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

Ning Song, Pei-Chieh Hsiao, Wei Zhang, Xi Wang, Jack Colwell, Zhongtian Li and Alison Lennon

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Never Stand Still | Faculty of Engineering | Photovoltaic and Renewable Energy Engineering

Outline

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  - Plating Approaches
  - What Happens to Cu After Plating
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- Self-Annealing of Plated Cu Fingers
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- Effects of Bias Current Density
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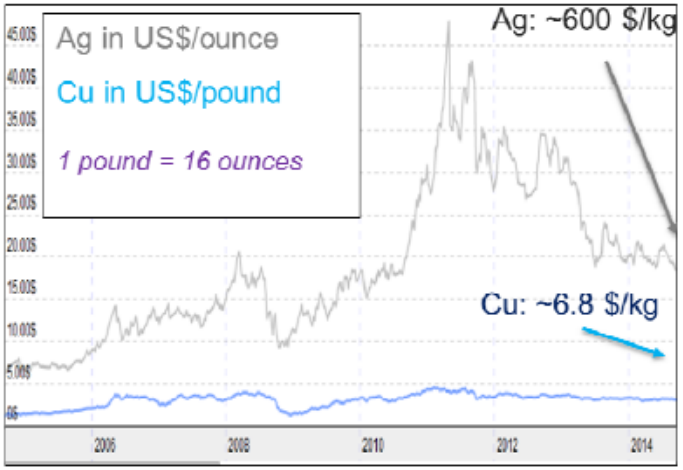
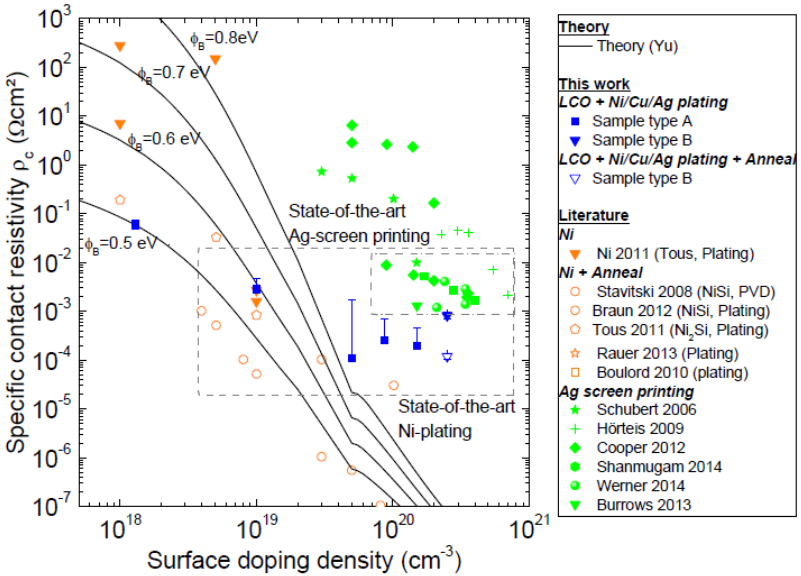
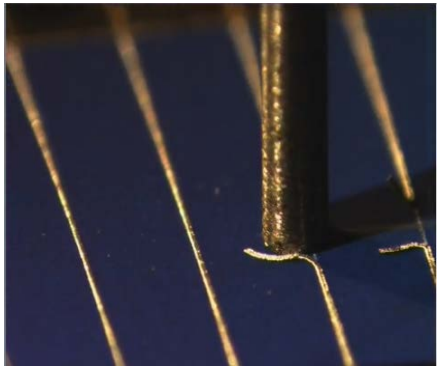
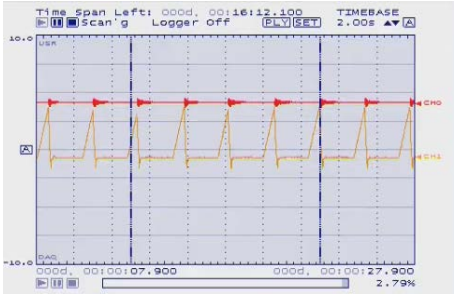
Why Ni/Cu?

- 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 mΩ-cm^2 contact resistivity at 3 ×10^{19} cm^{-3} P surface concentration.
  - Plated lines can be very thin and strong.









