𝔄𝔩𝔈𝔐𝔍; a brief history

[AlEMI=*Alloying Element effects in Migrating Interfaces*]
{alemi.ca}

For the 12th AlEMI meeting,
Delft, June 24, 25, 2013

Gary Purdy,
McMaster University

Outline:

- Origins of AlEMI; acknowledgements;
- Subsequent meetings;
- Early impact;
- Current emphases; some selected results;
- Future directions?
- (What's missing?)

The motivation:

a strong sense that too many questions remained unanswered about the fundamentals of alloying element effects on phase transformations (especially $\alpha \rightleftarrows \gamma$ in steels). (This in spite of years of experimental and theoretical work.)

The invitation (1999):

a proposal for a series of annual workshops, mainly informal.

The objectives:

- collaboration among interested individuals/groups;
- informal sharing/discussions of plans for new experiments;
- speedy transfer of new results among participants;
- reviews/extensions of theoretical understanding;
- reviews of experimental information already available;
- suggestions of directions for experimentation; evaluation of new techniques;
- consensus on what is needed to improve understanding;
- sharing of a common stock of high-purity alloys;
- advancement of the discipline.

(the original thought was that the major problems would be solved within five years!)

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AlEMI *I*:

October 2000, St. Louis, MO.

Participants:

Hub Aaronson
John Agren
Sam Allen
Suresh Babu
Yves Brechet
Masato Enomoto
Tadashi Furuhara
Bob Hackenberg*
Malcolm Hall
Mats Hillert
Chris Hutchinson*
Gerhard Inden
Ernst Kozeschnik
Zi-Kui Liu
Matthias Militzer
Jian-Feng Nie
Joakim Odquist*
Gary Purdy
Bill Reynolds
Sybrand van der Zwaag
John Vitek
Hatem Zurob*

(Many others have joined the AlEMI workshops over the past 12 years; this is a list of the participants of the first one. All who have contributed since then are gratefully acknowledged.)

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Subsequent workshops:

- 2001; Metz
- 2002; Columbus (with TMS meeting; published)
- 2004; Stockholm
- 2006; Grenoble
- 2007; Hamilton
- 2008; Tokyo (with ISIJ meeting)
- 2009; Stockholm
- 2010; Avignon (with PTM 2010)
- 2011; Vancouver
- (*AlEMI: A ten year history* - Met. Mater. Trans. A, Vol. 42A, (2011), p 3703.)
- 2012; Orlando (with TMS meeting; to be published)
- 2013; Delft

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What has been accomplished?

a sustained, often collaborative, effort to answer some deceptively simple questions; e.g.

Under what, if any, conditions are paraequilibrium (PE), and local equilibrium (LE), appropriate interfacial contact conditions for migrating α/γ interfaces in alloy steels?

or, a related question:

What is the expected volume fraction of ferrite formed after one hour of isothermal holding (in the $\alpha + \gamma$ field) of a previously austenitized simple (ternary) alloy steel specimen?

and many others

Anything else*?

- *Evaluation of new or newly enhanced experimental methods for the study of microstructure, interfacial structure and chemistry, texture, orientation, micro/nanoanalysis; application of these techniques to the foci of the workshop.*
- *Advancement of theoretical methods for the description of solute interactions with moving interfaces.*
- *Advancement of computational (modeling) methods for the simulation of the dynamics of solid-solid interfaces (PF, PFC, MD).*
- *Definition of new experimental boundary conditions, especially those that permit the separation of nucleation from growth; these include the study of controlled decarburization, and most recently, cyclic phase transformation.*
- *The use of specimens with predefined, controlled composition gradients (combinatorial methods) in the study of alloying element effects.*
- *Critical discussion of the bainite reaction, and the use of advanced experimental methods in its study.*

*Not all of these accomplishments/advances can be attributed solely to the AIEMI connection, but many can.

