Reliability Simulation with the Finite Element Analysis (FEA) of Redistribution Layer in Fan-out Wafer Level Packaging

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Outline

1. Introduction of my study
2. Examining Critical Energy Release Rate ($\mathcal{G}c$)
3. Analyzing Energy Release Rate ($\mathcal{G}$) by FEA
4. Discussion of Delamination Possibility ($\mathcal{G}/\mathcal{G}c$)
5. Conclusion of my results

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Introduction

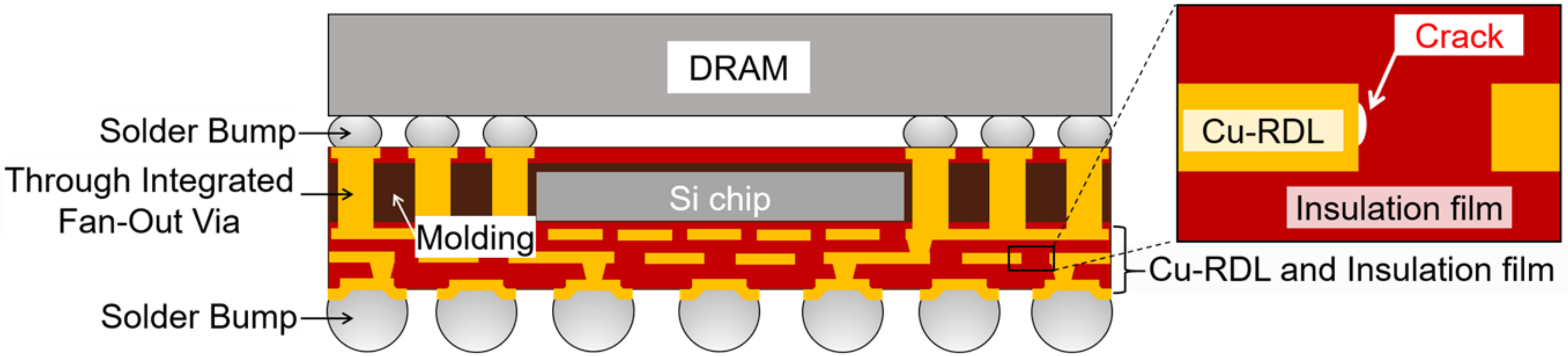

Fig.1 Fan-out PoP Package Illustration

Demand

- Smaller / Thinner
- High reliability
- Low cost

Solution

- Choosing best material
- Suitable structure
- Making R&D efficient

This Work

【 $\mathcal{G}c$ 】

Critical Energy Release Rate

①Peel test / Tensile test

②Creating master curve

③Calculating $\mathcal{G}c$

[Experiment]

【 $\mathcal{G}$ 】

Energy Release Rate

①Model / Temp. profile

②Simulation by FEA

③Calculating $\mathcal{G}$

[Simulation]

【Normalizing】

$\mathcal{G}/\mathcal{G}c$

; ≧1.0 ⇒ Delamination occur

; <1.0 ⇒ the larger value is, the higher possibility of delamination

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Method of Calculation

Critical Energy Release Rate ($\mathcal{G}c$)ref)

$$\underbrace{dU_{\mathrm{ext}}}_{\text{External workload}} = \underbrace{dU_{\mathrm{t}} + dU_{\mathrm{db}}}_{\text{Deformation energy}} + \underbrace{b\,\mathcal{G}_{\mathrm{c}}\,da}_{\text{Delamination energy}}$$

$$\mathcal{G}_c = \frac{P}{b}\left(1+\varepsilon_{\mathrm{a}} - \cos\theta\right) - \underbrace{h\int_0^{\varepsilon_a} \sigma \cdot d\varepsilon}_{\text{Tensile deformation}} - \underbrace{\frac{1}{2}\left(E\varepsilon_{\mathrm{y}}^2 h\right)\cdot f_1(k_0)}_{\text{Bonding deformation}}$$

Obtained from peel test

Obtained from tensile test

$$k_0 = \theta_0 \cdot \frac{3}{4\varepsilon_{\mathrm{y}}}$$

ref). A.J. Kinloch et al., “The peeling of flexible laminates”, *International Journal of Fracture*, Vol. 66, No. 1, (1994), pp. 45-70.

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Peel Test

$$\mathcal{G}_c = \boxed{\frac{P}{b}\left(1+\varepsilon_a - \cos\theta\right)} - h\int_0^{\varepsilon_a}\sigma\cdot d\varepsilon - \frac{1}{2}\left(E\varepsilon_y^2 h\right)\cdot f_1\left(k_0\right)$$

Obtained from Peel Test

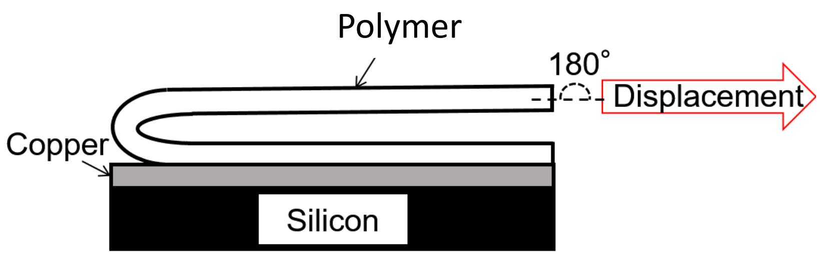


Fig.2 Illustration of Peel Test Specimen

P: Delamination load
θ: Peel angle
ε_a: Strain
b: Film width

Table.1 Condition of Peel Test

Control system	Displacement control
Peel angle [degree]	180
Displacement rate [mm/s]	0.002 / 0.017 / 0.17 / 1.7
Temperature [K]	298 / 348 / 398

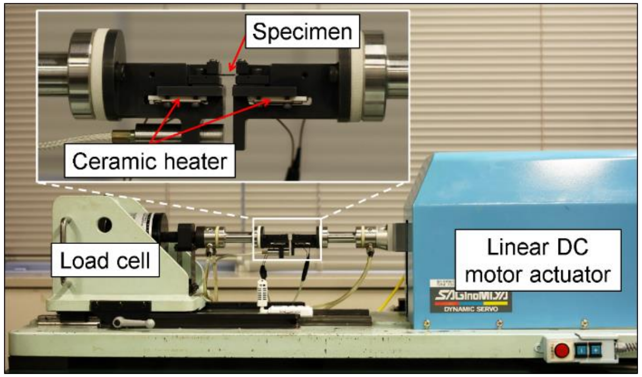


Fig.3 Peel Testing Machine

Tensile Test

$$\mathcal{G}_C = \frac{P}{b}(1+\varepsilon_a - \cos\theta) \underbrace{- \boxed{h\int_0^{\varepsilon_a} \sigma \cdot d\varepsilon} - \boxed{\frac{1}{2}\left(E\varepsilon_y^2 h\right)\cdot f_1(k_0)}}_{\text{Obtained from tensile test}}$$

