Phase transformation in Nb-microalloyed steels

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Phase transformation in Nb-microalloyed steels

- Focus on transformation occuring after deformation at high temperature
- Pre-requisite: Nb is causing a delay of the phase transformation due its interaction with the interface (see paper 039, Monday morning)
- How to describe the phase transformation kinetics?
- (Semi-) industrial approach -> simple ! but adequate for complex alloys

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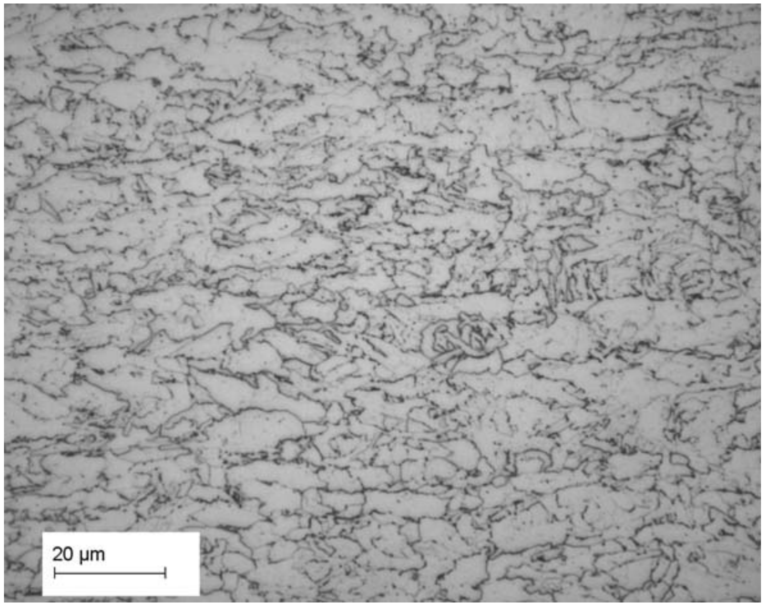
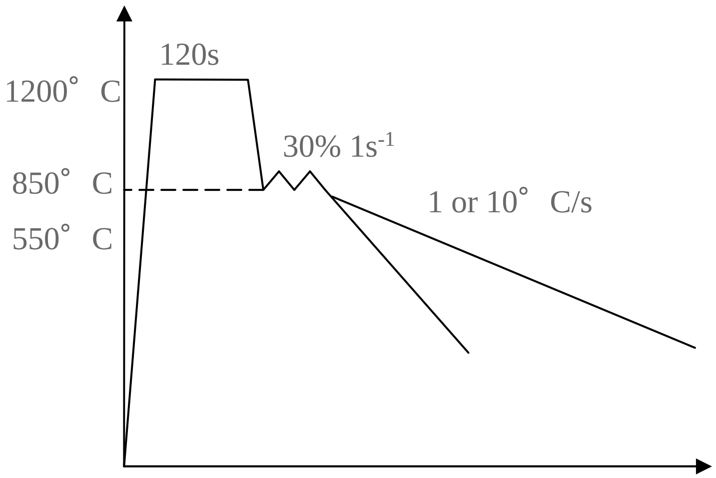
Typical microstructure