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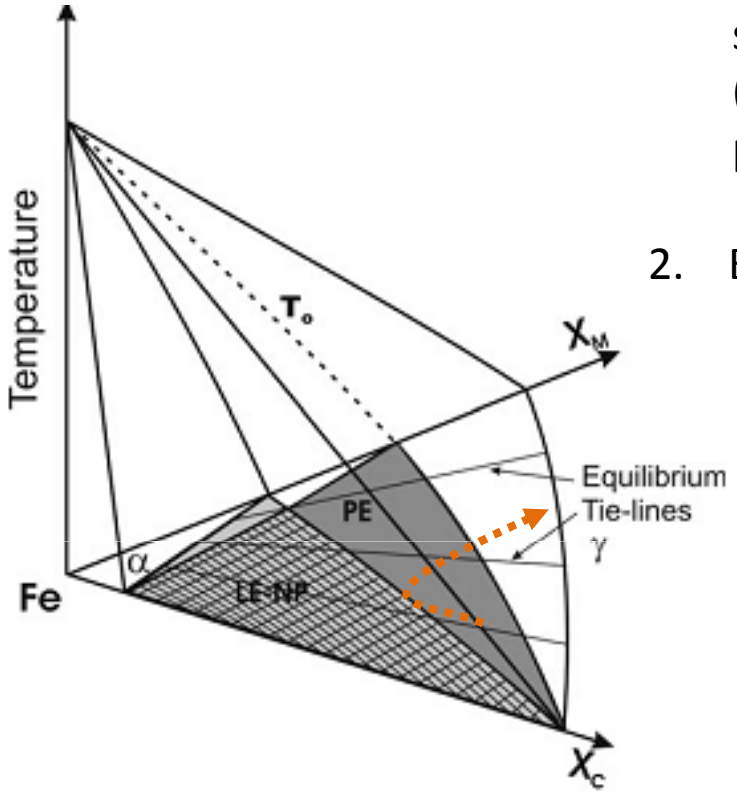
MAJOR FOCI OF THE WORKSHOPS



I. Models for the interaction of substitutional (M) and interstitial (C) solutes with moving α/γ interfaces. (Transition models, solute drag models, phase field approaches.)

2. Experimental conditions:
   combinatorial approach (M gradient),
   controlled decarburization (C gradient),
   cyclic transformation in $\alpha+\gamma$ field,
   high magnetic fields (γ -> $\alpha+\gamma$),
   massive transformations,
   lower temperature transformations :
   bainites (carbidic and "carbide-free"), (R. Hadian, this meeting), martensites

3. Experimental methods:
   optical, confocal, microscopy,
   dilatometry, resistivity,
   FEG TEM, STEM, SEM, EBSD, AFM,
   FIB, EMPA, SR, 3DAP, etc.

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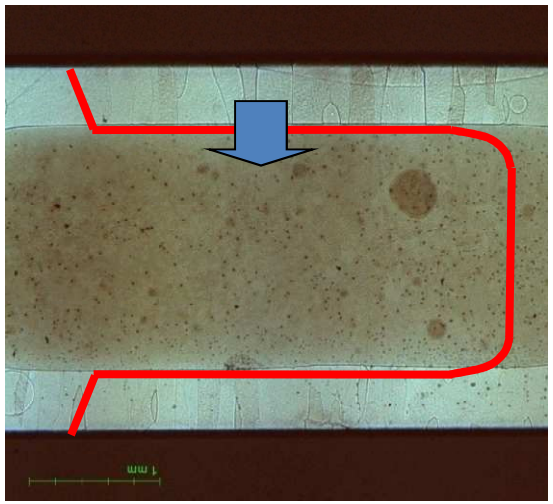
Some selected recent developments; experimentation/modeling:

a) Decarburization: (the initial results were presented at the 2nd AlEMI meeting in 2001 in Metz.)

