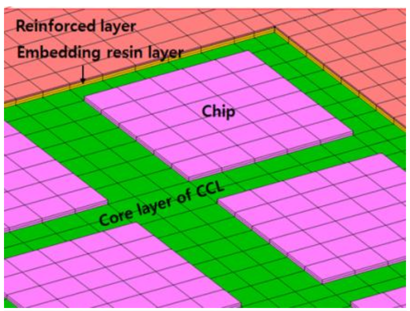
Warpage Optimization of Printed Circuit Boards with Embedded Active and Passive Components



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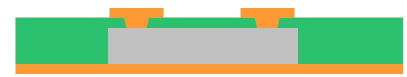
Outline

- **Introduction to chip embedding package and material**
- **Research results**
  - **- Background and scope**
  - **- R & D activities for simulation**
  - **- Warpage simulation**
- **Conclusion**
- **Appendix**
  - **- Feasibility test of new material**
  - **- Roadmap of new material**

Chip embedding package

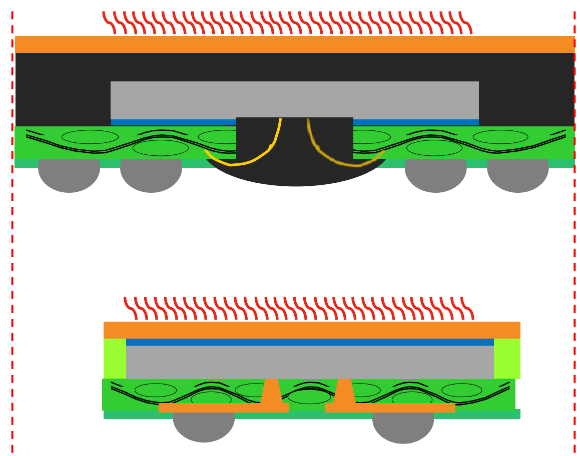
Chip with wires

Flip chip with bumps



Chip with vias

[1]



- **Driving forces**
  - **- Cost**
  - **- Electrical performance**
  - **- Thermal / Mechanical reliability**
  - **- Packaging density**

[1] Reference : ***QA Reliable Packaging Architecture for the Expansion of DRAM Capacity by Stacking Active-embedded Component , ITRI 2011***

Requirements for embedding materials

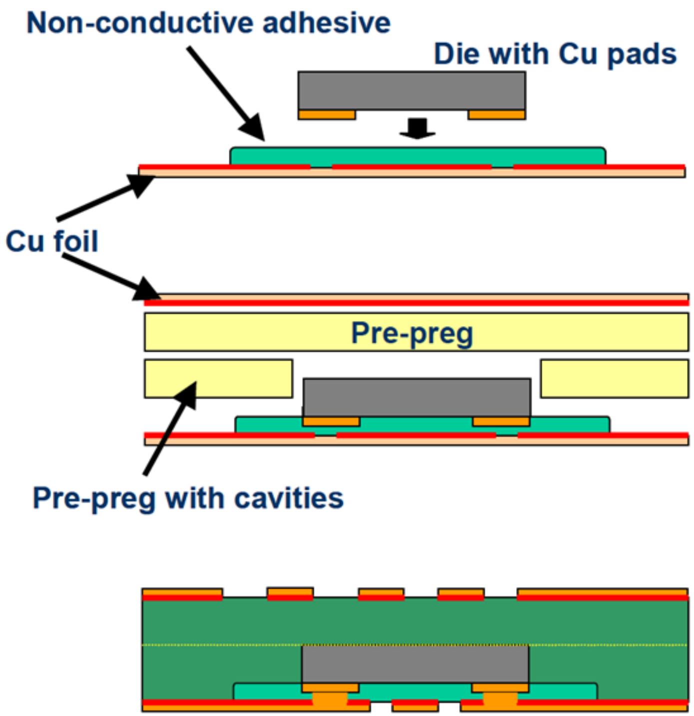
- **Processing**

  - Convenient handling
  - Void free
  - No damage of dies
  - Low warpage after pressing/laminating
  - Good leveling characteristics with different thicknesses of components
  - Suitable for fine pattern
  - Easy to mount SMD on a board
  - High yield

- **Material Properties**

  - High Tg, low CTE, high stiffness, low shrinkage
  - Dimensional stability, no cracks after TCT
  - Good adhesion on different surfaces (organic/inorganic/metal)
  - Melting flow for good wetting and embedding

Example for power application



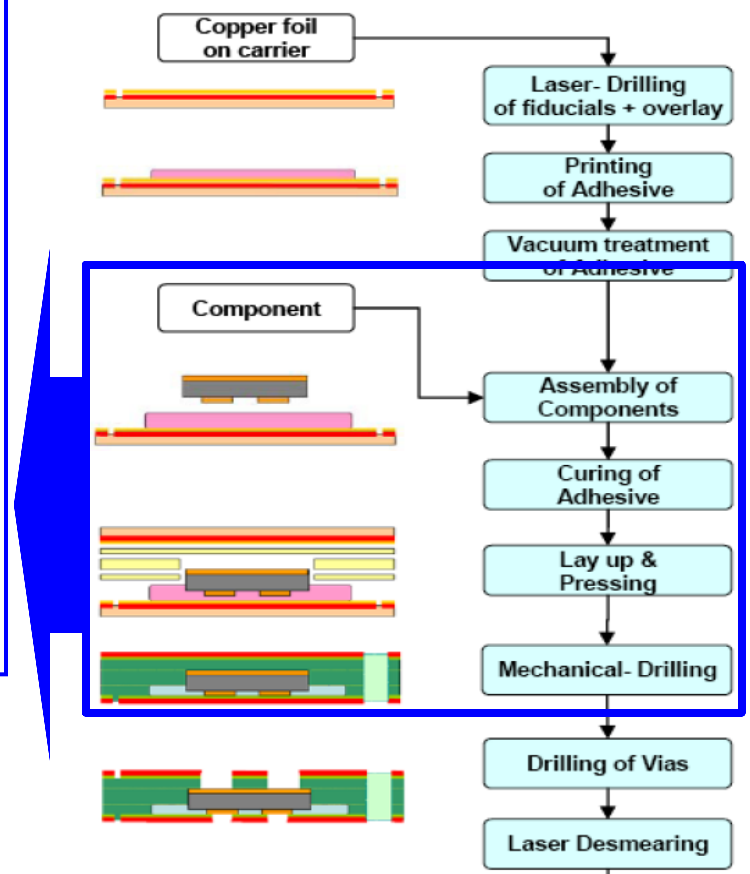
Bonding of thinned chips with Cu plating, on copper foils with laser drilled holes

Stacking of pre-cut pre-pregs with cavities over the bonded dies

Vaccuum lamination followed by microvia laser drilling and Cu plating

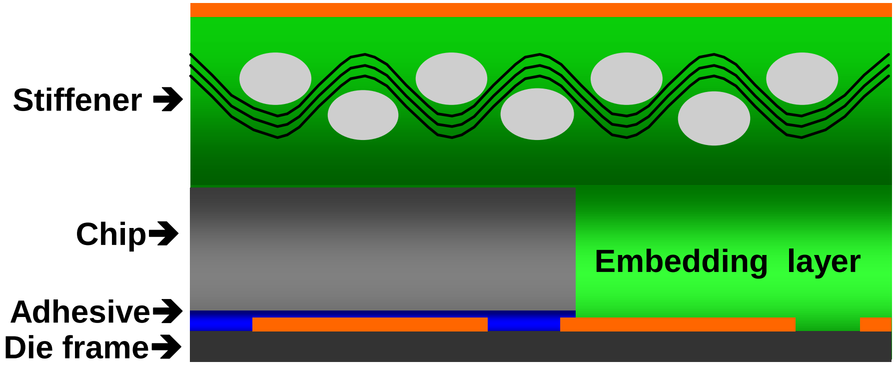
Figure 1 : Embedding technology face-down process flow.

