

**PE to LEMP transition in
Fe-Mn-C and Fe-Ni-C systems**

+

**Transient effects
associated with rapid temperature jumps
during decarburization**

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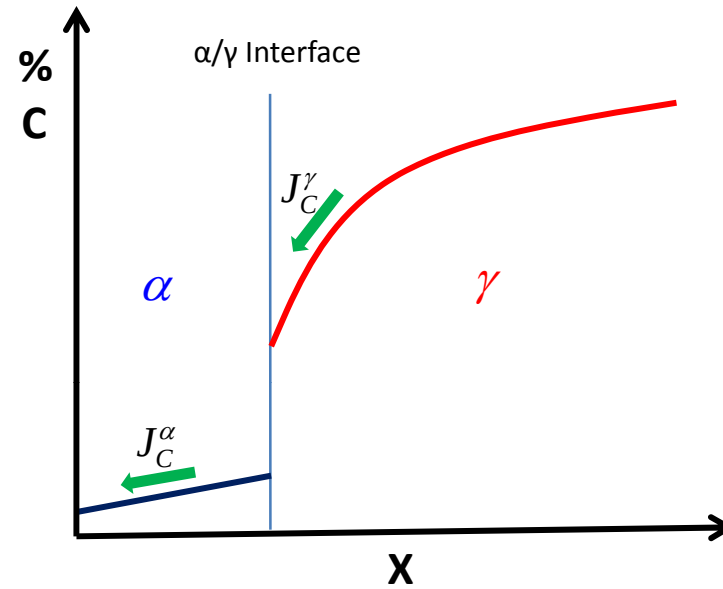
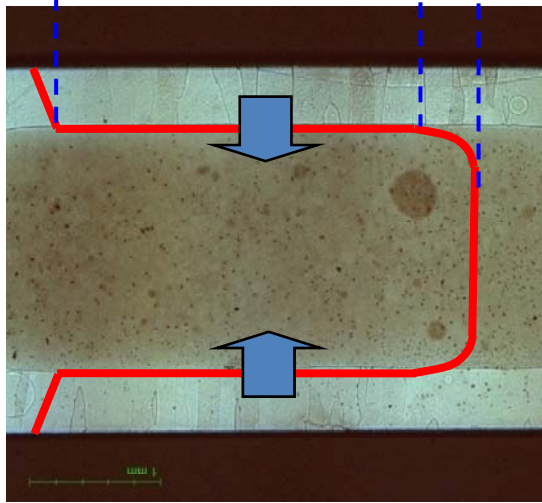
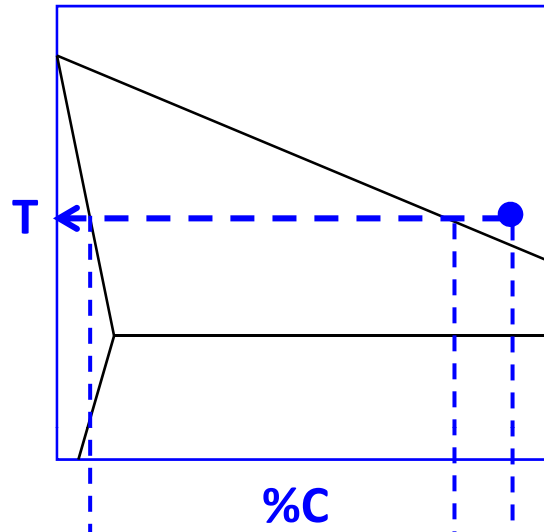
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Outline:

- Decarburization as a method for investigating kinetics of γ to α transformation
- PE o LNP transition in Fe-Mn-C and Fe-Ni-C systems
- Frustrated systems
 - What if we introduce a big temperature change during decarburization?
 - Results in Fe-C system
 - Discussion: Possible explanations for our observations
 - Expansion to ternary systems (Fe-Mo-C)
 - Results in Fe-Mo-C systems
- Summary

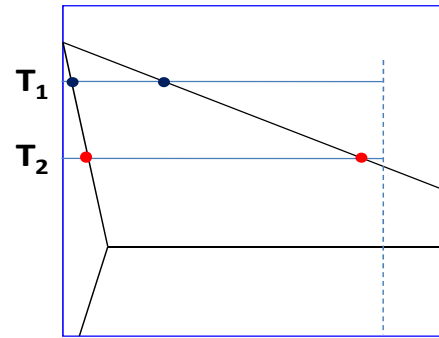
Decarburizing



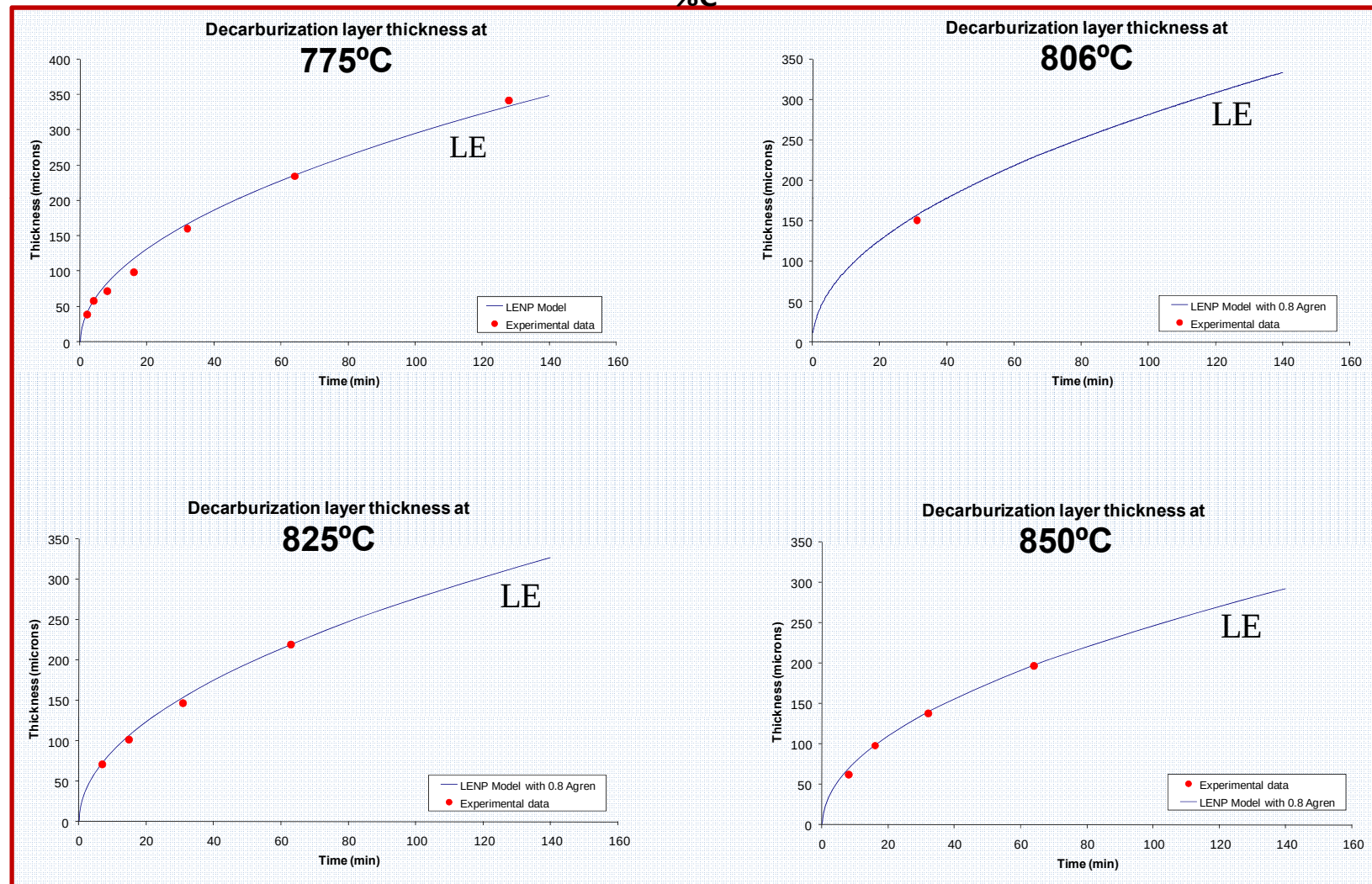
$$\frac{dz}{dt} = \frac{J_i^\alpha - J_i^\gamma}{C_i^\gamma - C_i^\alpha}$$

We can get both **positive** and **negative** velocities

Fe- 0.57_{wt%} C



%C



Boundary conditions in ternary Fe-C-*i* systems

(e.g. *i* = Mn, Si, Mo, Cr, Nb, Ti, V,...)

