Transient liquid phase bonding technology of Bi-Ni system for high-temperature packaging applications

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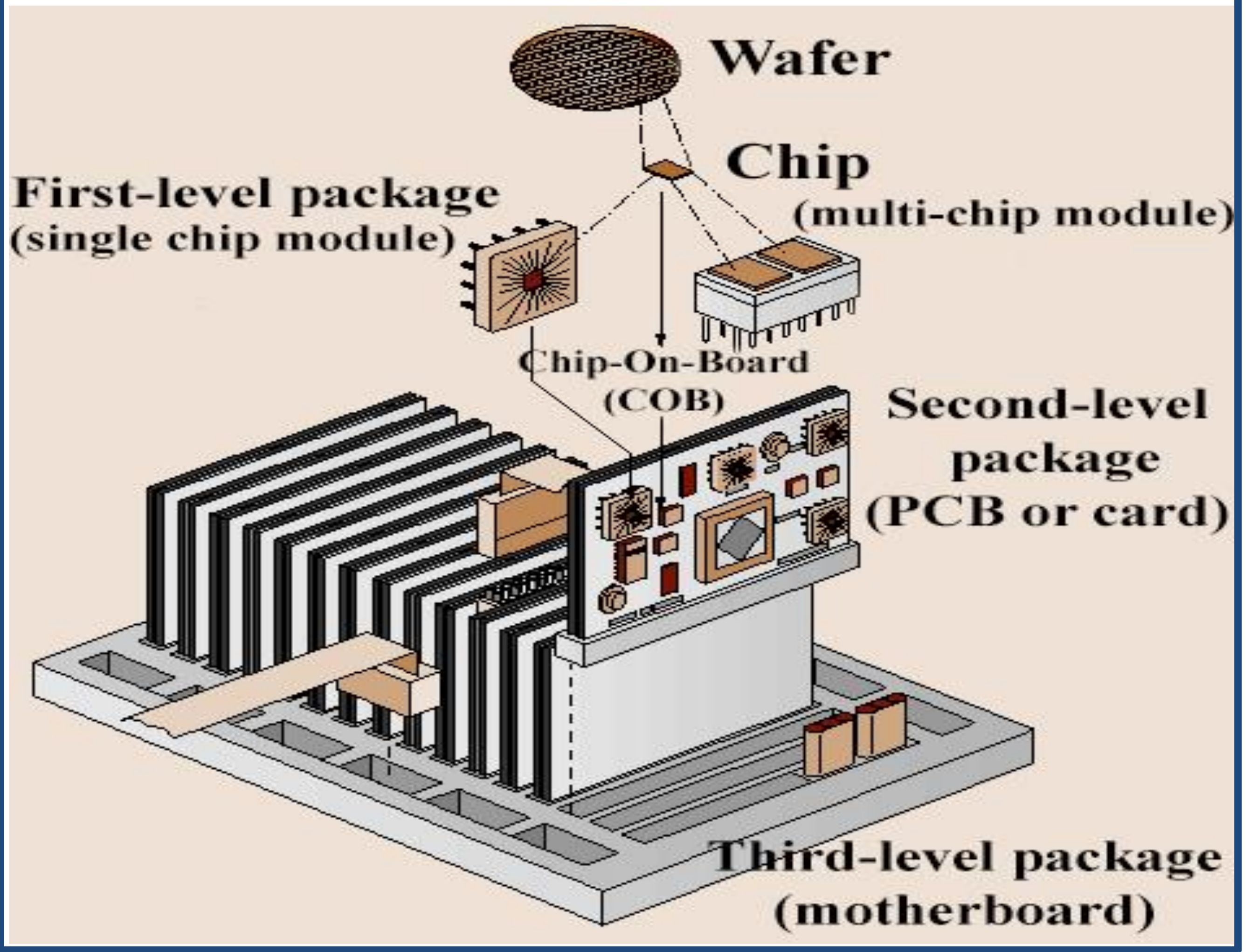
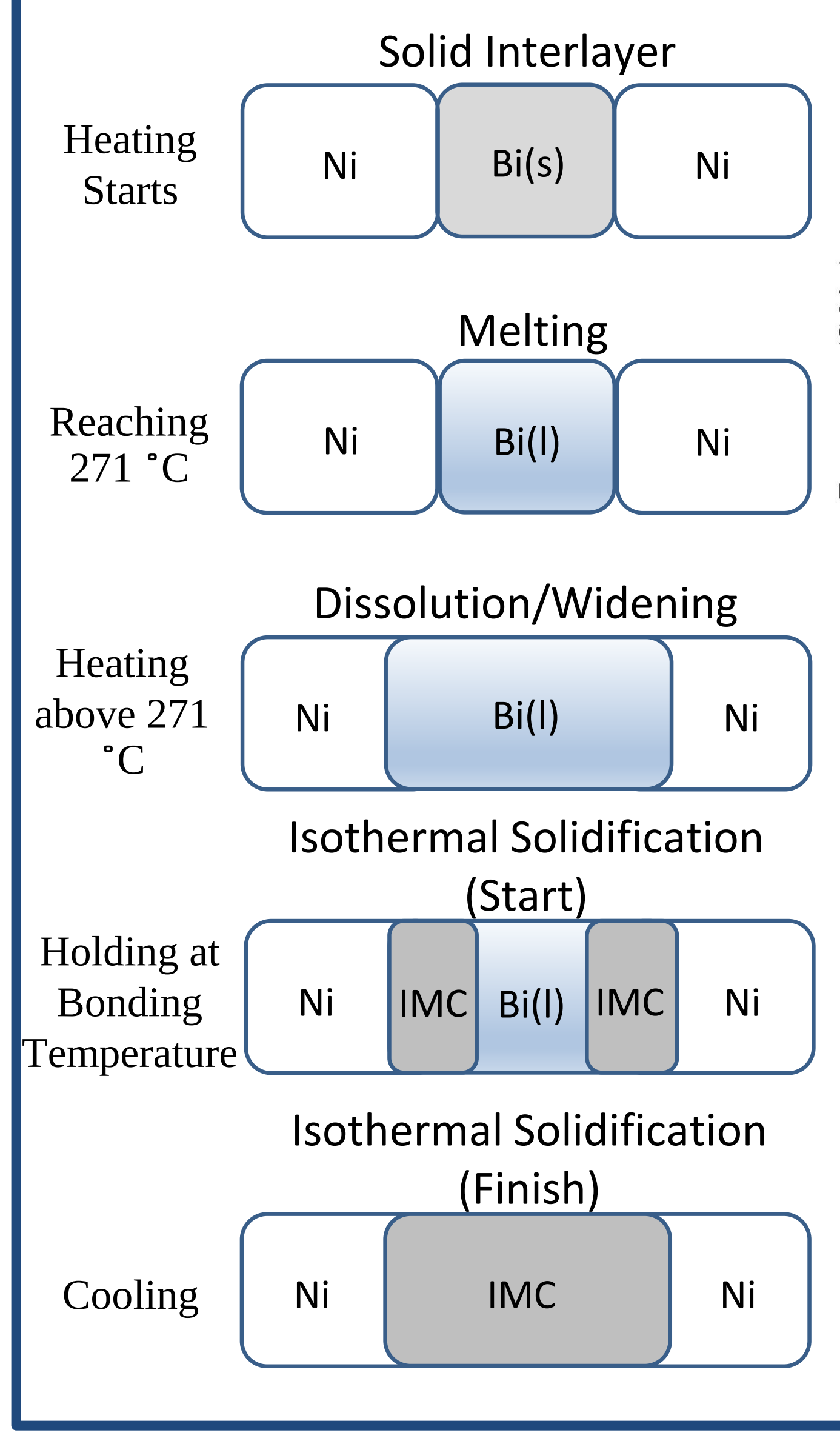
Overview

