Carbon Enrichment during Ferrite Transformation in Fe-Si-C alloys

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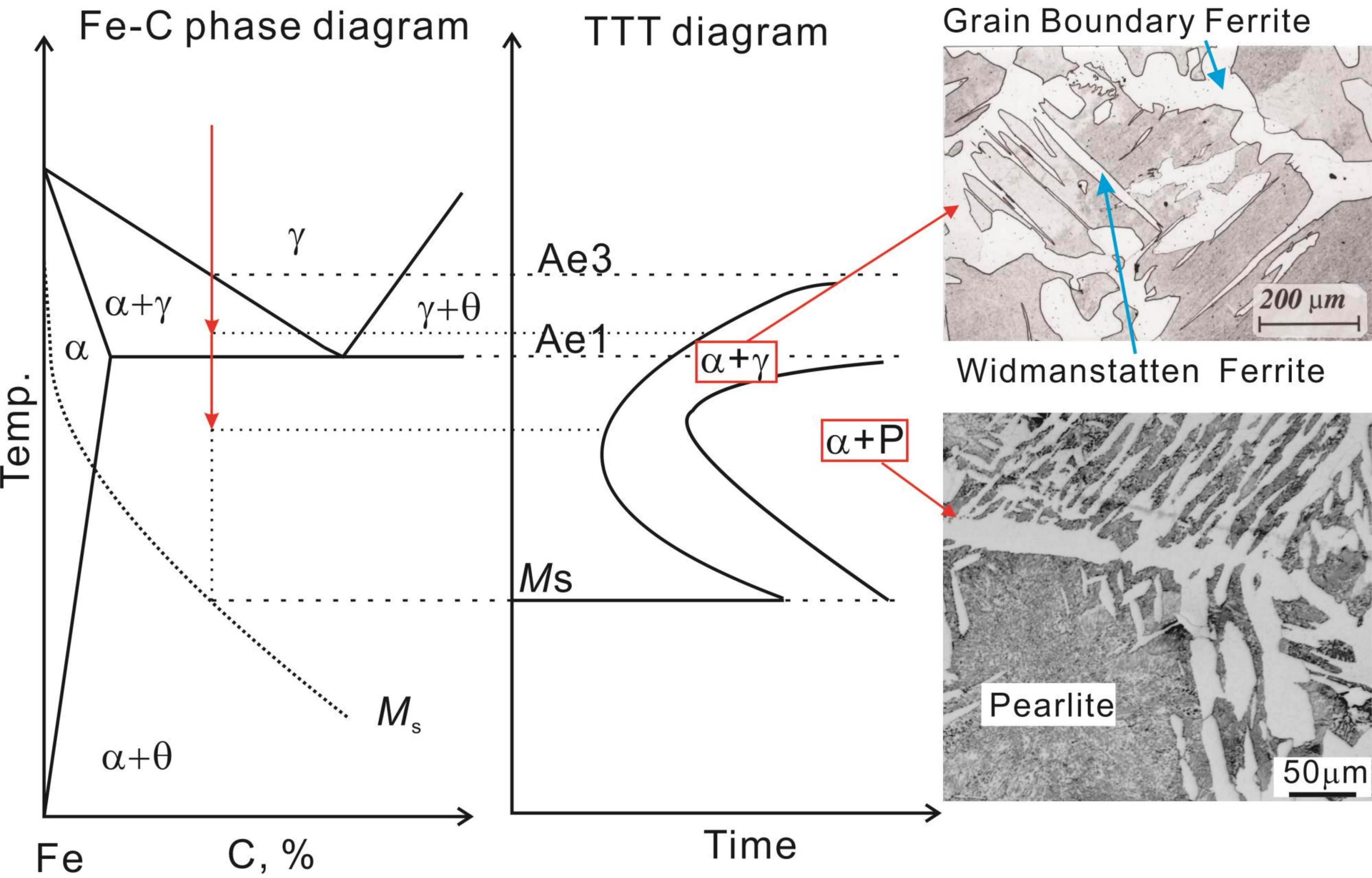
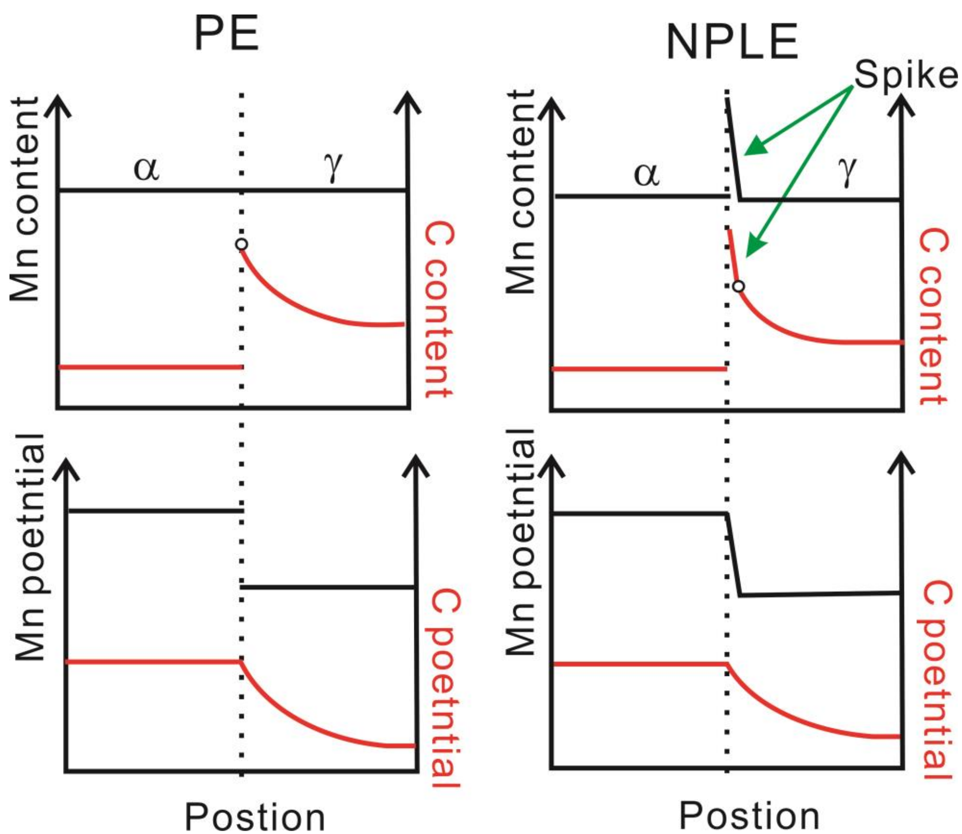
Proeutectoid Ferrite and followed Pearlite transformations

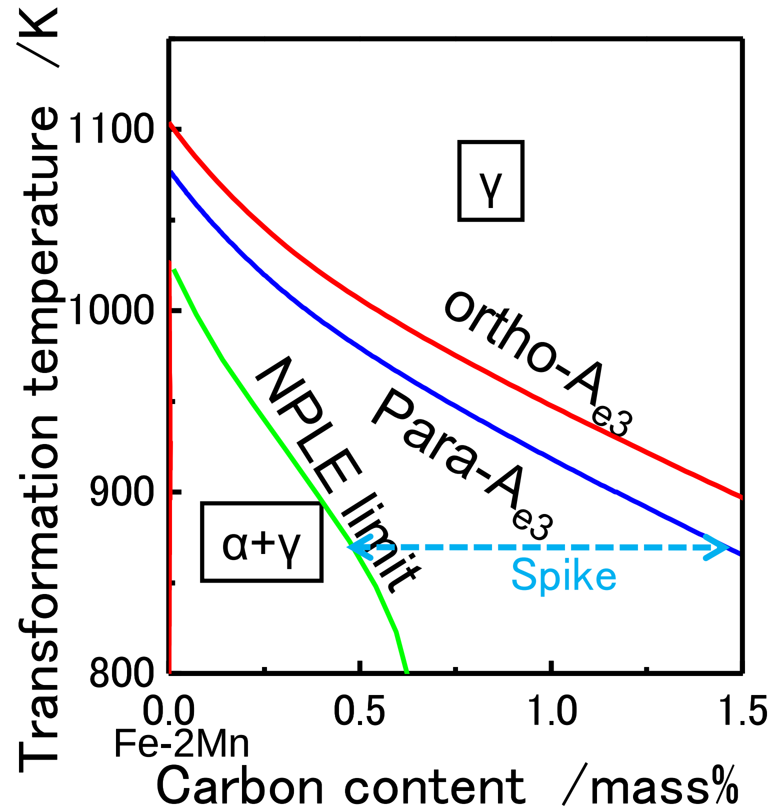


Non partitioning growth model

★Para equilibrium (PE)
★Negligible partitioning LE(NPLE)