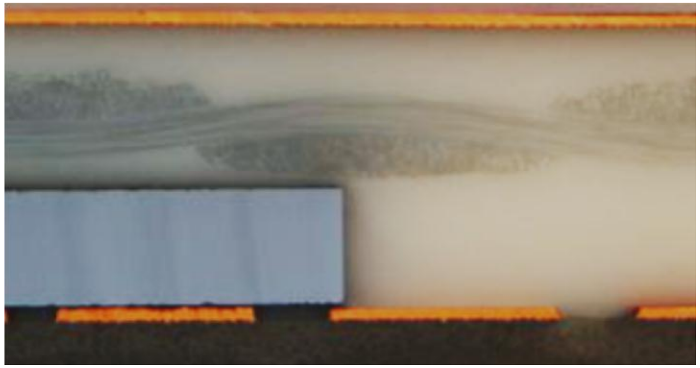
● Process flow



Reference : ***High density integration by embedding chips for reduced size modules and electronic systems , HEREMES 2010, Infineon, AT&S***

Structure of new embedding material



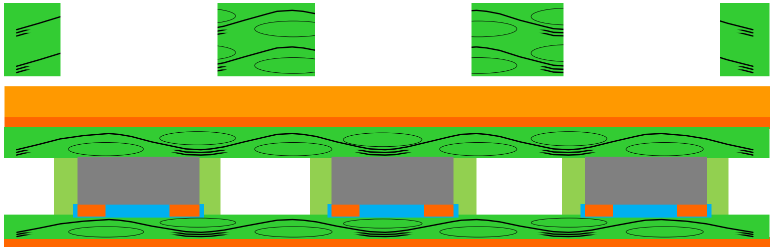


- **1st Layer : Glass reinforcement**
  - **CTE control, stiffness**
  - **Leveling, defined layer thickness above dies**

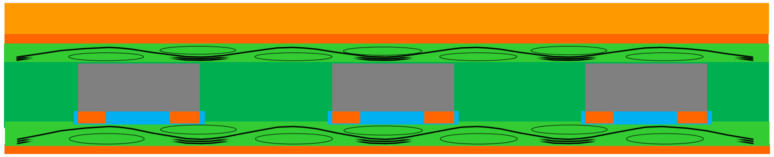
- **2nd Layer : Excess resin layer for encapsulation of components**
  - **Limit of thickness of chip: Depending on the design, up to 400 um**
  - **No voids and no contact of glass fibre to chips**
  - **No reliability failures caused by glass fiber protrusion**

Comparison of embedding process

- **Current process**



- **New process**



Reduction

- Number of materials
- Process steps
- Cost

Easier

- Handling
- Mounting SMD on the substrate

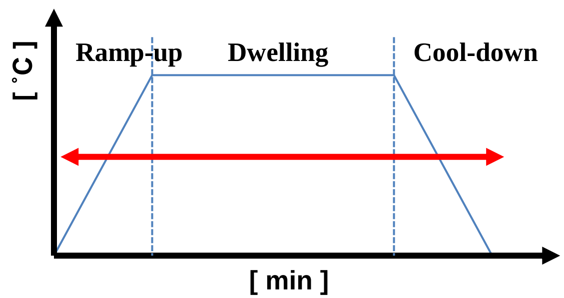
No!

- Cavity formation
- Voids due to solvent free manufacturing process of material
- Damage of chips
- Problem caused by glass fabric like a protrusion or chipping in the cavity

New simulation approach for warpage

● Conventional

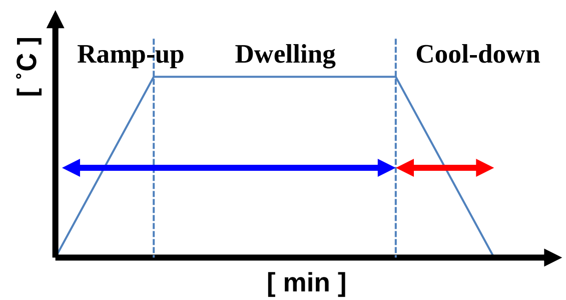
Input parameter for simulation
: Properties of cured materials



Material properties after curing

● New approach

Input parameter for simulation
: Properties of material during curing and after curing



Material properties after curing

Material properties during curing

*** Hypothesis**

The result of simulation is closer to reality if material properties during curing cycle are considered in addition to cured one.

Simulation approach for warpage

- **Activities for simulation**

- Definition of test layout Done

- Definition of key resin properties of interest Done

- Measurement of key resin properties over entire curing cycle Done

- Simulation of warpage during lamination and curing of resin Done

- Comparison of the simulated warpage with real physical samples using the same resins Open

- Finally simulation of warpage and reliability under conditions of reliability testing Open

Warpage mechanism during curing(1/4)

- **Cure-Thermal-Mechanically coupled analysis**
  - ✓ **Cure-thermal coupled analysis can be expressed as:**

$$C(T)\dot{T}+K(T)T = Q + Q^{I} + Q^{F} + Q^{C}$$

$C(T)$: The temperature – dependent specific heat

$K(T)$: The temperature – dependent thermal conductivity

T : The nodal temperature vector

$\dot{T}$: The time derivative of the temperature vector

Q : The external heat flux vector

Q^{I} : The heat flux vector due to plastic work

Q^{F} : The heat generated due to friction

Q^{C} : The heat generated due to curing

Warpage mechanism during curing(2/4)

- **Cure kinetics**
  - ✓ In a curing analysis, the cure rate is calculated for each time step. Assuming that the cure rate is defined as the function of the degree of cure and temperature of :

$$\frac{d\alpha}{dt} = f(\alpha, T)$$

  - ✓ The time integration of the degree of cure is done using backward Euler method:

$$\alpha_n{}^i = \Delta t \cdot f\left(\alpha_n{}^{i-1}, T\right) + \alpha_{n-1}$$

i : *iteration number for cure*
n : *current increment number*
$n-1$: *previous increment number*
f : *function defined by cure kinetics model*
Δt : *time step size of the increment*

Warpage mechanism during curing(3/4)

- **Cure Shrinkage Strain**
  - ✓ **The cure shrinkage strain is calculated according to the volumetric shrinkage due to curing process.**
  - ✓ The resin degree of cure shrinkage is defined as :

$$\alpha_S = \frac{V_r^{\ S}}{V_r^{\ S\infty}}$$

α_S : *The resin degree of cure shrinkage*

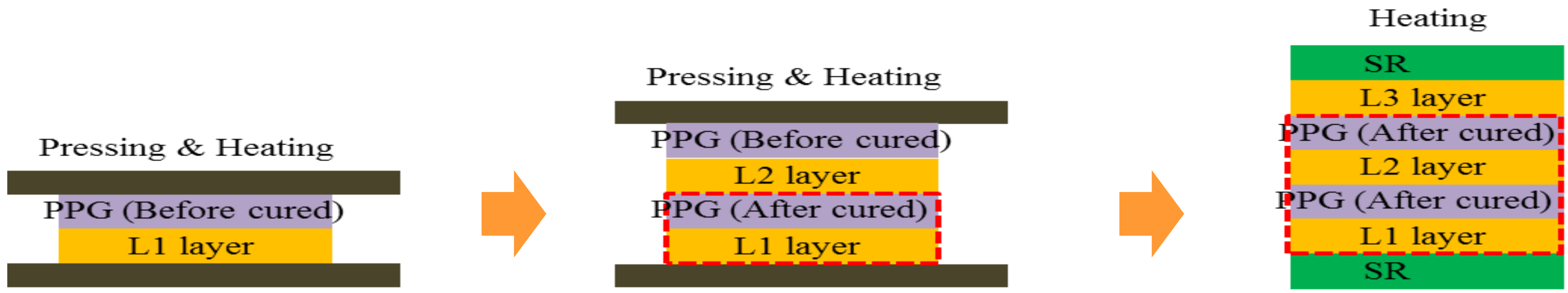
$V_r^{\ S}$: *The volumetric cure shrinkage*