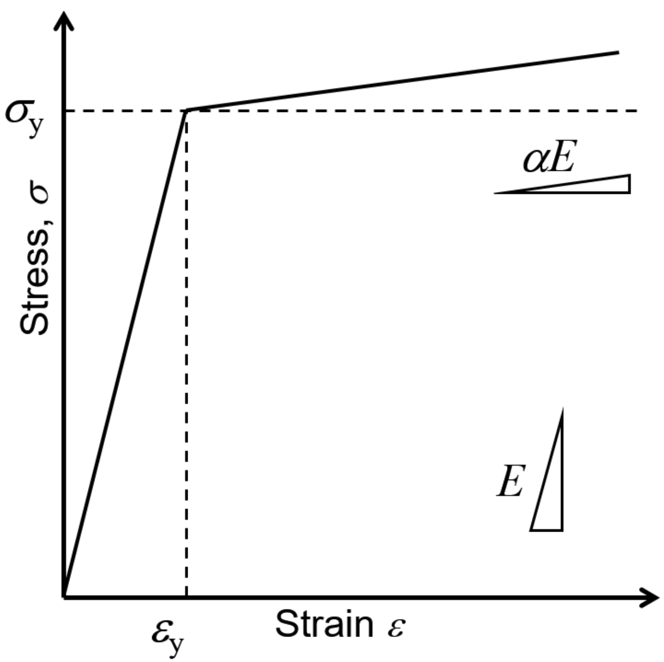


Fig.4 Stress-strain Curve

ε_y: Yield strain σ: Stress
E: Elastic modulus h: Film thickness
α: Strain hardening coefficient

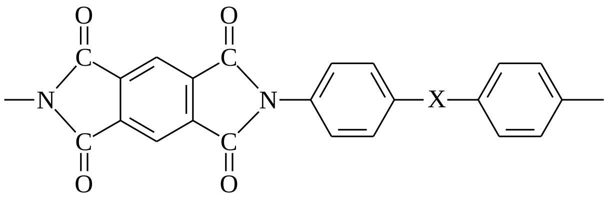
Table.2 Condition of Tensile Test

Control system	Displacement control
Displacement rate [mm/s]	0.002 / 0.017 / 0.17 / 1.7
Temperature [K]	298 / 348 / 398

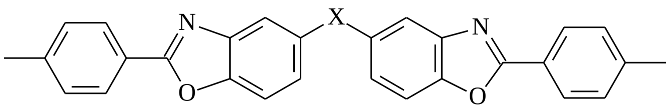
Materials

Table.3 Typical Properties of Polymer Materials

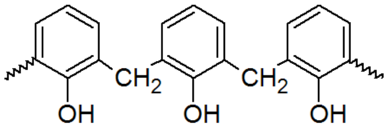
Material	PI-1	PI-2	PBO	PH
Polymer	Polyimide	Polyimide	Poly-benzoxazole	Phenolic resin
Cure Temp. [℃]	200	200	350	220
Tg [℃]	200	220	300	230
Elastic Modulus E [GPa]	**3.2**	**4.0**	**2.4**	**3.5**
CTE α_1 [ppm/K]	**60**	**50**	**45**	**36**



PI(Polyimide)



PBO(Polybenzoxazole)



PH(Phenolic resin)

Critical Energy Release Rate ($\mathcal{G}c$)

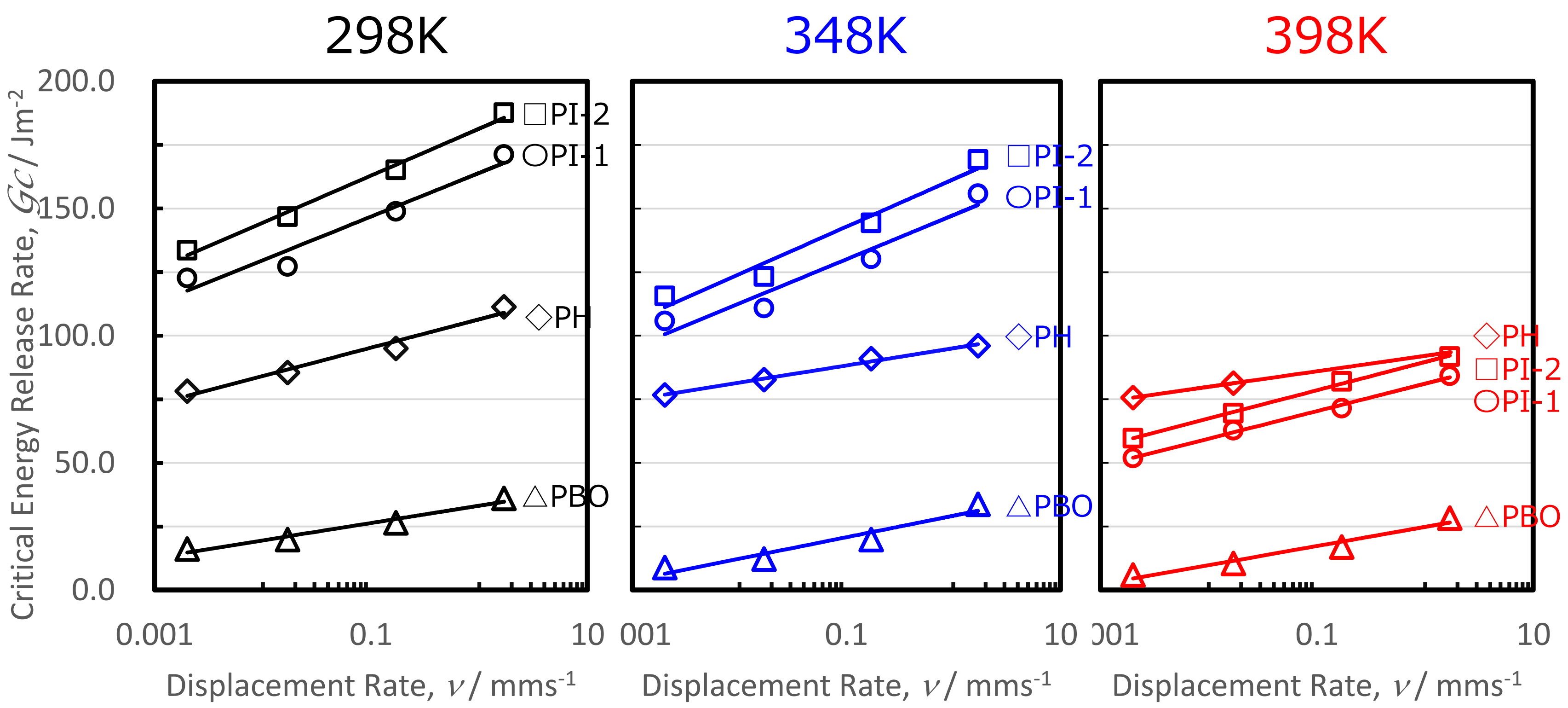


Fig.5 Relationship between displacement rate and Critical energy release rate ($\mathcal{G}c$) in each temperature

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Method of Creating Master Curve

