Fabrication, attachment and characterization of solder spheres with multi-layered thin-film coatings for socketing and surface mount applications

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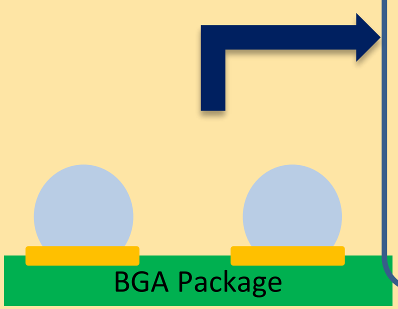
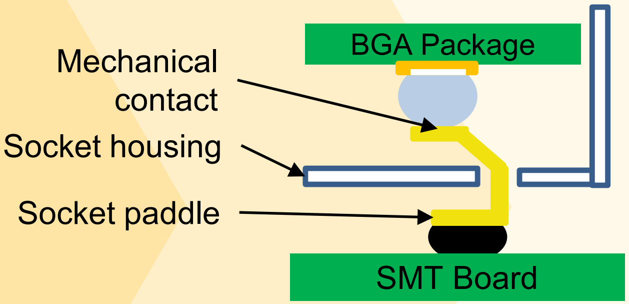
1. Requirements of Socketable BGAs

Research objective: Design and demonstrate a **universal board-level interconnection system** that can be reliably and simultaneously used in both socketing and SMT applications

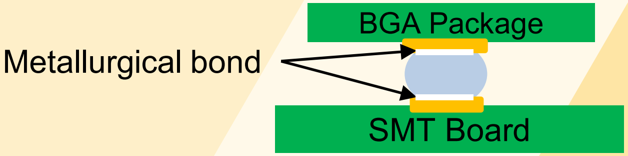


Socketing:



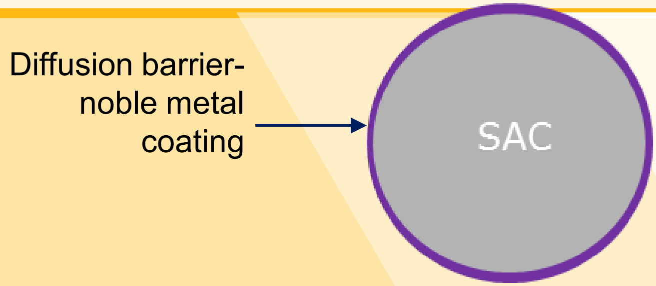
- Low contact resistance (<25mΩ)
- Latching force (<25g/pin)
- **Thermal aging stability** (100-120°C for 1000h)
- >20 reworkable cycles

SMT (board attach):



- **Standard reflow conditions** (<250°C)
- JEDEC thermal cycling reliability (1000cy. from -55°C to 125°C)
- JEDEC drop test reliability

