Performance and Reliability Issues of Flip Chip Joints

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Thermal Performance and Reliability Issue of Flip Chip Joint

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- Introduction of flip chip joint
  - Category of flip chip joint
  - Function
  - Trend
  - Electrical performance
- Performance
  - Thermal performance
- Reliability issues
  - Interface stability issue
  - Mechanical reliability issue

Flip Chip Solder Joint

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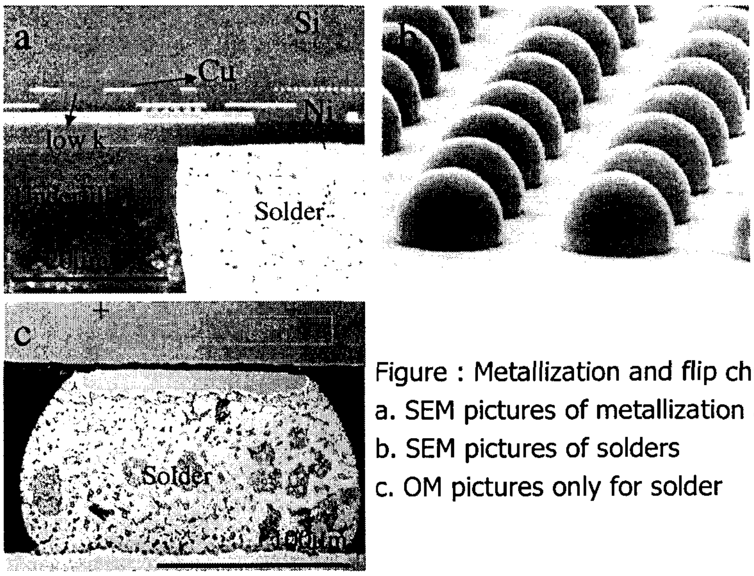

Figure : Metallization and flip chip bump
a. SEM pictures of metallization and solder
b. SEM pictures of solders
c. OM pictures only for solder

Materials and Bonding Process

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<table>
<tr><th></th><th colspan="2">Thermo-compression</th><th>Curing</th><th colspan="2">Reflow (melting)</th></tr>
<tr><td>Solder</td><td></td><td rowspan="2">Stud and solder bonding</td><td></td><td>C4</td><td rowspan="2">Stud and solder bonding</td></tr>
<tr><td>Stud
(Au, Cu, ...)</td><td>Stud bump bonding (SBB)</td><td rowspan="2">Isotropic conductive adhesive bonding (ICA)</td><td></td></tr>
<tr><td>Ag filler with epoxy</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Metal coated polymer</td><td>Anisotropic conductive adhesive bonding</td><td></td><td></td><td colspan="2"></td></tr>
</table>

Function of Electronic Packaging

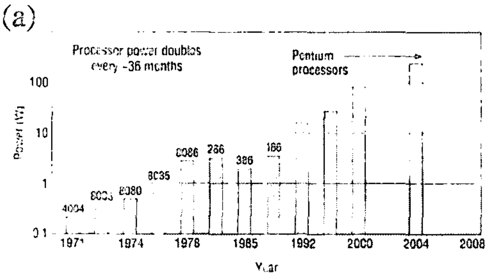
- Traditional functions
  - Power distribution
  - Signal distribution => electrical performance
  - Heat dissipation => thermal performance
  - Package protection

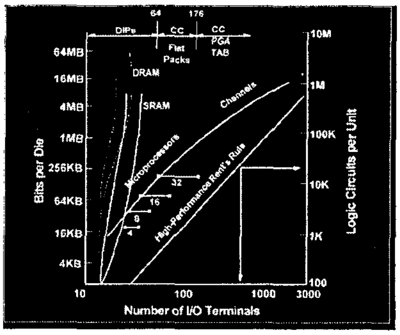
  *ref : Microelectronics Packaging Handbook, edited by R. Tummala et. al.