Example) PI-1

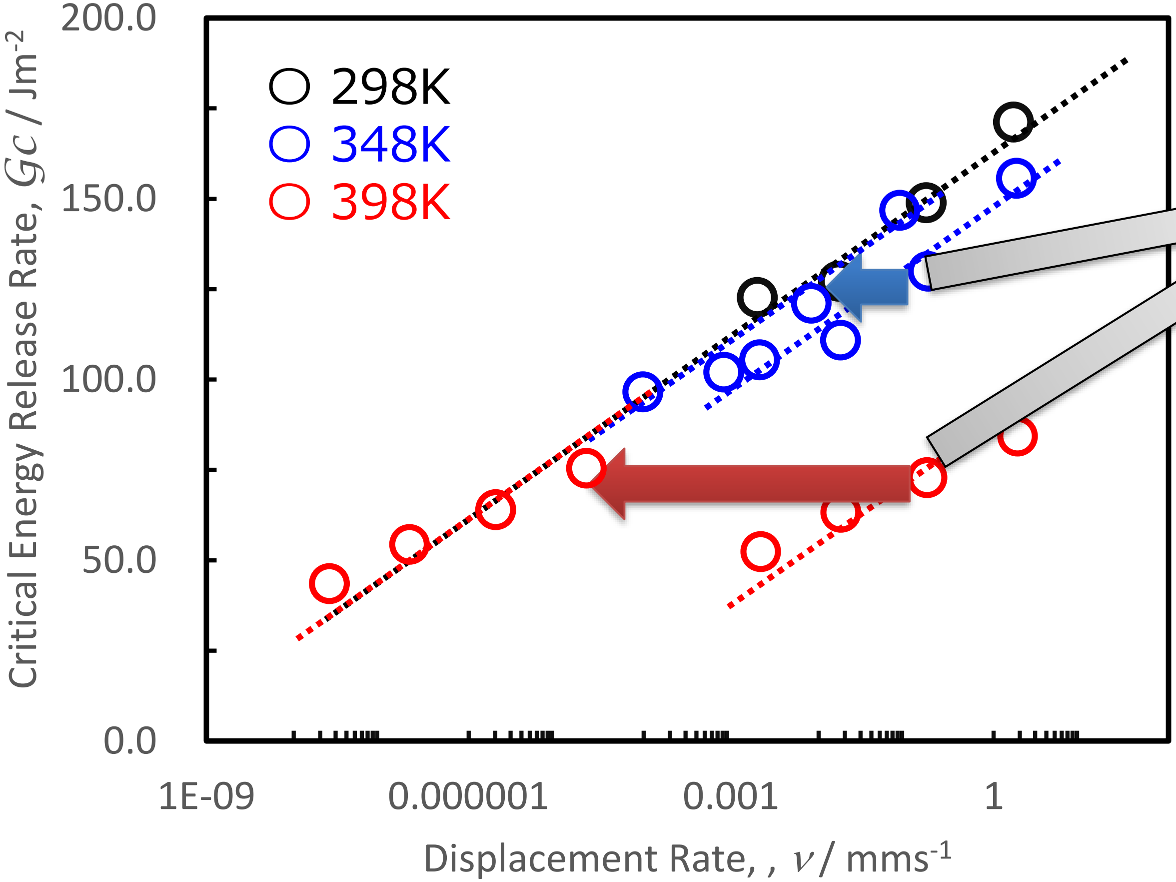

Fig.6 Relationship between displacement rate and Critical energy release rate ($\mathcal{G}c$) about PI-1

Arrhenius Plot

$$a_T = 3.04exp\left[13212\left(\frac{1}{T} - \frac{1}{298}\right)\right]$$

time−temperature superposition

Creating Master Curve

Master Curves of $\mathcal{G}c$

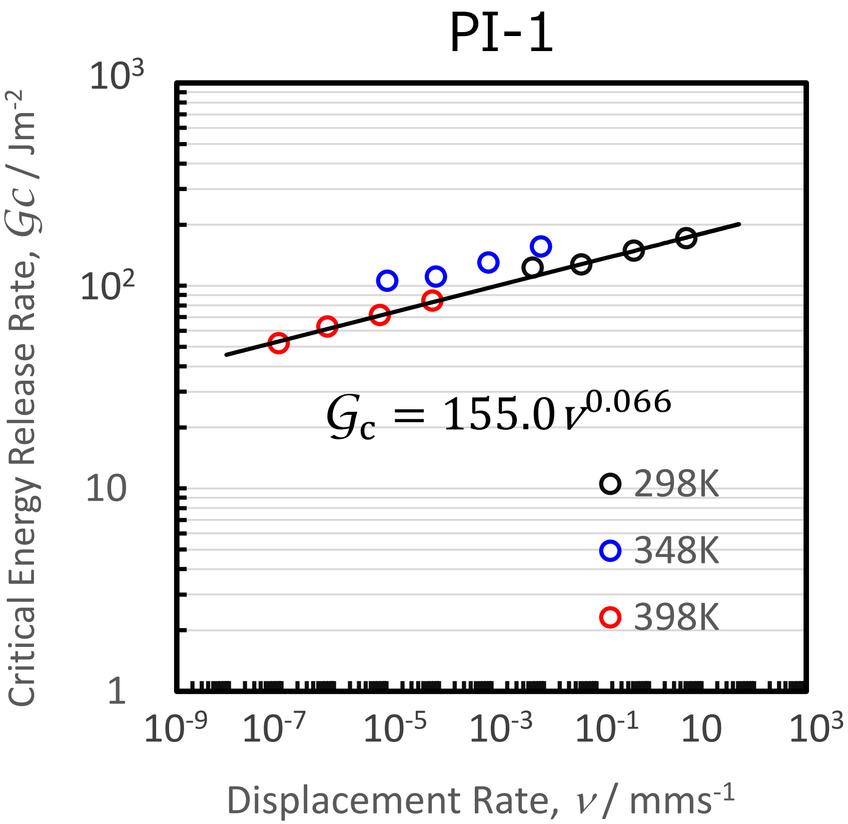

Fig.7 Master curves of function of critical energy release rate $\mathcal{G}c$ and displacement rate ν about PI-1

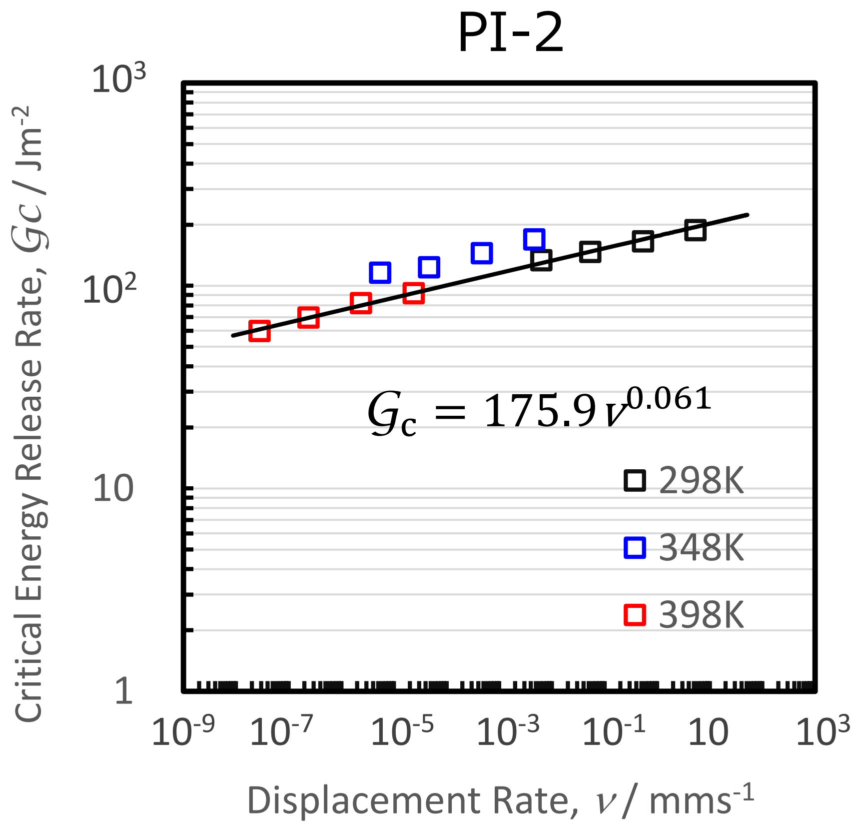

Fig.8 Master curves of function of critical energy release rate $\mathcal{G}c$ and displacement rate ν about PI-2

