POST-PLATING ANNEALING OF LIGHT-INDUCED PLATED COPPER FINGERS: IMPLICATIONS FOR RELIABLE METALLISATION

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Why Ni/Cu?

- Ag is an investment metal and hence its price fluctuates according to markets.
- Advantages of Ni/Cu plating:
  - Stable low cost, high conductivity.
  - Full area contact to silicon, high aspect ratio.
  - $1 \text{ m}\Omega\text{-cm}^2$ contact resistivity at $3 \times 10^{19} \text{ cm}^{-3}$ P surface concentration.
  - Plated lines can be very thin and strong.

Plating Approaches

**PROCESS 1**
- Plate Ni
- Anneal to form NiSi
- Remove unreacted Ni
- Plate flash Ni
- Plate Cu and cap with Ag

Developed by Motorola, then used by BP Solar (electroless plating).
Adapted by Suntech Power in their Pluto process (LIP).

**PROCESS 2**
- Ablate SiNₓ using UV ps laser

LIP Ni/Cu
- Cap with Ag
- Post anneal

Solderable busbars demonstrated by IMEC and Rena (using Innolas 355 nm ps laser)

What does post annealing do?
- Form NiSi?
- Improve contact resistance?
- Change Cu?
What Happens to Cu After Plating?

- Plated Cu can self-anneal at room temperature.
- Grains grow causing tensile stress inside thin fingers.
- If not managed then this can cause fingers to peel.
How to Measure Stress in Copper Fingers?

If the stress is large, deformation can be detected.

**X-Ray Diffraction (XRD) Peak Analysis**

**Cu XRD reference (No. 00-004-0836)**

<table>
<thead>
<tr>
<th>2Theta [°]</th>
<th>d-spacing [Å]</th>
<th>h</th>
<th>k</th>
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<tbody>
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<td>1</td>
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- Cu (111) and Cu (200) textures can indicate the stress inside the films.

Experimental

Ablate SiNₓ using 266nm ps laser (finger width 13µm) → LIP of Ni/Cu → Post anneal RTP (350 °C, 1 min, N₂)

<table>
<thead>
<tr>
<th>Property</th>
<th>Characterization methods</th>
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<tbody>
<tr>
<td>Microstructure</td>
<td>Focused ion beam (FIB) cross-sectional imaging</td>
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<tr>
<td>Crystallinity</td>
<td>X-ray diffraction (XRD)</td>
</tr>
<tr>
<td>Finger resistance</td>
<td>Four-point probe</td>
</tr>
<tr>
<td>Finger adhesion</td>
<td>A stylus scratch tester</td>
</tr>
</tbody>
</table>

All test structures plated using Macdermid Helios EP2.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Cu plating current density (mA/cm²)</th>
<th>Plating duration (min)</th>
<th>Mid-finger thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td>80</td>
<td>4</td>
<td>13.0 ± 1</td>
</tr>
<tr>
<td>Recommended (normal)</td>
<td>40</td>
<td>8</td>
<td>12.0 ± 1</td>
</tr>
<tr>
<td>Slow</td>
<td>20</td>
<td>16</td>
<td>10.5 ± 0.5</td>
</tr>
</tbody>
</table>
Measuring Adhesion of Plated Fingers

- Use stylus “scratch tester” to measure “dislodgement force” of the fingers

**Cut-Off Mode**
(Typically observed for screen-printed fingers)

**Dislodgement Mode**
(Typically observed for plated fingers)

Self-Annealing Monitored by FIB

Immediately after plating

**Fast**

Immediately after plating

**Normal**

Immediately after plating

**Slow**

After 7 h

After 1d

After 2d

After 15d

After 25d
Post Plating Annealing by RTP

- High plating rates have been shown to significantly reduce the force required to dislodge fingers.
- Post annealing increases the adherence of plated fingers.

Frequency histograms of finger adhesion measurements

- Post annealing increases the adherence of plated fingers.
- High plating rates have been shown to significantly reduce the force required to dislodge fingers.

X. Wang et al. (2016) Untangling the Mysteries of Plated Metal Finger Adhesion: Understanding the Contributions from Plating Rate, Chemistry and Grid, 43rd IEEE Photovoltaic Specialists Conference, Portland, Oregon, USA.
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- The fast plated fingers after RTP have larger grains and are more rigid.
- Rigid conductors are more difficult to break. The proceeding stylus imparts a lateral force which causes the fingers to peel.
The resistance of the Cu fingers also decreased by ~ 17% due to reduced scattering of electrons by impurities and grain boundaries.

Effects of Bias Current Densities

- High plating current density leads to faster and larger degradation of (111) texture and reduces the resistance in the Cu finger films due to more defects.

Rapid thermal annealing in N₂ after Cu plating provides a fast and effective way to drive out impurities, improve the crystallinity and conductivity of the fingers as well as leave the metal in a stable state with regard to internal stress.

Conclusions

- The microstructure of plated Cu conductors evolves with time after plating with grains growing from their as-plated grain sizes.
- These changes are driven by total energy minimisation and the grain growth results in increased tensile stress in thin plated fingers which has implications for ensuring adherent fingers.
- Post-plating annealing at 350 °C for 1 min can eliminate the time and texture evolution of the self-annealing process and therefore has important implications for reliable Cu plated metallisation.
- If not post annealing plated Cu, you need to be aware of what is occurring between plating and encapsulation. Fingers may continue to self-anneal once encapsulated.
Questions and Thank You!