- New requirements
  - Mobile Devices : Thinner, Smaller, and Less Power
  - Opto Devices : Three Dimensional Alignment and Hermetic Sealing
  - Flat Panel Display : Thinner and Low Temperature Process
  - MEMS : Hermetic and Fluxless Sealing
  - Telecommunication Devices : Faster and Less Signal Loss (low inductance interconnection)
  - Environment Compatible Materials : Pb-free, Freon-free, and so on
  - Bio-Compatible Materials : Non-toxic for Human Beings
  - Cost Reduction, More Reliable, EMI (Electro-Magnetic Interference) and so on ......

Trends of Microelectronic Devices

(a)





(c)

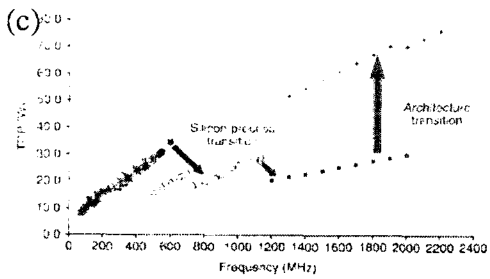


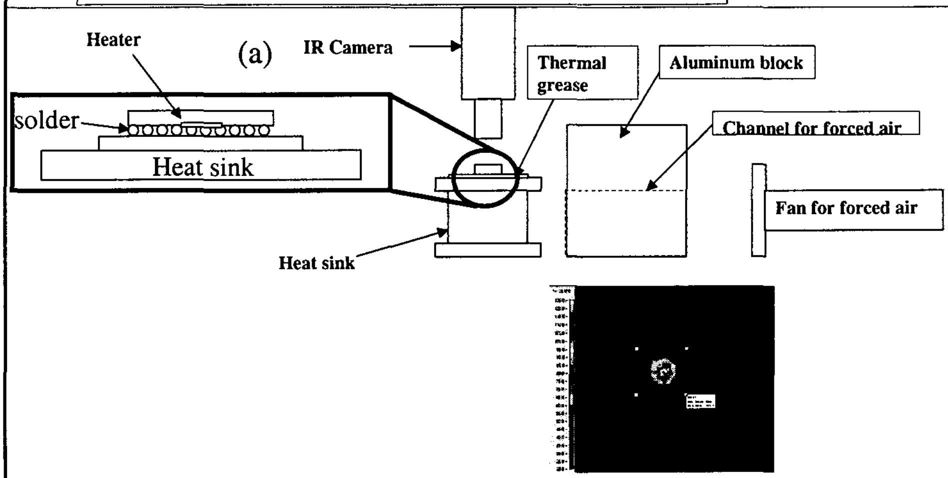
Fig. Trends of Microelectronics
(a) Power consumption of Pentium processor
(b) Number of I/O
(c) Thermal design of power

Ref. Issue of MRS Bulletin, published by MRS (Materials Research Society), (March 2003)

Thermal Performance of Flip Chip Technologies

- Au SBB (Stud Bump Bonding)
- Peripheral array of solder flip chip joint

Temperature Measurement with Flip Chip Solder



(b)

Figure Thermal measurement with flip chip (a) experiment set up for temperature measurement (b) single heater – fine measurement

Test Vehicle for Temperature Measurement

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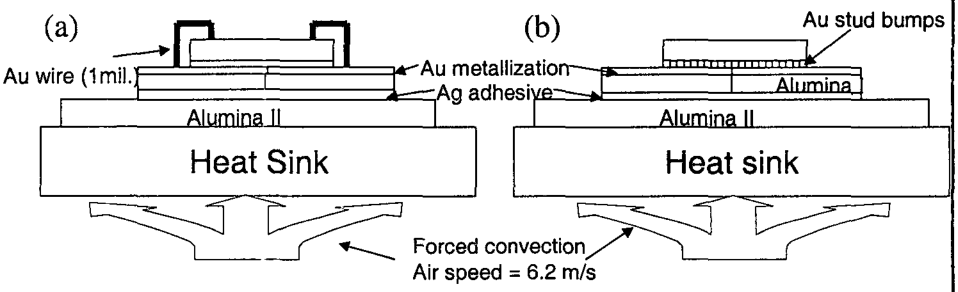