Plating Approaches

PROCESS 1

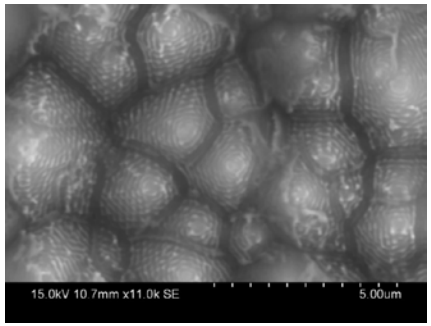
- Plate Ni
- Anneal to form NiSi
- Remove unreacted Ni
- Plate flash Ni
- Plate Cu and cap with Ag

Developed by Motorola, then used by BP Solar (electroless plating).

Adapted by Suntech Power in their Pluto process (LIP).

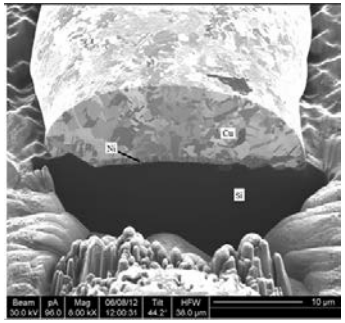
PROCESS 2

- Ablate SiN_x 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)

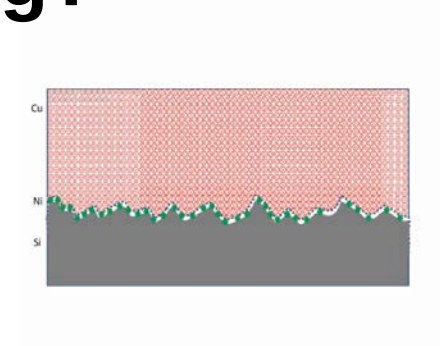


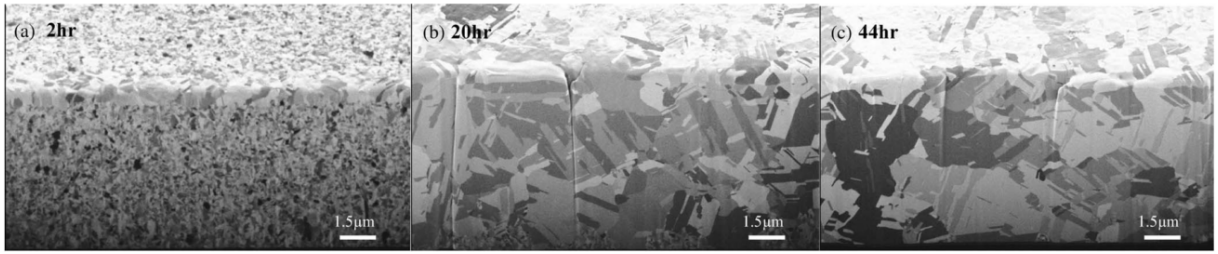
What does post annealing do?

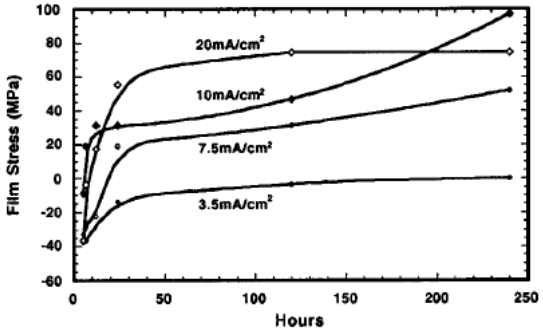
- **Form NiSi?**
- **Improve contact resistance?**
- **Change Cu?**

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.



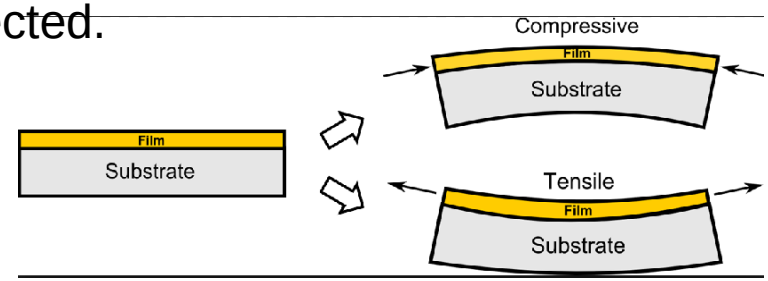




R. Huang et al. (2010) *Transactions of IEEE* ,10, 47-54.
H. Lee et al. (2003) *J. Appl. Phys*., 93, 3796-3804.

How to Measure Stress in Copper Fingers?