2. Unique Approach



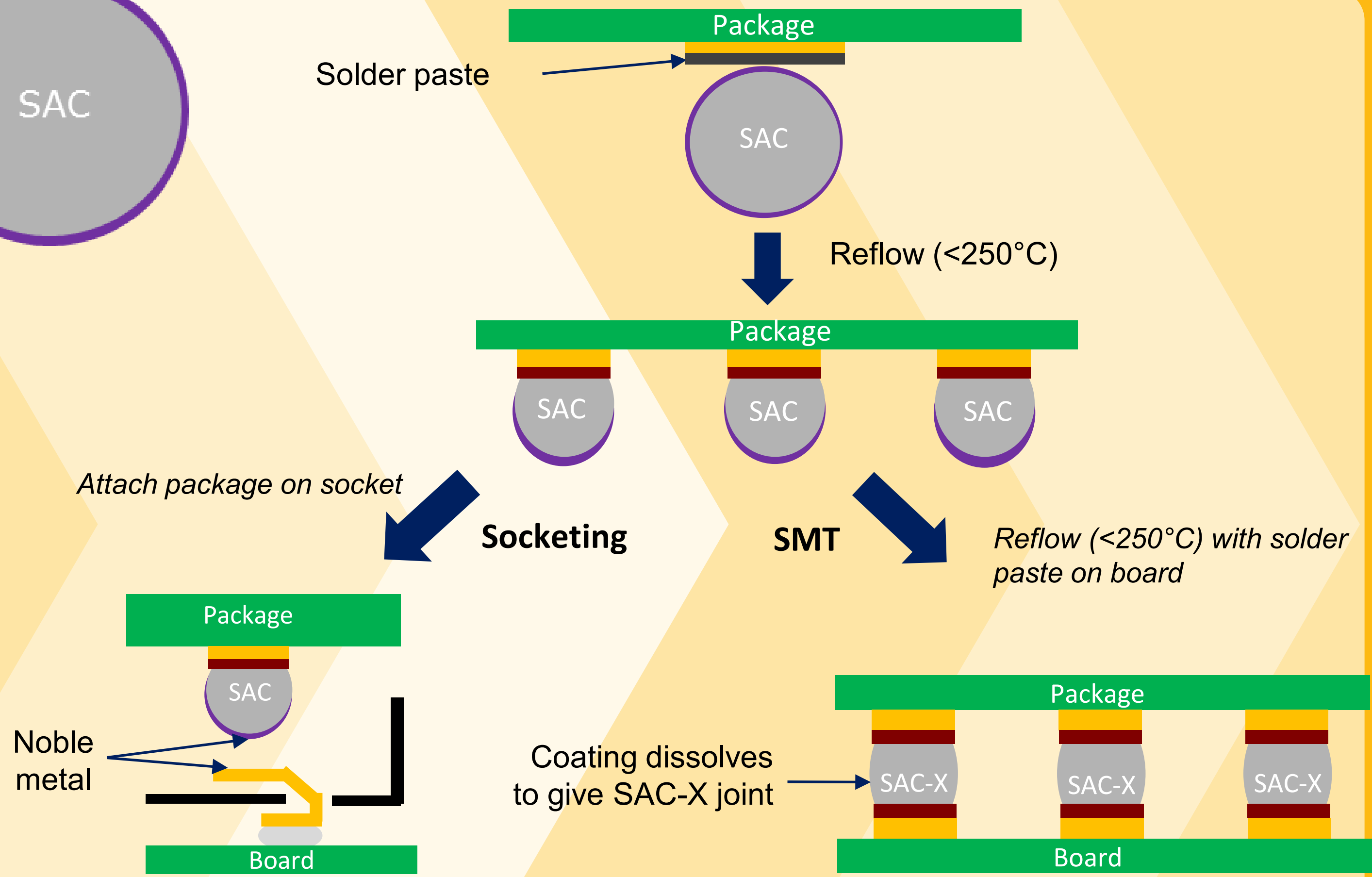
Material selection strategies

Approach 1: Traditional diffusion barrier/noble metal coating

- Ni/Au
- Co/Au

Approach 2: Eutectic forming systems

- Sn-Bi/Ag
- Sn-Bi/Au
- Sn-Zn/Au



Ball fabrication

Ball assembly

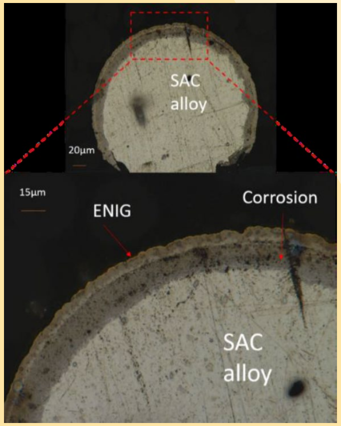
Ball characterization

- Socketing
- SMT

3. Prior Work

3.1 ENIG coating process on solder spheres

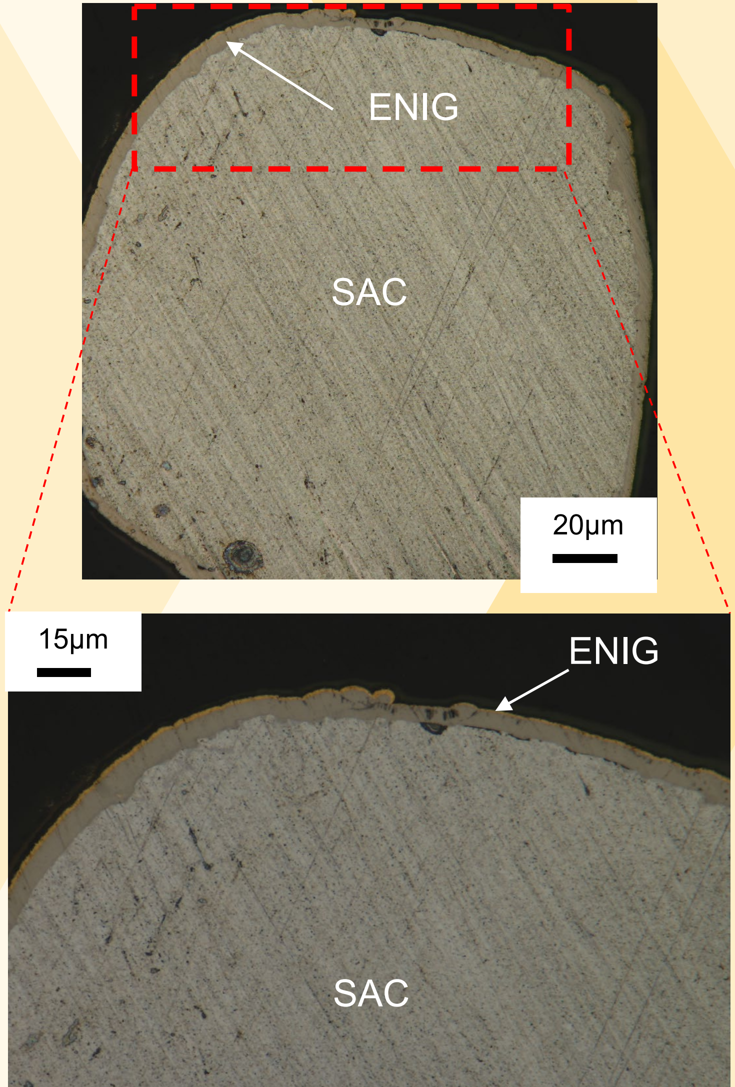
Challenges with standard ENIG on solder



Modified process flow for ENIG coating on solder

RIE surface clean / controlled acid dip
⇩
Ni seed layer sputtering
⇩
Activator
⇩
Eless Ni
⇩
Immersion Au

Cross-section with modified process flow



Coating process with a combination of sputtering and electroless plating developed

Ability to fabricate coated spheres in large scale for further processing at Intel