Due to environmental issues, the use of Pb in electronics packaging is restricted. We are developing Bismuth-Nickel transient liquid phase bonding (TLPB) as a joining method for components in high temperature electronics as a substitute for Pb-based solders. This technique can be used for SiC modules in power electronics (over 500°C), automotive underwood electronics and downhole drilling equipment. Pure Bi with melting temperature of 271 ˚C is quite brittle due to its rhombohedral crystal structure and exhibits low thermal conductivity. By TLP bonding we are able to produce Bi-Ni intermetallic compounds with higher temperature capabilities (up to 614°C). TLPB can be made by sputtered Bi thin film on Au layer (70 nm for Ni protection). On heating process, Bi melts and reacts to Ni to form a structure of intermetallic compounds with higher melting temperature than Bi. Intermetallic phase forms via isothermal solidification in bond region during reflow. It was shown that temporal evaluation of two intermetallic phases, Bi_3Ni and BiNi, along with the remaining Bi, are responsible for the mechanical properties and durability of TLPB **[1-3]**.

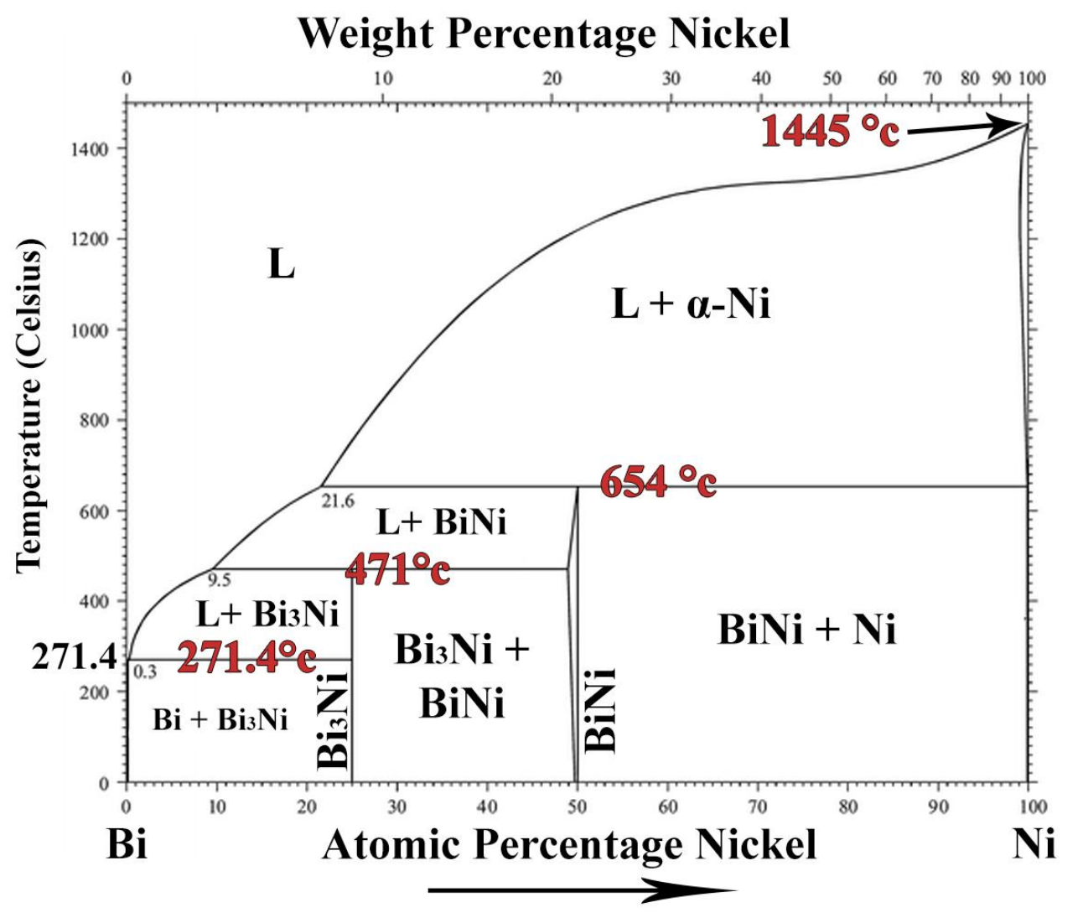


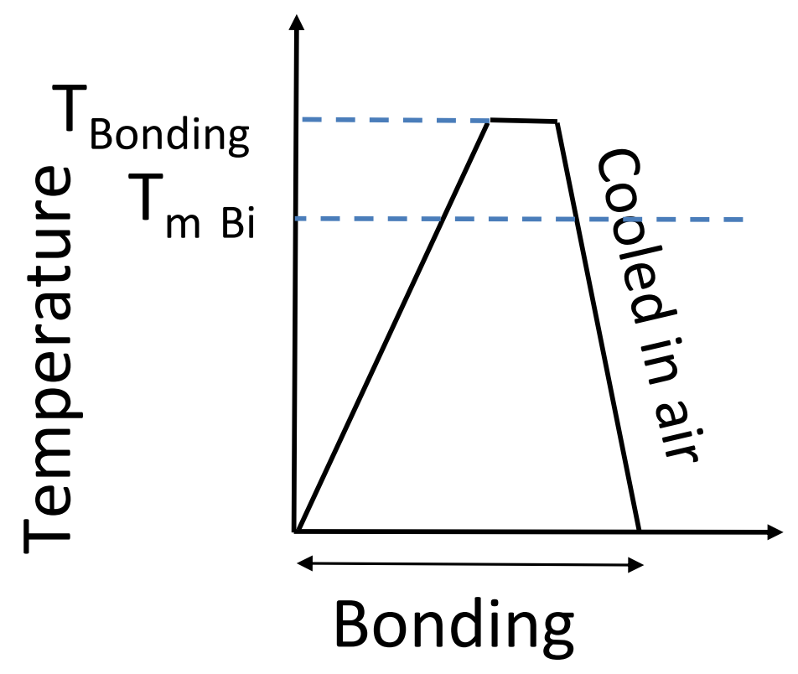
Bi-Ni TLP bonding

Schematic of IMC growth during reflow process [4]