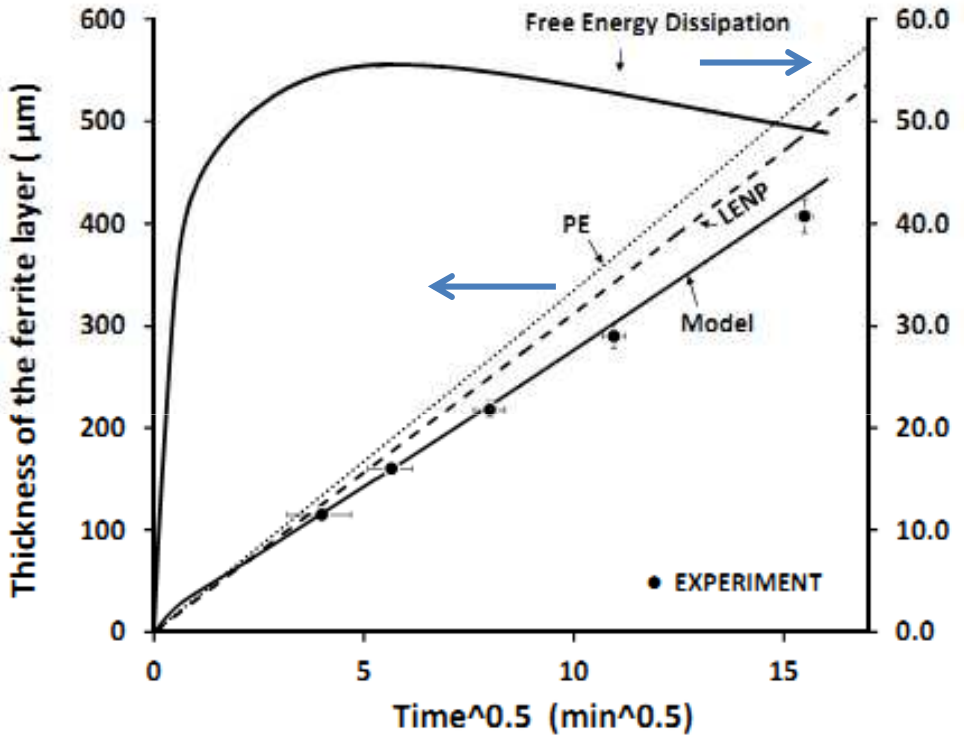


i) now have precise kinetic data on a wide range of alloy compositions (Fe-X-Si, X=Ni, Mn, Cr, Mo, Si) and temperatures, including new data on Fe-C-Co (0.5-20 % Co).

Qui et al, Met. Mat. Trans A 2013;44:3472 (+This meeting)

ii) a model has been developed that accounts for departures from PE and LENP in these systems. The model also accounts for the observed fractions of ferrite precipitated at austenite grain boundaries under (conventional) conditions of supersaturation.

Zurob, Panahi et al, Met. Mat. Trans A 2013;44:3456 (+This meeting)



J/mol

Ferrite layer growth in Fe-0.77%C-10%Co at 825°C, after Qui et al

b) Cyclic transformation:

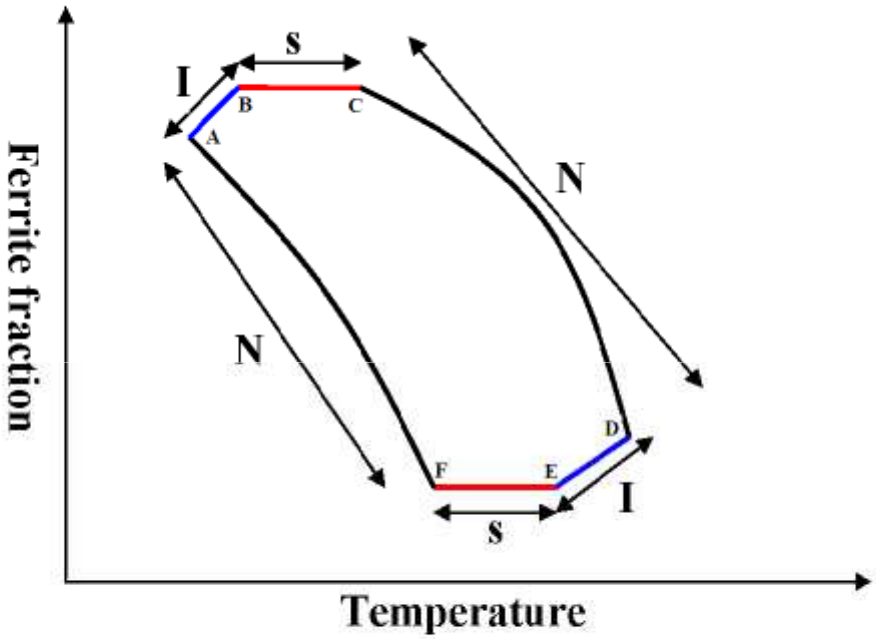
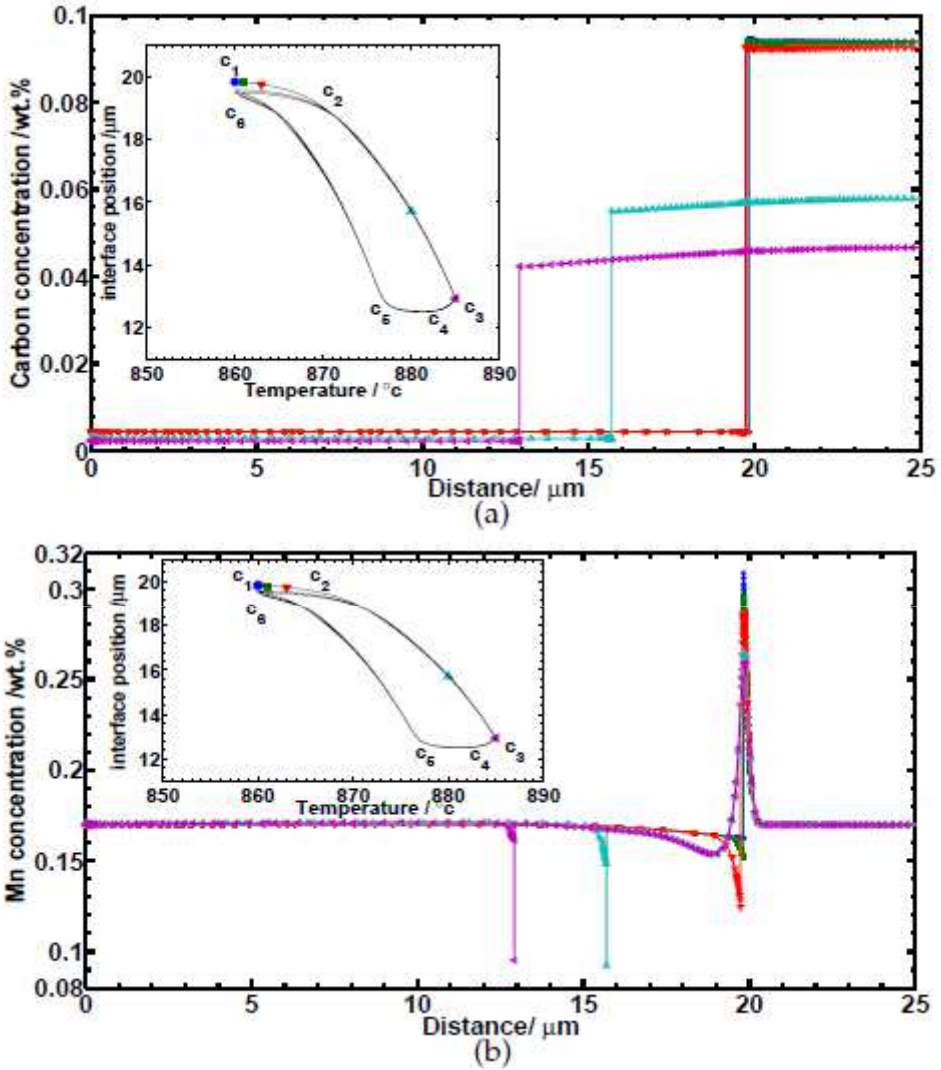