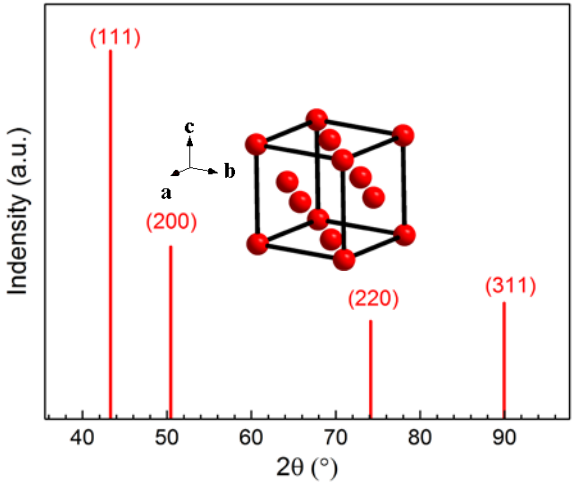
If the stress is large, deformation can be detected.

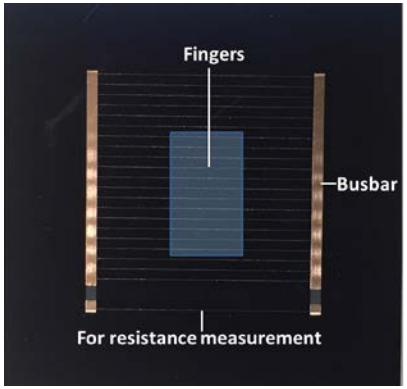


X-Ray Diffraction (XRD) Peak Analysis

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

2Theta [°]	d-spacing [Å]	h	k	l
43.298	2.0880	1	1	1
50.434	1.8075	2	0	0
74.139	1.2780	2	2	0
89.934	1.0900	3	1	1





- Cu (111) and Cu (200) textures can indicate the stress inside the films.

H. Lee et.al. (2003) Correlation of stress and texture evolution during self- and thermal annealing of electroplated Cu films, *J. Appl. Phys*., 93, 3796-3804.

Experimental

Ablate SiNx using 266nm ps laser (finger width13µm)

↓

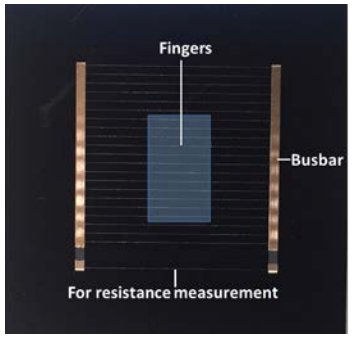
LIP of Ni/Cu

↓

Post anneal

RTP (350 °C, 1 min, N_2)

Property	Characterization methods
Microstructure	Focused ion beam (FIB) cross-sectional imaging
Crystallinity	X-ray diffraction (XRD)
Finger resistance	Four-point probe
Finger adhesion	A stylus scratch tester

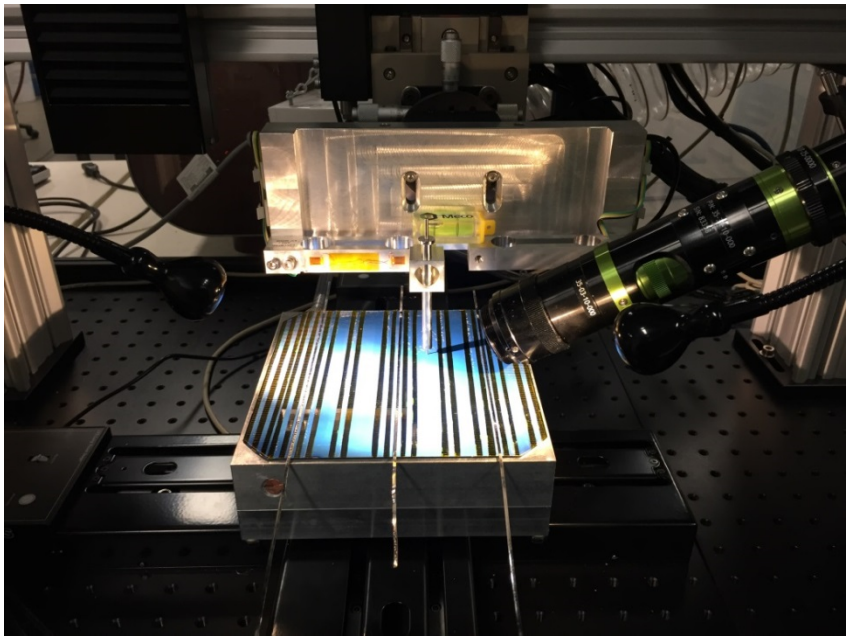


Mode	Cu plating current density (mA/cm^2)	Plating duration (min)	Mid-finger thickness (µm)
Fast	80	4	13.0 ± 1
Recommended (normal)	40	8	12.0 ± 1
Slow	20	16	10.5 ± 0.5

All test structures plated using Macdermid Helios EP2.

