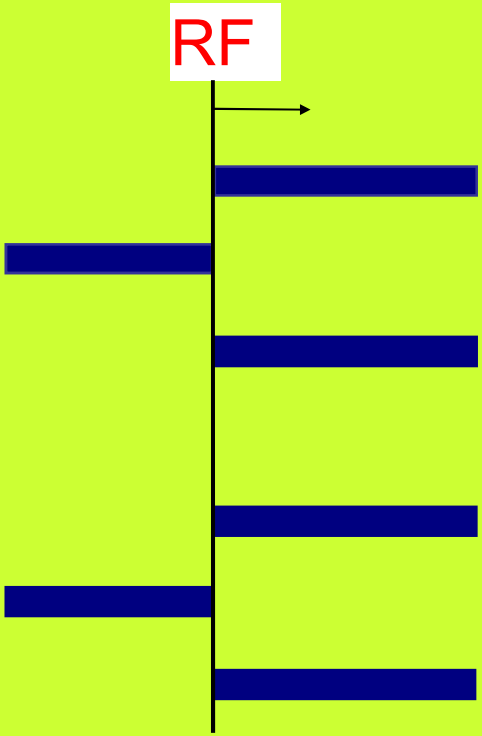
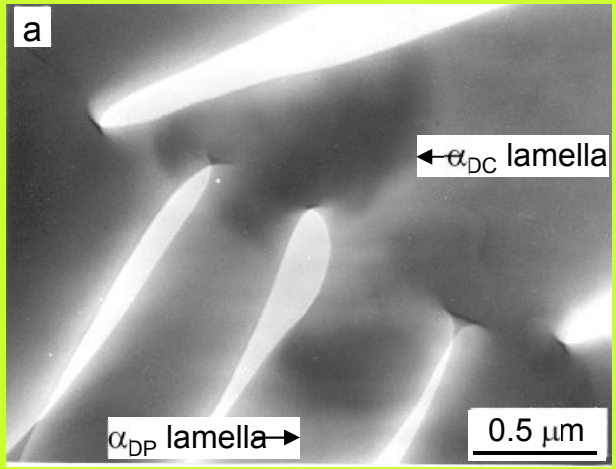
Discontinuous coarsening

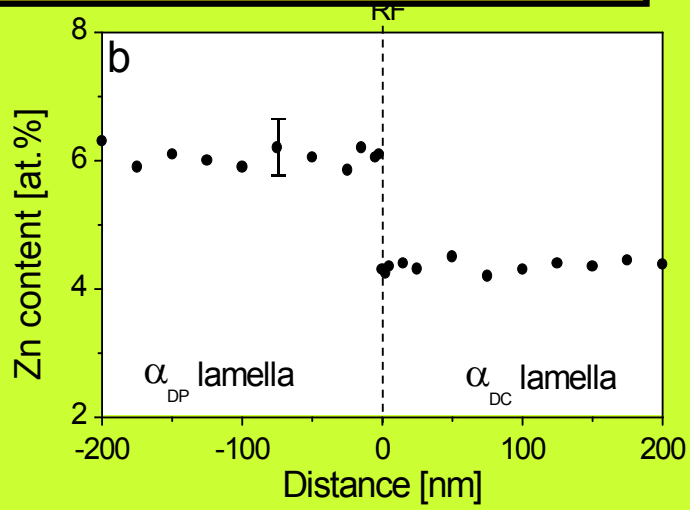


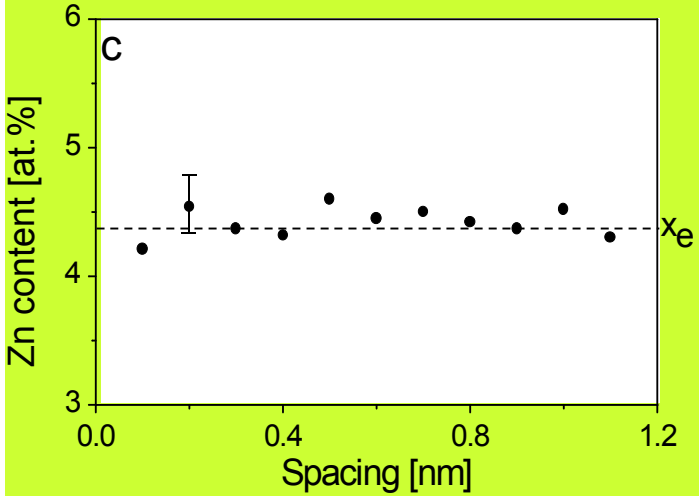
Ni-10 at.% Sn aged at 924 K for 4 h,
M.Frebel, B. Predel, M.Klisa,
Z. Metallkunde 65 (1974) 469

$(\alpha+\beta)_{fine} \rightarrow (\alpha+\beta)_{coarse}$

Discontinuous coarsening



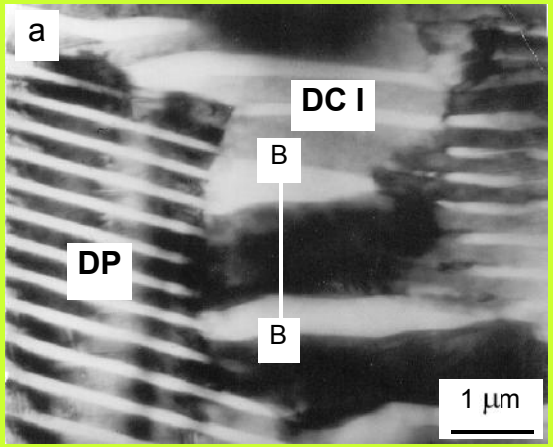


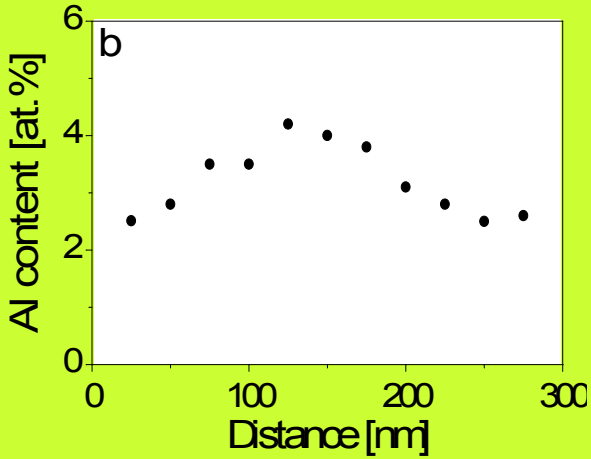


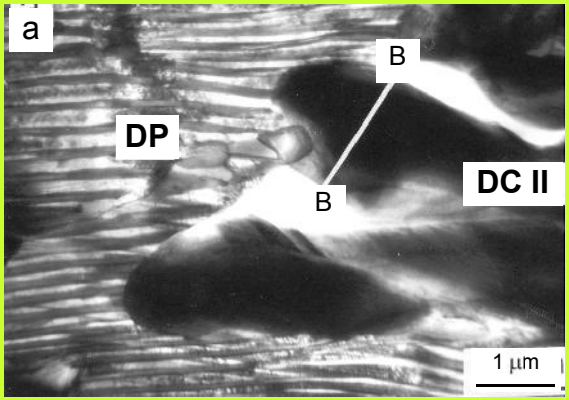
- Thickness of the α lamella several times larger than for DP,
- Abrupt concentration change across RF (α_{DP}/α_{DC} interface),
- Usually flat solute concentration profile across the α_{DC} lamellae corresponding to equilibrium concentration, x_e.
- Possibility of further DC reactions (DC II, DC III).