$V_r^{\ S\infty}$: *The maximum volumetric cure shrinkage*

  - ✓ The resin degree of cure shrinkage **calculates the cure shrinkage strain** :

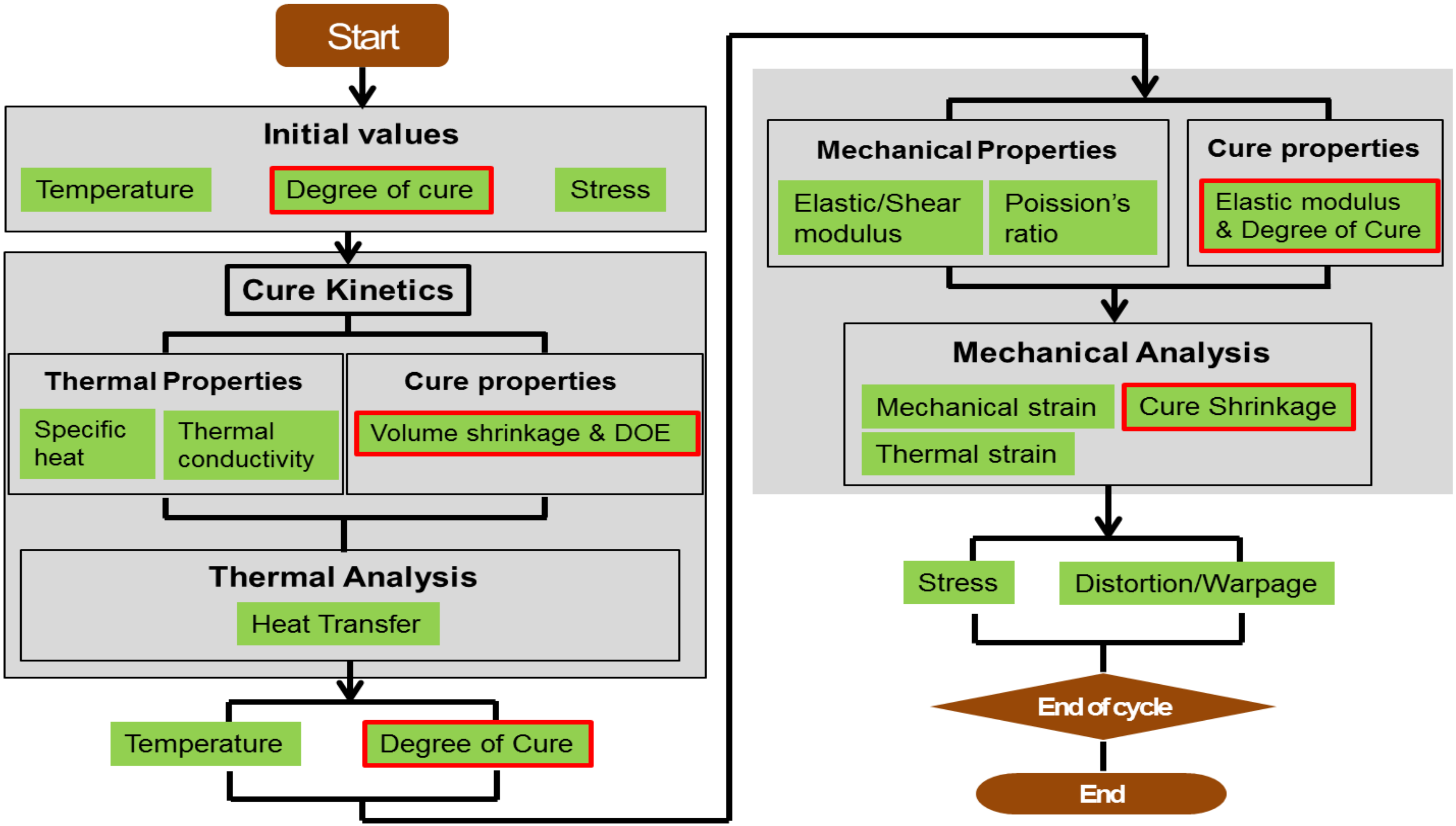
$$\varepsilon_r^{\ S} = \left(1 - V_r^{\ S}\right)\left(1 - V_r^{\ S}\right)^{\frac{1}{3}} - 1$$

Warpage mechanism during lamination process



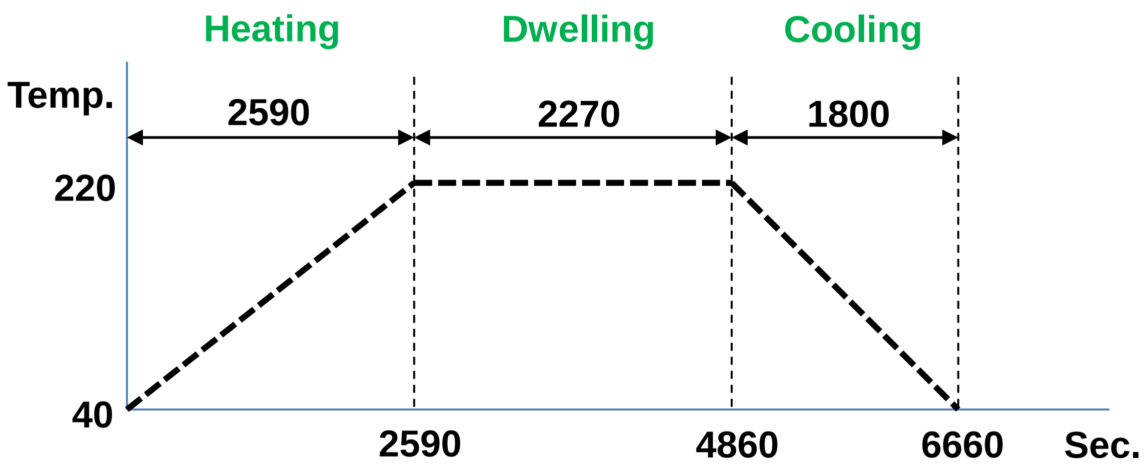
Step	warpage	Stress
1st. step	• Displacement to the xy-plane is happened by shrinkage of PPG • Displacement to the thickness direction is restraint by pressing force even though PPG shrinkage happened.	• Stress is occurred by PPG shrinkage and deformation restrain of substrate to the thickness direction
2nd. step	• Displacement to the x-direction and y-direction increases after end of 2nd. step • Displacement to the z-direction little changes. • Warpage is affected by PPG shrinkage and deformation restrain of substrate to the thickness direction	• Stress increased after end of 2nd. step by PPG shrinkage and deformation restrain of substrate to the thickness direction
3rd. Step **(Warpage to Z-direction)**	• Displacement to the x-direction and y-direction decreases after end of 3rd. step by much deformation to the thickness direction. • Displacement to the z-direction greatly increases because of unrestraint boundary condition.	• Stress is a little released by large deformation to the thickness direction. • Stress is not perfectly disappeared because PPG material was fully cured during the 1st. and 2nd. lamination process before stress released