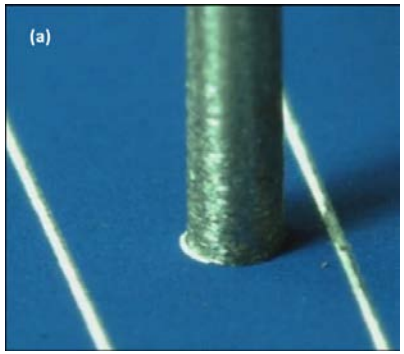
Measuring Adhesion of Plated Fingers

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



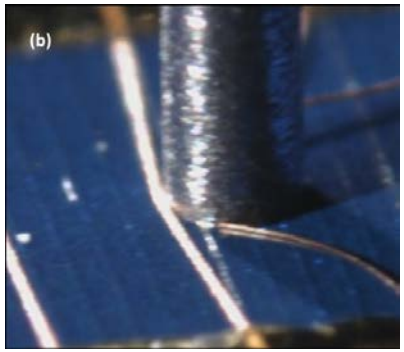
Cut-Off Mode

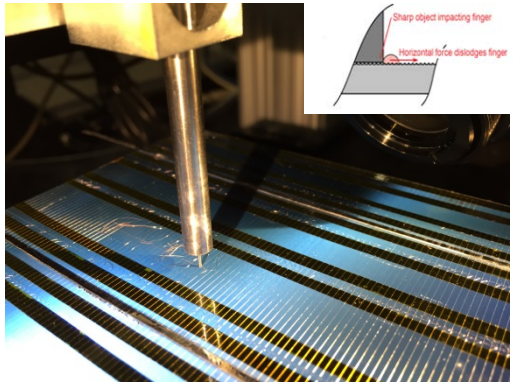
(Typically observed for screen-printed fingers)

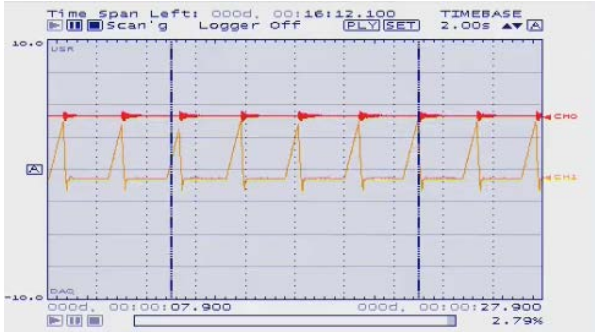


Dislodgement Mode

(Typically observed for plated fingers)





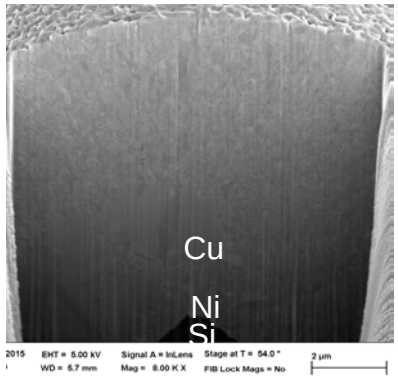


T. Young et al. (2014) Design and characterization of an adhesion strength tester for evaluating metal contacts on silicon solar Cells, IEEE PVSC, 2550-2553.