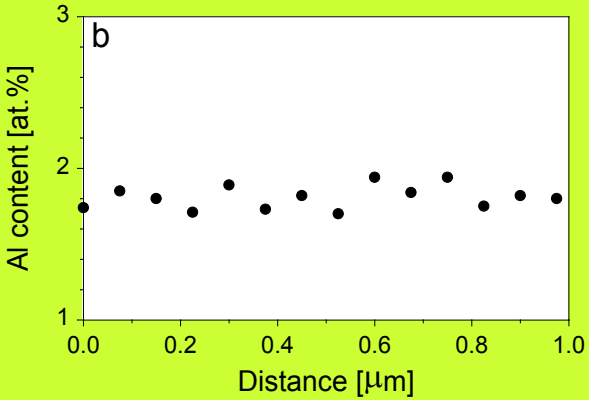
Al-22 at.% Zn aged at 450 K for 350 h

Discontinuous coarsening



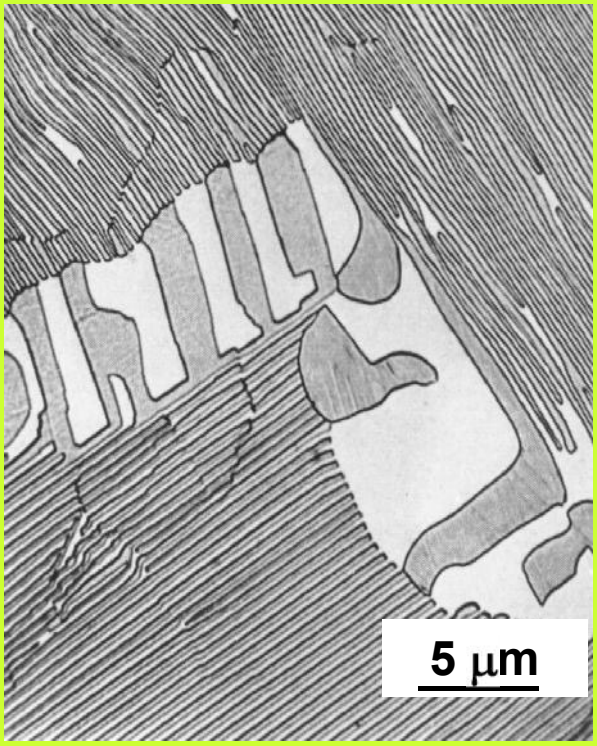




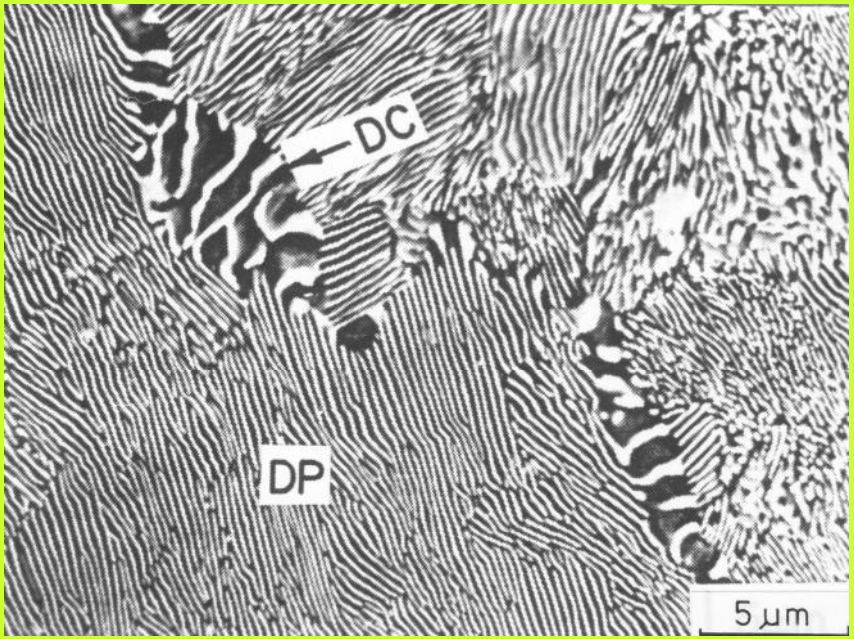


P. Zięba:
Acta Mater. 46 (1998) 369
Co-13 at.% Al
aged for 20 days at 850 K.

Discontinuous coarsening

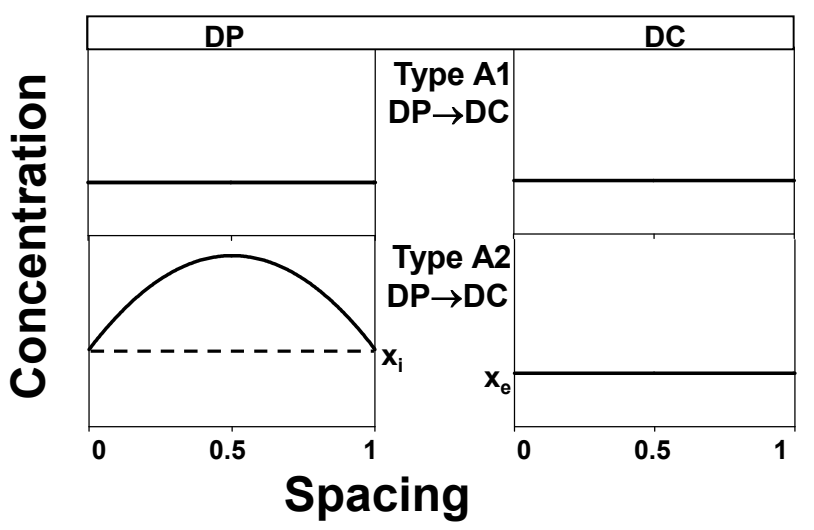


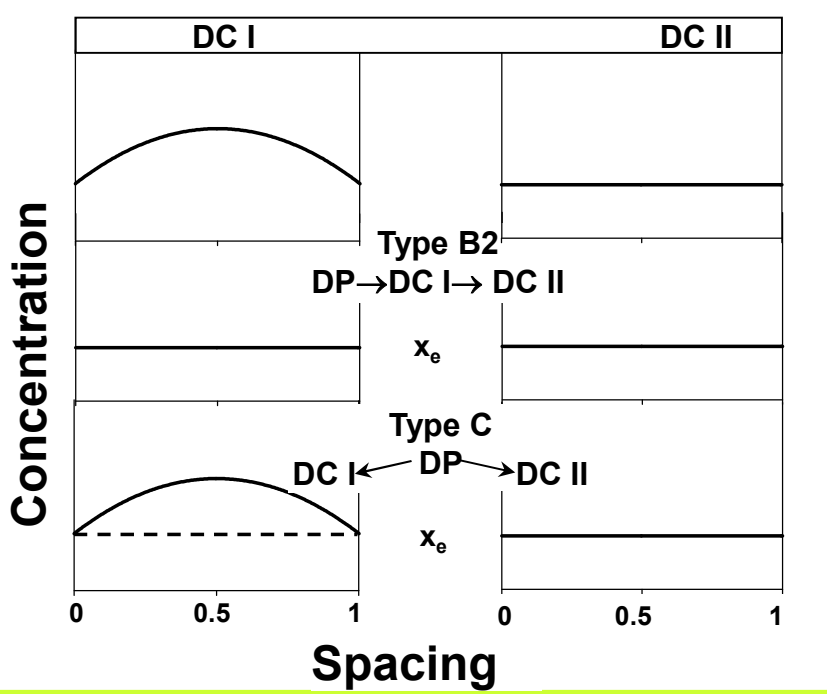
J.D. Livingston, J.W. Cahn:
Acta metall. 22 (1974) 495
Co-Si alloy aged 4 days at 373 K



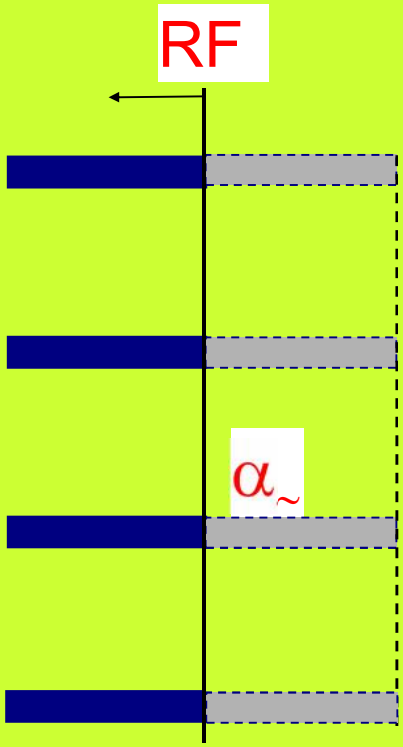
Y.Yang, G. Sarkar, R.A. Fournelle:
Acta metall. 27 (1979) 1147
Al-39.3 at.% Zn aged at 523 K for 1 h

