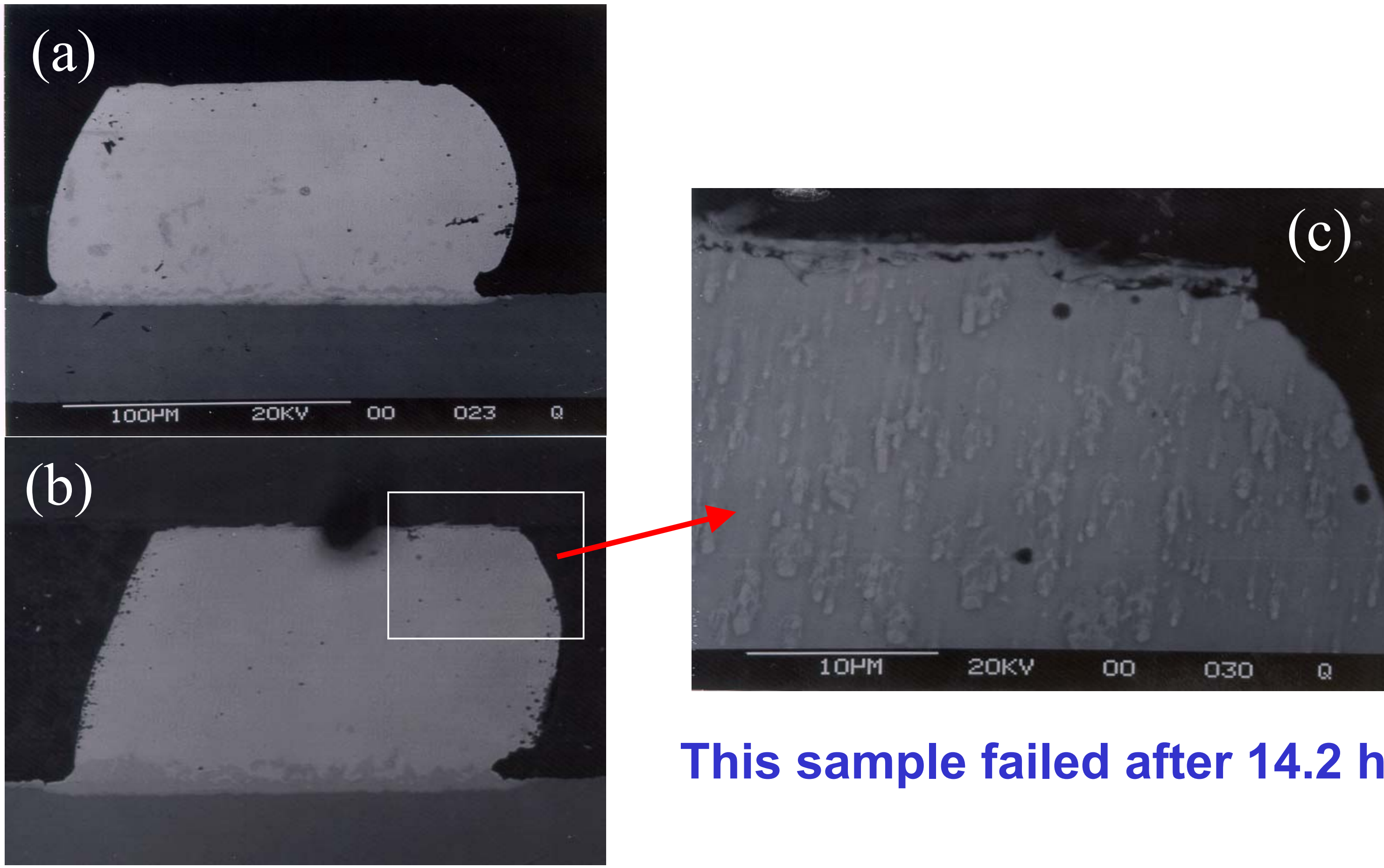
(hrs)

	1.5 A ($1.9x10^4$ A/cm^2)		1.8 A (2.25 x10^4 A/cm^2)		2.2 A (2.75 x10^4A/cm^2)	
	Expected	**Actual**	**Expected**	**Actual**	**Expected**	**Actual**
100 ^{o}C			380	97	265	63
125 ^{o}C	108	573*	79.6	43	55.5	3
140 ^{o}C	46	121	34	32	24	1

* not failed, These MTTF are averaged value of three samples

24 samples tested (three samples for each test condition)
8 samples cross-sectioned **by W.J.Choi**

Failure Mode in Pb-free (SnAgCu) Solder Bump



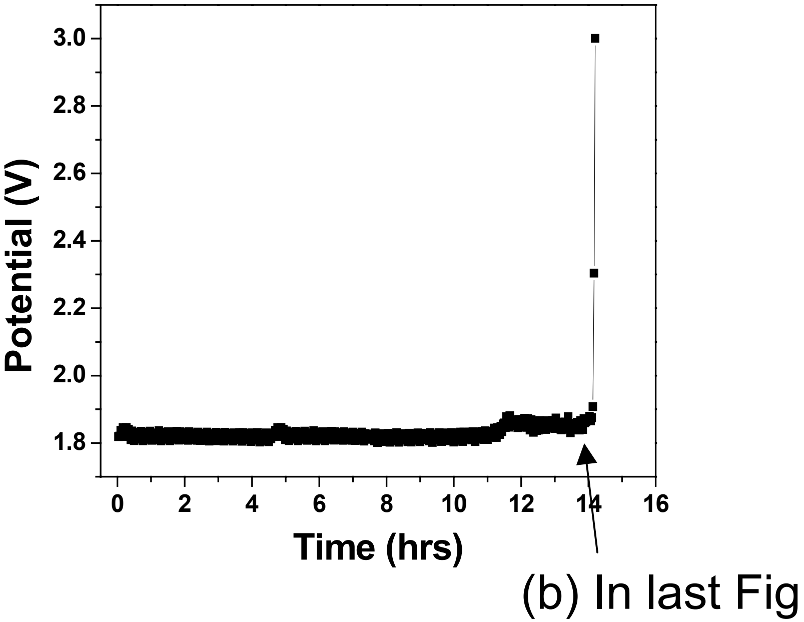
This sample failed after 14.2 hrs

Fig. Void propagation and failure at 140 °C and 2.4 Amps (3.0E4 A/cm^2)
(a) Before current stressing (b) After 14 hours : not failed
(c) Magnified picture of (b)

Failure in SnAgCu Solder bump on Thin Cu/Ni(V)/Al UBM

MTTF on SnAgCu solder bump

	1.8 A 2.25E4 A/cm^2	2.2 A 2.75E4 A/cm^2	2.4 A 3.0E4 A/cm^2
125 ^{o}C	580 hrs	112 hrs	83 hrs
140 ^{o}C	132 hrs	94.5 hrs	14.2 hrs
160 ^{o}C	99 hrs	21 hrs	2 hrs



140 ^{o}C , 2.4 Amps

UBM (Under Bump Metallization) Study for Pb-free Electroplating Bumping : Interface Reaction and Electromigration

Se-yeong Jang, Juregen Wolf, Woon-Seong Kwon, Kyung-Wook Paik
Dept. of Materials science and Engineering
KAIST (Korea Advanced Institute of Science and Technology)

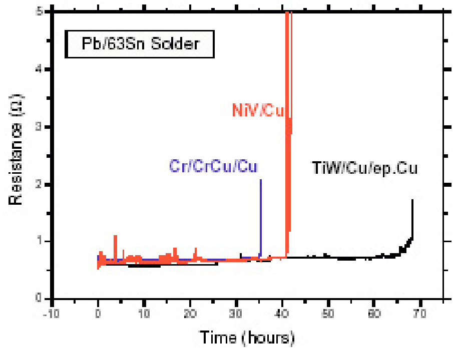


Fig.6 The resistance change vs time for Pb/63Sn solder bumps on three different UBMs.
($J = 3.58 \times 10^4$ A/cm^2, T = 140 °C)