Master Curves of Gc

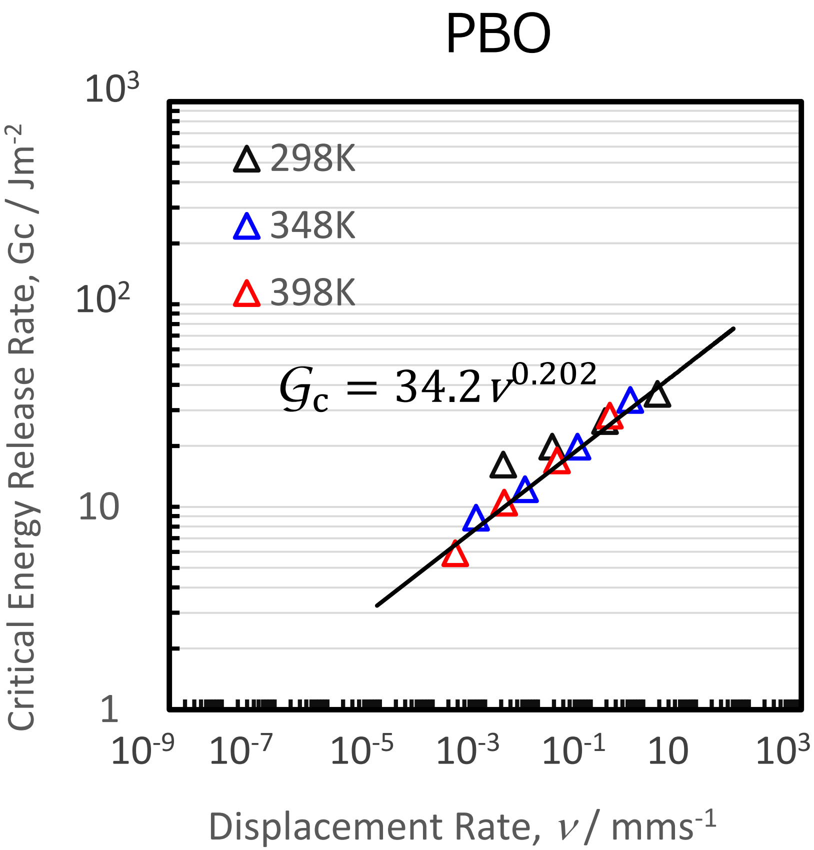

Fig.9 Master curves of function of critical energy release rate Gc and displacement rate v about PBO

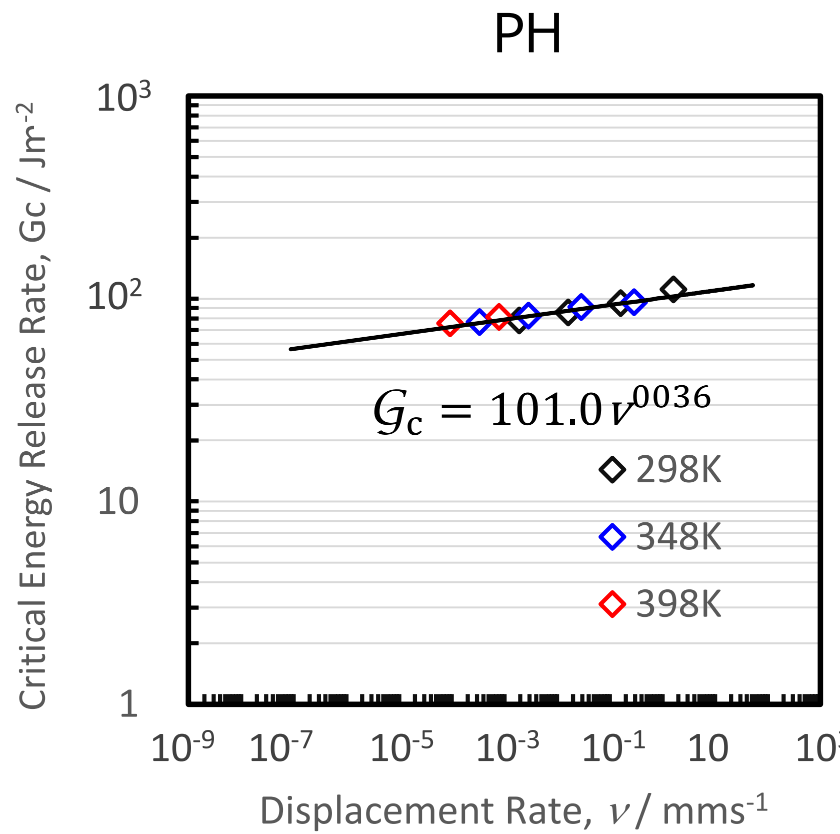

Fig.10 Master curves of function of critical energy release rate Gc and displacement rate v about PH

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Finite Element Analysis

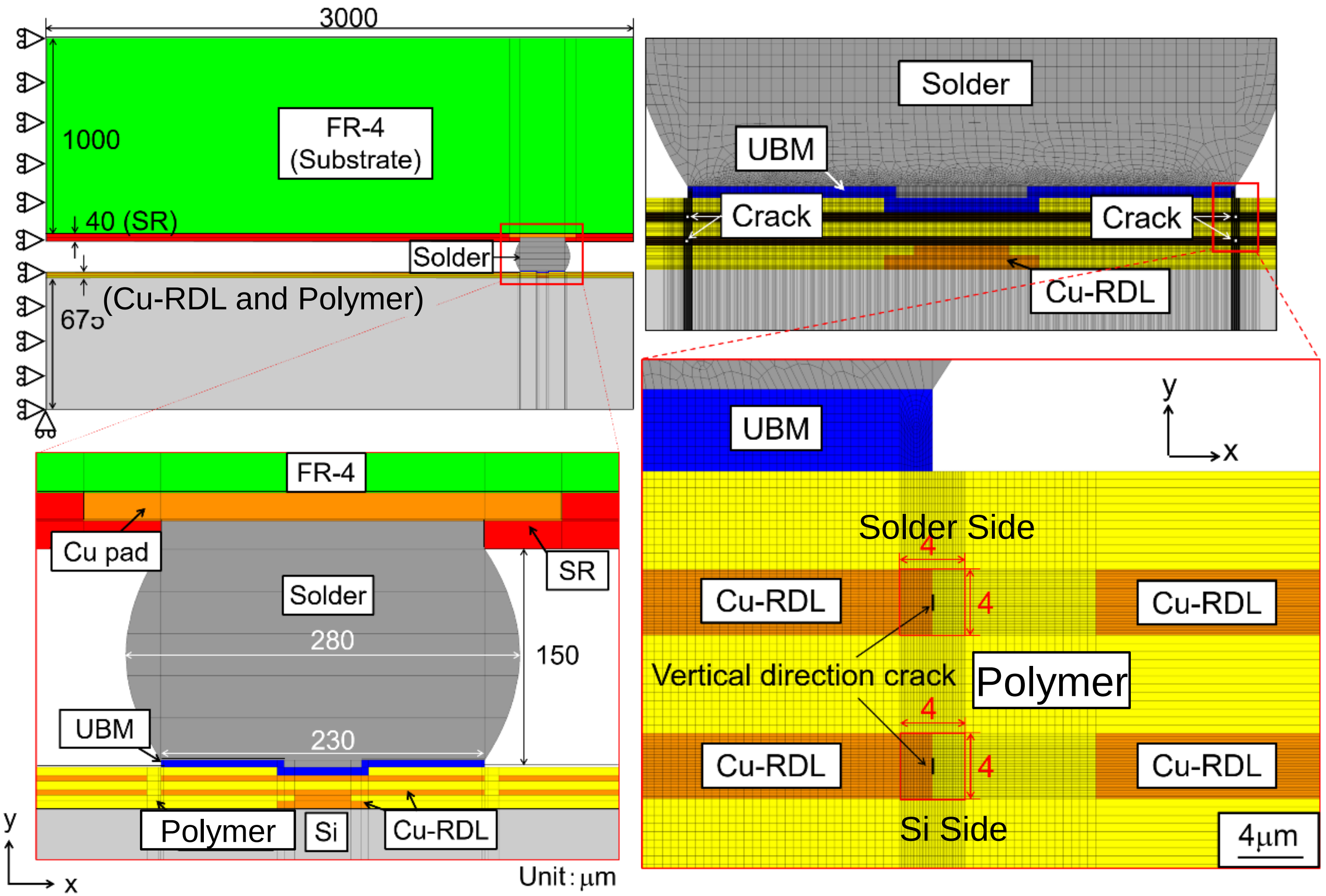

Fig.11 FEA Model

Materials

Table.4 Typical Properties of FEA Model Components

Materials	Property	Modulus [GPa]	CTE [ppm/K]	Poisson's ratio
Cu	Elasticity	129.8	17	0.34
FR-4		22	T-dependent	0.28
SR		2.6	T-dependent	0.29
UBM		199.5	13.1	0.3
Si		168	2.6	0.35
Solder	Creep	76.087-0.109T	0.3	0.3