	C	Mn	Si	Ti	Nb	Ni	N
B	0.067	1.6	0.29	0.021	0.07	0.25	31

Reference microstructure

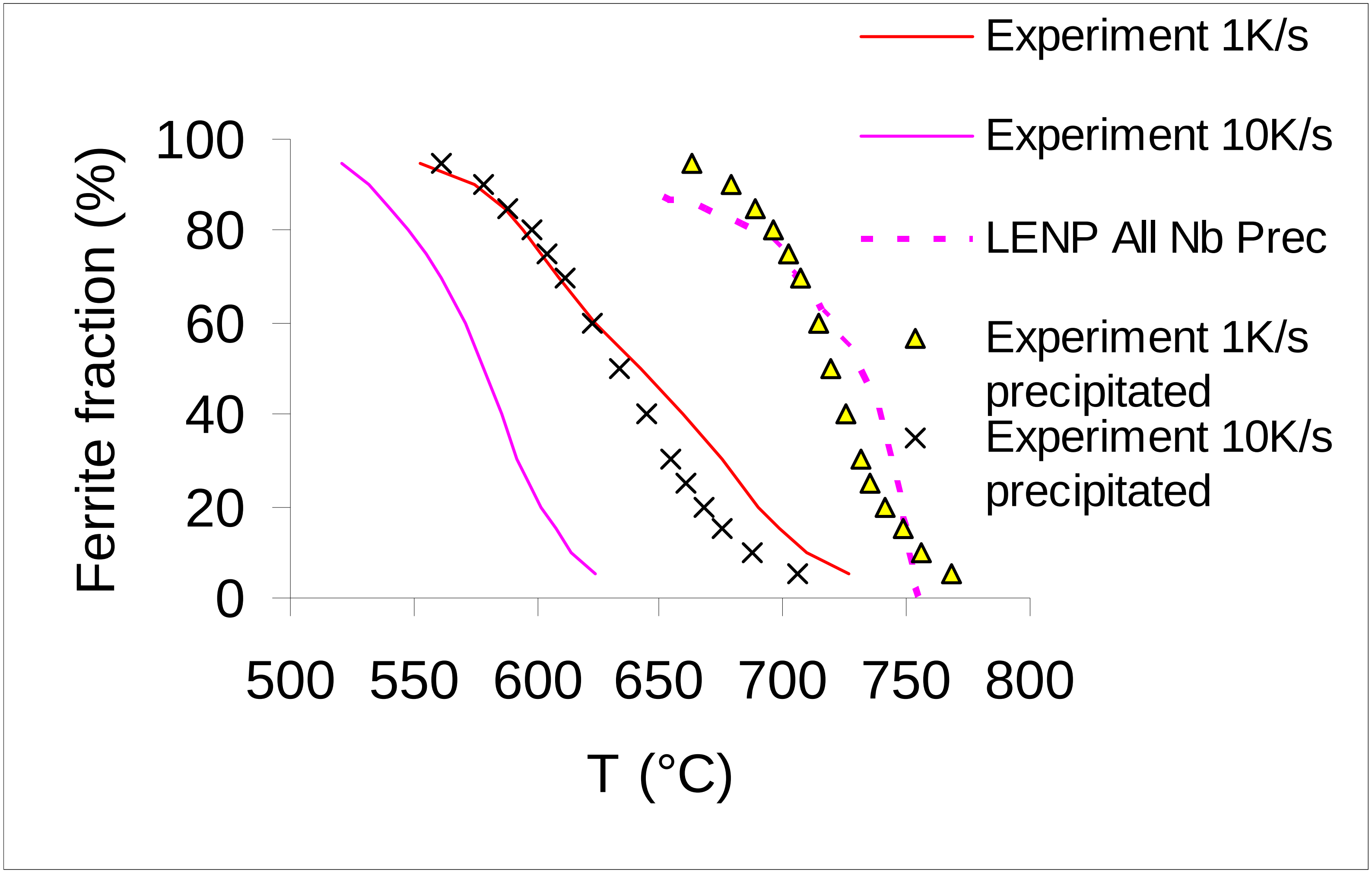




Experiments on Bähr dilatometer

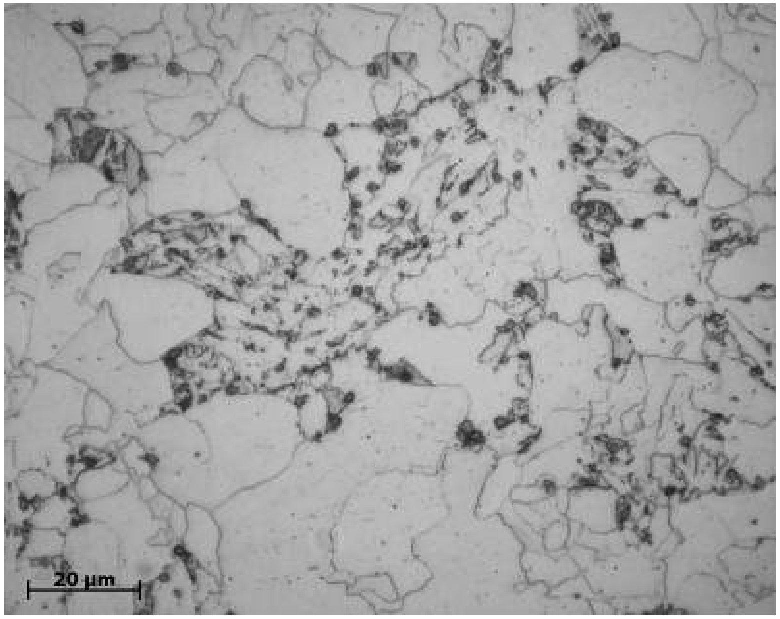
Phase transformation kinetics

Strong delay compared to LENP solution

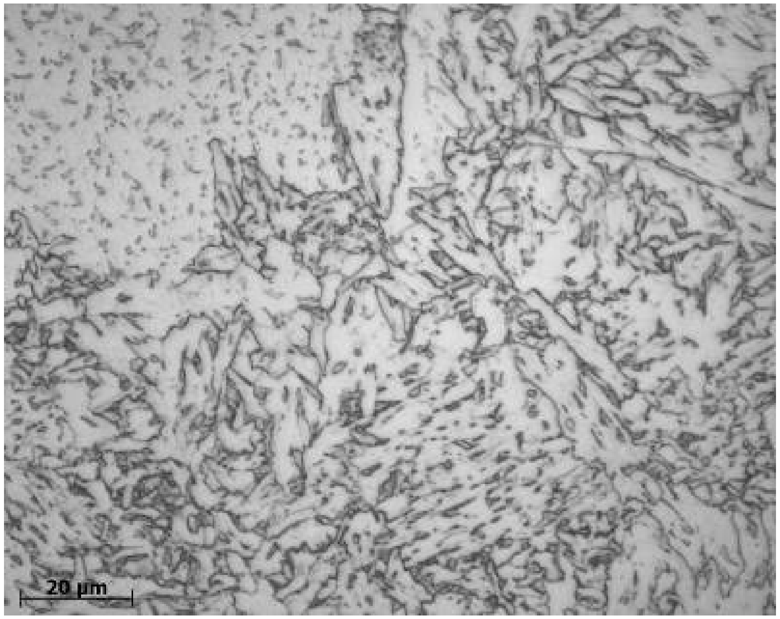


Phase transformation kinetics

- How does the microstructure looks like after dilatometry



1K/s



10K/s

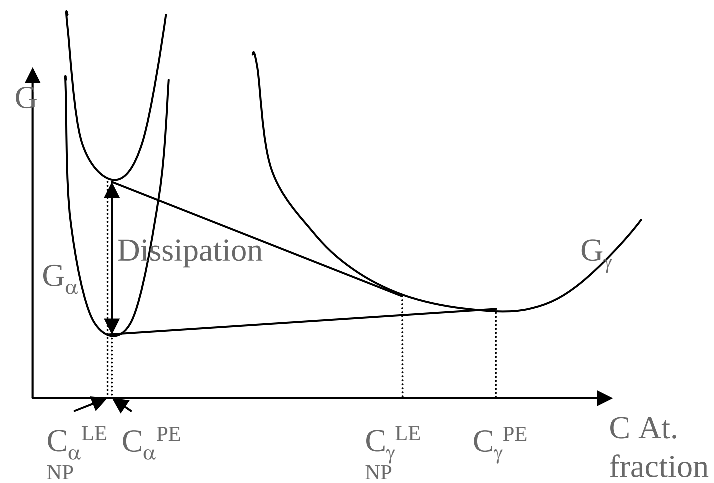
Size of austenite grains ~60µm

Estimation of the dissipation at the interface

- Reduction to a binary system Fe*-C, where Fe* is the equivalent subsitutional element
  - No partiotionning of substitutional elements

$$x_i = \frac{[X_i]_\alpha}{[Fe]_\alpha} = \frac{[X_i]_\gamma}{[Fe]_\gamma} \qquad X_i = Mn, Si, Ni$$

$$\mu_\alpha^{Fe*} = \frac{[Fe]_\alpha \cdot \mu_\alpha^{Fe} + \sum [X_i]_\alpha \cdot \mu_\alpha^X}{[Fe]_\alpha + \sum [X_i]_\alpha}$$



- The driving force for the phase transformation

$$DF = \left(\mu_\gamma^{Fe*} - \mu_\alpha^{C}\right)\cdot\left(C^\gamma - C^\alpha\right) + \left(G^\gamma - G^\alpha\right)$$

