Au-Sn Eutectic chip-bonding for high heat flux vapor chamber applications

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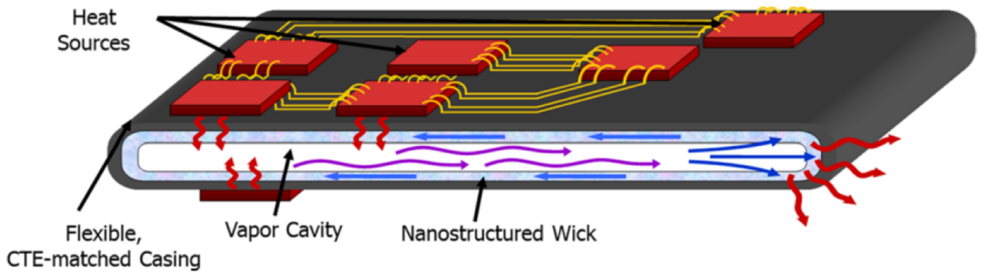

Bar-Cohen et al. (2015)

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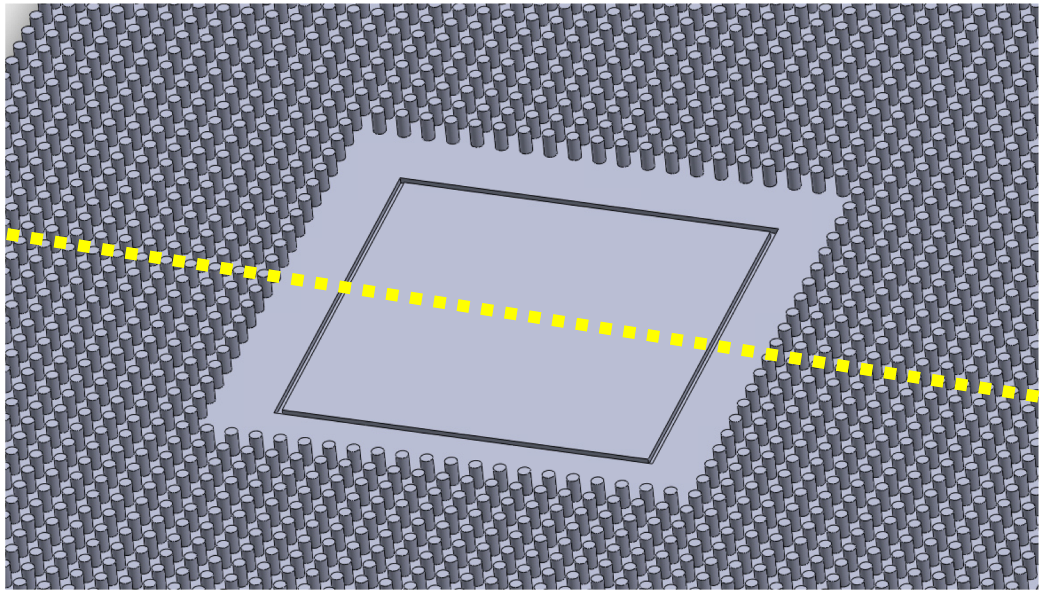
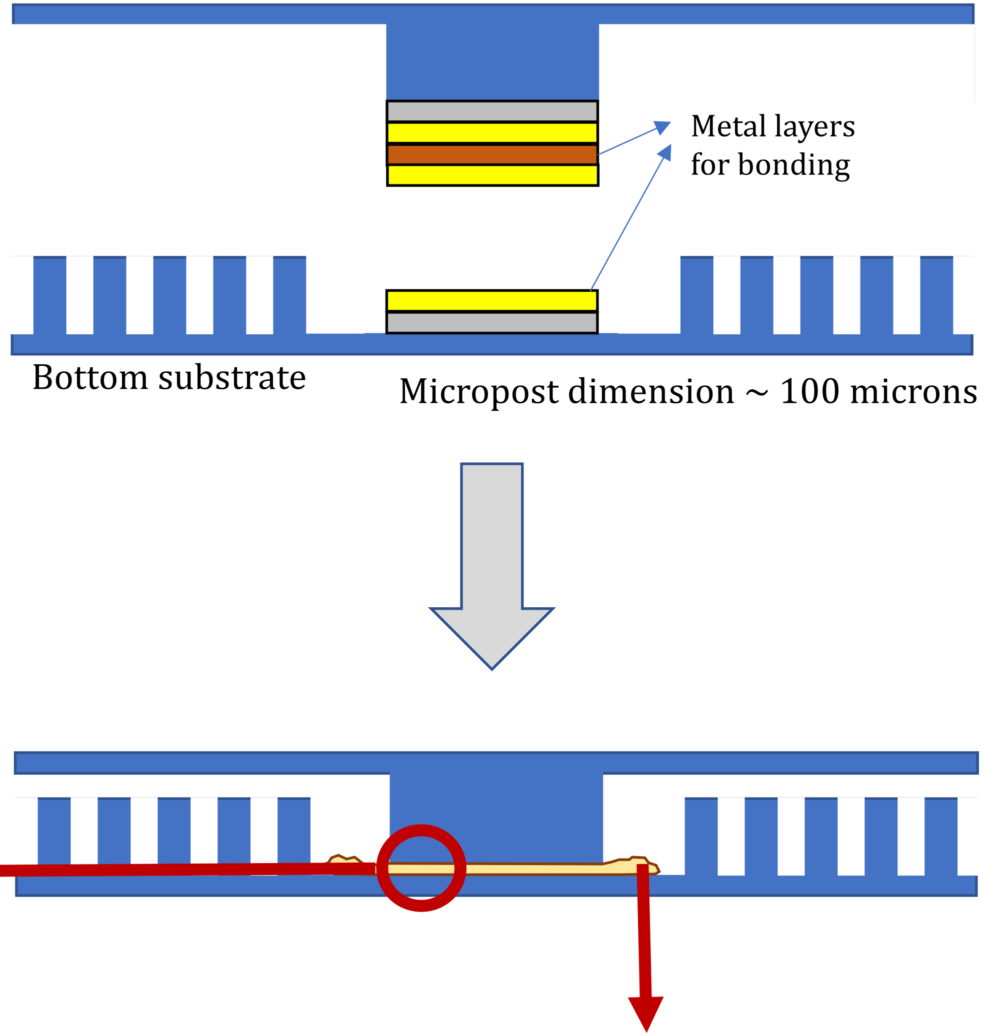
Motivation

Microstructured bottom substrate inside a vapor chamber (3D)



Inside of the proposed vapor chamber design

Cross
section
side view



Important parameter –

- Robustness, Strength – Bond Quality and overflow

Design of Experiment – Bond Quality

Objective (Goals)

- Achieve high bond strength and quality keeping low bond area
- minimize overflow of eutectic alloy
- Push boundaries on understanding Au-Sn Eutectic bonding

Variables

- Substrate Materials
  - Lower substrate – Si
  - Upper Substrate – Pyrex
- Recipe
- Bonding Temperature
- Bonding Time

(Jung and Kwon, ENGR241, 2016)

- Bonding Pressure
- Bonding Area

Primary Variables

Main parameters

Bonding Areas

- 9 mm^2 49mm^2 100mm^2

Bonding Temperatures

- 379^{0}C   350^{0}C   320^{0}C (eutectic temp: 280^{0}C)

Bonding Time

- Thermocompression: 300 seconds
- Bonding :1500 seconds

Bonding Forces

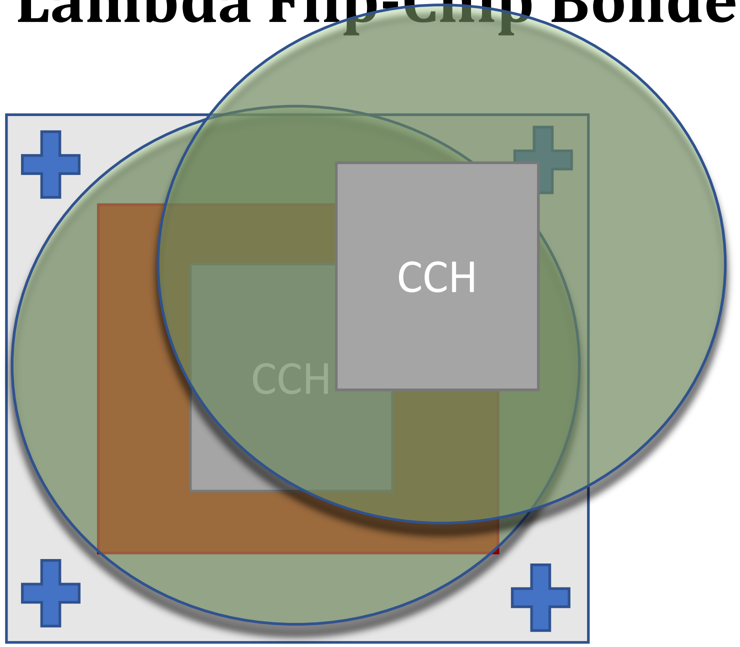
- 50N   70 N   100 N

Cooling of bonded chip

- To room temperature for 1000 seconds

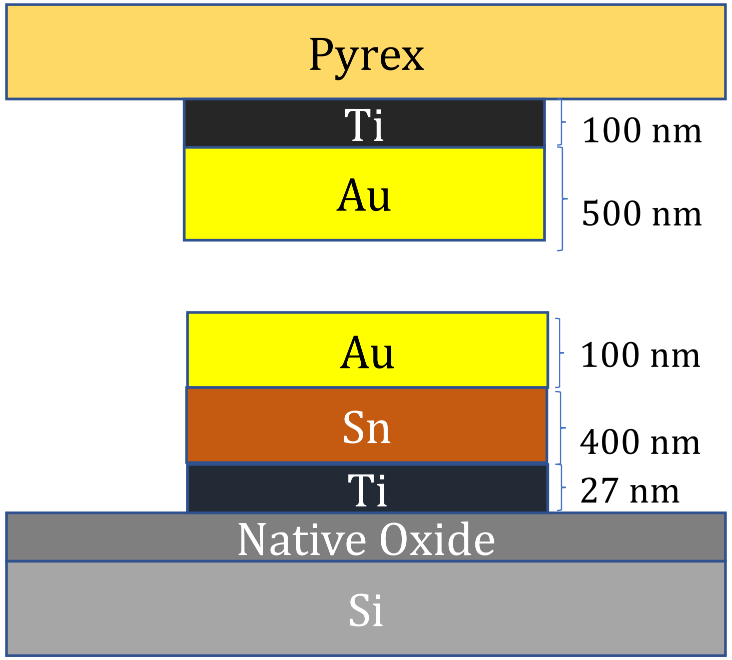
Bonding : Fine-tech Lambda Flip-Chip Bonder