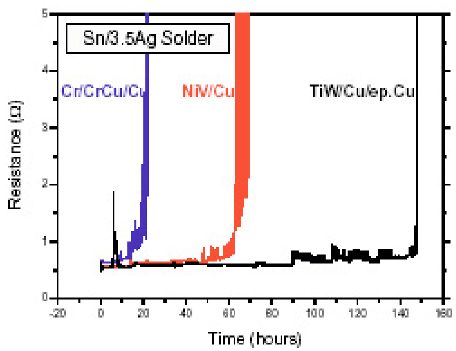


Fig.8 The resistance change vs time for Sn/3.5Ag solder bumps on three different UBMs.
($J = 3.58 \times 10^4$ A/cm^2, T = 140 °C)

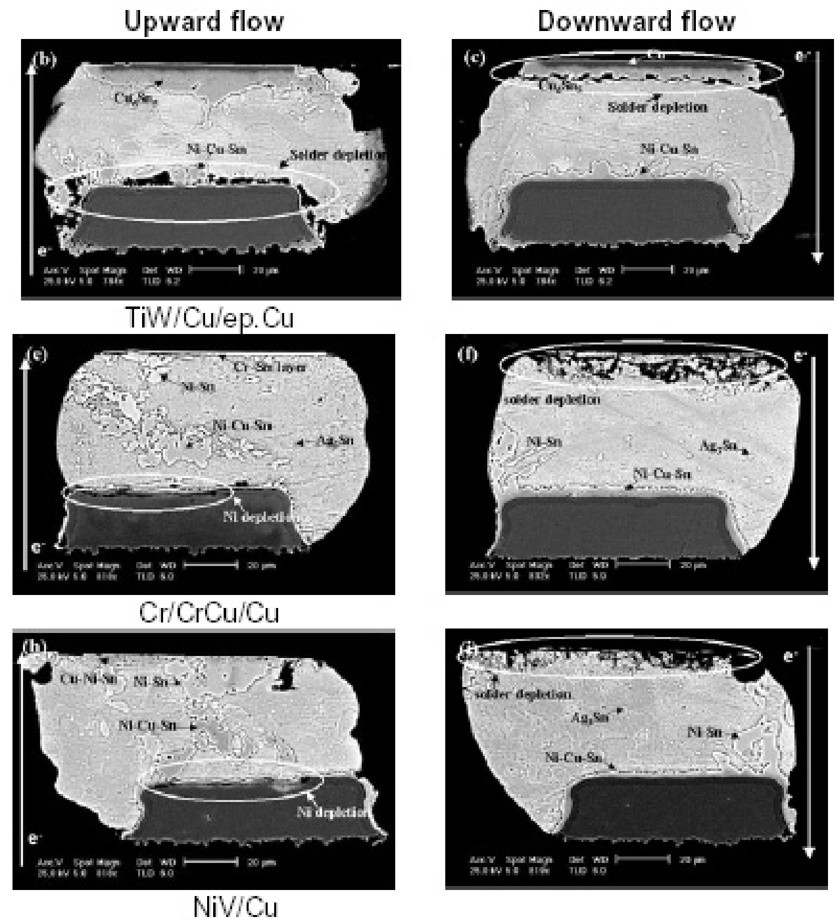
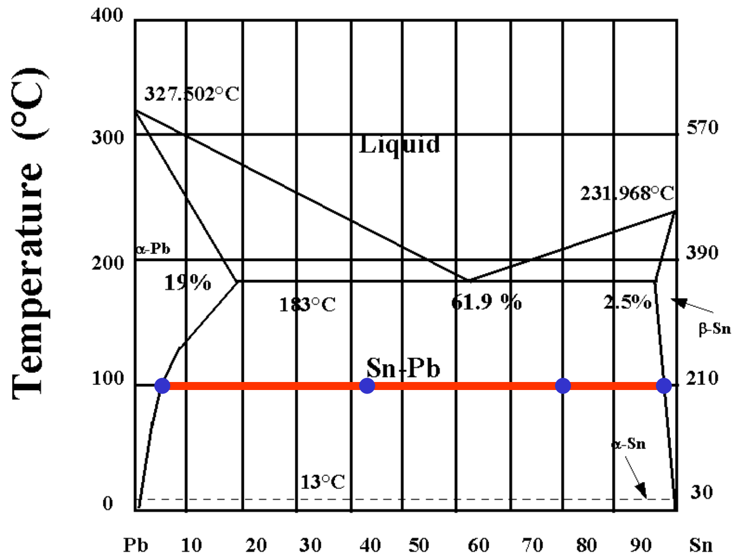
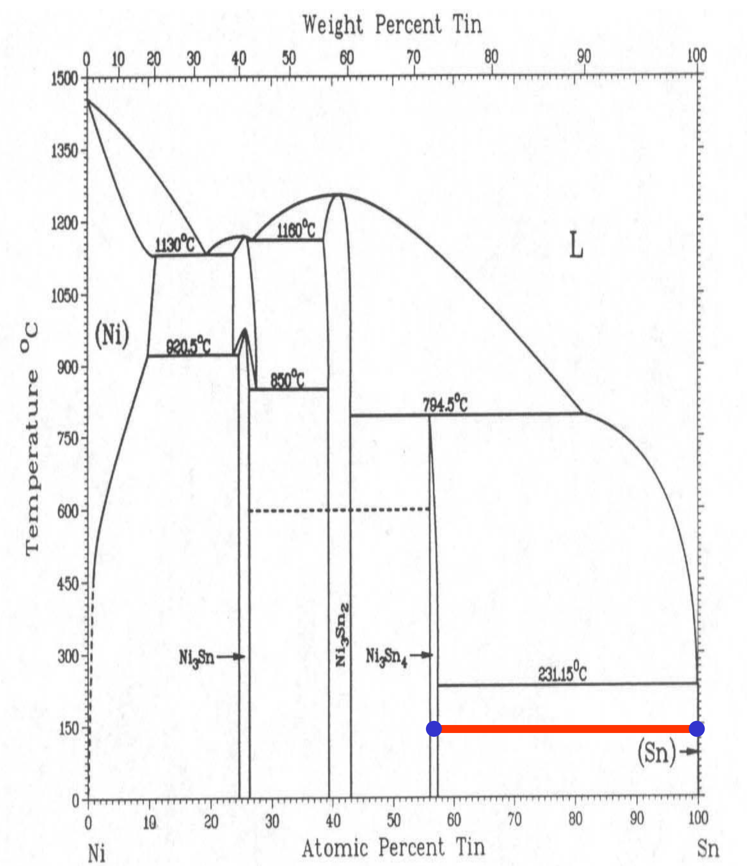


Fig.9 Cross-sectional images of Sn/3.5Ag bumps after thermo-electromigration failure

No chemical potential gradient as a function of composition below the eutectic temperature