- The dissipation due to the formation of a spike

$$DS = \sum_i x_i \cdot \left(\mu_\gamma^i - \mu_\alpha^i\right)$$

Estimation of the dissipation at the interface

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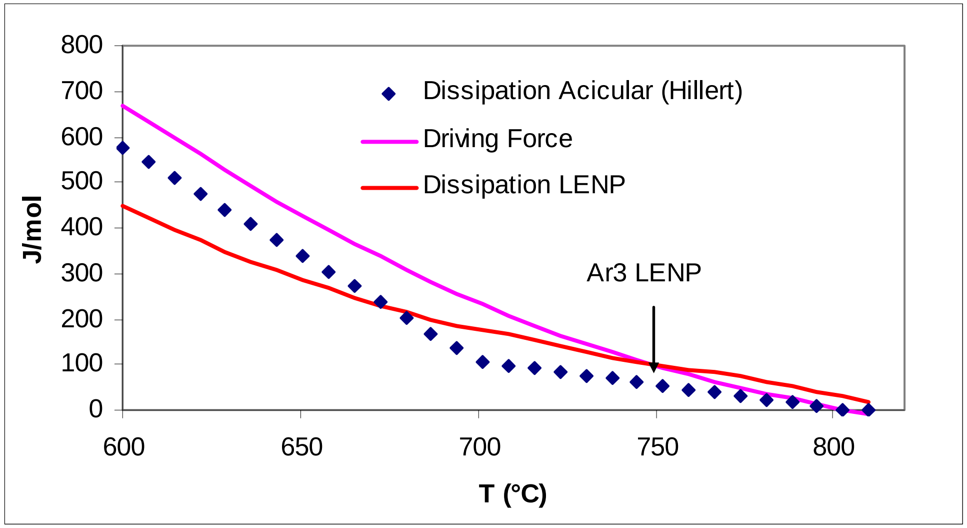
- Comparison between driving force & dissipation
- Also plotted, dissipation for bainite according to Hillert, Hoglund Agren, Met Trans 2004

$$\Delta = f(T) + g(T, Mo, Cr)$$



•Dissipation LENP > Dissipation “bainite” until 680° C

•Sum of dissipations not possible: leads to impossible transformation

•For ferrite, need of an extra dissipation mechanism to explain the delay of the phase transformation down to 700° C in presence of Nb

•At 700° C, difference between driving force and dissipation ~50J/mol

Extra dissipation mechanism for Nb-steels?

- Classical way to introduce an extra dissipation mechanism: mobility
  - mobility data very variable
  - Results very sensitive to the cooling rate & grain size

$$D^m = \frac{v}{M}$$

  - Experimental evidences that the grain size has almost no influence on the phase transformation in the considered condition

Extra dissipation mechanism for Nb-steels?

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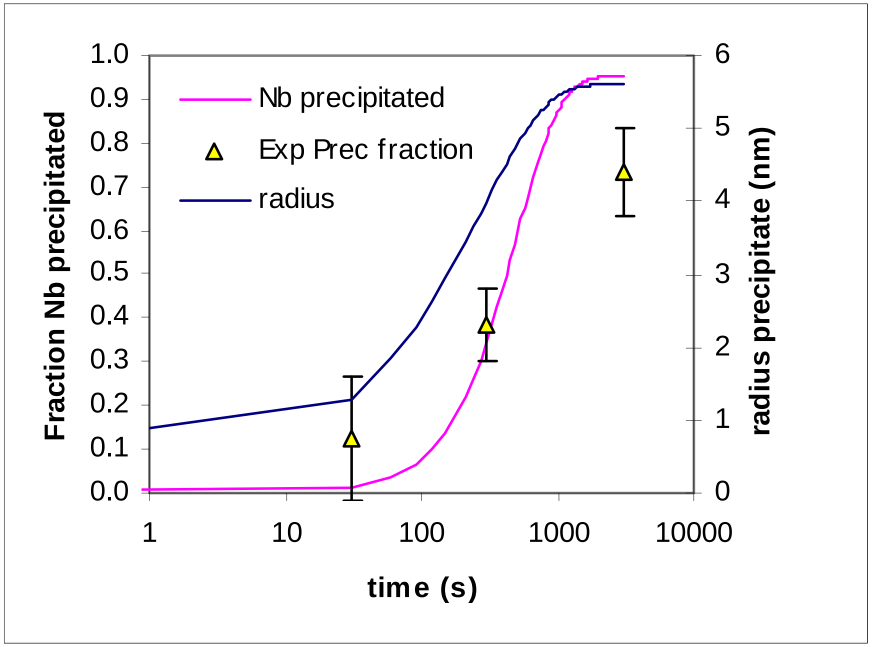
- Zener Pinning ?
  - Max Zener pressure:
  - Radius of the precipitates
    - Compute from cells (growth of one nucleus)
    - Distance between nuclei to fit the measured precipitated fraction

$$Z = \frac{3 \cdot \gamma \cdot Fv}{2 \cdot r}$$



Surface energy ~0.75J/mol

Dissipation due to Zener pressure:

$$DZ = \frac{3 \cdot \gamma \cdot Fv}{2 \cdot r} \cdot V_m < 1J/mol!$$

Extra dissipation mechanism for Nb-steels?