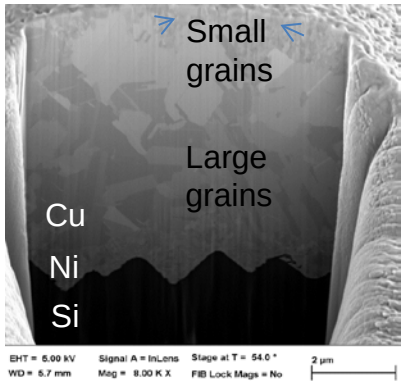
Self-Annealing Monitored by FIB

Immediately after plating

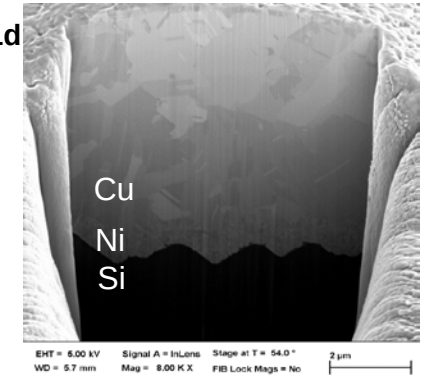
Fast



After 7 h

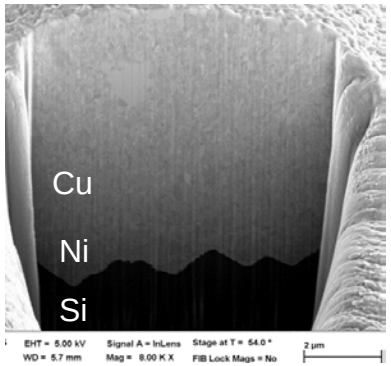


After 1d

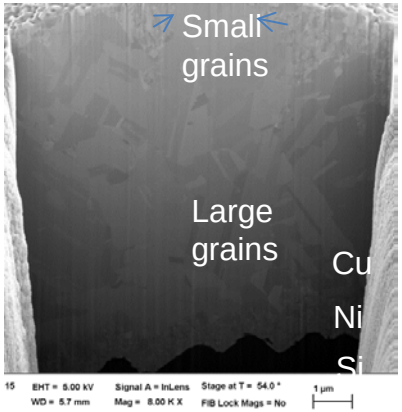


Immediately after plating

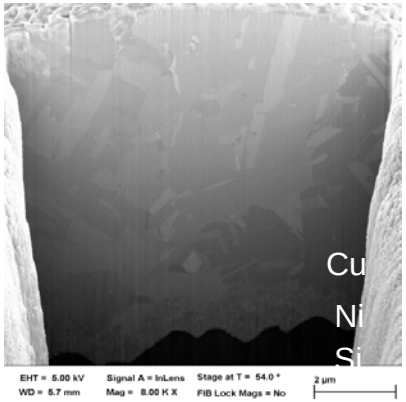
Normal



After 1d

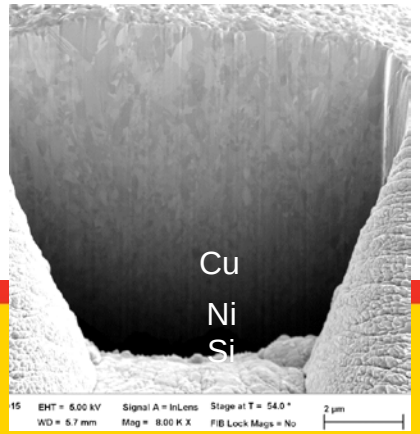


After 2d

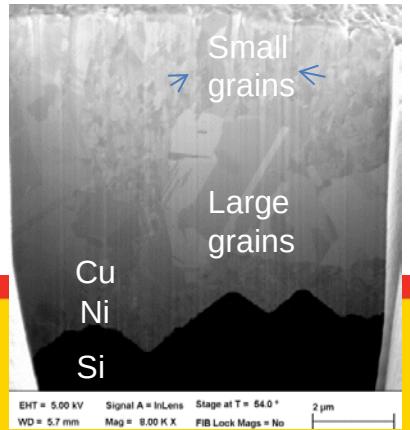


Immediately after plating

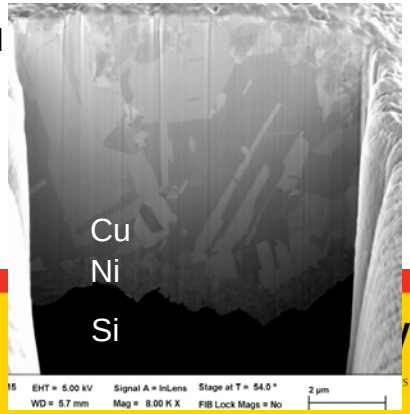
Slow



After 15d

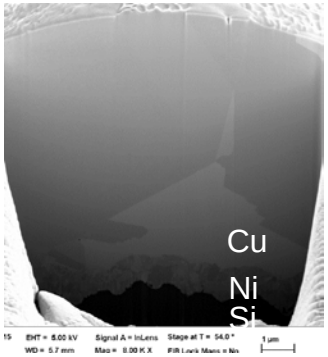