Creep constitutive equation of solder; Garofalo’s rule

$$\dot{\varepsilon}_{ss} = 5.75\times10^{6}\left[\sinh\left(0.03\sigma\right)\right]^{7.8}\exp\left(-\frac{70000}{RT}\right)$$

$\dot{\varepsilon}_{ss}$: Creep strain rate
σ : Stress
R: Gas constant
T: Temperature

Temperature Profile

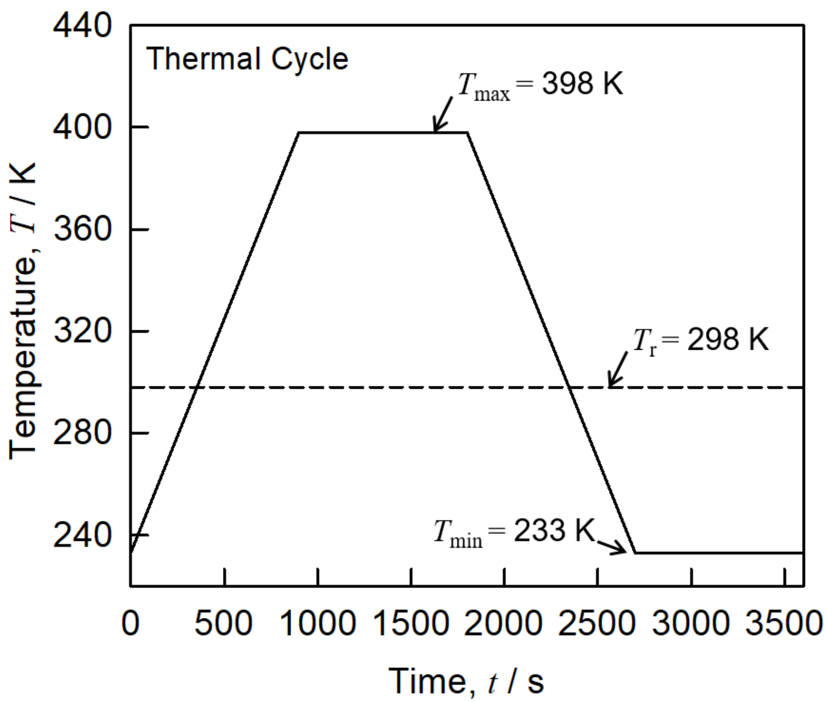

Fig.12 Temperature profile for thermal cycle

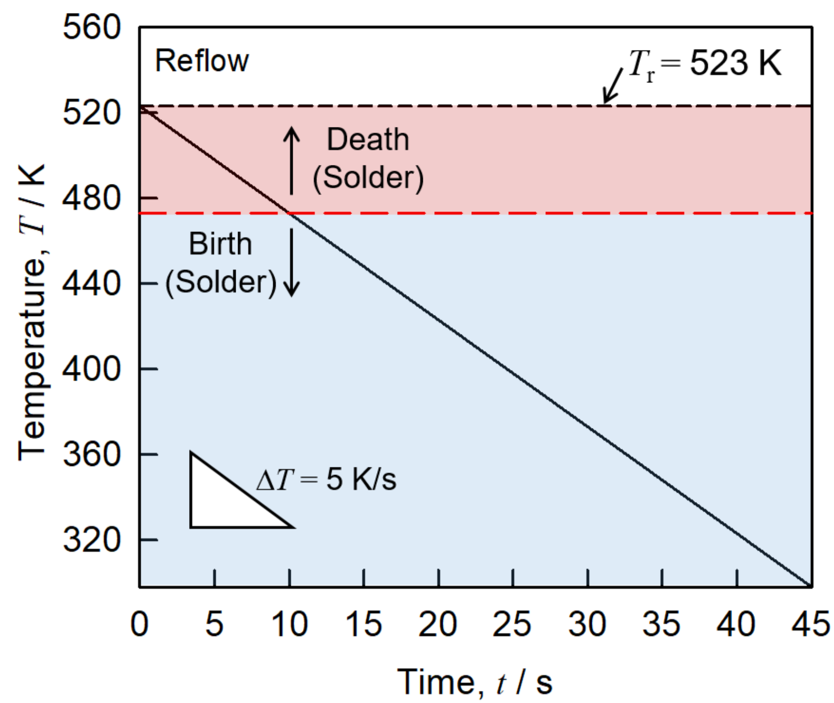

Fig.13 Temperature profile for reflow process

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Effects of E and α on G

Changing for E and α of **PI-1**

Table.5 Levels and Magnifications of each Factors

	level		
	-1	0 (standard)	1
Elastic modulus, E	×0.5	×1	×1.5
Thermal expansion coefficient, α	×0.7	×1	×1.3