Discontinuous coarsening

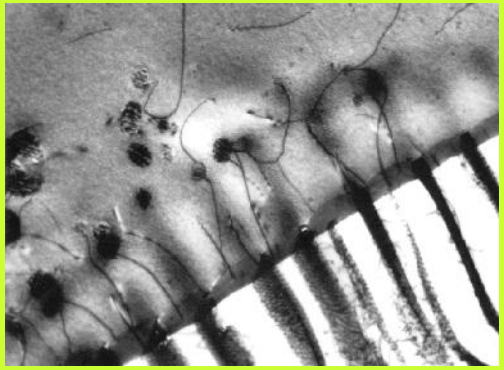




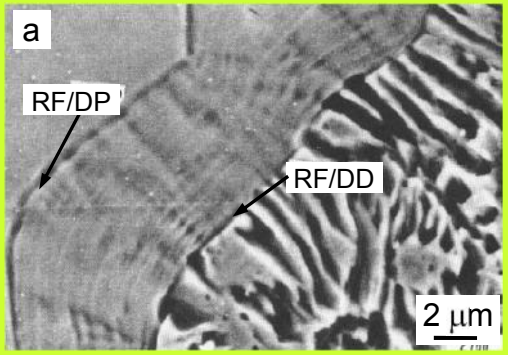
Discontinuous dissolution-principle



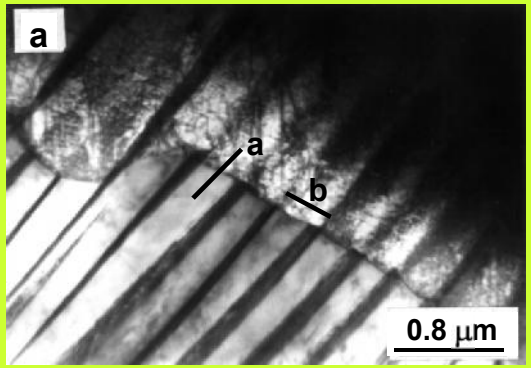
$\alpha + \beta \rightarrow \alpha_{\sim}$



Al-22 at.% Zn aged at 448 K for 540 s. Dissolution at 603 K for 1 s
P. Zięba:
PhD dissertation, IMIM PAN 1987

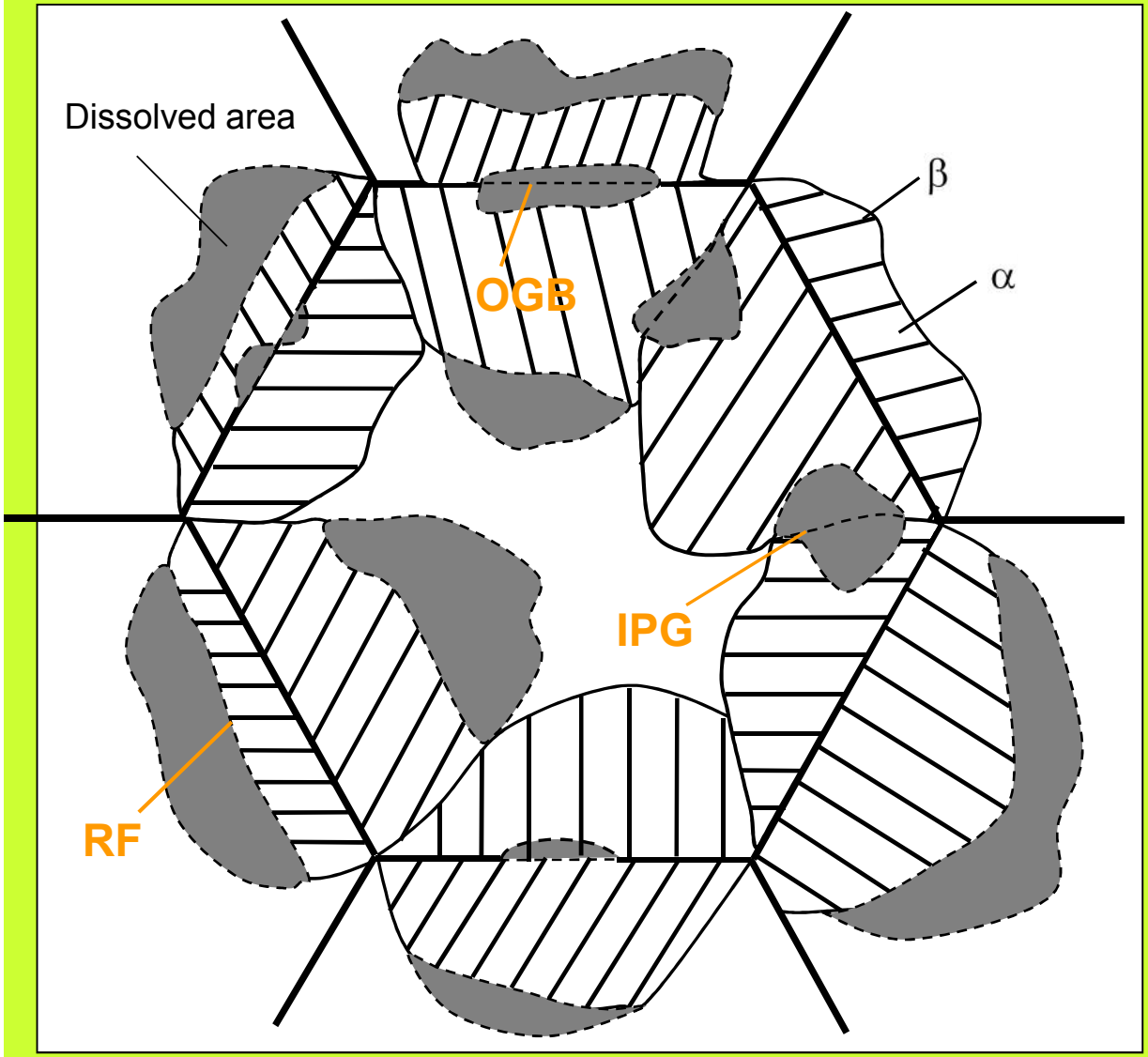


Fe-13.5 at.% Zn aged at 723 K, Dissolution 886 K
T.H. Chuang, R.A. Fournelle, W. Gust, B. Predel:
Z. Metallkde 80 (1989) 175



Ni-4 at.% Sn starzony 200 h w 725 K, a następnie przez 60 h w 775 K. Rozpuszczanie przez 30 s w 945 K
P. Zięba, W. Gust:
Acta Mater.47 (1999) 2641

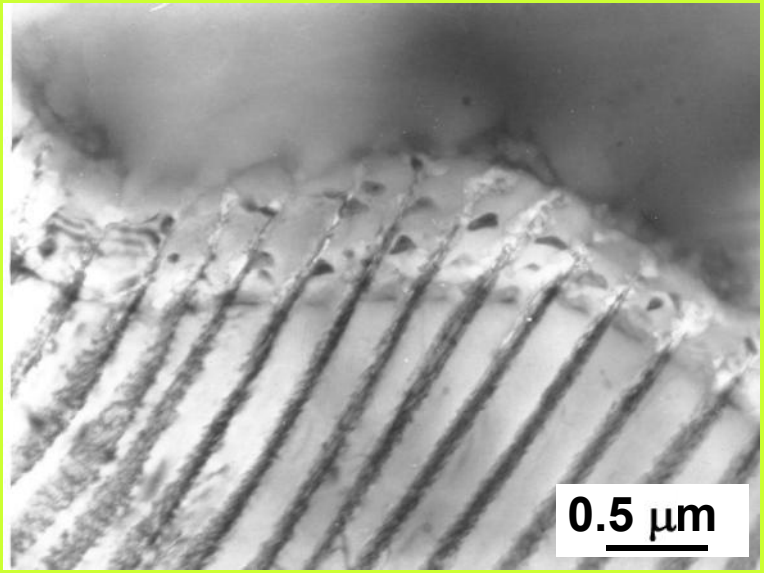
DD-initiation sites



- Primary grain boundary (OGB)
- Reaction front of DP (RF)
- Impingement of two co-lonies of discontinuous precipitates (IPG)

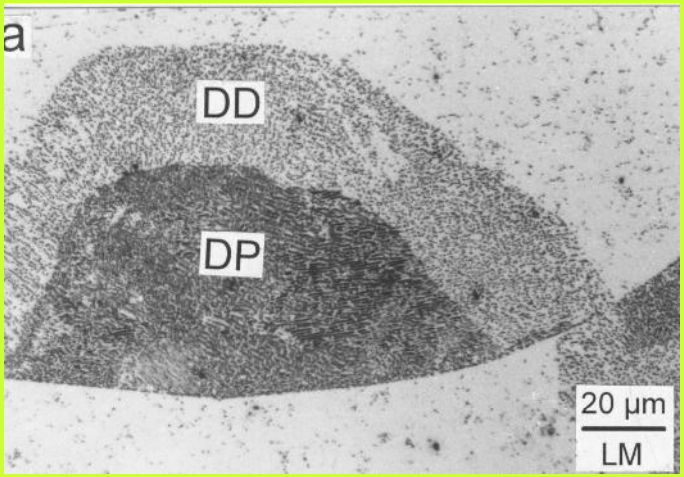
DD-morphology

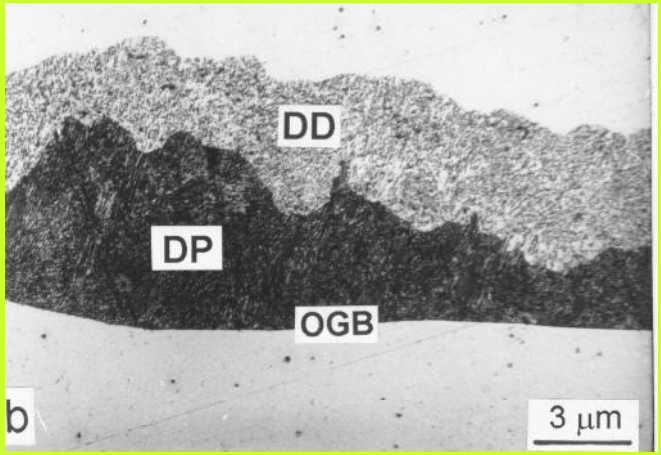
Ni-4 at.% Sn aged at 775 K for 200 h. Dissolution at 945 K forz 15 min