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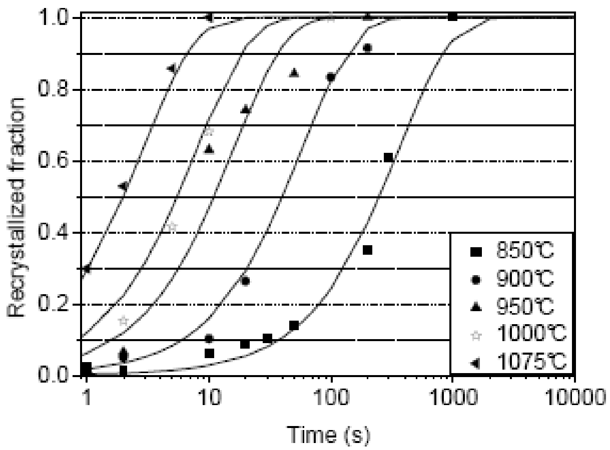
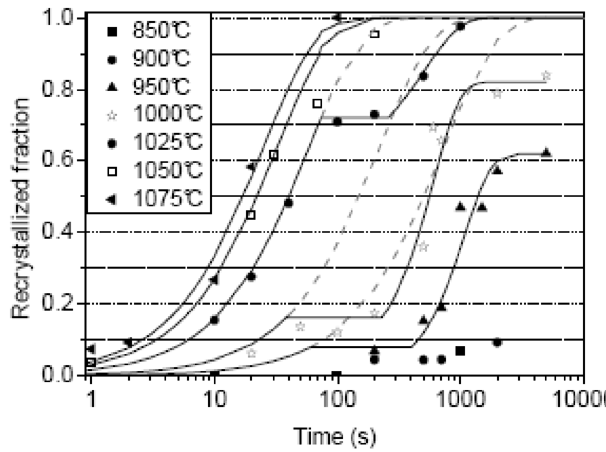
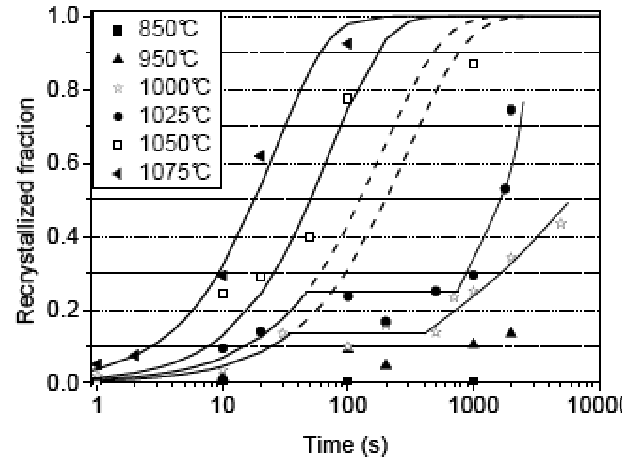
- Other possibilities?
  - Solute drag?
    - For recrystallization, solute drag of Nb-microalloyed steels is well known
    - … but is much less efficient than pinning of grain boundaries by precipitates



C-Mn



11ppmC-Mn-0.16%Nb



C-Mn-0.16%Nb

- Driving force for recrystallization smaller than for phase transformation

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Extra dissipation mechanism for Nb-alloyed steels

- Hyptohesis: to delay the phase transformation, we need precipitates in the grain boundaries
- … but Zener Pinning seems insufficient
- Is it possible to revise our view?

$$Z = \frac{3 \cdot \gamma \cdot Fv}{2 \cdot r}$$

  – Classical formula for Zener pinning assumes homogeneous distribution of precipitates according to their radius and mass balance
  – What if elements segregate to the grain boudary or lateral diffusion of elements in the grain boundary?
    - Zener pinning becomes “enhanced” by the larger amount of solute available