Vertical phase diagram
(Fe-2Mn-C)



Ferrite transformation in Fe-Si-C alloys

•Previous studies

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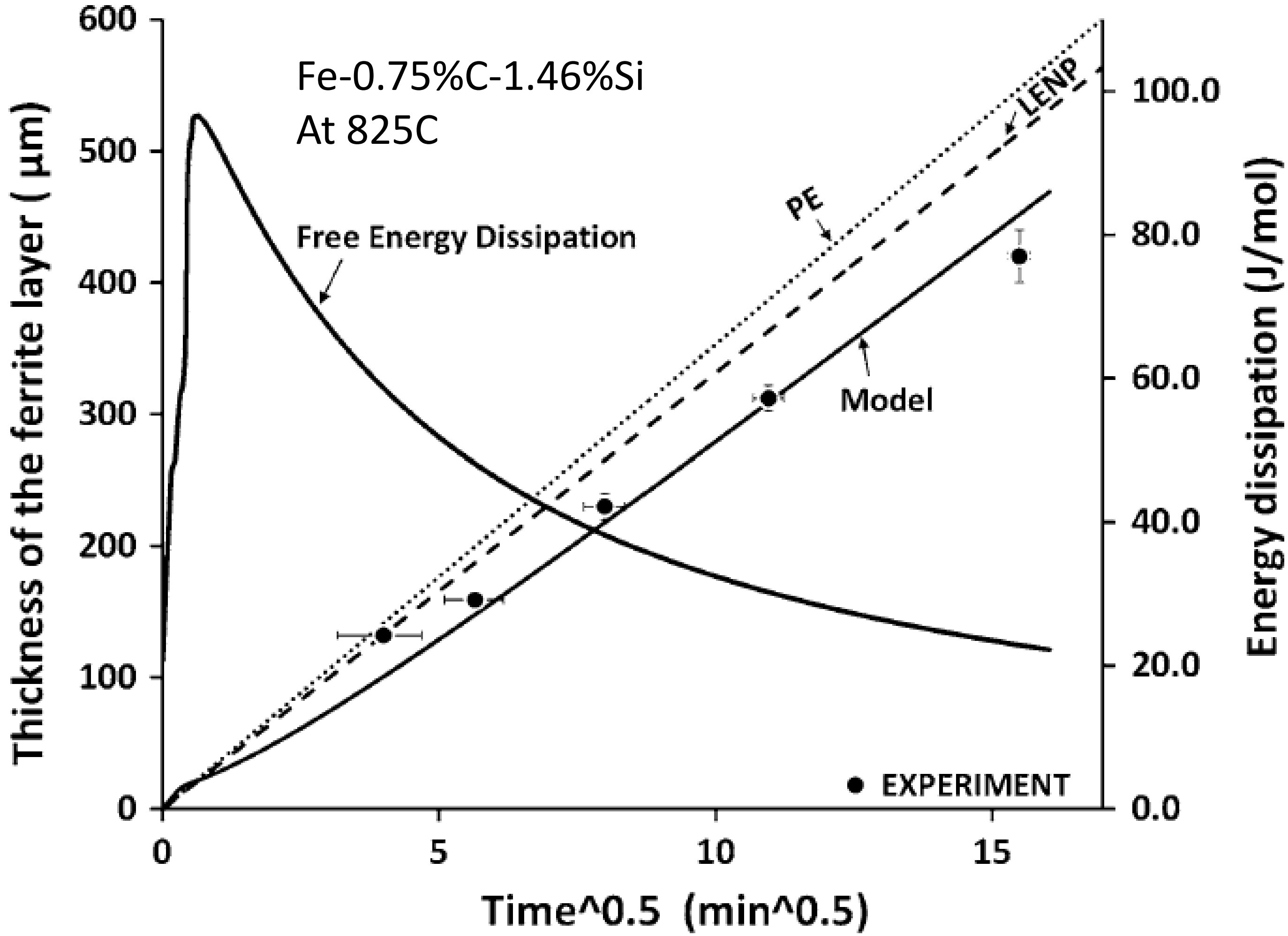


- Effect of Solute drag effect at very early stage

*Qiu, C., *et al*. (2013). *MMTA*. 44(8): 3472

Objective

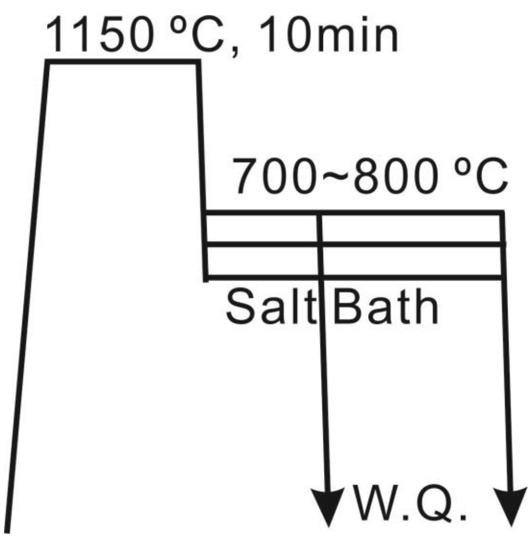
To clarify the ferrite transformation mechanisms by characterizing its kinetics and element partitioning behavior in Fe–Si–C alloys

Experimental Procedure

Alloys

Alloy	Composition, mass%		
	C	Si	Fe
1.5Si	0.375	1.48	Bal.
3Si	0.379	3.09	Bal.

Heat Treatment



Microstructure observation:

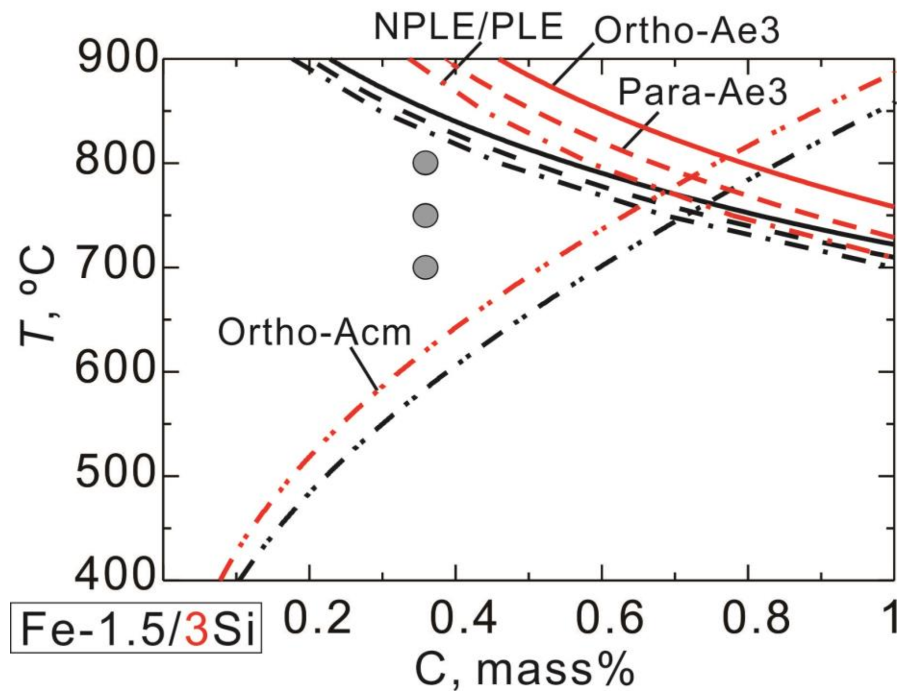
Optical Microscopy (OM), SEM, EBSD

Volume fraction measurement

Point counting (SEM)