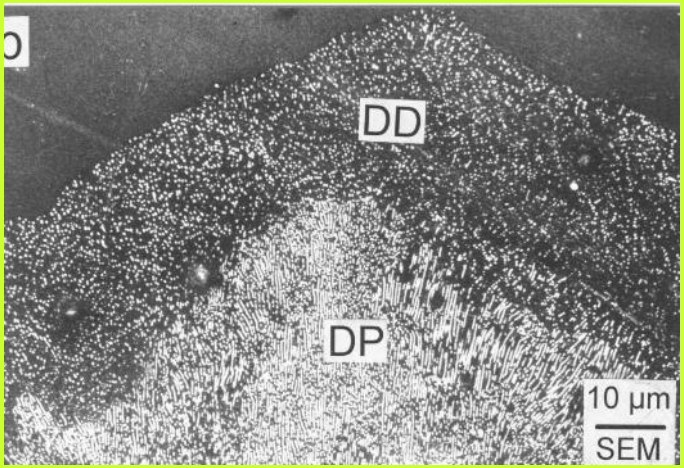


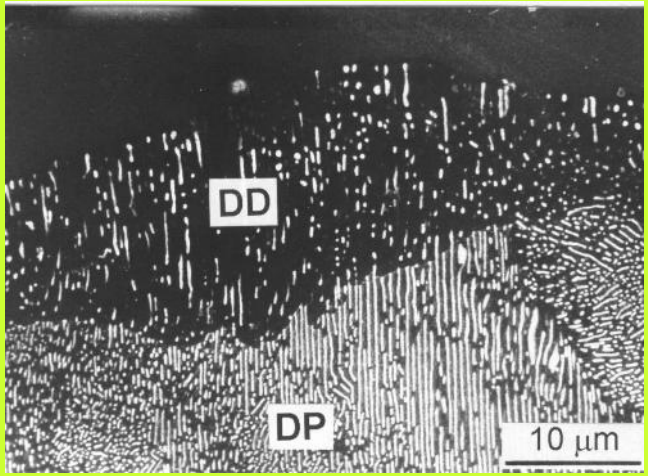
Al-22 at.% Zn aged at 450 K for10 min. Dissolution at 560 K for 5 s

DD-morphology





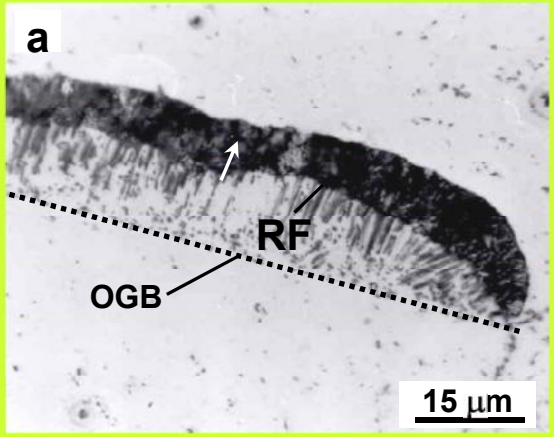


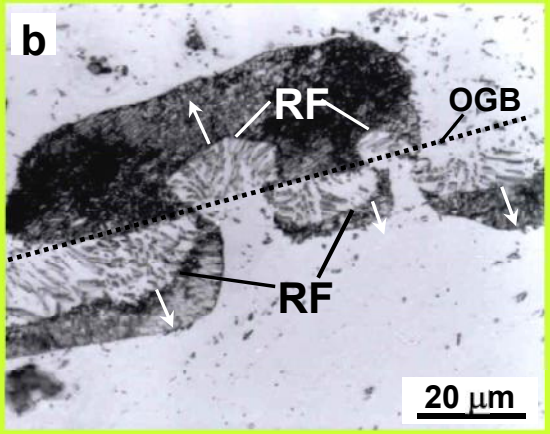


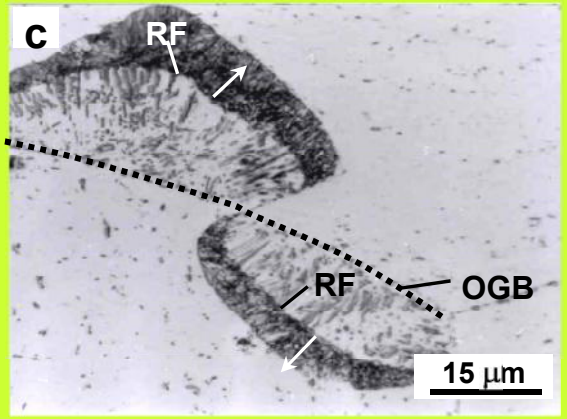
D. Bradai, P. Zięba, W. Gust, M. Hadi Kanifi: *Practical Metallography* 35, (1998) 673
D. Bradai, M. Kadi Hanifi, P. Zięba, W.M. Kuschke, W. Gust: *Journal of Materials Science* 34, (1999) 5331

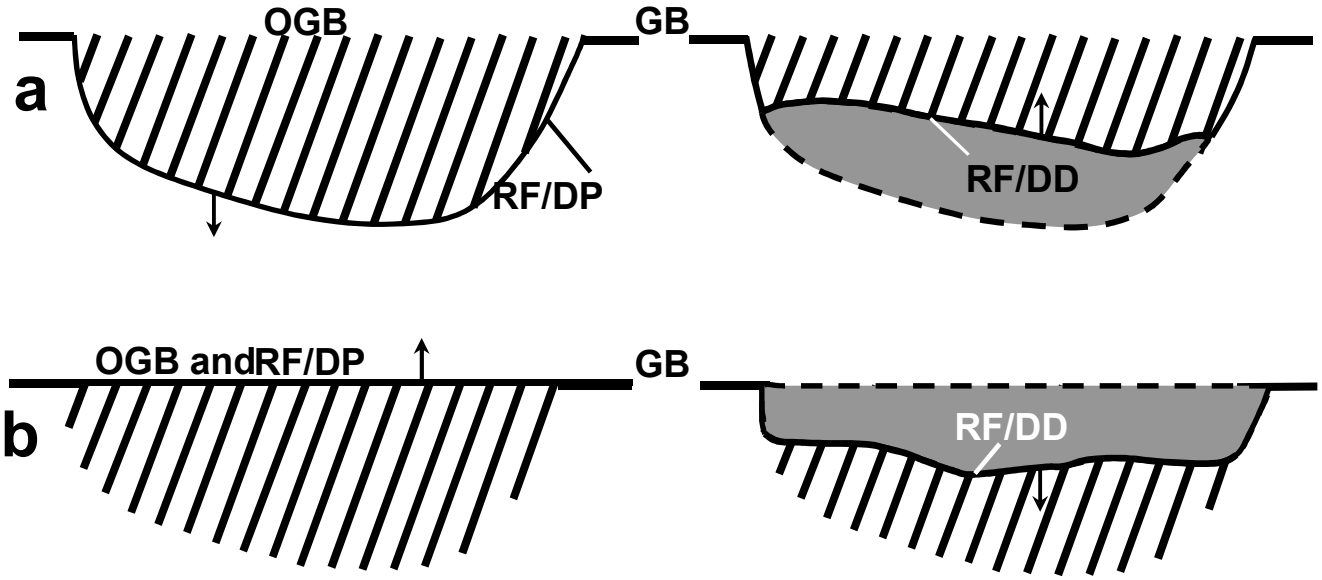
DD- morphology

Mg-10 wt.% Al aged at 495 K for 30 min, then annealed at 695 K for 30 min (times). Subsequent ageing at 495 K for 30 min and annealled at 645 K for 7 min.
D. Bradai, P. Zięba, E. Bischoff, W. Gust: *Materials Chemistry and Physics* 72 (2001) 401