“Reverse” DIGM / discontinuous precipitation combined with phase transformation

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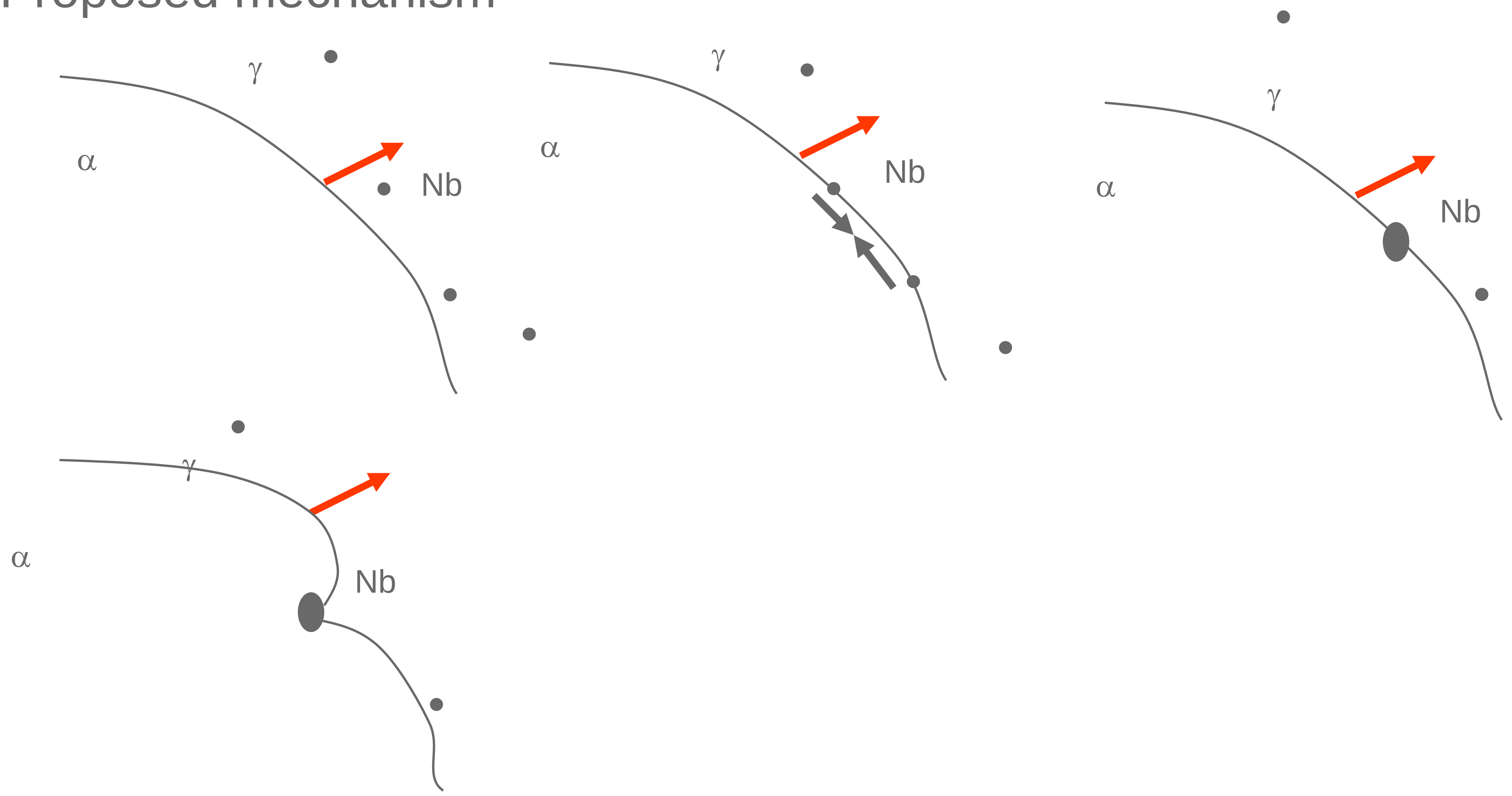
- In DIGM, diffusion induces the movement of grain boundaries, and let eventually an enriched zone behind it
- In the proposed mechanism, movement of the grain boundaries is due to the phase transformation
- Moving grain boundaries will cross a large volume in which lateral diffusion is possible. Due to the structure of the grain boundary, nucleation of precipitated is easier and are leading to sinks for Nb
- Consequently, the movement of the grain boundary leads to enhanced precipitation with very high density
- The prerequisite for this mechanism is not the presence of precipitates, but the availability of Nb able to precipitate. The movement of the grain boundary acts as a trigger and a “concentrating” mean

“Reverse” DIGM / discontinuous precipitation combined with phase transformation

- Proposed mechanism



Thank you for your attention

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