# Developments in low-temperature metal-based packaging

2011. 12.14

Jiyoung Chang and Liwei Lin
Ph.D. Candidate, Department of Mechanical Engineering
University of California at Berkeley




## Contents

- Project & Research goals
- Low temperature metal packaging
  - Dry thermocompression
  - Rapid Thermal process
  - Solder pre-reflow
  - Insertion of thin metal layer
- Summary


# Research goals

**Center for Micro/Nano Scaling Induced Physics (MiNaSIP) in U.C.Berkeley**
- Subgroup research with Freescale™ semiconductor

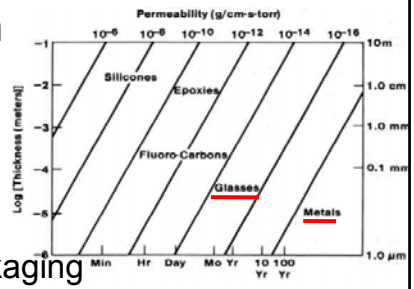
- Flux-less bonding
- Short bonding time & Low bonding temp.
- Sub-100μm width bonding ring
  - → Photolithography definable & Electroplating
- Hermetic sealing
  - → Low permeability required
- CMOS compatible process

BSAC

3

# Material selection

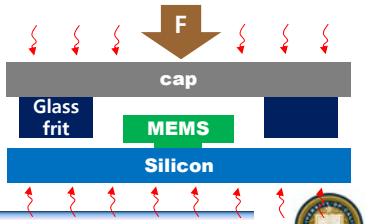
- Material Selection Criteria
  - Temperature
  - Deposition & bonding method
  - Permeability
  - Mechanical properties




*__Glass Frit :__ Popular in MEMS packaging

- Deposition : Screen-printing (min.w≈150μm)
- Temperature : 450 ˚C
- Time :15-30 minutes
- Mechanical : Brittle

→ ***Metal bonding***

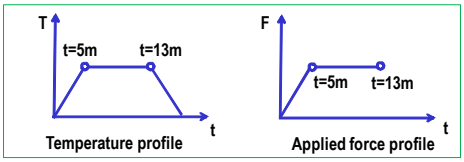



BSAC

4

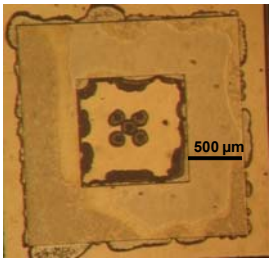
## Dry Thermo-Compression (SnCu-Cu)

- 227 > $T_{bond}$ > 232

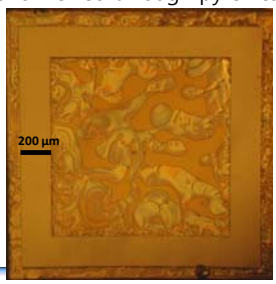



< Flipchip bonding parameters >

- Results:
  - No bond or Solder reflowed
- Low process controllability
  - Non-planar surface issue
  - Surface oxidation may prevent inter-diffusion




Bond viewed through pyrex cap

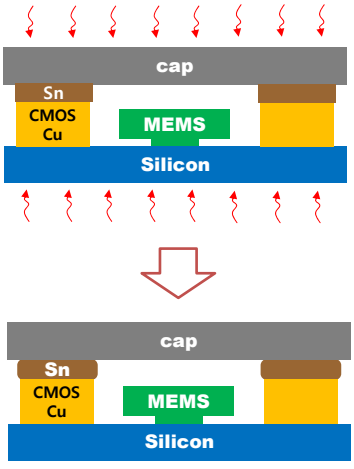



BSAC

5

## Sn Reflow Bonding via RTP

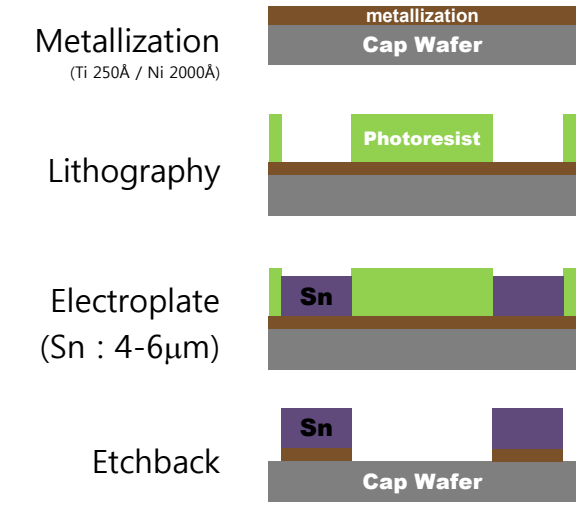
- RTP (Rapid Thermal Process)
  - Short bonding time with high temperature ramping up speed to prevent solder's squeezing out
- Solder reflow benefits
  - ✚ Less sensitive to surface non-uniformities
  - ✚ Low force