- Alignment Issue

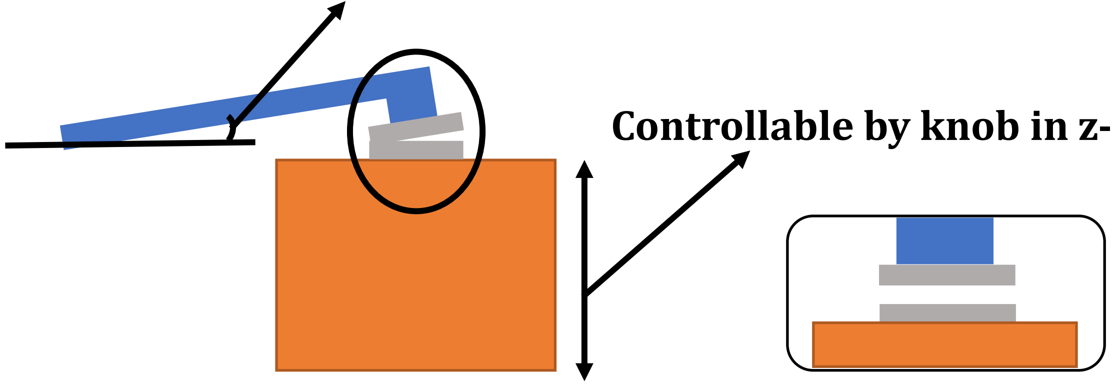


15mm x 15mm

Substrates before Bonding

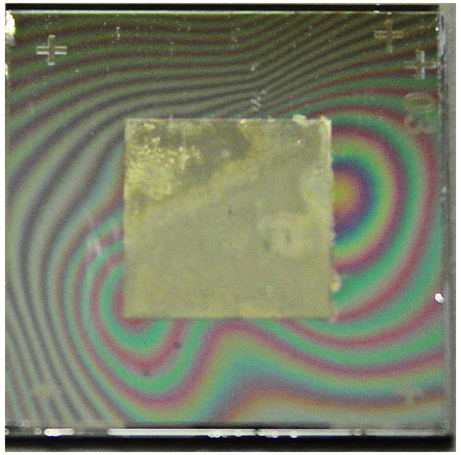


- Non-Uniform Pressure Application

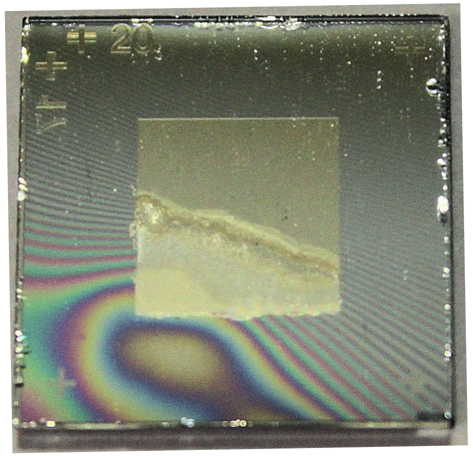


Controllable by fine arm

Controllable by knob in z-direction

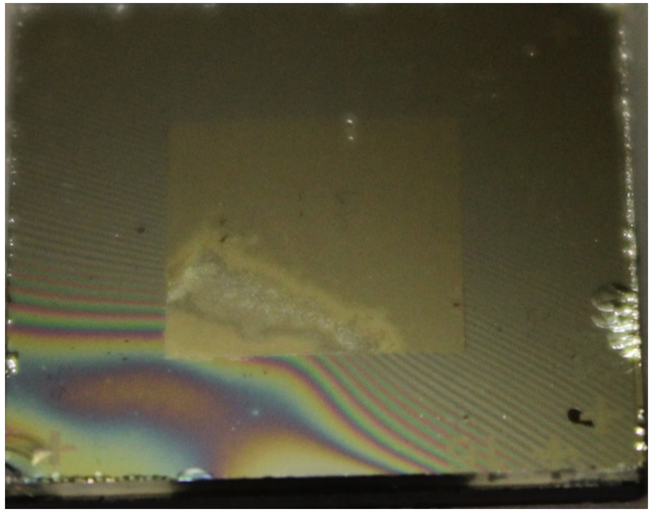


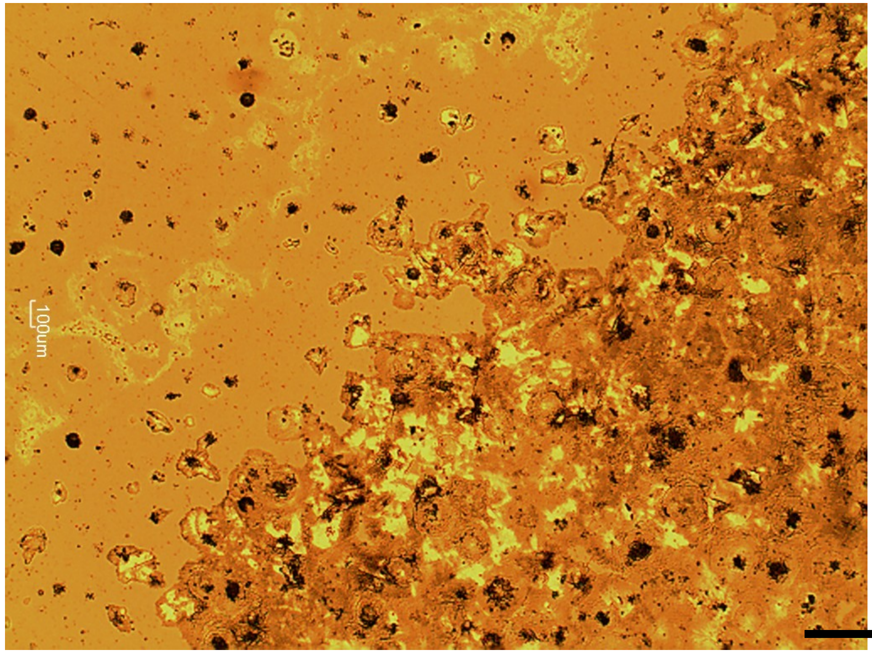
More or Less Uniform pressure

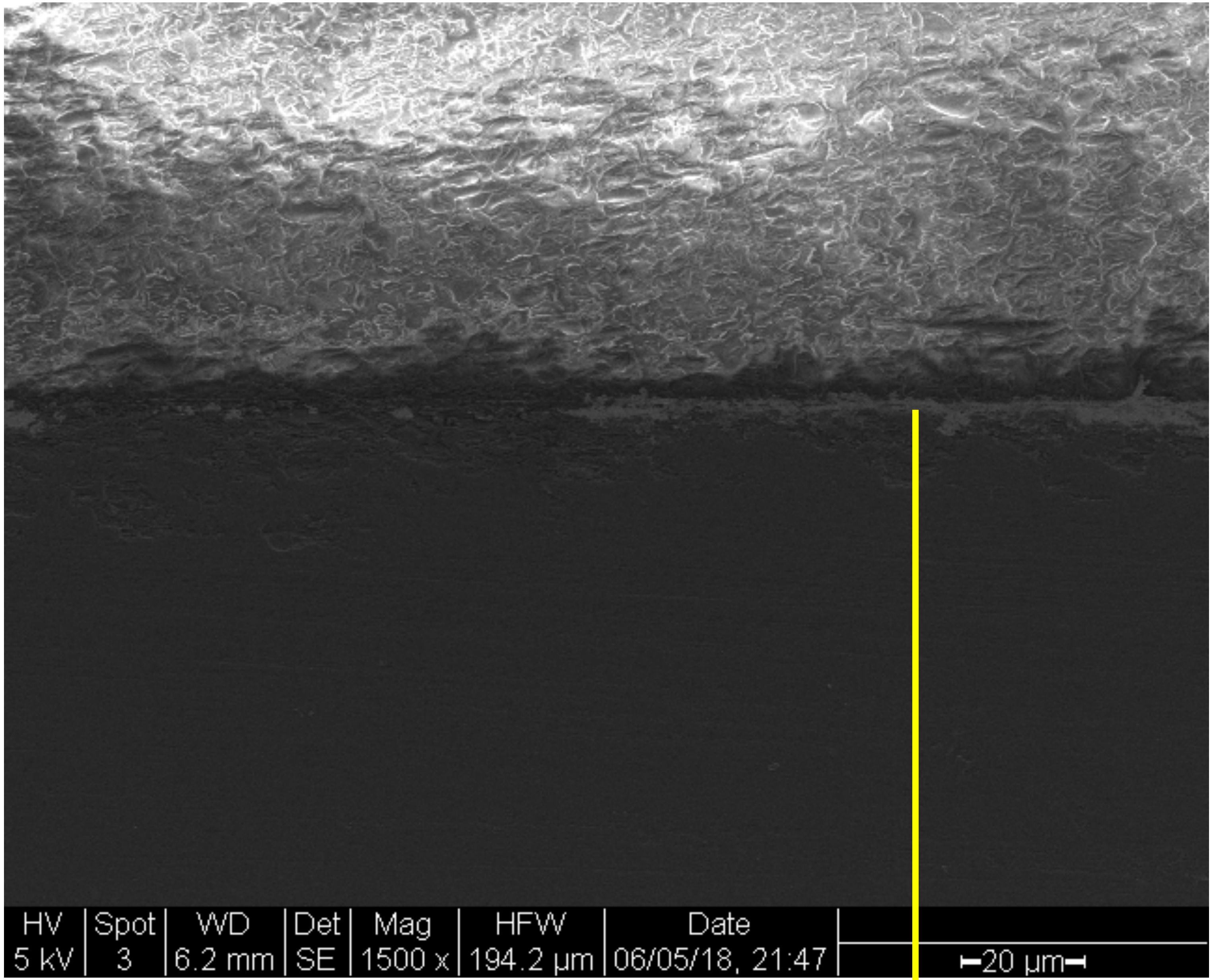


One Sided pressure application

Bonding non-uniformity

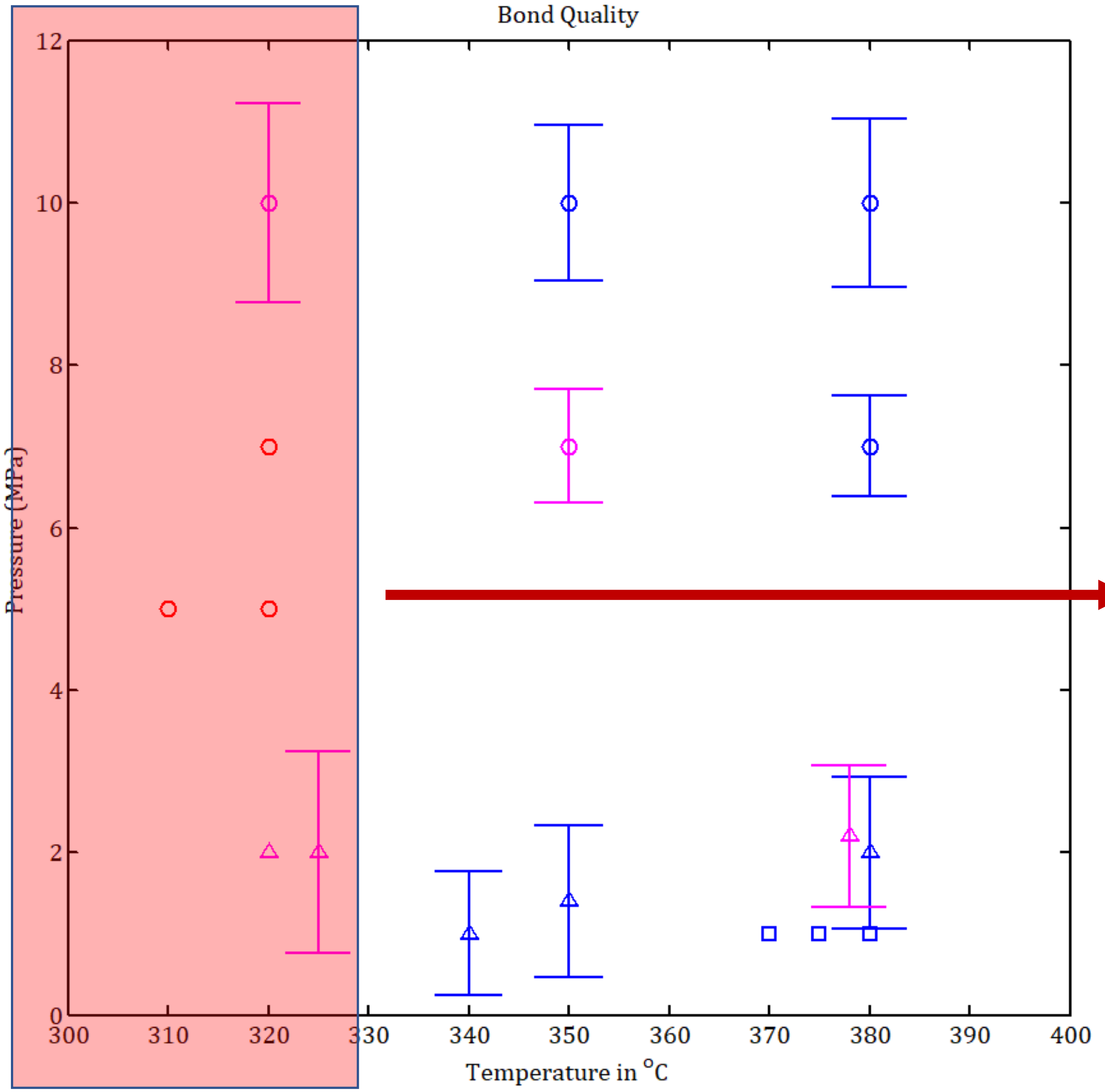






Bonded Region

Results : Bond Quality and uniformity



Legend