Figure 4.1: The sketch of a typical type I cyclic phase transformations. I=Inverse transformation stage(blue), S=Stagnant stage (red), N=Normal transformation stage (black).

Hao Chen et al; <u>many</u> recent publications, this meeting

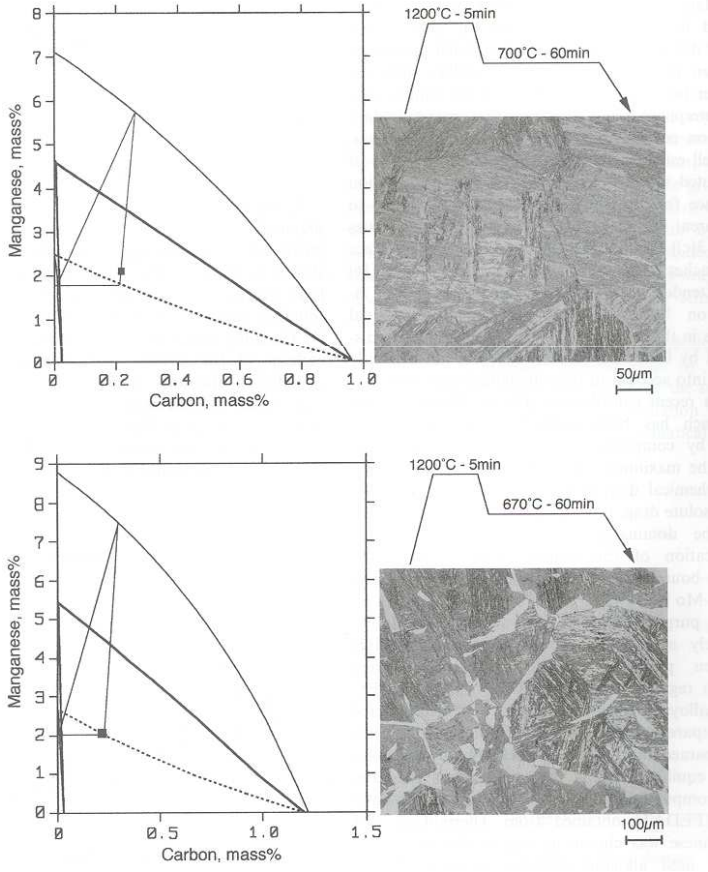


Hao Chen et al,

c) Measurement of ferrite fraction, austenite carbon content, ferrite growth kinetics in isothermally transformed specimens:

Liu Z-Q, Miyamoto G, Yang Z-G, Furuhara T, Acta Mat 2013; 61:3120

FEG-EMPA studies of carbon content in martensite (austenite) at cessation of ferrite growth.