Figure. Schematic diagram for (a) wire bonding and (b) flip chip bonding

Wire Bonding and Flip Chip (Au stud)

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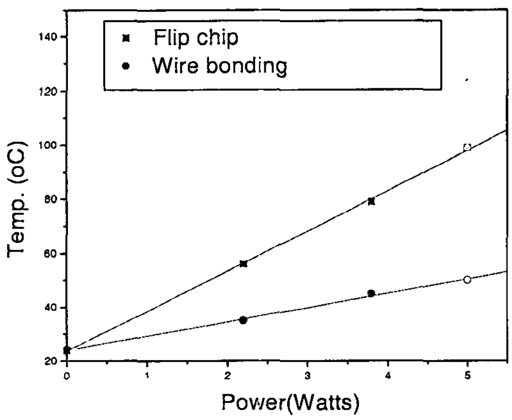


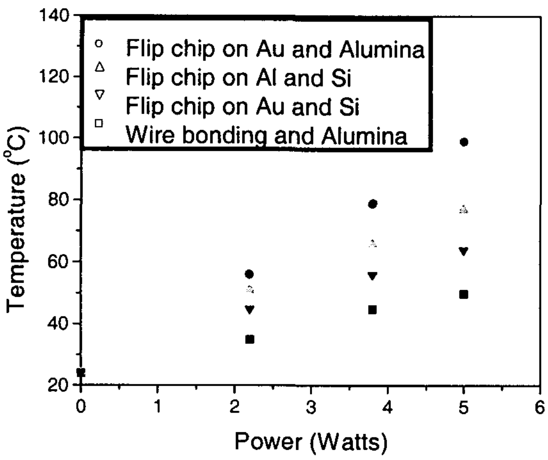
Contact area and height

- Wire bonding
  - Si = 6.5 x 3.5 (mm^2) = 22.75 (mm^2)
  - Ag adhesive height ~ 50 (μm)
- Flip chip bonding
  - # of Au studs = 60
  - Diameter of Au stud ~ 60 (μm) diameter
  - Total Area = 0.17 (mm^2)
  - Height of stud ~ 40 (μm)

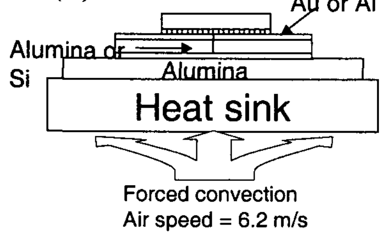
Thermal conductivity(W/m·K)

- Si = 150
- Ag adhesive = 3.2 @121°C
- Gold = 297

Substrate Effect to Thermal Performance of Au SBB

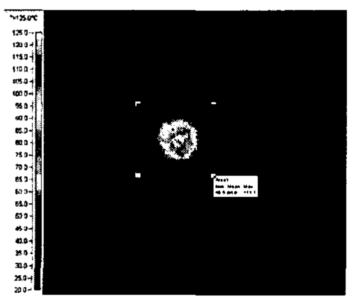


(b)



Temperature Measurement

(a)



(b)