IMCs : Bi_3Ni, BiNi





Method

Bonding component

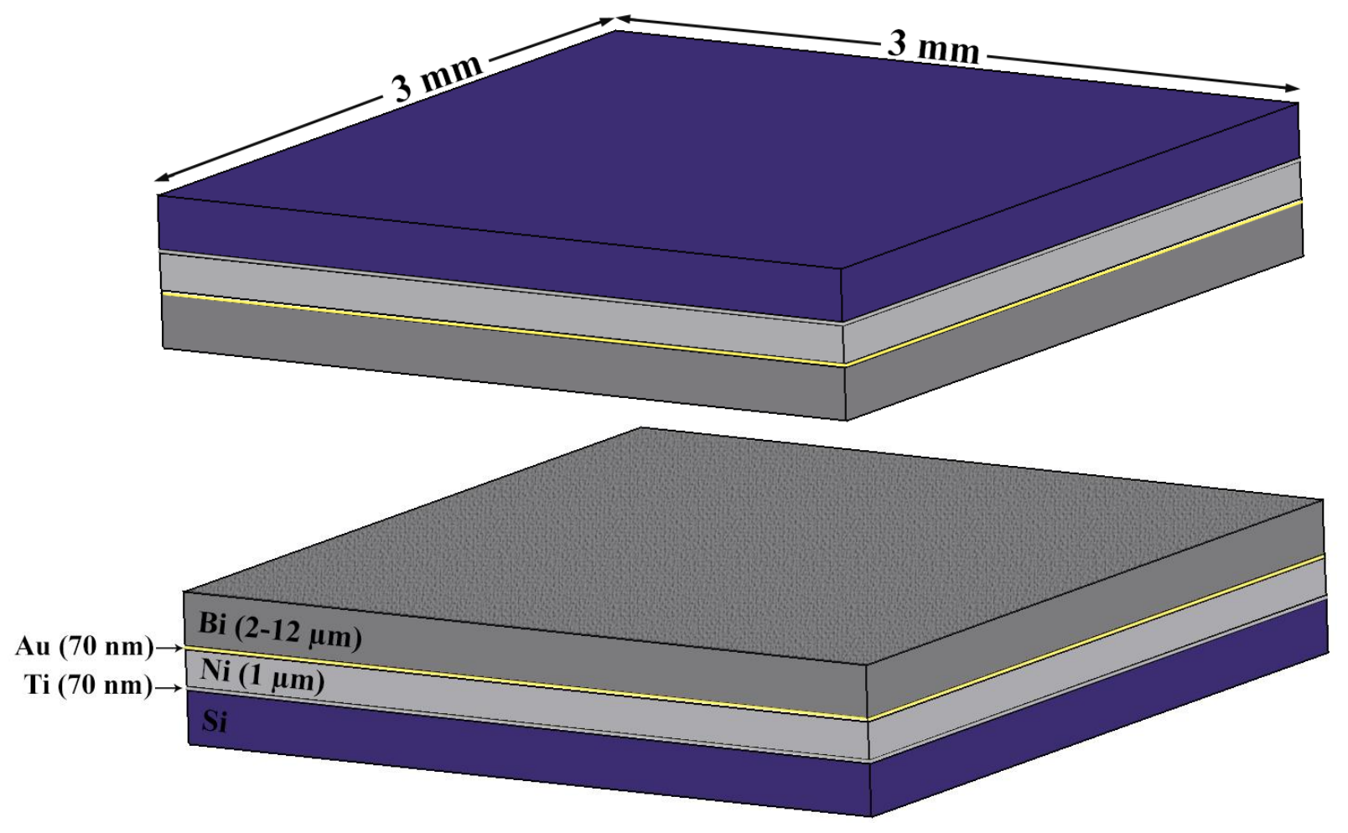
i) Thin film approach

Sputtered Bi on Si die

Backside metallization

Ti (70 nm) / Ni (1000 nm) / Au (70 nm)

dimensions: 1/8" x 1/8"

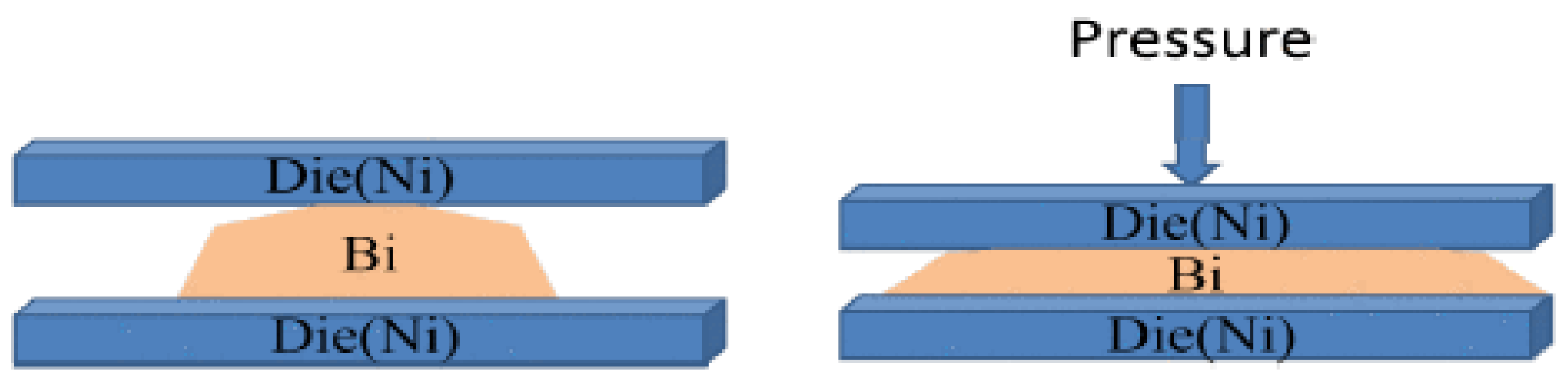


Sputtering target from Angstrom Sciences (pure Bi, 99.999%)