(Oi et al, 2000)

d) Bainites:

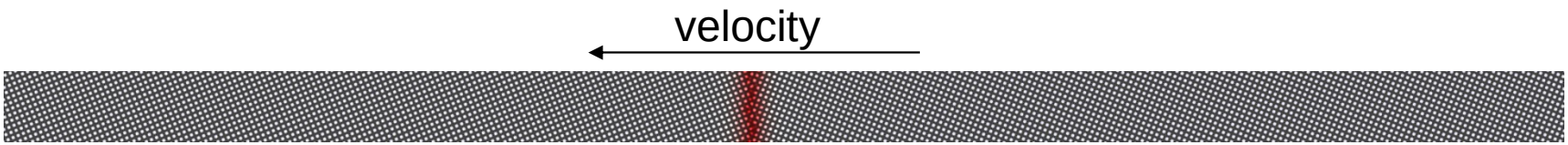
- *in situ* studies (ρ, δ, om, csm, SR);
- inverse bainite, symmetry;
- comparison of carbide-free, carbidic bainites, autotempered martensites;

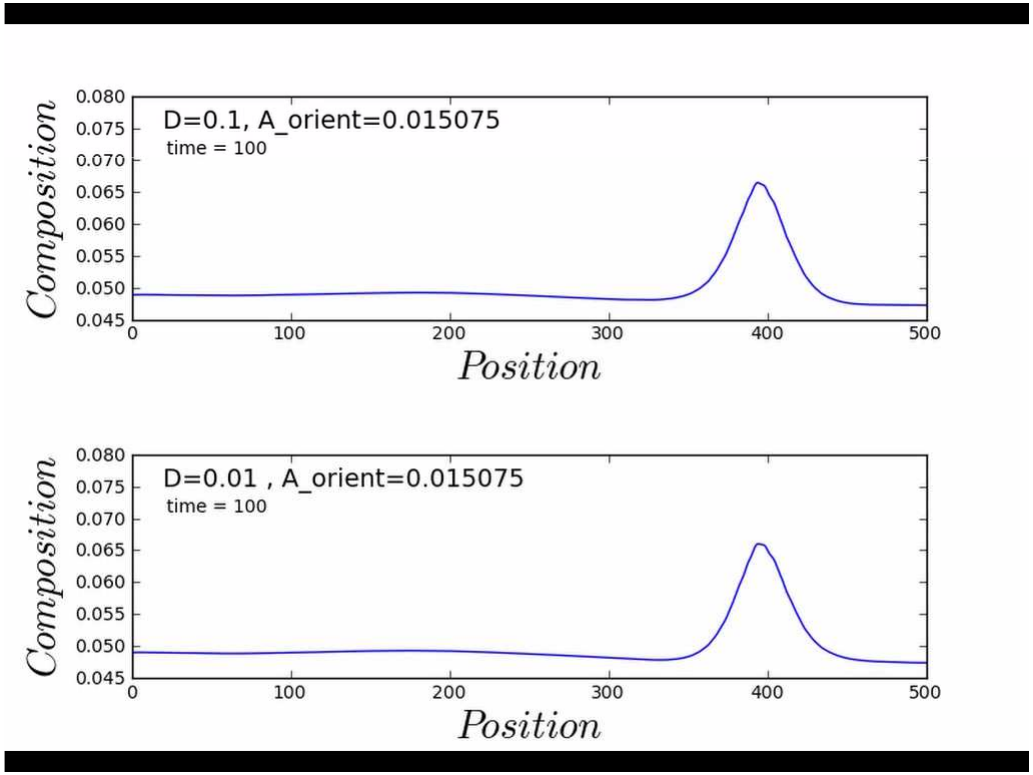
  Sherri Hadian, this meeting
- studies of bainite formation below Ms;
- ausforming response, kinetics;

  Gong et al, Acta Mat, 2013;61:4142; McMaster studies.