BSAC

6

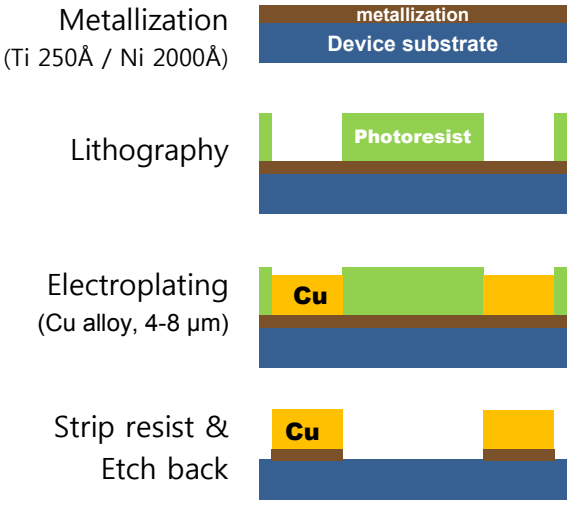
## Cap wafer fabrication Process Flow




BSAC

7

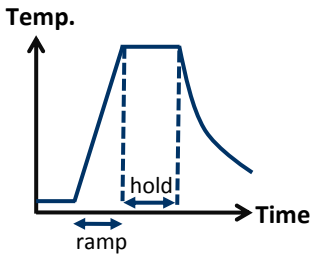
## Substrate wafer fabrication Process Flow



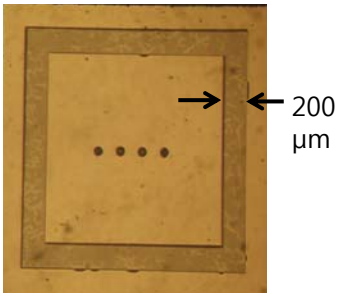

BSAC

8

# RTP Bonds – Minimal Thermal Budget




$T_{max}$ =250-300 ˚C
ramp = 10 seconds
hold = 10 seconds




- Thermal budgeting compared to glass frit
  - Time reduction – 10-50X
  - Temperature reduction – 1.5-2X

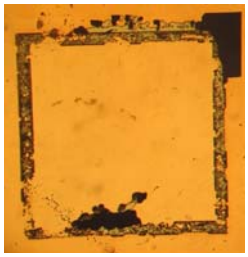
BSAC



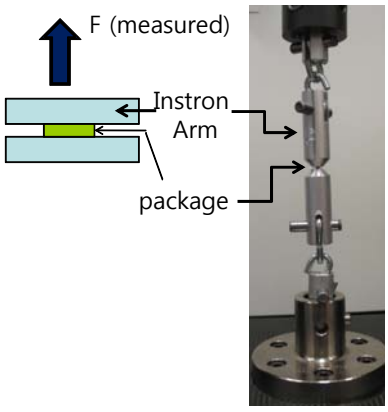
# Mechanical strength comparable with glass frit

| Material System | Bond Strength (MPa) |
|---|---|
| Glass frit (thermo-compression) | 8.5 |
| Solder reflow (RTP) | 7.5 |

pull-tested bond



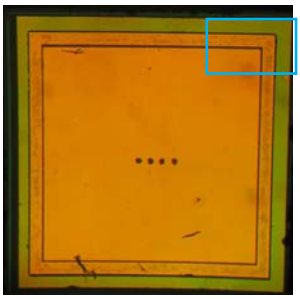
**Pull-Test Setup**

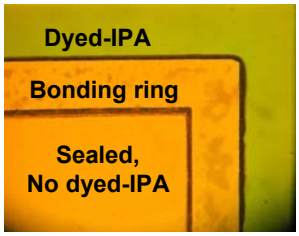



BSAC

## Leak & Autoclave Test

- Dyed-IPA leak test
  - Gross-leak detection
  - Small surface tension of IPA allows quick permeation through voids






- 12-hour Autoclave test failed : 125°C & 24psi

BSAC

11

## Why hermetic test failed??

- *Formation of leakage pass-through due to…*
- Void formation
  - Gas trapping during bonding process
  - Metal oxide on surface prevents reflow of solder
- Non-uniform bonding along the bonding ring
  - Lack of uniform pressure applied during bonding