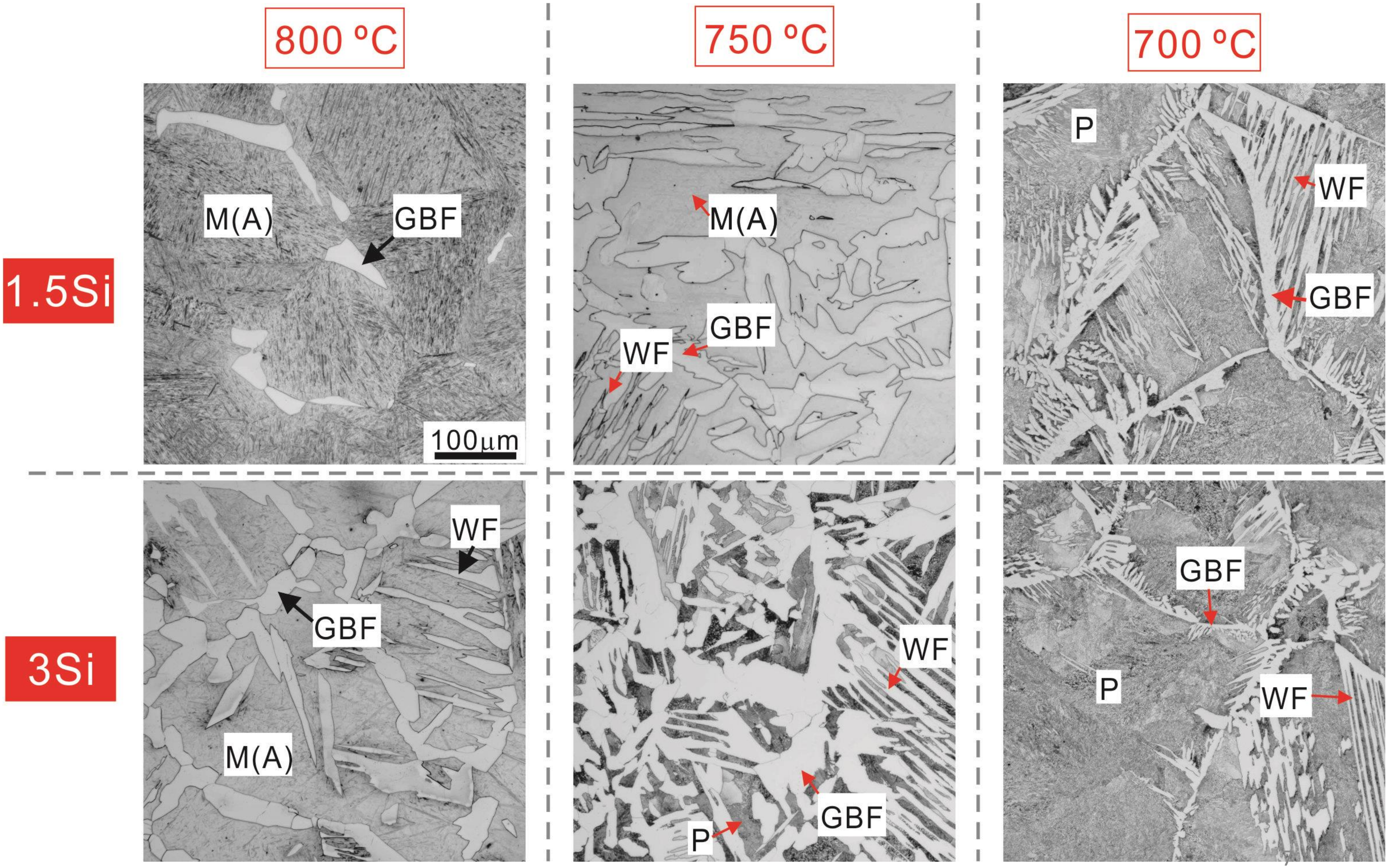
Composition measurement

FE-EPMA



Microstructure

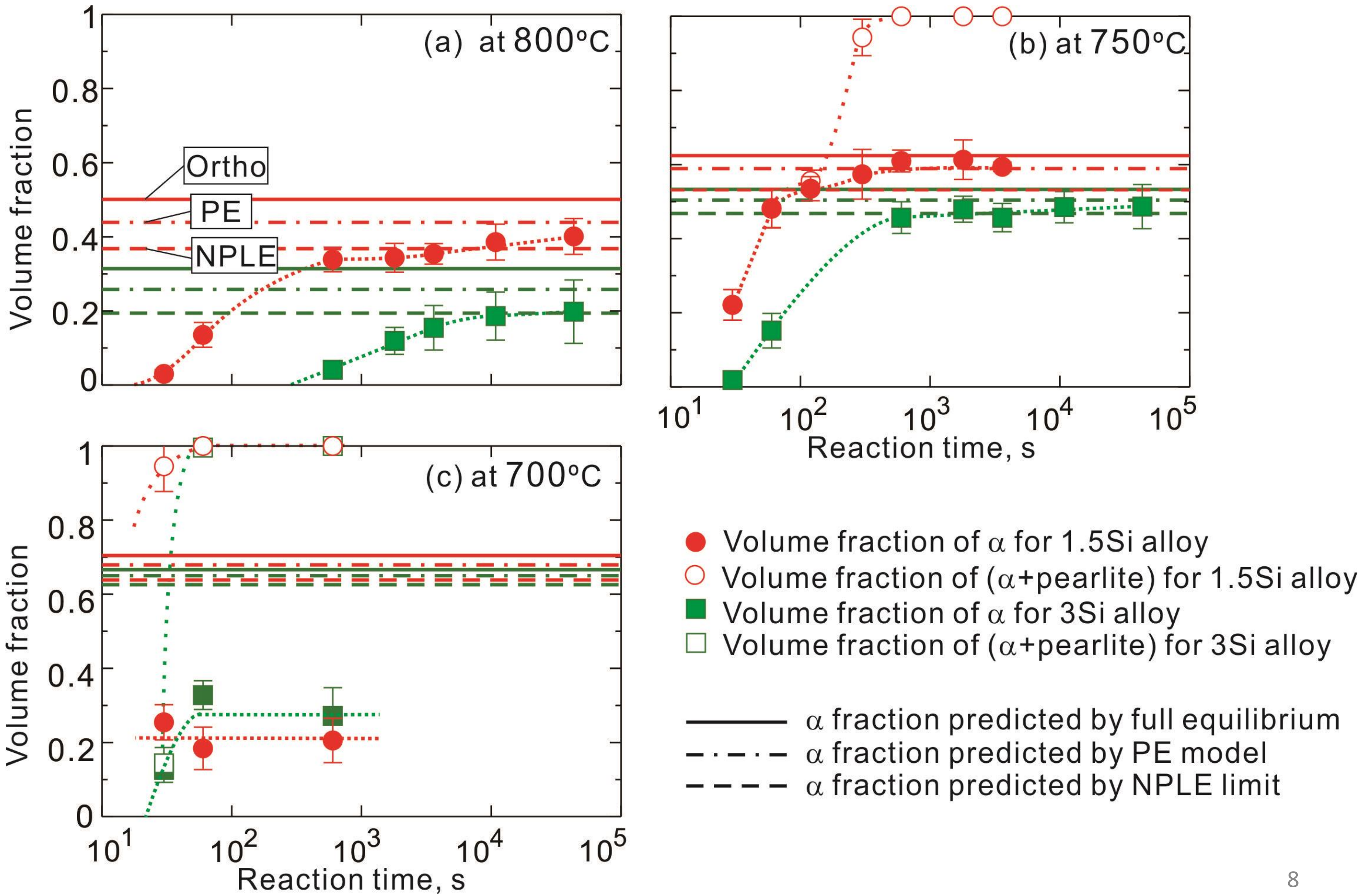
*All Specimens are transformed for 10 min



*GBF: grain boudary α; WF: Widmanstatten α; M(A): martensite (prior γ)

Transformation Kinetics

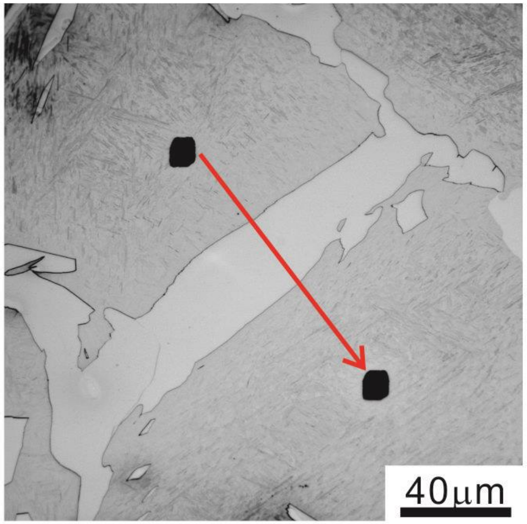
*Kinetic Transition occurs when reaching NPLE limit

