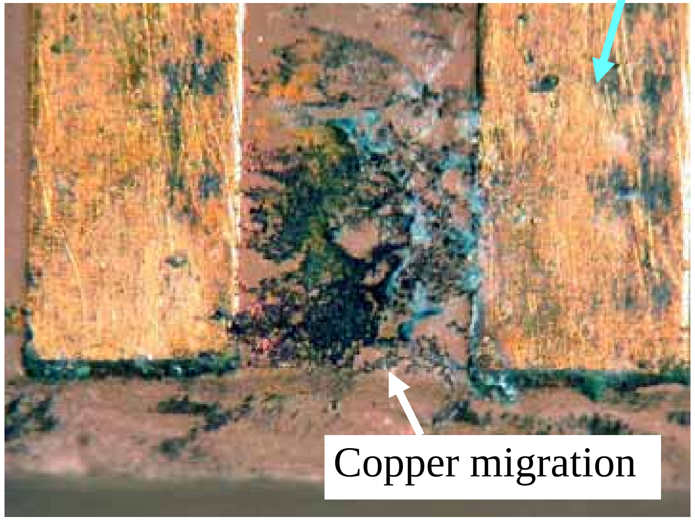
Ionic Migration on Printed-Circuit Boards

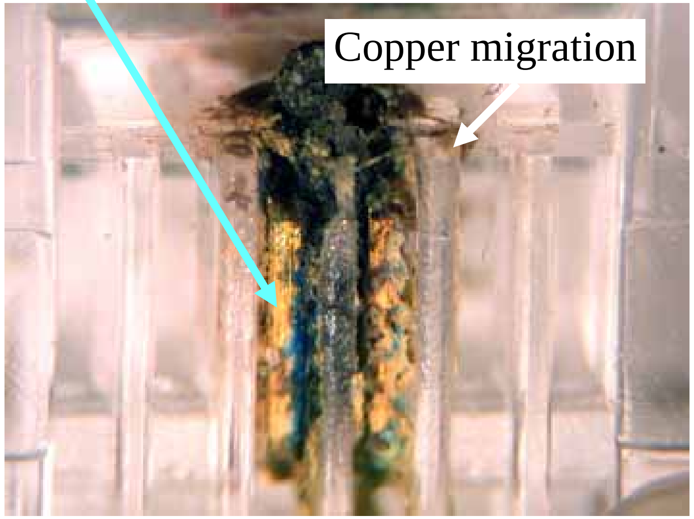
ESPEC CORP.

CONTENS

Migration occurring on electronics components

Gold plated copper terminal

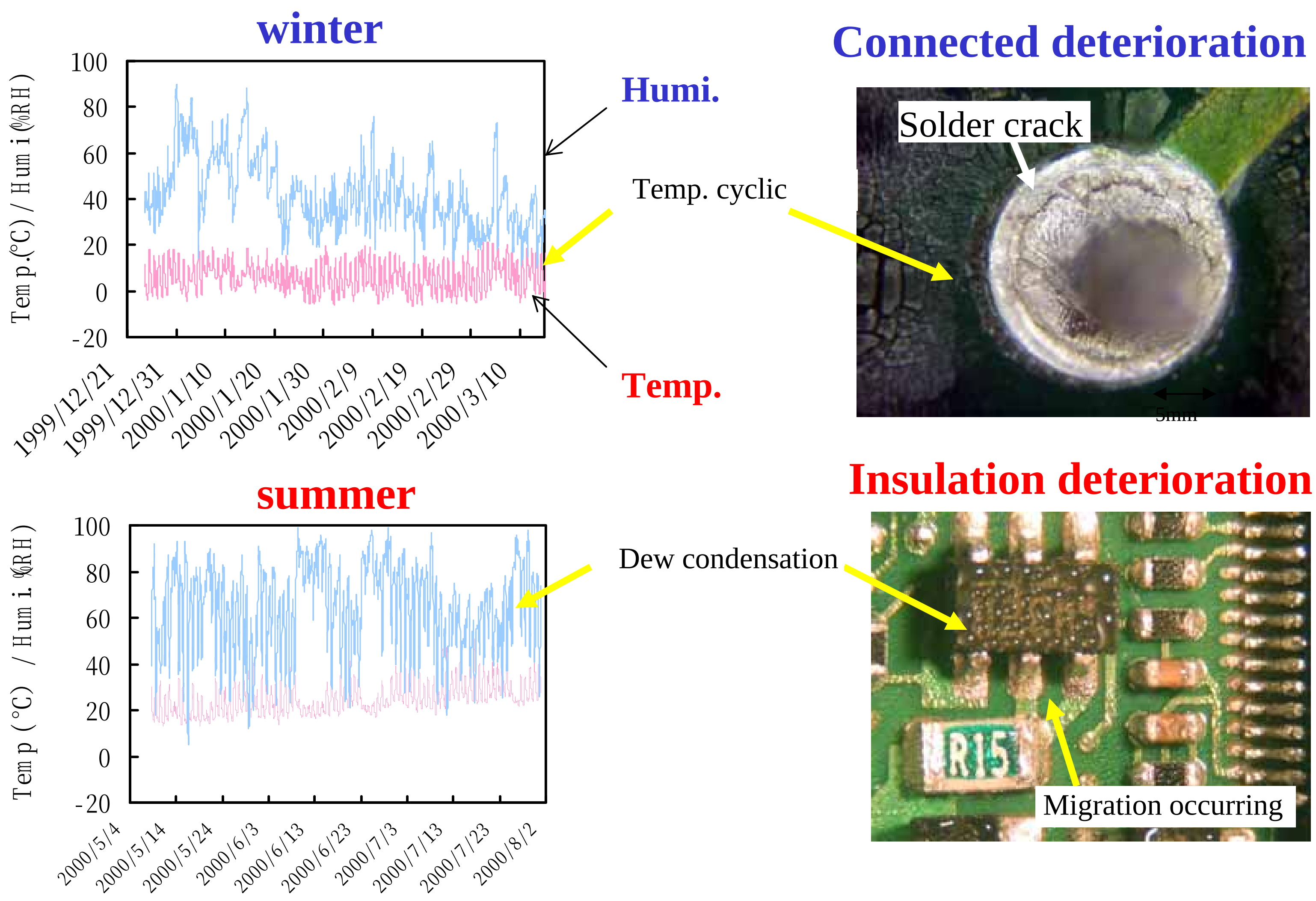




(a) Copper migration on PCB

(b) Copper migration on telephone connector

Failure on PCB and environmental stress



(a) Temperature and humidity in automobile

(b) Failure on PCBs

Factors of failure on PCB

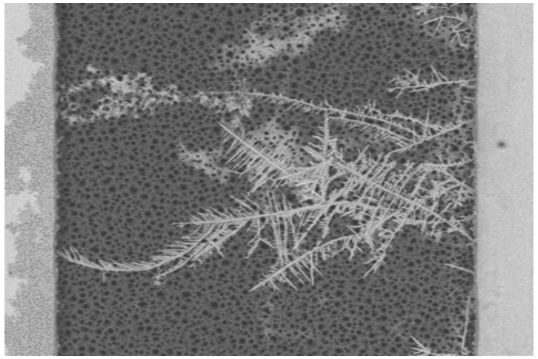
	Failure mode	*Factor — phenomena*	*result*
Failure phenomena	**Connected deterioration**	Fatigue – solder clack Oxidation – contact defective Abrasion	***Increase of contact resistance*** ↓ **Breakdown**
	Insulation deterioration	Corrosion – **migration** Adhesion – water absorption Transform – decrease in insulation distance	***Decrease in insulation resistance*** ↓ **Breakdown**

About ionic migration

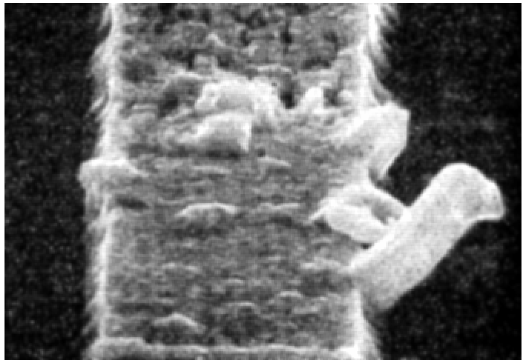
Classification of migration phenomenon

Reaction	Classification	Phenomenon	Failure part
Electrochemistry	Ionic migration (electrochemical migration)	The metal ionizes, a metallic ion migretes by the electric field.	Between wiring for PCBs
Physical	Electro migration	Interaction of metallic atom and electron	Aluminum wiring of semiconductor
	Stress migration	A metallic atom migrates by the mechanical stress.	
	Themal migration	A metallic atom migrates by the thermal stress.	