Para-Equilibrium

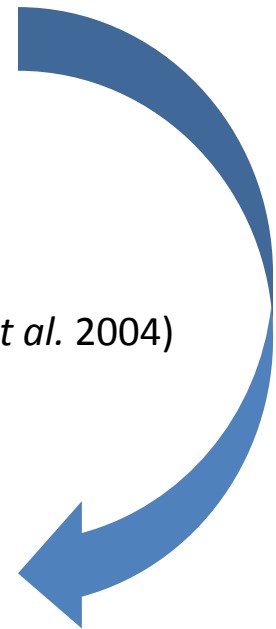
$$\left\{ \begin{array}{l} \mu_C^\alpha = \mu_C^\gamma \\ \mu_M^\gamma - \mu_M^\alpha = -\left(\mu_{Fe}^\gamma - \mu_{Fe}^\alpha\right) \cdot \frac{X_{Fe}}{X_M} \end{array} \right.$$

Transition Models

(e.g. Odqvist *et al.* 2002, Hutchinson *et al.* 2004)

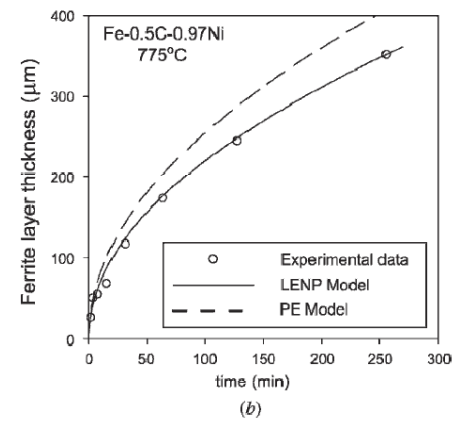
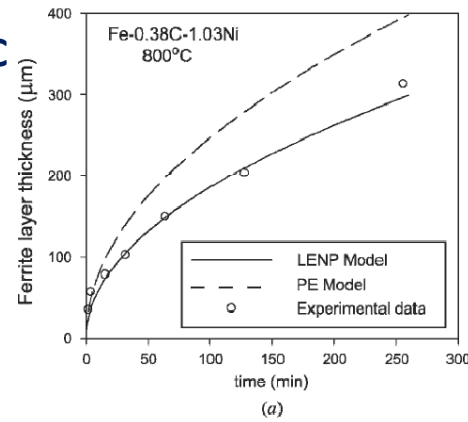
Local Equilibrium (LE-P & LE-NP)

$$\left\{ \begin{array}{l} \mu_C^\alpha = \mu_C^\gamma \\ \mu_{Fe}^\alpha = \mu_{Fe}^\gamma \\ \mu_i^\alpha = \mu_i^\gamma \end{array} \right.$$



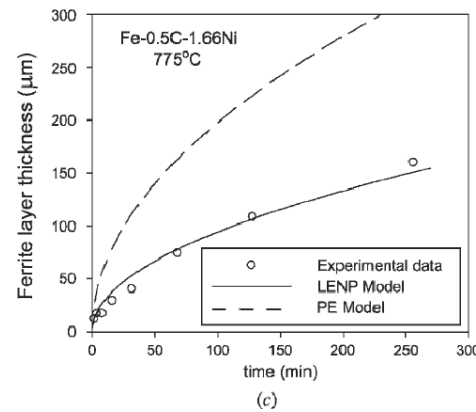
Fe-Ni-C

800 °C

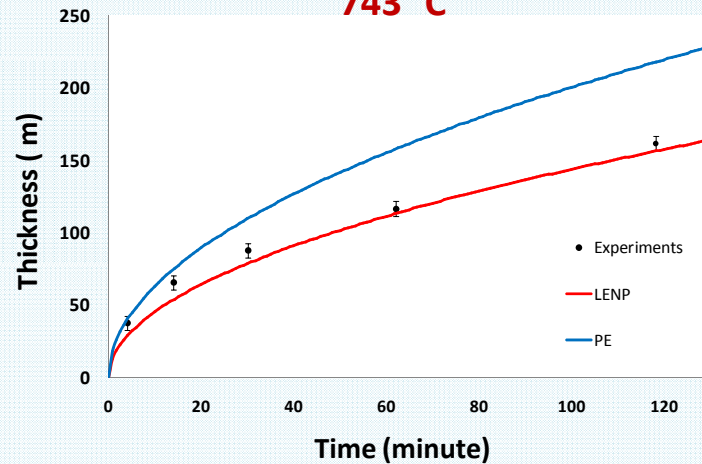


775 °C

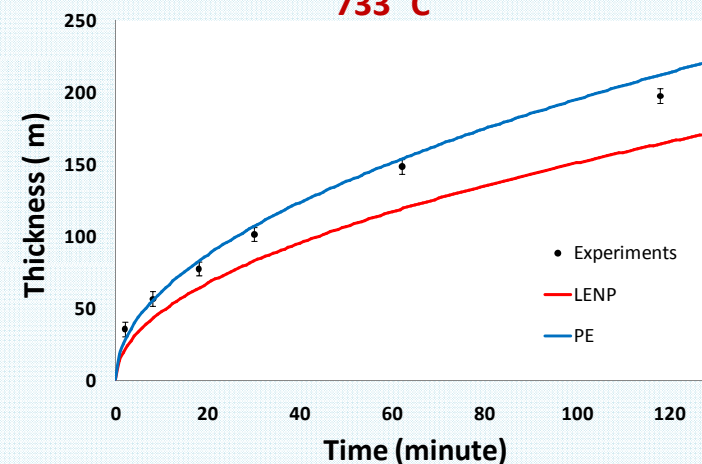
C.R. Hutchinson, H.S. Zurob
and Y. Brechet, *Metall.
Mater. Trans. A*, Vol. 37
(2006), p.1711.



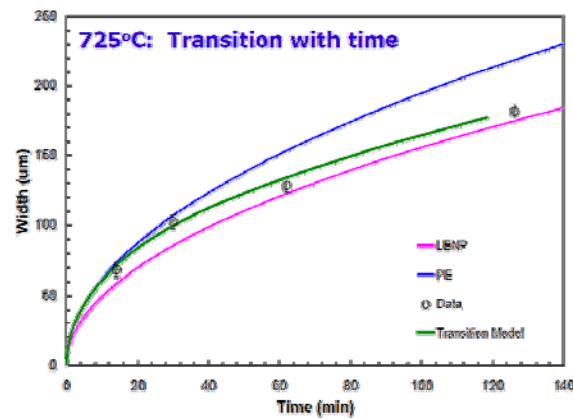
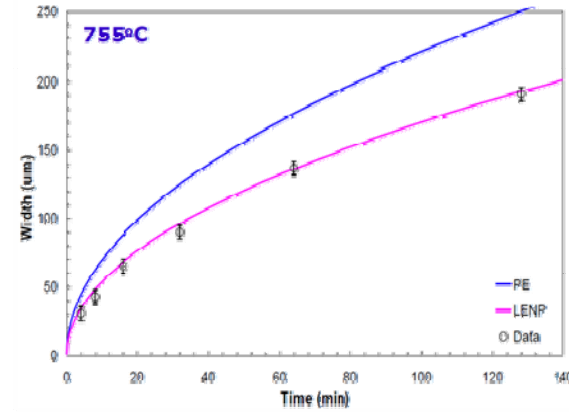
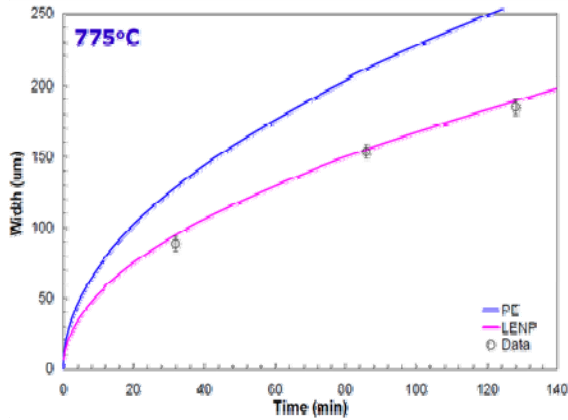
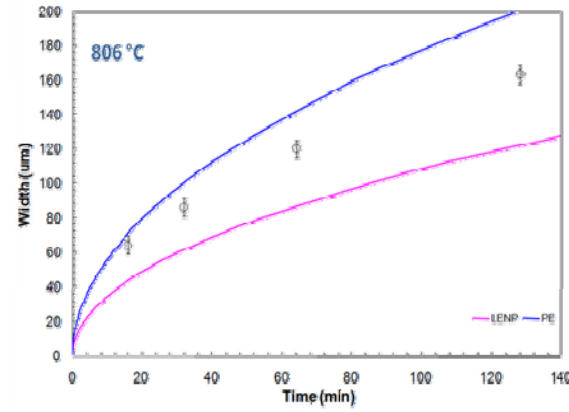
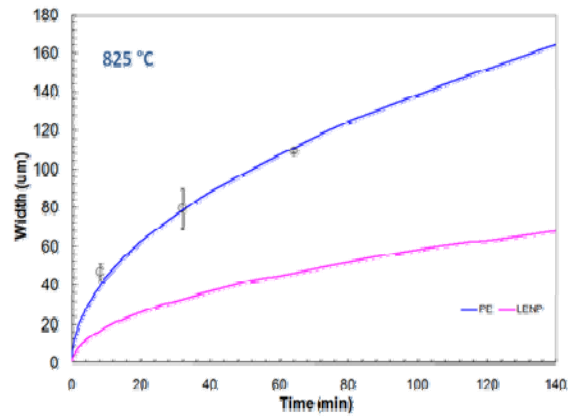
Fe - 1.72 Ni - 0.51 C
743 °C



Fe - 1.72 Ni - 0.51 C
733 °C



Fe-Mn-C (Fe - 1.0 wt% Mn - 0.57 wt% C)