Some recent developments; simulation:
a) Phase Field Crystal model
courtesy M. Greenwood

Greenwood M, Sinclair C, Militzer M, Acta Mat. 2012;60:5752



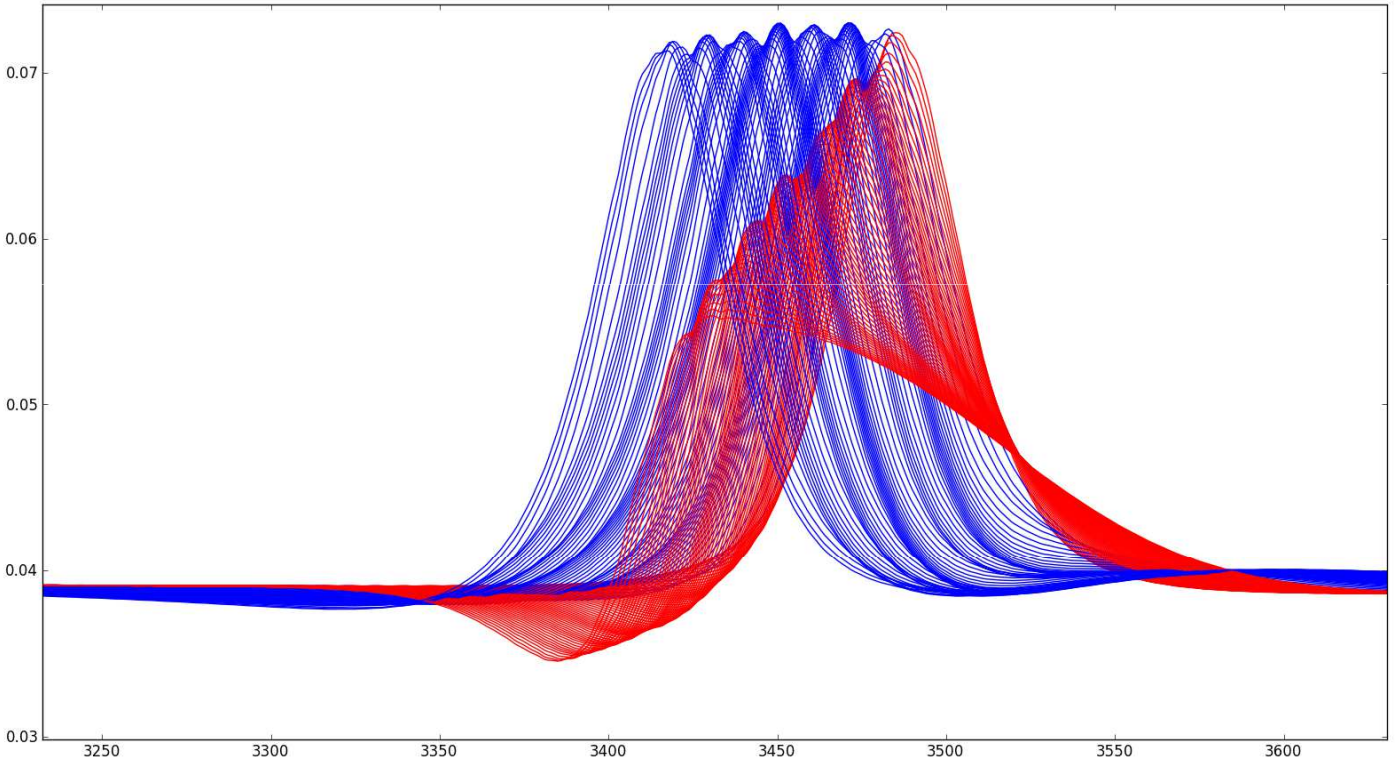


1. At constant driving pressure the diffusion constant of the composition field slows the movement of the interface.
2. At different diffusivities the compositional profile (line) around the interface (dots) becomes asymmetrical due the driving pressure and the resistance to move by the solute.