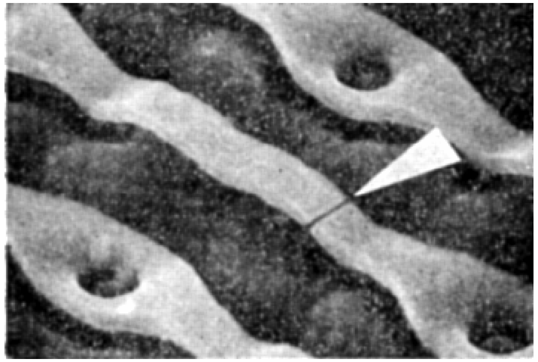
(a) Ionic migration (electrochemical migration)



(b) Electro migration



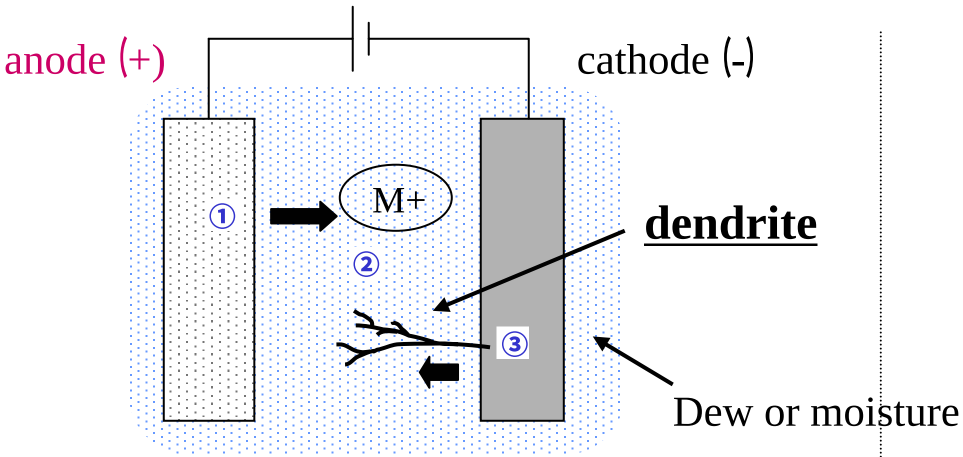
(c) Stress migration



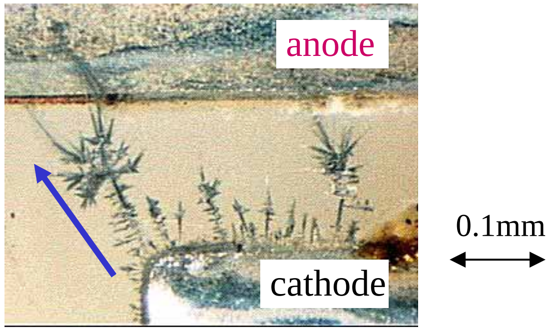
Reference (b) (c): Tsuneo Ajiki: “reliability of semiconductor device”, Nikkagiren, 1988

The forms of Ionic Migration

(a) Dendrite

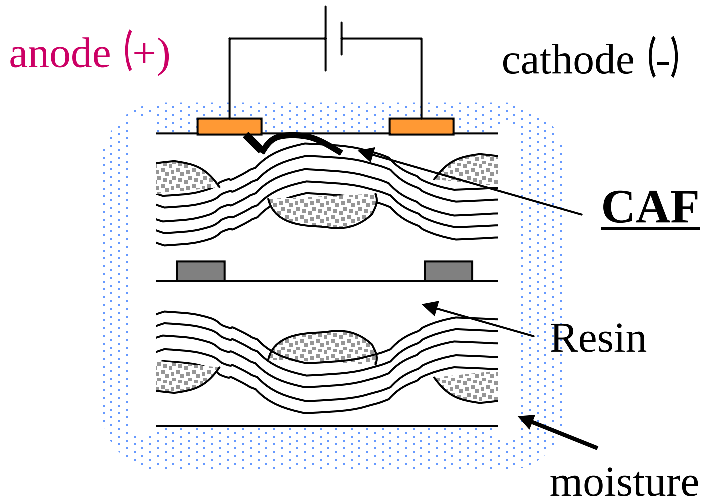


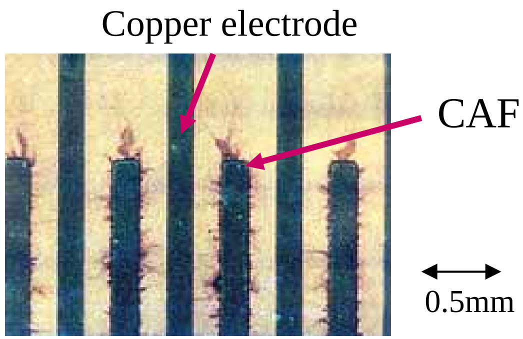
Phase1: metallic dissolution
Phase2: metallic ion migrate
Phase3: metallic deposition



Solder dendrite on PCB

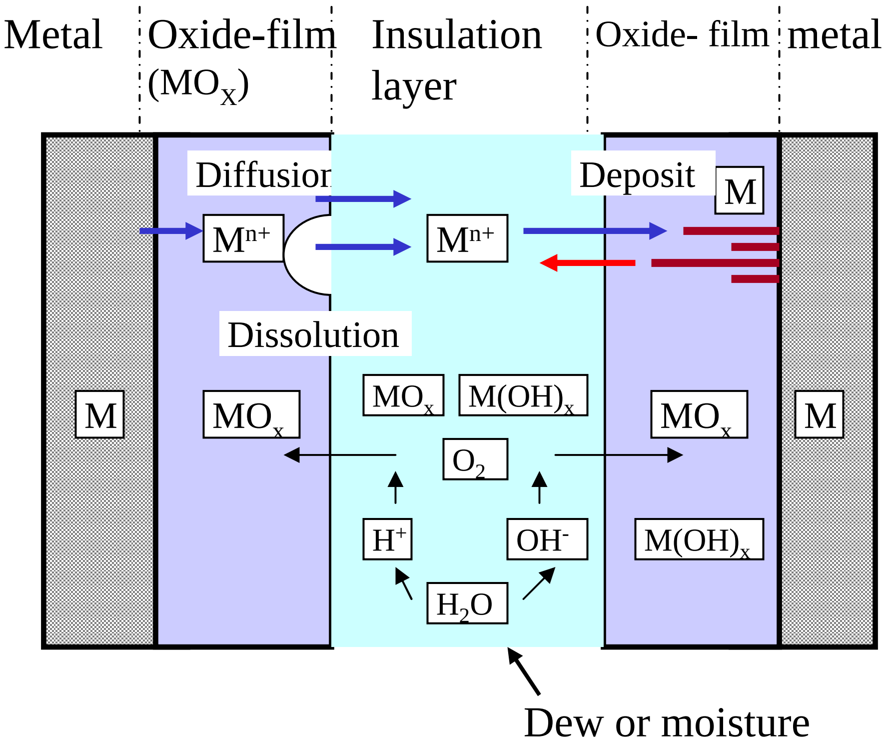
(b) CAF (Conductive Anodic Filament)





Copper CAF in PCB

Reaction mechanism of Ionic Migration



Anode (+)

Cathode (-)

Ⅰ Anodic reaction

$M \rightarrow M^{n+} + ne^-$ ··············(1)

$H_2O \rightarrow 1/2O_2 + 2H^+ + 2e^-$ ·········(2)

$M + H_2O \rightarrow MO + 2H^+ + 2e^-$ ········ (3)

Ⅱ Cathodic reaction

$M^{n+} + ne^- \rightarrow M$ ·················(4)

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ ··········(5)

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ ··········(6)

$2M^+ + 2OH^- \rightarrow M_2O + H_2O$ ········(7)

$M^{2+} + 2OH^- \rightarrow M(OH)_2$ ···········(8)

Ⅲ Reaction between electrodes

$2M^+ + 2OH^- \rightarrow M_2O + H_2O$ ·········(9)

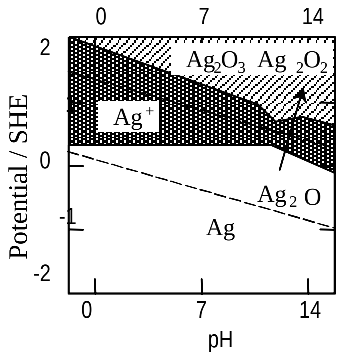
$M^{2+} + 2OH^- \rightarrow M(OH)_2$ ···········(10)

Acceleration factor of Ionic Migration

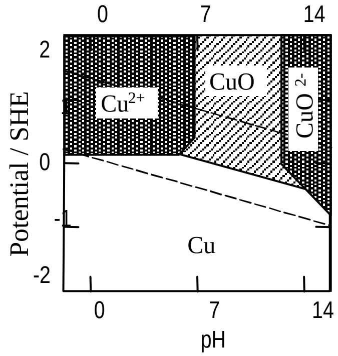
Factor	Acceleration condition
Materials	（ Fast） Ag＞Cu＞Pb＞Sn-Pb Solder＞Sn＞Au（ Slow）
Temperature	High Temp
Humidity	High humidity
Voltage	High voltage
pH	Acidity
Ionic impurities	Halogen material (Chlorine, Bromine)
Printed-cuircuit board material	Paper phenol > Glass epoxy > Polyimide > Ceramic

Acceleration factor : materials *(Pourbaix potential - pH diagrams)*

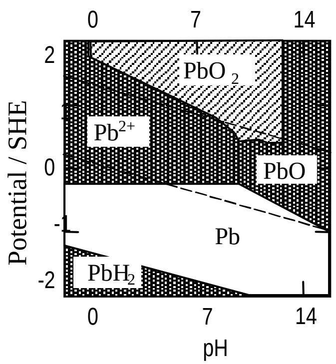
Silver (Ag)



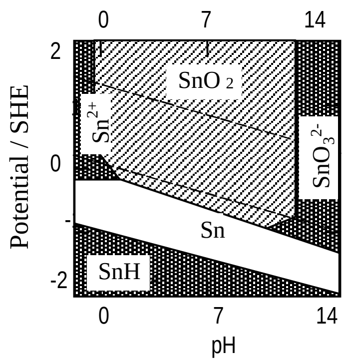
Copper (Cu)



Lead (Pb)