▬ Bond > 45% **(SUCCESS!)**

▬ Bond < 45%

▬ No bond

○ Small (Bonding area 9mm^2)

△ Medium (Bonding area 49mm^2)

□ Large (Bonding area 100mm^2)

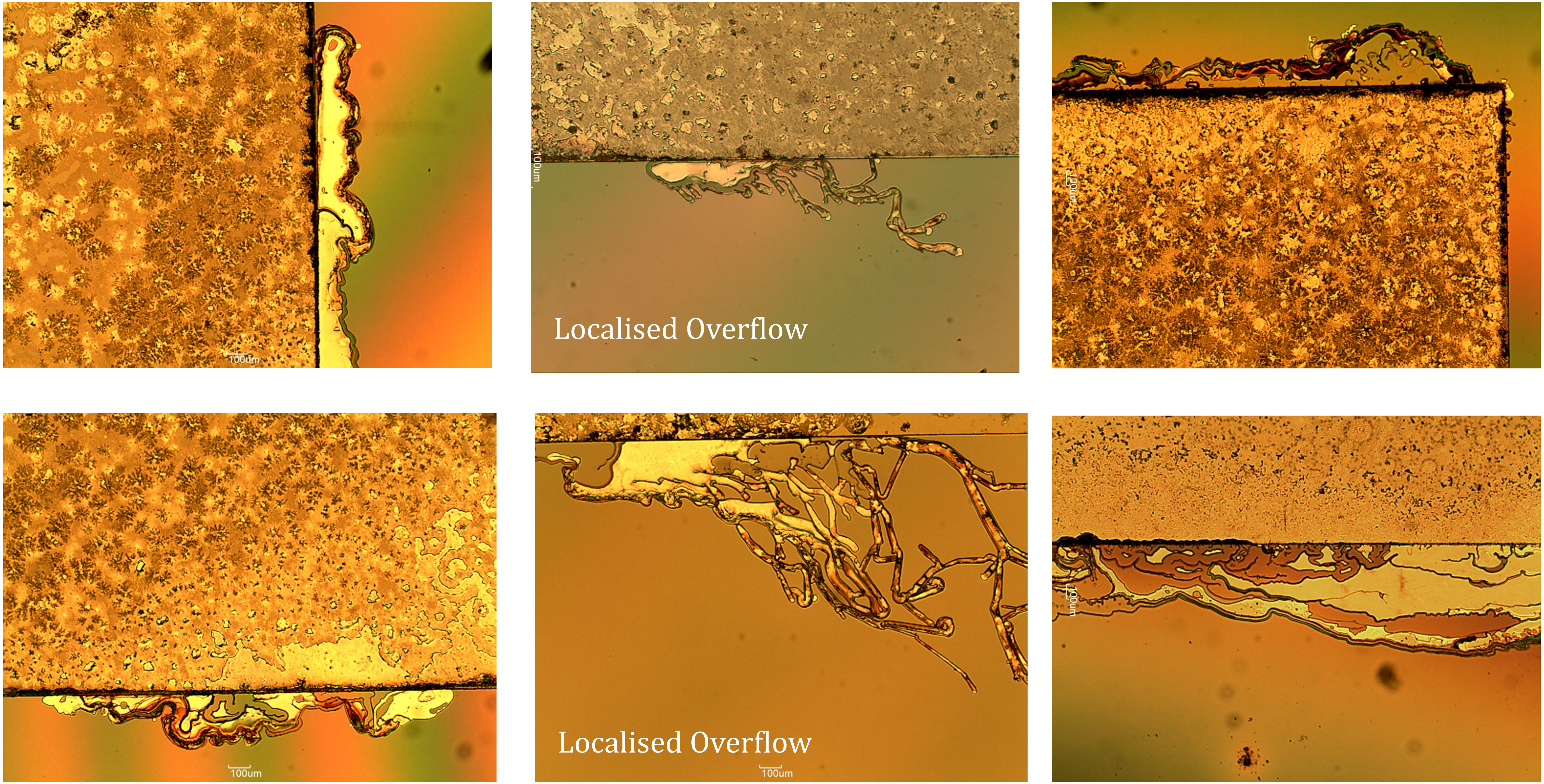
Error-bar: Total Length of overflow (mm)

Temperatures less than 330°C is not sufficient for successful bonding

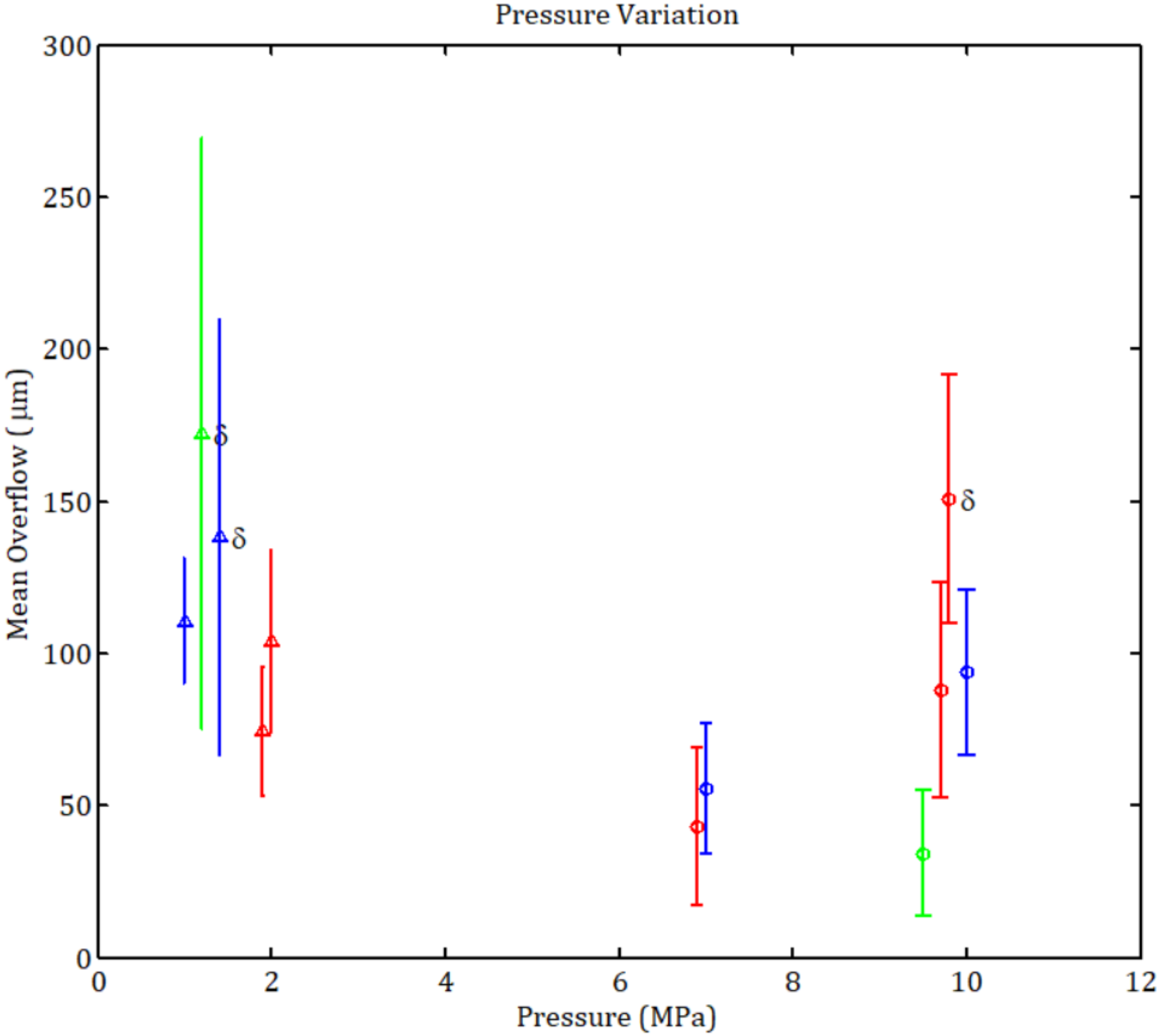
Increased success at higher temperature

No discernible success trend with Pressure

Bonding Results : Overflow



Results : Bond Overflow



Legend

🟦 70 N

🟥 100 N

🟩 50 N

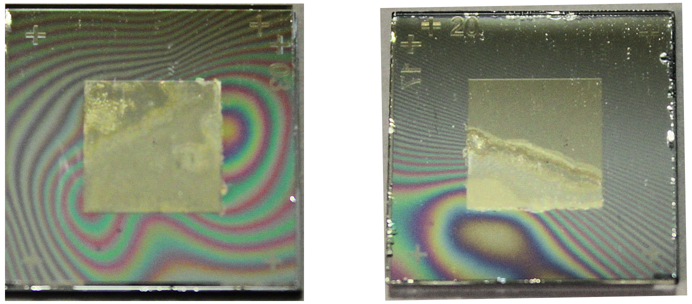
○ Small (Bonding area 9mm^2)

△ Medium (Bonding area 49mm^2)