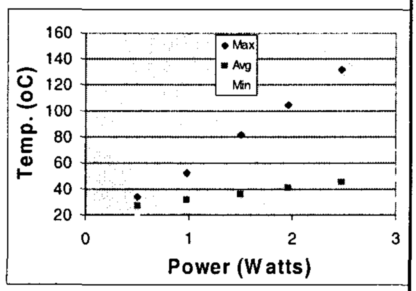
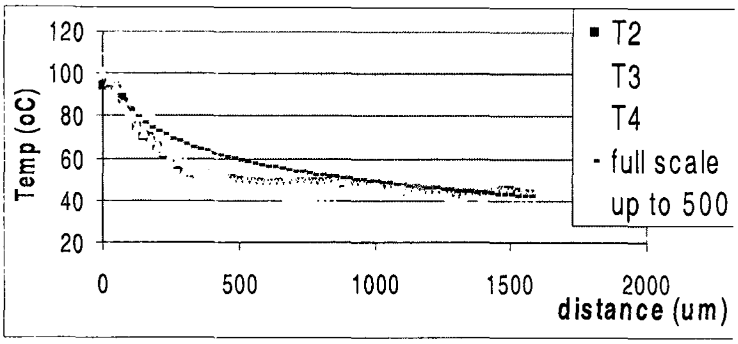


Figure
(a) IR camera image and (b) Temp. vs. power

Temperature Distribution for Steady State



$$\frac{1}{r}\frac{d}{dr}(kr\frac{dT}{dr}) = 0$$

$$T(r) = \frac{T_{\text{edge of heater}} - T_{\text{edge of die}}}{\ln(r_{\text{edge of heater}} - r_{\text{edge of die}})} \times \ln(\frac{r}{r_{\text{edge of die}}}) + T_{\text{edge of die}} = C_1 \ln(r) + C_2$$

Summary for Thermal Performance

- Wire bonding has better heat dissipation than Au SBB because of the difference of contact area.
- For Au SBB, the contact resistance between Au SBB and substrate/chip is a key factor for heat dissipation.
- For localized heater, the highest temperature is about 85°C higher than the average temperature.
- For localized heater, the temperature very sharply drops. 65°C drop in 300 um distance.
- The calculated temp. distribution are well matched with the measurement up to 300 um, but not farther.

Reliability Issue of Solder on e'less Ni

- Interface stability
- Mechanical reliability

Interface Stability in Flip Chip Joint

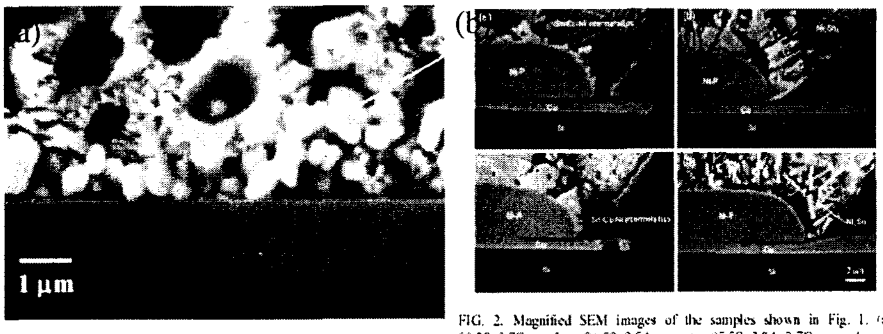


FIG. 2. Magnified SEM images of the samples shown in Fig. 1. (a) 99.3Sn0.7Cu, (b) 96.5Sn3.5Ag, (c) 95.5Sn3.8Ag0.7Cu, and (d) 96Sn2Ag2Bi.

Figure (a) Spalling off of Intermetallic Compound on Thin Ni Film

(ref. P.G.Kim et.al., J. Appl. Phys. v.86, p.6746(1999))

(b) Spalling off of intermetallic Compound on electroless Ni

(ref. J. W. Jang et.al., J. Appl. Phys. V.88, p.6359(2000))