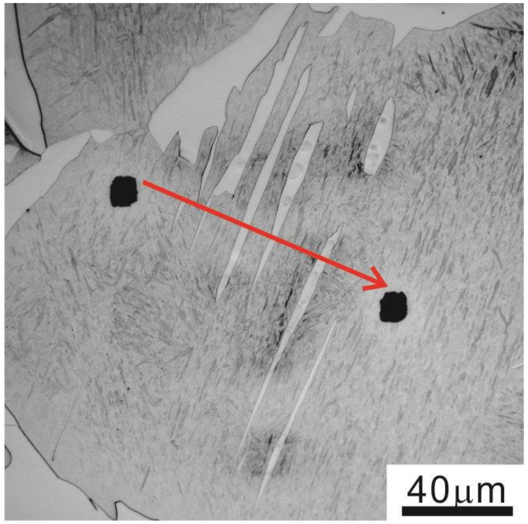


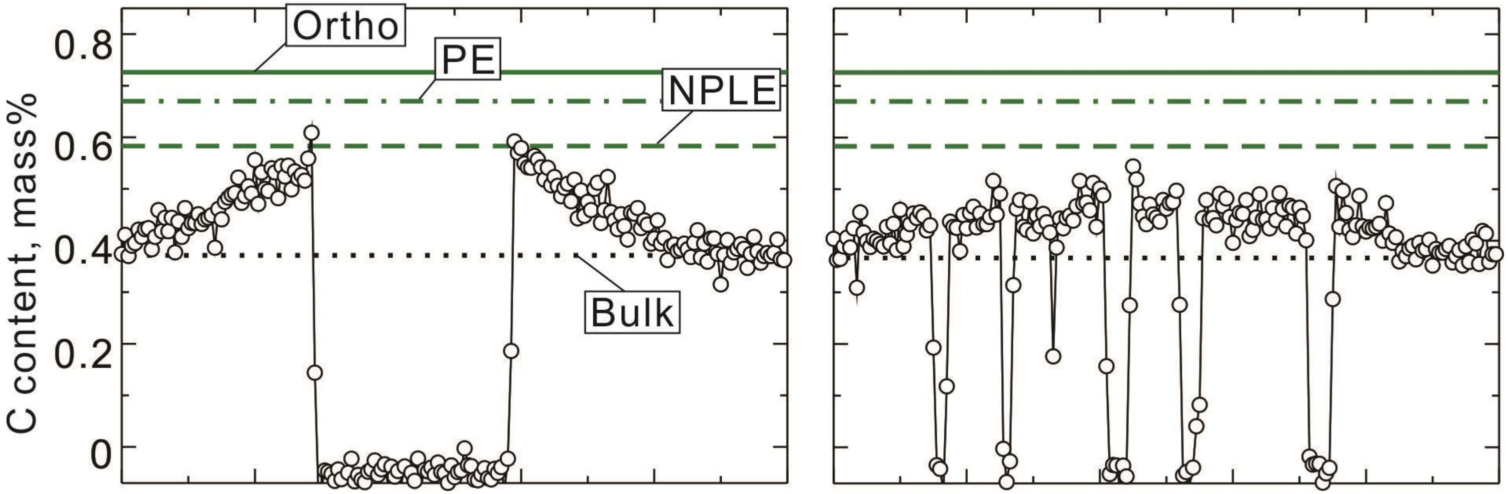
Carbon Enrichment at GBF/γ, WF/γ interfaces

*GBF: grain boudary α; WF: Widmanstatten α

*Specimen: *3Si alloy at 800 C for 10 min*







Summary on Carbon Enrichment at GBF/γ, WF/γ interfaces

*GBF: grain boudary α; WF: Widmanstatten α

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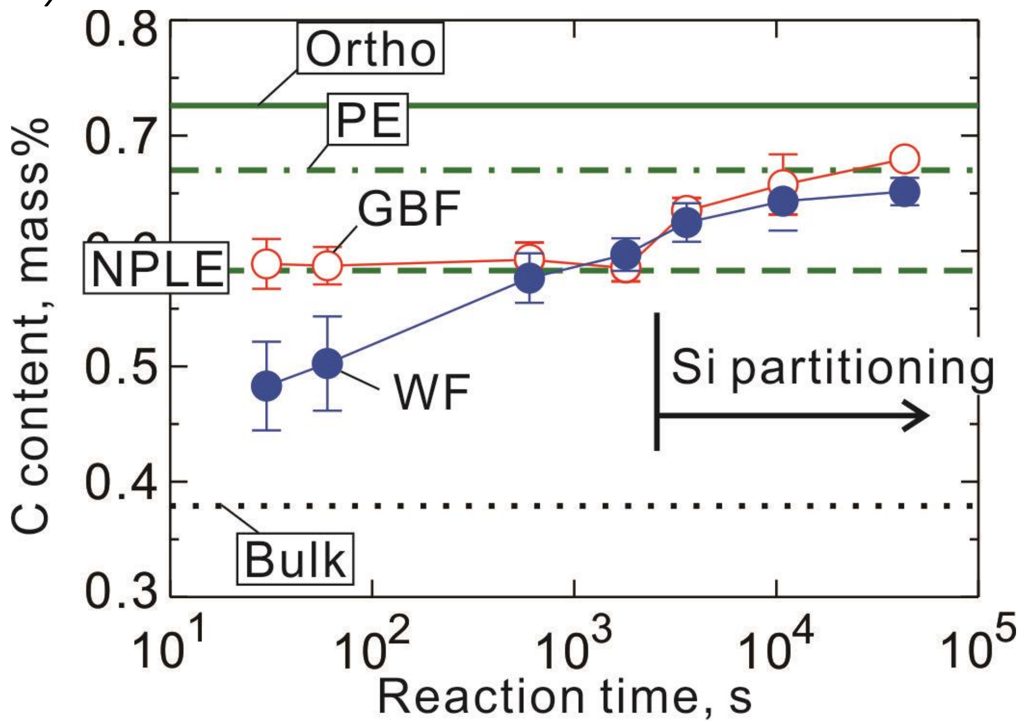


Non-partitioned α growth stage:

- GBF/γ : agree with NPLE prediction
- WF/γ : deviate from NPLE, deviation gradually diminish