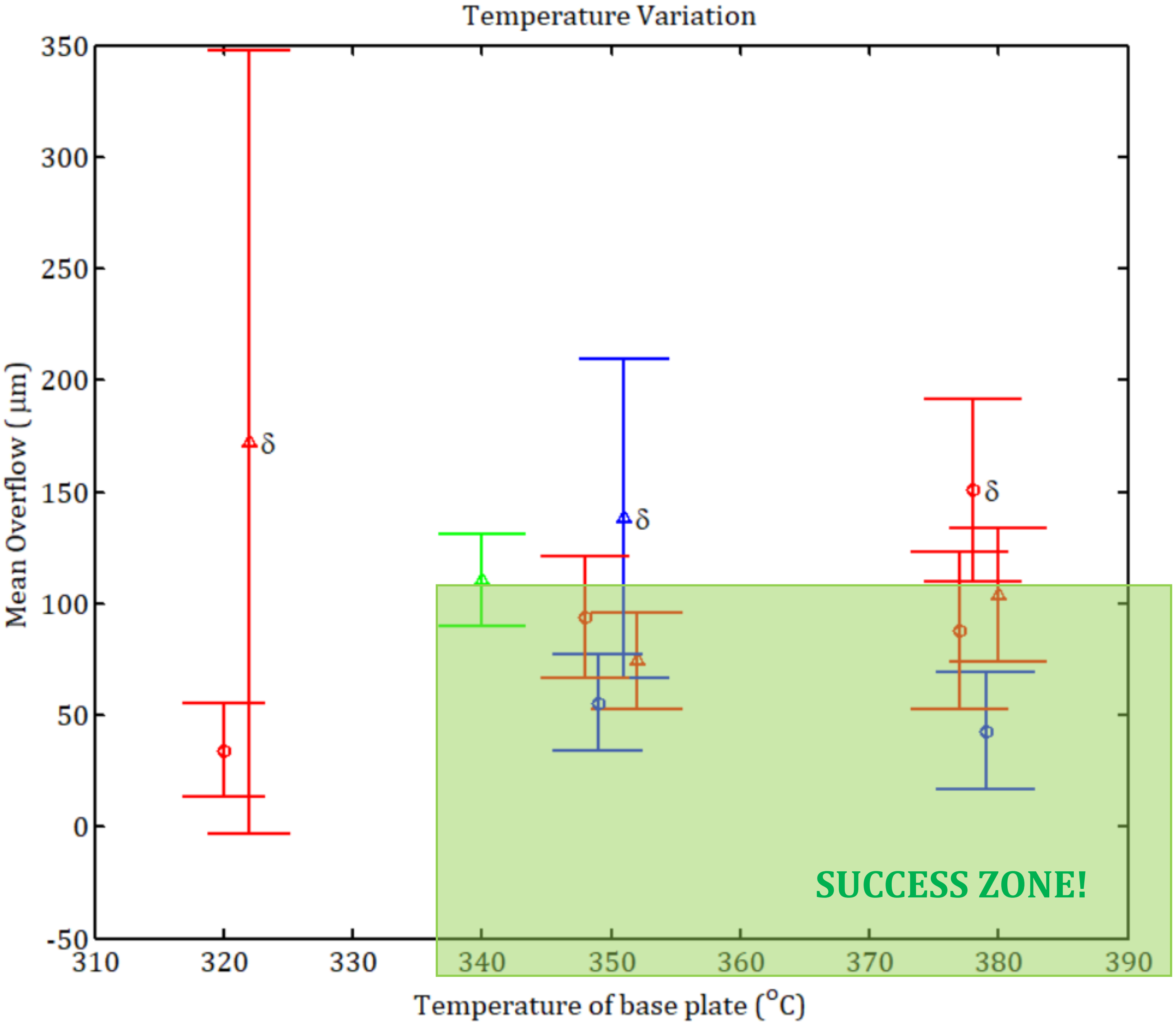
Error-bar: Standard Deviation of overflow (mm)

Successful bonding occurs at all Pressures provided they are higher than 0.5 MPa

The uniformity of Pressure is much more important than magnitude of Pressure



Results : Overflow



Legend

🟩 320 ^{0}C

🟦 350 ^{0}C

🟥 379 ^{0}C

○ Small (Bonding area 9mm^2)

△ Medium (Bonding area 49mm^2)

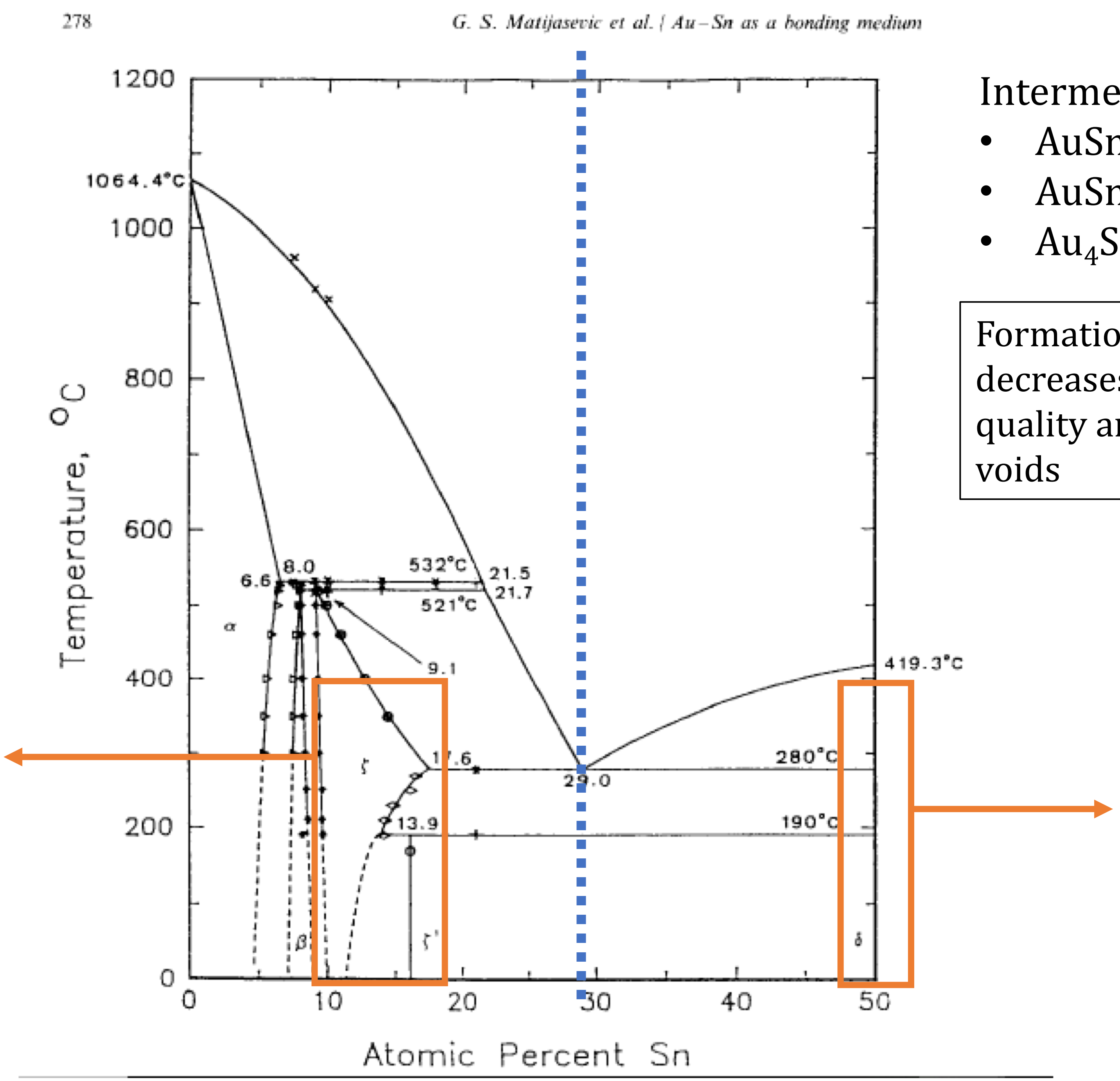
Error-bar: Standard Deviation of overflow (mm)

Effect of pressure non-uniformity can be neutralised a little by increasing temperature