Mechanical Reliability Issue in Flip Chip Joint

$\gamma = \Delta l/h$

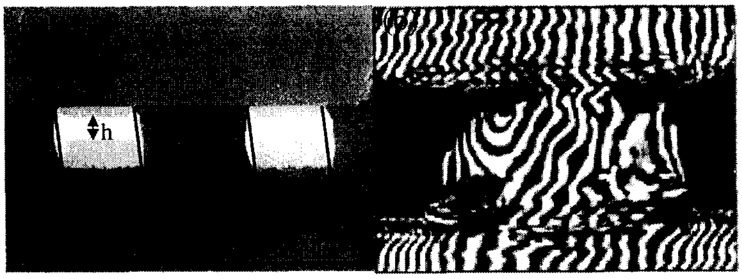
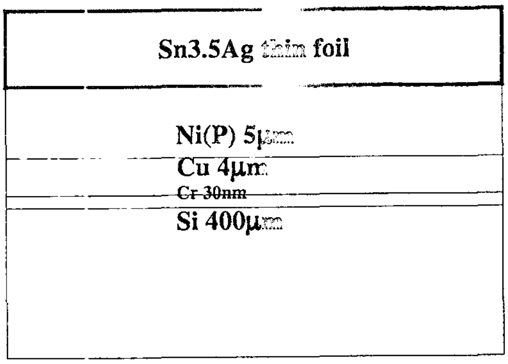


Figure (a) Displacement of flip chip solder joint
(b) Moire pattern in flip chip joint

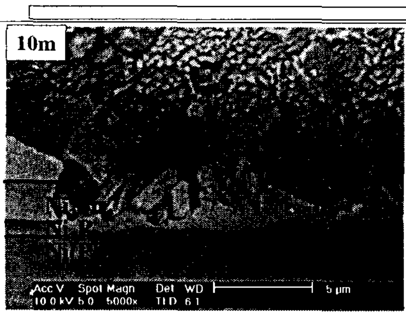
Moire Pattern Ref.
: E. A. Stout et. al. IEEE Trans. Adv. Packag. v. 23, no. 4, p.637 (2000)

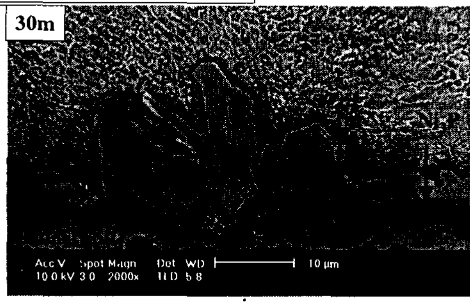
- Mechanical reliability issue for stress
  - Stress from thermal mismatch between Si and PCB
  - Thermal fatigue and creep during usage

Schematic cross-sectioned view of interfacial reaction sample

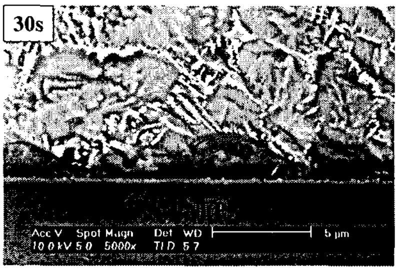


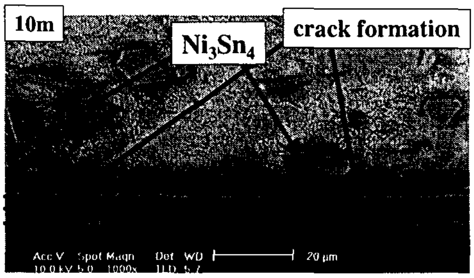
Reaction between electroless Ni and Sn3.5Ag (I)





P wt% => Min.



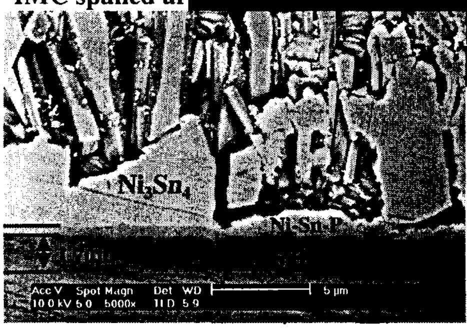


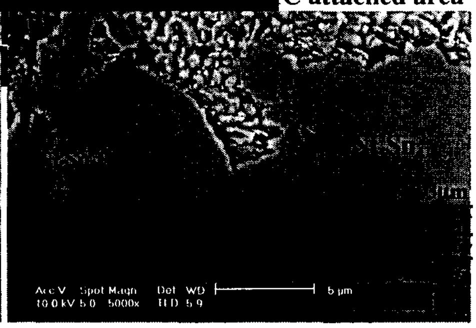
P wt% => Max.