- RF sputter
- 60 s pre-heat
- Deposition rate: ~ 0.5 µm per min

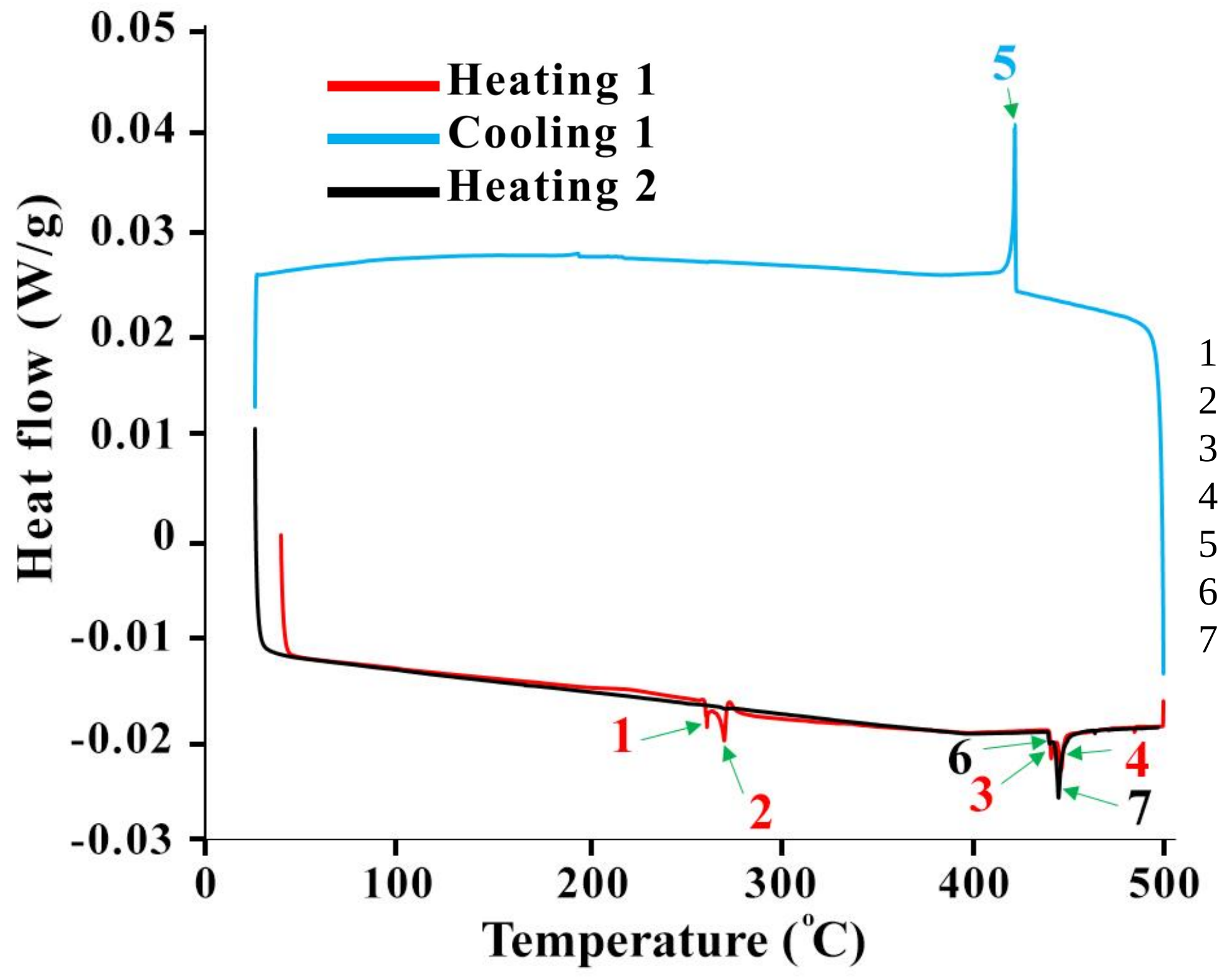
ii) Bismuth preform

Pure Bi pieces cut from its ingot rod (99.999%; Goodfellow, Huntington, UK) were used as an interlayer.



Differential scanning calorimetry (DSC) analysis

Bi sputtered sandwich sample

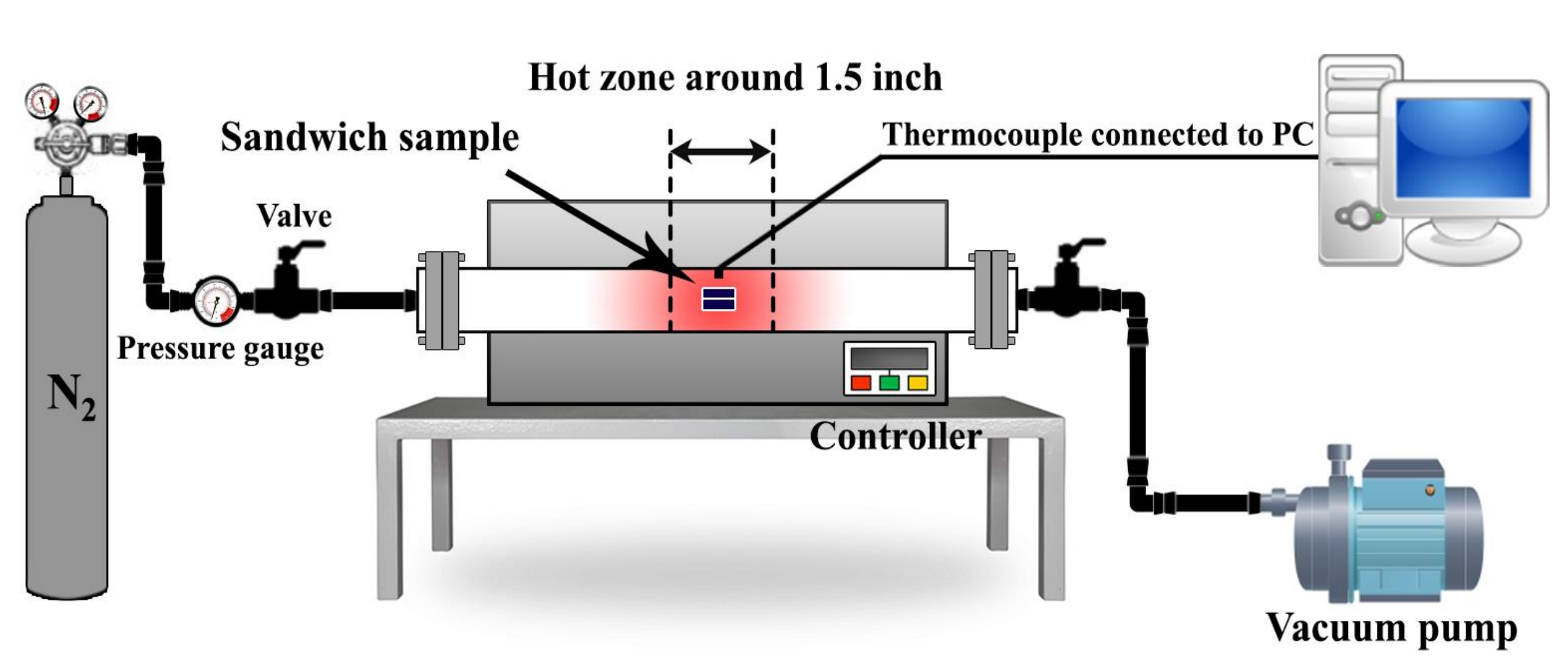


Peak Label

1) Nucleation of Bi_3Ni
2) Melting of pure Bi
3) Nucleation of BiNi
4) Melting of Bi_3Ni
5) Undercooling of Bi_3Ni
6) Nucleation of BiNi
7) Melting of Bi_3Ni