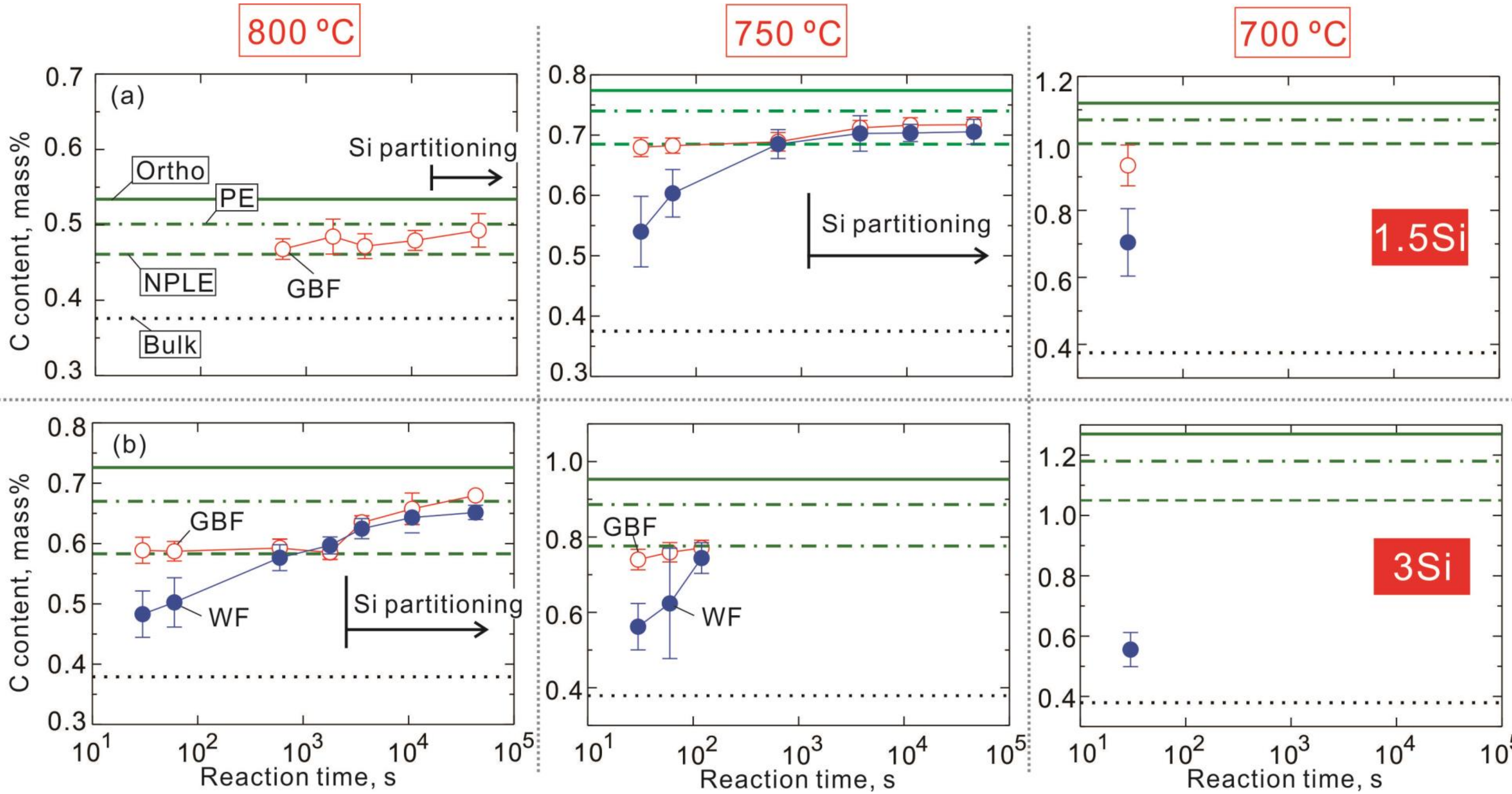
When Si starts partitioning

- GBF/γ, WF/γ : Both gradually increase

Summary on Carbon Enrichment at GBF/γ, WF/γ interfaces

*GBF: grain boudary α; WF: Widmanstatten α

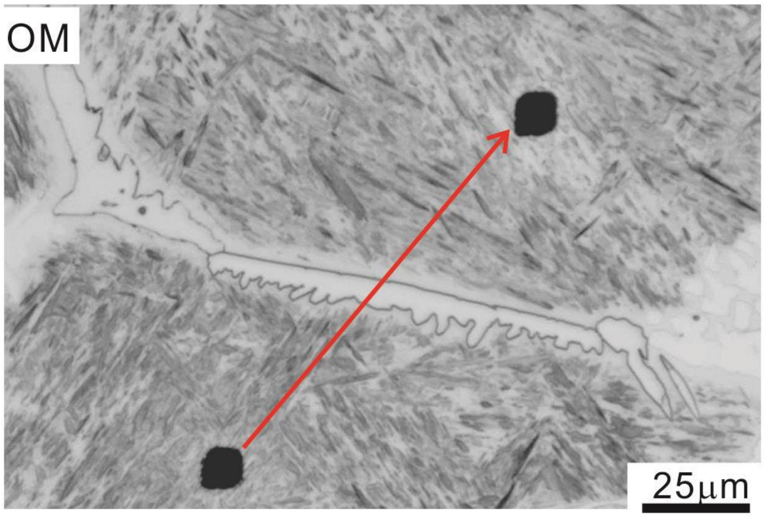
*Note: Focusing on ***non-partitioned*** α growth stage

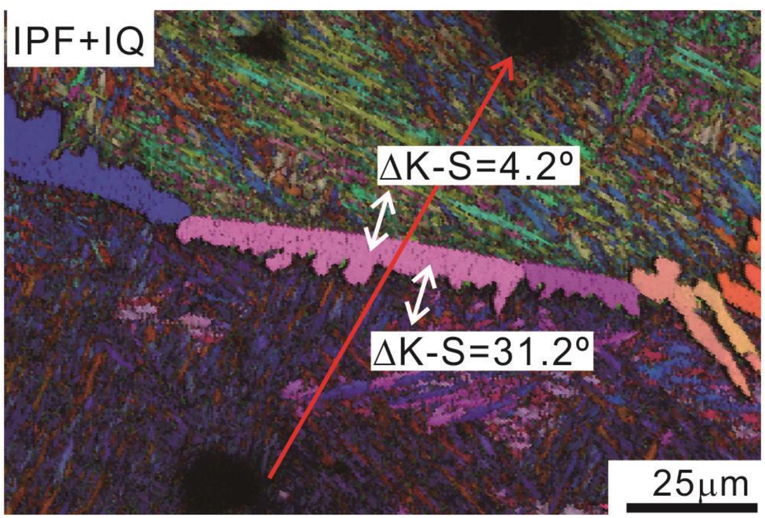


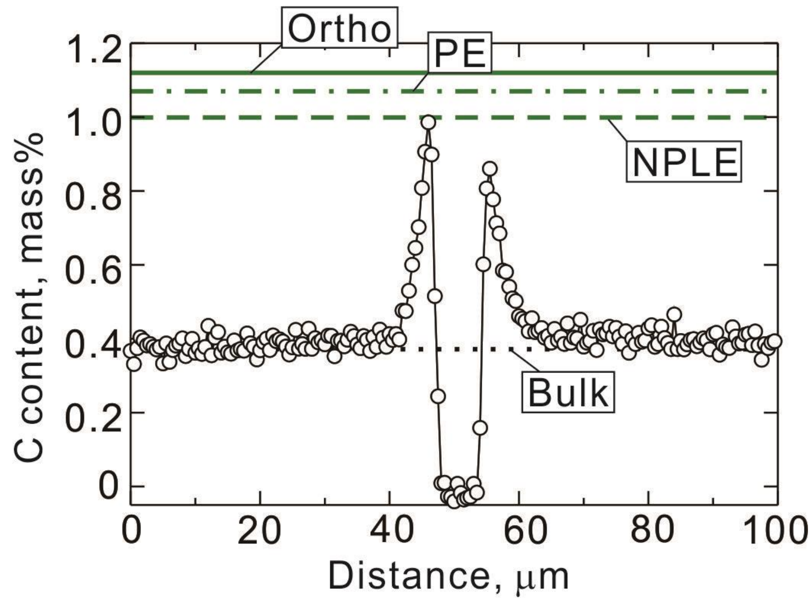
Effect of Interface Coherency on Carbon Enrichment

*GBF: grain boudary α; WF: Widmanstatten α

*Specimen: *1.5Si alloy at 700 C for 30s*





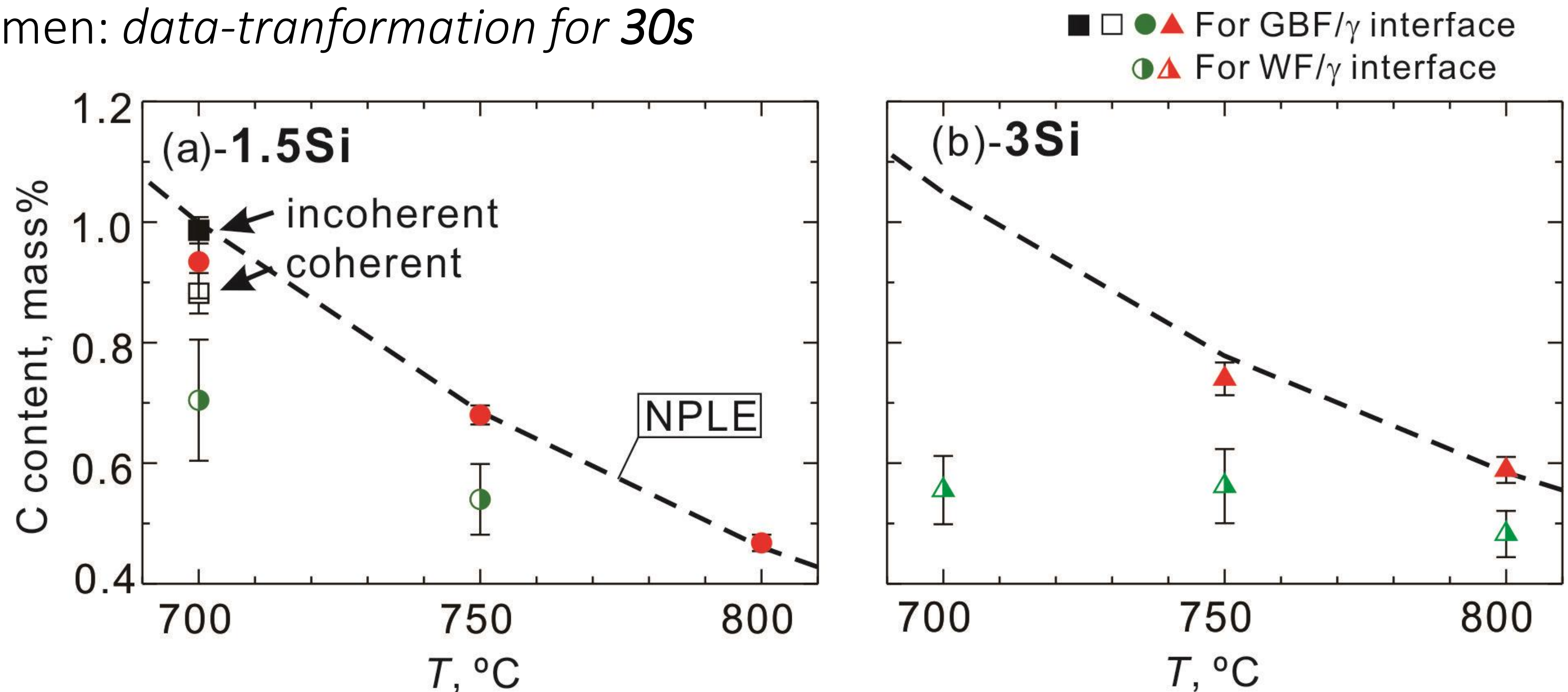


- Incoherent GBF/γ: agree with NPLE
- Coherent GBF/γ: deviate from NPLE
- WF/γ: deviation may also result from interface coherency

Discussion: agreement with NPLE limit

*Specimen: *data-tranformation for* ***30s***

Deviation from PE



The width of Spike: $d_{\text{spike}} = \dfrac{D_{\gamma}^{X}}{v_{\text{Interface}}}$

Is it possible to develop a spike?