4. Coated solder ball attach

4.1 Solder paste wicking challenge

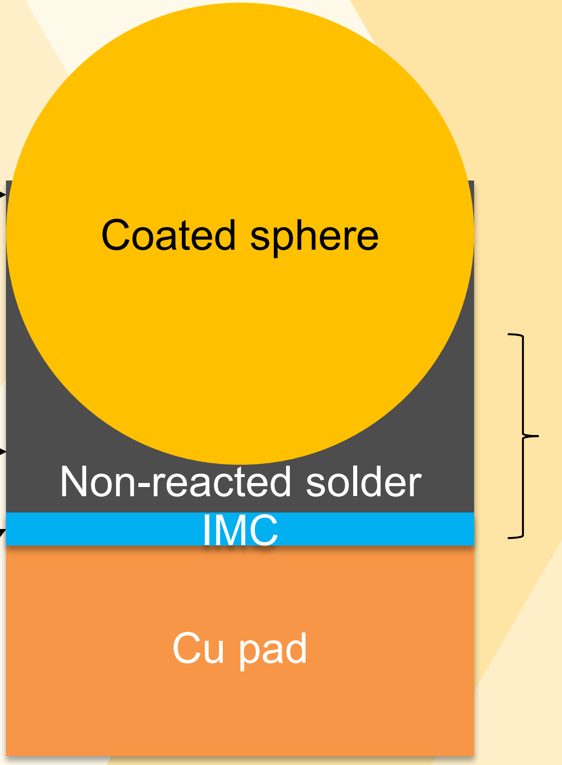
Objective: Form strong joint with package with preservation of outer Au surface
Challenge: Complete solder paste wicking due to excellent wettability of Au

Phenomena occurring during reflow affecting joint strength:

Wicking of paste on Au surface and surface dissolution of coating

Reflowed, non-reacted solder in the joint

Surface dissolution of surface finish on pad and subsequent IMC formation with SF/pad

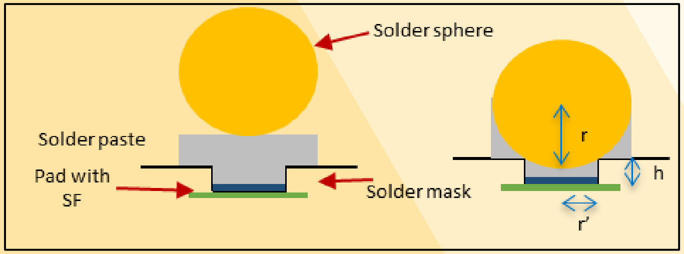


Complete wicking of solder paste on coated spheres

4. Coated solder ball attach

4.2 Theoretical solder paste volume calculations

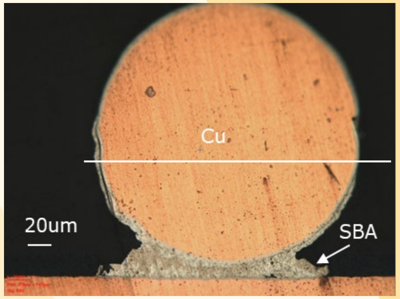
Theoretical limits



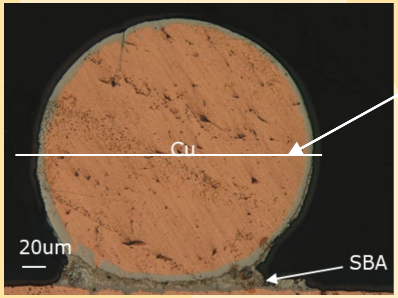
$$Vsp = \pi(r^3 + (r')^2 h) - \frac{2}{3}\pi r^3$$