Tin (Sn)



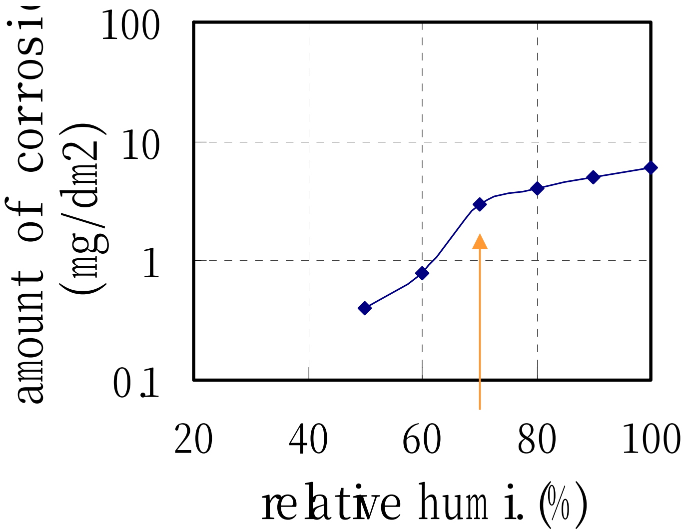
Acceleration factor : materials (Energy of oxide - film)

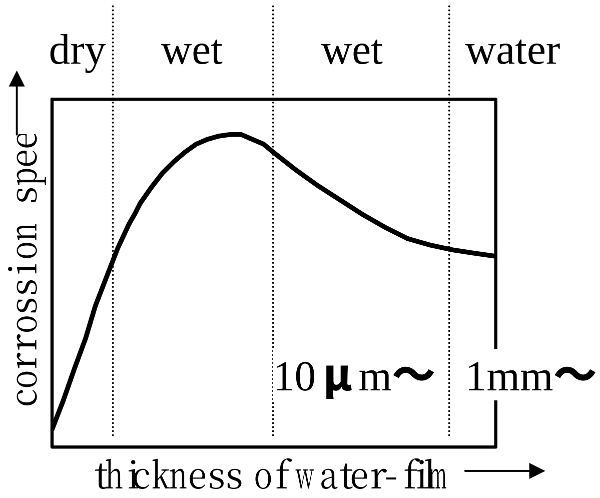
Gibbs free energy change of metal oxide-film

Stability

metal oxide-film	$\triangle Gf^{o}$ (kJ/ mol)
SnO_2	-515.47
Bi_2O_3	-496.64
Pb_2O_3	-321.92
ZnO	-321.92
SnO	-257.32
PbO	-189.33
CuO	-127.19
Ag_2O	-10.75

Acceleration factor : Humidity *(water – film and corrosion)*



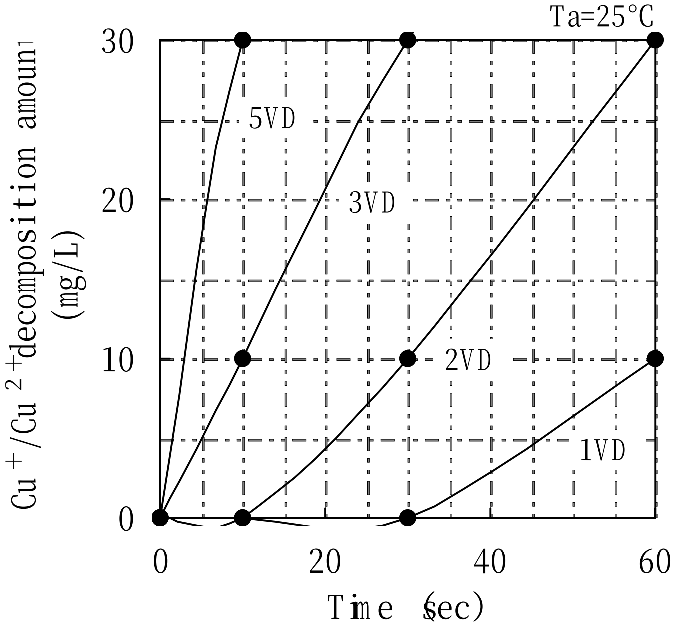


(a) Relative humidity and corrosion of metal(iron)

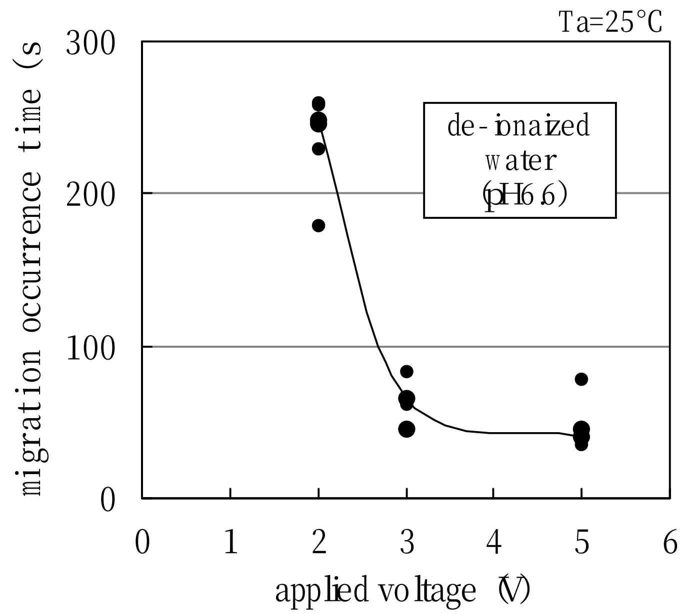
(b) Thickness of water-film and corrosion speed

Reference (a): varon, w. : Trans, faraday soc., 23, 113(1927)
(b):Tomashov, N D.: corros., 20, 7t(1964)

Acceleration factor : Voltage



(a) Quantitative characteristics of elution: voltage and copper ions



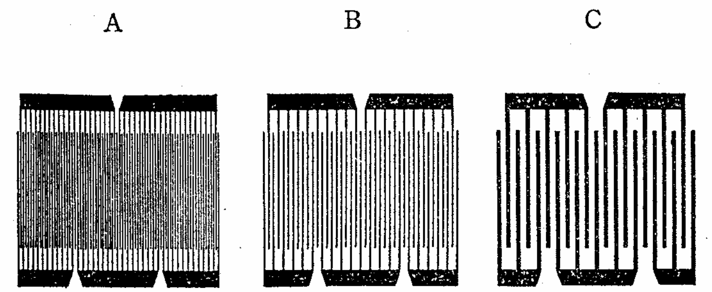
(b)The relationship between applied voltage and migration occurrence

Test methods

Test standards for Insulation evaluation

Standard	Test name	Test conditions	Applied voltage	Measurement Voltage
IPC-TM-650-2.6.13	Assessment of Susceptibility to Metallic Dendritic Growth Uncoated Printed Wiring	25°C De-ionized water: 60ml	0～20V/DC (MAX.15mA)	
ANSI-J-STD-004	Requirement for Soldering Fluxes	85°C,85%RH, 168H	50V / DC	100V / DC
JIS-Z-3284	Solder Paste	40°C,90-95%RH, 1000H	45 to 50V / DC	100V / DC
		85°C,85 to 90%RH, 1000H	45 to 50V / DC	100V / DC
IPC-TM650-2.6.3	Moisture and Insuration Resistance of printed boards	35°C,85 to 93%RH, 4days	100 V / DC	Decided in consultation with purchaser
		50°C,85 to 93%RH, 7days	100V / DC	

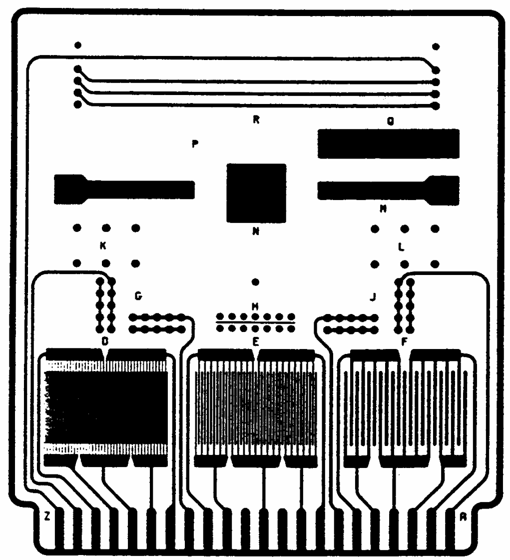
Migration test pattern on PCB



単位 mm

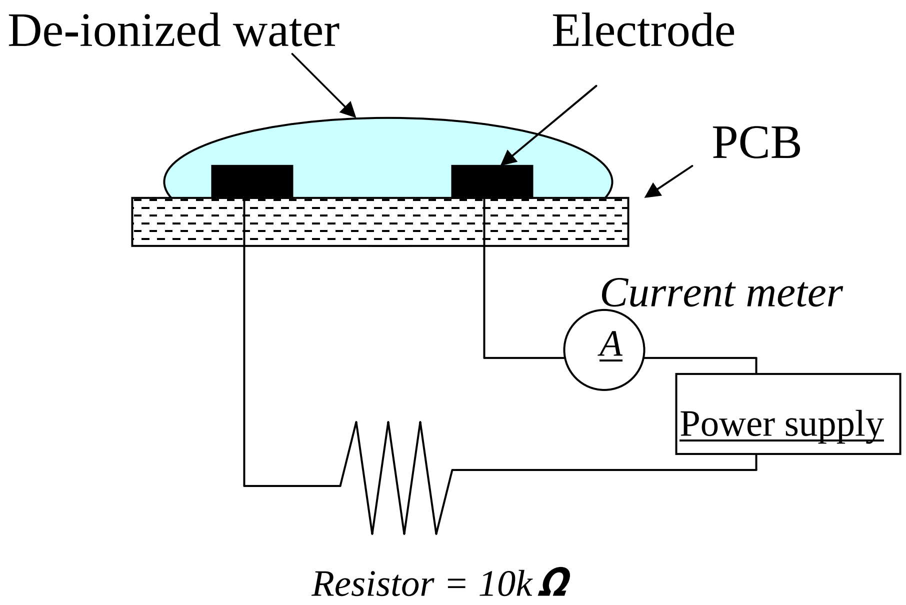
	A	B	C
導体幅	0.165	0.318	0.635
導体間隔	0.165	0.318	0.635
重ね代	15.75	15.75	15.75