Pb-Sn



Ni-Sn

Failure of SnAgCu Solder Bump on Thick Film UBM

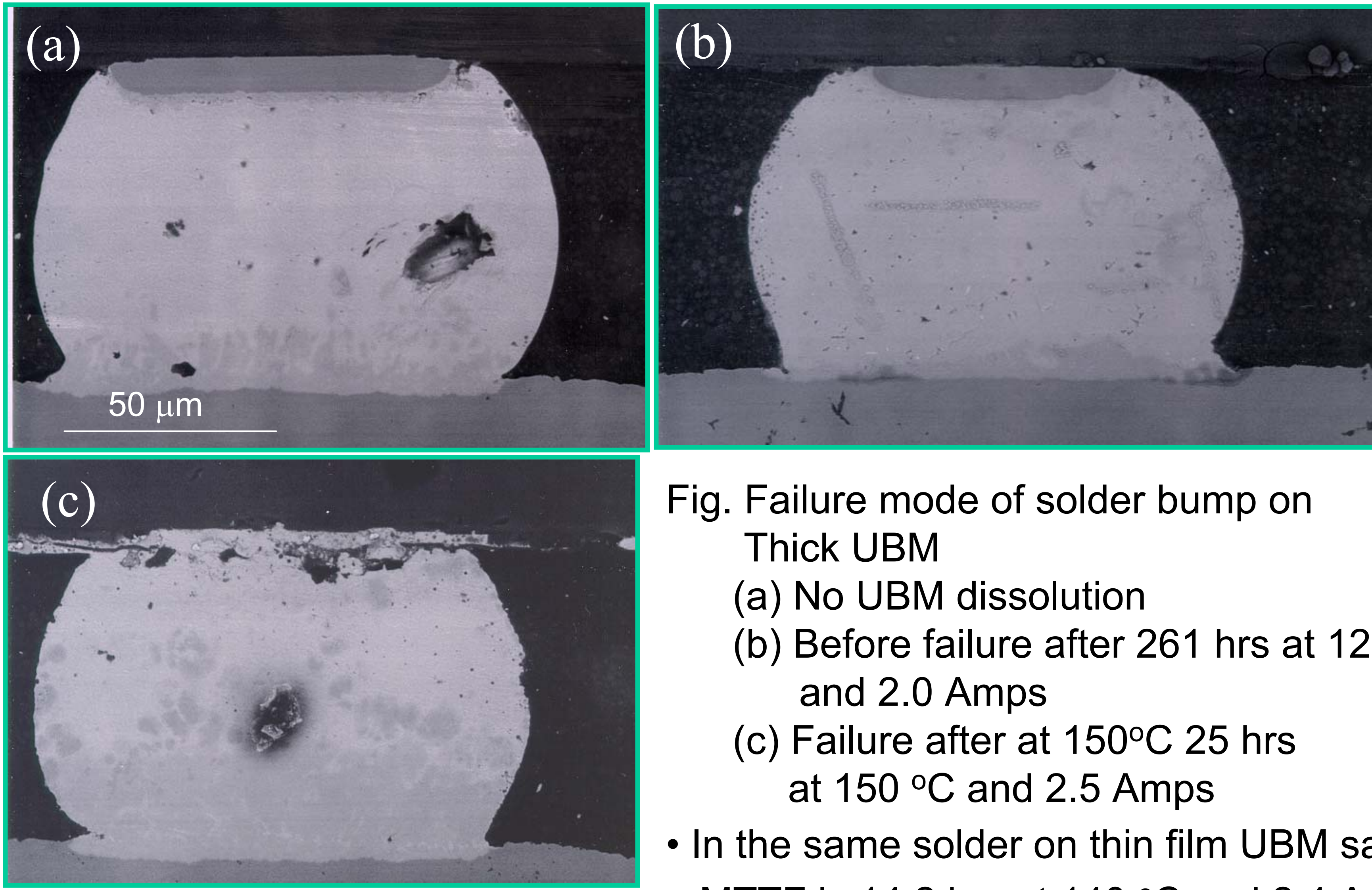
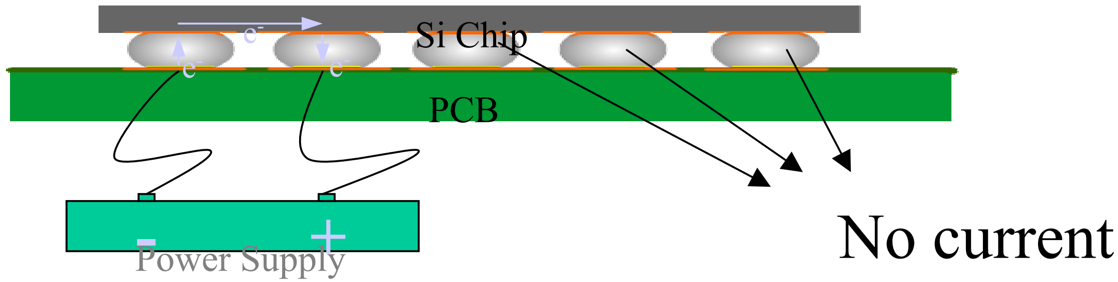


Fig. Failure mode of solder bump on Thick UBM
(a) No UBM dissolution
(b) Before failure after 261 hrs at 125^{o}C and 2.0 Amps
(c) Failure after at 150^{o}C 25 hrs at 150 ^{o}C and 2.5 Amps

- In the same solder on thin film UBM sample, MTTF is 14.2 hrs at 140 ^{o}C and 2.4 Amps

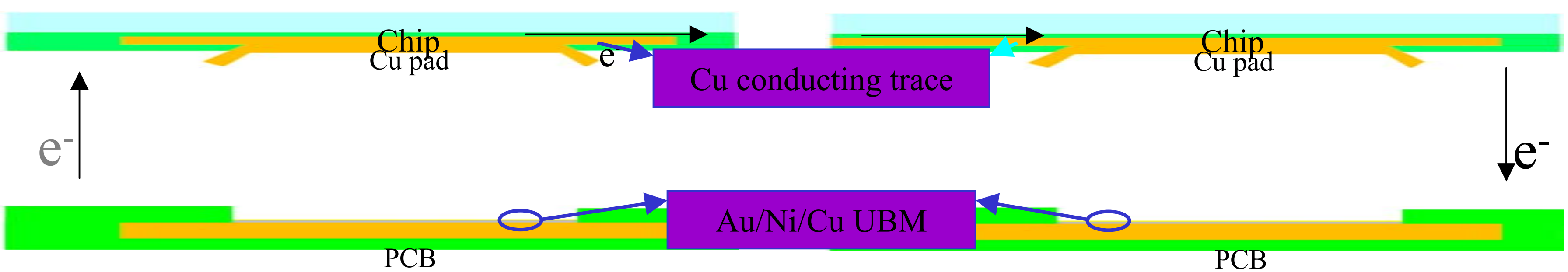
Experiment



Schematic diagram of experimental setup.

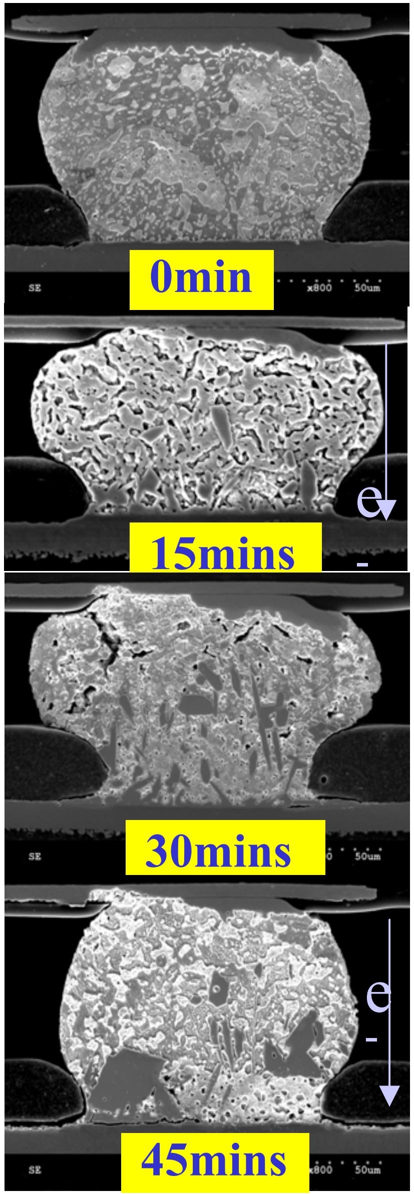
Experimental Conditions:

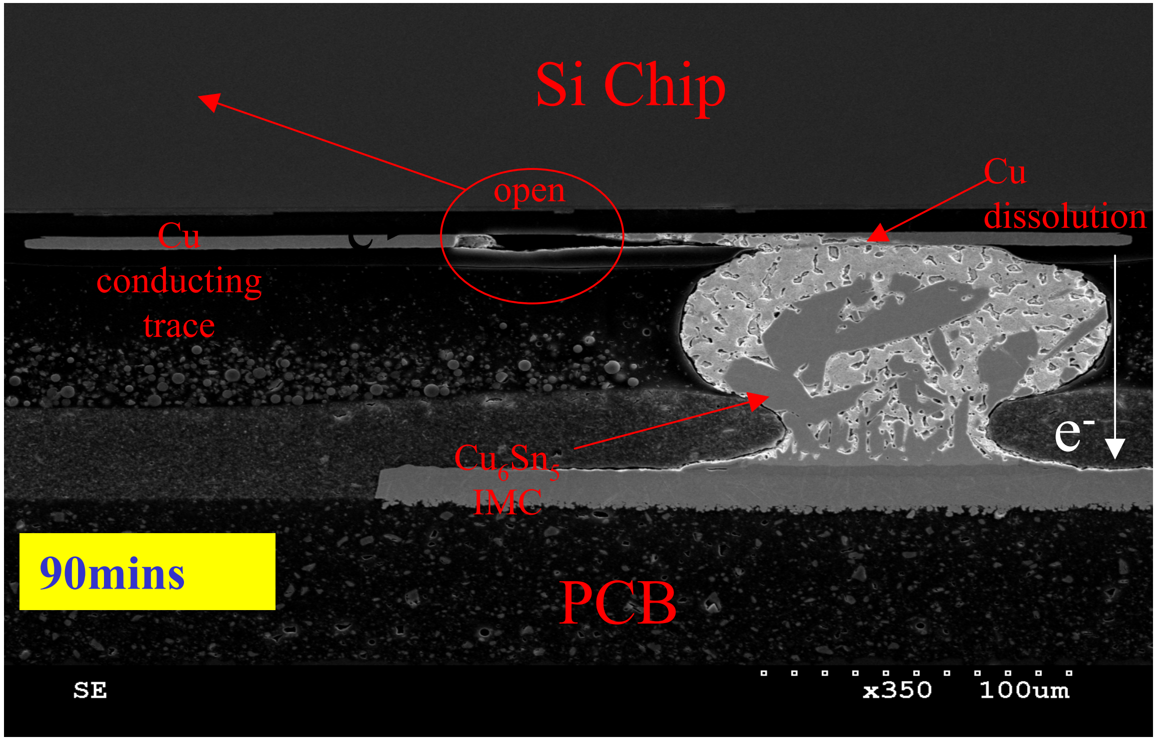
- Temperature of environment: 100℃
- Time of passing electric current:
  15min, 30min, 45min, 60min, 75min, 90min, 95min (short)
- Current 1.27 A per joint, Current density 2×10^4 A/cm^2



Current direction, chip side metallurgy (pure Cu), and substrate side metallurgy (Au/Ni/Cu) used in this study.

Electromigration in SnPb solder bump



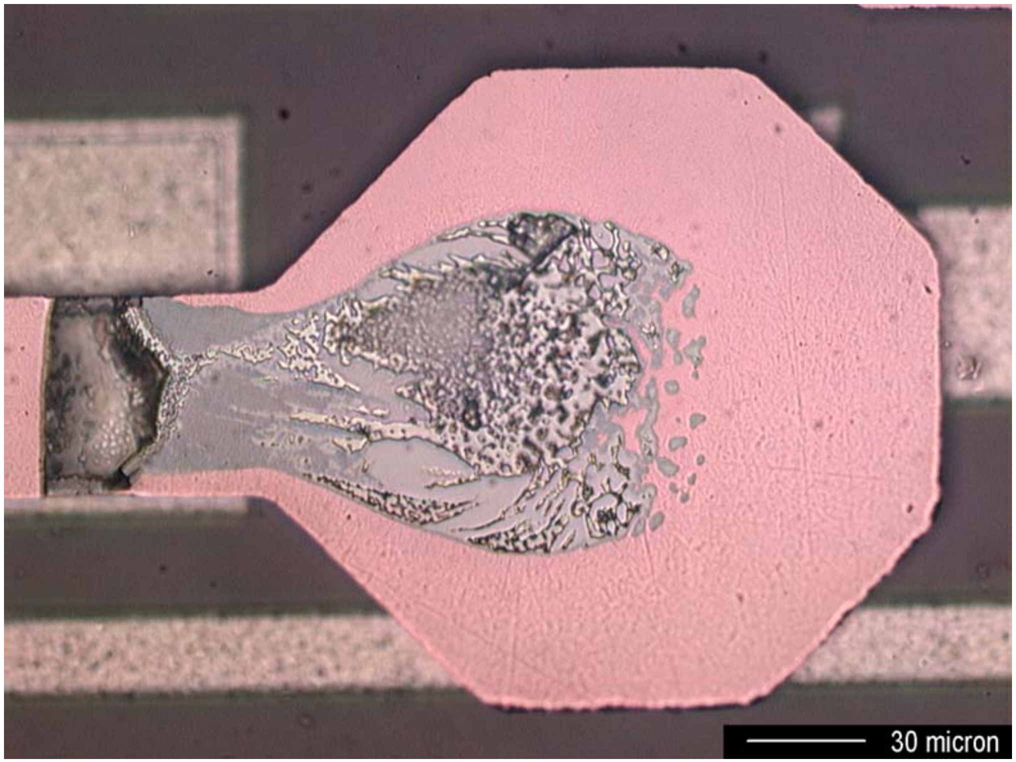


$I = 1.27A,\ T = 100℃,$

From Professor R.Kao

in National Central Univ. in Taiwan

The Top View of the Cu Conducting Trace at Chip Side (solder joint had been polished away carefully)



Optical micrograph of the top down cross-section at Cu conducting trace

- The dissolved Cu region was back-filled with solder.
- The failure took place between back-filled solder and Cu conducting trace

Proc. 6th Internl. Vacuum Congr. 1974
Japan. J. Appl. Phys. Suppl. 2, Pt. 1, 1974

Room Temperature Interaction in Bimetallic Thin Film Couples

King-Ning Tu and Robert Rosenberg

IBM thomas J. Watson Research Center
Yorktown Hights, New York 10598

Table. Intermetallic compounds formed at room temperature

	Pb	Sn
Cu	-	Cu_6Sn_5
Ag	-	Ag_3Sn
Au	$AuPb_2$	$AuSn_4$
Ni	-	Ni_3Sn_4
Pd	$PdPb_2$	$PdSn_4$
Pt	$PtPb_4$	$PtSn_4$