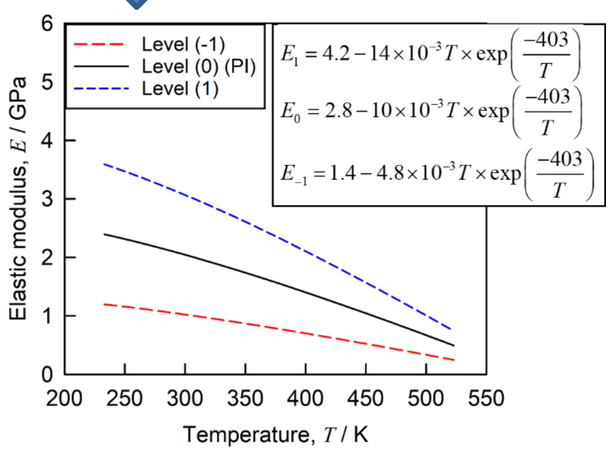

Fig.14 Relationship between temperature and E

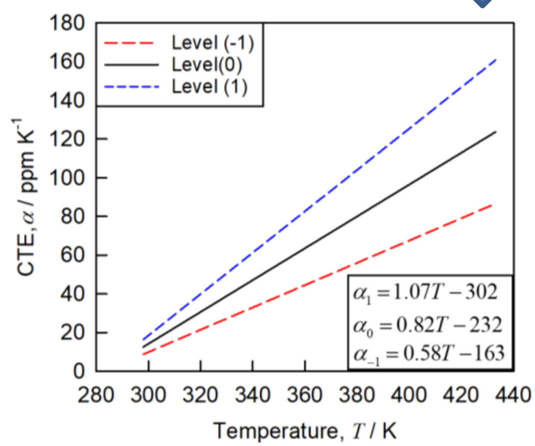

Fig.15 Relationship between temperature and α

Interaction Effect of E and α

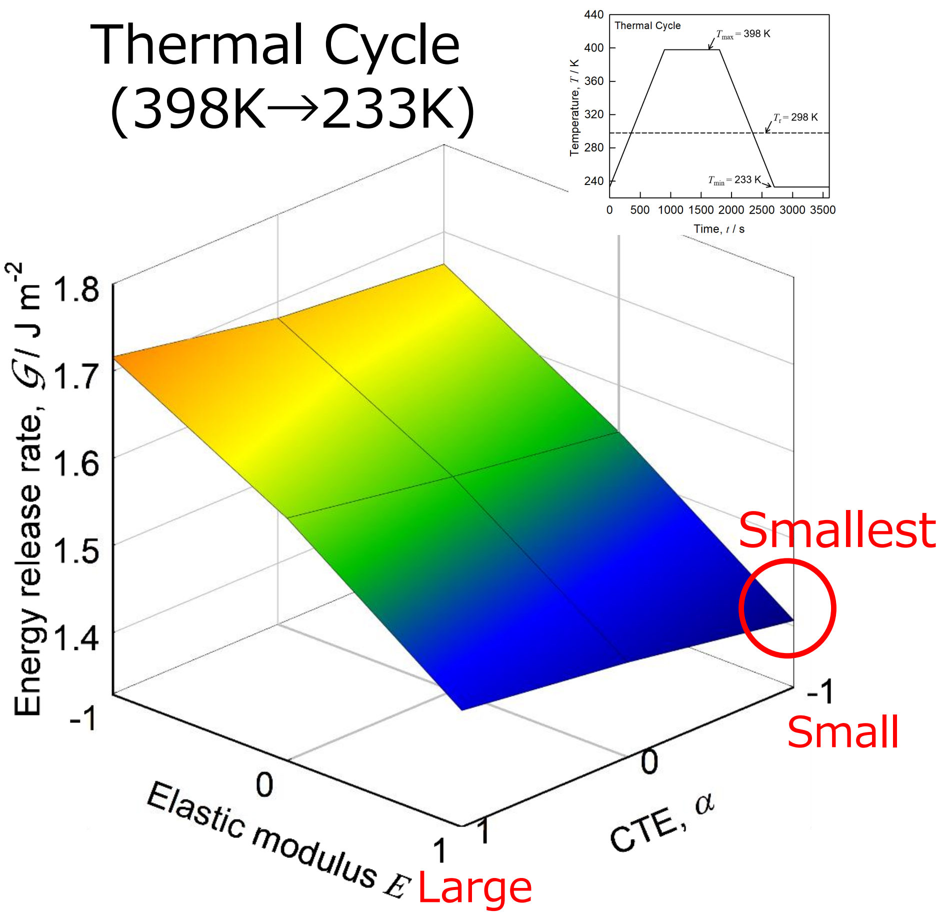

Fig.16 Interaction Effect of E and α on $\mathcal{G}$ in thermal cycle (398K→233K)

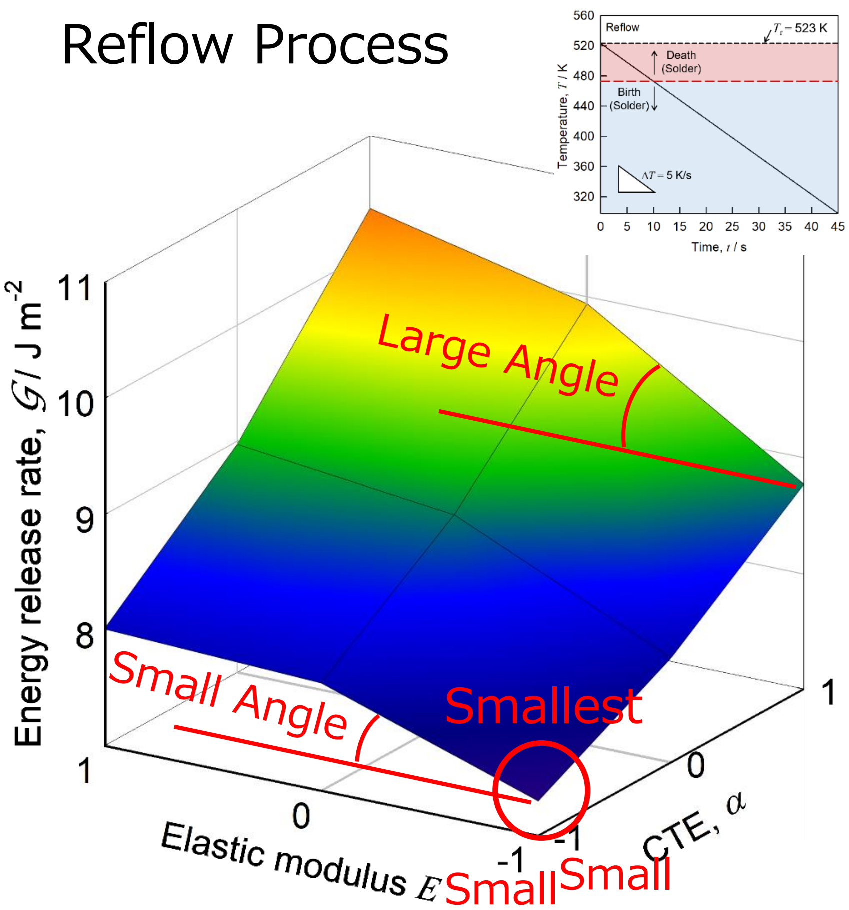

Fig.17 Interaction Effect of E and α on $\mathcal{G}$ in reflow process (523K→233K)

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Relative parameters

Table.6 Relative Parameters of Gc, E and α

	PI-1	PI-2	PBO	PH
Critical energy release rate, G_c	○High	○High	×Low	△Middle
Elastic modulus, E	High	High	Low	High
Thermal expansion coefficient, α	×High	△Middle	△Middle	○Low