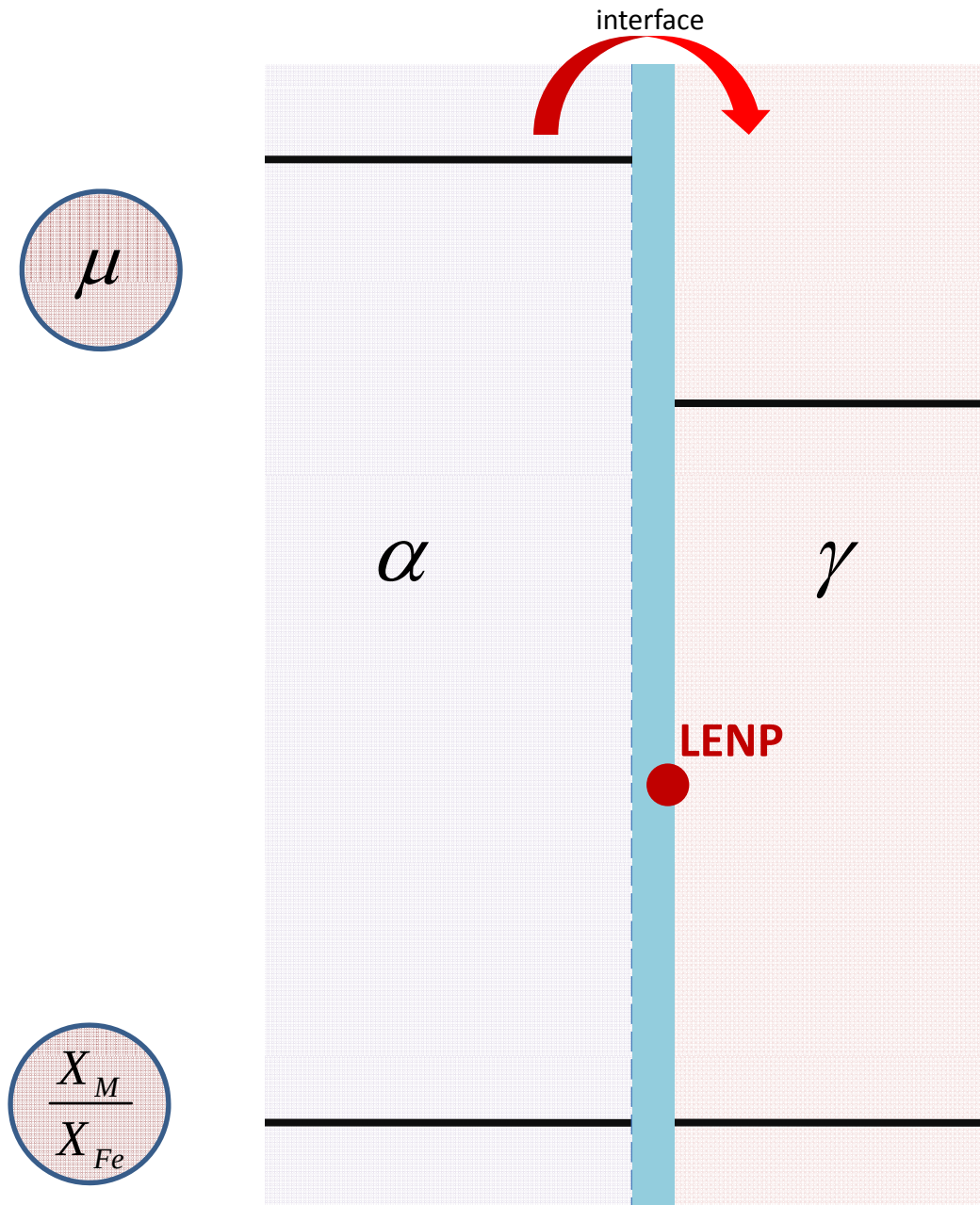
PE

LENP

T

PE

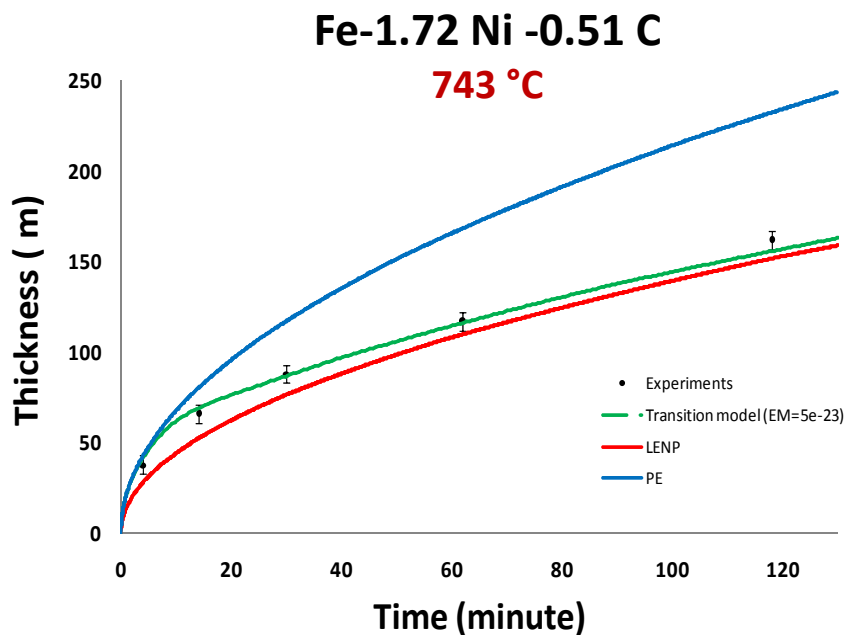
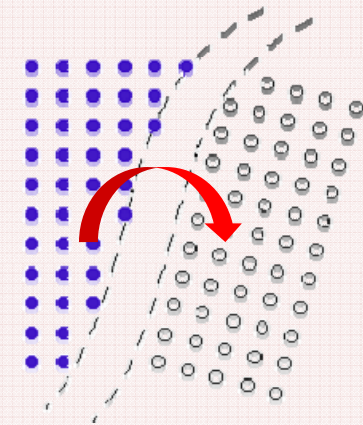
Hutchinson *et al.* Transition Model (2004) :



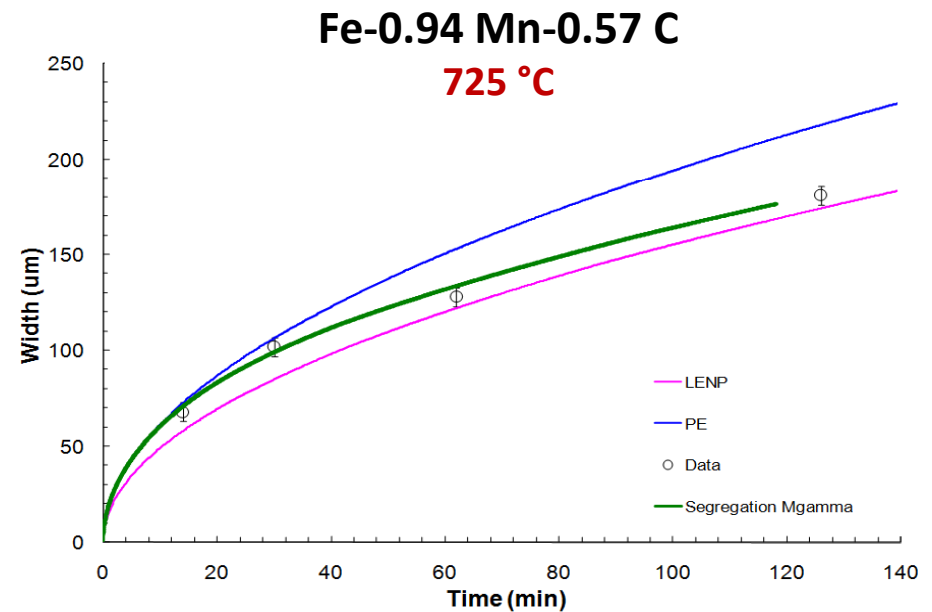
Hutchinson et al. Transition Model (2004) :

$$\Delta G^{DF} = \frac{(U_M^{fcc} + U_M^{bcc})}{2} \cdot (\mu_M^{fcc} + \mu_M^{bcc}) + \frac{(U_{Fe}^{fcc} + U_{Fe}^{bcc})}{2} \cdot (\mu_{Fe}^{fcc} + \mu_{Fe}^{bcc})$$

$$J_M^{\alpha \rightarrow \gamma} = \frac{X_M^b}{V_m} \cdot \frac{M_M^{Trans-int}}{V_m} \cdot \frac{(\mu_M^\gamma - \mu_M^\alpha)}{\delta} \left(1 - \exp \left(\frac{-D_M^{Trans-int}}{v\delta} \right) \right)$$



Ni cross interface mobility $\approx 10 \times M_{Ni}^\gamma$

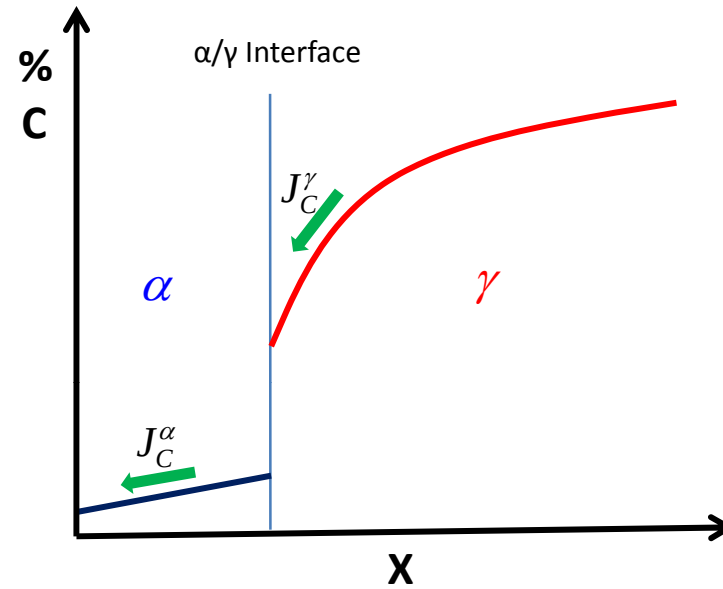
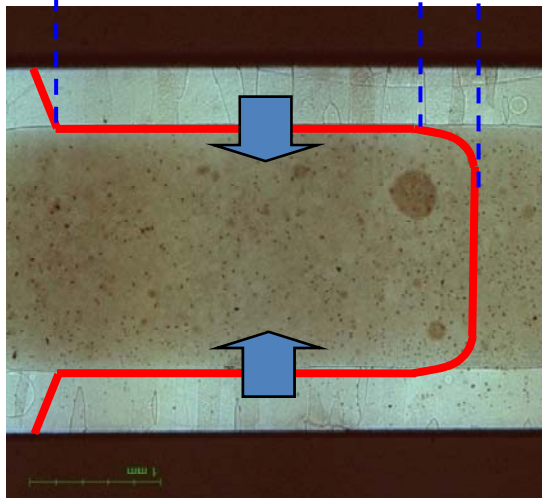
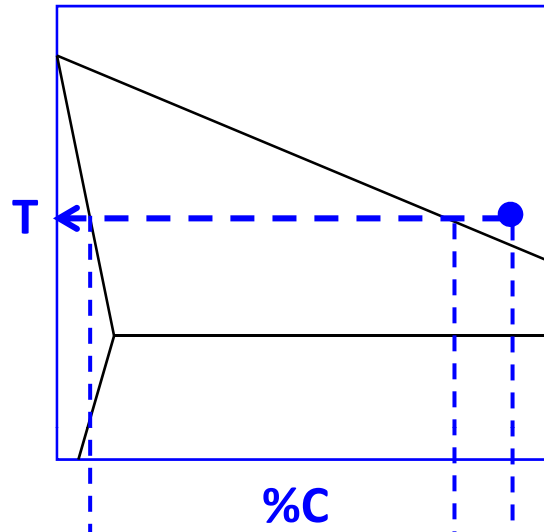