Reflow process

Schematic of the reflow furnace used in this research



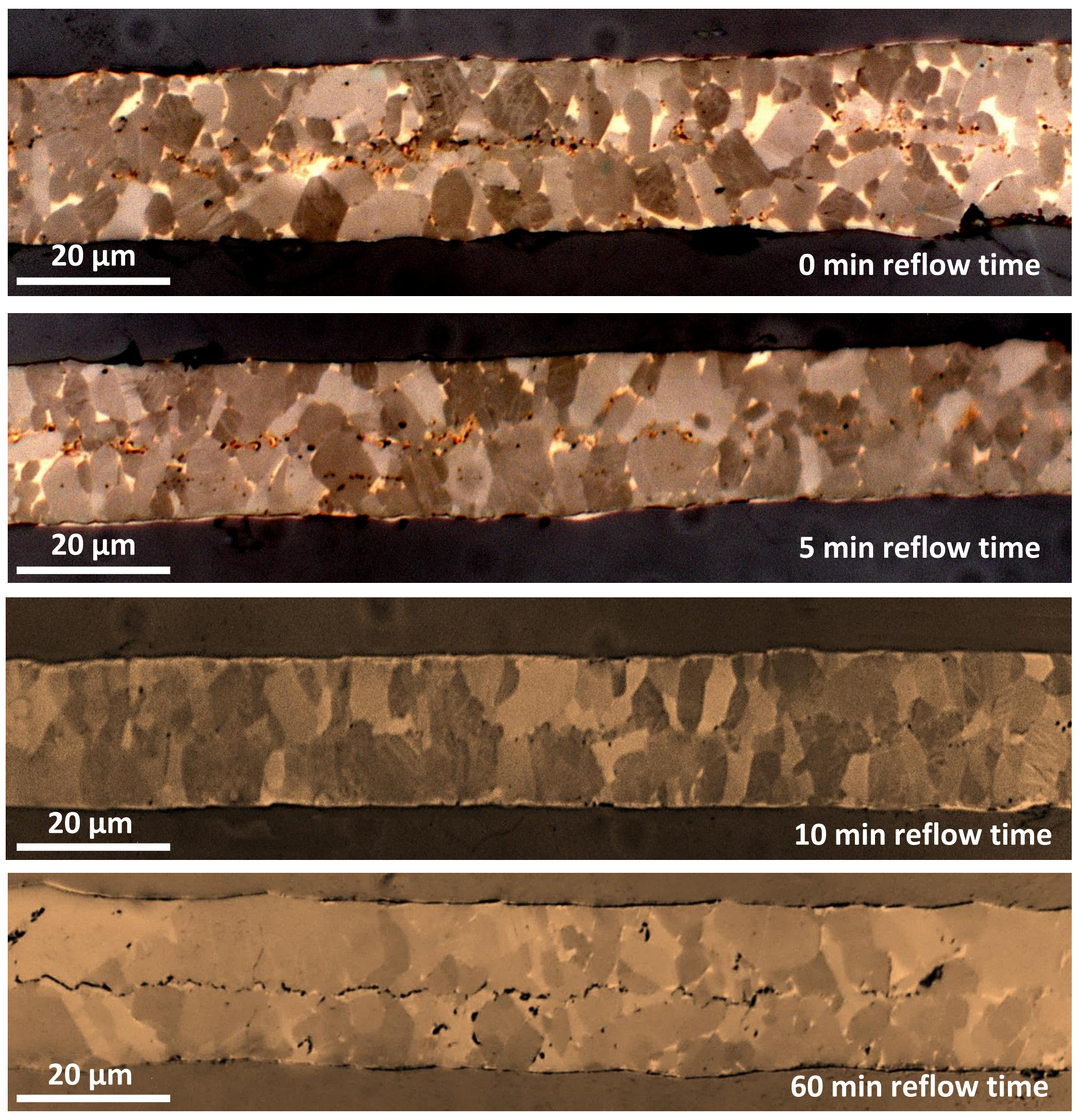
Acknowledgements

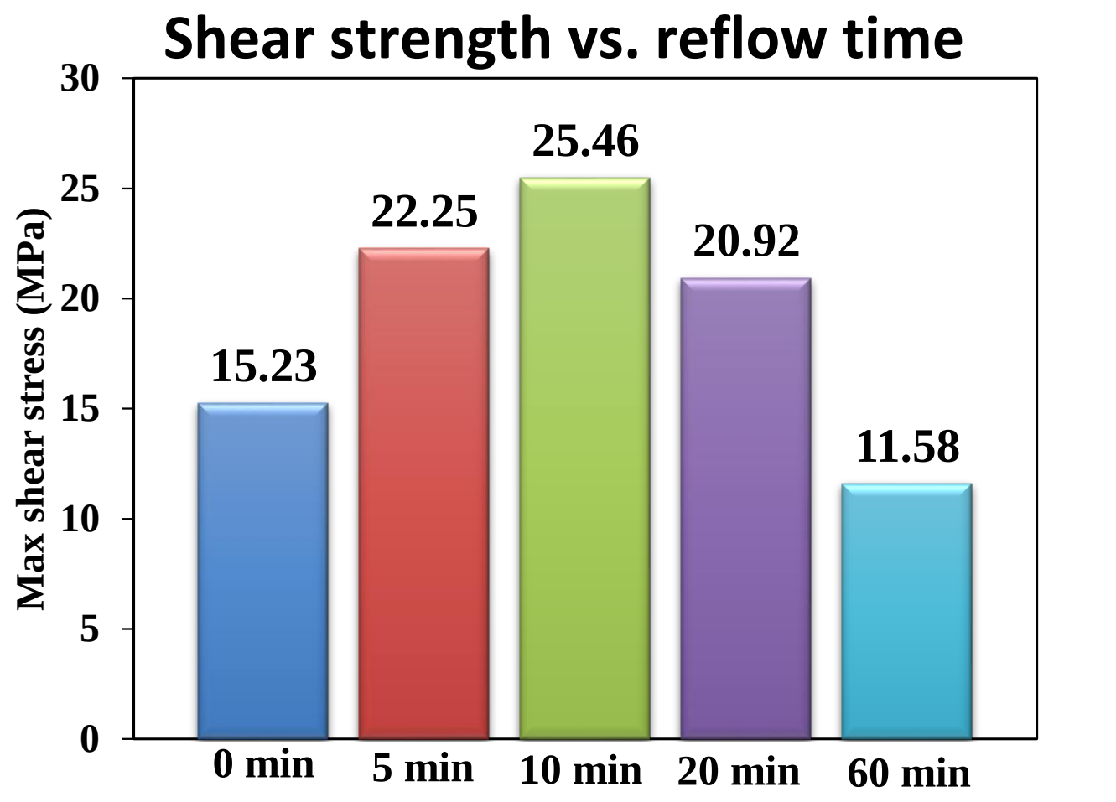
- Special thanks to Prof. Cotts and his research group for the reflow setup system and experiments.
- All characterizations were done in The Analytical and Diagnostics Laboratory (ADL) at ITC, Binghamton University.