Overflow increases with increasing temperature

Temperature required > 340^{o}C

Phase Diagram



Au_5Sn

AuSn

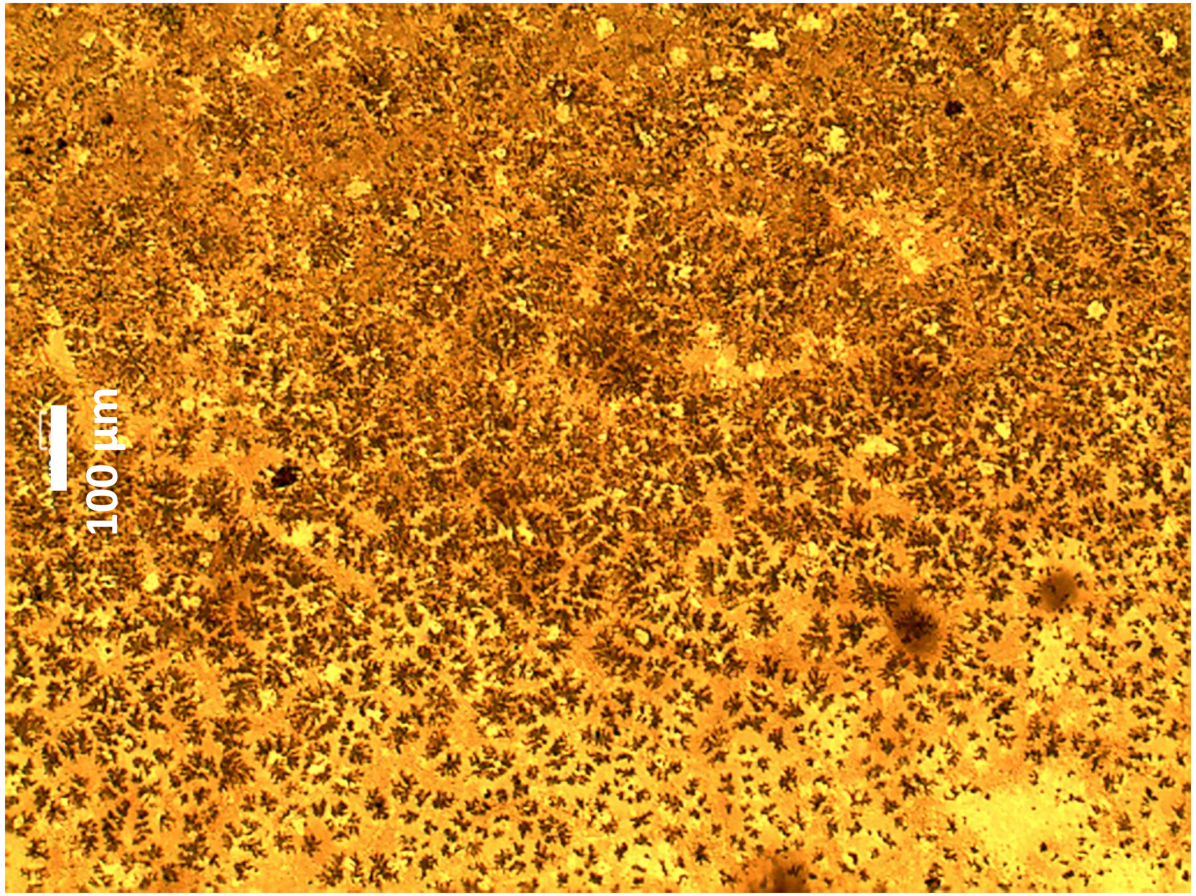
Intermetallics –

- $AuSn_2$
- $AuSn_4$
- Au_4Sn

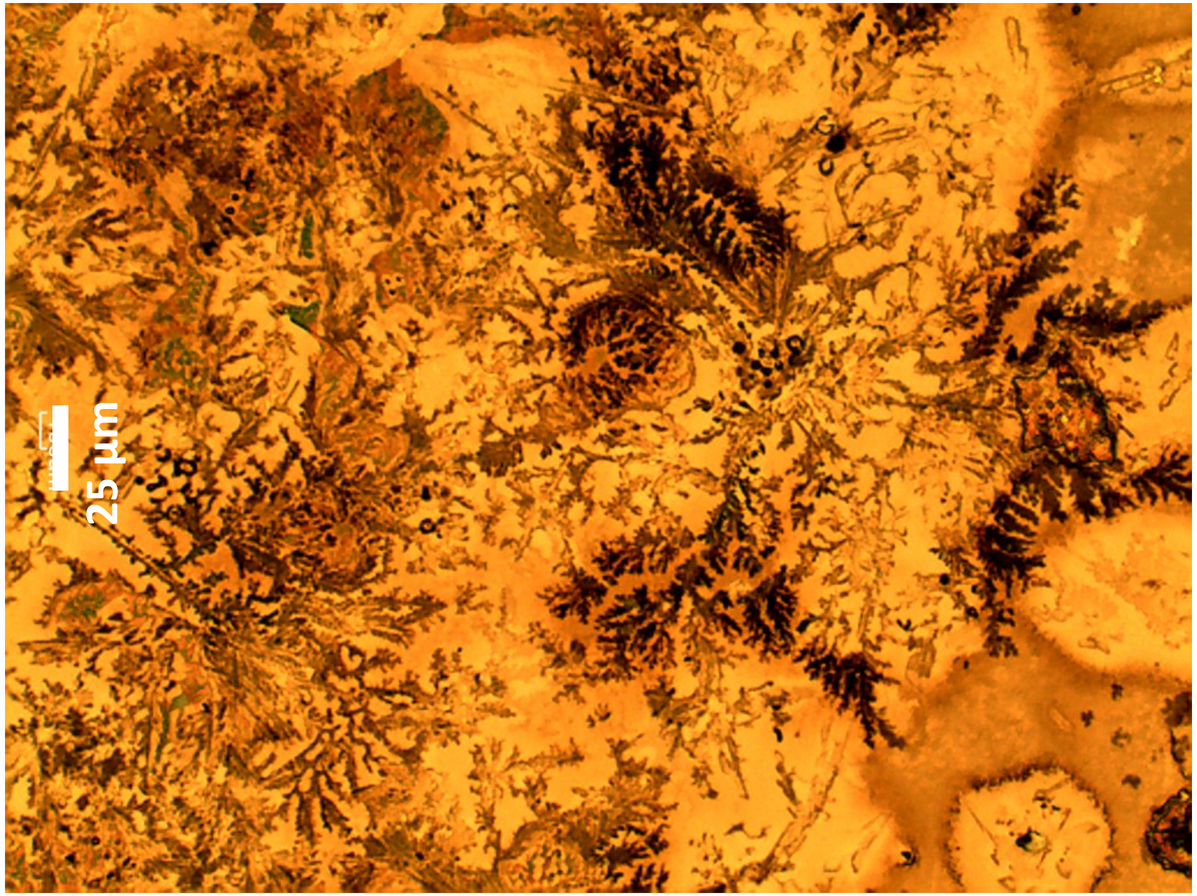
Formation of IMC decreases bond strength, quality and produces voids