→ **Pre-reflow process approach**

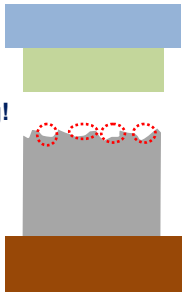
BSAC

12

# Pre-Reflow process

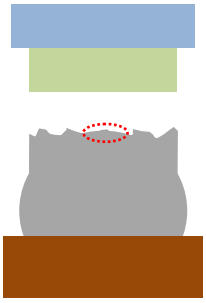
♦ Purpose of Pre-reflow process

- Break the surface oxide layer and reflow fresh solder
- To minimize gas trapping which causes void formation in bonding area



Gas Trapping!

Without Pre-Reflow



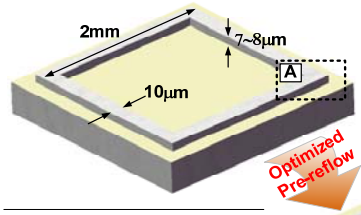
Small initial contact area!

With Pre-Reflow

BSAC

13

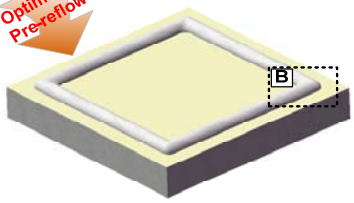
# Pre-reflow bonding concept

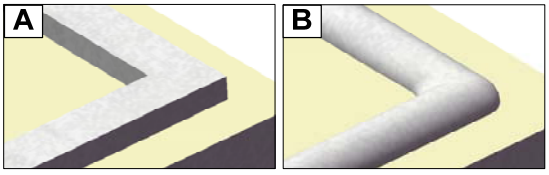



**Pre-reflow MEMS packaging**
- Fluxless
- Narrow bonding ring : ≈10μm
- Short Process time : ≈3min
- Good hermetic property
- Low cost

Optimized Pre-reflow

| | Pre-reflow | Glass-Frit |
|---|---|---|
| Width | ≈10μm | >150μm |
| Time | ≈3min | 15~30min |

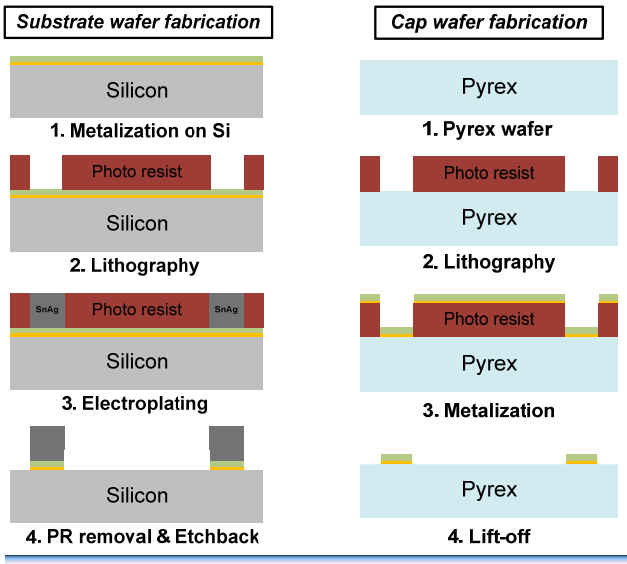



BSAC

14

# Device fabrication




BSAC

15

# Pre-reflow profile optimization

- Process parameters in typical solder ball reflow process
  - Temperature gradient in preheat zone
  - Soak temperature and time when using Flux
  - Temperature gradient from soak to maximum temperature
  - Maximum peak temperature
  - Cooling gradient in cooling zone
  - Total heating time
- Current solder reflow profile is optimized for **solder ball to form sphere shape not for square line form solder**

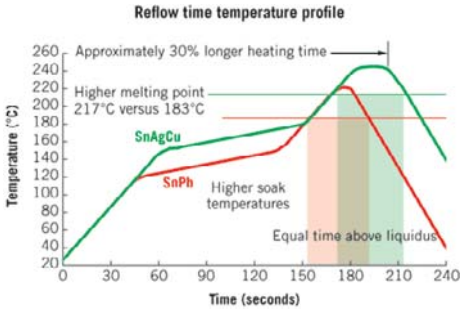
  → Reflow profile needs to be modified for line shape bonding