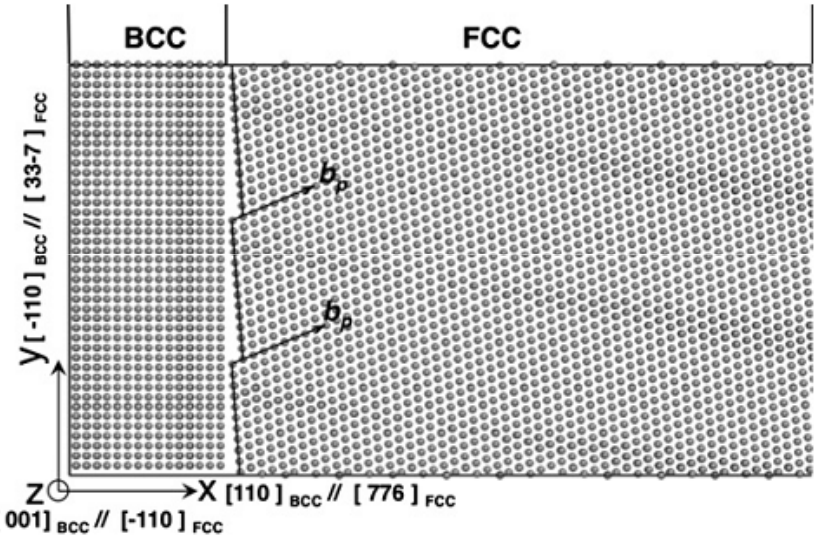
Ternary solute drag :
M. Greenwood

$$D_A \neq D_B$$

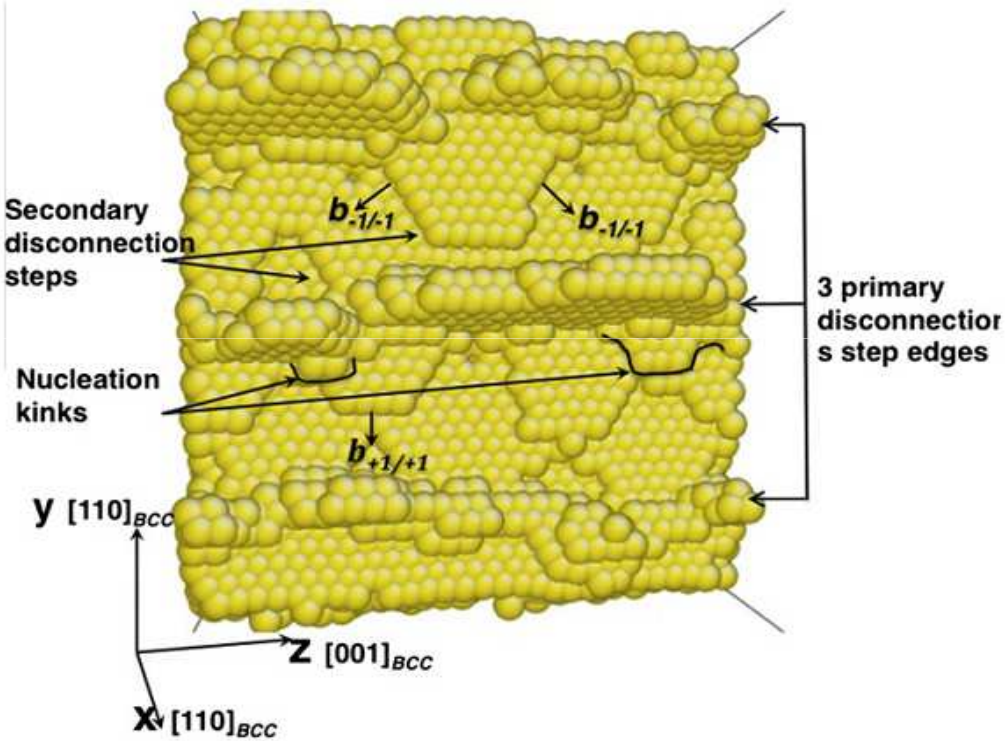
Lower Driving Pressure



b) Molecular dynamics simulation of γ → α transformation in pure Fe:
Song H, Hoyt JJ, Acta Mat., 2013;61:1184



(110)α//(776)γ; [001]α//[-110]γ



Growth interface;
≈N/W related ferrite/austenite

Of particular personal interest:
(current enthusiasms)

- austenite formation
- ferrite growth at lower temperatures
- Widmanstatten growth
- variant selection
- bainite formation (through Ms)
- ausforming