Bonding Results : Microstructure

Initial Dendrite Formation

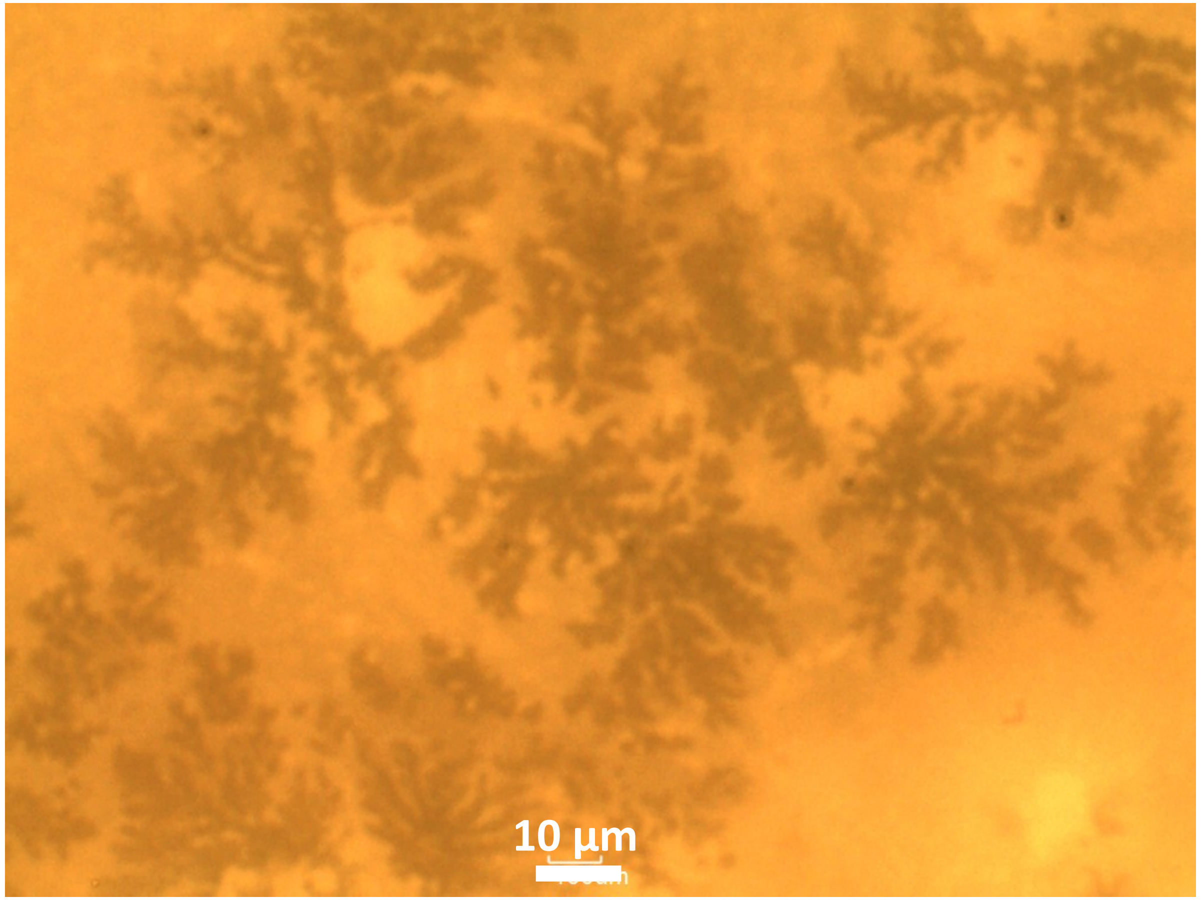


Dendrites Merging

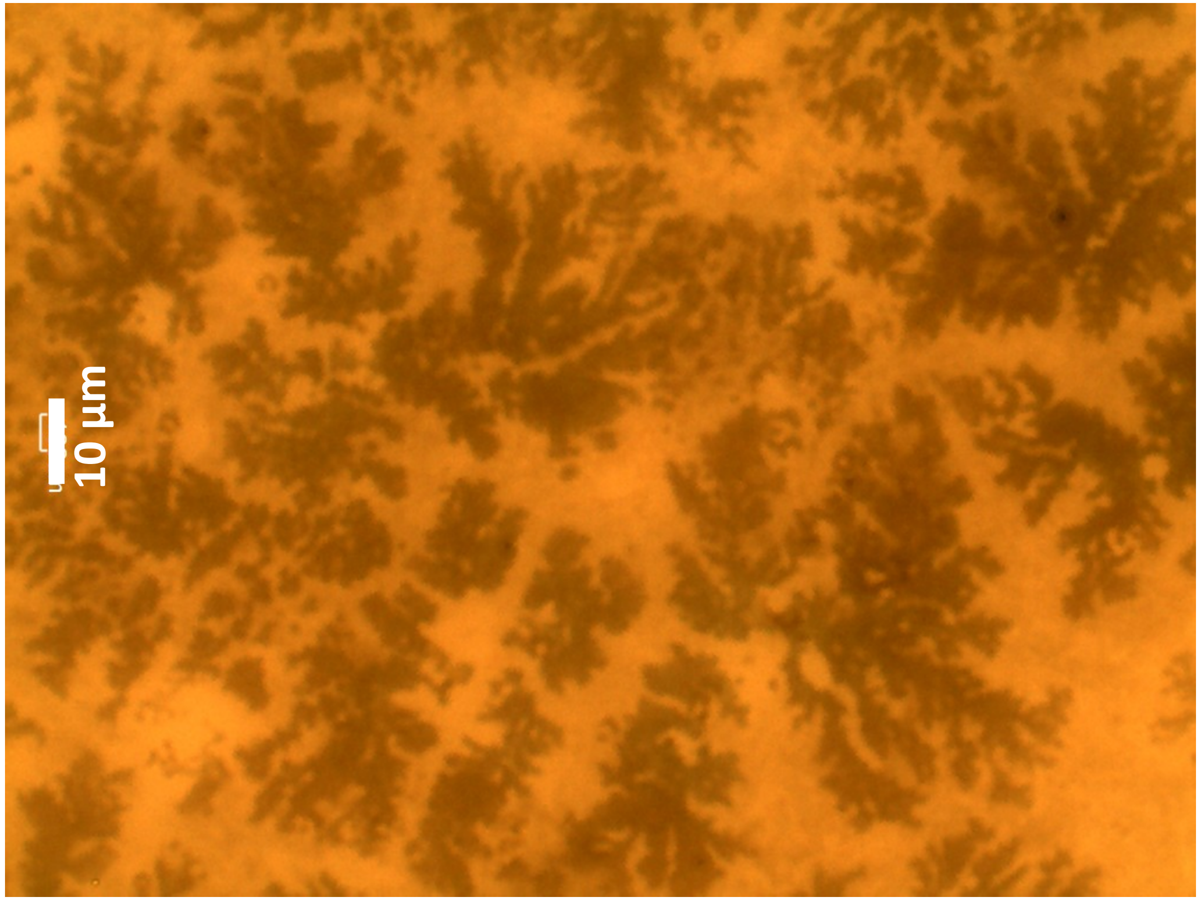


Dendrites: Information about the cooling rates

Sparse Dendrites



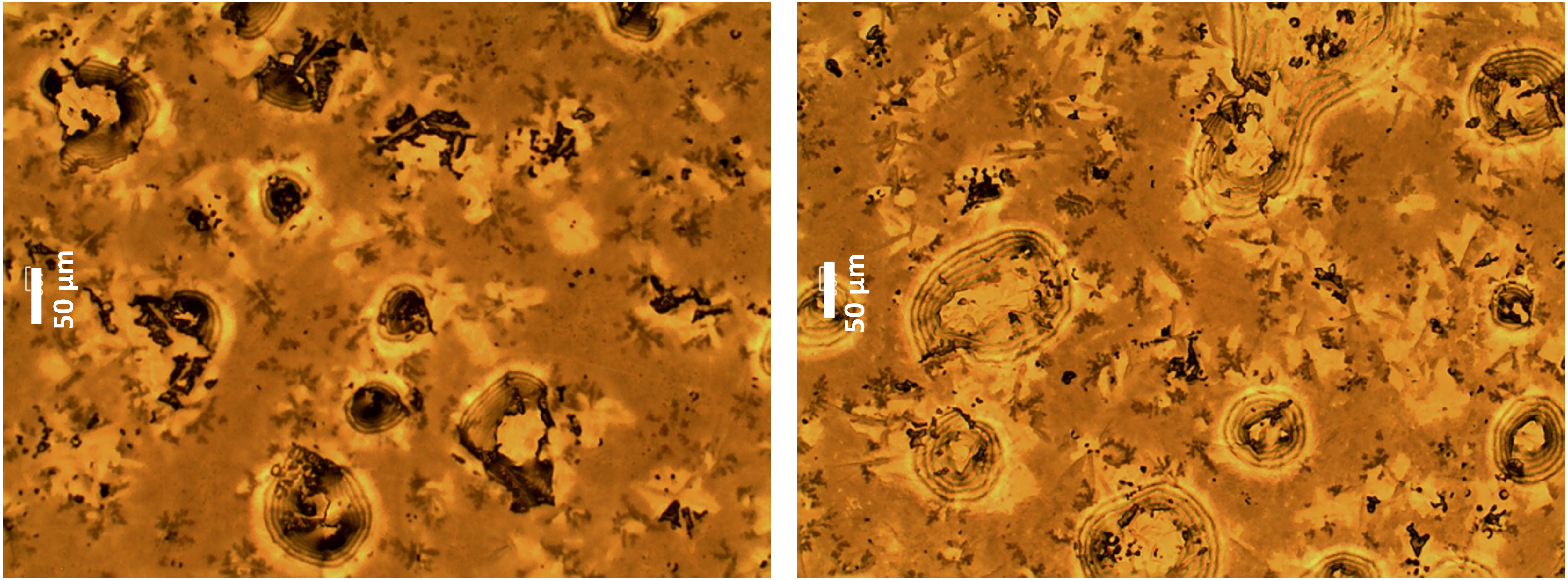
Closely-spaced Dendrites



Higher cooling rates results in the formation of sparse dendrites and smaller grain sizes

Kirkendall Voids

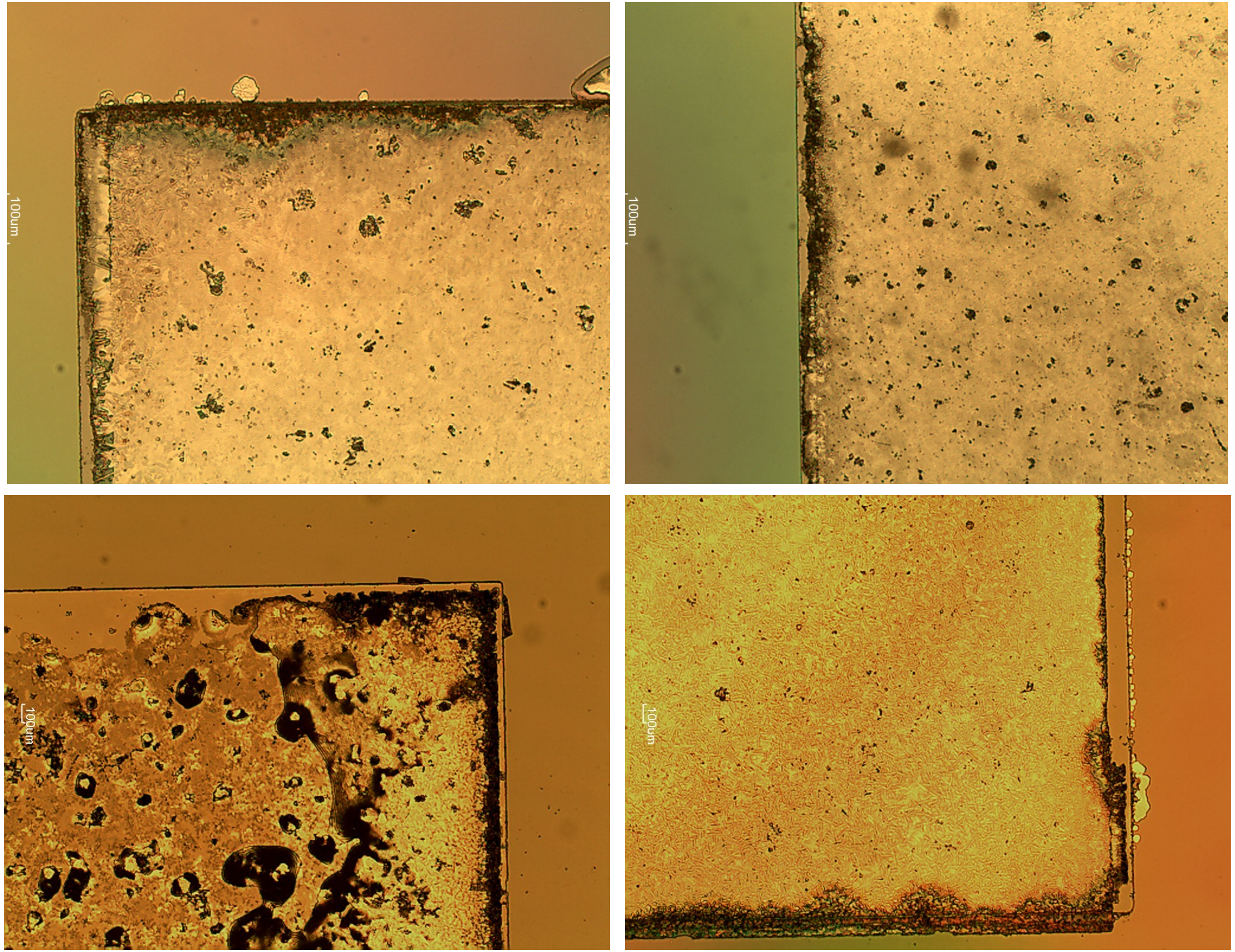
Formed at interfaces because of different diffusion rates of different species (Au/Sn)



Why is this exciting?

- We can use interferometry to detect voids formed at the interface of Pyrex chip without breaking it open
- Also an indication that the bond is really weak and bad.

Restriction of Overflow by misalignment (accidental) of bonding sites



How it happens –

- Unreacted metal at edge acts as stopping layer
- Oxidized Tin at the edge acts as a sealant and restricts eutectic metal within the bonded zone

Why is this exciting?

- Saves time consuming, complicated and expensive litho steps involved in making stoppers, trenches or grooves

Success rate?

7/8

Conclusions & Suggestions

Suggestions for Au-Sn bonding –

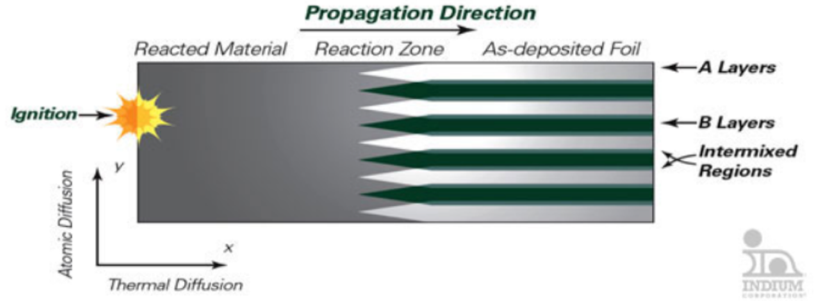
- T_{bond} > 330°C
- Pressure uniformity is very important (P > 0.5 Mpa)
- Flip chip bonder is not the best option for larger bond areas (>0.3 mm^2)

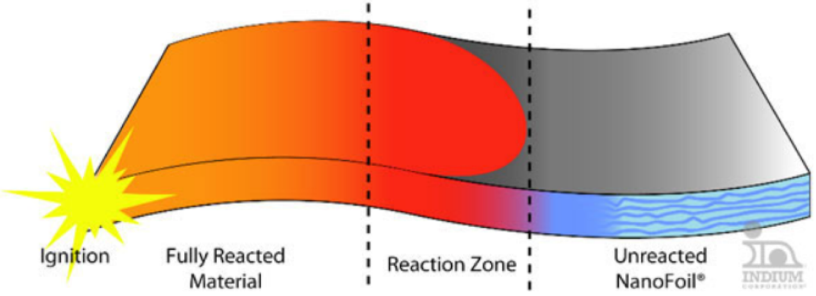
Tilt Issue fix (flip chip bonder)

- Perform a set of experiments by taking one pyrex and one Si wafer while varying Z – positions of the base plate.
- The uniformity of interference rings will give information about pressure uniformity for varying Z.
- Perform final experiments with that specific Z value.

Future Scope

- Effect of cooling rate on bond uniformity and strength (dendrite length and spacing has a positive correlation with cooling rate)
- Interferometry to detect voids (quantitative prediction)
- Misalignment to restrict overflow
- Localized heating using electrical source and patterned heater lines for eutectic bonding instead of heating up holder and base.