(a) IPC test pattern

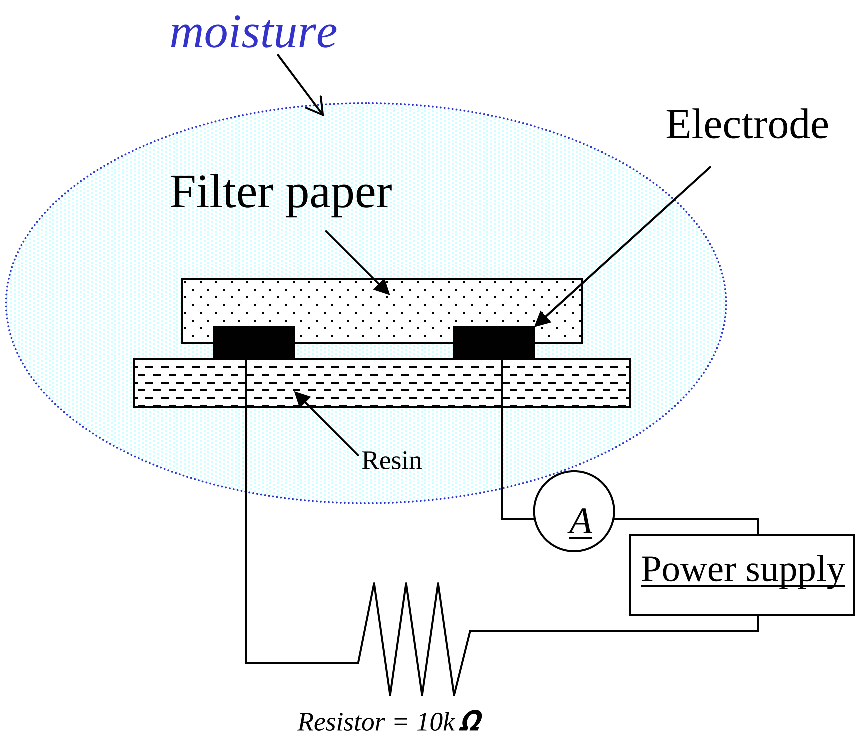


(b) IPC multi-purpose test board

Test methods : Simple migration test



(a) Water drop test



(b) Filter paper test

Test methods : Environmental migration test

Temperature / humidity chamber

HAST

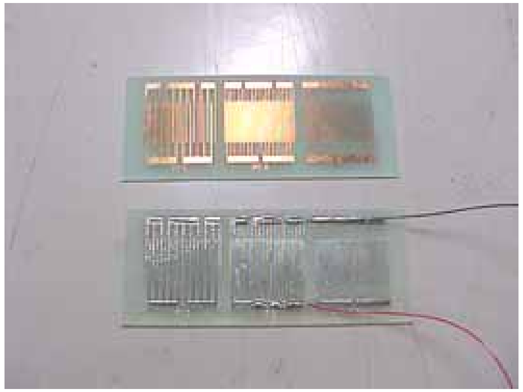
(a) Evaluation by absorption

Dew condensation cyclic chamber

Temperature / humidity cyclic chamber

(b) Evaluation by dew

measurement method : Manual measurement



(1) specimen

(3) Insulation resistance meter (HP4329)

(2) High Temp/High Humi. test

(4) Insulation resistance meter (HP4339)

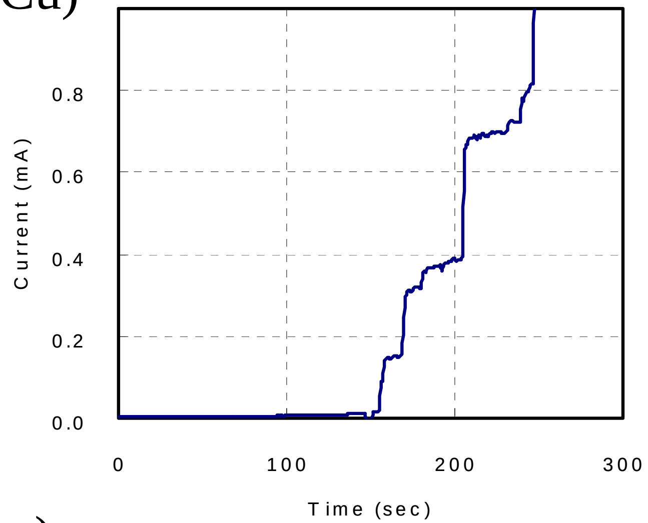
Insulation resistance test of PCBs

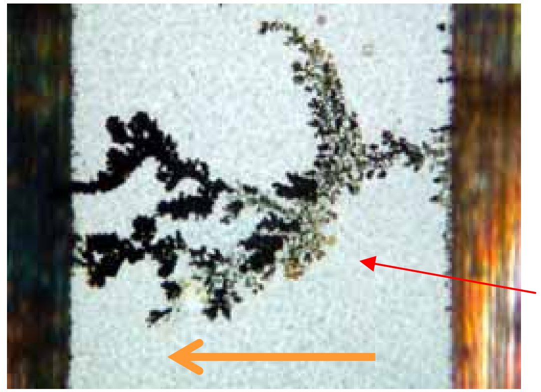
Results of Water Drop test (Cu and Ag, 2V/DC bias)

Change in current

External appearance after testing

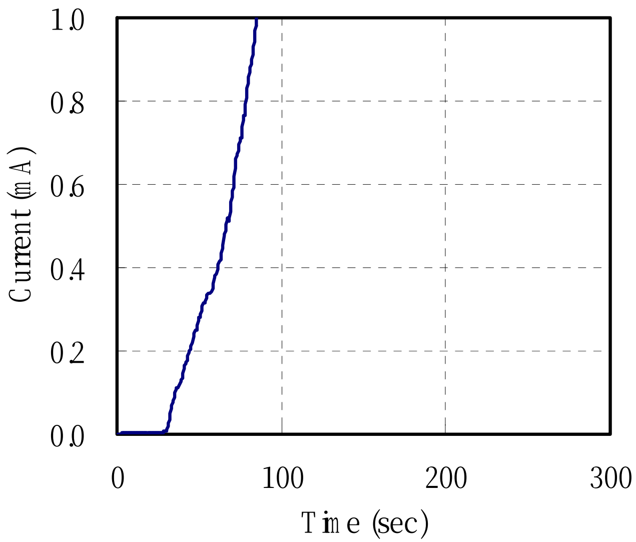
Copper (Cu)

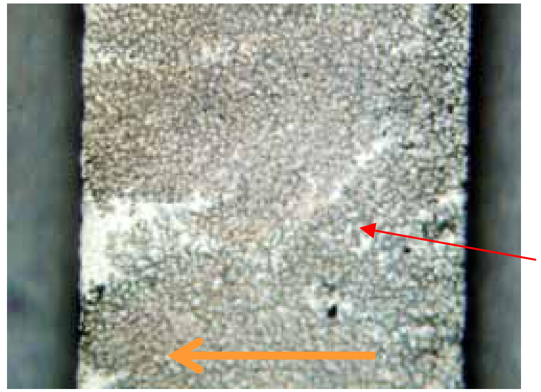




Copper migration

Silver (Ag)





Silver migration

anode (+)

cathode (-)

Surface insulation resistance (SIR) test for PCB

(a) Test condition

Test conditions	40℃, 87% 60℃, 87% 85℃, 85% 1000Hr
PCB material	Glass-cloth epoxy (FR-4) IPC-B comb pattern (Gap=0.3mm)
Applied voltage	50V / DC
Mesurement intervals	1 Hr

(b) Specimen

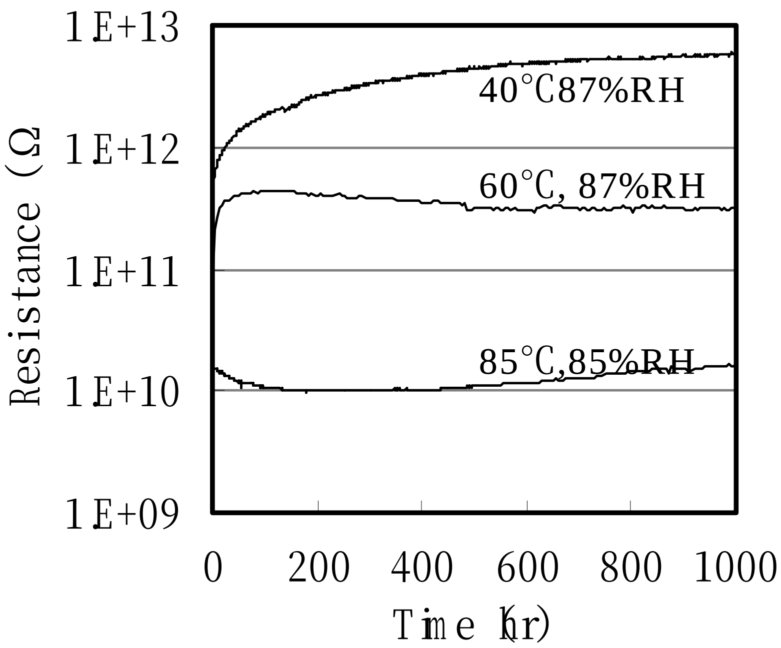
Grass-epoxy PCB

Ionic migration evaluation system (ESPEC)