- r = Ball radius
- r' = Pad radius
- h = Solder mask thickness – surface finish thickness

Experimental validation with coated Cu spheres

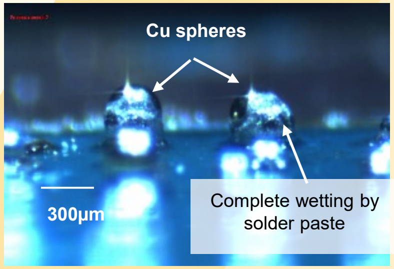


- Paste dia: 205µm
- Wicking height: 147µm



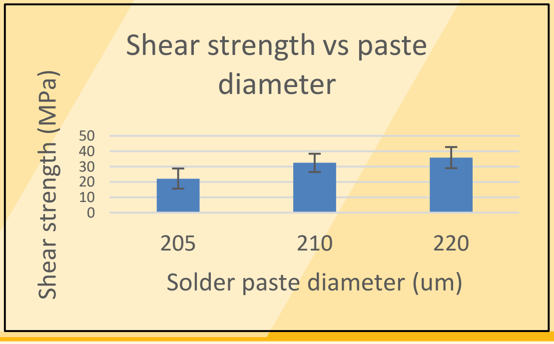
- Paste dia: 210µm
- Wicking height: 135µm

- Horizontal line indicates the wicking height
- SBA: SnBiAg solder paste



- Paste dia: 250µm
- Complete wicking

Ball diameter (2r) (µm)	Pad diameter (2r') (µm)	Solder mask thickness (h) (µm)	Vsp (μm^3)	Stencil thickness (µm)	Stencil diameter (µm)
225	200	15	1.96E6	50.8	222
250	200	15	2.51E6	50.8	251



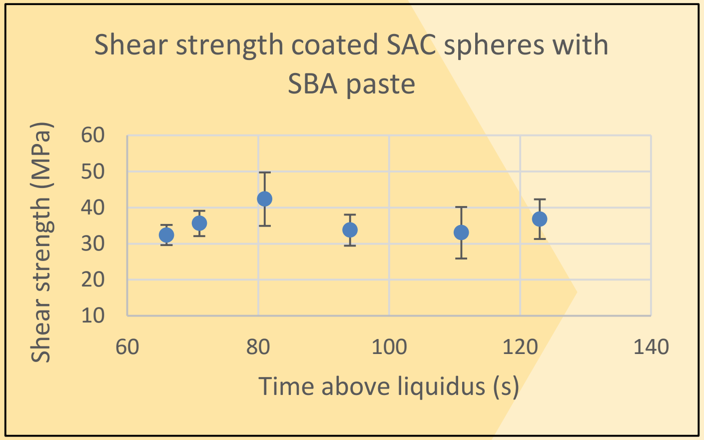
Highest shear strength obtained with printing aperture ~ theoretical limit