After 25d



Post Plating Annealing by RTP

Fast



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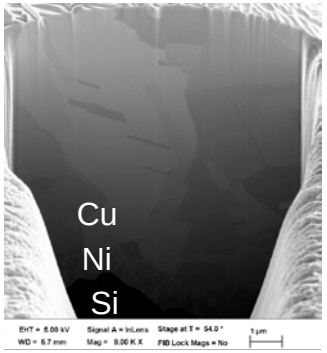
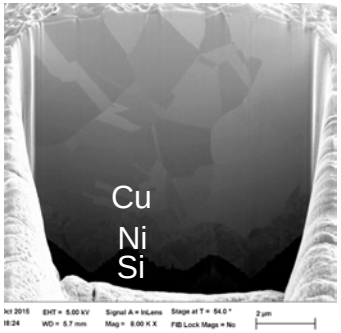
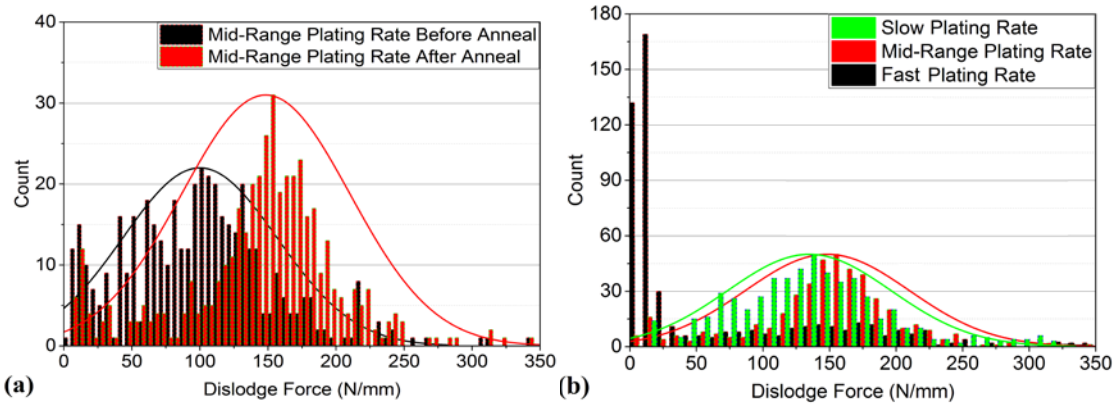


Slow





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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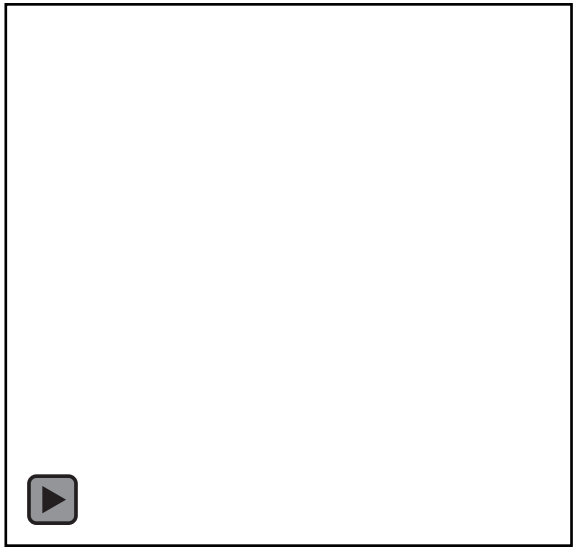
Fast



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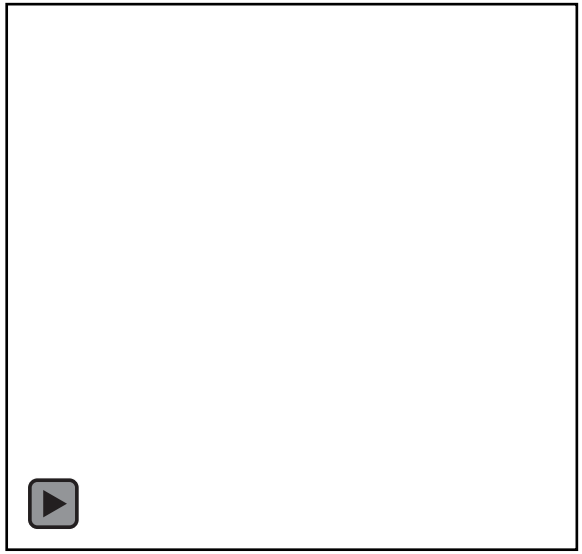
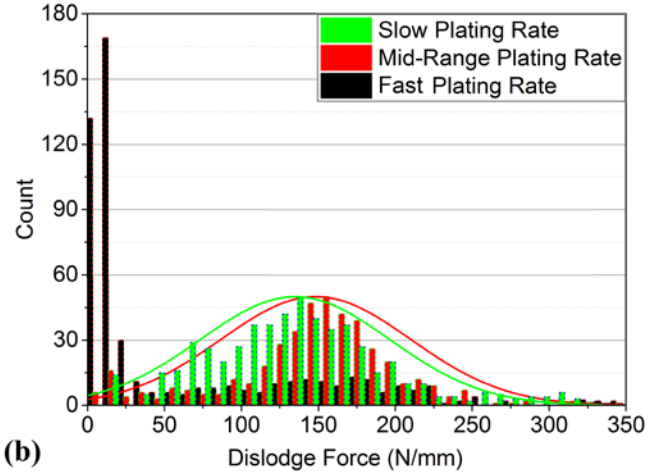
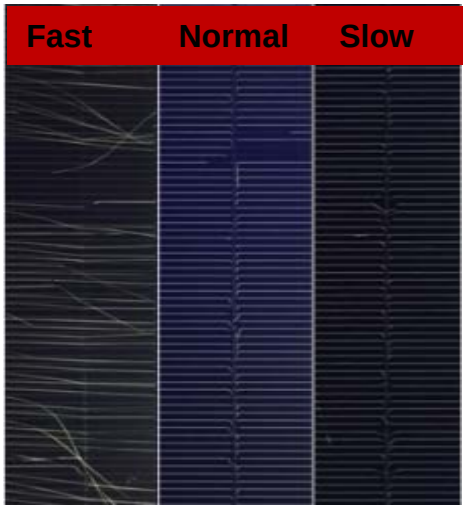