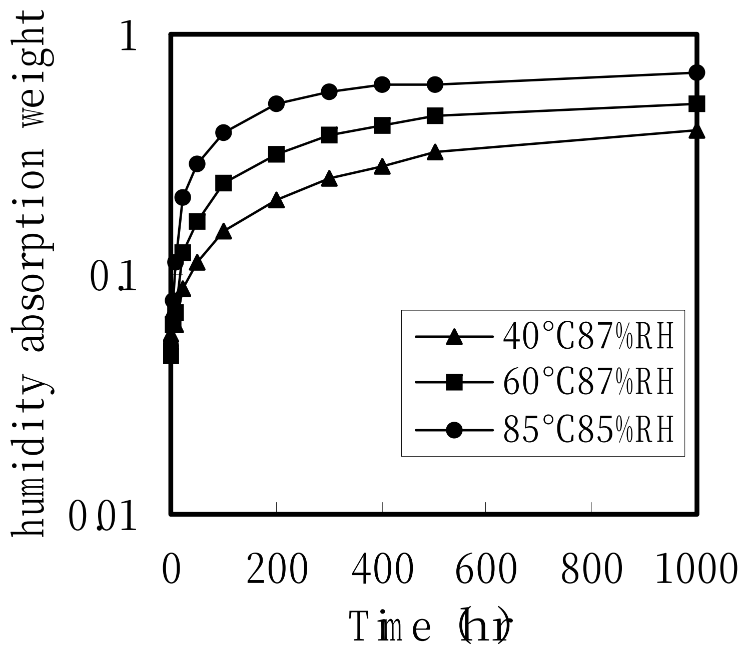
Wiring situation

Results of SIR test (Copper pattern PCB, 50V/DC bias)

Change in insulation resistance



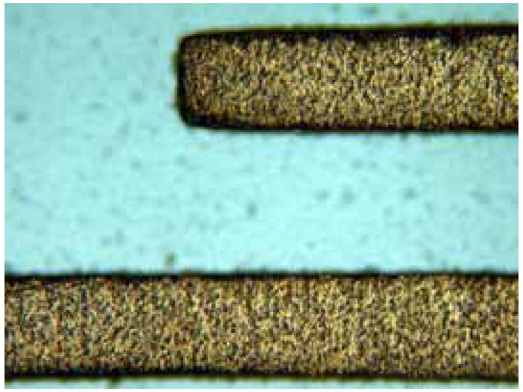
Change in absorption characteristic



Results of SIR test (Copper pattern PCB, 50V/DC bias)

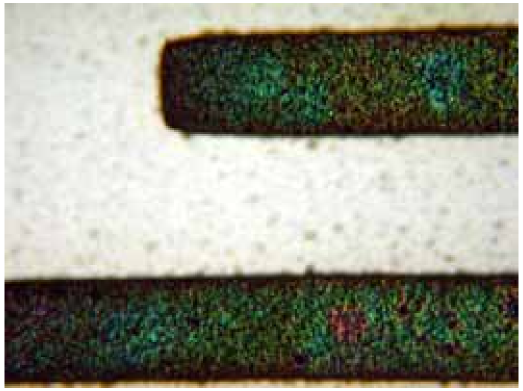
External appearance after testing (2000Hour)

40℃, 87%



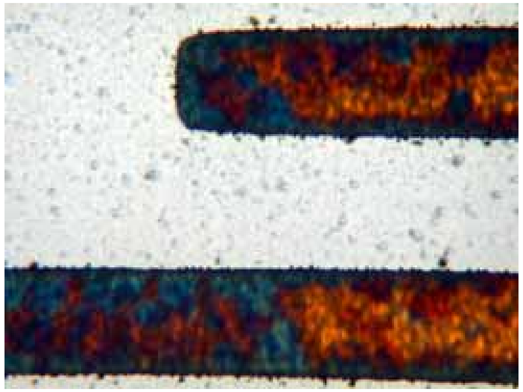
No migration

60℃, 87%



No migration

85℃, 85%



anode (+)

cathode (-)

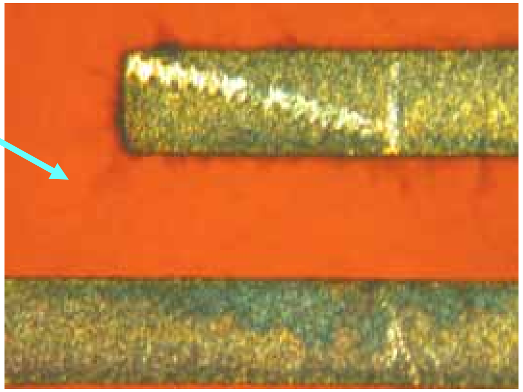
No migration

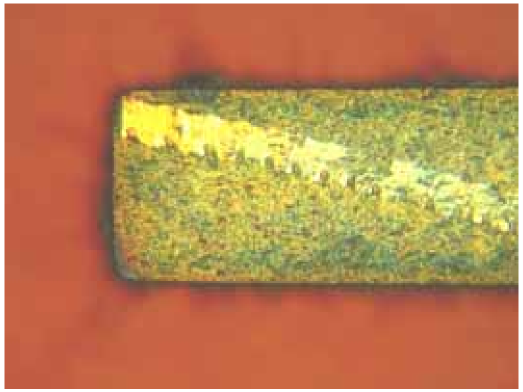
Example : Results of SIR test (Paper phenolic PCB)

External appearance after testing

85℃, 85%, 50V/DC, 2000Hr

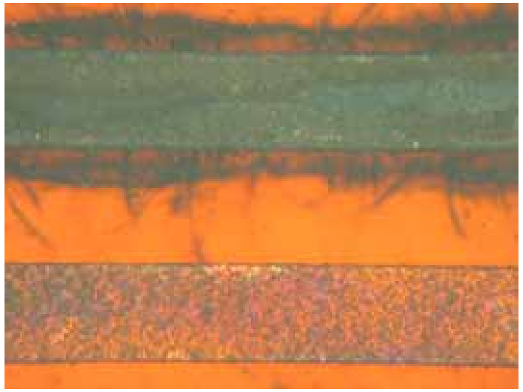
CAF





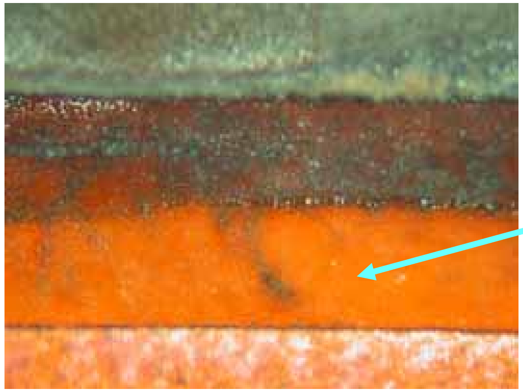
CAF growth

110℃, 85%, 5V/DC, 300Hr



anode (+)

cathode (-)



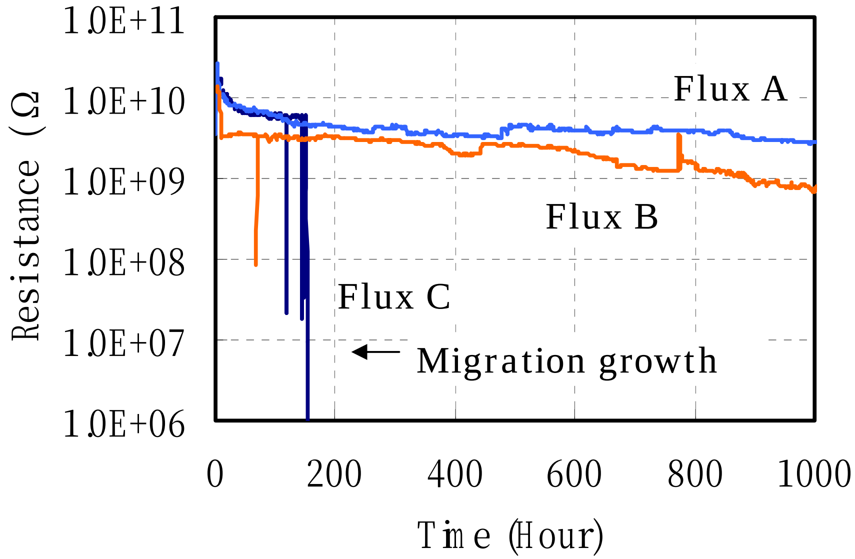
CAF

CAF growth

Example : Results of SIR test (Flux and Dew test)