Complete wicking with printing aperture > theoretical limit

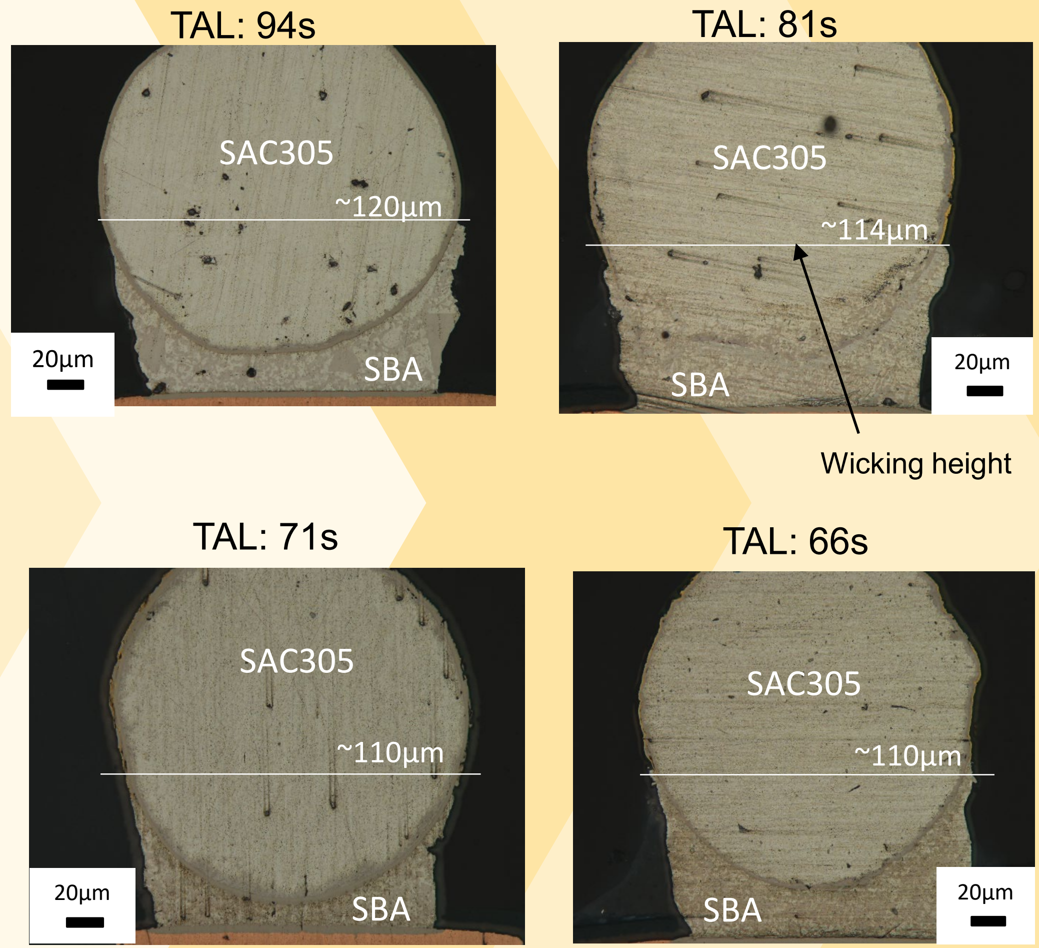
4. Coated solder ball attach

4.2 Wicking and shear strength dependence on reflow time

- Sn57Bi1Ag (SBA) solder paste used to attach coated spheres to the package
- SBA paste printing diameter: 250um



10 spheres per data point



TAL: Time above liquidus

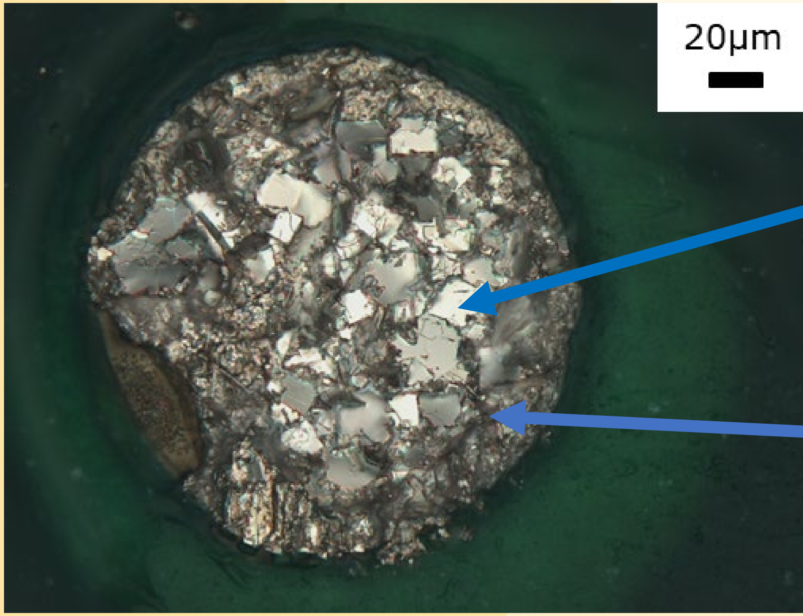
High shear strength obtained with control of wicking and joint formation by controlling solder paste volume and TAL

~40 sec window in reflow time to get controlled wicking and significant shear strength