Thank You

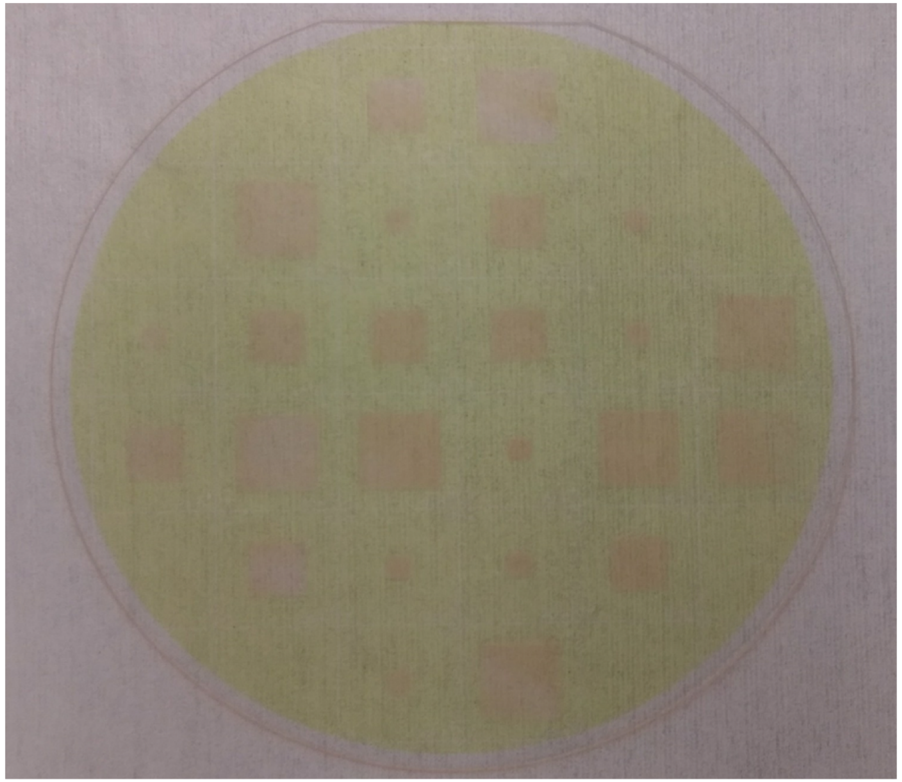
Top view of eutectic alloy of a broken sample

Surface Area of the bonding region(% of the 1 cm x 1cm)	Bond Parameters(Si substrate)							
	T_{uniform} (°C)	$\Delta t_{\mathrm{uniform}}$ (min)	T_{bond} (°C)	Δt_{bond} (sec)	Force(N)	Cooling(S)	Bond Type	Result
S11_04_04(s)	300	5	320	1500	50	1000	Eutectic	No bond
S21_18_07(s)	300	5	350	1500	50	1000	Eutectic	partially bonded, check phases
S20_14_17(s)	300	5	380	1500	50	1000	Eutectic	partially bonded, check phases
S16_05_18(s)	300	5	320	1500	70	1000	Eutectic	No bond
S12_09_12(s)	300	5	350	1500	70	1000	Eutectic	partially bonded
S13_02_18(s)	300	5	380	1500	70	1000	Eutectic	partially bonded
S15_05_05(s)	300	5	320	1500	100	1000	Eutectic	partially bonded, check phases
S14_21_09(s)	300	5	350	1500	100	1000	Eutectic	partially bonded, check phases
S8_14_14(s)	300	5	380	1500	100	1000	Eutectic	partially bonded, check phases
S22_12_07(m)	300	5	320	1500	50	1000	Eutectic	bad bonding
S1_02_24-Recipe 2(m)**	300	5	350	1500	50	1000	Eutectic	partially bonded, check phases
S23_22_17(m)	300	5	380	1500	50	1000	Eutectic	partially bonded, check phases
S24_09_19(m)	300	5	320	1500	70	1000	Eutectic	bad bonding
S18_15_06(m)	300	5	350	1500	70	1000	Eutectic	partially bonded, check phases
S25_19_02(m)	300	5	380	1500	70	1000	Eutectic	partially bonded, check phases
S17_03_06(m)	300	5	320	1500	100	1000	Eutectic	bad bonding
S19_03(m)	300	5	350	1500	100	1000	Eutectic	partially bonded, check phases
S4_24_16-Recipe 3_HT(m)**	300	5	380	1500	100	1000	Eutectic	partially bonded, check phases

Double Exposure

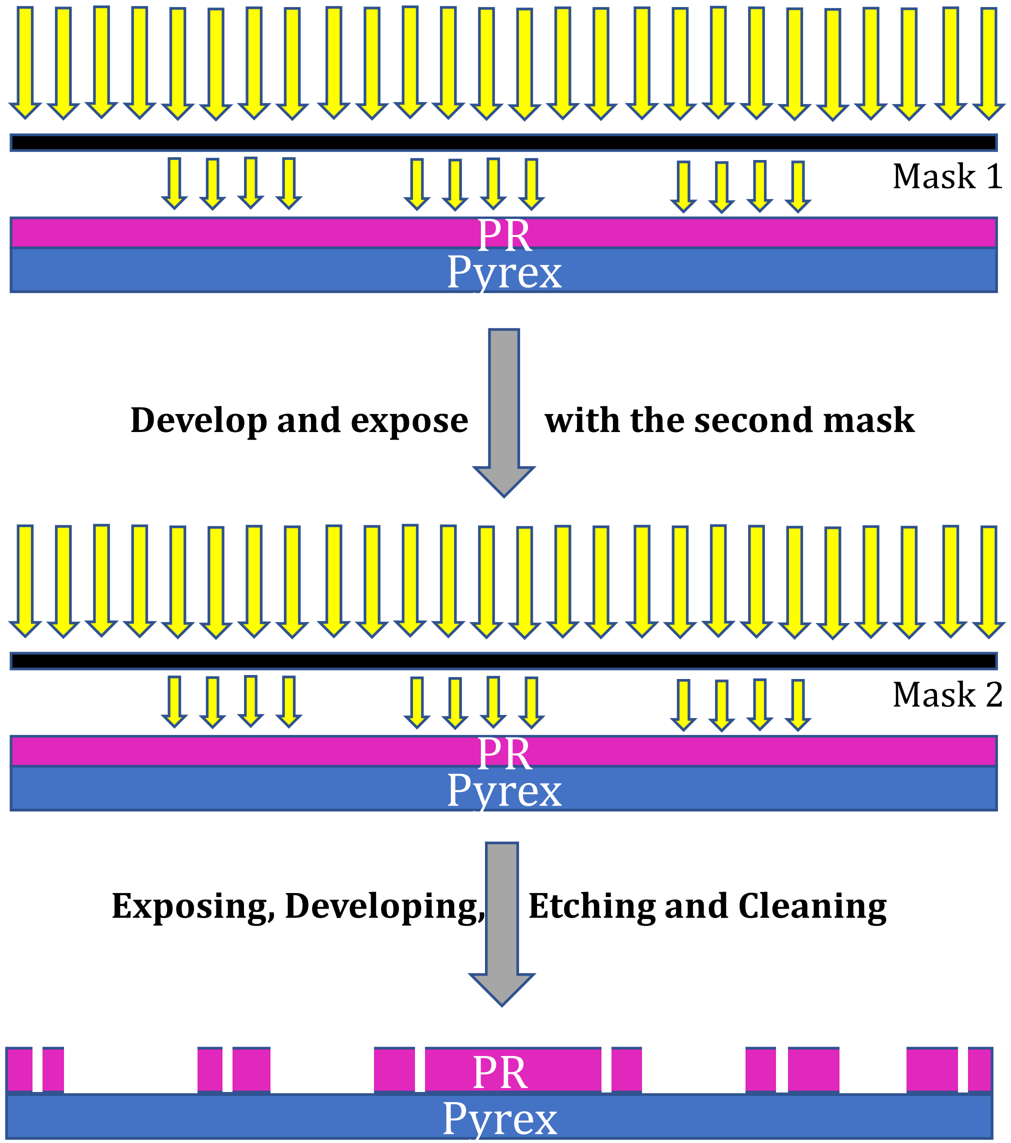
Exposure Duration – 0.8 ~ 1 s (for 1 µm PR)

Exposure Duration – 1.8 ~ 2.4 s (for 1 µm PR)



PR residue as a result of insufficient exposure time (0.9 s) during second exposure