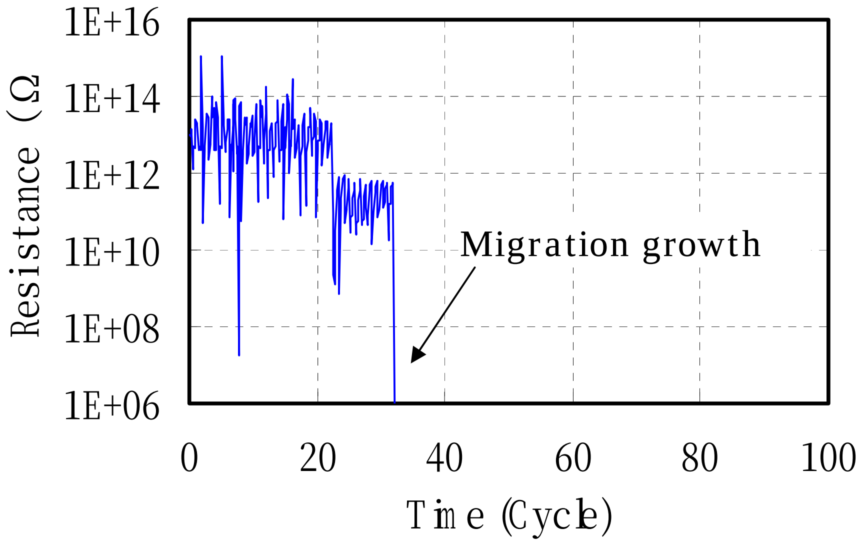
Evaluation of soldering flux

(85℃85%, 50V/DC bias)



Dew cyclic test

(5℃/25℃90%, 5V/DC bias)



Life estimated formula of insulation failure

IPC-9201 (Surface Insulation Resistance Handbook)

$$t2 = t1 \times \exp[(\frac{\mathrm{Ea}}{\mathrm{R}})(\frac{1}{T1} - \frac{1}{T2})] \times \exp[b(\frac{1}{RH1} - \frac{1}{RH2})] \times (\frac{A2V2}{A1V1})$$

The Institute of Electrical Engineers of Japan (Report No. 772)

$$AF = \exp\left(\frac{Ea}{R}(\frac{1}{T1} - \frac{1}{T2})\right) \times \left(\frac{RH2}{RH1}\right) r \times \left(\frac{V2}{V1}\right) n \times \left(\frac{D1}{D2}\right) m$$

Ea = Activation energy (Glass Epoxy PCB = 1eV)

R = Boltzmann's Constant (8.63×10^{-5} eV/k)

T1, RH1, V1, D1, t2 = Practice use Temp., Humi., Voltage, Electrode Distance, Time

T2, RH2, V2 , D2, t1= Accreted test Temp., Humi., Voltage, Electrode Distance, Time

B, A1,A2, r, n, m = constant (r=3, n=2)

Life estimated formula of insulation failure

$$AF = \exp\left(\frac{Ea}{R}\left(\frac{1}{T1} - \frac{1}{T2}\right)\right) \times \left(\frac{RH2}{RH1}\right)r \times \left(\frac{V2}{V1}\right)n \times \left(\frac{D1}{D2}\right)m$$

- ***Ea*** = Activation energy

  (Glass Epoxy PCB = 1eV)
- ***R*** = Boltzmann's Constant (8.63×10^{-5} eV/k)
- Practice Temp.(T1)=45℃, Humi.(RH1)=85%

  Voltage(V1)= 5V
- Test Temp(T2)=85℃, Humi.(RH2)=85%

  Voltage(V2)=5V, 2000Hr
- ***r, n*** = constant (r=3, n=2)

- AF1= $\exp[1.16 \times 10^{4} \times (1/318-1/358)]$

  = exp(4.1) = 59
- AF2 = $(85/85)^{3}$ = 1
- AF3 = $(5/5)^{2}$ = 1

※AF=59×1×1 = **59**

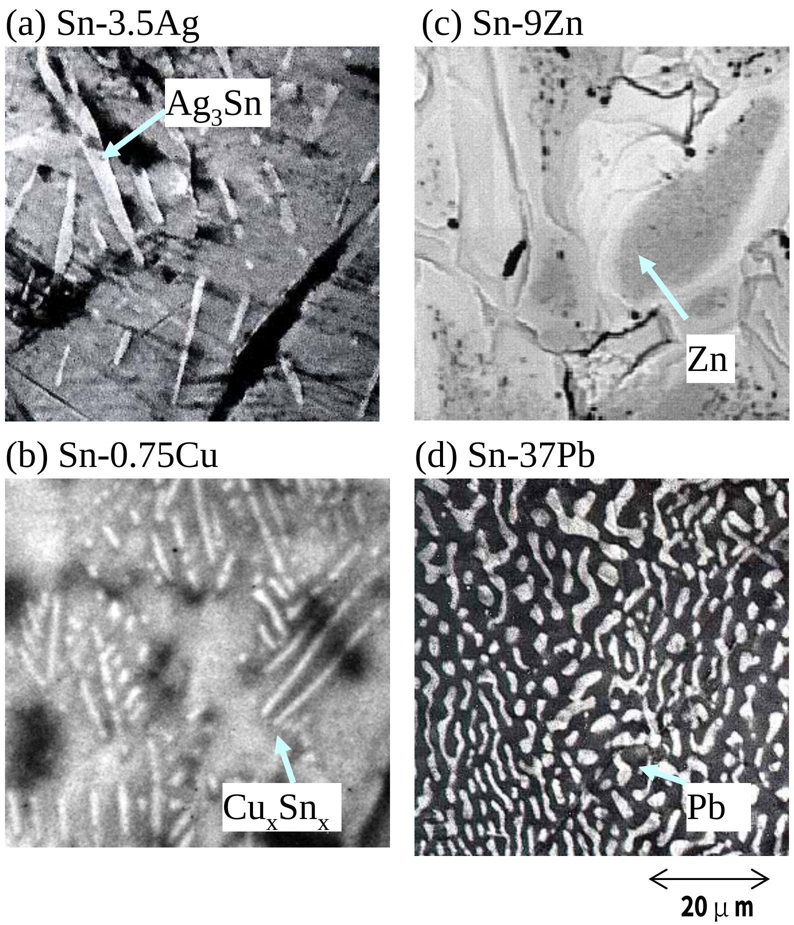
Life Time = 2000Hr×AF

= 118000Hr = **13.4 years**

Reference: The Institute of Electrical Engineers of Japan (Report No. 772)

Solder alloy migration

Factors of Solder alloy migration

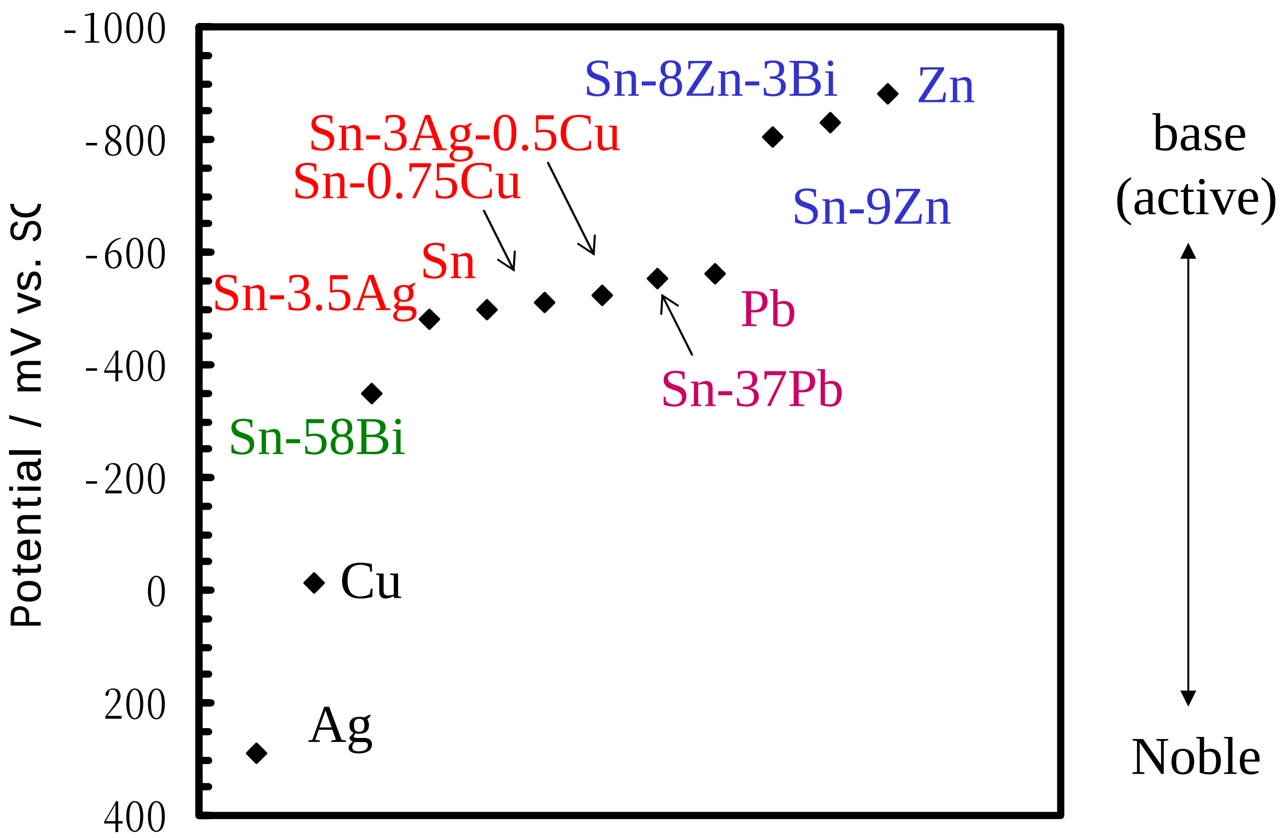


(a) SEM image of solder surfaces

	materials	Reaction	$E°$ (V vs.SHE)
base	Zinc	$Zn^{2+}+2e^{-}=Zn$	-0.763
↑	Tin	$Sn^{2+}+2e^{-}=Sn$	-0.138
	Lead	$Pb^{2+}+2e^{-}=Pb$	-0.126
	Hydorogen	$2H^{+}+2e^{-}=H_2$	0.000
	Bismath	$Bi^{3+}+3e^{-}=Bi$	0.215
↓	Copper	$Cu^{2+}+2e^{-}=Cu$	0.337
Noble	Silber	$Ag^{+}+e^{-}=Ag$	0.779