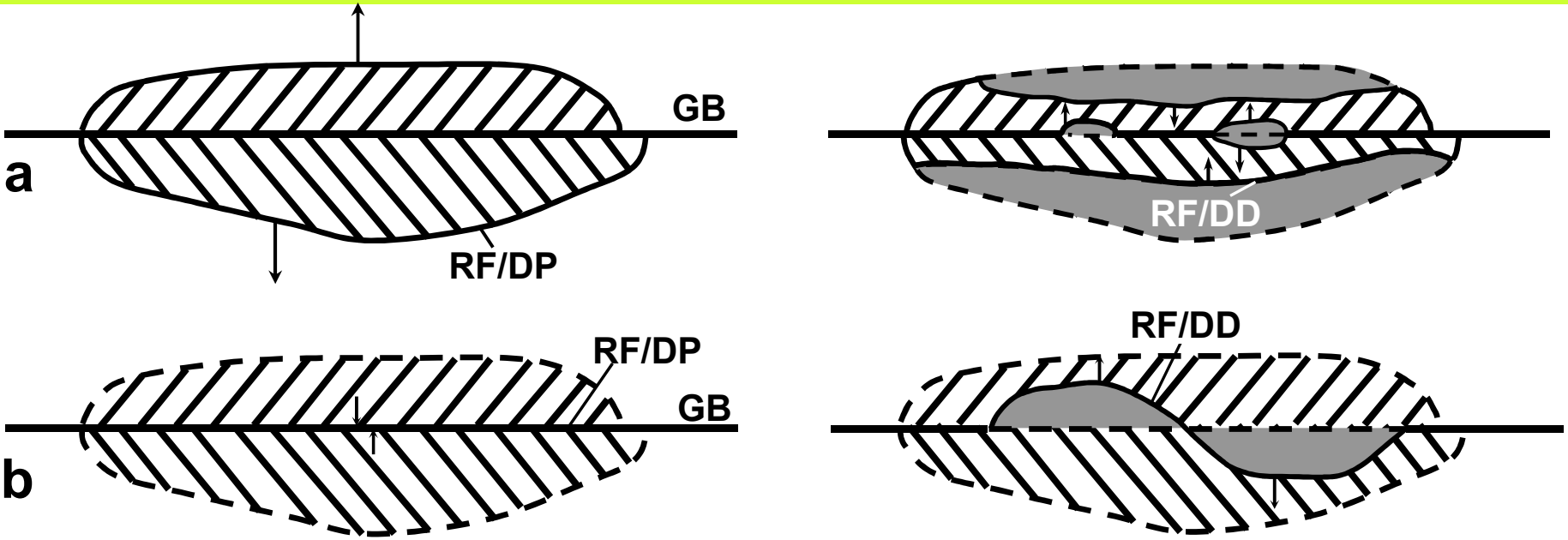




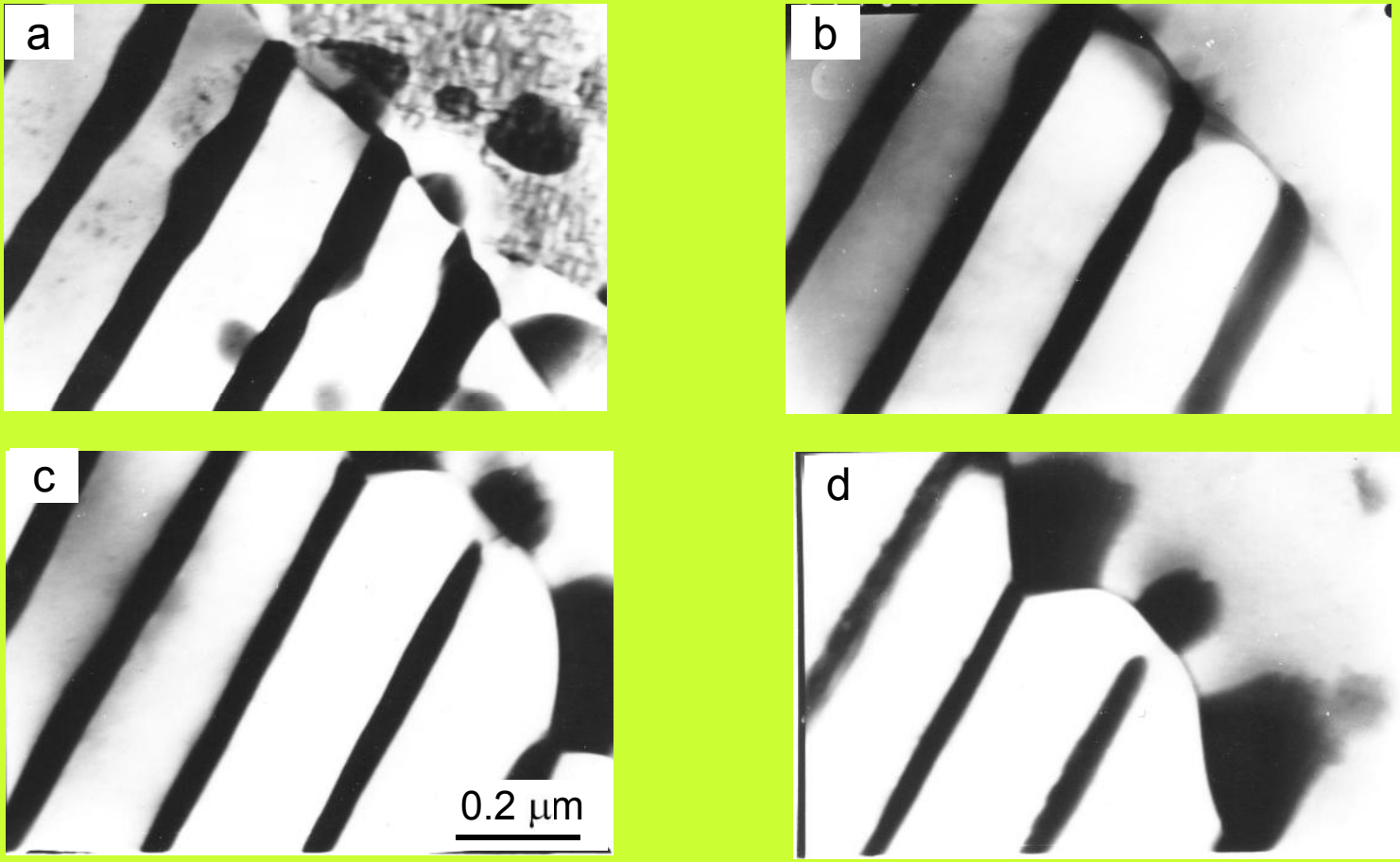




DD-morphology

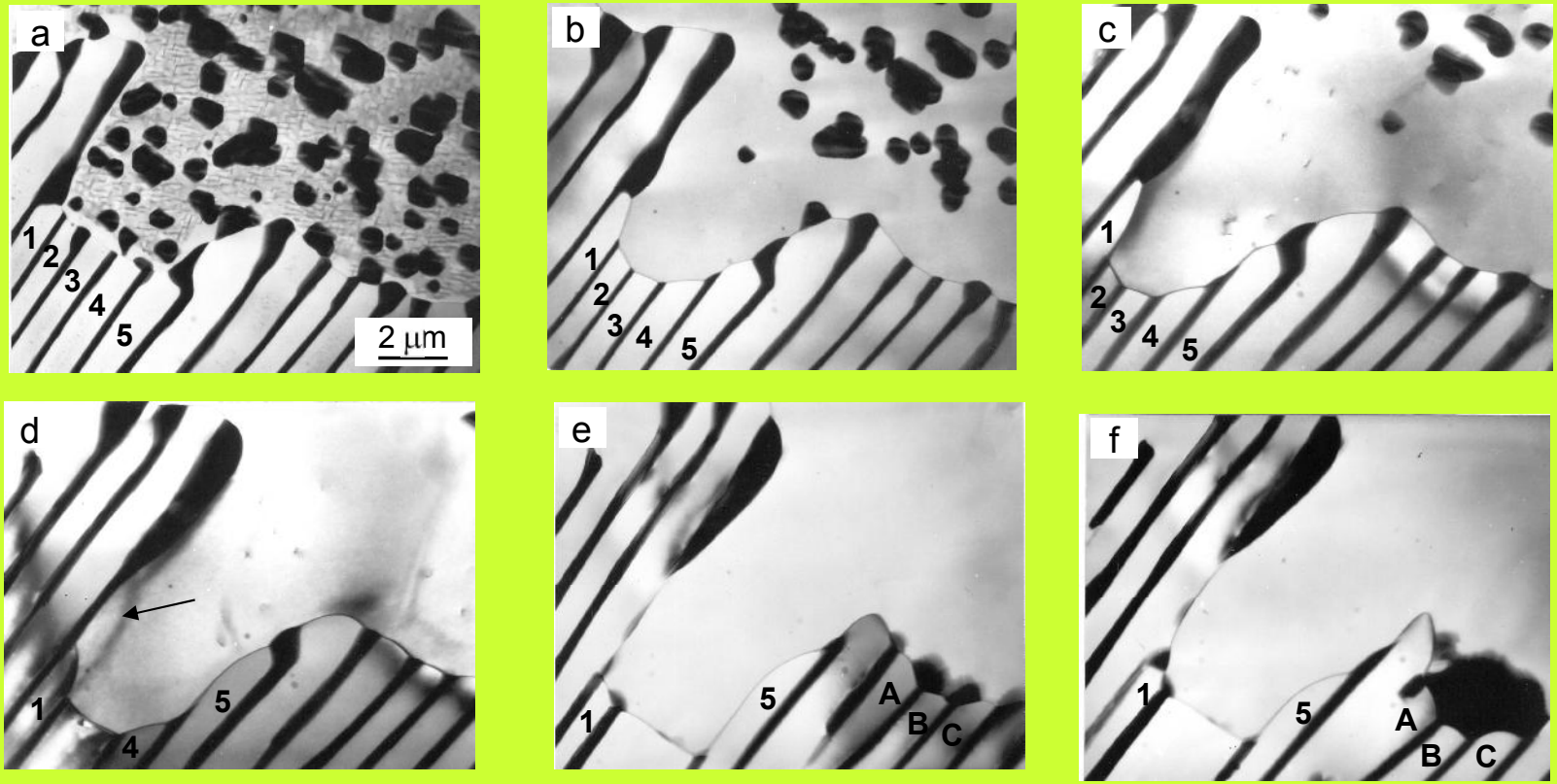


DD-in situ studies



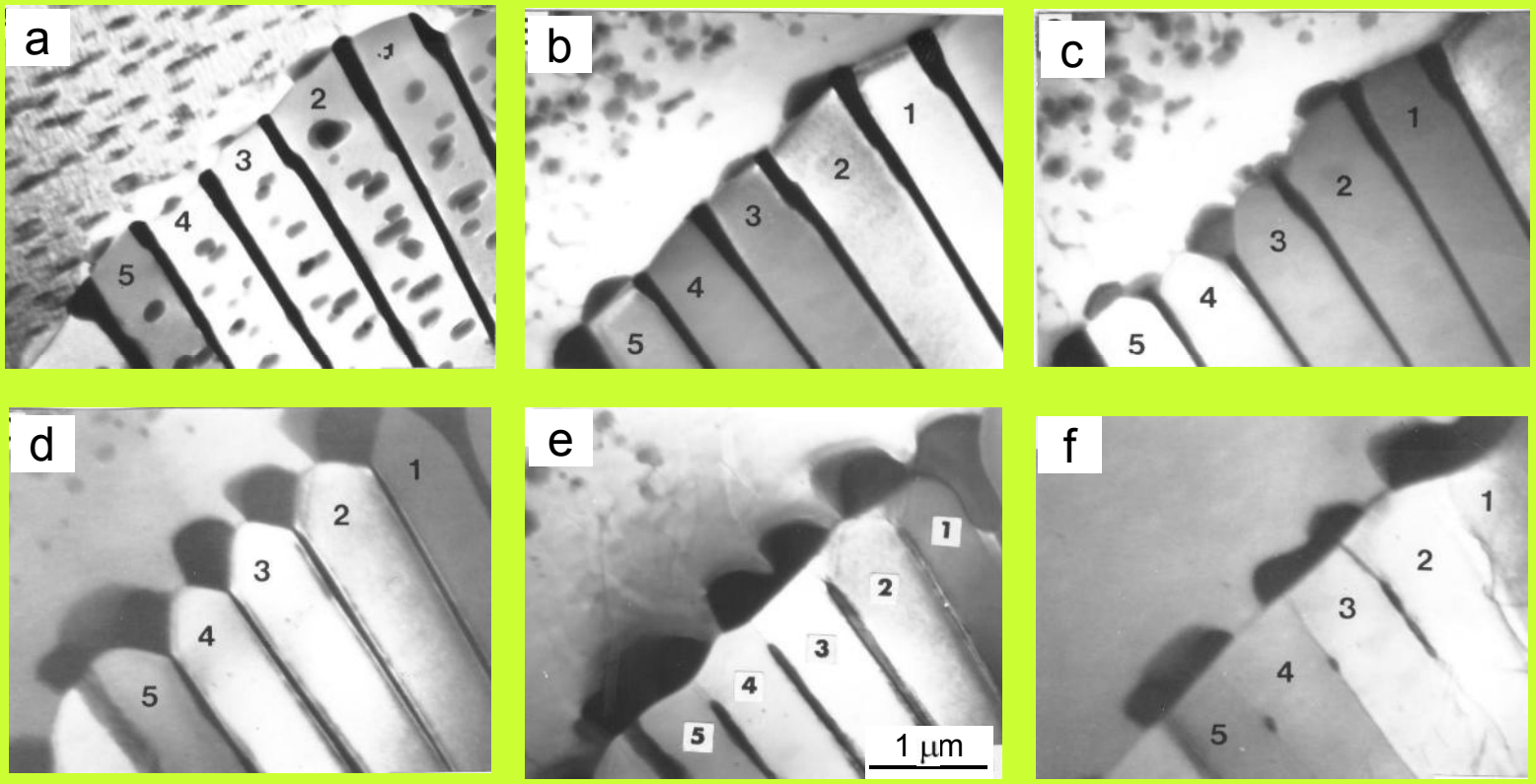
P. Zięba, J. Morgiel: *Scripta Metall. Mater.* 30 (1994) 1177
P. Zięba: *Z. Metallkunde* 90 (1999) 9
Al-22 at.% Zn aged at 440 K for 20 min. Dissolution at 575 K for 10 sec

