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Comprehensive Study on 2.5D Package for Board-Level Reliability in Power Cycling and Thermal Cycling

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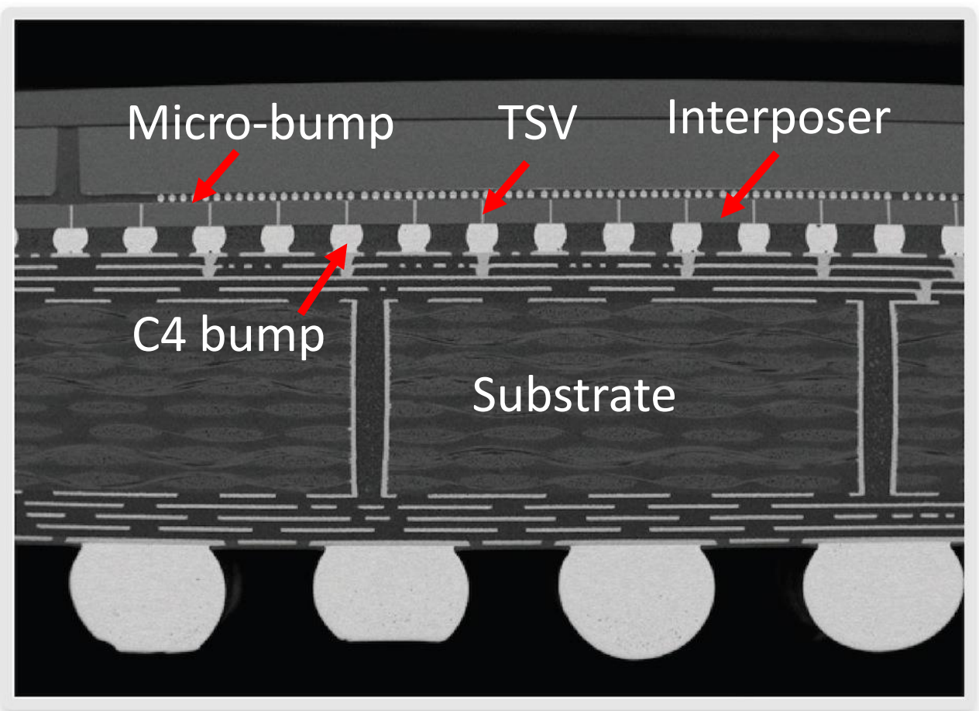
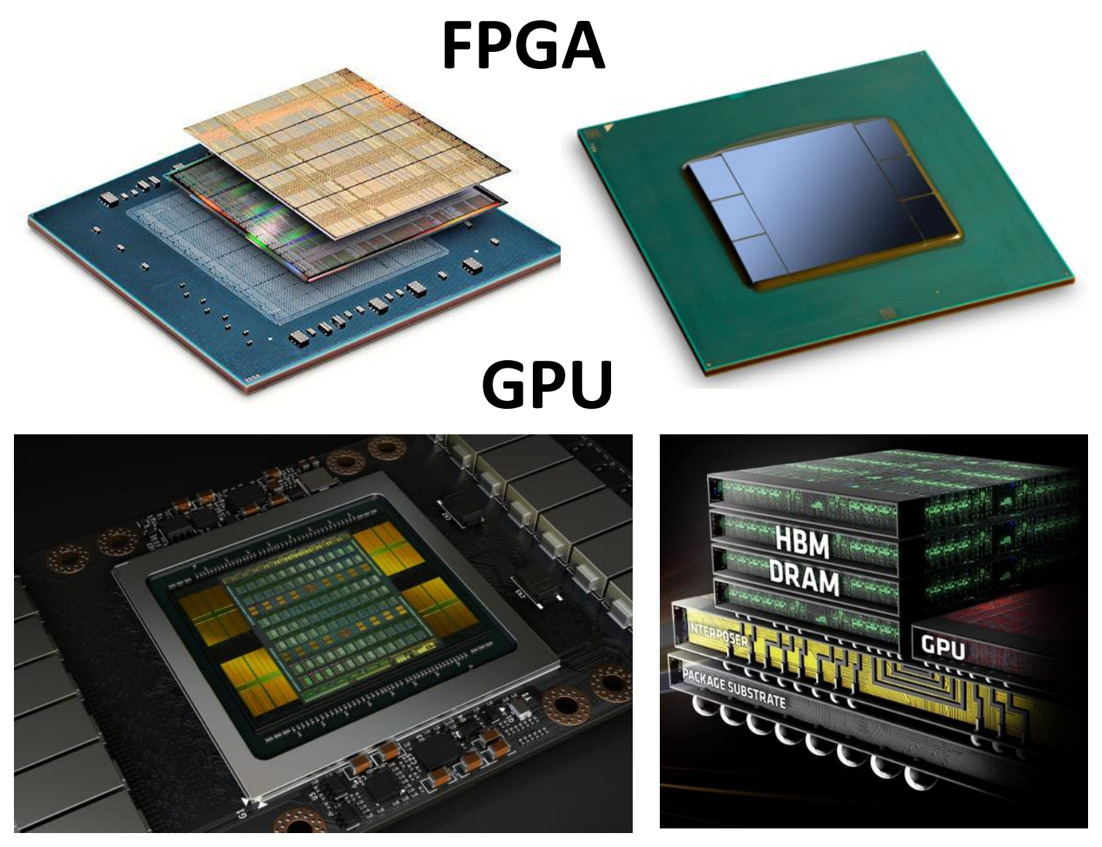
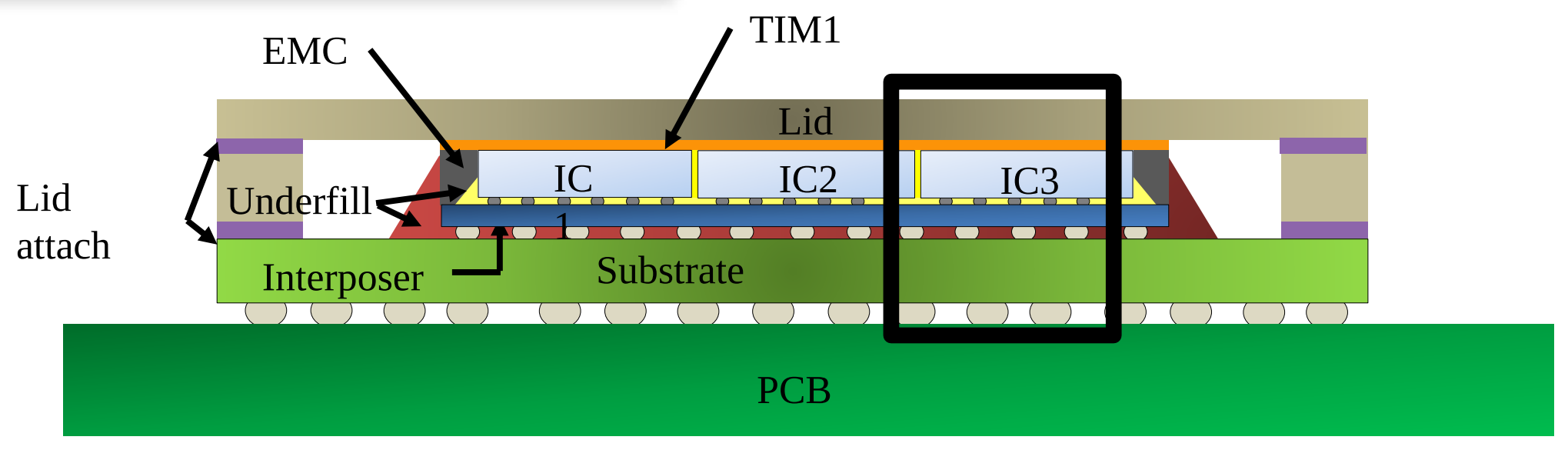
Background

2.5D IC package arranges multiple chips in a planar fashion around a silicon interposer.