$\mathcal{G}/\mathcal{G}c$ Normalized in the Thermal Cycle

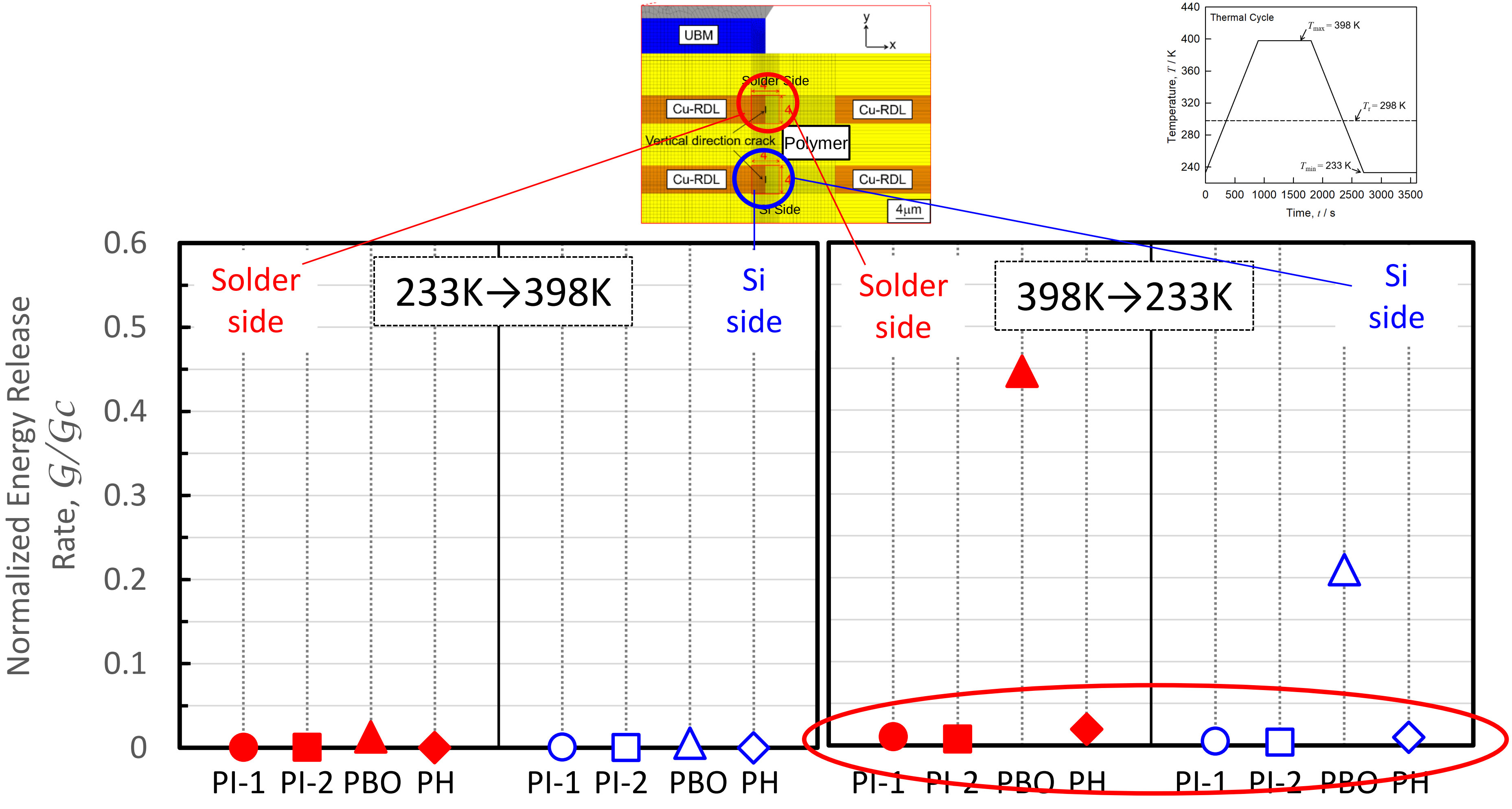

Fig.18 G/Gc normalized in the thermal cycle

$\mathcal{G}/\mathcal{G}c$ Normalized in the Thermal Cycle

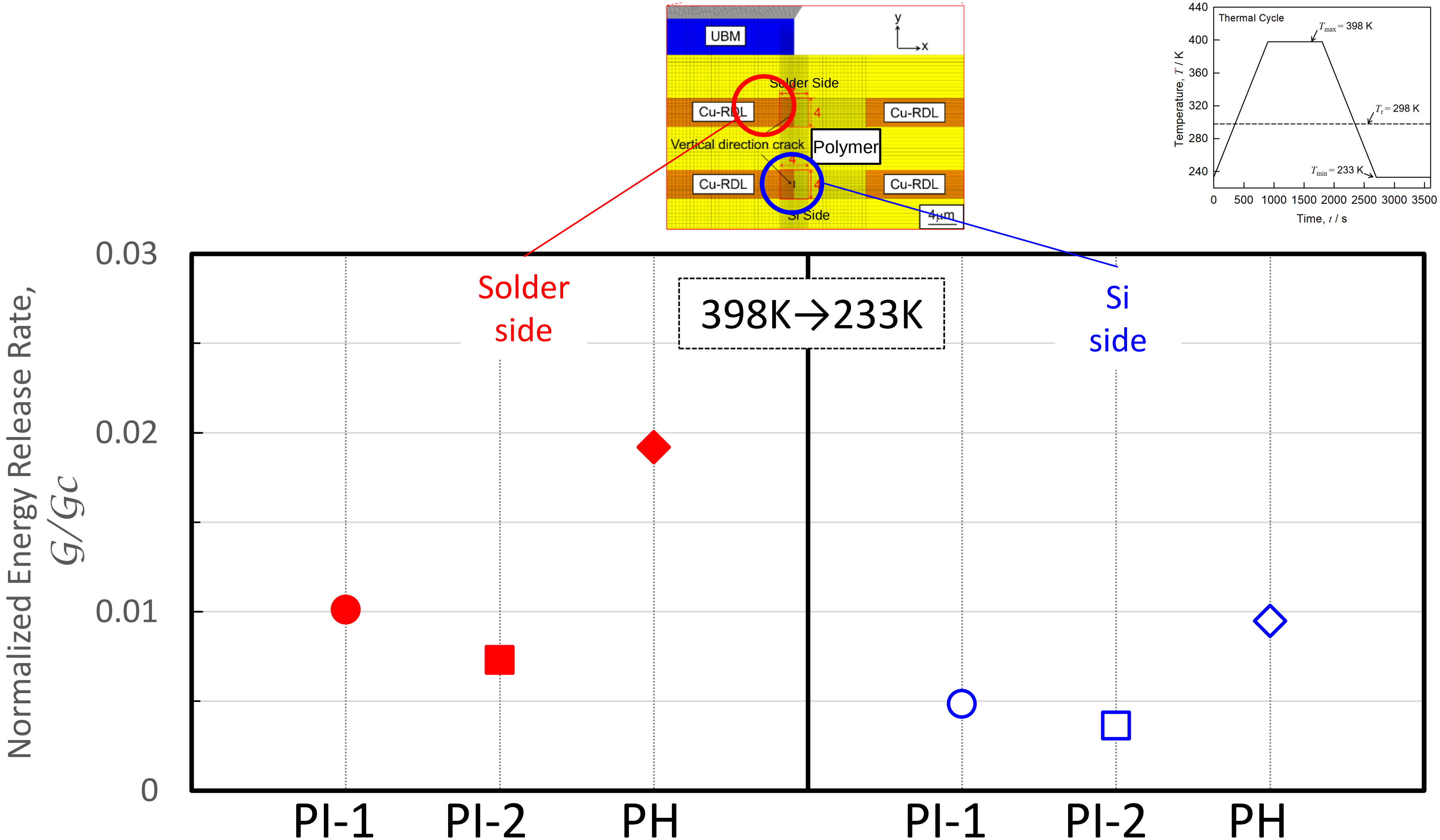

Fig.19 G/Gc normalized in the thermal cycle (without PBO)

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$\mathcal{G}/\mathcal{G}c$ Normalized in the Reflow Process