Simulation approach for warpage(1/2)



Simulation approach for warpage(2/2)

● **Curing profile**



1st. Analysis during heating period

Results of 1st analysis were used as intitial condition for 2nd analysis

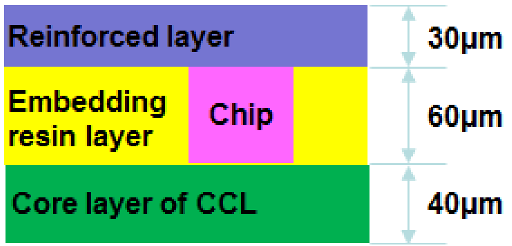
2nd. Analysis during dwelling period

Results of 2nd analysis were used as intitial condition for 3rd analysis

3rd. Analysis during cooling period

Simulation cases

- **9 simulation cases for the material combination**



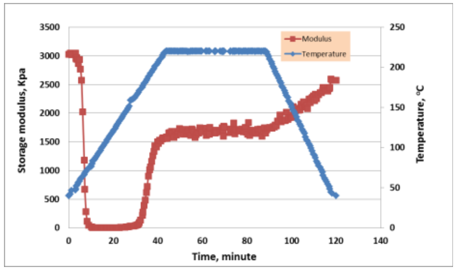
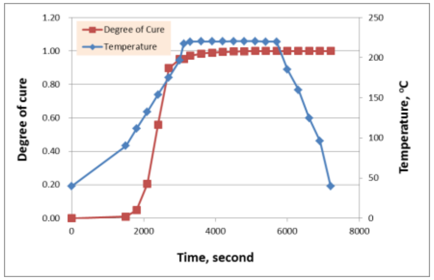
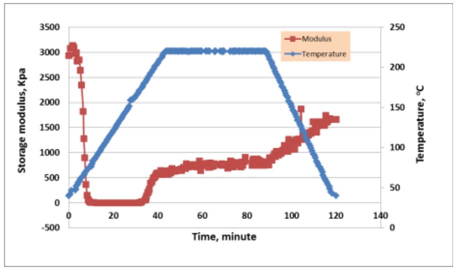
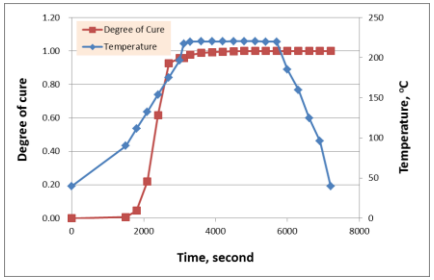
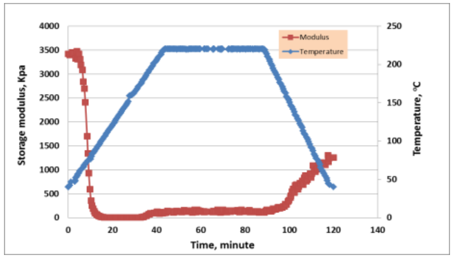
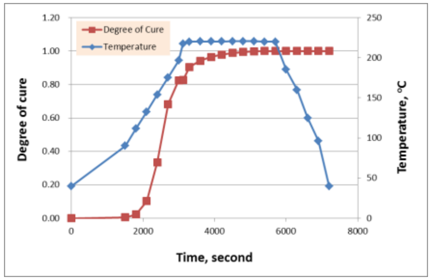
No.	Reinforced layer	Embedding resin layer	Material
1	A(Reinforced) High modulus, Low CTE	High modulus, Low CTE	A
2		Middle modulus, Middle CTE	B
3		Low modulus, High CTE	C
4	B(Reinforced) Middle modulus, Middle CTE	High modulus, Low CTE	A
5		Middle modulus, Middle CTE	B
6		Low modulus, High CTE	C
7	C(Reinforced) Low modulus, High CTE	High modulus, Low CTE	A
8		Middle modulus, Middle CTE	B
9		Low modulus, High CTE	C

Resin key parameters

Layer	Item	Comment
Reinforced layer	**Storage modulus [GPa]**	**Measured on cured sample by DMA**
	CTE (z-direction) [ppm/K]	**Measured on cured sample by TMA**
Resin only layer	**Heat conductivity [W/mK]**	**Measured on cured sample**
	Storage modulus [GPa]	**Determined with rheometer over the entire curing cycle**
	CTE [ppm/K]	**Determined from the volume change using PVT method over the entire curing cycle**
	Density [g/cm^3]	**Determined on uncured material**

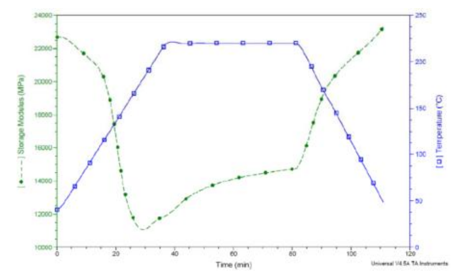
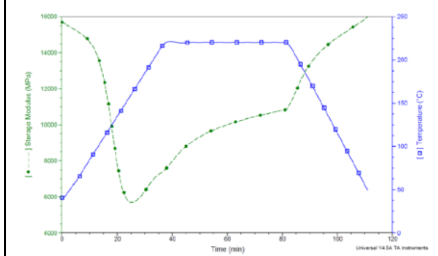
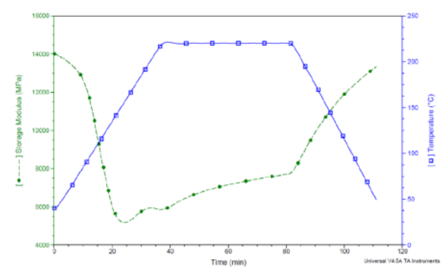
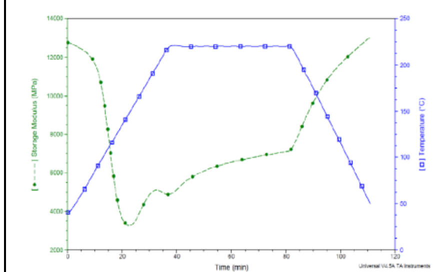
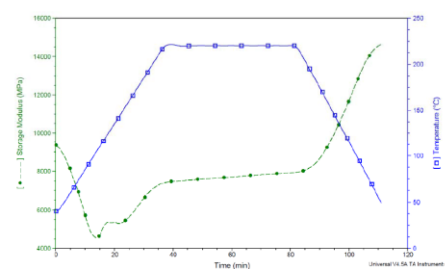
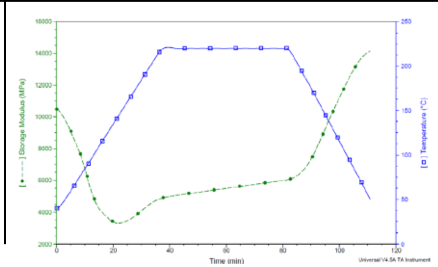
Properties of the embedding materials

- **Isotropic characteristics**

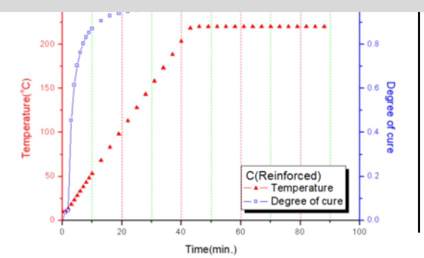
Material	Modulus	Degree of cure
A		
B		
C		