BSAC

16

# Typical solder ball reflow profile

- **Typical solder ball reflow profile**
  - SnAgCu & SnPb case
  - ≈ 20ºC~30ºC higher peak temperature than melting temperature
  - ≈ 40sec of time above melting temperature
  - Total of 3~5min of process



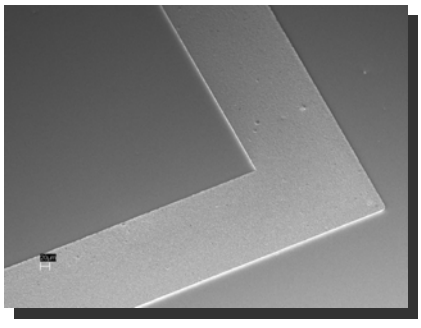

BSAC

• *Denis Barbini et al. "Process Considerations for optimizing a reflow profile", SMT/July 2005, www.smtmag.com*

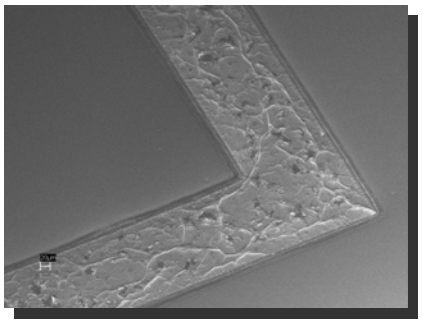
17

# **SnAg** solder with Pre-reflow test

- Electroplated Sn(96.5)Ag(3.5) eutectic solder
- Bonding ring dimension: Width ≈200μm, Height ≈6μm



Before reflow



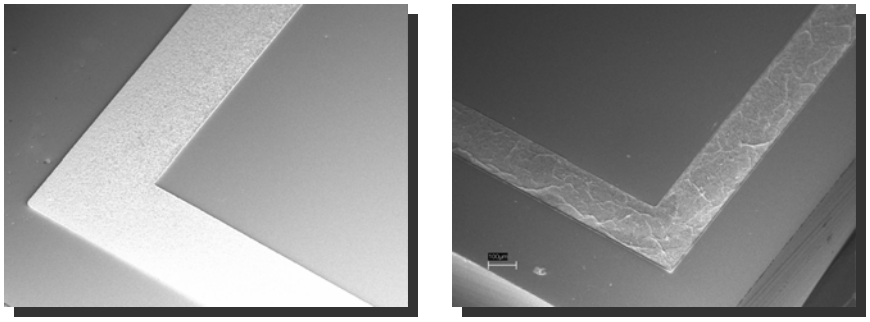
After reflow

BSAC

18

## **SnCu** eutectic solder with Pre-reflow test

- Electroplated Sn(99.3)Cu(0.7) eutectic solder
- Bonding ring dimension: Width ≈ 200μm, Height ≈5μm