At 800 °C -30s for 1.5Si, the d_{spike} is caculated to be 0. 084 nm

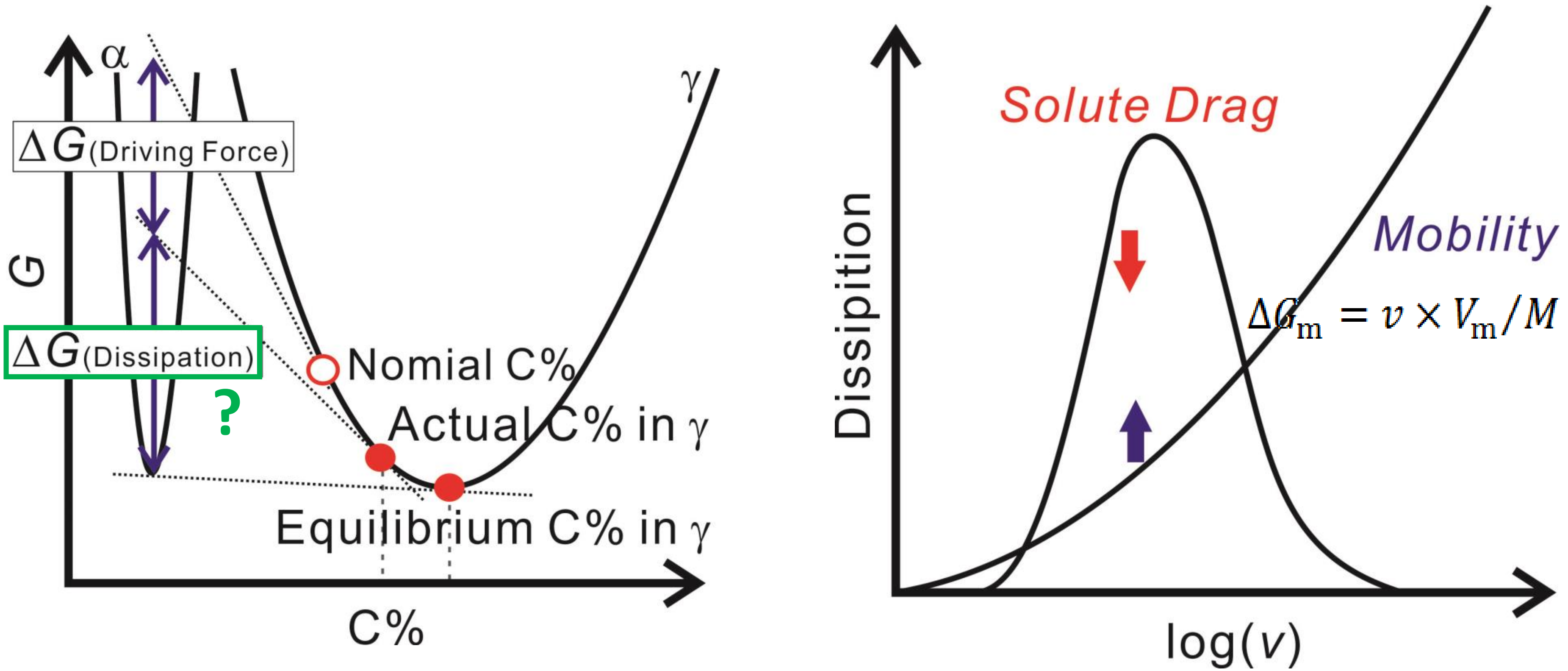
γ lattice constent: ~0.4 nm

If the spike moves inside the interface, d_{spike} =11~1510 μm

*The diffusivity along γ grain boundary is used (Fridberg *et al*. (1969), *Jern. Ann.*)

Spike development Possible if diffusion in both austenite and interface is involved

Discussion: where the additional dissipation came from?



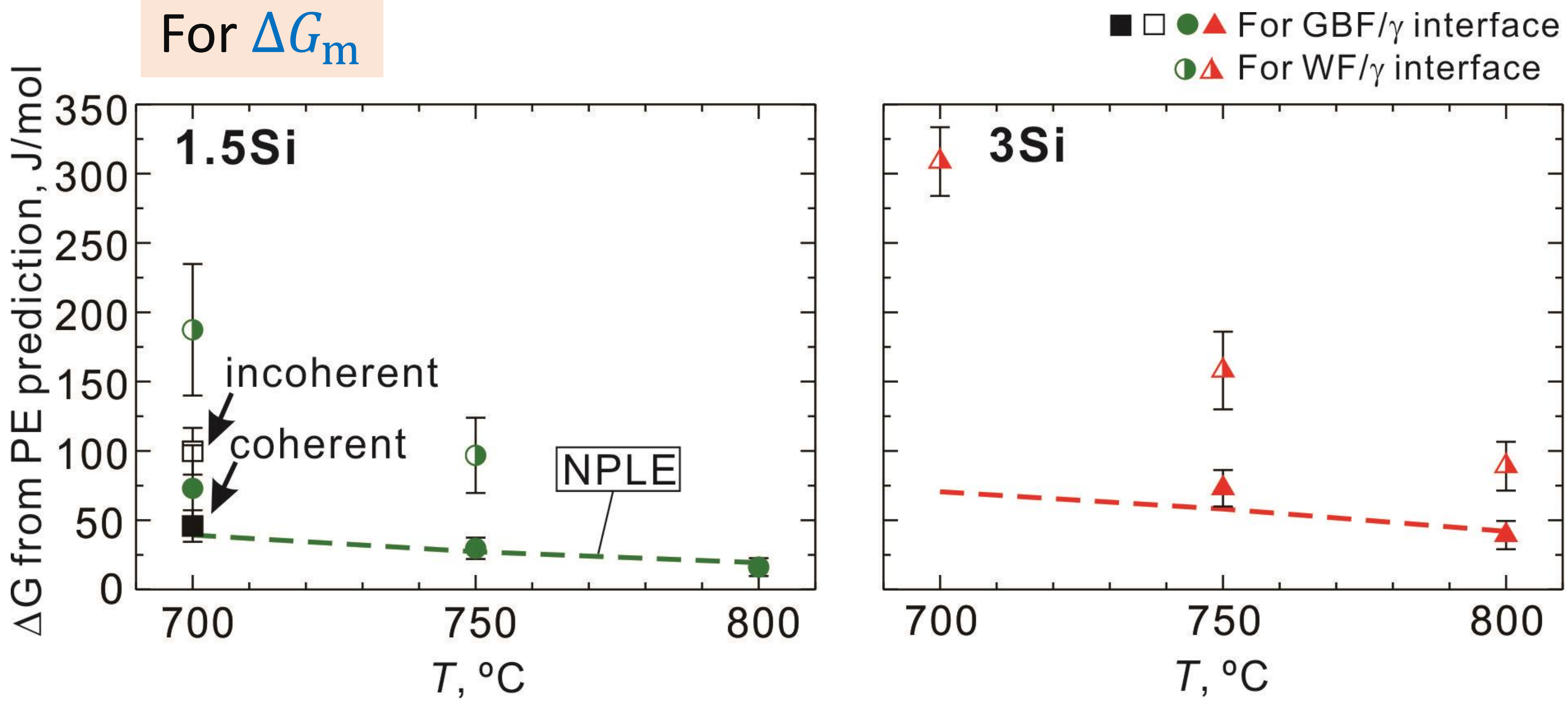
Coherent interface, compared with *incoherent ones*,

- *M* is smaller, ΔG(intrinsic friction) is ***larger***
- Fewer site for segregation and migrate slower, → ΔG(solute drag) is ***smaller***