Advantages of 2.5D IC packaging methodology

- Heterogeneous Integration – Dies do not have to utilize the same process technology or function
- Reliable and Affordable – TSV fabrication & multi-level assembly technologies get mature
- High I/O density, More functions, High performance efficiency, Latency reduction, Improvement of inter-die bandwidth/power

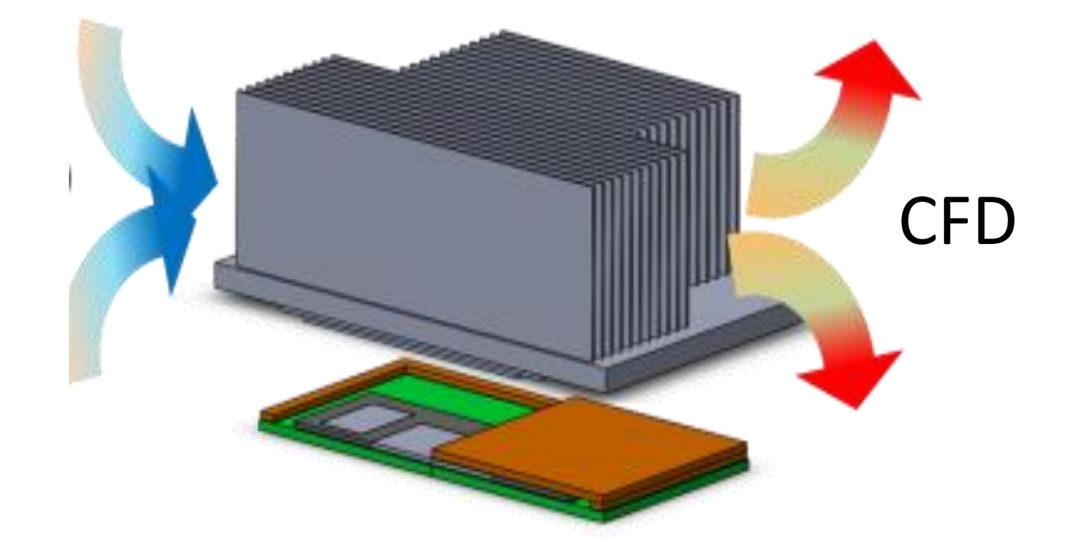
Large die area in 2.5D packages brings challenge to board level reliability in thermal/power cycling (package warpage due to CTE mismatch).

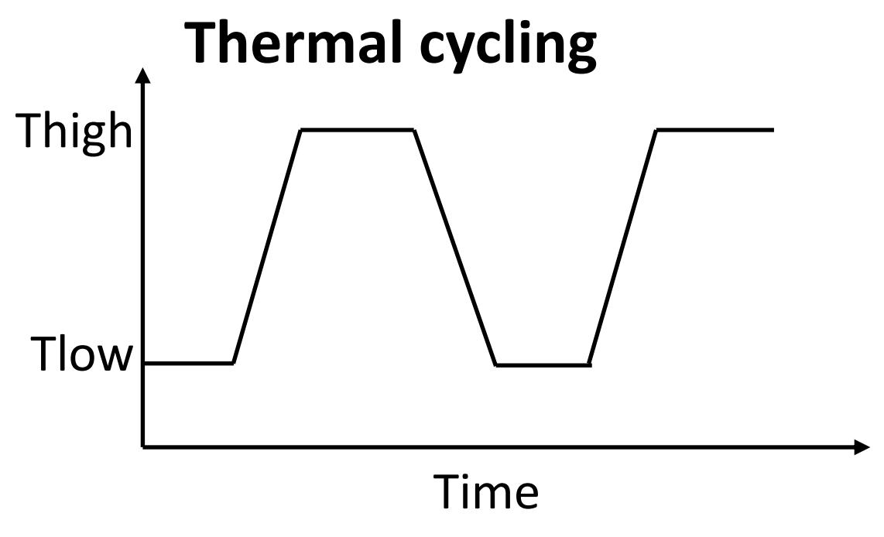
Motivation

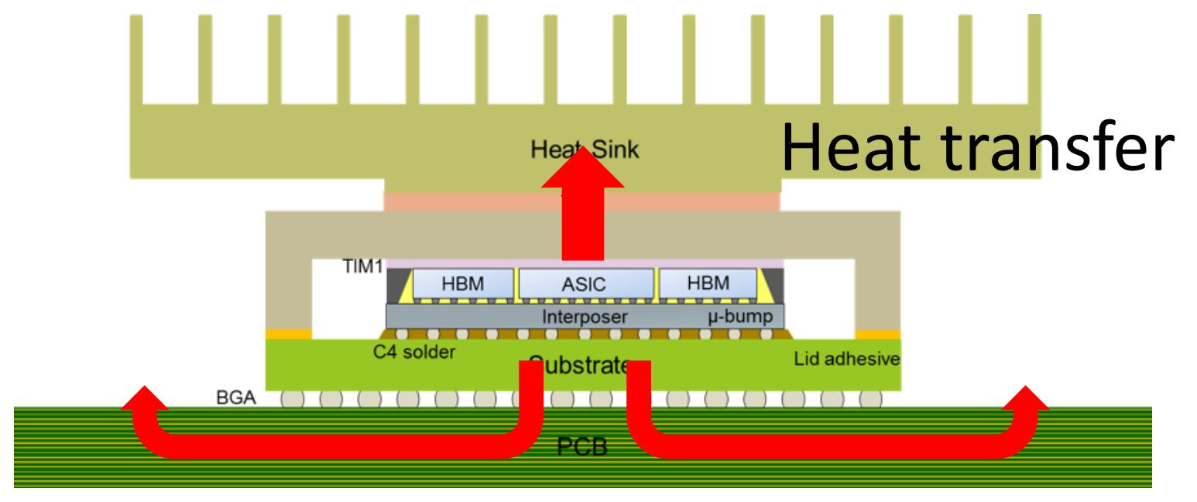
Simulating power cycling is important since it is close to the actual use condition of 2.5D package applications. Previously, averaged convective heat transfer coefficients on surfaces were used in conjugate simulations, which has limitations.