Cu, Ag, Au, Ni, Pd, Pt

Interstitial Diffusion

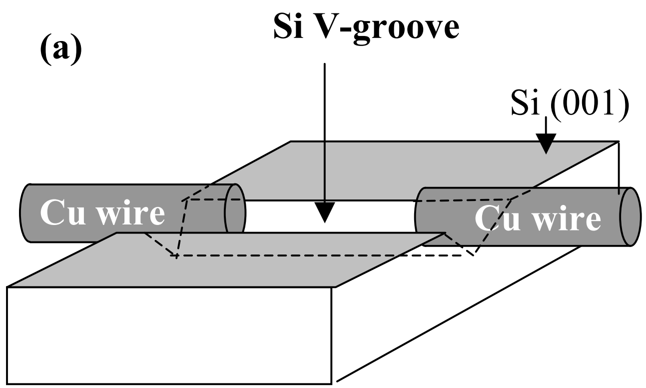
Si, Ge, Sn, Pb

Electromigration in V-Groove Line

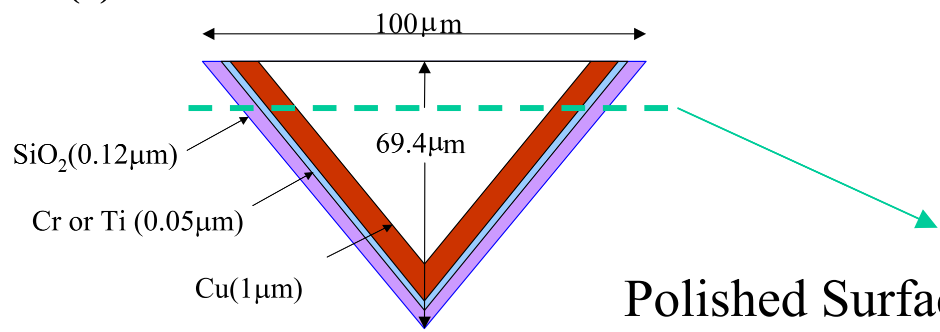
$J = 2.8 \times 10^4$ amp/cm^2

$T = 150\ ^oC$

(a)

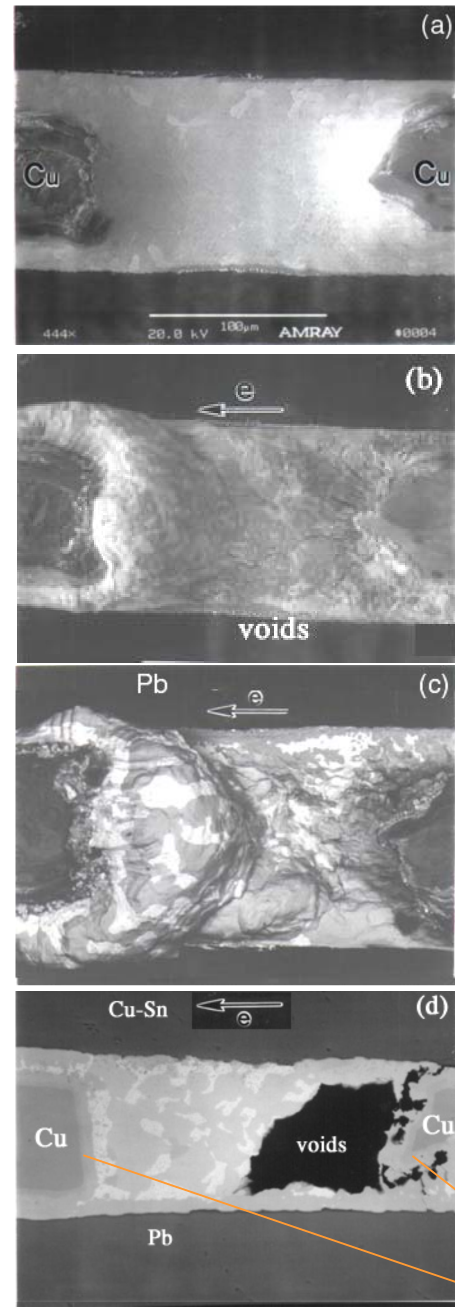


(b)



Polished Surface

SEM Images



0 day

4 days

8 days

8 days

IMC

Redistribution of Pb Concentration

E-PbSn: 150 μm length, 110 μm width
After 8 days @ 2.8×10^4 A/cm^2 and 150^{o}C

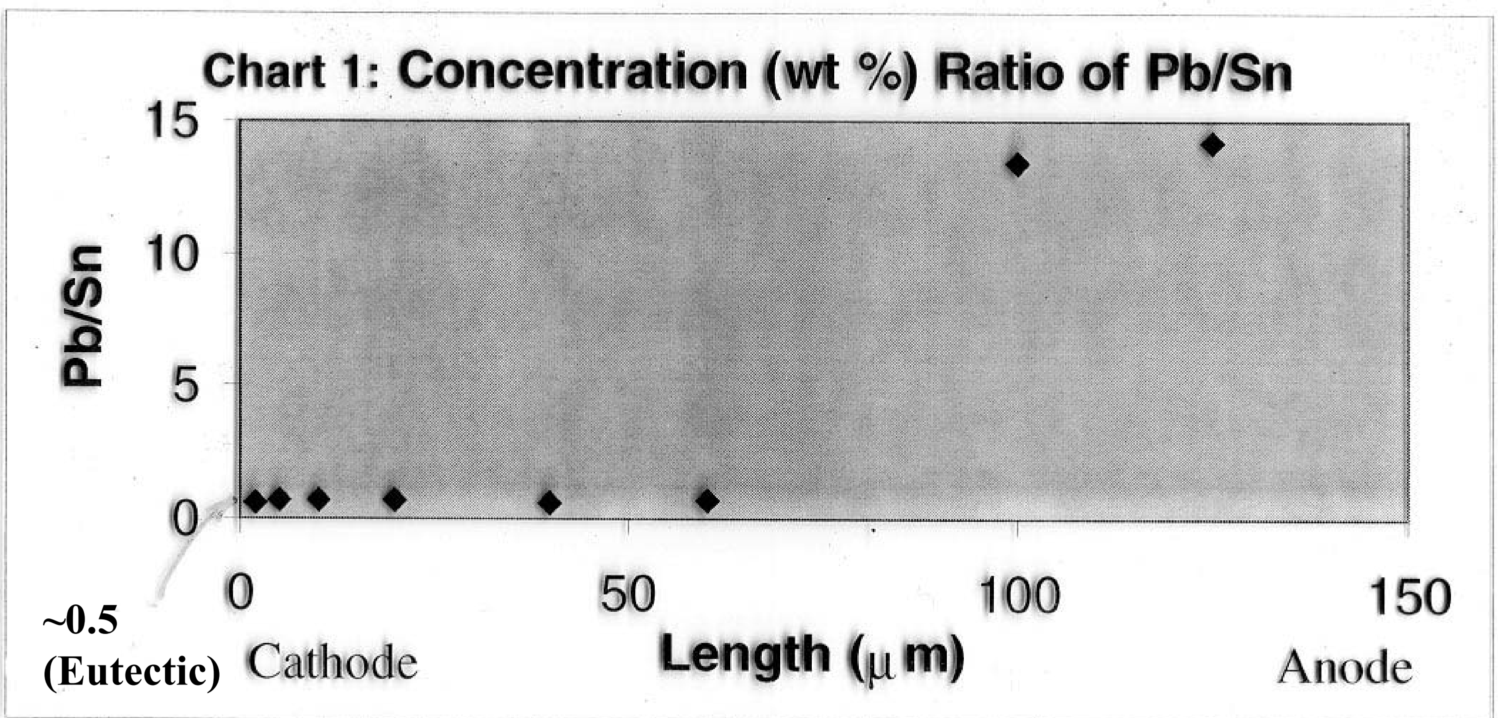


Chart 1: Pb accumulated at the anode side => **Pb is dominant diffusing species**