Discussion: a discussion on α/γ interface mobility

Intrinsic mobility could be calculated from: $M = v \cdot V_m / \Delta G_{\mathrm{m}}$

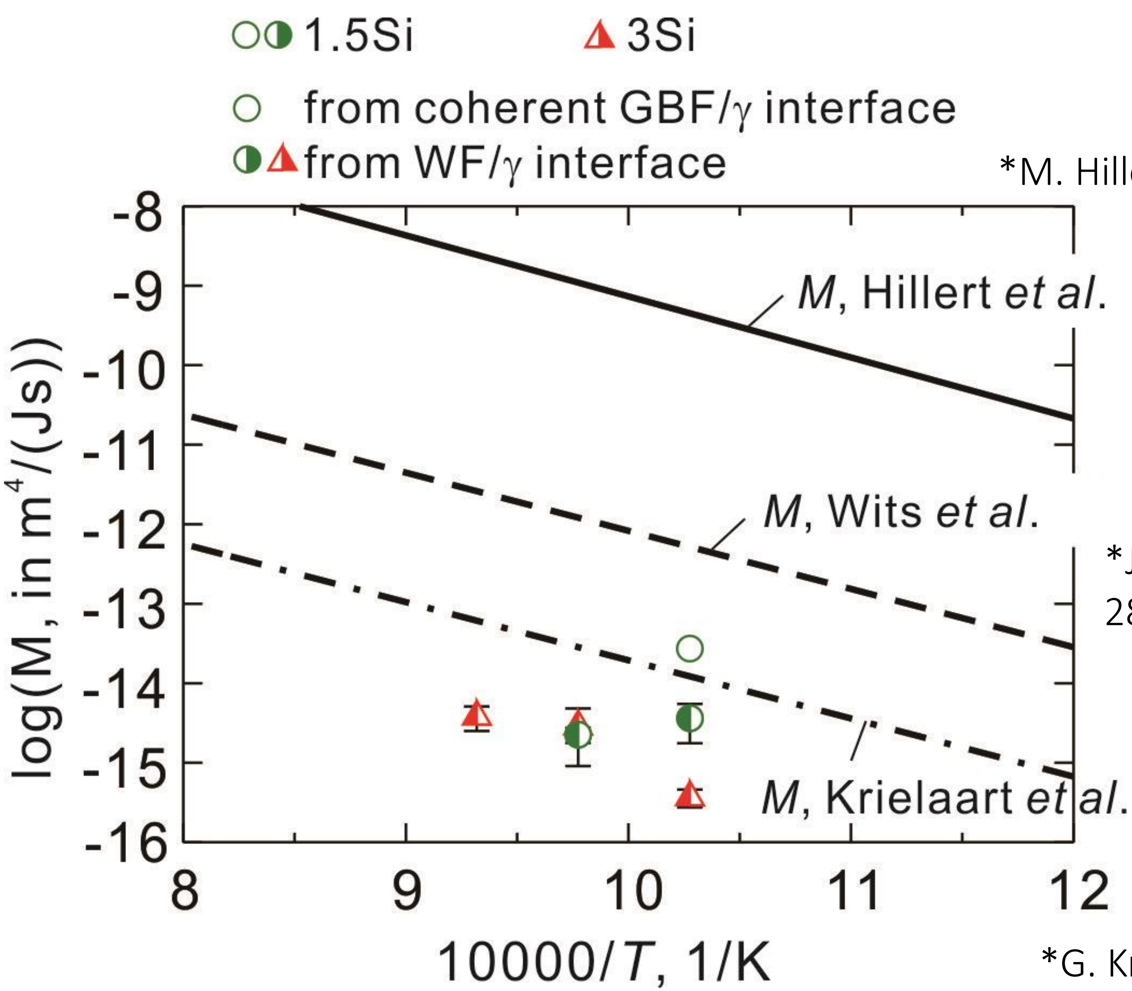
For ΔG_{m}



For v

- From GBF thickness change, estimate $\boldsymbol{v}$ of coherent GBF/γ
- From WF thickness change, estimate $\boldsymbol{v}$ of WF/γ

Discussion: α/γ interface mobility estimation



*M. Hillert, Metall. Trans., 6(1975): 5-19.

*J. Wits et al., Mater. Sci. Eng. A., 283(2000): 234-241.

*G. Krielaart, S. van der Zwaag, Mater. Sci. Technol. 14(1998):10-18.

Summary

- NPLE limit gives well description on:
  - Carbon enrichment of incoherent GBF/γ interface during non-partitioned growth stage;
  - α transformation kinetics transition.

- Deviation of C enrichment at coherent GBF/γ and WF/γ interfaces from NPLE limit at beginning stage is observed. Such deviation is mainly caused by intrinsic friction.

- Mobility of coherent GBF/γ and WF/γ are estimated and is compared with the expressions for incoherent α/γ interfaces.

Additional explanations

Slide 19: Mn, Si comparison
Slide 20-21: Effect of Si partitioning

Slide 23: Equations used estimating GBF/gamma interface velocity
Slide 24: Measurement of WF thickness

Comparison between Fe-Mn-C and Fe-Si-C systems

	α / γ stabilizer	Interaction with C
Mn	γ	Attractive
Si	α	Repulsive

↑

Suppressing θ precipitation

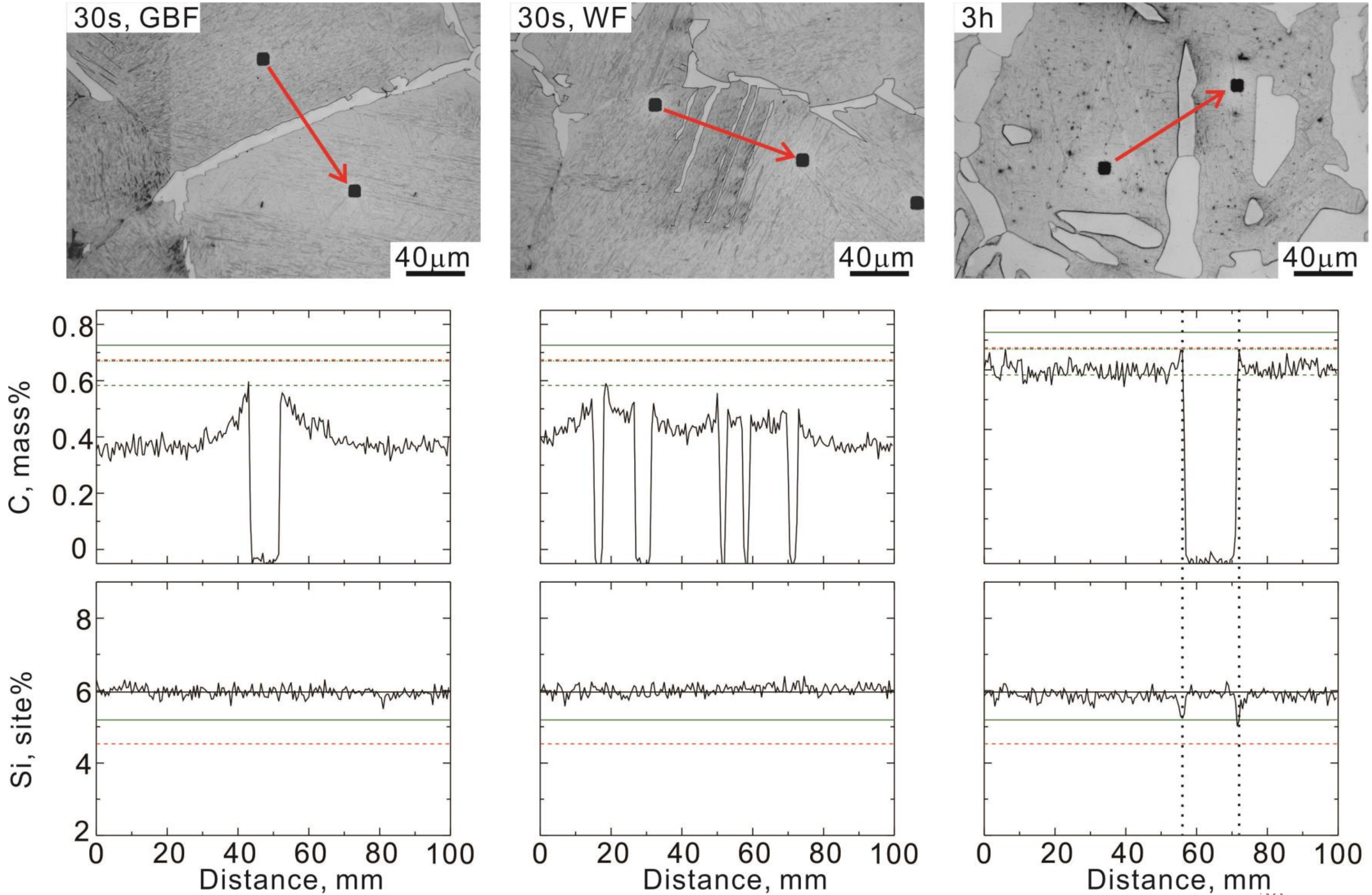
Widely added in transformation induced plasticity (TRIP) steels.