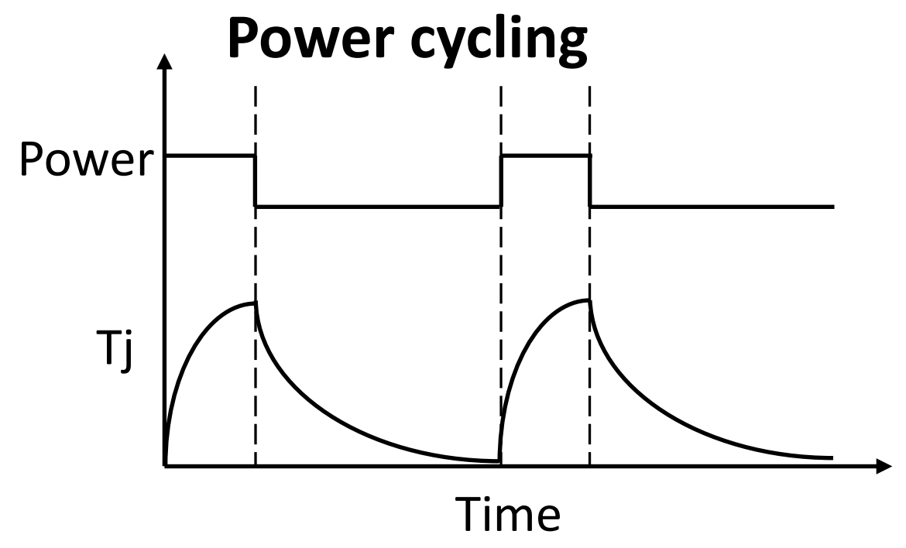
Objective

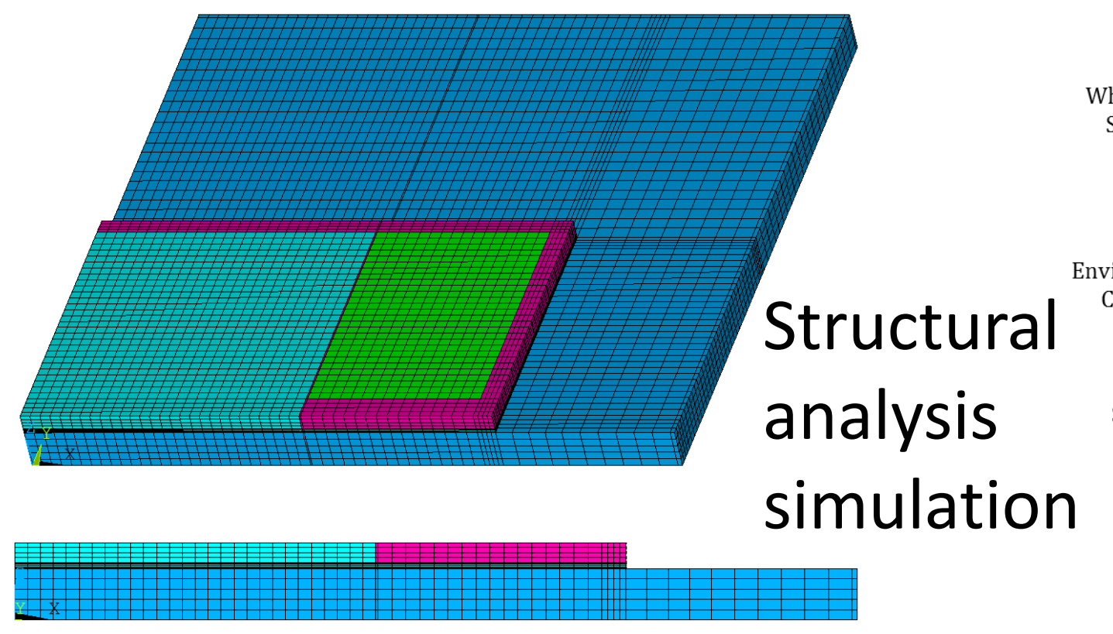
- To develop a methodology for thermal-fluid-structural analysis on power cycling for 2.5D package assemblies
- To establish trustworthy simulation models by multi-step validations