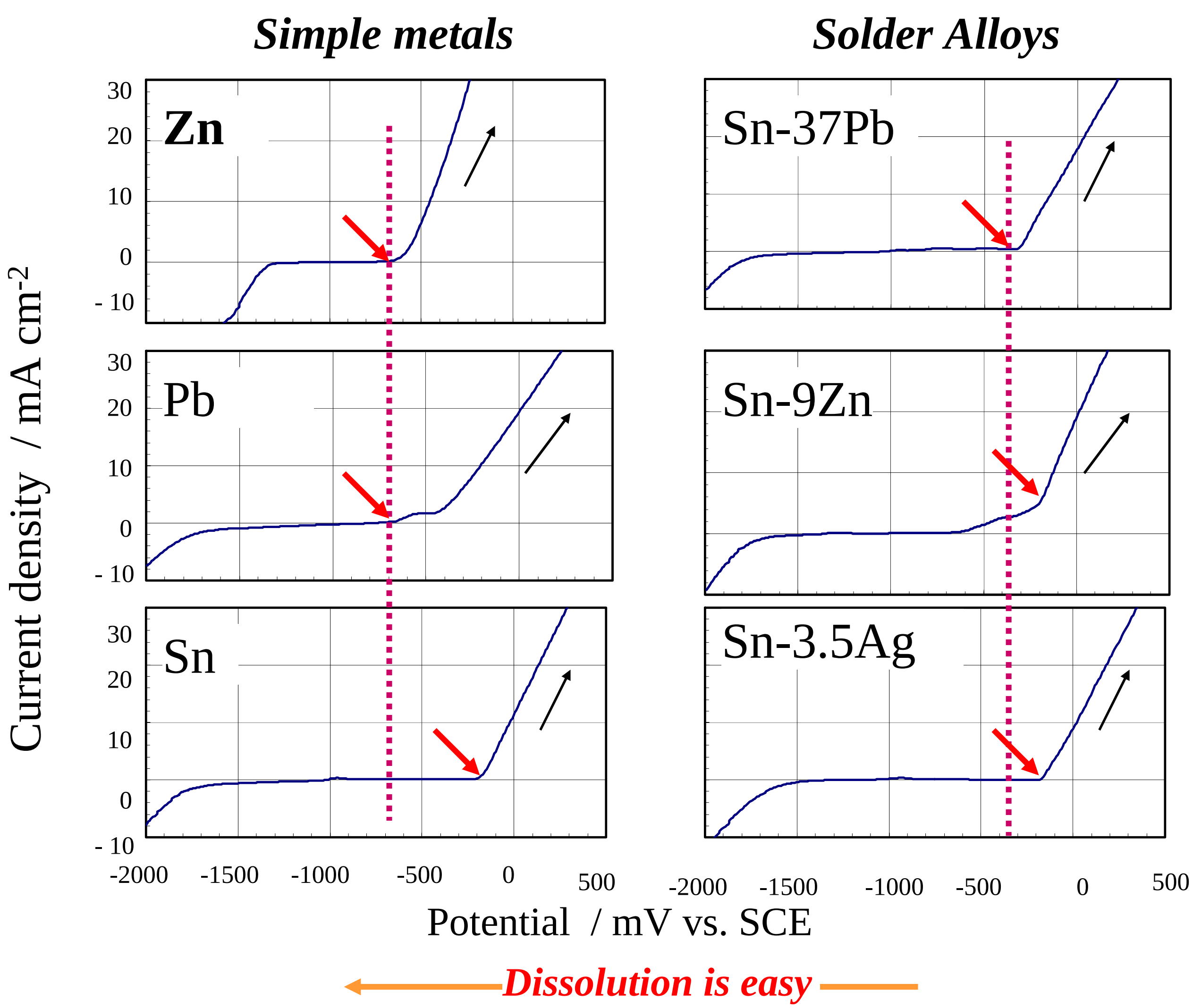
(b) Standard potential of solder composition materials

Electrochemical characteristics (Static characteristic)



Rest potential of each type solder (in 0.1M KO_3 aqueous solution)

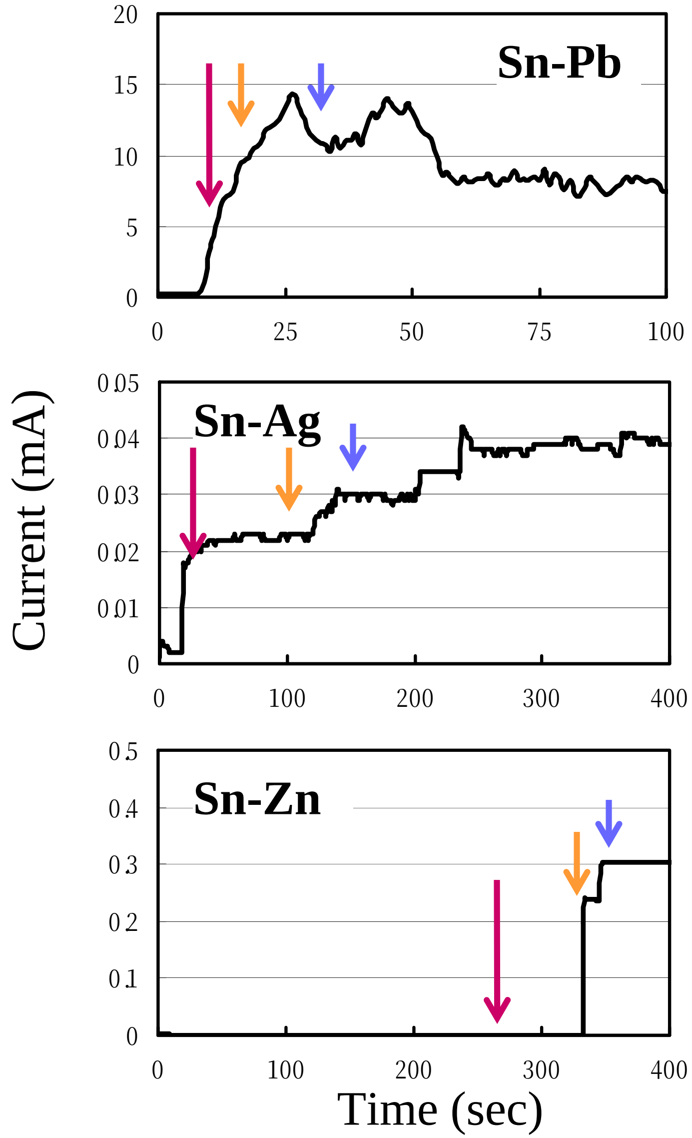
Electrochemical characteristics (Dynamic characteristic)



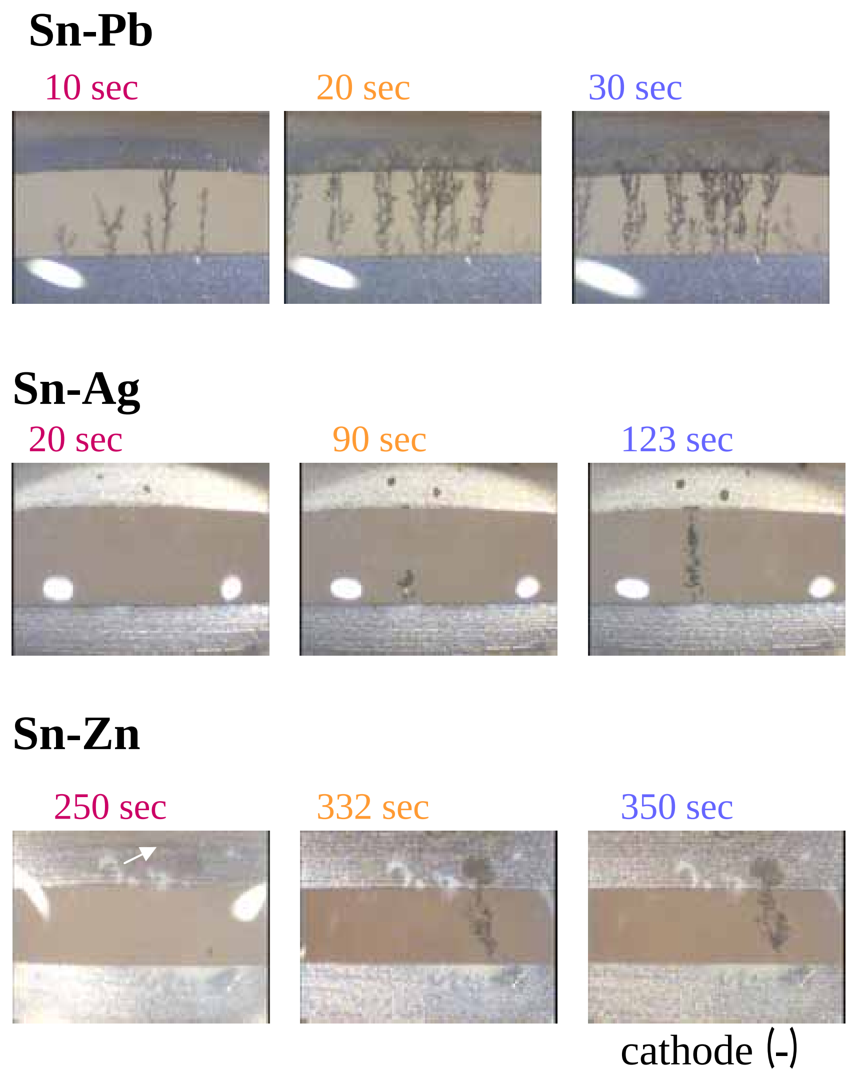
Current - potential curves = dissolution characteristic (in 0.1M KO_3 aqueous solution)