Room Temperature Electromigration in Eutectic SnPb solder on V-groove

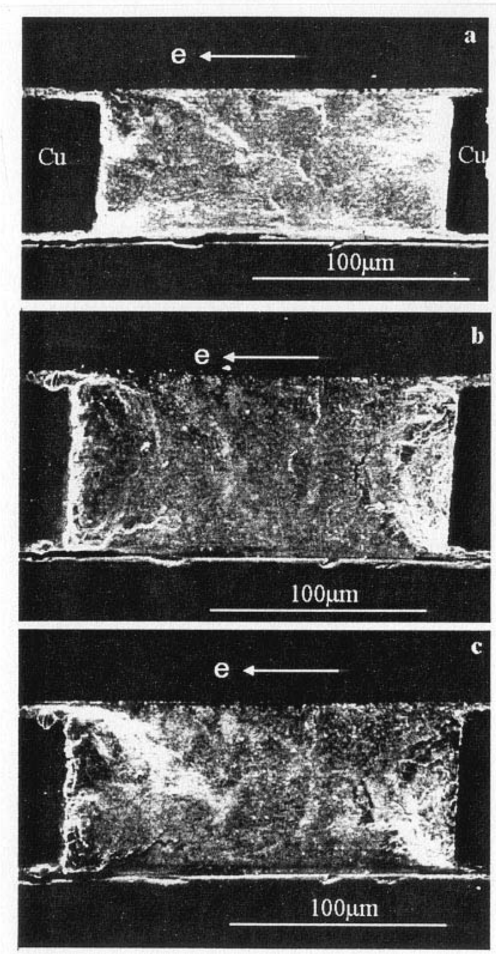
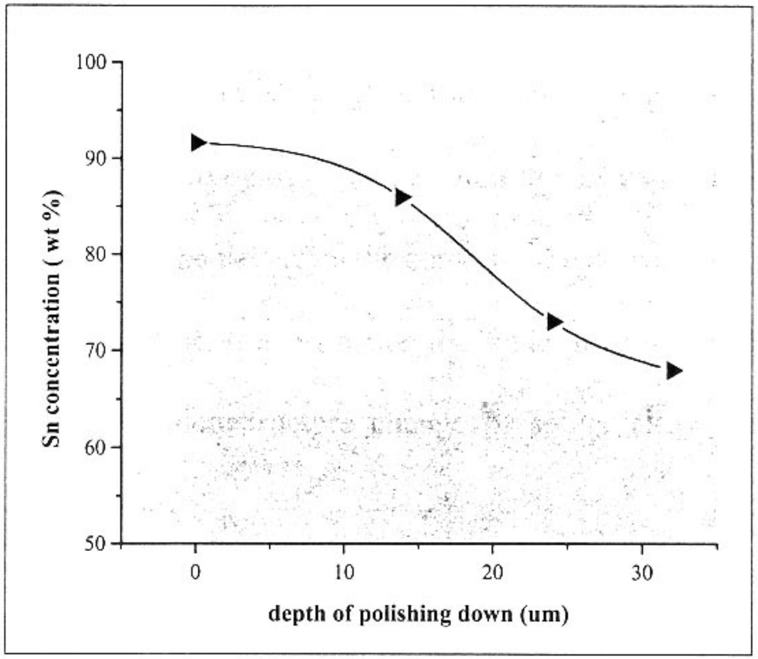


Fig. Electromigration phenomenon in Eutectic SnPb solder line stressed by a current density 5.7x104A/cm^2 at RT for 4 days, 8 days, and 12 days

Polishing down from the surface (µm)	Polishing from anode to cathode side				
	0	45	90	135	180
0	91.66 %	89.33 %	86.04 %	86.00 %	69.34 %
13.8	86.49 %	86.02 %	-	79.95 %	68.42 %
23.6	69.63 %	-	68.11 %	66.76 %	67.42 %



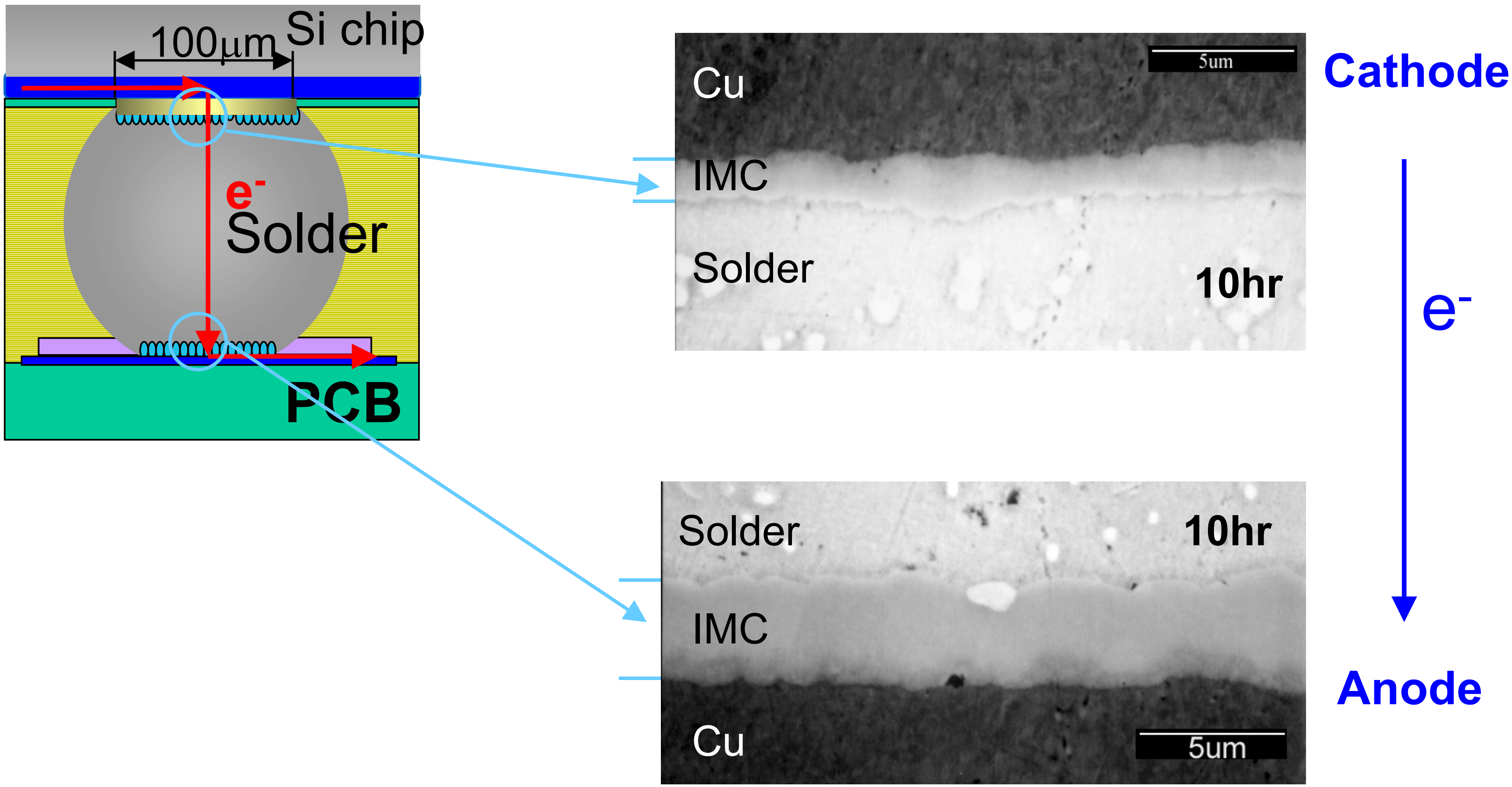
The Polarity Effect of Electromigration on Intermetallic Compound (IMC) Formation in Solder V-groove Samples

- Experiment and Results
  - –Morphology change of IMC: polarity effect
  - –Thickness change of IMC: polarity effect