Microstructural evaluation on bonded area

Polarized OM

Bi preform between two Si die (Ni) reflowed at 330 ℃ in vacuum furnace with 1-2 ℃/s as heating rate

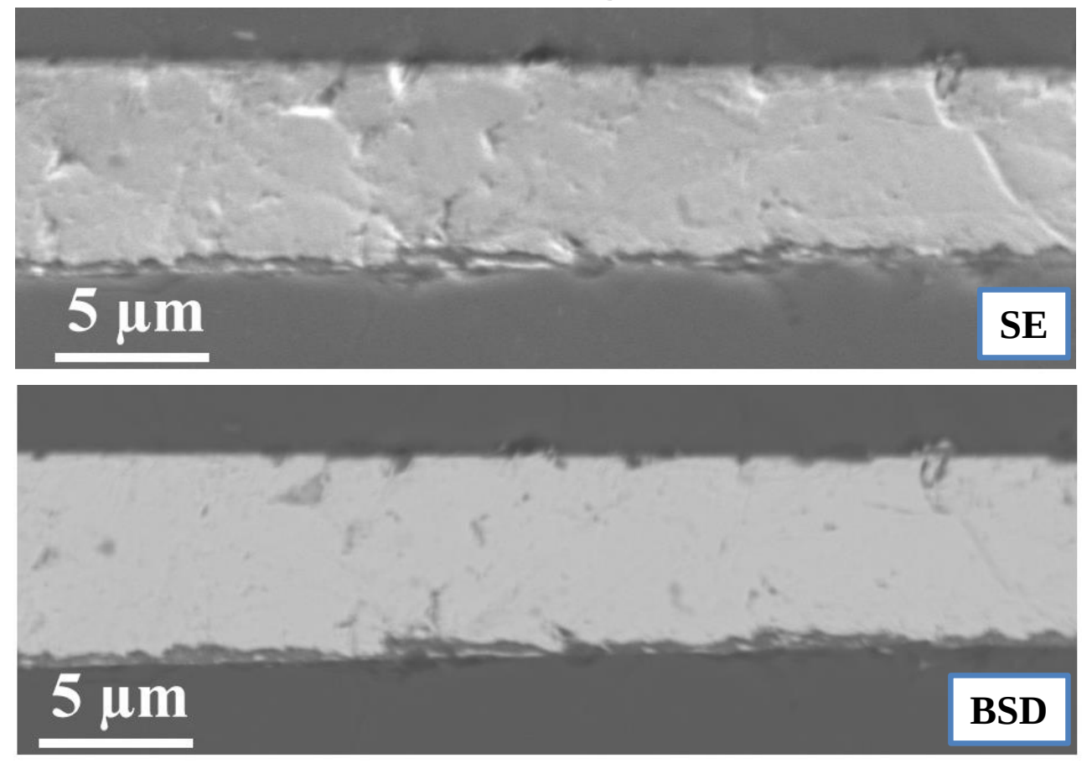




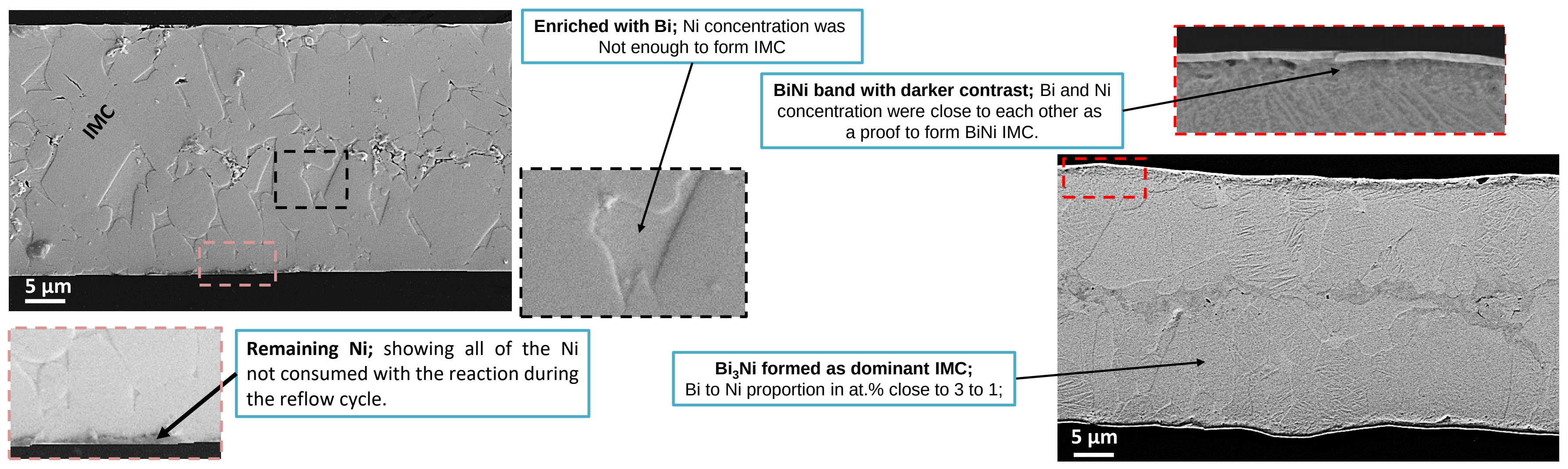
Bi sputtered sandwich sample

Reflow at 330℃ for 30 min with 65 ℃/s as heating rate

Max shear strength ≈ 15 MPa



BSD investigation



Enriched with Bi; Ni concentration was Not enough to form IMC

BiNi band with darker contrast; Bi and Ni concentration were close to each other as a proof to form BiNi IMC.

Remaining Ni; showing all of the Ni not consumed with the reaction during the reflow cycle.

Bi_3Ni formed as dominant IMC; Bi to Ni proportion in at.% close to 3 to 1;

Parameters affecting TLP bond quality

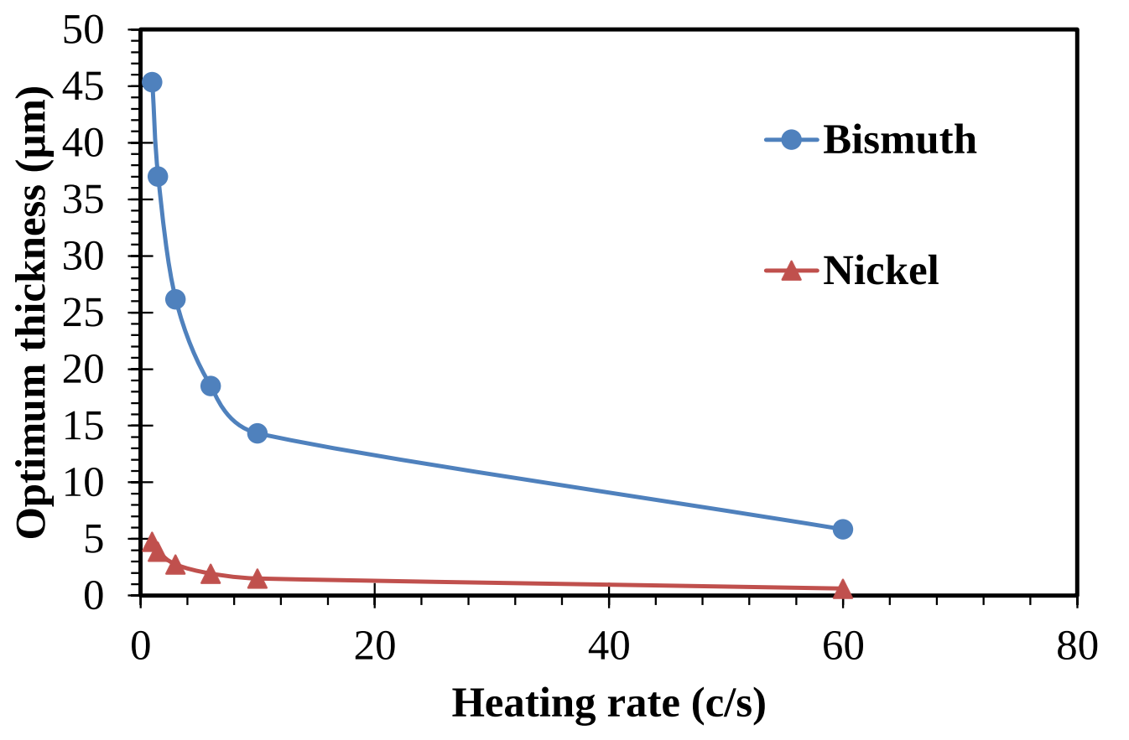
- Surface cleaning before reflow to remove an oxide scale
- Heating rate; increasing heating rate could avoid forming IMC before reaching to the melting point of interlayer.
- Optimum thickness of interlayer **[5]**;