DD-in situ studies



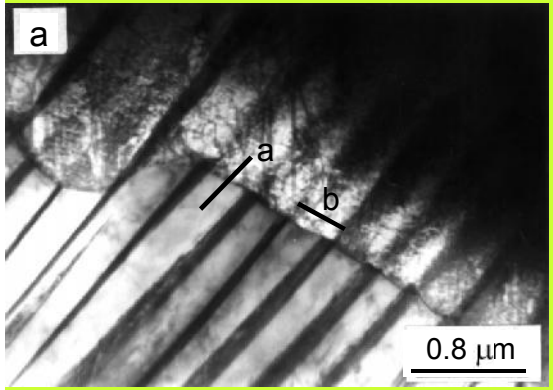
P. Zięba: *Z. Metallkunde* 90 (1999) 9
Al-22 at.% Zn aged at 450 K for 10 min. Dissolution at 550 K for 30 s

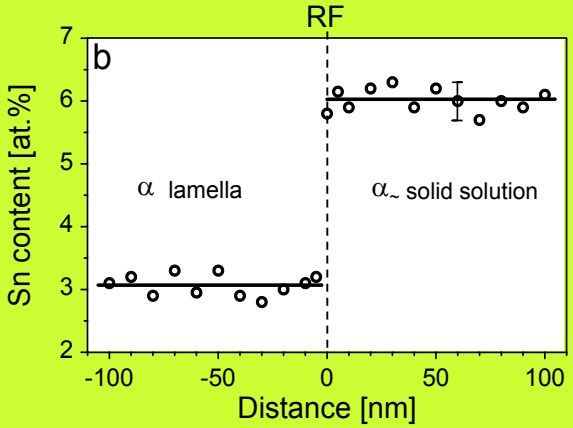
DD-in situ studies

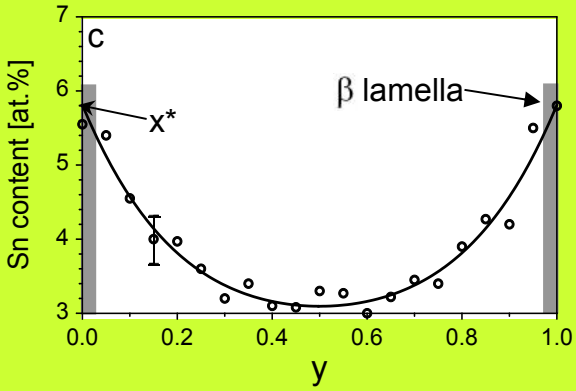


P. Zięba, A. Pawłowski: *Mater. Sci. Eng.* A187 (1994) 57
Al-22 at.% Zn aged at 450 K for10 min. Dissolution at 570 K for 20 s