Reaction between electroless Ni and Sn3.5Ag (II)

IMC spalled ar

C attached area





Cross-sectional TEM of Ni(P)/Sn3.5Ag

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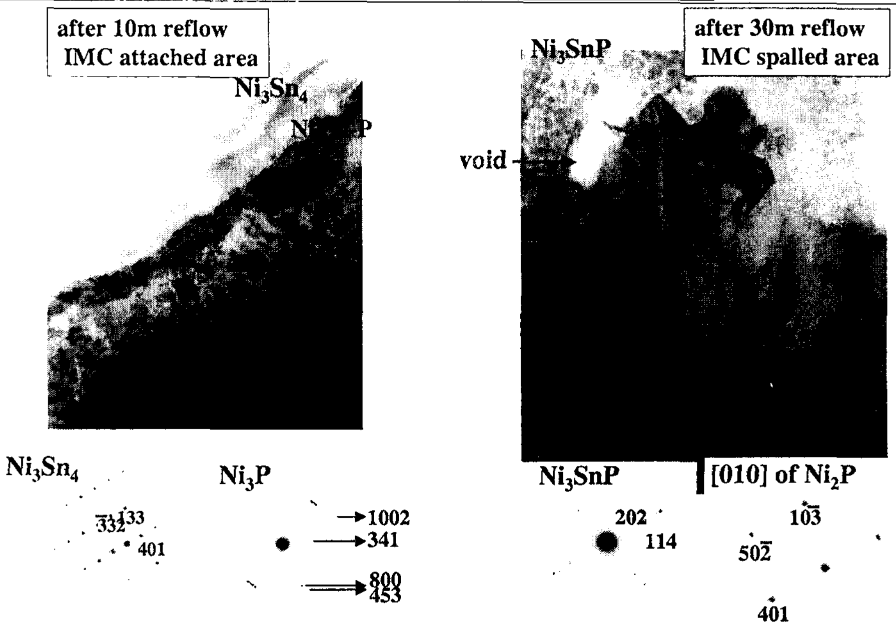

Mechanical Shear Test

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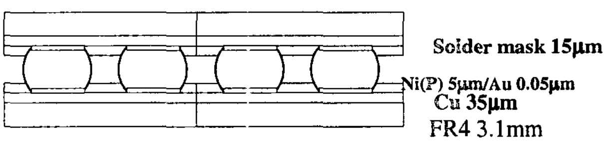
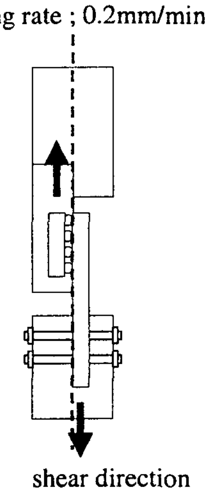
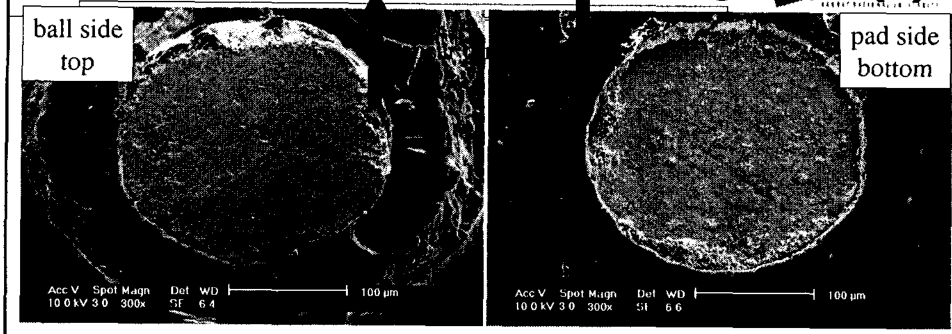
solder ; Sn3.5Ag, Sn3.0Ag0.5Cu
16 solder pads having 250μm diameter