5. Shear interface analysis

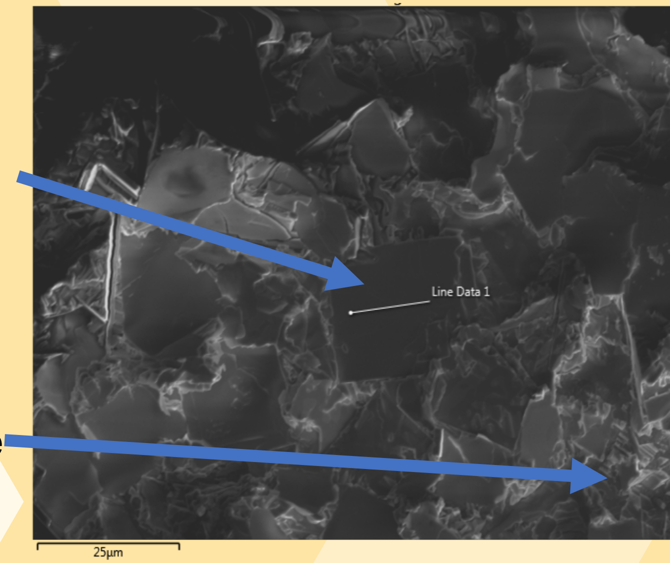
5.1 SBA paste

Pad-side shear interface



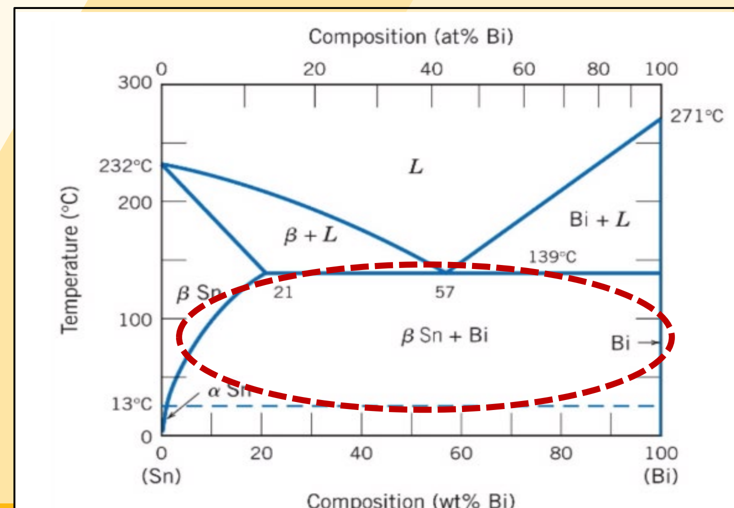
Faceted phase

Non-faceted phase



Brittle fracture through the solder paste fillet is observed – expected owing to high brittleness of SBA

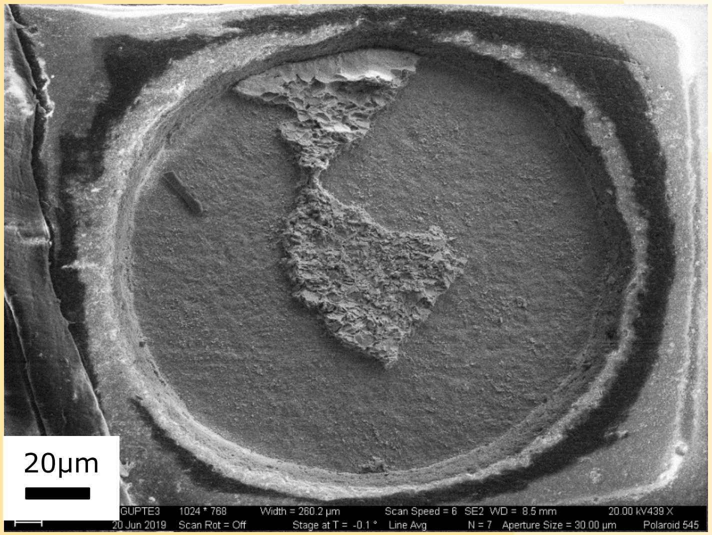
Faceted and non-faceted phases formed as a result of nucleation of phases at different temperatures and compositions



