Effects of Bath contamination on electroplated solder bumps

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January 26, 2016
Outline

1 Introduction

2 Experiment

3 Results
   - Cu contaminated Ni bath
   - Ni contaminated SnAg bath
   - Cu contaminated SnAg bath

4 Summary/Conclusions
Chip manufacturing

Silicon Die

Substrate
Wafer Level Packaging

- Photoresist (PR)
- Under Bump Metallurgy (UBM)
- Silicon Wafer
- Ni Plating
- SnAg Plating
- Photoresist Strip
- UBM Etch
- Flux / Reflow

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Multi-metal Plating

- Common to plate multiple metals on same equipment.
  - Minimize oxidation between metal depositions
  - Increase production flexibility
  - Reduce risks due to equipment down-time

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Contamination Risks

- Drag out risks:
  1. From Cu bath into Ni bath
  2. From Ni bath into SnAg bath
  3. From Cu bath into SnAg bath

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Experiment Details

- Baths were contaminated with metal constituents, not full baths with additives → avoid complications with proprietary additives.
- Contamination levels: 0, 10, 100, 500 ppm.
- Test vehicles: patterned wafers 75 μm via with 50 μm resist, and blanket Au seed wafers.
Criteria

- Bath stability
- In-film contaminant incorporation
- Morphology
- Bump height non-uniformity, coplanarity, defects
- Intermetallic compounds (IMC) formation
- Shear strength
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Cu contamination in Ni bath

- SIMS showed Cu incorporation corresponding to contamination level.
Cu dropping out of Ni bath

- Auto-plate onto Ni pellets
- Cu oxide formation (may affect pump performance)
At 500 ppm, Cu contamination level dropped to pre-contamination level given enough recirc time.

Film morphology was restored as a result.
Cu contaminated Ni bath affected the plated Ni morphology.

Bad Ni morphology = Bad SnAg morphology

= Bump height defect (height/shape violation)

Higher Cu contamination \(\rightarrow\) more defects \(\rightarrow\) higher non-uniformity
Post reflow analysis

- After UBM etch and reflow, bumps appeared normal.
- FIB/SEM showed IMC further into solder for 500 ppm.
- Shear strength decreased and varied more for 500 ppm.
Summary: Cu contaminated Ni bath

- Cu contamination at $\geq 100$ ppm affected Ni/SnAg bumps:
  - Caused dendritic Ni morphology. This in turn affected SnAg morphology, bump height non-uniformity, coplanarity, defects.
  - Increased IMC formation further into SnAg
  - Reduced shear strength

- Cu contaminant was reduced over time by:
  - Auto-plating onto Ni pellets, forming oxide sludge
  - Restored Ni morphology.
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Ni contamination in SnAg bath

- Ni contaminant stayed in the bath, even at 500 ppm.
- Note that this was a SnAg system with inert anodes.
Effect of Ni on thin SnAg film

- SIMS showed no Ni incorporation at all contamination levels, even at 500 ppm.
- Reason was that Ni has a more negative standard electrode potential and was in much lower concentration.

Electrode Reactions

<table>
<thead>
<tr>
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<th>$E^0$ [V]</th>
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<tbody>
<tr>
<td>$Ag^+ + e^- \leftrightarrow Ag_{(s)}$</td>
<td>+0.80</td>
</tr>
<tr>
<td>$Sn^{2+} + 2e^- \leftrightarrow Sn_{(s)}$</td>
<td>-0.13</td>
</tr>
<tr>
<td>$Ni^{2+} + 2e^- \leftrightarrow Ni_{(s)}$</td>
<td>-0.25</td>
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Ni effect on Ni/SnAg bump heights

- Ni contamination did not affect Ni/SnAg morphology
- No effect on bump height non-uniformity, coplanarity and defect.
Post reflow analysis

- After UBM etch and reflow, bumps appeared normal.
- FIB/SEM also showed no difference.
- Shear strength varied but no trend seen.
Summary: Ni contaminated SnAg bath

- Ni was not incorporated into SnAg films at all levels
- No apparent effect on SnAg morphology, bump height non-uniformity, coplanarity, IMC formation and shear strength

Ni contamination, up to 500 ppm, does not affect Ni/SnAg bumps at all
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Cu contamination in SnAg bath

- Cu contaminant stayed in the bath, even at 500 ppm.
- Note that this was a SnAg system with inert anodes.
Effect of Cu on thin SnAg film

- SIMS showed Cu being incorporated at ≥ 100 ppm.
- No Cu incorporated at 10 ppm.

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</tr>
<tr>
<td>$\text{Sn}^{2+} + 2e^- \leftrightarrow \text{Sn}_{(s)}$</td>
<td>-0.13</td>
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</table>
Effect on Cu/SnAg bump heights

- No effect on bump height defect, non-uniformity and coplanarity.
- Cu contamination caused a rougher SnAg surface (small pits).
Post reflow analysis on Cu/SnAg

- After UBM etch and reflow, bumps appeared normal.
- FIB/SEM also showed no difference.
- Shear strength at 100 ppm was distinctly higher.

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Summary: Cu contaminated SnAg bath

- Cu was incorporated into SnAg films at $\geq 100$ ppm.
- Cu affected bump surface roughness at 500 ppm.
- No apparent effect on SnAg morphology, bump height non-uniformity, coplanarity, IMC formation.
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Conclusions:

- Cu contamination in Ni bath affected Ni and therefore SnAg morphology for Ni/SnAg bumping:
  - Almost all criteria of the SnAg layer were affected. Higher contamination led to worse result.
  - Ni bath recovered over time because of Ni “dropping” out of bath.

- Ni contamination in SnAg bath for Ni/SnAg bumping had no effect on SnAg at up to 500 ppm contamination.

- Cu contamination in SnAg bath for Cu/SnAg bumping had no effect on SnAg at contamination level <100 ppm for Cu/SnAg bumping. Little effect when level ≥ 100 ppm.
Bibliography