Properties of the embedding materials

- **Anisotropic characteristics**

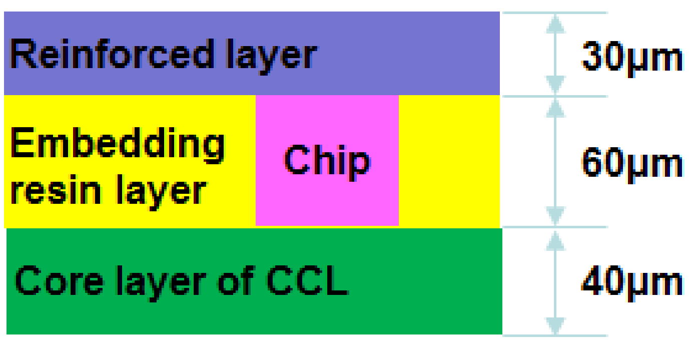
Material	Modulus x-direction	Modulus y-direction
A Reinforced		
B Reinforced		
C Reinforced		

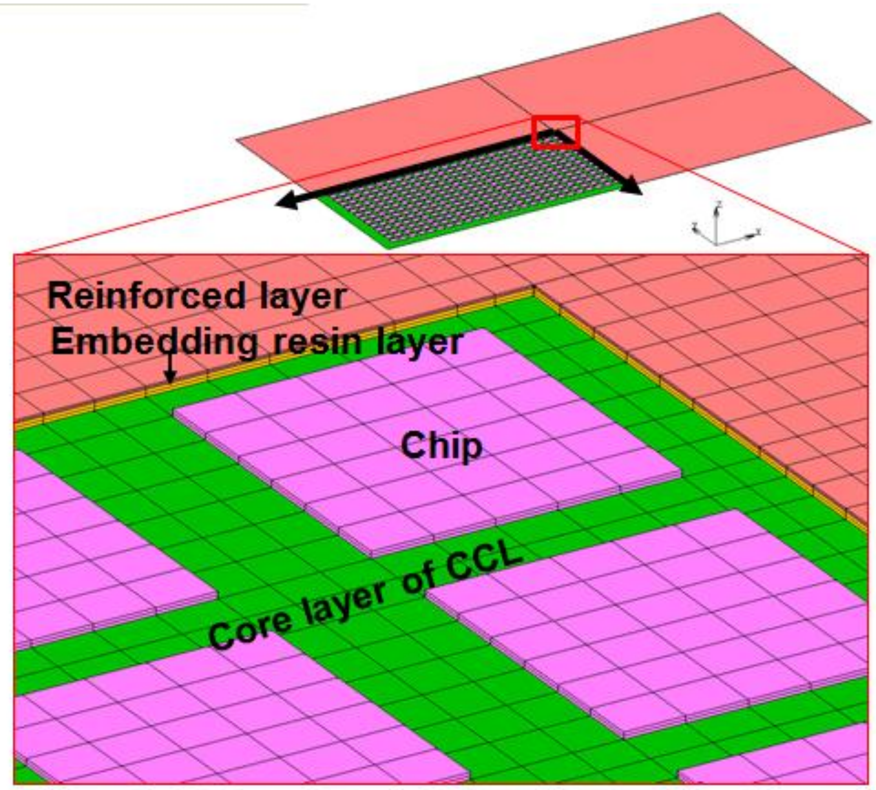
The modulus to y-direction of a reinforced layers were input as the modulus to z-direction. Because it is very difficult to obtain the modulus to z-direction by measuring method. Also, the modulus to z-direction is not major parameter to warpage rather than that to x,y direction.