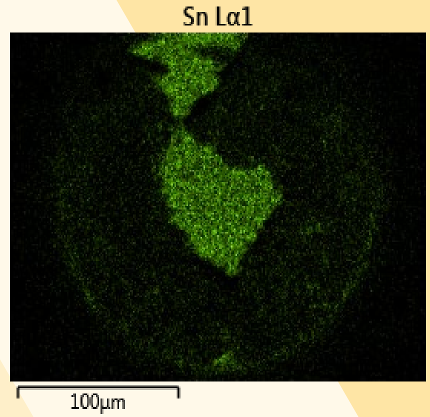
5. Shear interface analysis

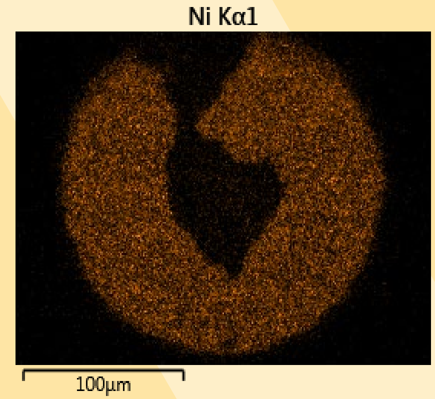
5.2 SAC305 paste

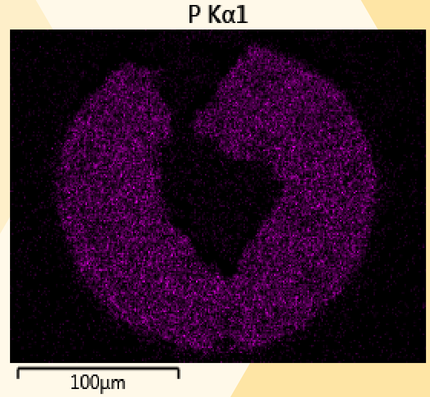
Package side



Shear interface of ball attached with SAC305 paste







EDX maps of shear interface

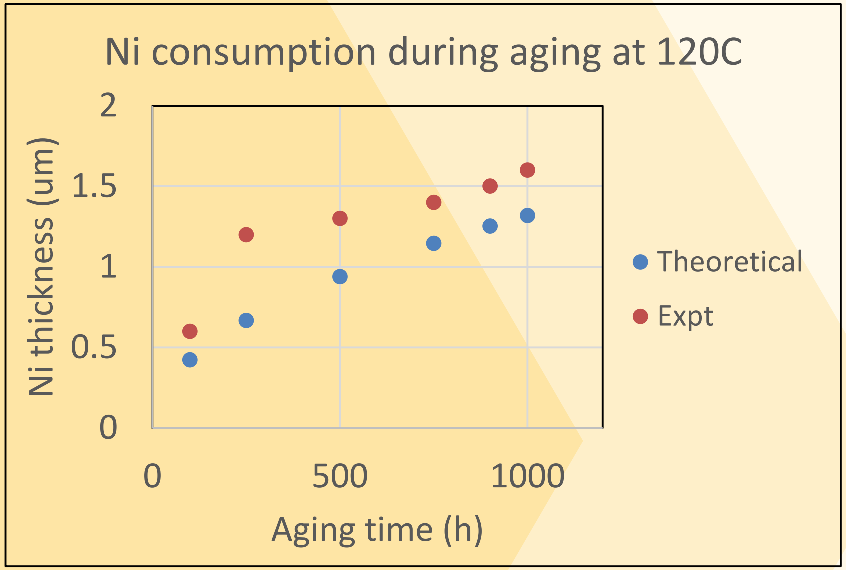
P content in surface finish ~ 20%

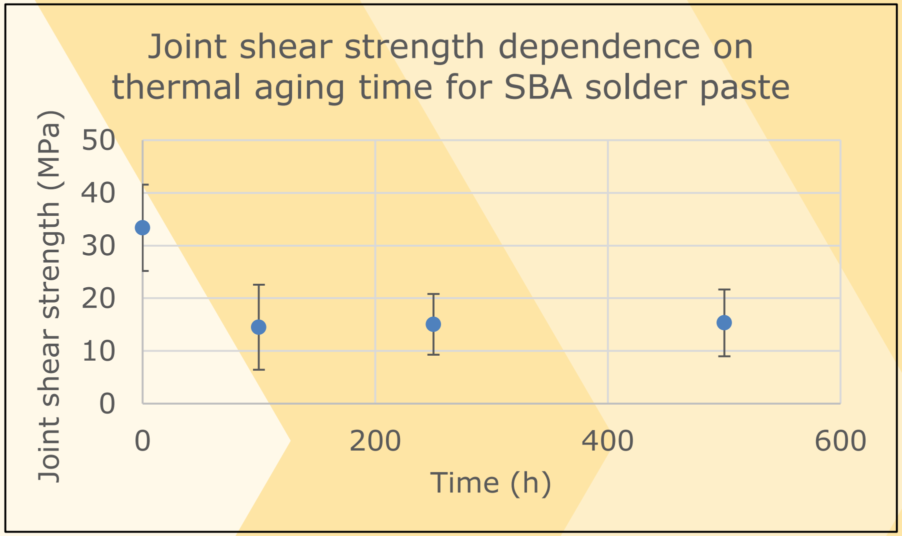
- For coated ball attached with SAC305 paste, brittle fracture occurs partially through solder paste and IMC
- Sn-Ni-P IMC formed at interface