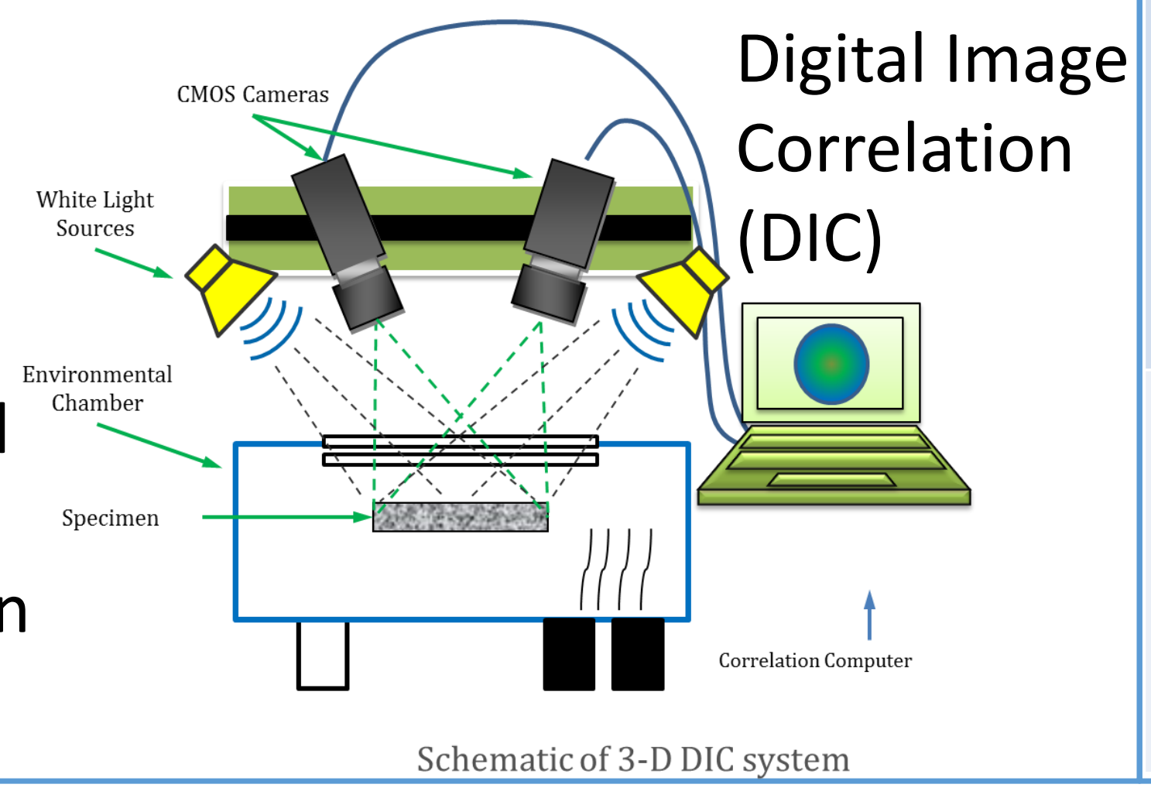






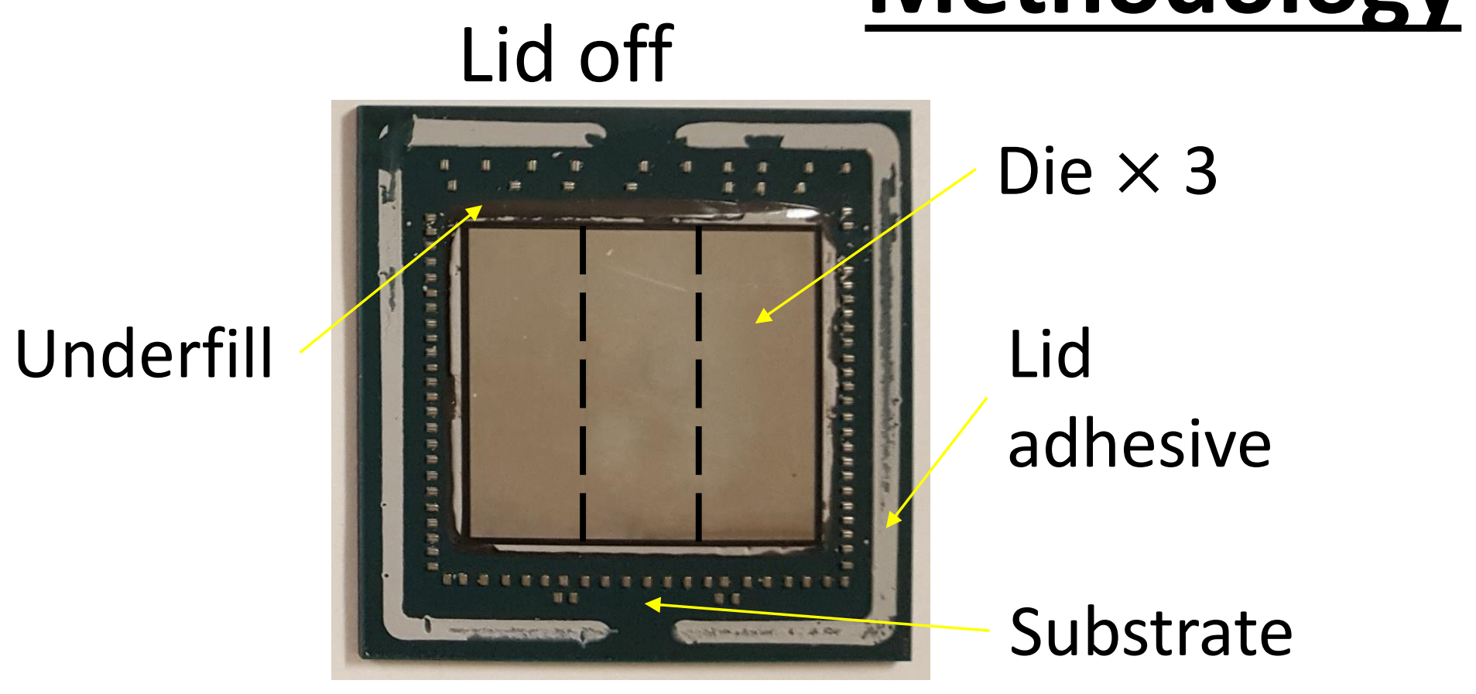


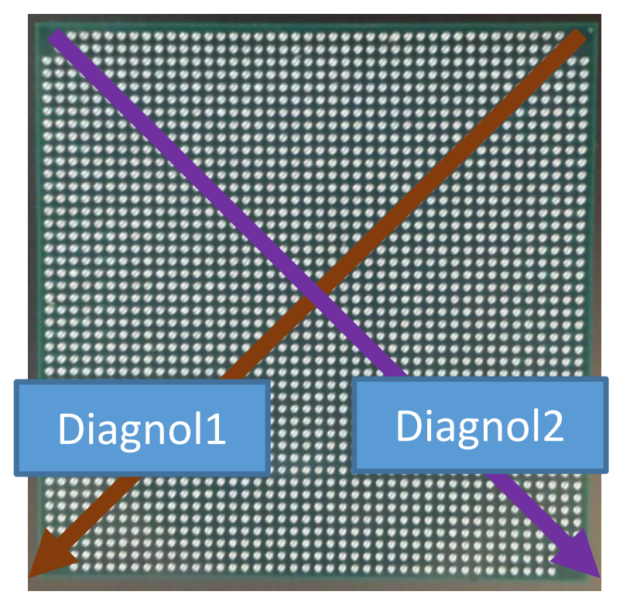




Schematic of 3-D DIC system

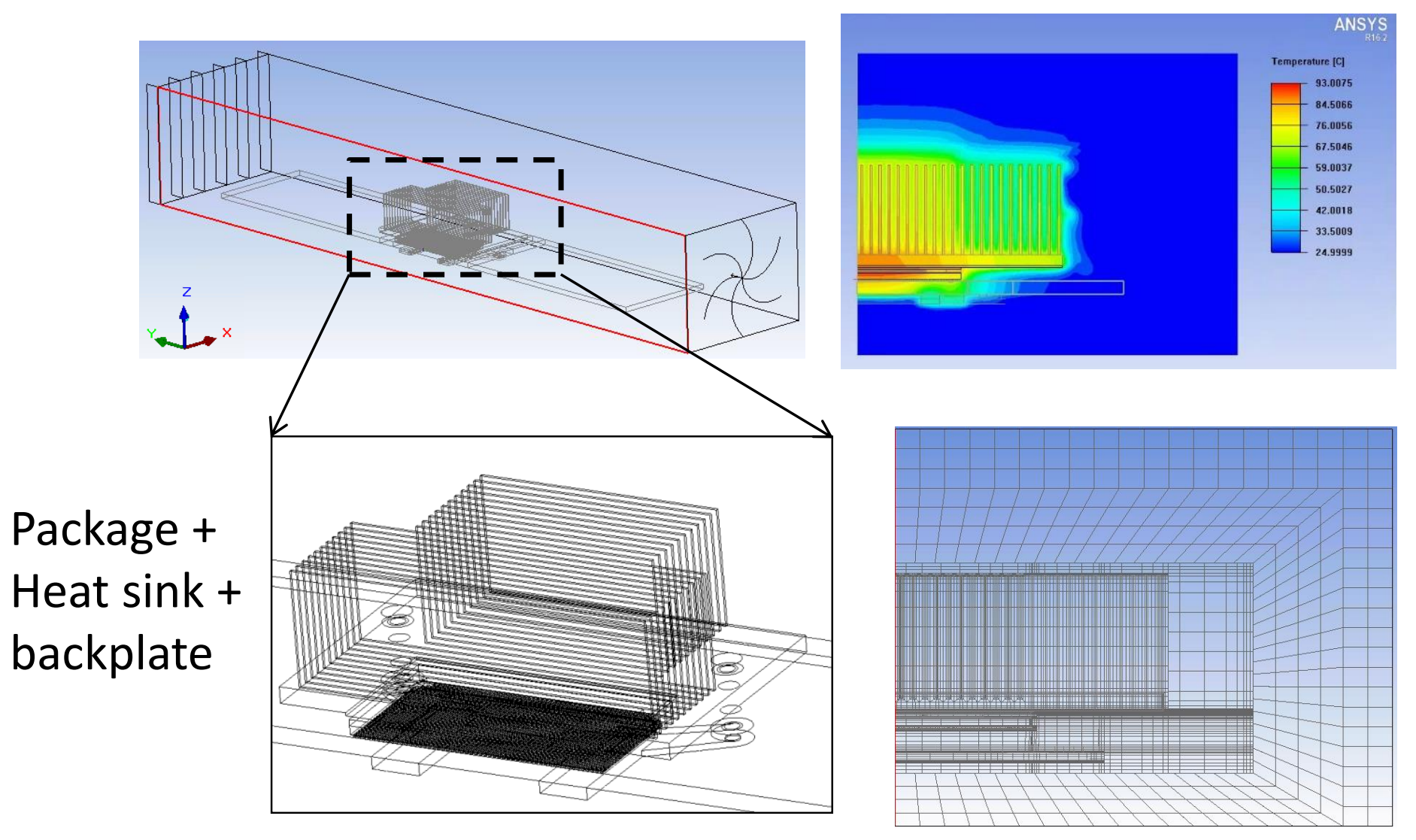
Methodology

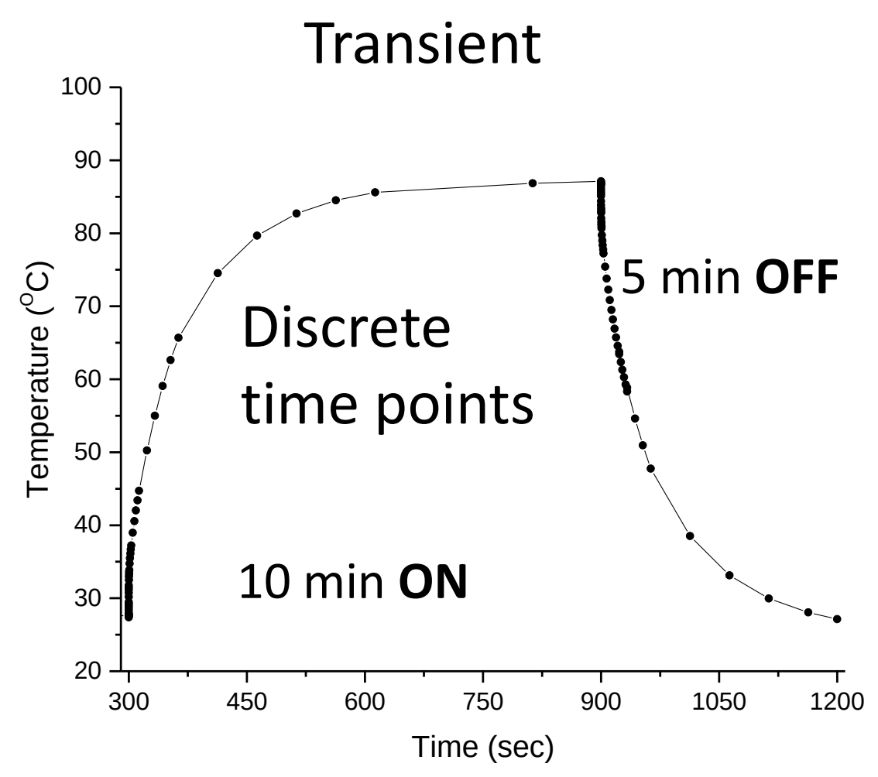




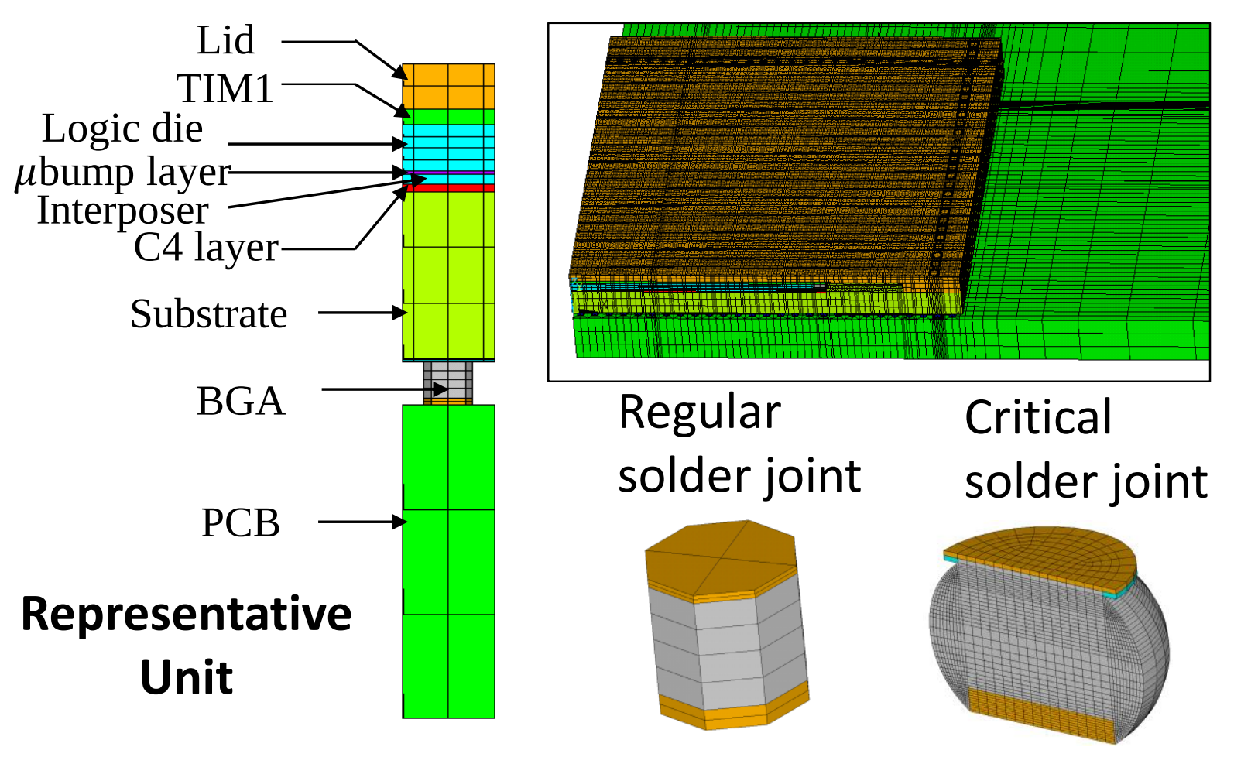
1. Transient Thermal-Fluid Analysis for Power Cycling (conjugate CFD)

Forced air convection, Heat generation 50 watt per die