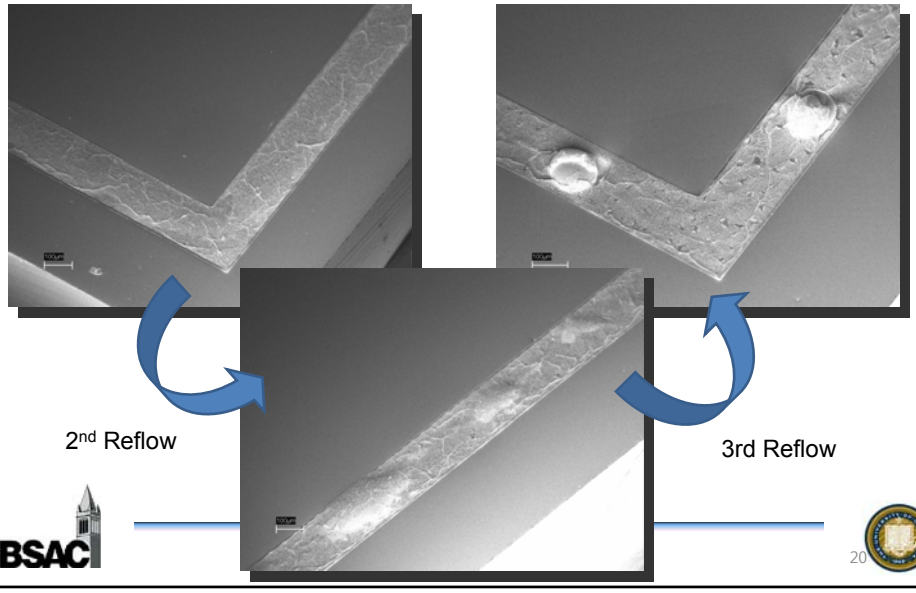
Before reflow

After reflow

BSAC

19

## **SnCu** solder with multiple reflow processes



2nd Reflow

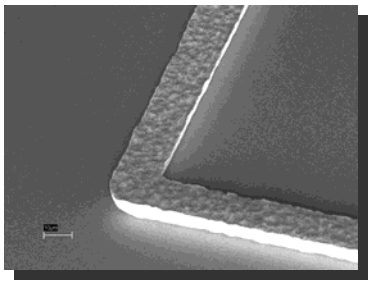
3rd Reflow

BSAC

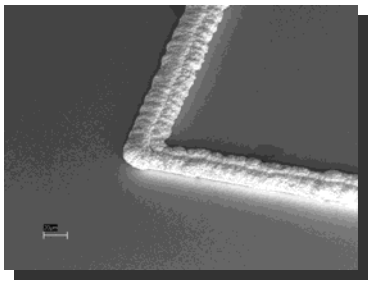
20

## Low Width to Height ratio bonding ring

- Electroplated 10μm and 20μm width bonding ring
- Width to Height ratio - 1.5:1~2:1



Electroplated **SnAg**
with 10μm width bonding ring



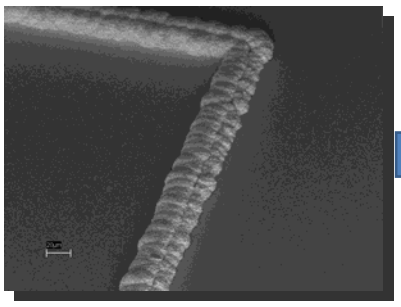
Electroplated **SnCu**
with 20μm width bonding ring

BSAC

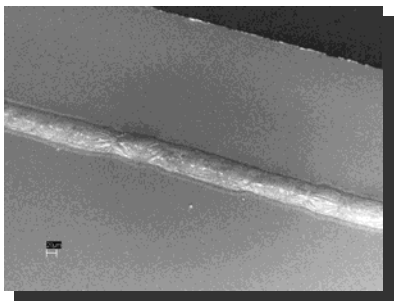
21

## SnCu reflow test results

- Reflow profile modification
- Formed half-cylinder after reflow
- Partially non-uniform clogging surfaces observed



Reflow



Electroplated SnCu
with 20μm bonding ring

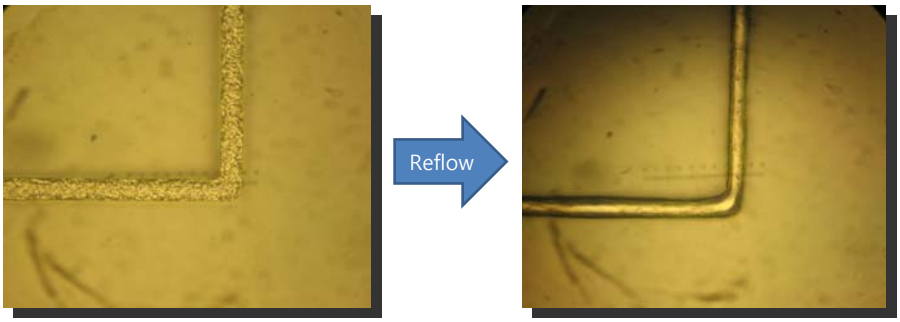
After reflow

BSAC

22

## SnAg 10μm width ring pre-reflow results

- Reflow profile optimized in RTP
- Uniform half-cylinder shape achieved
- No clogging or solder gathering was observed