Mn cross interface mobility $\approx M_{Mn}^\gamma$

Frustrated System!

What if we significantly changed the temperature
during decarburization?

Decarburizing

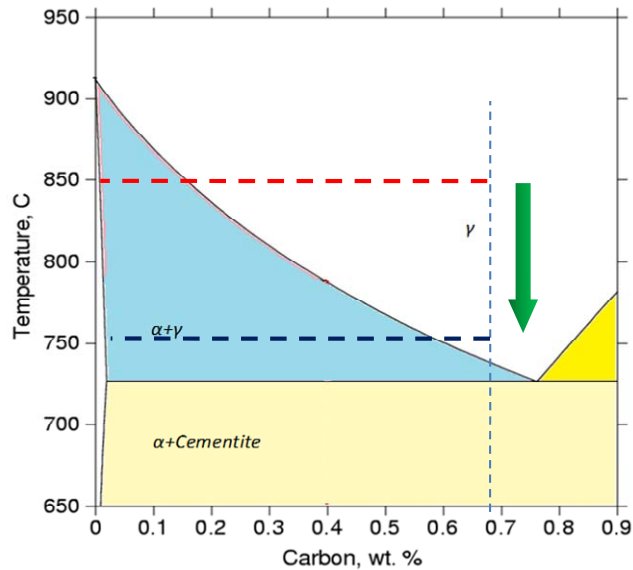


$$\frac{dz}{dt} = \frac{J_i^\alpha - J_i^\gamma}{C_i^\gamma - C_i^\alpha}$$

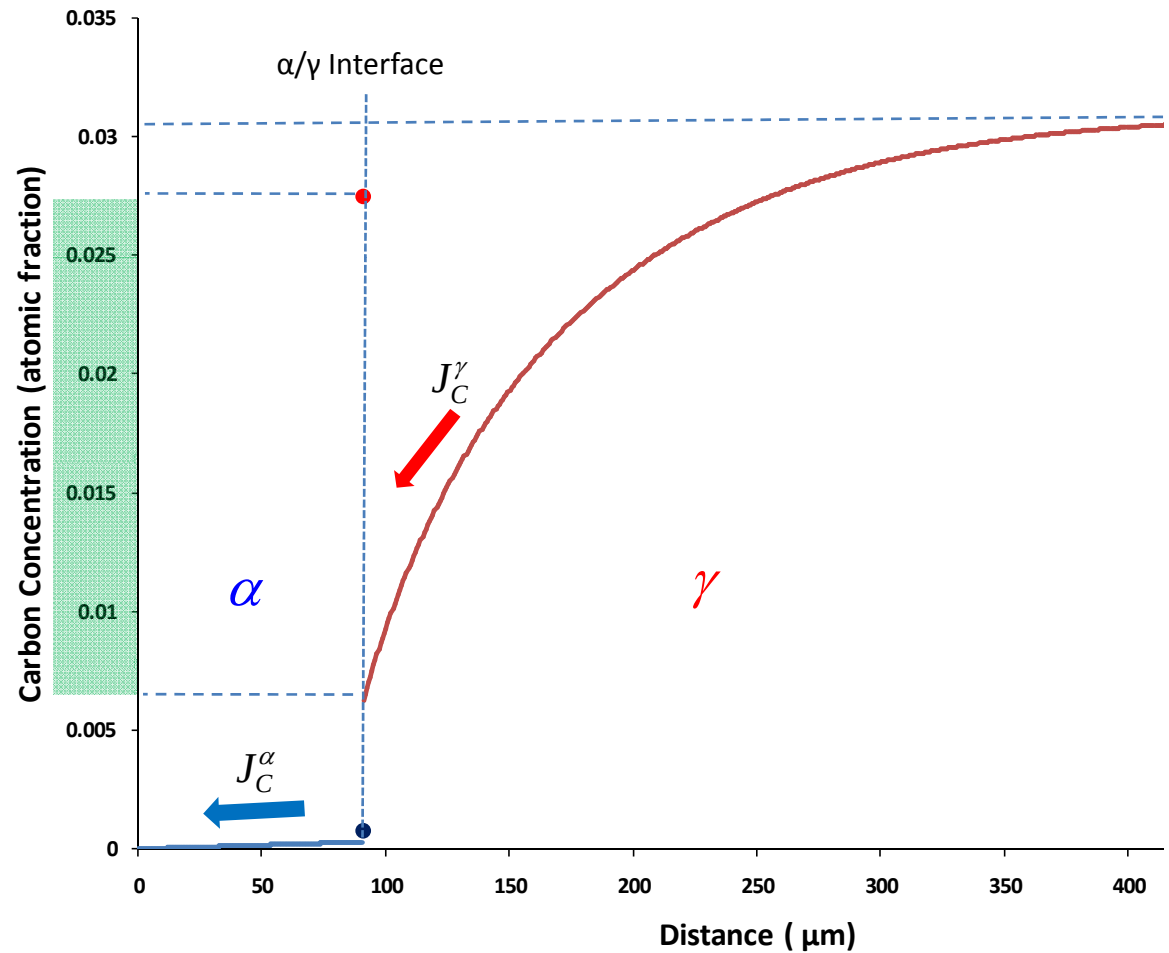
We can get both **positive** and **negative** velocities