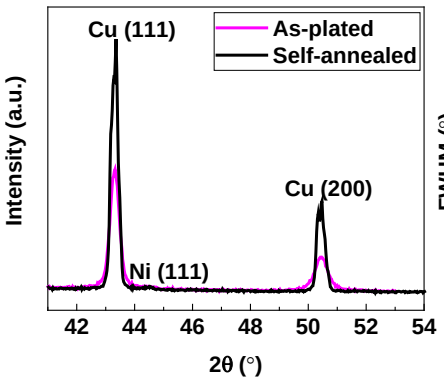


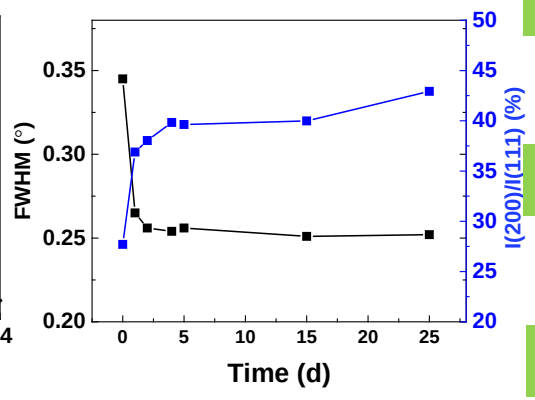
- The fast plated fingers after RTP have larger grains and are more rigid.
- Rigid conductors are more difficult to break. The proceeding stylus imparts a lateral force which causes the fingers to peel.

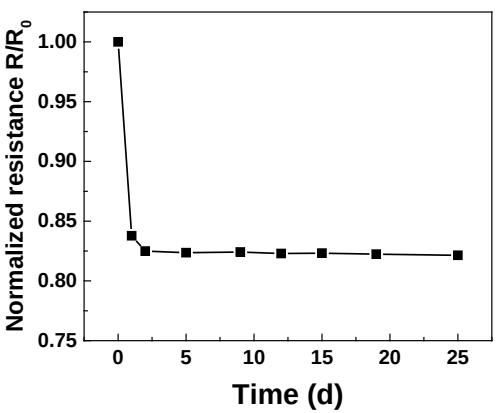
X. Wang et al. (2016) Untangling the Mysteries of Plated Metal Finger Adhesion: Understanding the Contributions from Plating Rate, Chemistry and Grid, 43rd IEEE Photovoltaic Specialists Conference, Portland, Oregon, USA.

Self Annealing Evolution of Cu fingers

Correlation between stress and texture development







Cu face-centered film

↓ Surface and interface energy minimisation

(111) Texture dominant

↓ Minimisation of the total energy caused by impurities, dislocations and grain boundaries

Grain growth

↓

Tensile stress

↓ Strain energy minimisation

Increased (200) Texture — Minimised total energy

- The resistance of the Cu fingers also decreased by ~ 17% due to reduced scattering of electrons by impurities and grain boundaries.

H. Lee, S. S. Wong, and S. D. Lopatin (2003) Correlation of stress and texture evolution during self- and thermal annealing of electroplated Cu films, *J. Appl. Phys*., 93, 3796-3804.