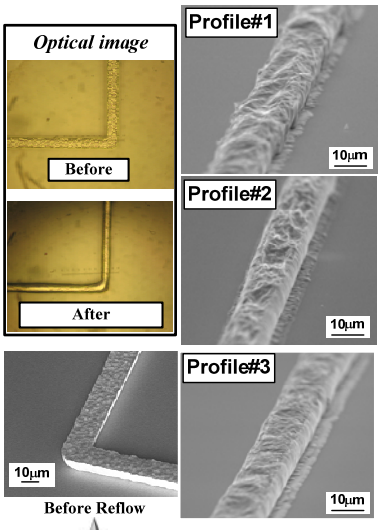

Electroplated SnAg
with 10μm width bonding ring

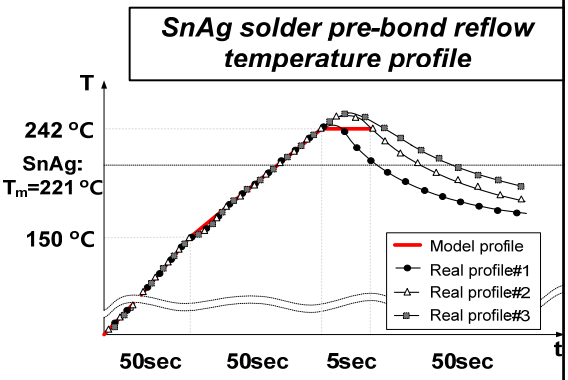
After optimized reflow

BSAC

23

## SnAg 10μm width ring pre-reflow obtimization

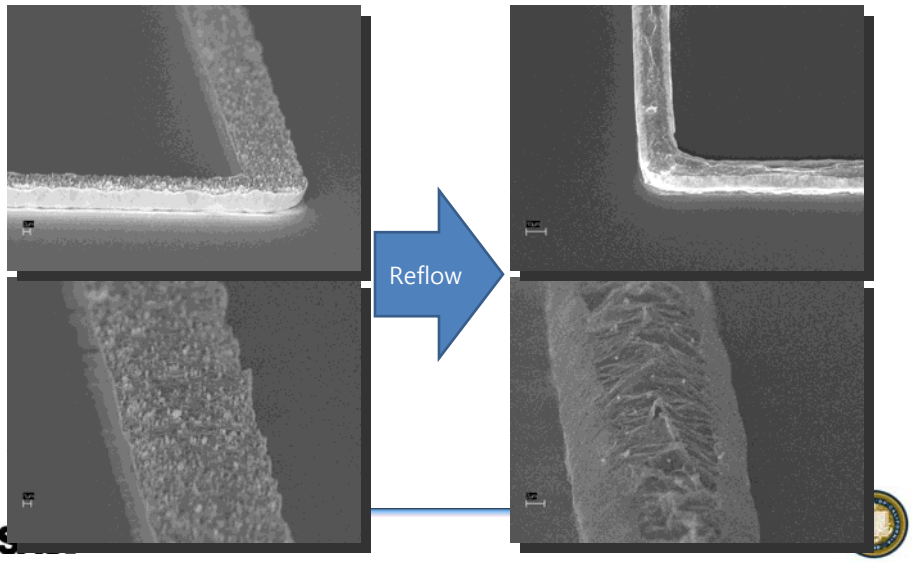



BSAC

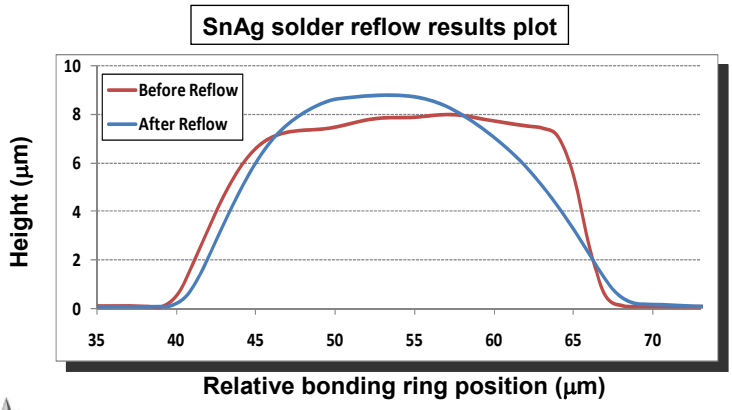
24

## SEM image of SnAg bonding ring after pre-reflow



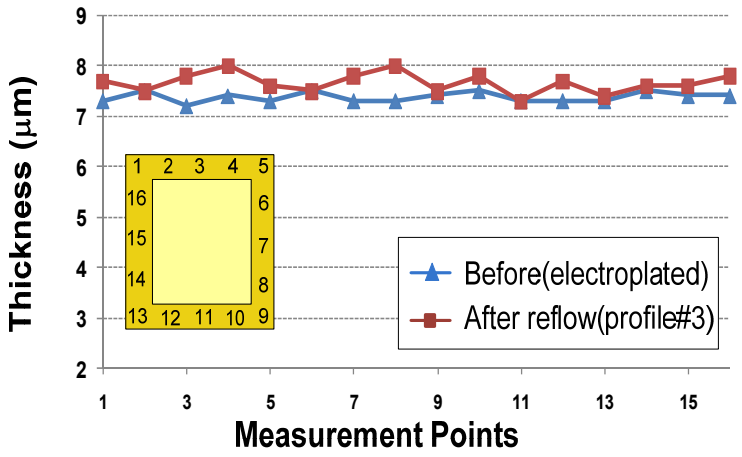

## SnAg reflow results

- Surface profile measurement by micro profiler(ASIQ®)
- Half-cylinder shape formation after reflow