2. Finite Element Model



Rule of Mixture

Calculating effective material properties of for C4 bumps and μbump with underfill

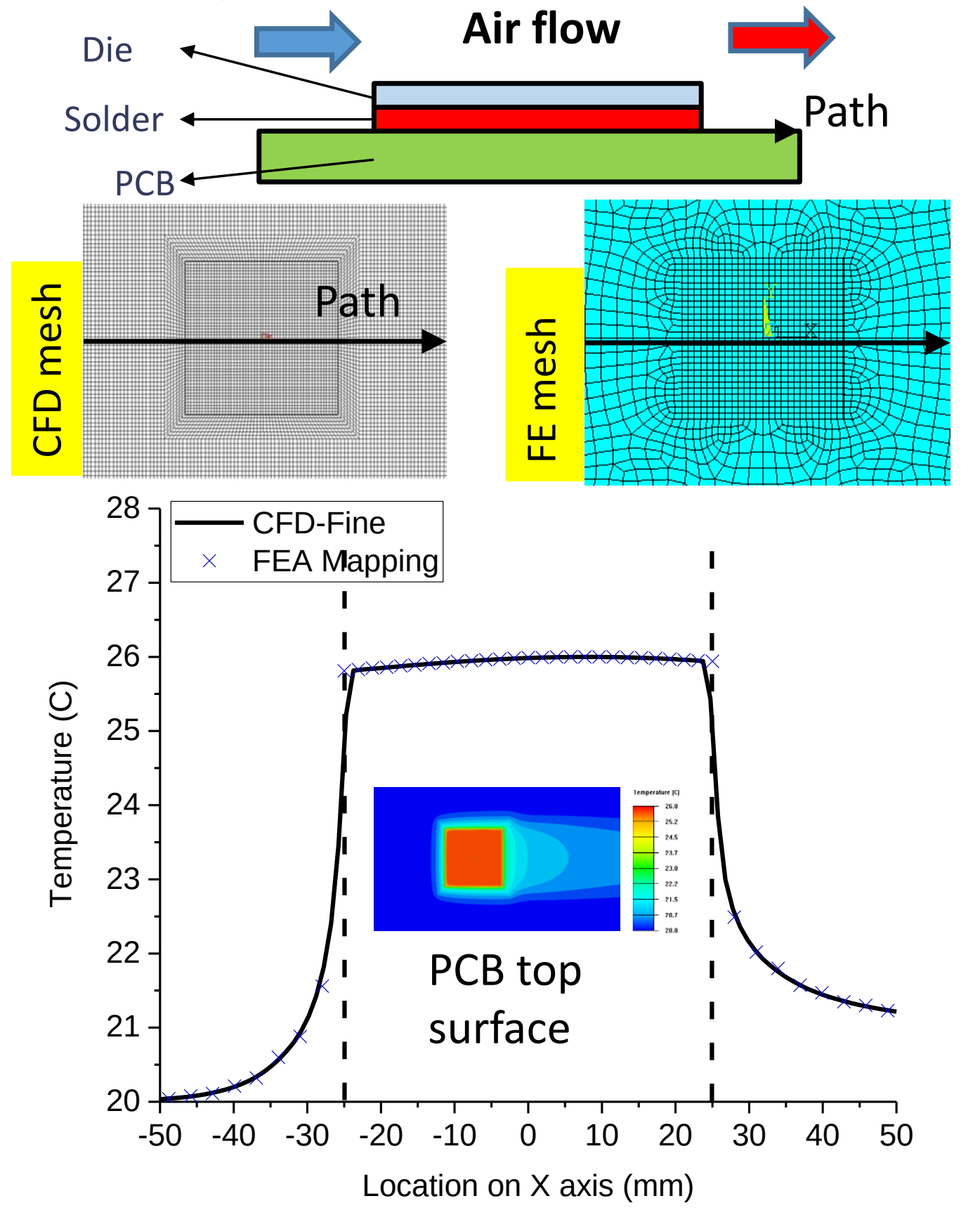
$$E_{x,y}^{eff} = \frac{1}{\left[\frac{c_s}{E_s} + \frac{c_u}{E_u}\right] - \frac{c_s c_u (\nu_s E_u - \nu_u E_s)^2}{E_s E_u (c_s E_s + c_u E_u)}}$$

$$\alpha_z^{eff} = \frac{E_s \alpha_s c_s + E_u \alpha_u c_u}{c_s E_s + c_u E_u}$$