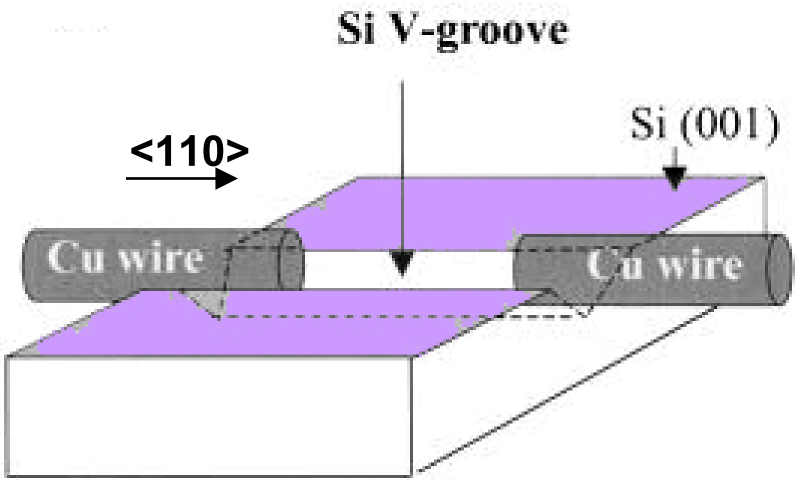
- Analysis and Discussion

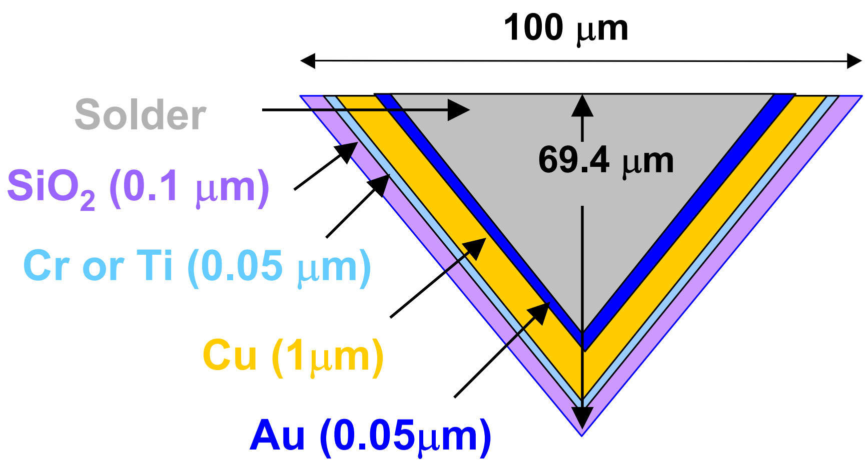
Polarity Effect of EM on IMC Thickness

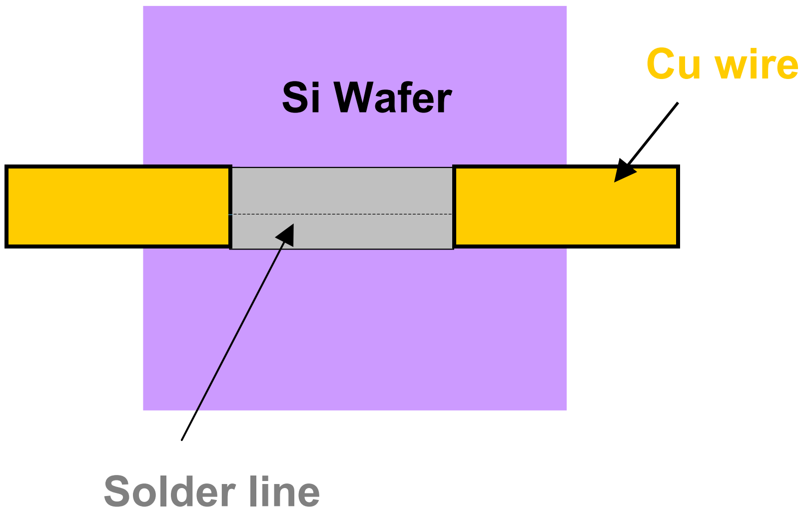
3.2×10^4 A/cm^2, 180^{o}C



Sample Preparation



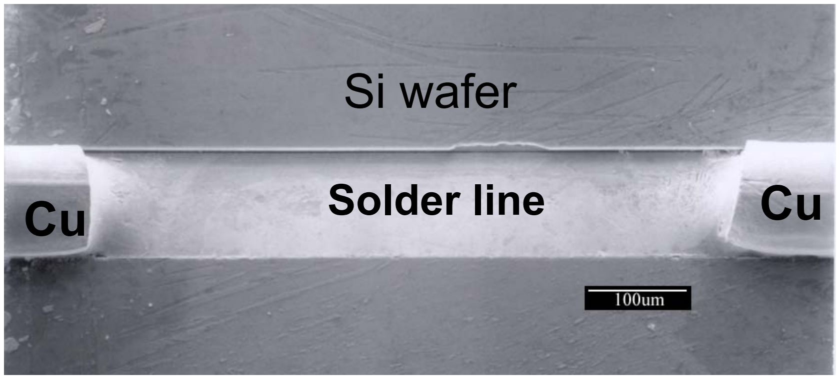




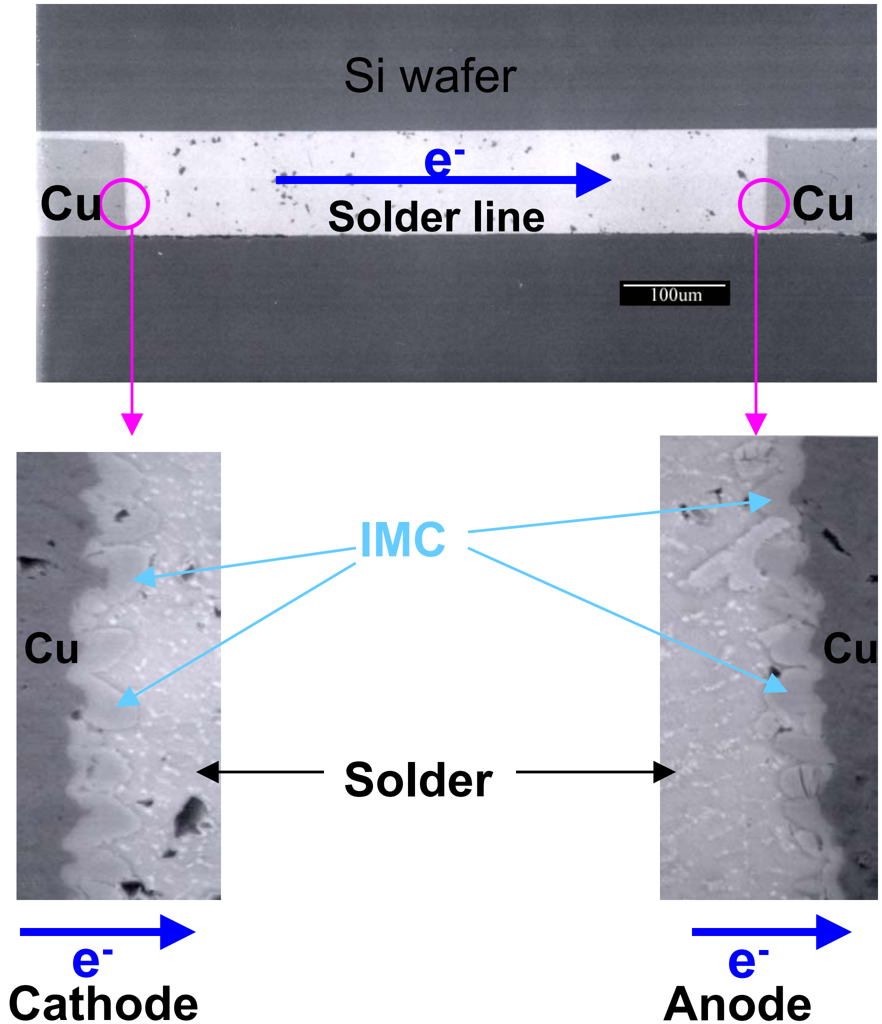
- **Advantage of V-groove sample**:
  - Comparable dimension and current density as real flip chip solder joints
  - Easy to make and observe
  - Higher current density comparing with traditional samples