BSAC

# Height uniformity measurement



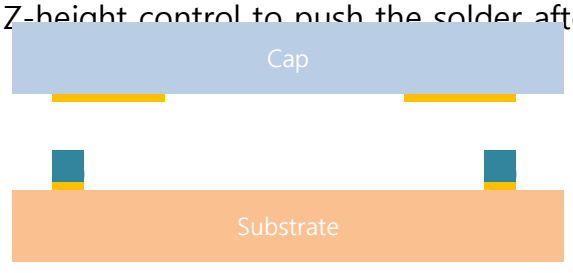

BSAC

27

# Flipchip bonding result

| | material | Width | Height |
|---|---|---|---|
| **Substrate** | SnAg solder | ≈10μm | ≈7~8μm |
| **Cap** | Ni | 150μm | ≈200nm |

- Optimized reflow profile in pre-reflow was applied in Flipchip
- Z-height control to push the solder after pre-reflow

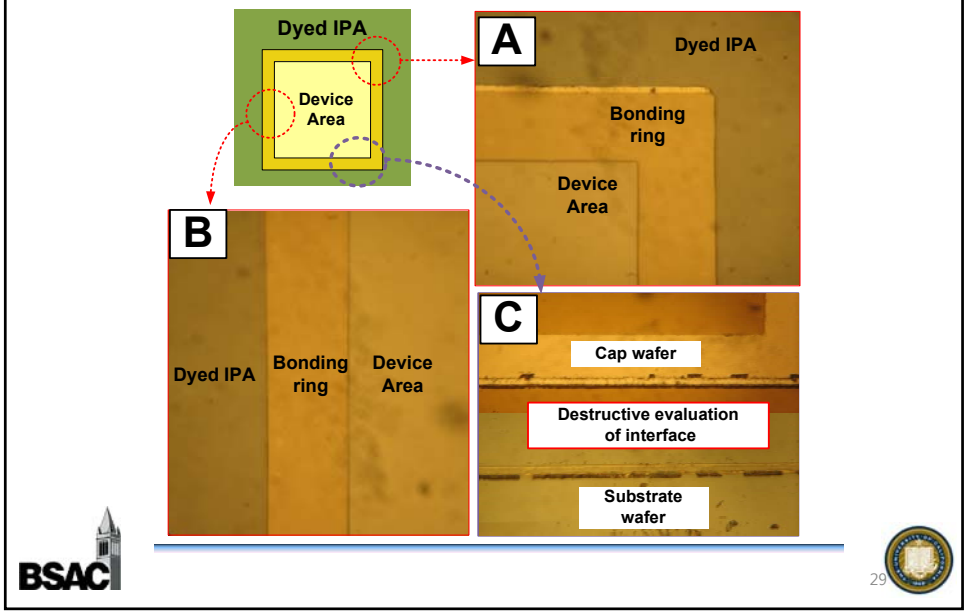



1. **Heating**
2. **Solder pre-reflow**
3. **Bonding with z-control**

BSAC

28

# Leak test result

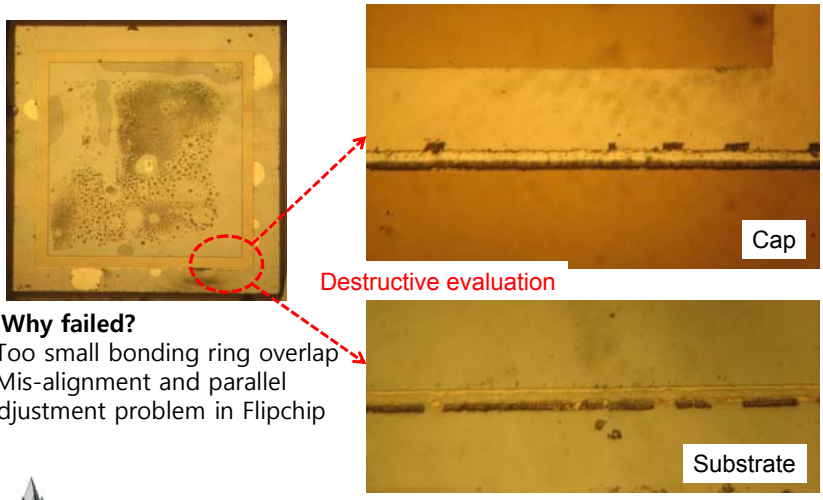



BSAC

29

# Hermeticity test

- 12-hour Autoclave test failed




- **Why failed?**

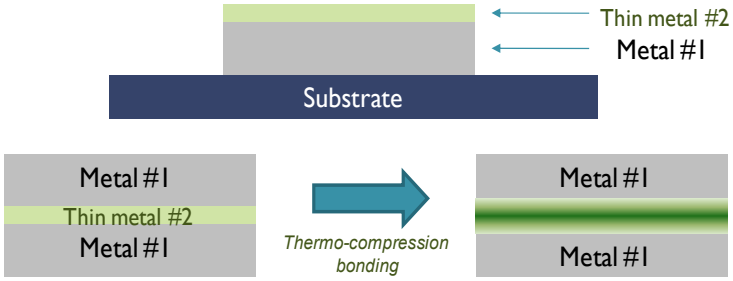
-Too small bonding ring overlap
-Mis-alignment and parallel adjustment problem in Flipchip

BSAC

30

## Thin metal layer insertion approach

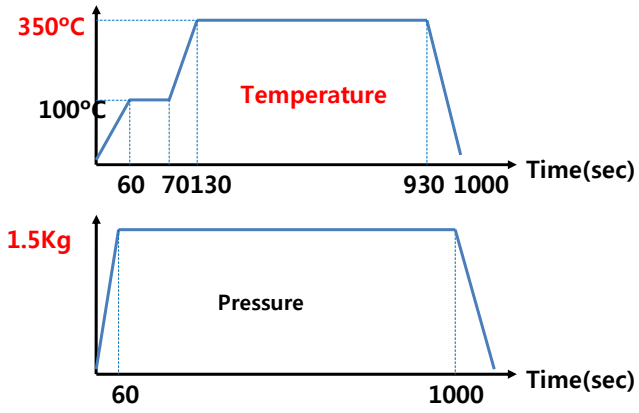
- Alloy formation b/w bonding metal (Al)
- Stronger bonding than pure Al-Al bonding at same bonding condition




BSAC

31

## Temperature/pressure condition

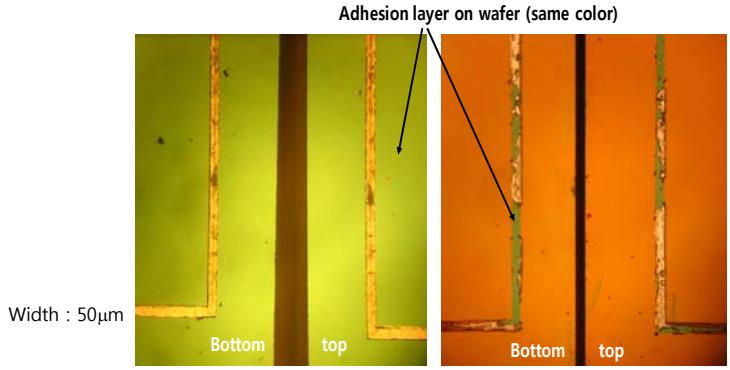



- Lower bonding pressure (15MPa)
- Lower bonding temperature(350°C, Tm(Al)=660°C)