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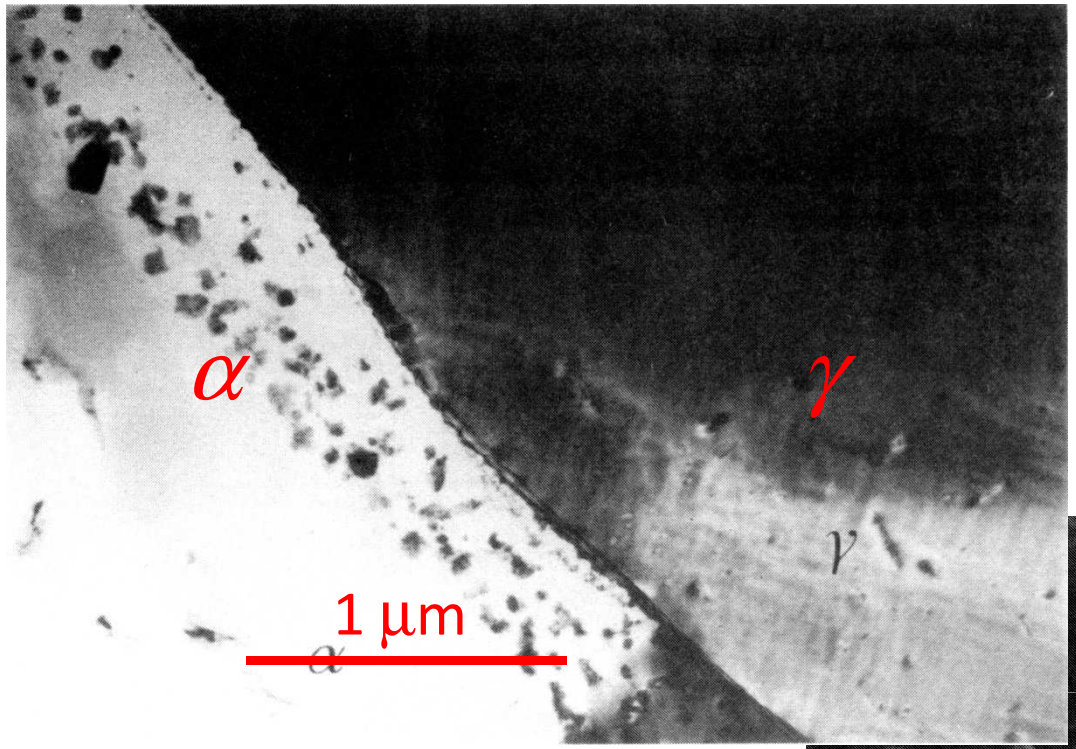
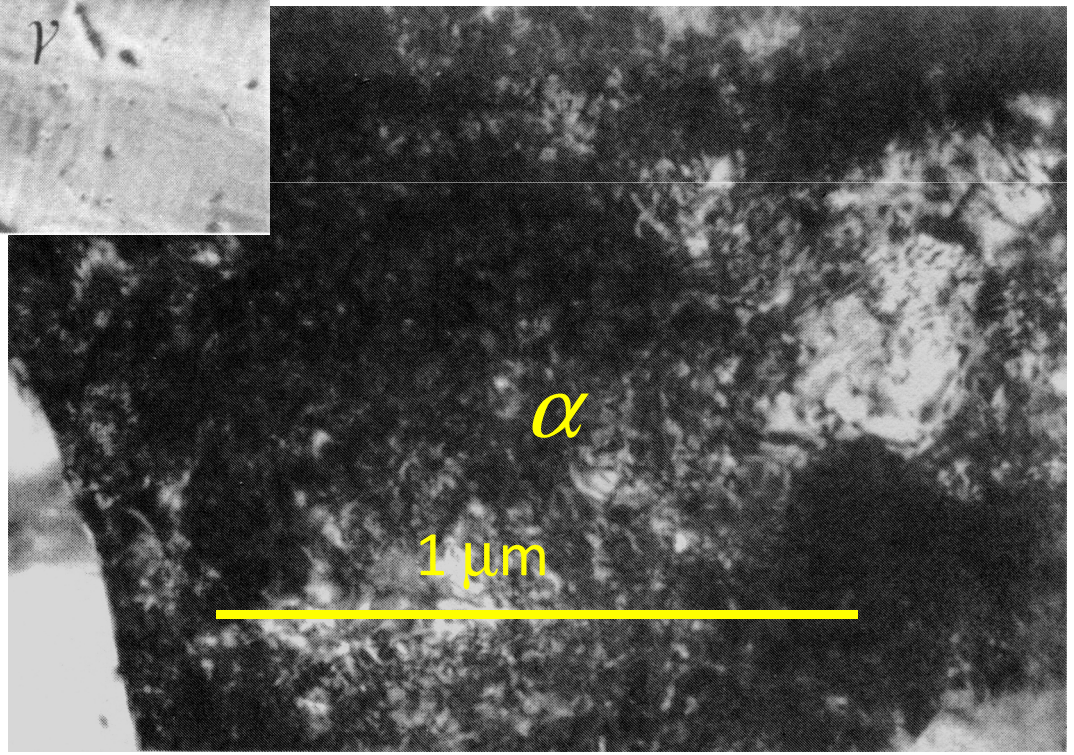


DISLOCATED FERRITE
α, γ, Mo_2C at 620°C
Fe-0.38%C-0.9%Mo

The same area, after transformation of γ to dislocated ferrite at 480°C



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Trends: What's next?

- greater convergence among experiment, modeling, simulation;
- emphasis on *in situ* studies at all levels;
- more emphasis on austenite formation, pearlites, Widmanstatten precipitation, bainites, martensites, Q&P structures, interaction of deformation and transformation, massive transformations;
- Other little-understood phenomena:

  * ferrite formation above Ae3;
    (Ghosh C, Basabe VV, Jonas JJ, Kim YH, Yue S, Acta Mat 2013;61:2348)

  * "dislocated ferrite".

  * approach to full equilibrium (after PE, LE-NP growth).

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Thank you