DD-solute concentration profiles

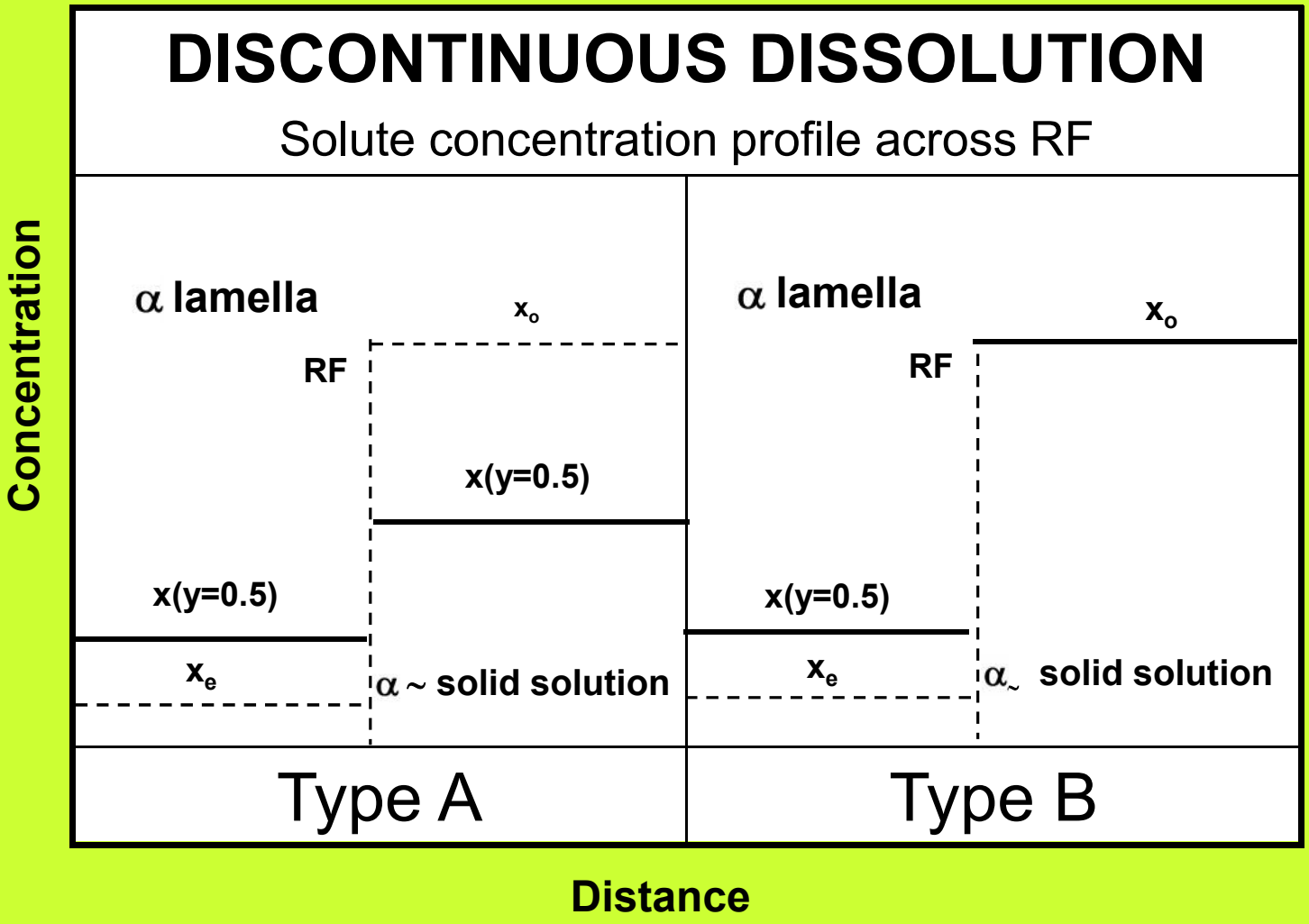




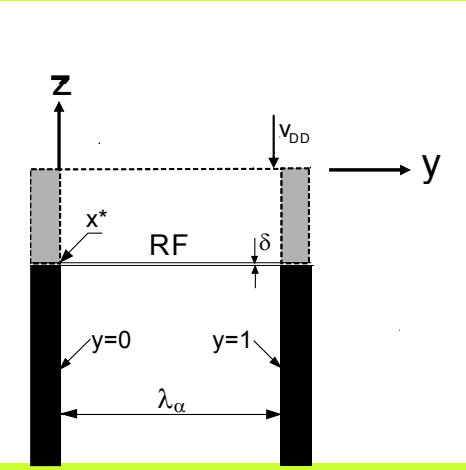


Ni-4 at.% Sn aged 200 h at 725 K, and then 60 h at 775 K. Dissolution for 30 s at 945 K
P. Zieba, W. Gust: *Acta mater.* 47 (1999) 2641

- "Ghost images" showing inhomogemeity of solute concentration in $\alpha_{\sim}$ solid solution formed due to dissolution,
- Abrupt change of solute content across the reaction front (line a),
- „U" shape of solute concentration profile in $\alpha_{\sim}$ solid solution measured along line b,
- The highest value of solute content (denoted as *x**) corresponding to the place just behind the dissolved tip of the β phase,
- „Depth" of solute concentration profile much more pronounced that „height" during DP reaction.


DISCONTINUOUS DISSOLUTION
Solute concentration profile across RF
Concentration
α lamella
x_o
RF
x(y=0.5)
x(y=0.5)
x_e
α ~ solid solution
α lamella
x_o
RF
x(y=0.5)
x_e
α~ solid solution
Type A
Type B
Distance

DD- model



T-T equation

K.N.Tu, D.B. Turnbull

***Metall. Trans.* A2 (1971) 2509**

Assumption: p=z, A constant incorrectly calculated

Z-P equation

P. Zięba, A. Pawłowski: *Scripta Metall.* 20 (1986) 1653

$$x'(y)=A\cdot\sinh(zy\lambda_\alpha)+B\cdot\cosh(zy\lambda_\alpha)+\frac{a}{p^2-z^2}\cosh(py\lambda_\alpha)-\frac{b}{p^2-z^2}\sinh(py\lambda_\alpha)+x_o$$

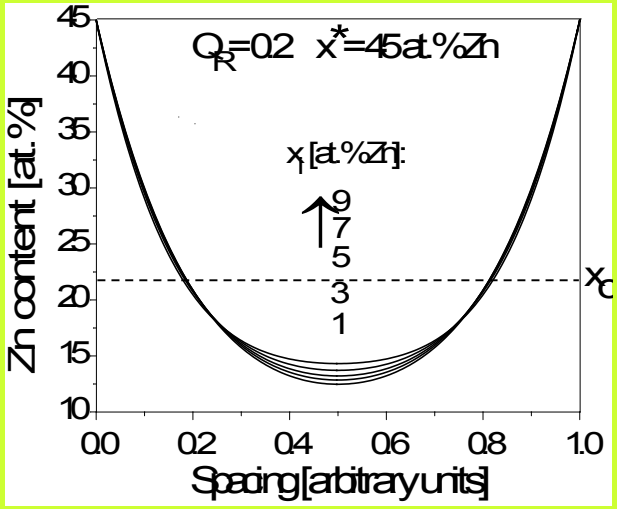
$$p=\left(\frac{v_{DP}}{s\delta D_b}\right)^{\frac{1}{2}},\ z=\left(\frac{v_{DD}}{s\delta D_b}\right)^{\frac{1}{2}}$$

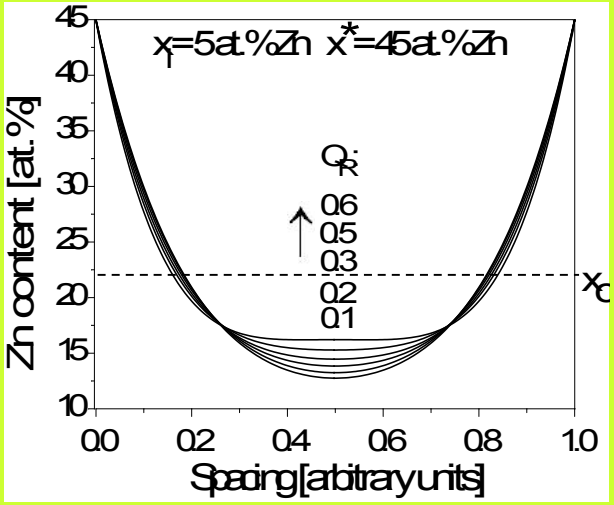
A,B,a,b = f(x_o, x_e, x*, λ_α, z, p)