Fe - 0.67 wt% C

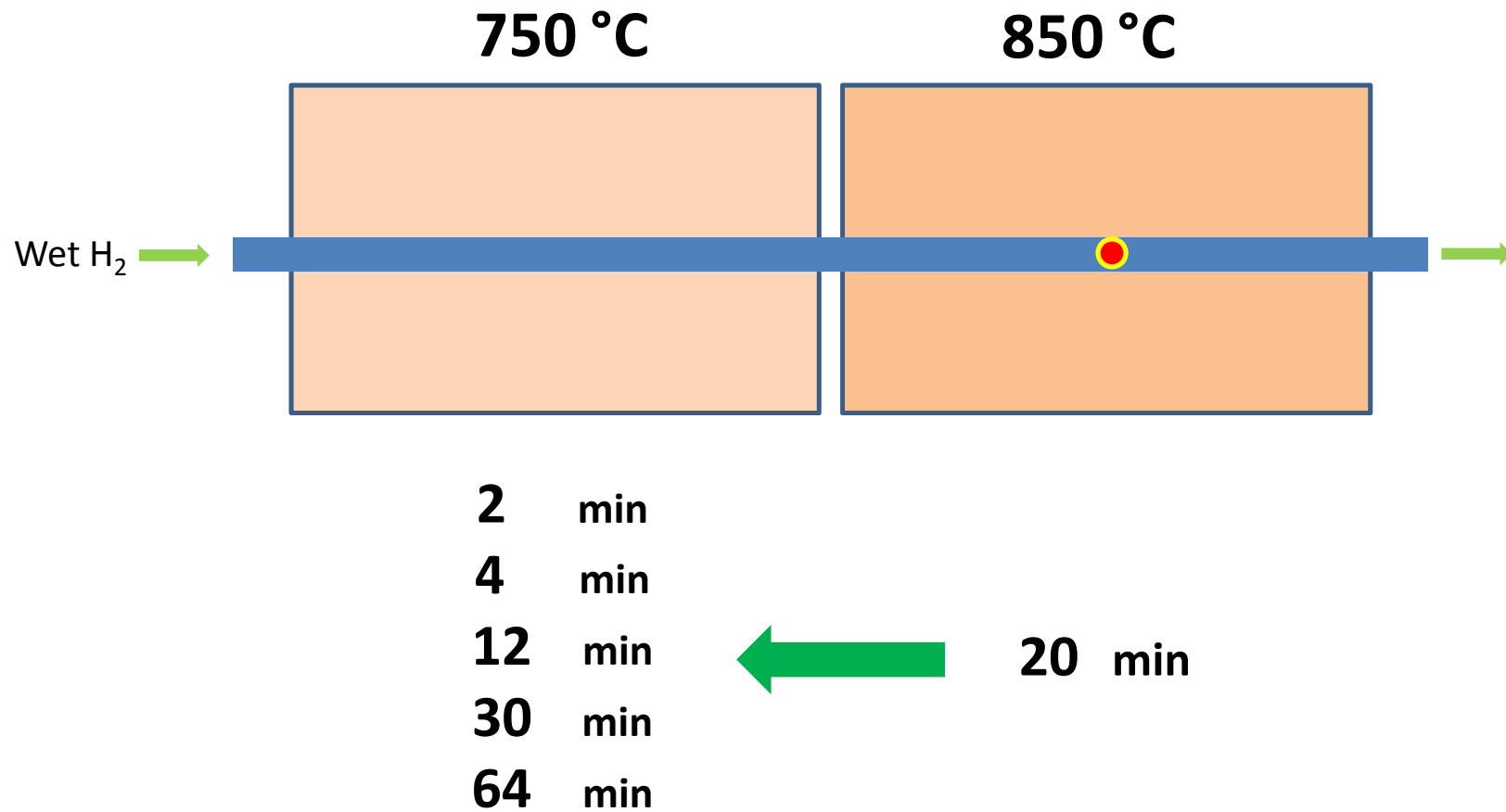
850 °C → 750 °C

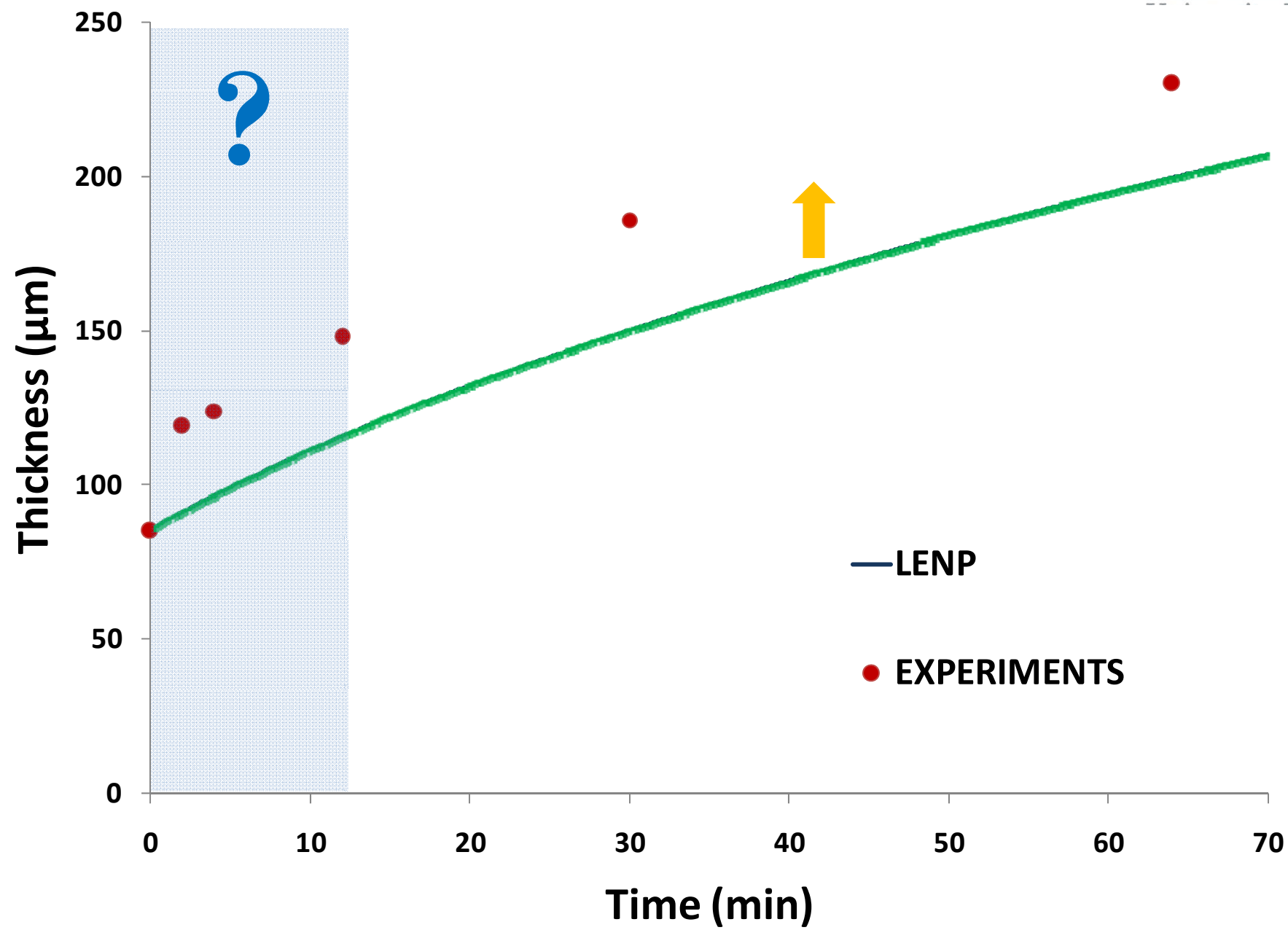


850 C - 20 min-----> 750 C

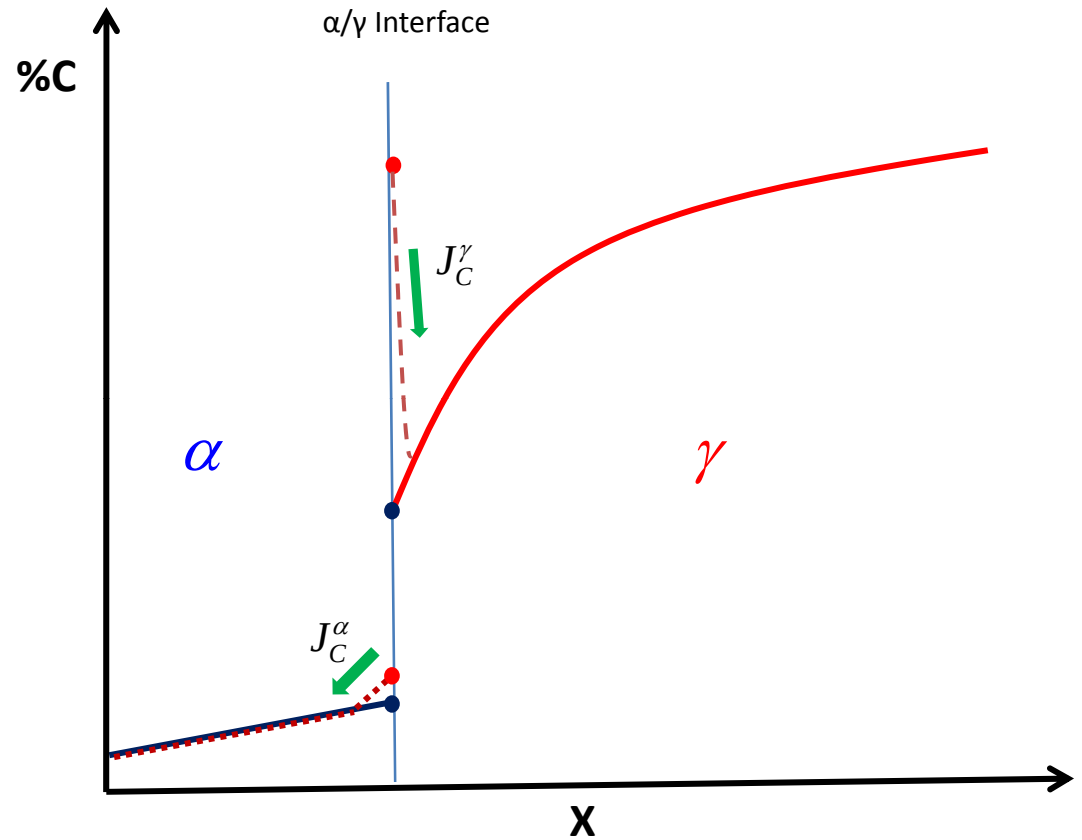
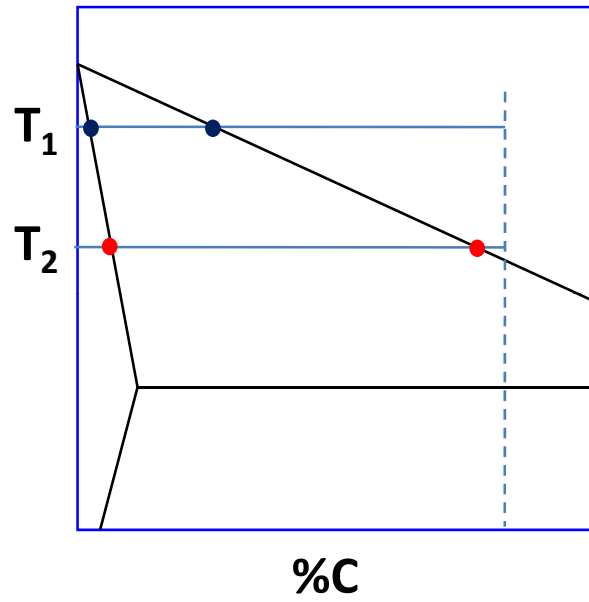