Finite element modeling

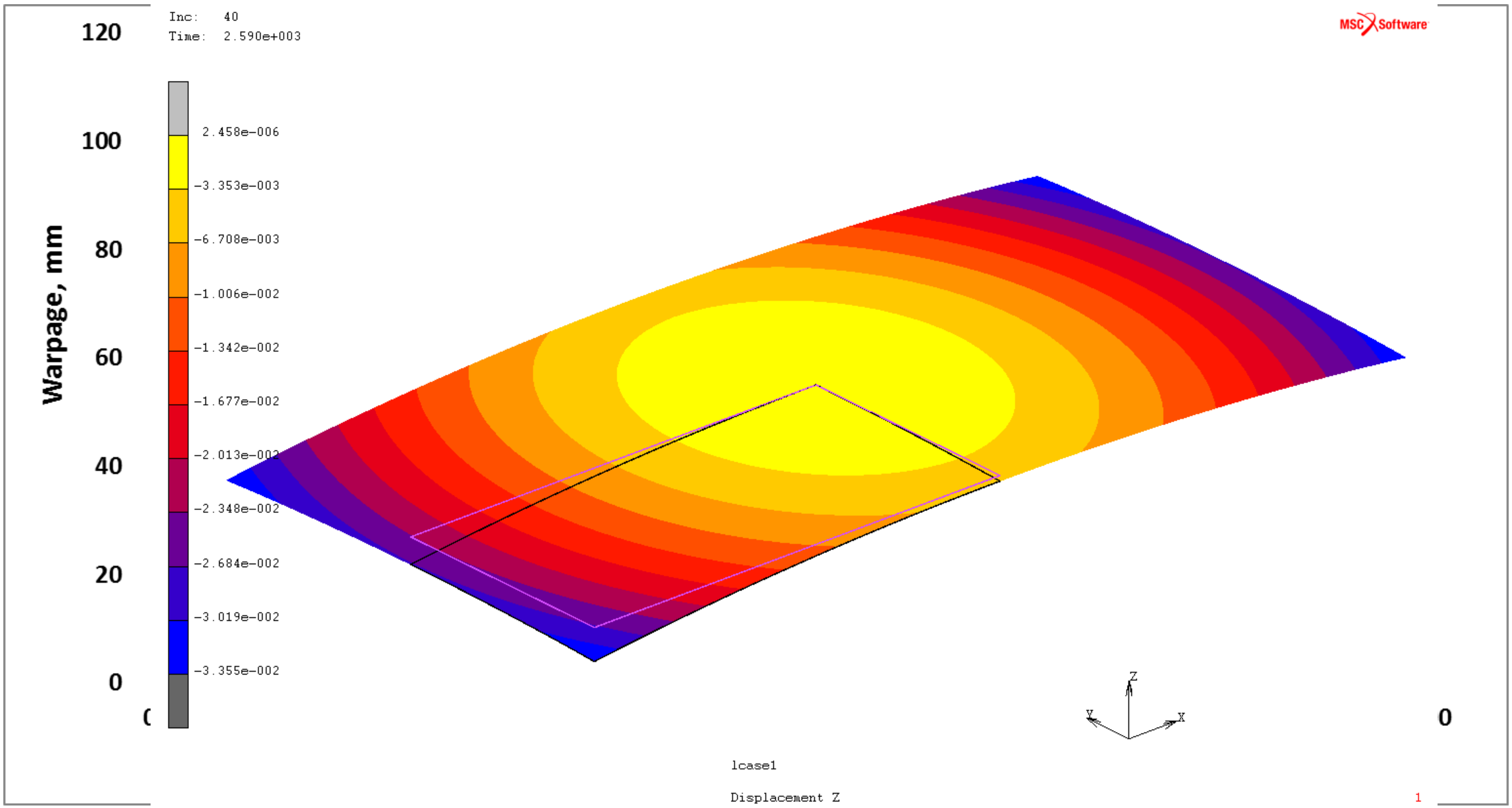
- ¼ modeling for symmetric goemetry





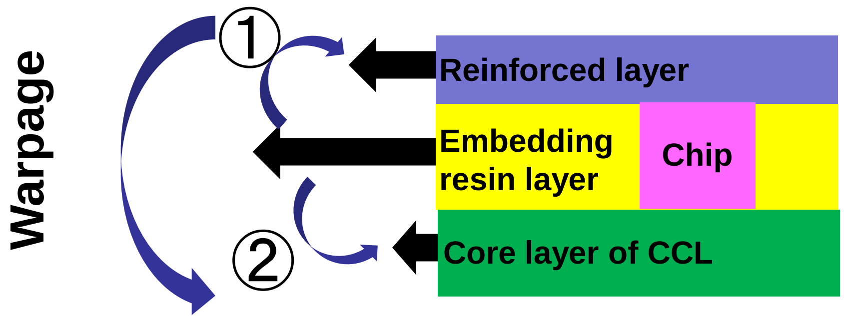
Warpage simulation results

- **Warpage after curing**



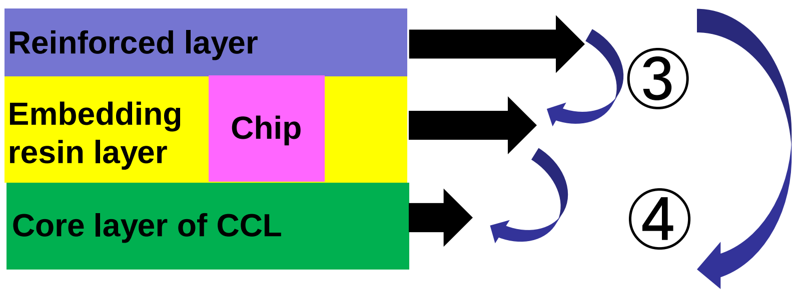
Warpage analysis

Combination for the maximum warpage
Reinforced: Resin C / Embedding: Resin A



- Warpage pattern was smile because CTE of the 1st layer and 2nd layer were larger than that CTE of core
- Minimum warpage predicted with the lowest CTE of 1st layer and the highest CTE of 2nd layer
- ① and ② were interfered each other. These restraint warpage.

Combination for minimum warpage
Reinforced: Resin B / Embedding: Resin C



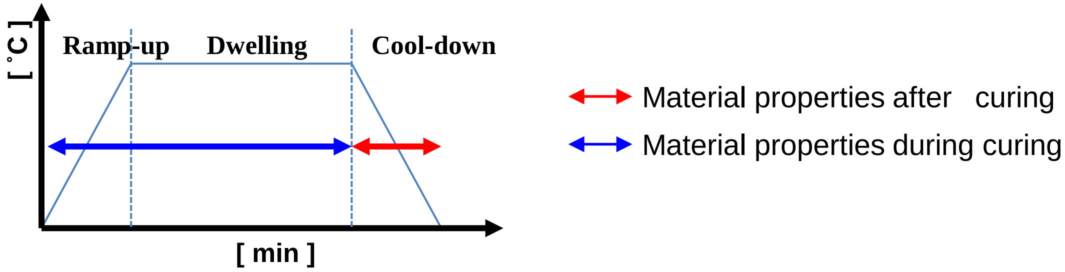
- Warpage pattern was smile because CTE of the 1st layer and 2nd layer were larger than CTE of core
- Maximum warpage predicted with the highest CTE of 1st layer and the lowest CTE of 2nd layer
- ③ and ④ contributed to make warpage to same smile direction. These amplified warpage.

Conclusion

- **Importance of the properties during curing**

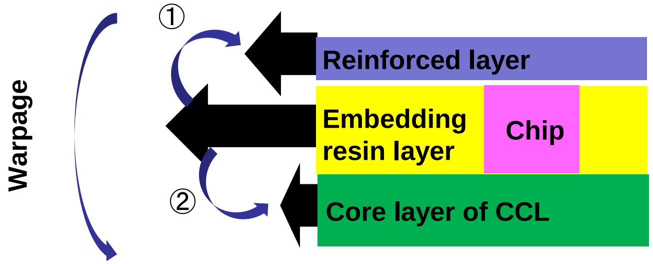
- Curing analysis has to be carried in a PCB level to improve understanding warpage mechanism. Specially it is very important in a laminating process due to cure shrinkage of PPG as a function of degree of cure.

- Therefore, it is strongly demanded that curing properties should be measured in material maker.



- **Embedding material combination**

- Large deformation at the embedding resin layer is more effective to reduce warpage of the embedded package.



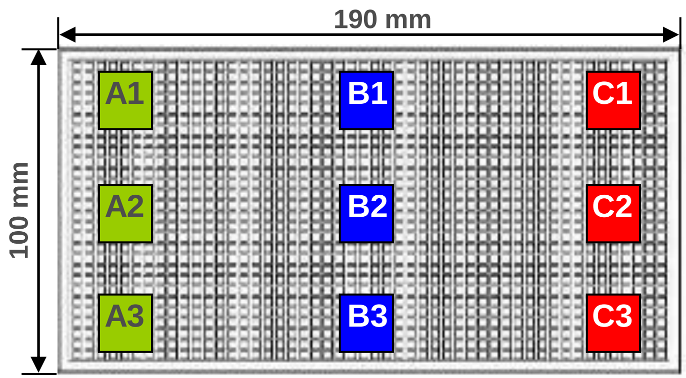
very much for your attention.

Appendix

- Thickness distribution of new material
- Void free of new material
- Embedding performance for thick components
- Current capability of new material
- Roadmap of new material

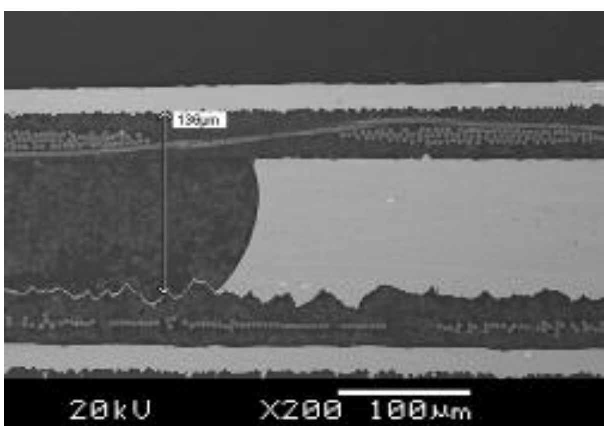
Thickness distribution of new material

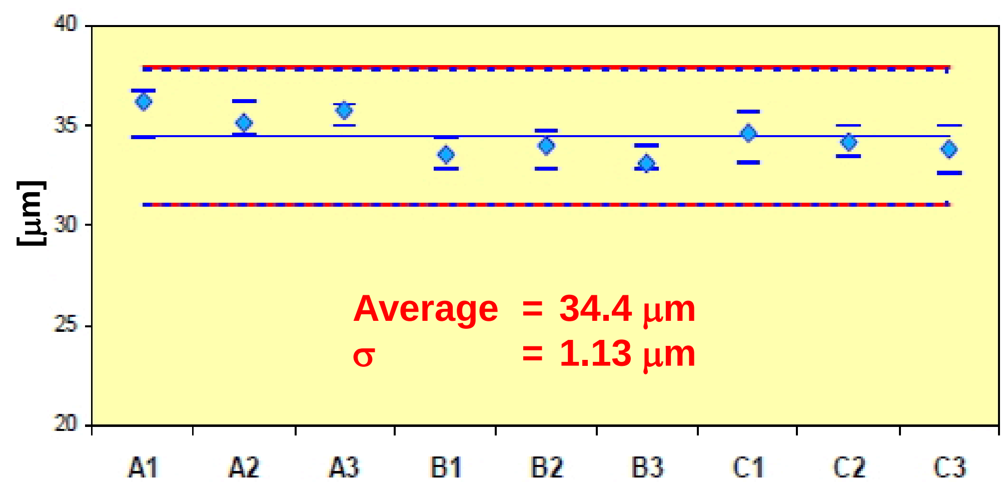
● Test vehicle



- 190 mm x 100 mm
- Number of dies (Cu dummy) : 50 x 28
- Die thickness (Cu dummy) : 100 µm
- Dielectric distance on dies : ca. 35 µm