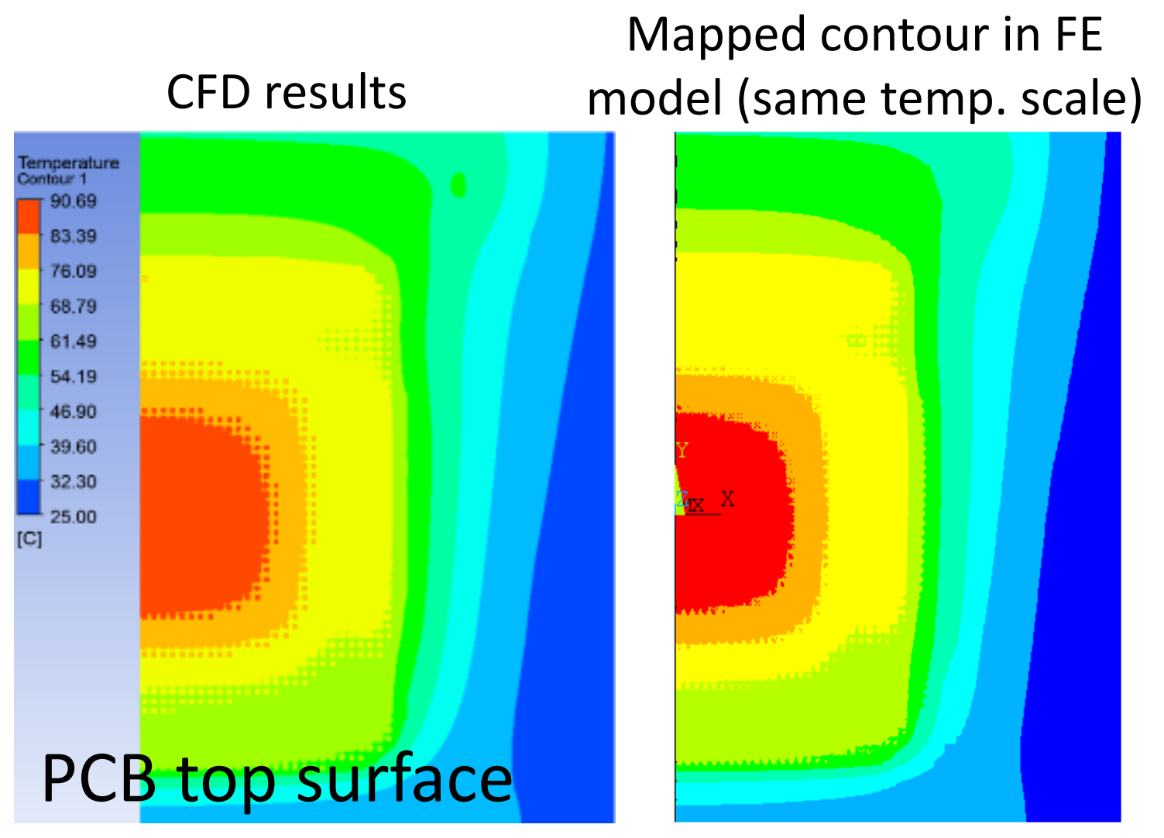
$$\alpha_{x,y}^{eff} = (1+\nu_u)\alpha_u c_u + (1+\nu_s)\alpha_s c_s - \alpha_z^{eff} \nu_{xz}^{eff}$$