BSAC

32

# Pull Test results




-Same bonding parameter was applied for both cases

-Strong bonding at the contact interface for <Al+Sn20nm to Al bonding>

- No strong bond was made for Al to Al bonding case

BSAC

33

# Summary

- Proof-of-Concept : Metal bonding for possible replacement of glass-frit
  - CMOS-integrated process
  - Compatible mechanical strength with glass-frit
- Rapid Thermal bonding result(no pre-reflow)
  - Successful leak-test for 200μm bonding ring
  - Failed 12hr hermetic test
- Solder reflow profile optimization for sub-100μm metal bonding solution
  - Reflow profile optimization for 10mm SnAg boding ring
  - Uniform half-cylinder shape reflow results
- Solder pre-reflow bonding of SnAg 10μm bonding ring using Flipchip
  - Optimized reflow profile used for bonding
  - Possibility of sub-100μm bonding ring in MEMS packaging
- Metal insertion approach
  - Al-Sn-Al approach showed better bonding quality than pure Al-Al bonding
  - Lower temperature and pressure

BSAC

34

# Acknowledgement


- IEEE-CPMT
- Prof. Liwei Lin
- Mr. Kedar Shah

- Sponsor
  - Freescale™ semiconductor
  - DARPA


*Thank you!!*

BSAC