Experiments



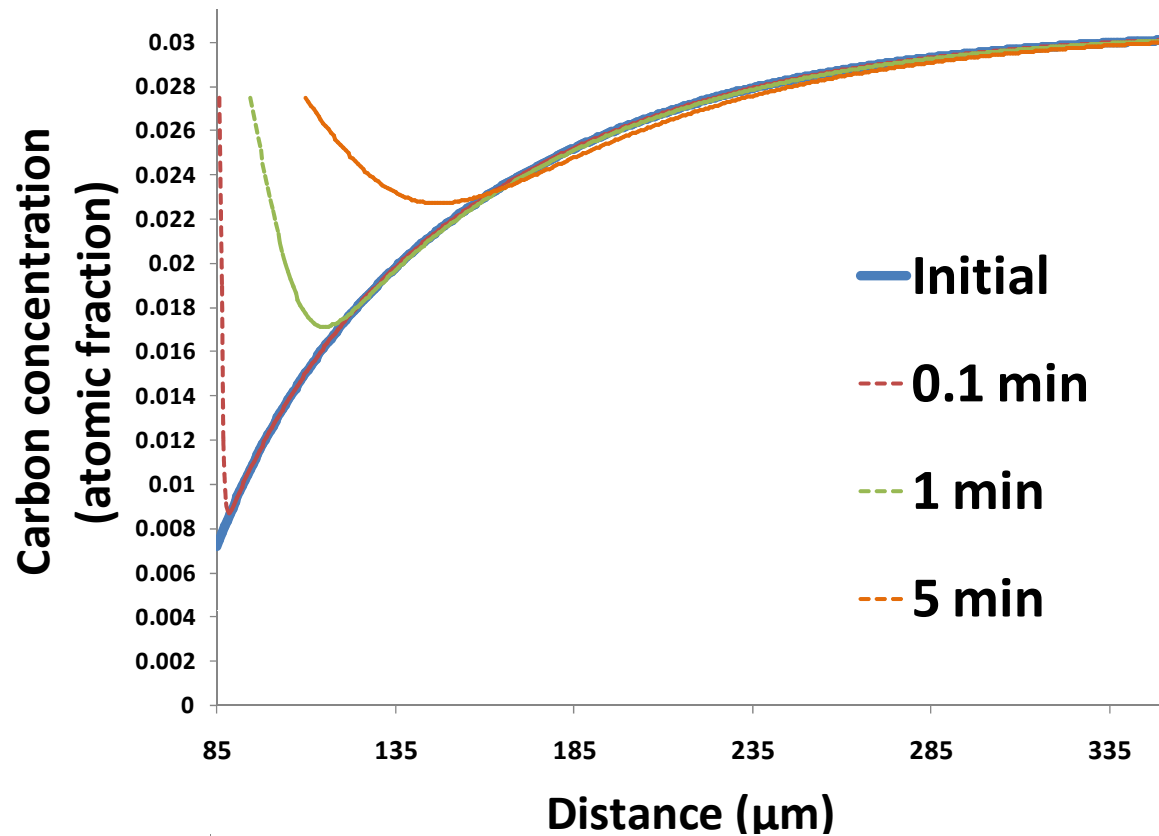


Full equilibrium at the interface

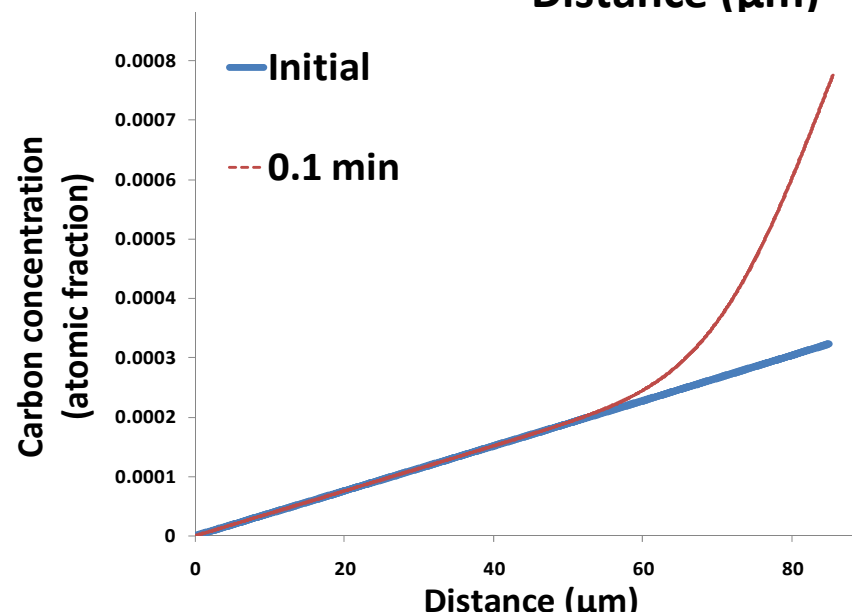


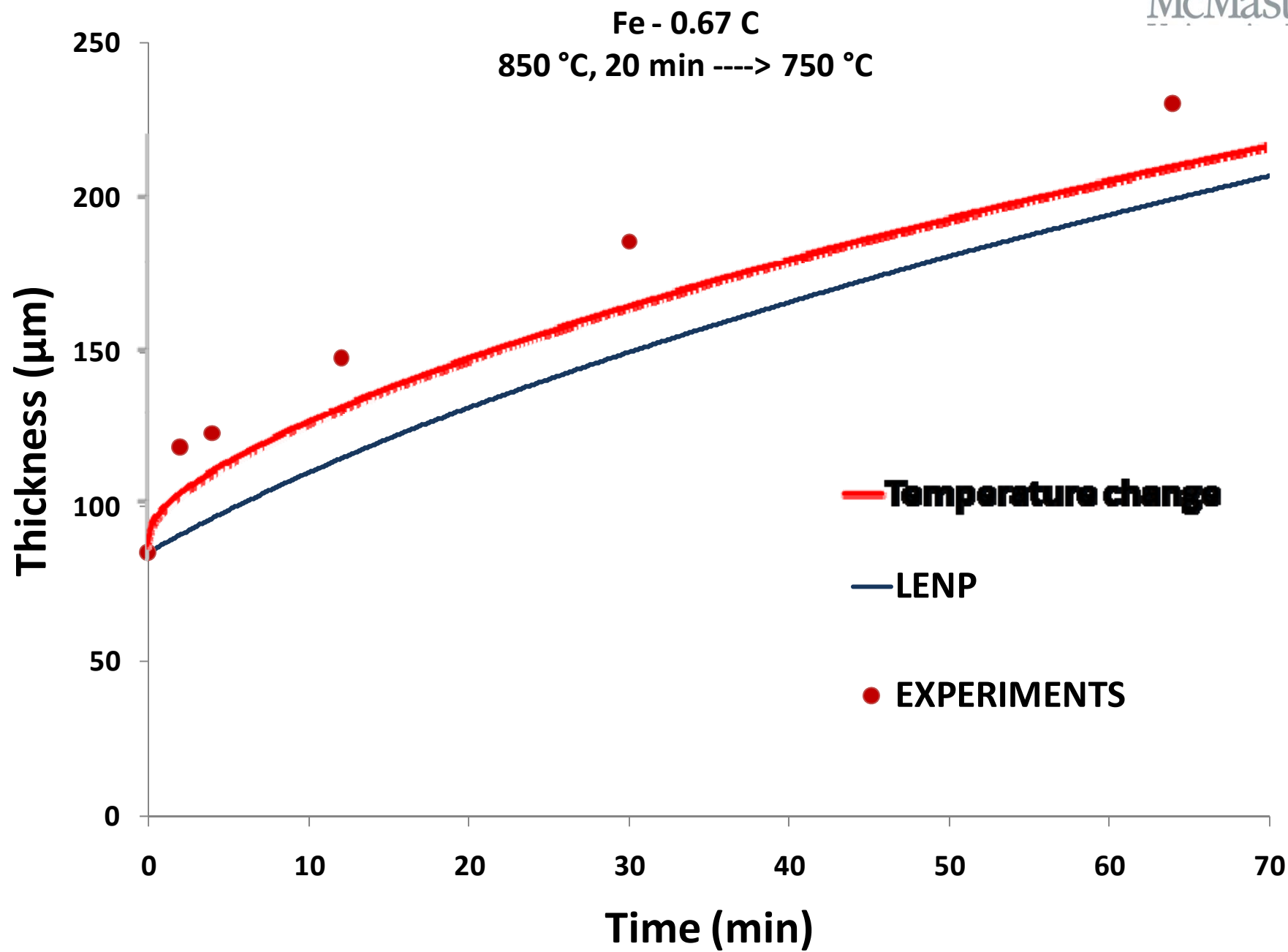
$$v = \frac{J_i^\alpha - J_i^\gamma}{C_i^\gamma - C_i^\alpha}$$