3. Temperature Mapping From CFD Mesh to FE Mesh

Demo cases to show quality of data mapping



Mapping for 2.5D package assembly

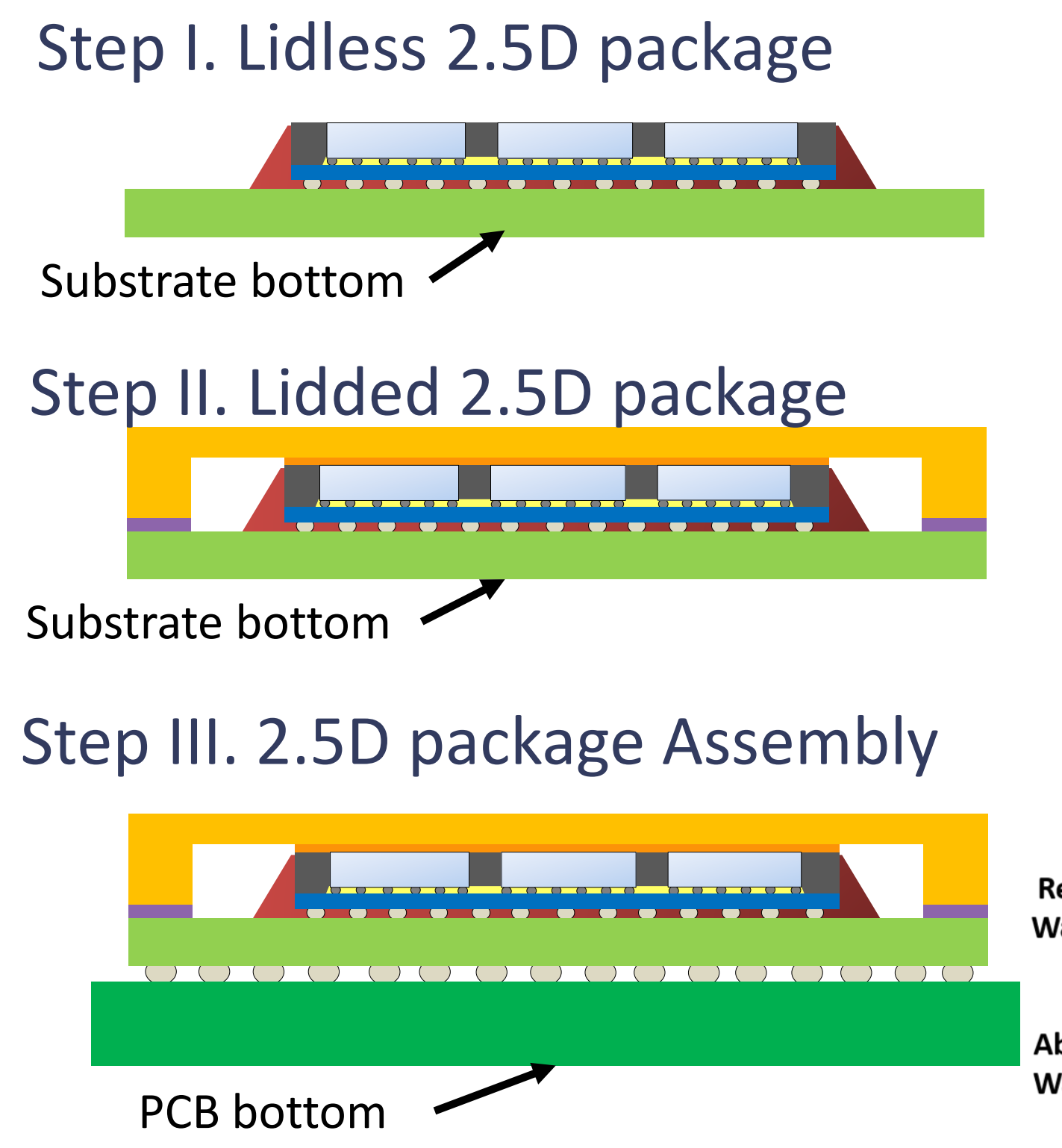


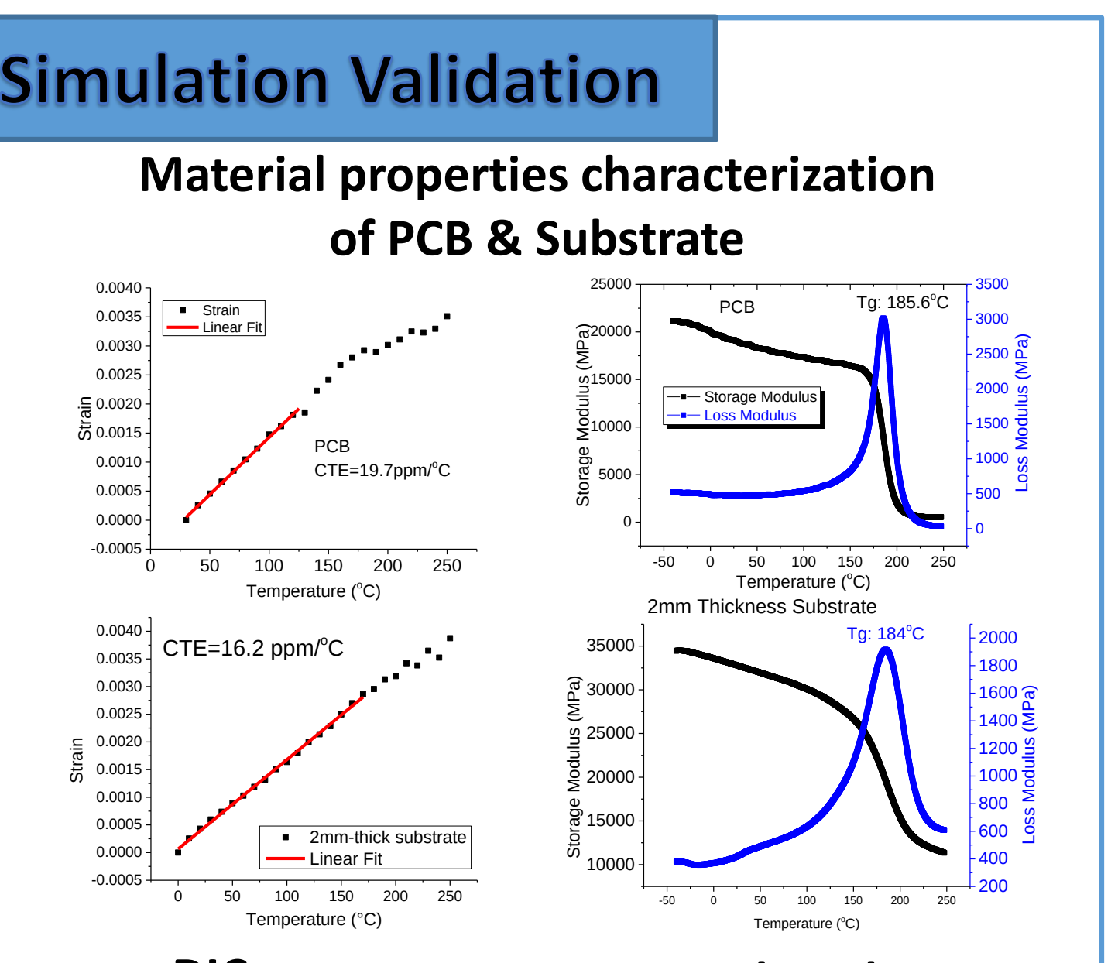
To perform a proper temperature mapping

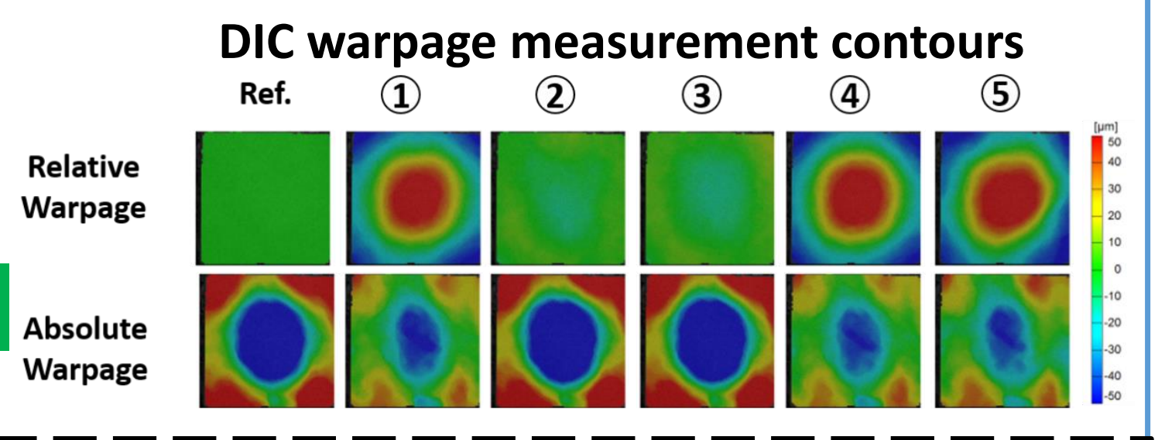
1. Finer CFD mesh than FE in solid zone
2. Discontinuous mesh in CFD model
3. Mapping at discrete time points (transient analysis)

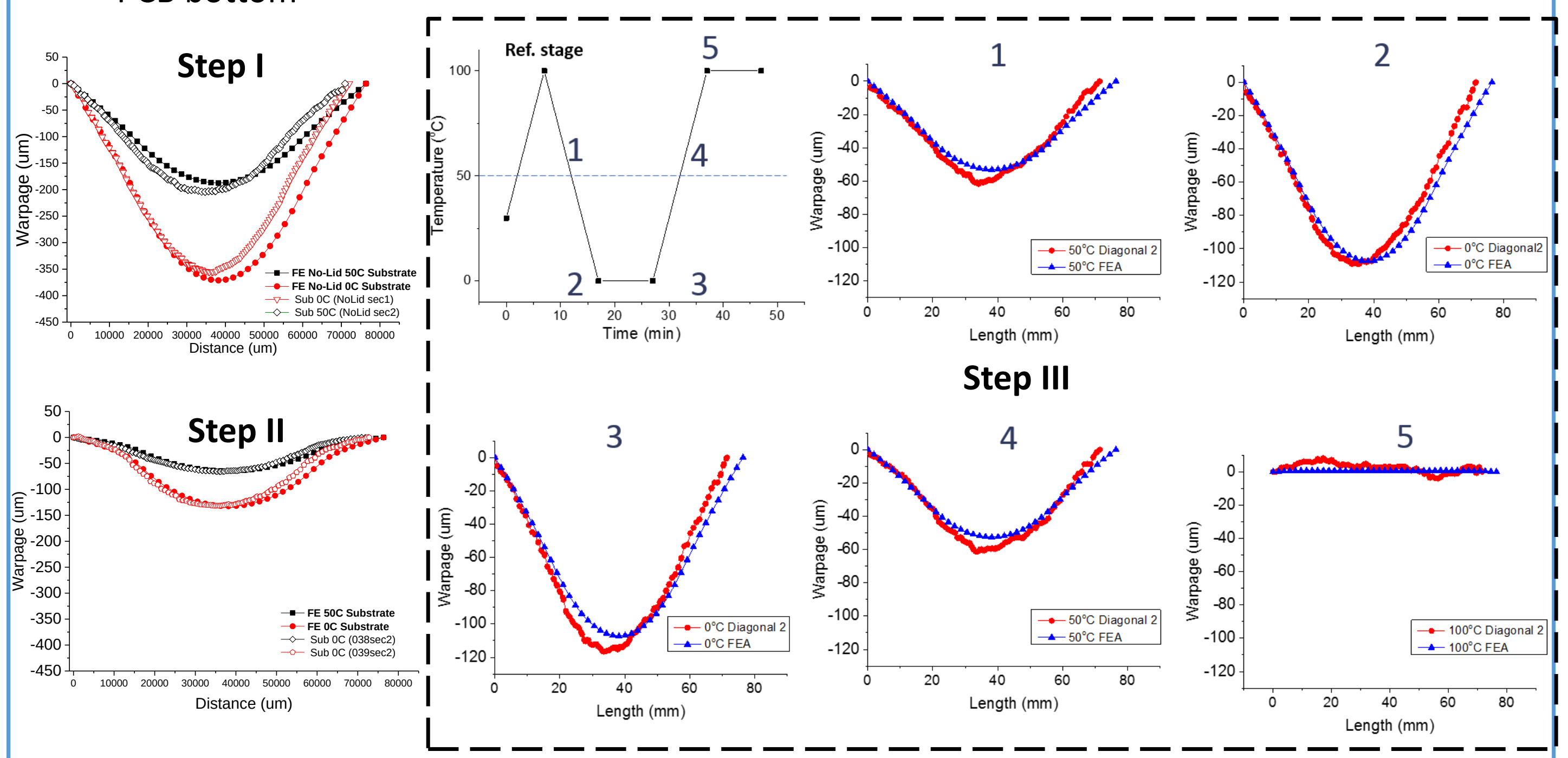
Using Convective Heat Transfer Coefficient (HTC)	Using Temperature Data Mapping
Pros • No data stability issue because temperature solution is solved by heat transfer physics in FEA. Easier implementation for quick assessment.	*Pros* • Nonuniform temperature distribution is transferred from CFD to FEA. No extra work is needed to divide surfaces.
Cons • Area dividing may be needed for surfaces having high temperature gradients. Results depend on HTC averaging.	*Cons* • To ensure data stability, finer mesh in solid zone of CFD is usually needed since temperature data are interpolated during mapping.