Ferrite transformation

- Effect of morphology and holding time

3Si alloy at 800 °C

*GBF: grain boudary ferrite; WF: Widmanstatten ferrite



Ferrite transformation

• Effect of morphology and holding time

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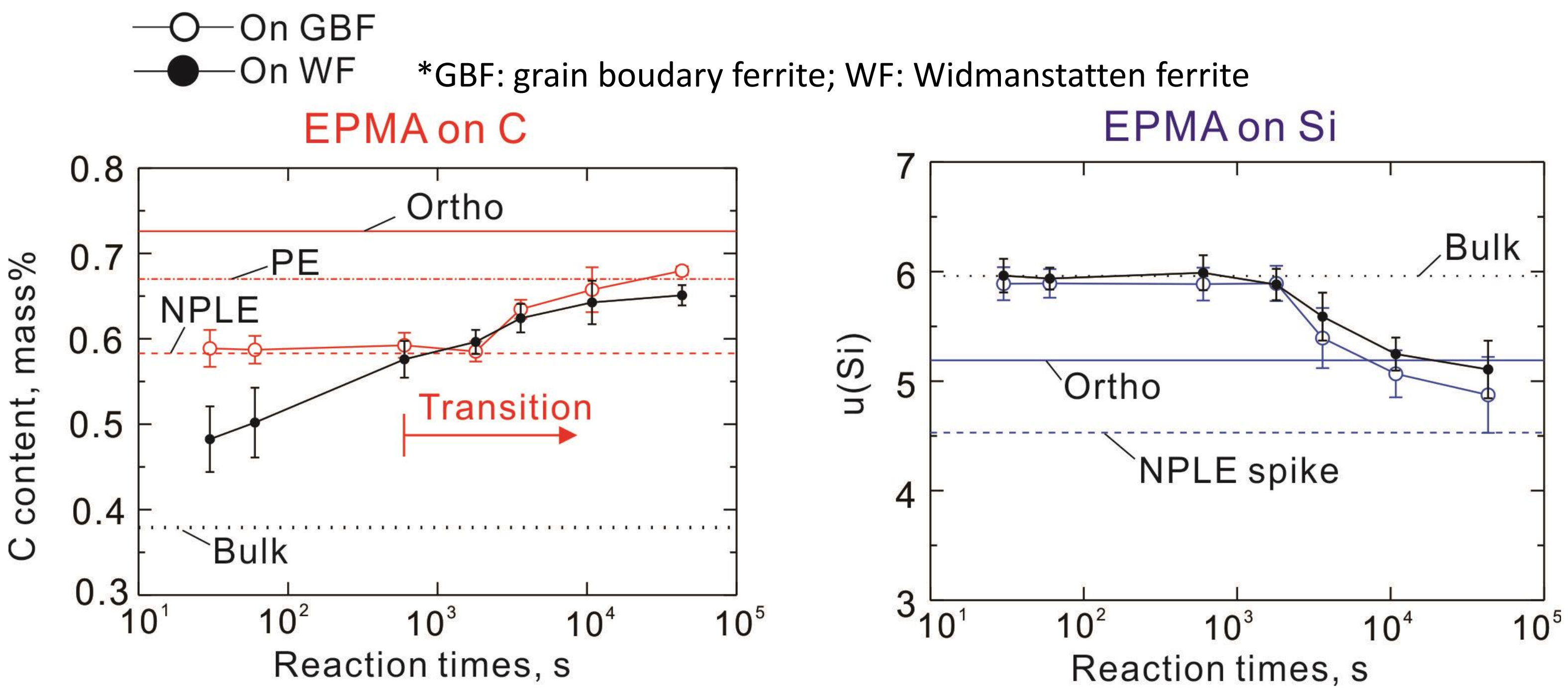


✓ For carbon enrichment

- GBF agrees well with NPLE limit during non-partitioned α growth
- WF deviates from NPLE limits and the deviation gradually diminishes .

✓ Si partitioning is observed for prolonged reaction and higher C% corresponds to a lower Si% at the interface

Equations used estimating GBF/gamma interface velocity

$$d_{\mathrm{GBF}} = \frac{\sqrt{\pi}}{4} f_{\mathrm{GBF}} \cdot d_{\gamma} \quad \textbf{(1)}$$

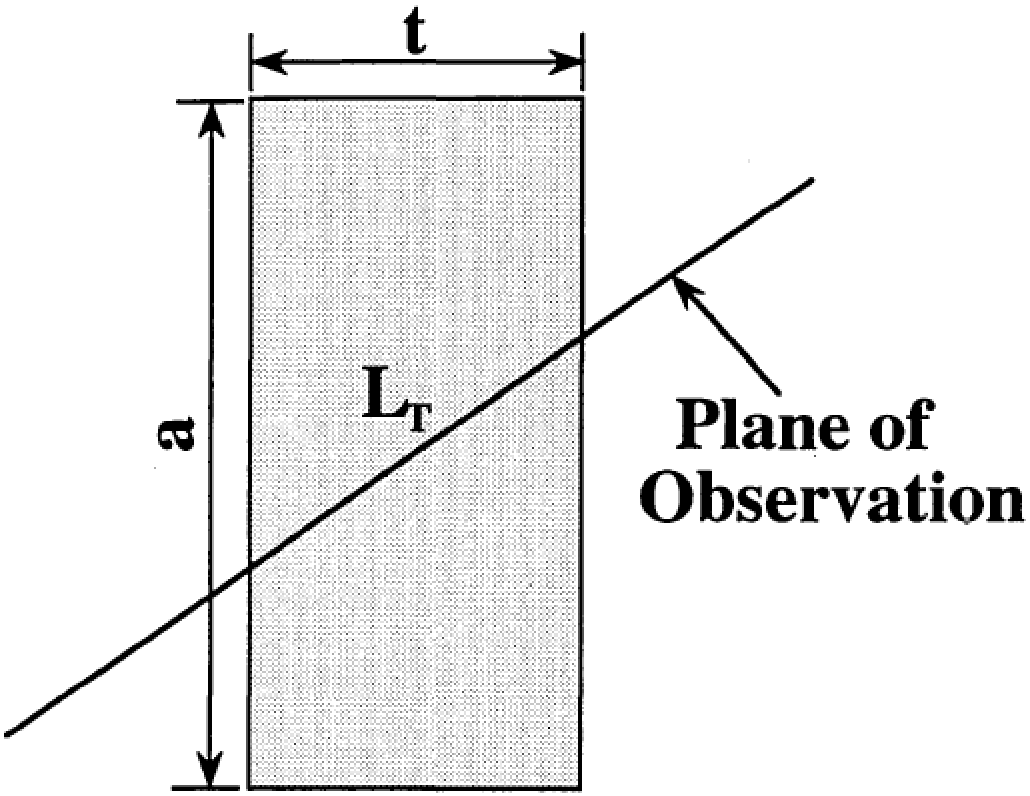
$$d_1 = \alpha \cdot (t_1 - \Delta t)^{0.5} \quad \textbf{(2)}$$

$$d_2 = \alpha \cdot (t_2 - \Delta t)^{0.5} \quad \textbf{(3)}$$

$$\alpha = \sqrt{\frac{{d_2}^2 - {d_1}^2}{\Delta t}} \quad \textbf{(4)}$$

$$v = \frac{{d_2}^2 - {d_1}^2}{\Delta t \cdot d_1} \quad \textbf{(5)}$$

Measurement of WF thickness



WF thickness measurement:
LT is shortest distance perpendicular to the longitudinal dimension of the WF plate at half length site (L_{T}).
The same procedure is repeated for >30 different plates for each specimen and results are averaged.

The relationship** follows,

$$L_{\mathrm{T}} = 2t$$

Ref:
Chang, L. and H. Bhadeshia (1995). "Austenite films in bainitic microstructures." Materials Science and Technology 11(9): 874-882.

**C. MACK: Proc. Camb. Philos. Soc., 1956,52, 246.