**Austenite
Carbon profile**



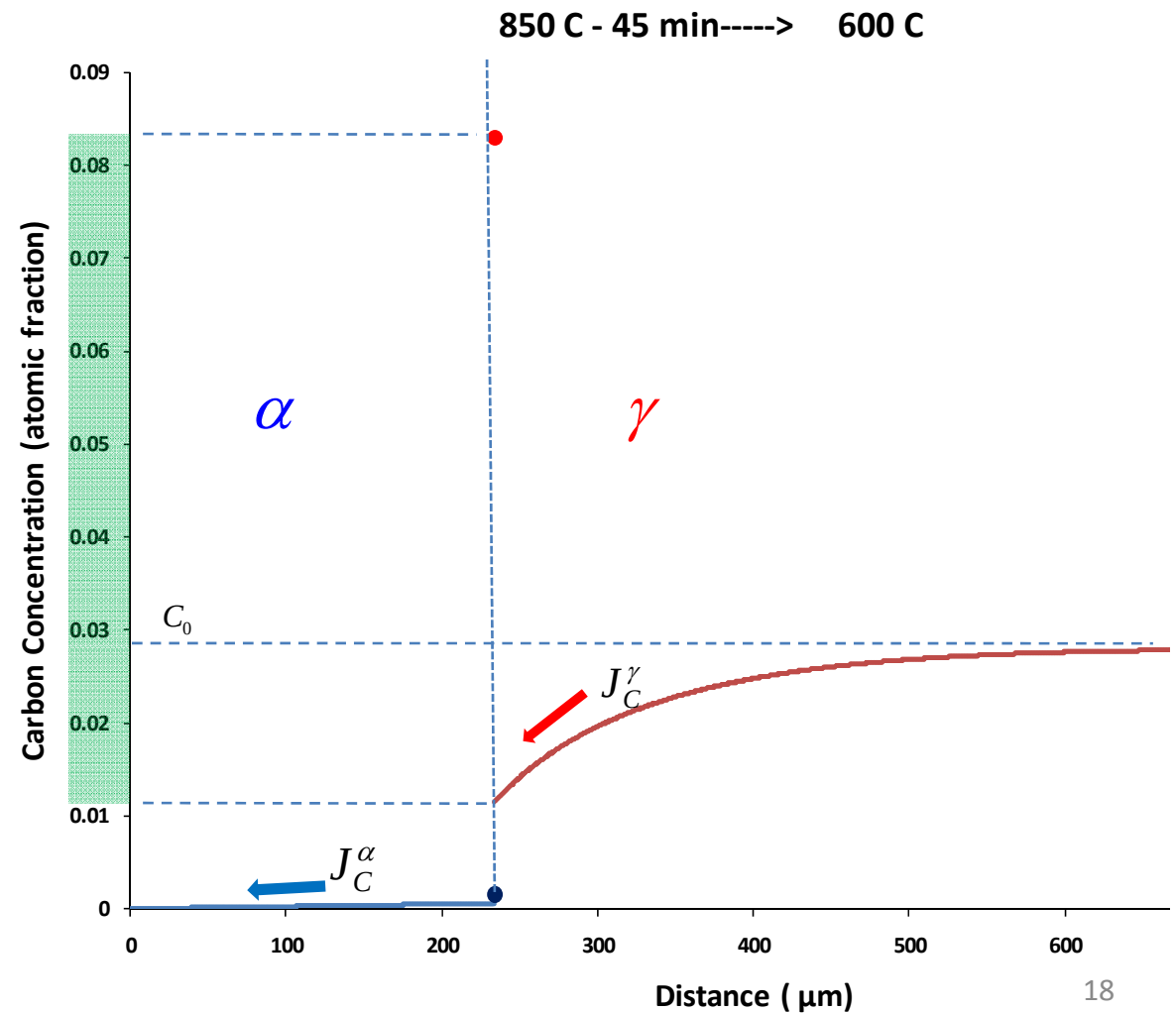
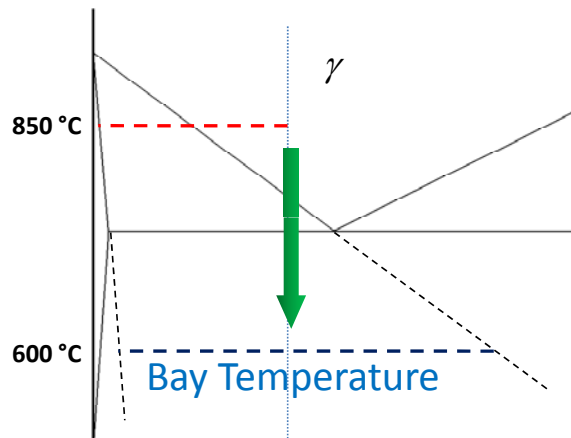
**Ferrite
Carbon profile**

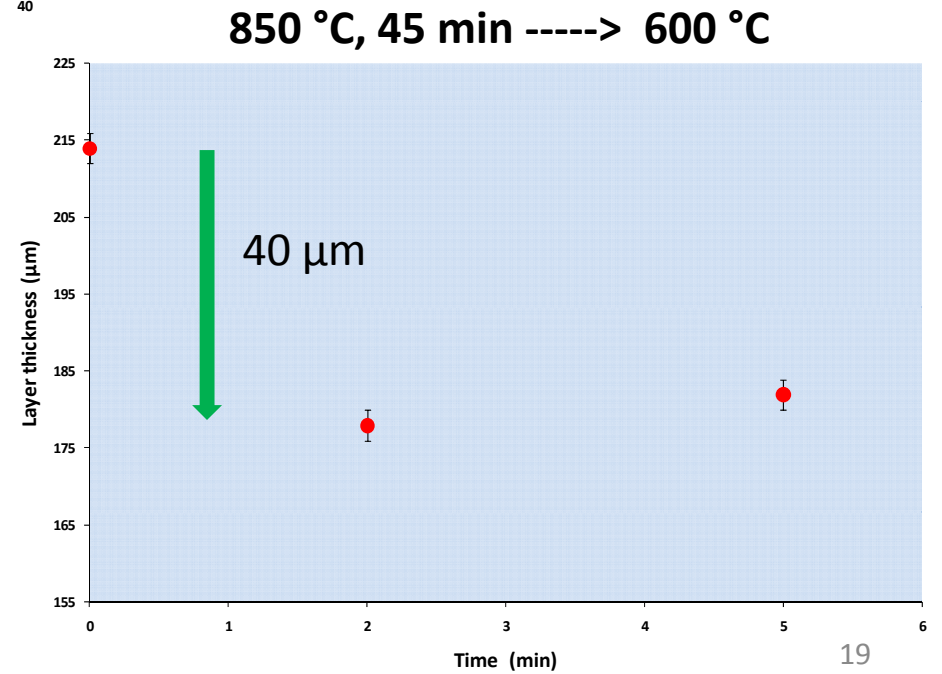
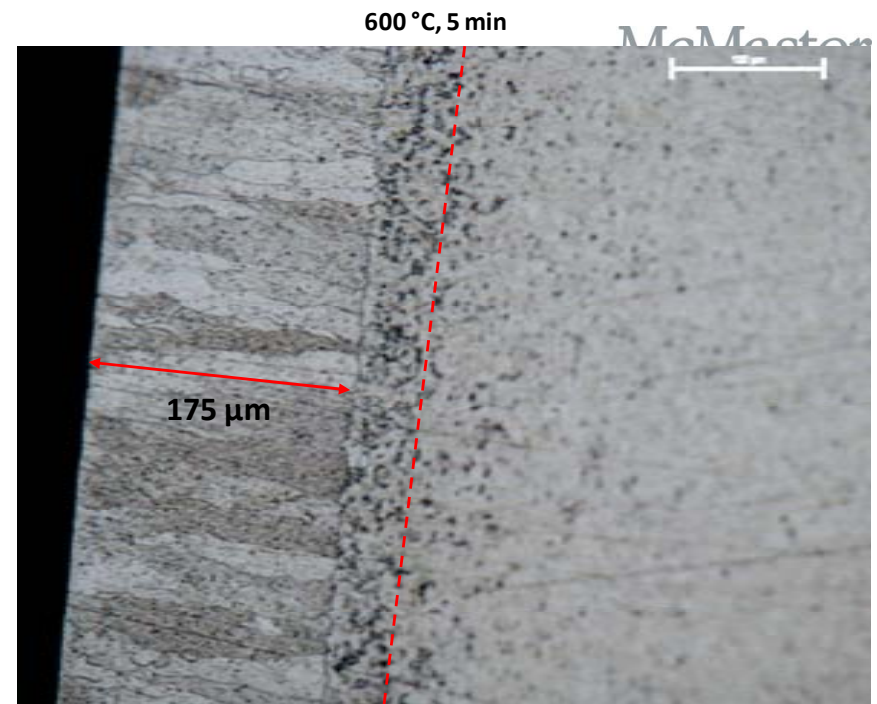
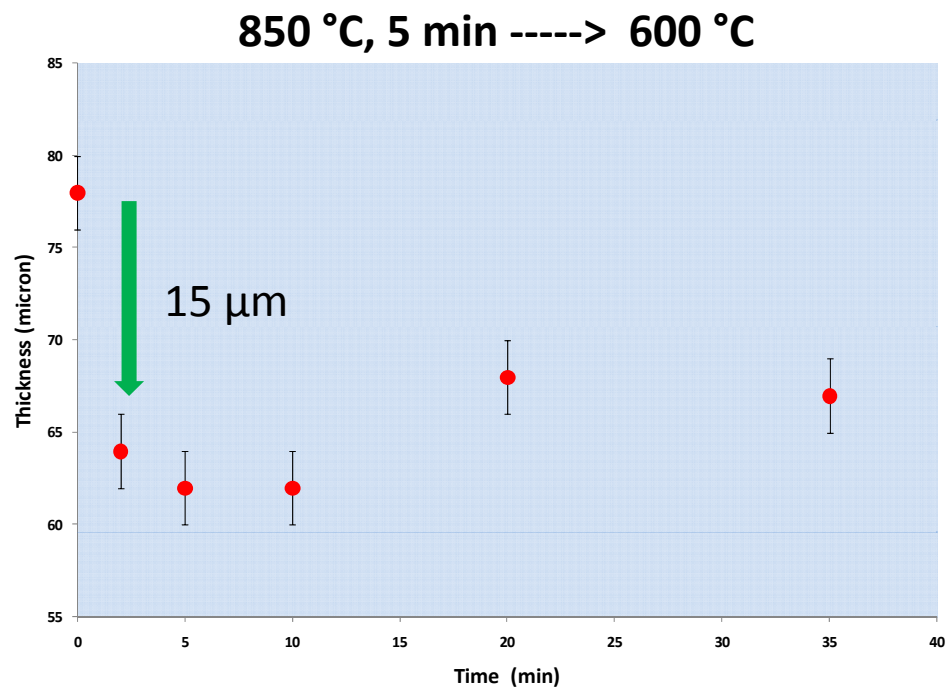