$$h_{Optimum} = 2h_{IMC} \times C_A(\rho_{IMC}/\rho_{Bi})^2 \qquad h_{Optimum} = 2h_{IMC} \times (1.075) \qquad h_{IMC}=\sqrt{2k_p t_{heat}}$$

$$X_{Bi} = 9.533\ Y_{Ni}$$

For growth of Bi_3Ni

Parameter	Description	Value
C_A	Mass fraction of interlayer for Bi_3Ni, (%)	91.43
ρ_{IMC}	Density of IMC (Bi_3Ni), ($^g/_{cm^3}$)	10.9
ρ_{Bi}	Density of interlayer (Bi) near m. p., ($^g/_{cm^3}$)	10.05
K_p	Growth constant, (µm²/s)	0.927
Q	Activation energy around m. p. , (kJ/mol)	132.9



Conclusion

- ➢ Bi_3Ni forms first with either bulk or interface nucleation depending on the remaining of a Ni layer; BiNi forms at the interface between Bi_3Ni and Ni with slower growth kinetics compared to that of Bi_3Ni.
- ➢ With decreasing the thickness of Bi as an interlayer, a continuous crack can be seen due to shrinkage related to phase transformation to IMC. With increasing heating rate, thinner TLP bonds could be achieved based on the calculation above.
- ➢ Best bonding maintaining good mechanical reliability could contain a full IMC layer with a remaining Ni layer on the Si die.

References

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