Lower volume of solder in fillet → fracture mode changed from ductile to brittle

6. Thermal aging characterization for socketing

Thermal aging at 120 C



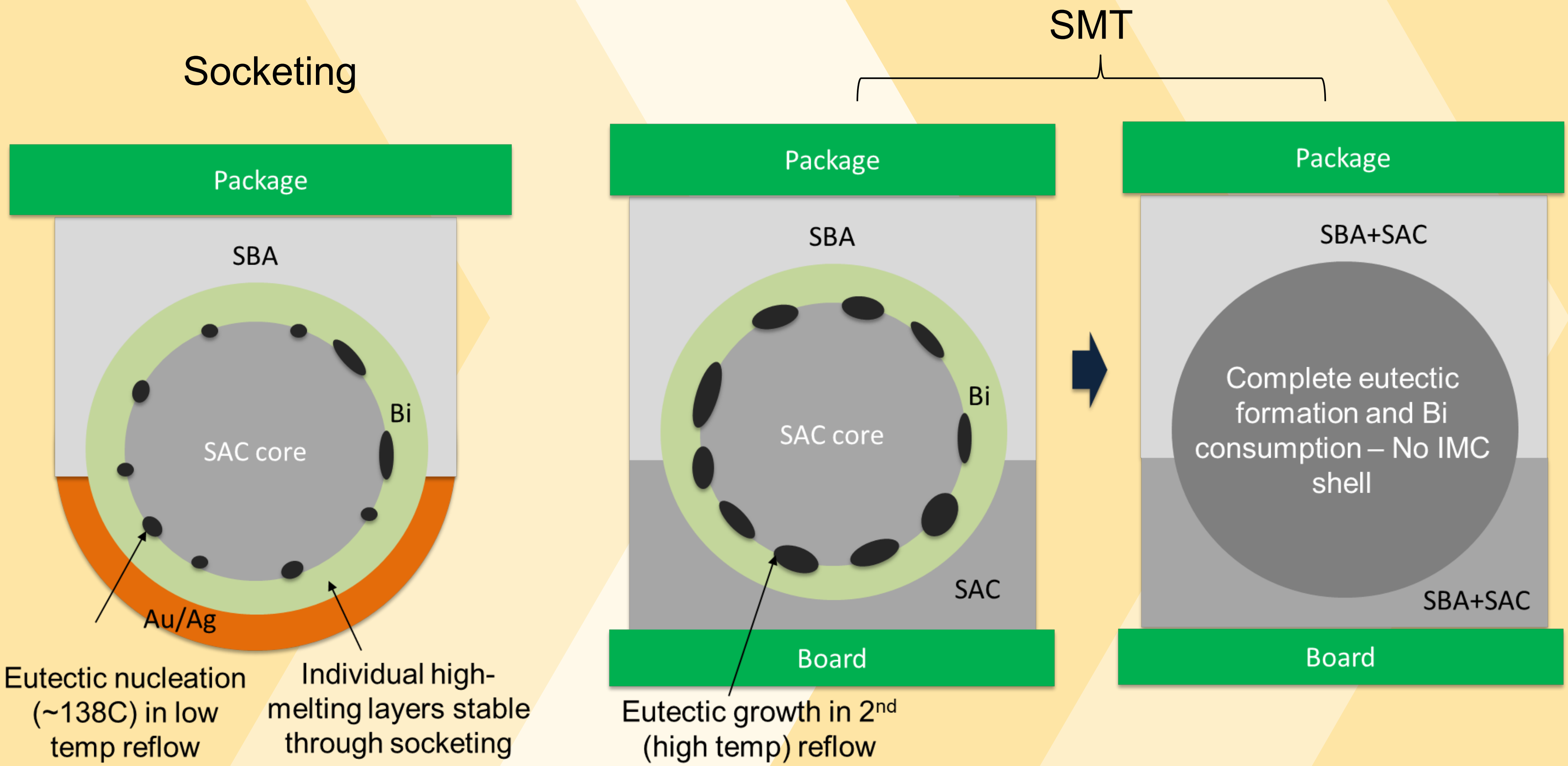


- Experimental values follow theoretical predictions
- Experimental values are higher than theoretical predictions – diffusion model considerations

- Shear strength reduced with aging and stabilized at ~15MPa - trend follows predictions from literature (Coyle, 2000)
- ~57% reduction in joint shear strength. Reduction due to **1) grain coarsening** and **2) depletion of solder volume** in the joint during aging due to wicking of paste on the ball

7. Eutectic forming diffusion barriers

Diffusion barriers forming eutectics with Sn, such as Bi, can aid in getting complete solder ball collapse during SMT



8. Summary and project timeline

Summary:

- Fabricated ENIG coated solder spheres
- Understood and developed ball-attach process of coated spheres
- Characterized coated solder spheres for socketing by thermal aging

Future work:

- Design socketing and SMT test vehicles
- Develop Bi coating process on solder spheres

			2019	2020			
			Q4	Q1	Q2	Q3	Q4
Done	Approach 1: Ni-Au coating	Diffusion modeling					
Done		Coating fabrication					
Done		Coated ball attach study					
Progress		Contact modeling					
Progress		Thermomechanical modeling					
Progress		Socketing TV (with Intel)					
Progress		SMT TV					
Done	Approach 2: Bi-Au coating	Diffusion modeling					
Progress		Coating fabrication					
Stall		Socketing TV					
Stall		SMT TV					