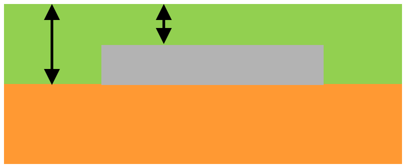
● Dielectric thickness on dies

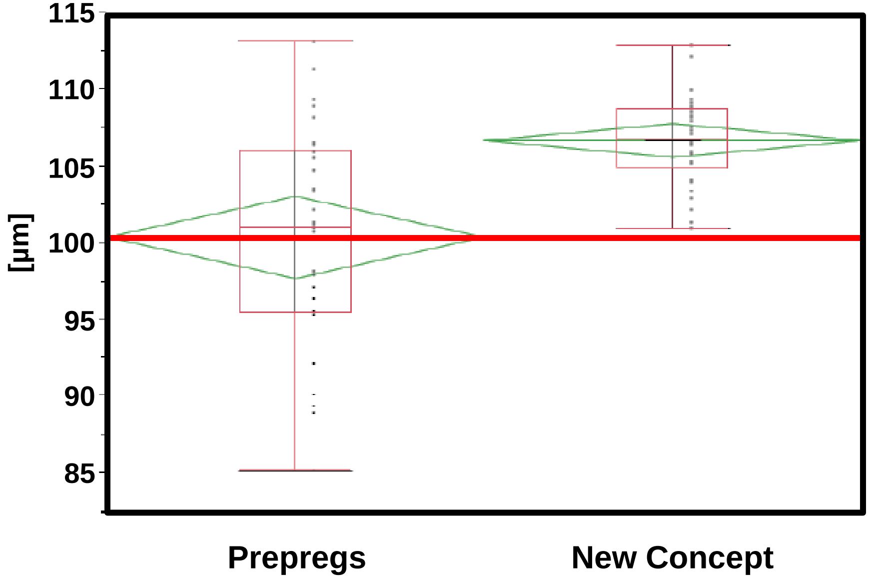


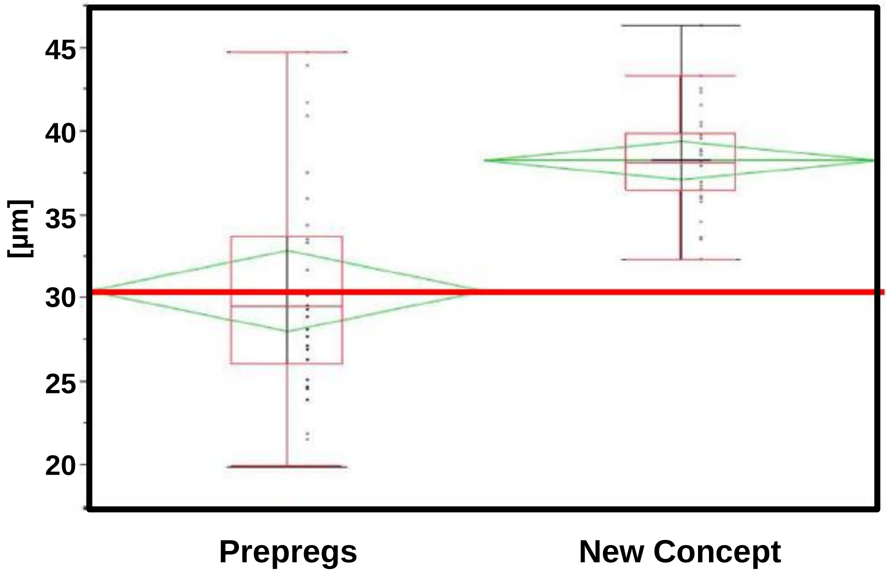


Thickness distribution of new material

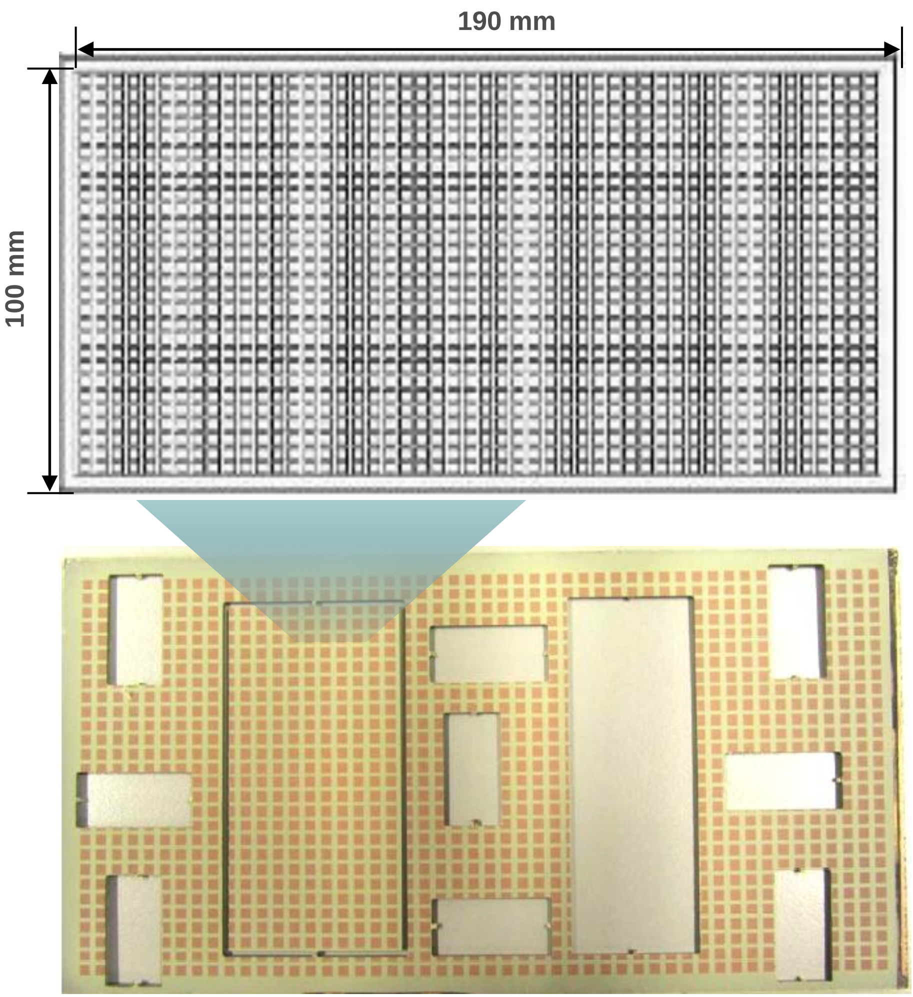
- Comparison with prepregs

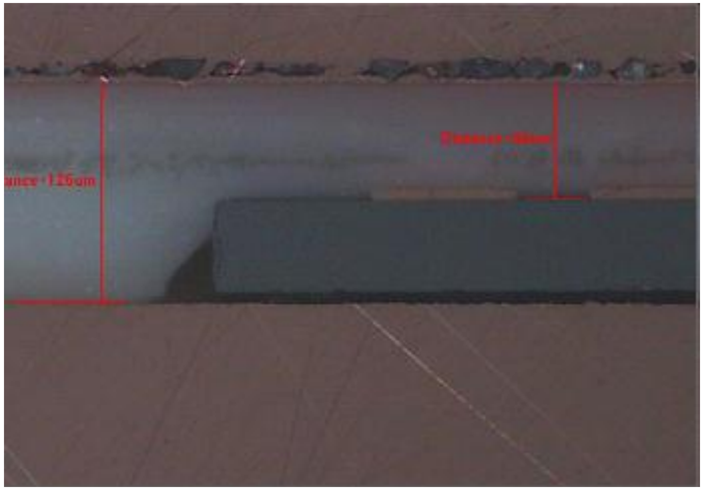






Void free of new material





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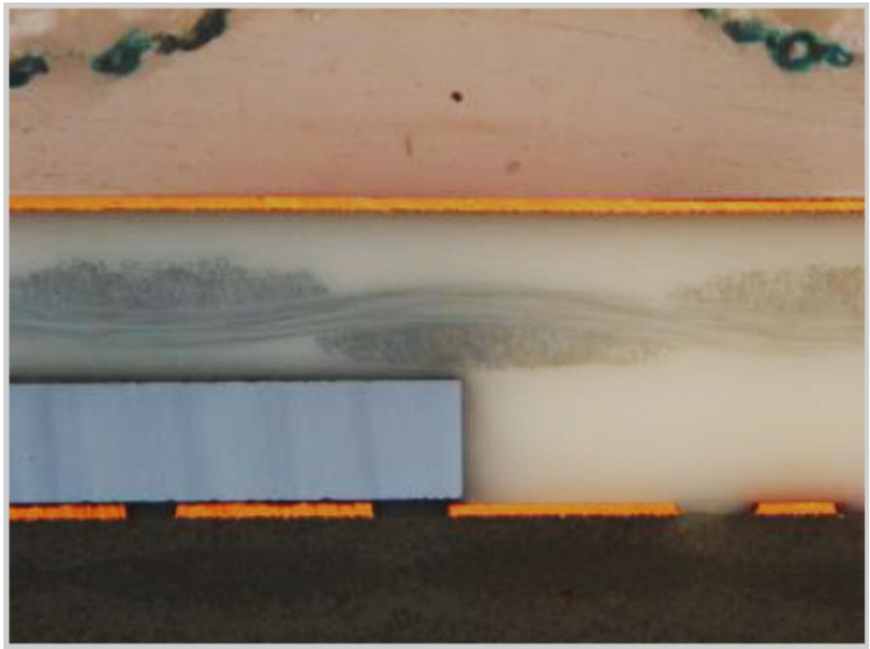
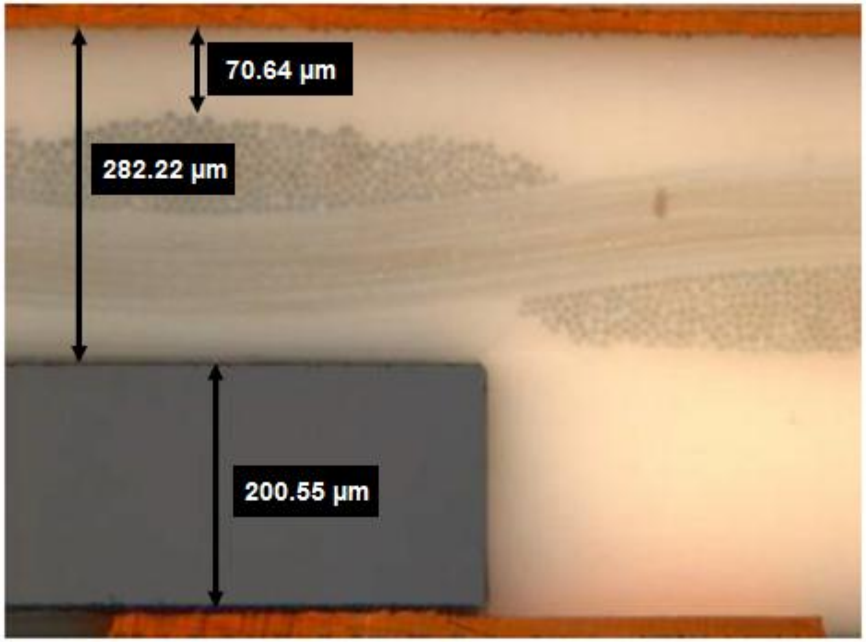
Embedding performance for thick components

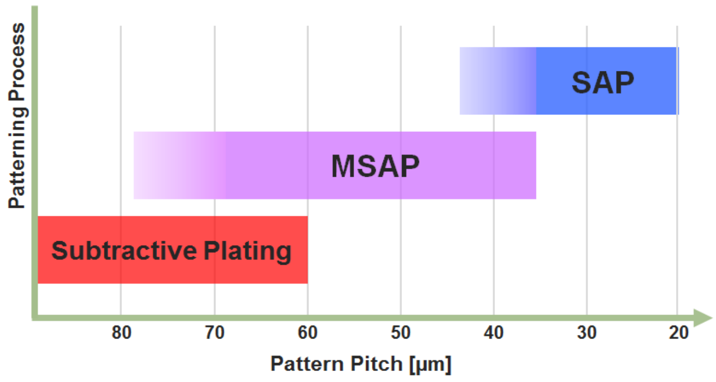
- **Dies of 200 µm thickness in Lab. trial**



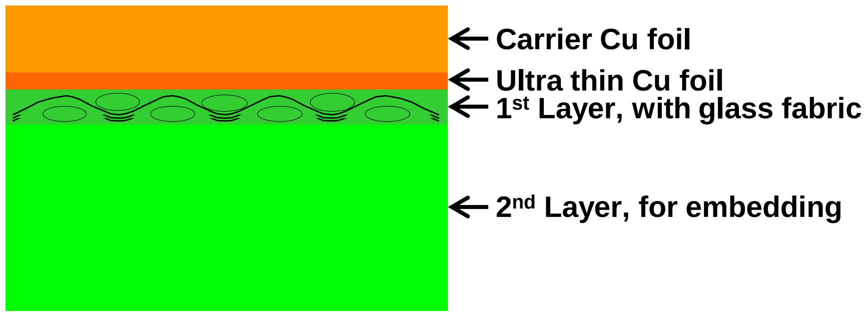


Current capability of new material

● **Pattern pitch of process**



● **Structure of embedding material**



Subtractive	(A)MSAP	SAP
Cu foil 18 to 140 μm in thickness	Ultrathin and low profile Cu foil with carrier	Under development

Dielectric Thickness [μm]		Under development
1st layer	25 to 80	Over 80 μm in sampling stage
2nd layer	10 to 150	Up to 400 μm in sampling stage

Roadmap of new material

Embedding material

		2012	2013	2014	2015	2016
Tg [˚C]	by DMA	220	> 230	> 250	> 250	> 250
CTE [ppm/K]	w/o G/F	35	< 30	25	17	17
	w G/F	14	< 12	< 11	< 10	< 10
Patterning Capability		Sub. MSAP	Sub. (M)SAP Buried P	Sub. (M)SAP Buried P	Sub. (M)SAP Buried P	Sub. (M)SAP Buried P
Dk	w/o G/F	-	-	< 3.0	< 3.0	< 3.0
Df	at 5 GHz	-	-	0.010	0.010	0.010
Thickness [μm]	1st Layer	25 ~ 80	25 ~ 80	25 ~ 100	25 ~ 110	25 ~ 120
	2nd Layer	20 ~ 180	20 ~ 180	20 ~ 200	20 ~ 300	20 ~ 350