Typical Sample View

Solder V-groove sample after reflow



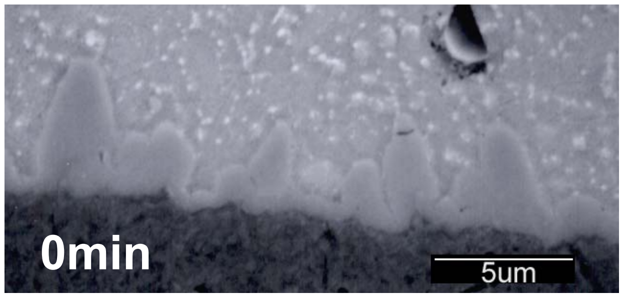
Polished sample ready for EM test

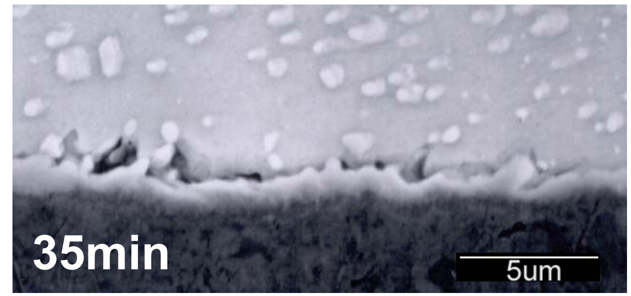


- Width of solder line: ~ 100μm
- Length of solder line: ~ 600-800μm

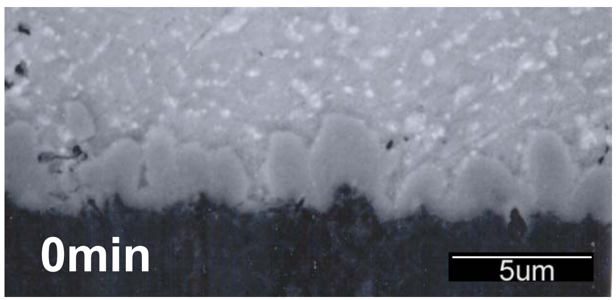
Comparing of Morphology Change

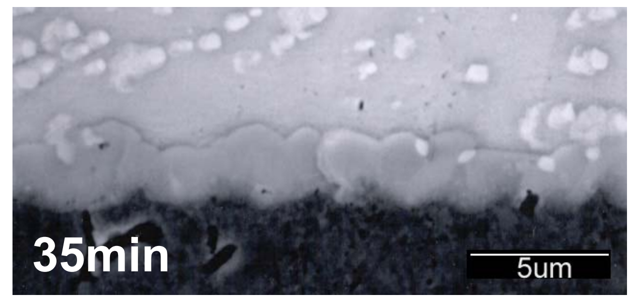
Cathode
($4x10^4$ A/cm^2, 150^{o}C)



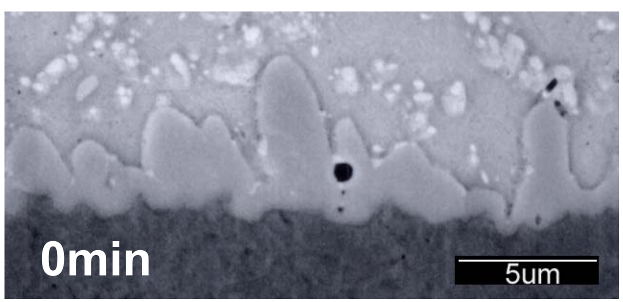


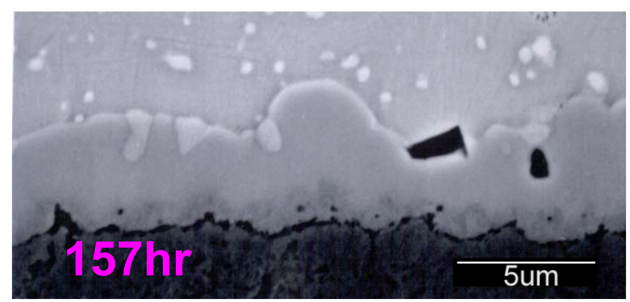
Anode
($4x10^4$ A/cm^2, 150^{o}C)





No Current
(150^{o}C)

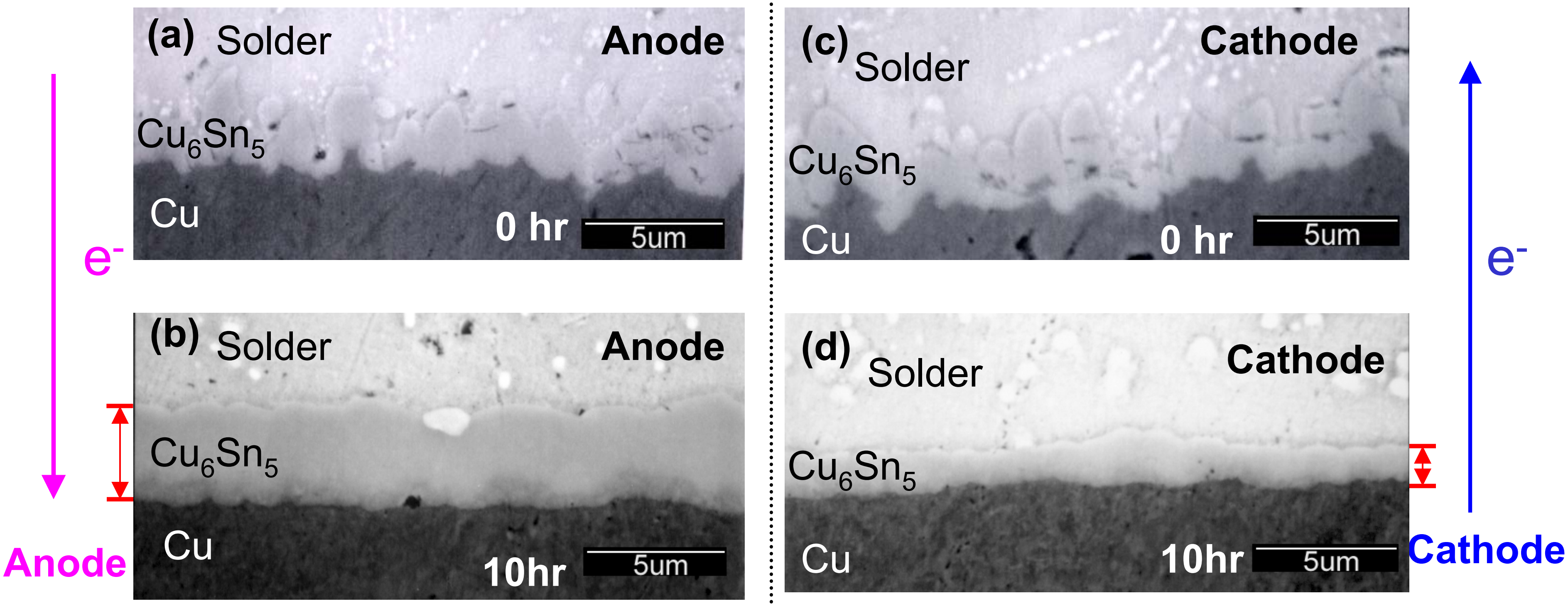




EM effect on Thickness Change of IMC

Anode (3.2x10^4 A/cm^2, 180^{o}C)

Cathode (3.2x10^4 A/cm^2, 180^{o}C)



EM effect on Thickness Change of IMC (cont.)