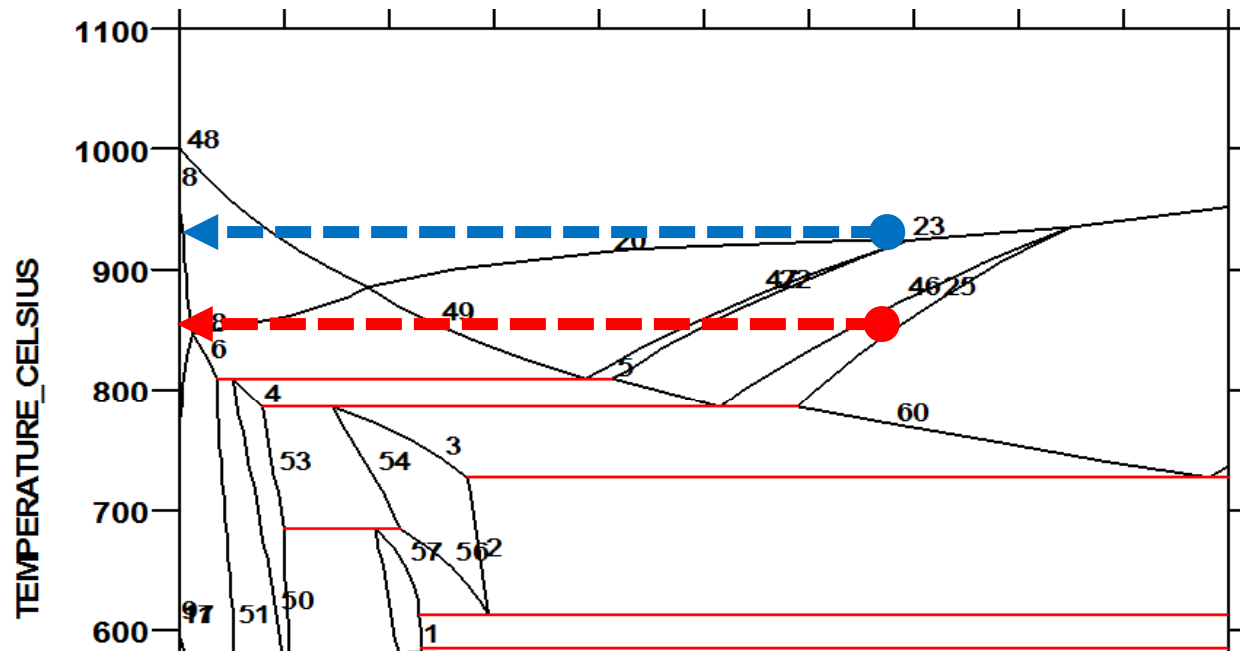
Fe - 1.86 wt% Mo - 0.65 wt% C

850 °C → 600 °C

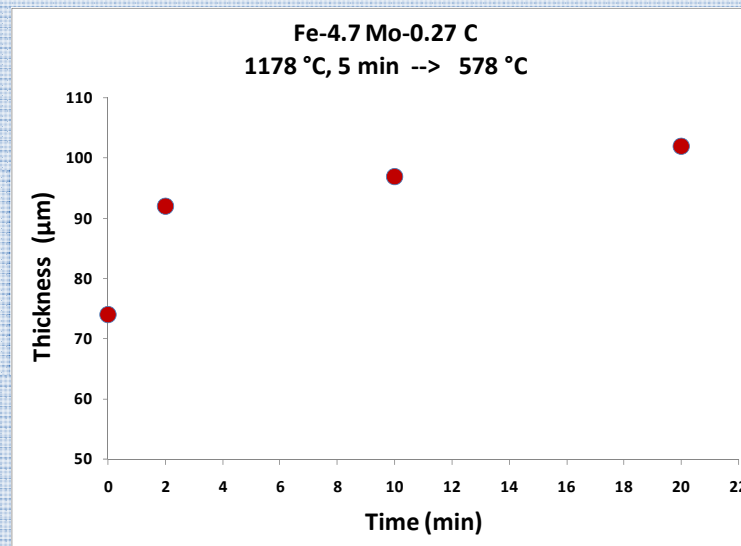
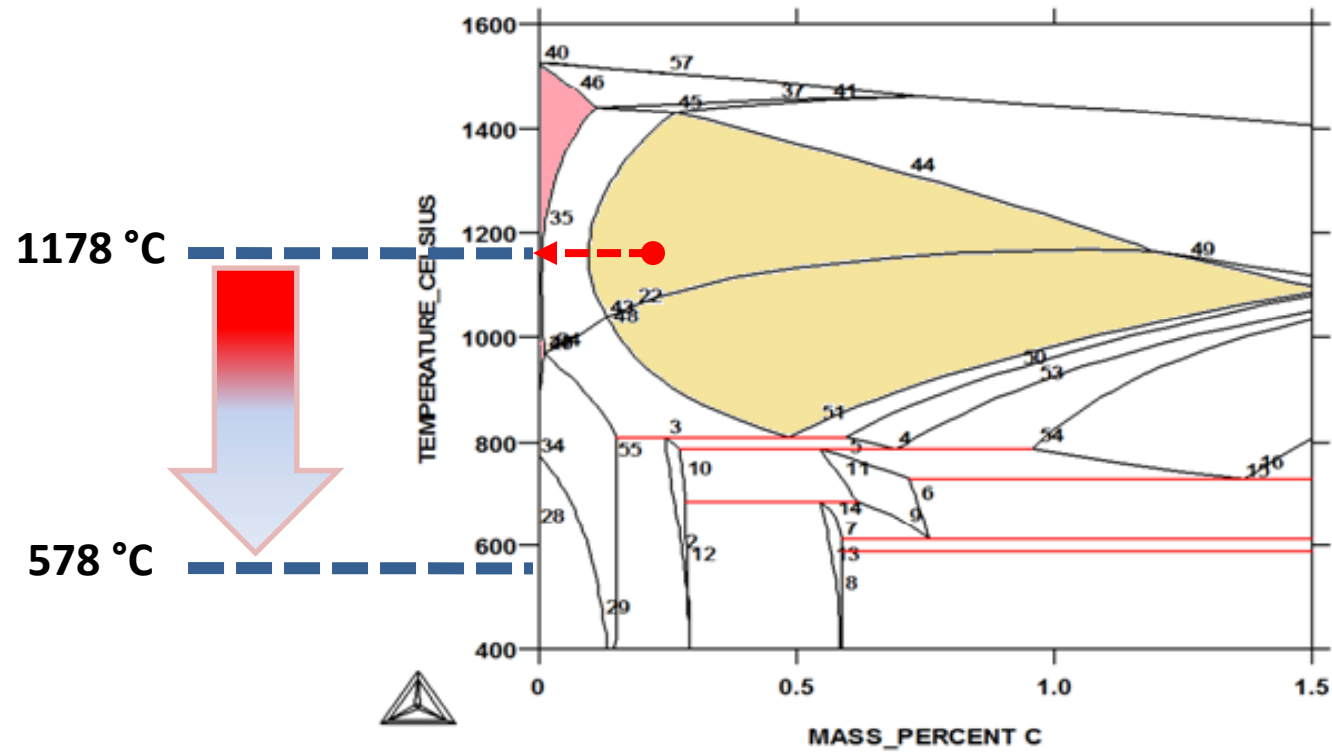




Fe - 1.85_{wt%} Mo - C



Fe – 4.72 wt% Mo – 0.27 wt% C



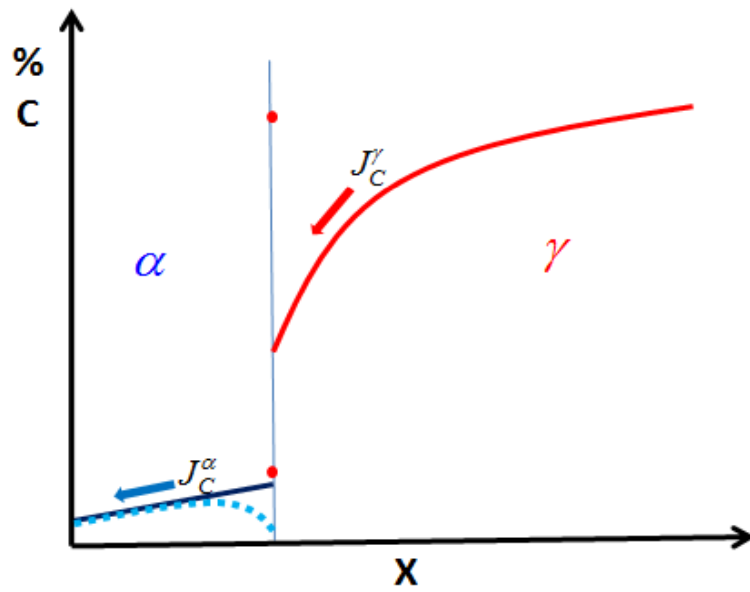
Summary:

- **Experimental observation of PE to LENP transition**
 - Calculation of Trans-Interface mobility of Ni and Mn in Fe-Mn-C and Fe-Ni-C systems according to Hutchison's transition model.
- **Frustrated systems**
 - Interface acceleration in binary Fe-0.67 C system and Fe- 4.72 Mo -0. 27 C
 - Backward motion in Fe- 1.85 Mo- 0.62 C

Acknowledgement:

- Dr. Yves Brechet
- Dr. Dmitri Malakhov

*Thank you
for your attention*



$$v = \frac{(J^\alpha - J^\gamma)}{(C^\gamma - C^\alpha)} = \frac{D^\alpha \left(\partial C^\alpha / \partial z \right)_{z=z^*} - D^\gamma \left(\partial C^\gamma / \partial z \right)_{z=z^*}}{(C^\gamma - C^\alpha)}$$