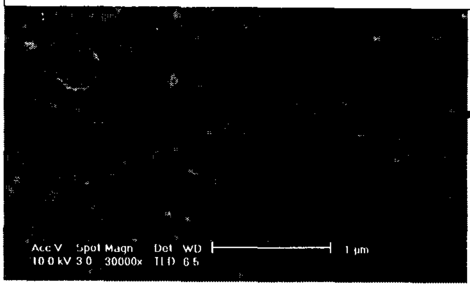




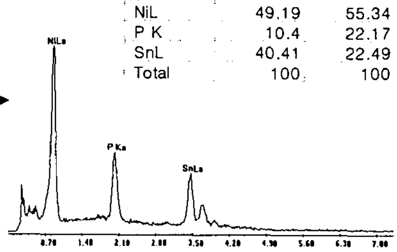
Brittle-fractured Surfaces of Sn3.5Ag/Au/Ni(P)



both surfaces covered with same material

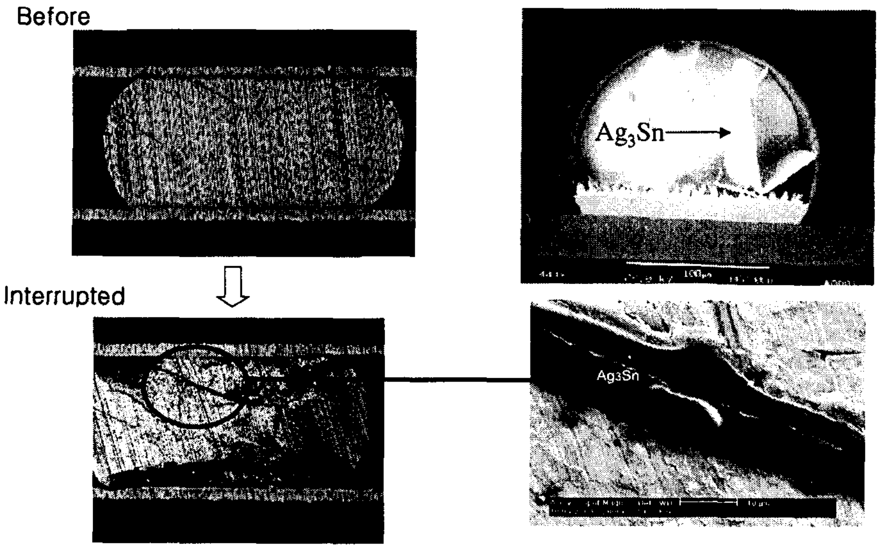


EDX



Element	Wt %	At %
NiL	49.19	55.34
P K	10.4	22.17
SnL	40.41	22.49
Total	100	100

Interaction btw. Chemical and Mechanical Reliability



Ref. S.W. Shin et. al., TMS Fall Meeting (2003)

Summary

- Phosphor contents are critical to the interfacial reaction and IMC behavior
  - If content is too low, the dissolution rate will be very fast.
  - If content is too much, the cracks during interfacial reaction and the IMCs spalling will easily occur.
- The spalling of IMCs caused the brittle fracture of solder joint under shear test.
- IMCs from chemical reaction influences to the mechanical properties and life time.
- Composition changes from chemical reaction influence to the life time.

Acknowledgment

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- Dr. Y. C. Sohn (EPL & CEPM,KAIST)

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