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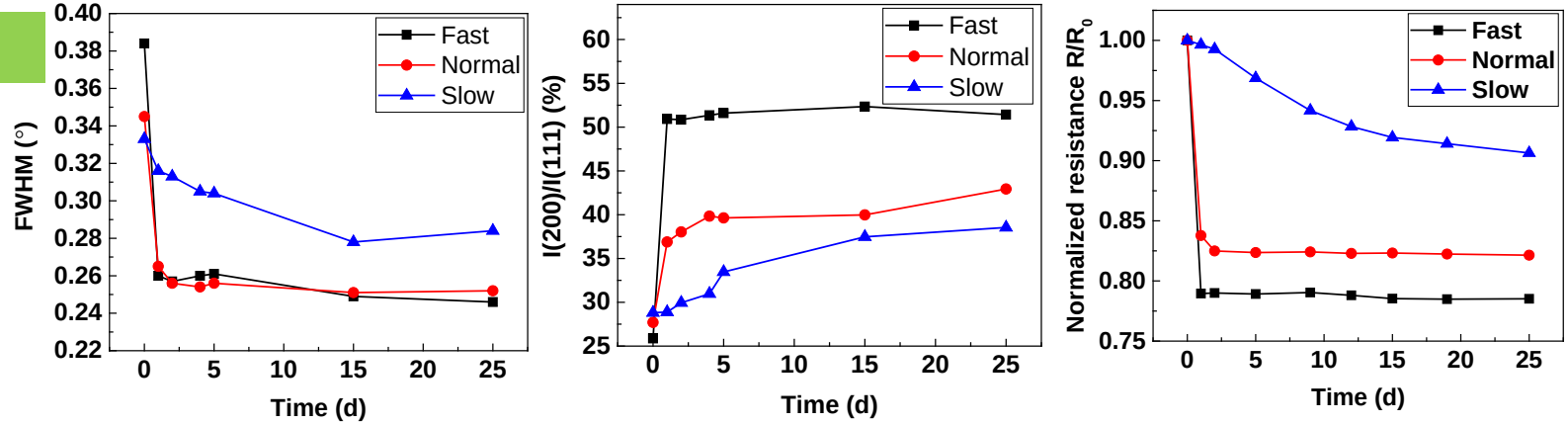
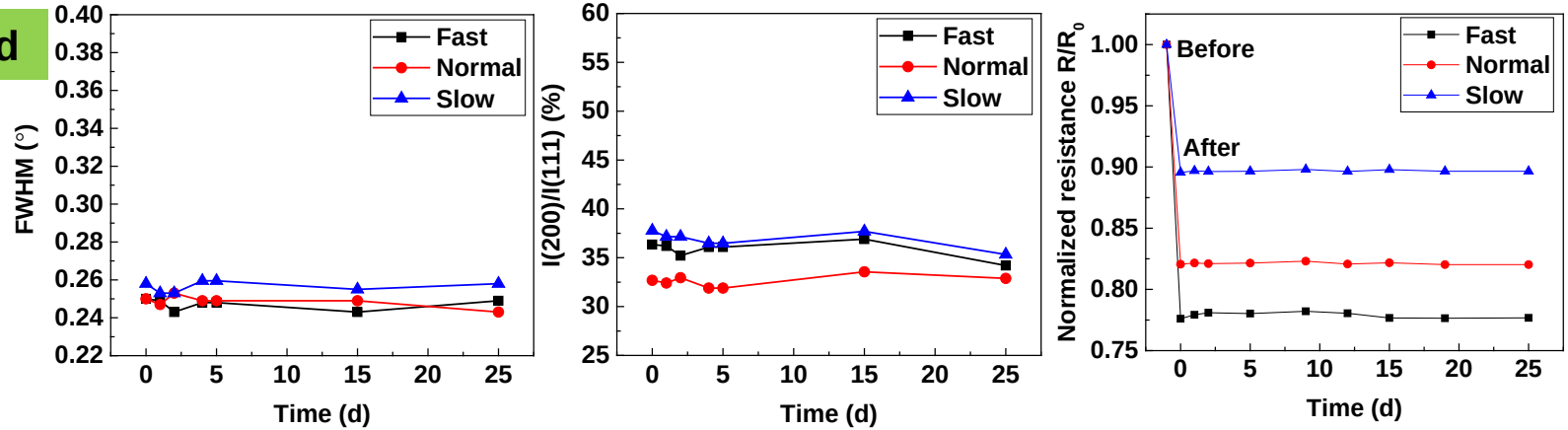
Effects of Bias Current Densities

Self-annealed



- 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.

RTP- annealed



- Rapid thermal annealing in N_2 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.

C.-T. Lin and K.-L. Lin (2004) Effects of current density and deposition time on electrical resistivity of electroplated Cu layers, *J. of Mat. Sci: Materials in Electronics*, 15, 757-762.

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 ℃ 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!

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