Pyrex Wafers

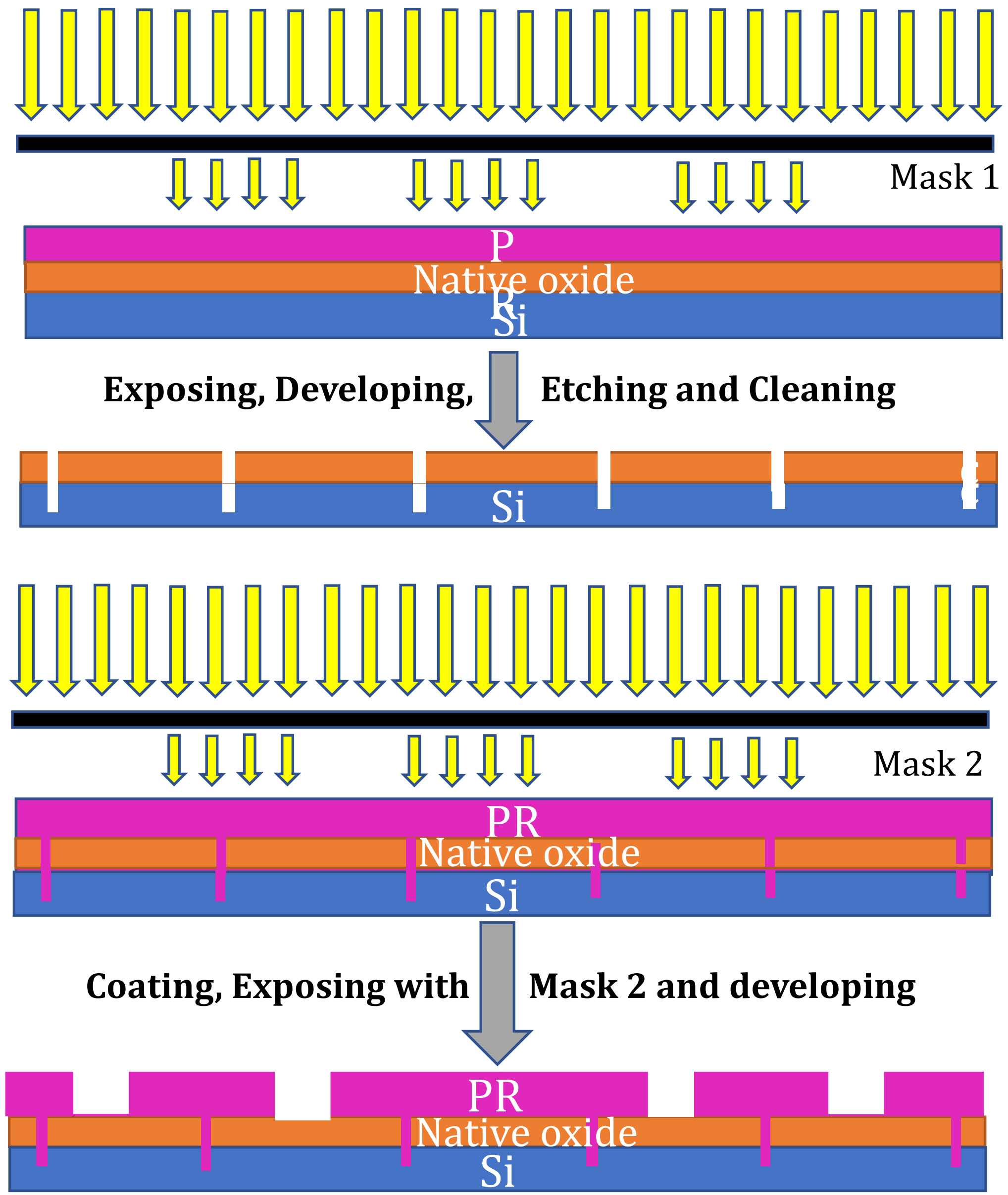


Develop and expose with the second mask

Exposing, Developing, Etching and Cleaning

Sample Fabrication

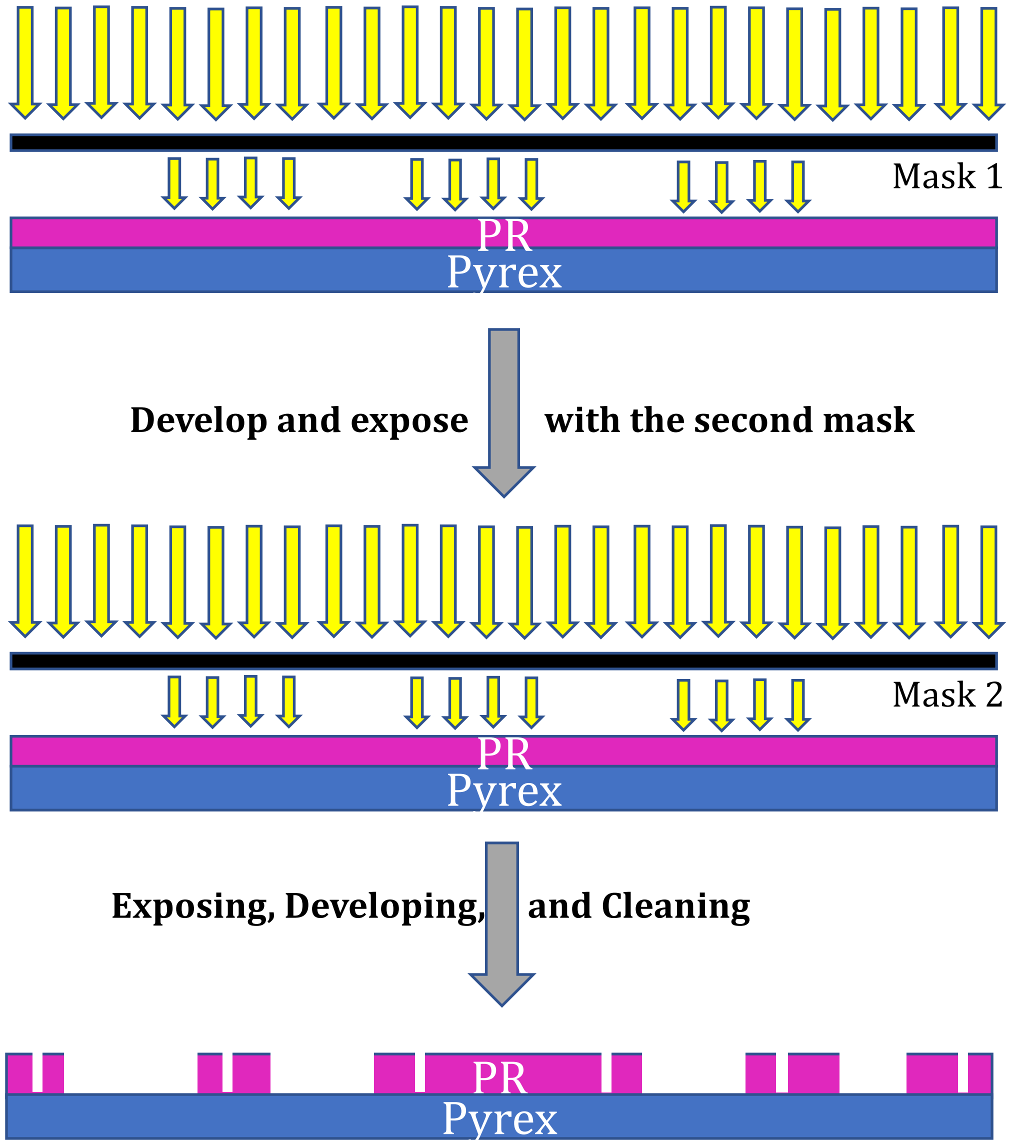
Silicon Wafers



Exposing, Developing, Etching and Cleaning

Coating, Exposing with Mask 2 and developing

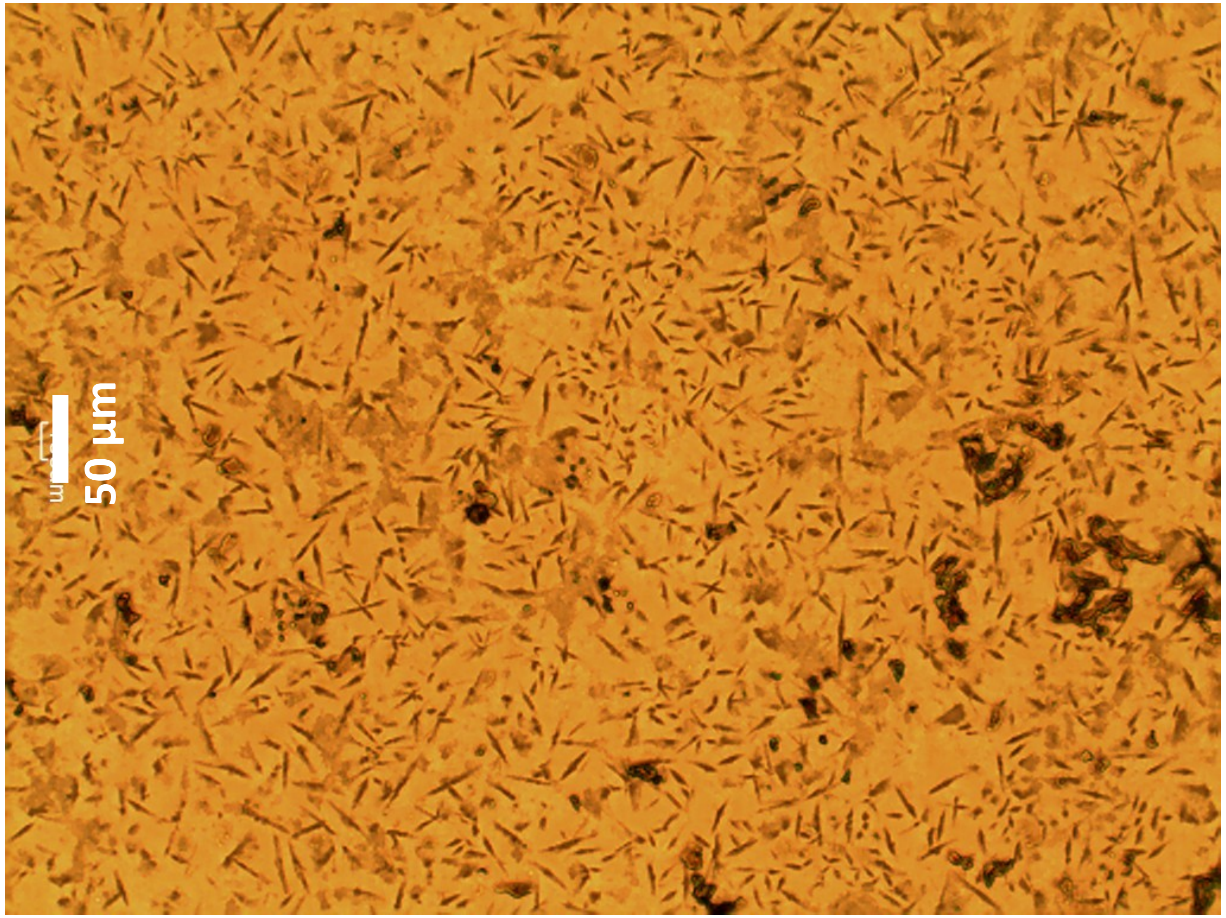
Pyrex Wafers

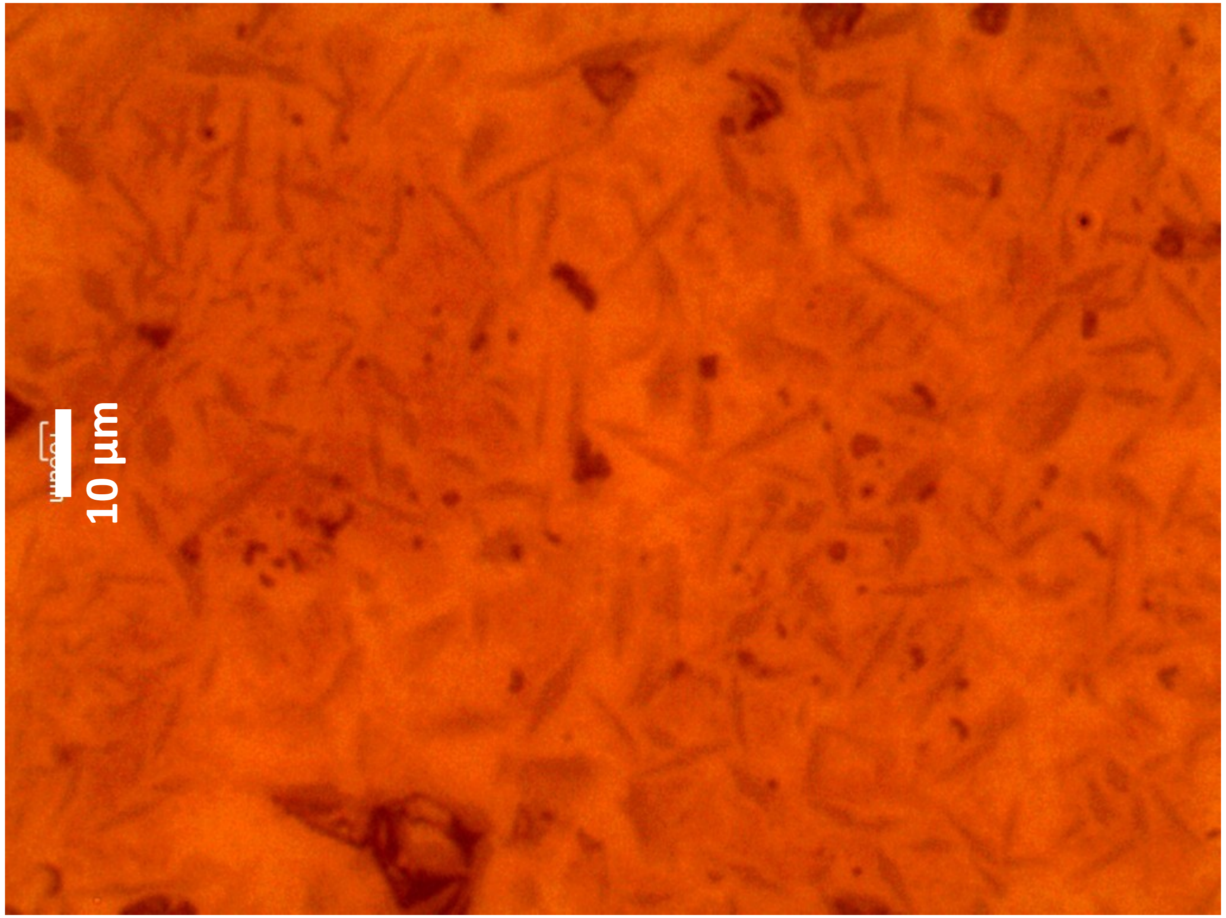


Develop and expose with the second mask

Exposing, Developing, and Cleaning

Needles (Rice Grains)





Early stages of dendrite formation caused by very high cooling rate

Au rich microstructure formed because of incomplete diffusion of Au into Sn (high cooling rate)