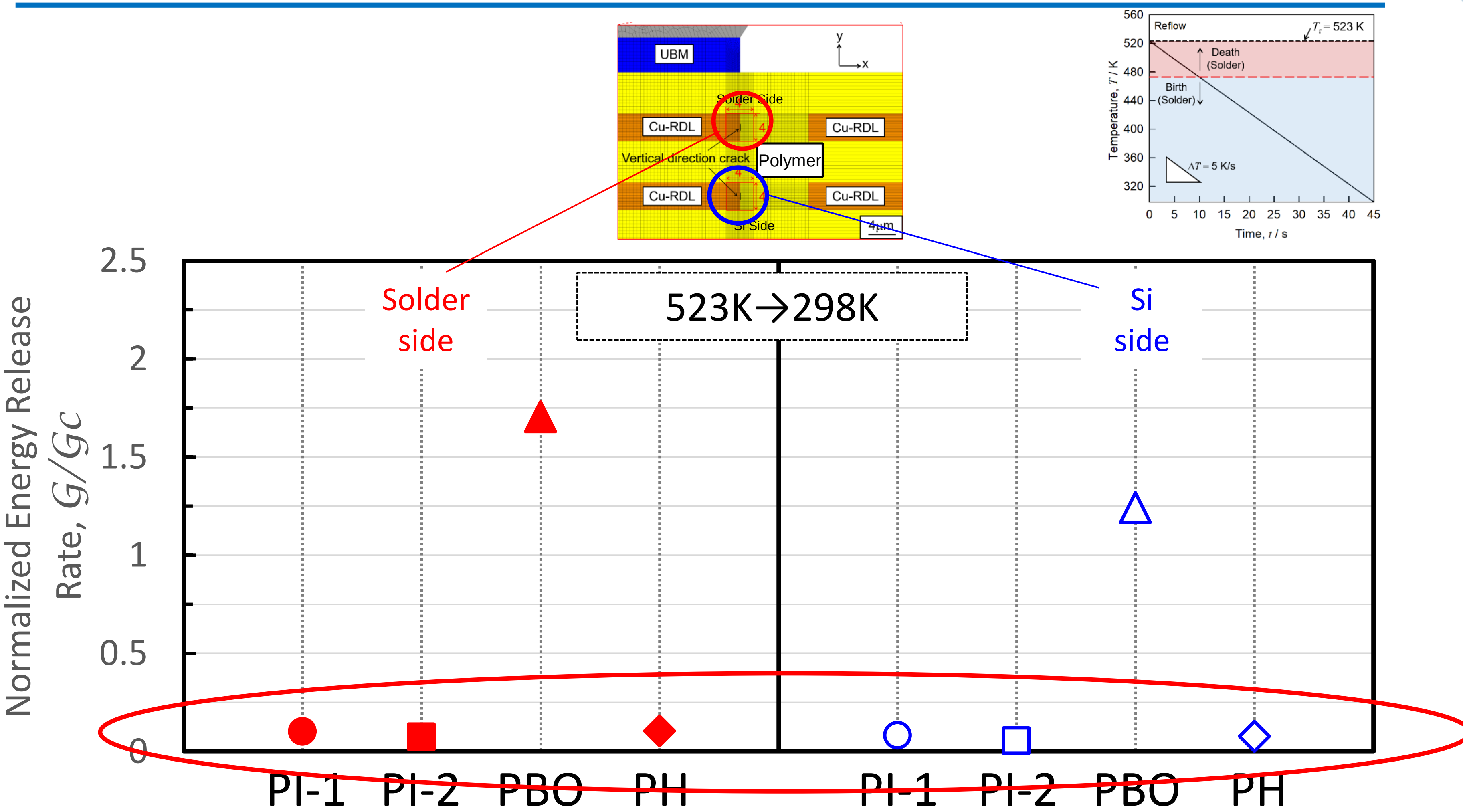
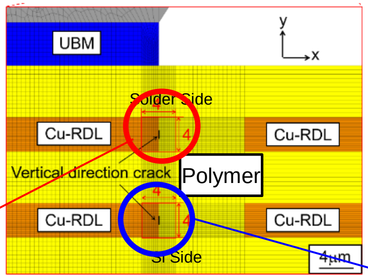
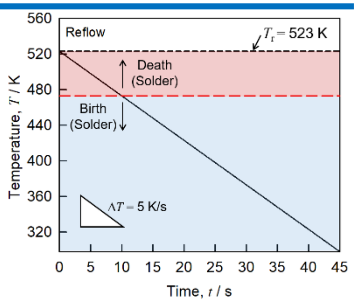


Fig.20 G/Gc normalized in the reflow process

$\mathcal{G}/\mathcal{G}c$ Normalized in the Reflow Process





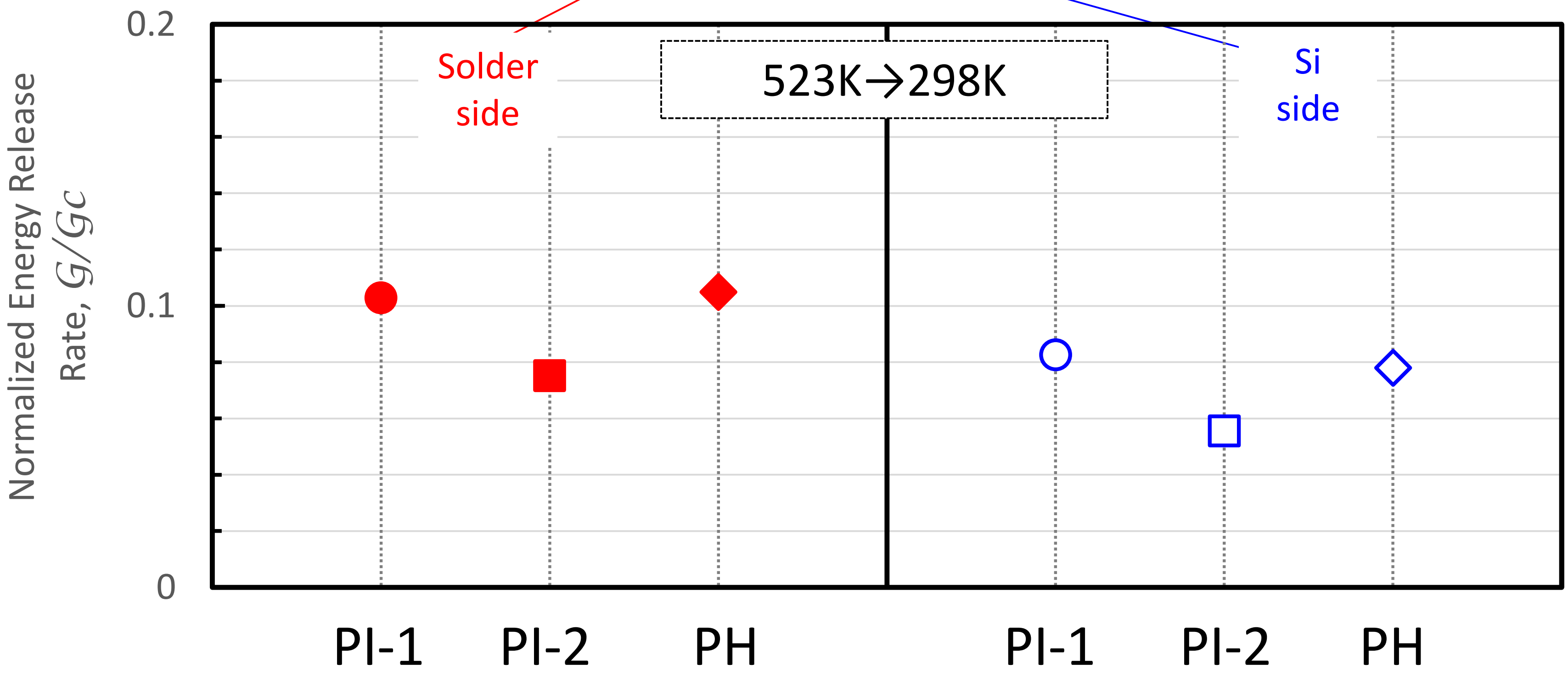


Fig.21 G/Gc normalized in the reflow process (without PBO)

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Conclusion

✓ This study has made it possible to simulate the delamination possibility of Cu/Polymer interface at arbitrary temperatures and displacement rates from basic material data and FEA analysis of the FOWLP structure.

✓ This knowledge can be used to develop polymer materials with high reliability

✓ More importantly, we can know the reliability under arbitrary conditions in advance about various materials and various package structures.

Future Works

✓ We have been attempting integrated simulation of delamination and material fracture by combining this study with the Fatigue Crack Propagation Test of materials.

✓ If these two can be integrated, it is possible to discriminate between the case of delamination occurring and the case of material fracture occurring according to differences in materials and package structures.

✓ We can be expected to select an optimal material for the designed package structure, and/or to be used as a design guide for a high reliability package structure.

Creating for Tomorrow

The commitment of the Asahi Kasei Group:

To do all that we can in every era to help the people of the world make the most of life and attain fulfillment in living.

Since our founding, we have always been deeply committed to contributing to the development of society, boldly anticipating the emergence of new needs.

This is what we mean by “Creating for Tomorrow.”

Asahi KASEI