Water Drop test - 1 (5V/DC bias)

Change in current



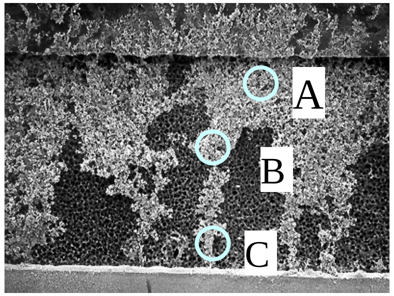
Process of migration deposits



Water Drop test - 2 (SEM analysis)

SEM image of migration deposits

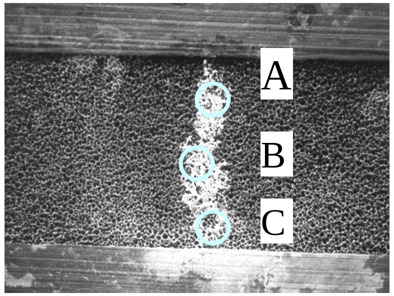
Sn-Pb



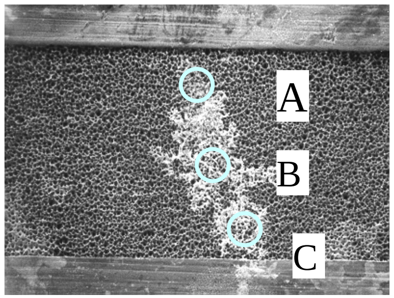
anode (+)

cathode (-)

Sn-Ag



Sn-Zn



200 μm

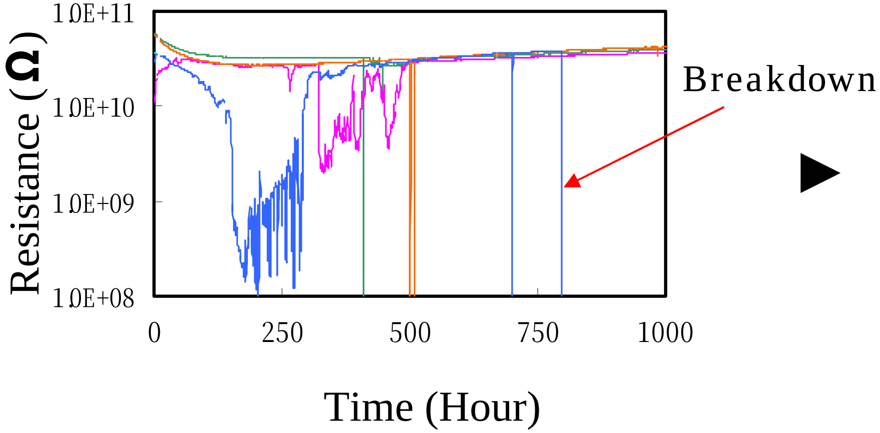
Compositional analysis of migration deposits

solder	Point A	Point B	Point C
Sn-Pb	Sn = 63% Pb = 37%	Sn = 46% Pb = 54%	Sn = 47% Pb = 53%
Sn-Ag	Sn = 100% Ag = 0%	Sn = 100% Ag = 0%	Sn = 100% Ag = 0%
Sn-Zn	Sn = 98% Zn = 2%	Sn = 93% Zn = 7%	Sn = 97% Zn = 3%

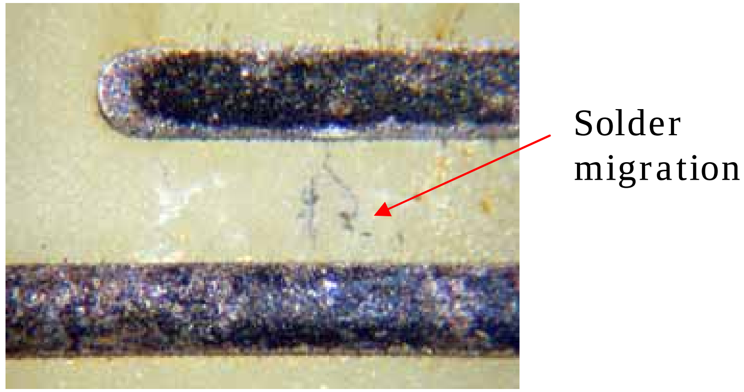
Surface insulation resistance test (50V/DC bias, 85 ℃85%)

Change in insulation resistance

Sn-37Pb

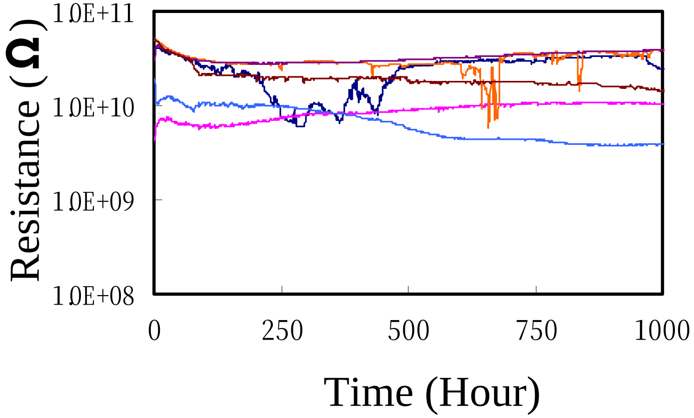


▶

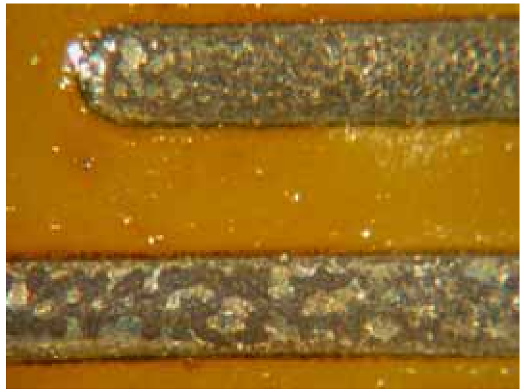


Migration occurring

Sn-Ag-Cu

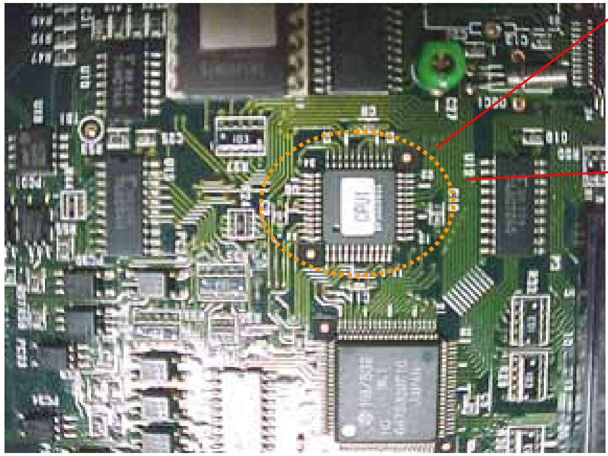


▶



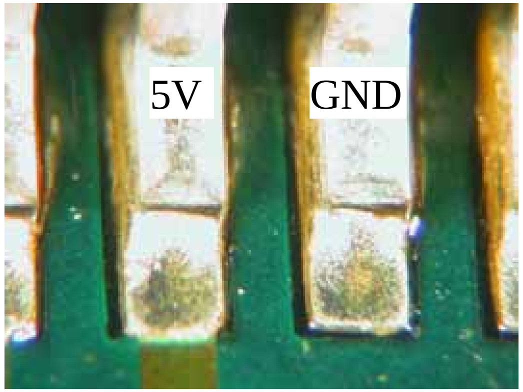
No migration

Evaluation using mounting PCBs (THB Testing, 5/DC bias, 80℃90%)



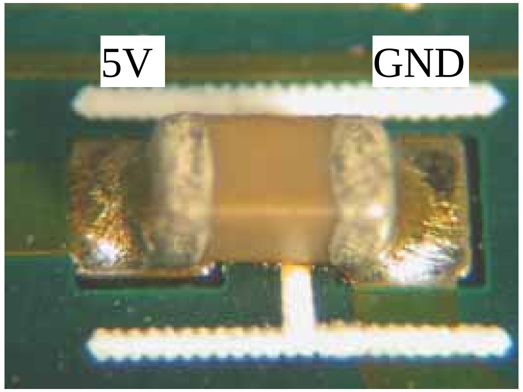
Sn-Ag-Cu solder

Terminal of QFP (spacing:0.5mm)



No migration

Chip capacitance (spacing:0.8mm)



No migration

END