4. Structural Analysis & Multi-Step Simulation Validation



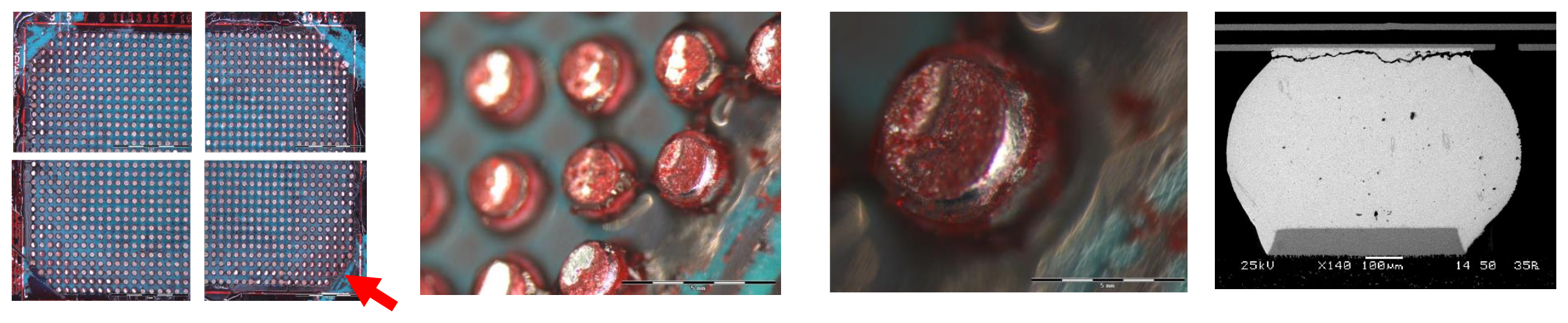


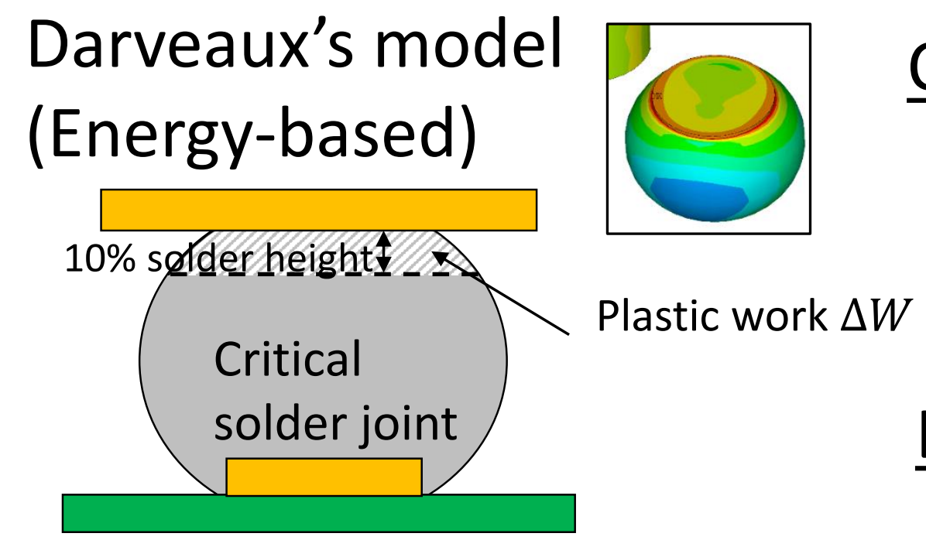




Discussion

Failure mode at critical solder joint in thermal cycling was investigated and fatigue life prediction was performed.



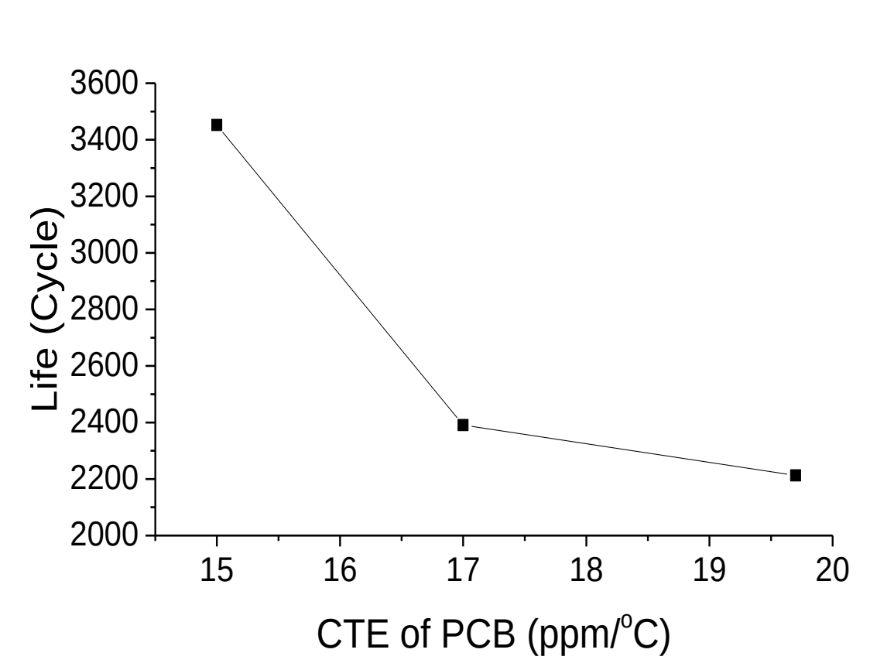


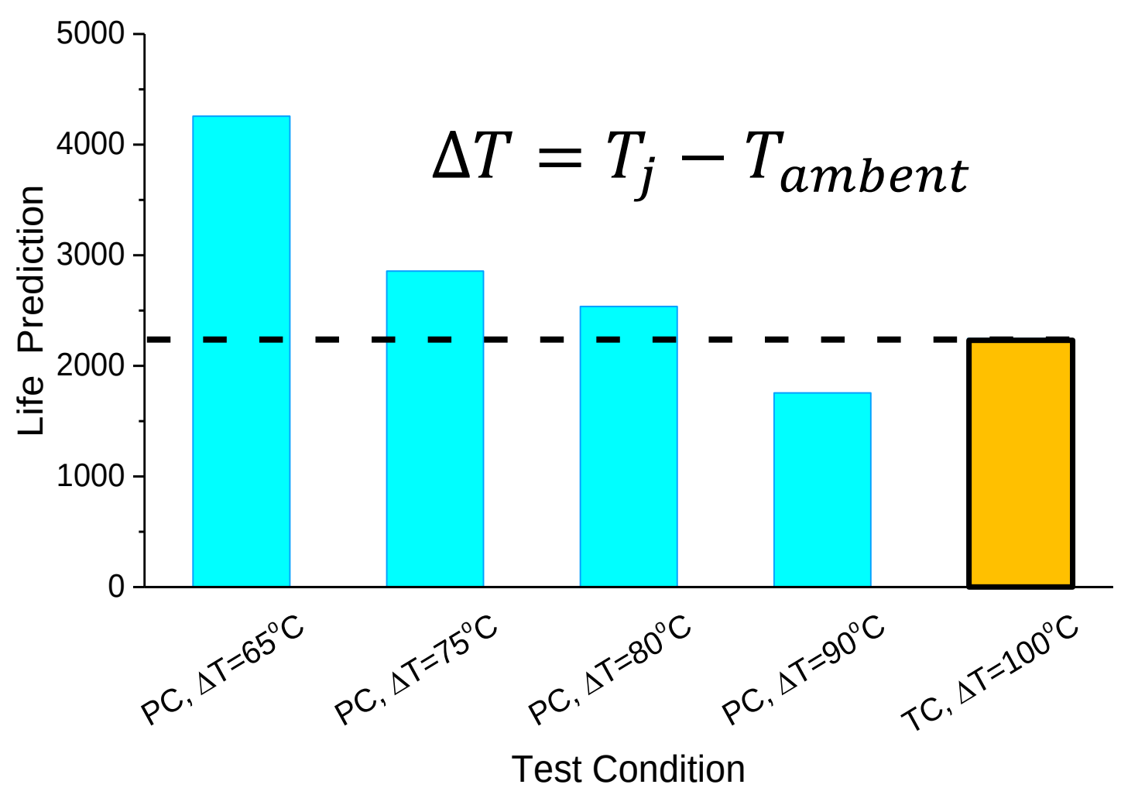
Crack initiation $N_0 = K_1(\Delta W_{ave})^{K_2}$

Crack growth $\frac{da}{dN} = K_3(\Delta W_{ave})^{K_4}$

Lifetime in cycle $N_f = N_0 + \frac{a}{da/dN}$

Lifetime test data (N50%, N63.2%, early failure etc.) of 2.5D package assembly in the past were used to determine constants ($K_1 \sim K_4$) above. Parametric study was performed regarding material selection to give suggestions on 2.5D package design for board-level reliability.





Conclusion

- Thermal-fluid-structural analysis method with temperature mapping was developed for life prediction of 2.5D packages in power cycling, offering assessment for actual use condition.
- High quality temperature mapping & multi-step validation were performed to establish trustworthy simulation models.