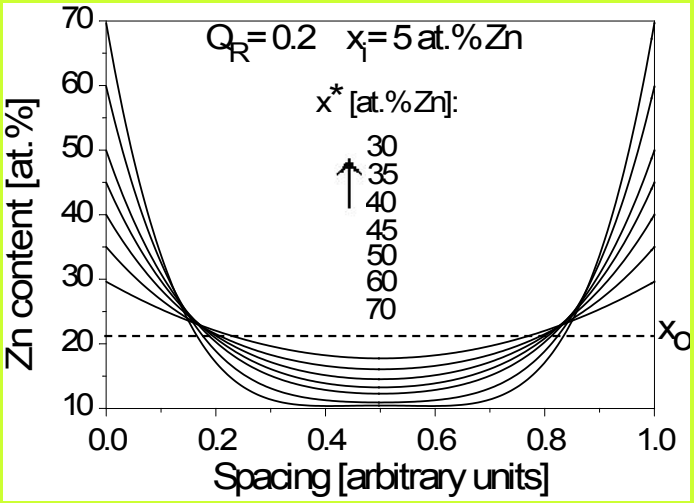
Considering atoms flux at the tip of β phase lamella

$$\lambda_\beta x_\beta=\frac{2}{z}\left[\left(x^*-x_o-\frac{z^2(x_o-x_i)}{p^2-z^2}\right)\tanh(z\lambda_\alpha/2)+\frac{pz(x_o-x_i)\tanh(p\lambda_\alpha/2)}{p^2-z^2}\right].$$

DD-simulation







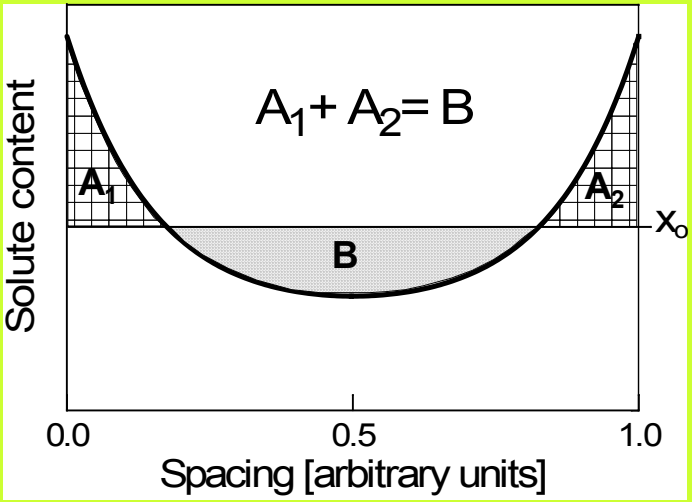
$$Q_R(y) = \frac{x(y) - x_i}{x_o - x_i} = 1 - \frac{\cosh\left[(y - 0.5)p\lambda_\alpha\right]}{\cosh\left(p\lambda_\alpha / 2\right)}$$

P. Zięba, W. Gust
***Interface Science* 6 (1998) 309**

DD- validity of Z-P equation

P. Zięba, W. Gust: *Interface Science* 6 (1998) 309

Only those concentration profiles are admissible for which the areas above and under the level of the concentration x_o fulfill the relation $A_1+A_2=B$



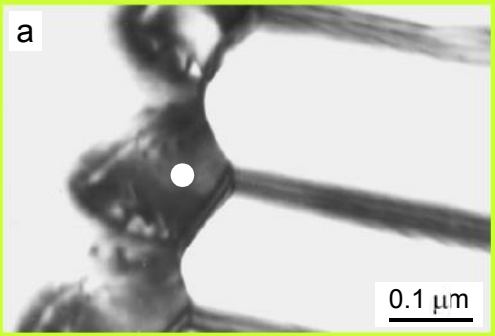
$$\int_0^1 \left(x'(y) - x_1\right) dy = 0$$

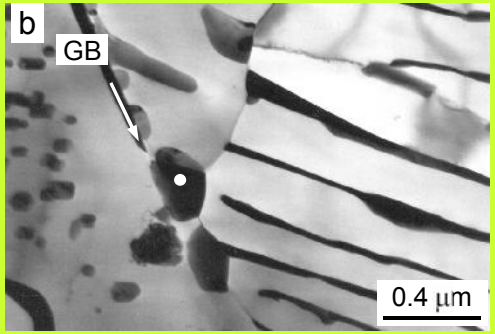
$$x_1 = x_o + \frac{2}{\lambda_\alpha}\left[\frac{B}{z}\tanh\left(\frac{z\lambda_\alpha}{2}\right) + \frac{a\tanh\left(p\lambda_\alpha/2\right)}{p\left(p^2 - z^2\right)}\right].$$

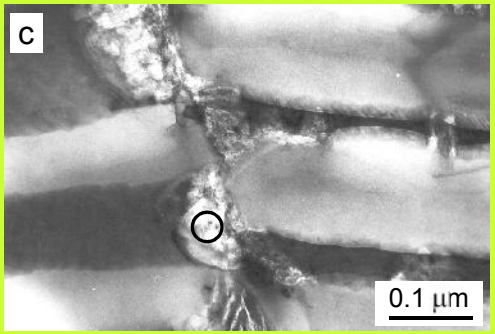
If $x_1 = x_o$, then

$$x^* = x_o + \frac{a}{p^2 - z^2}\left[1 - \frac{z\tanh\left(p\lambda_\alpha/2\right)}{p\tanh\left(z\lambda_\alpha/2\right)}\right]$$

DD –x* concentration







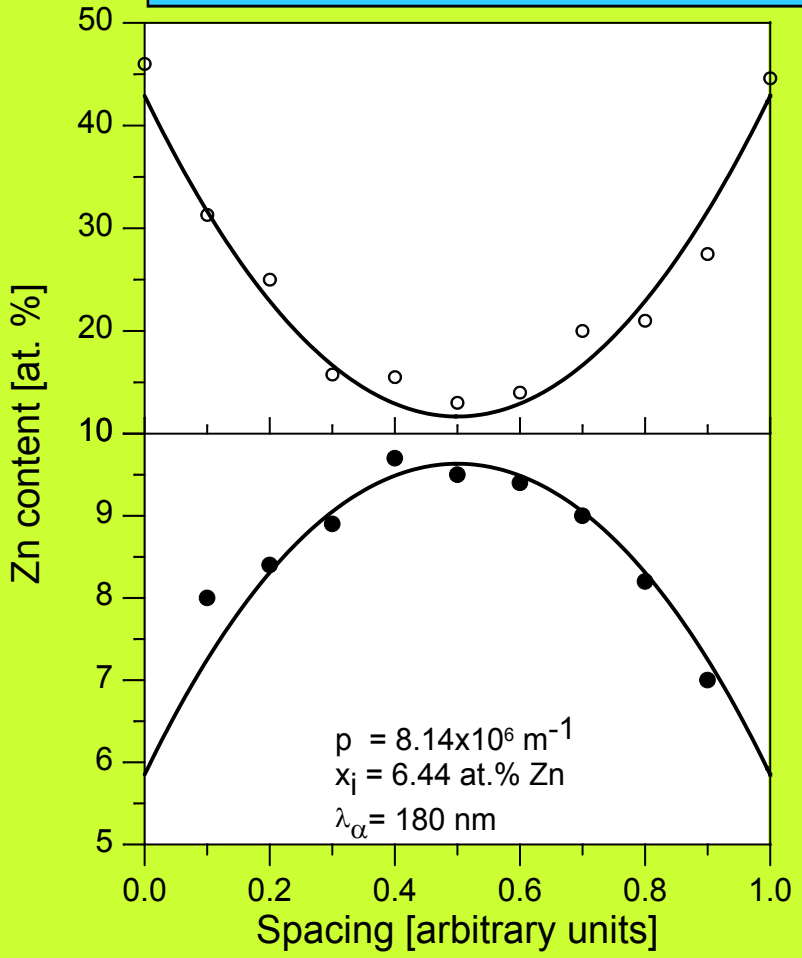
RF **OGB** **IPG**

P. Zięba, W. Gust: *Inter. Mater. Rev.* 43 (1998) 70
Al-22 at.% Zn aged at 450 K for 3 min

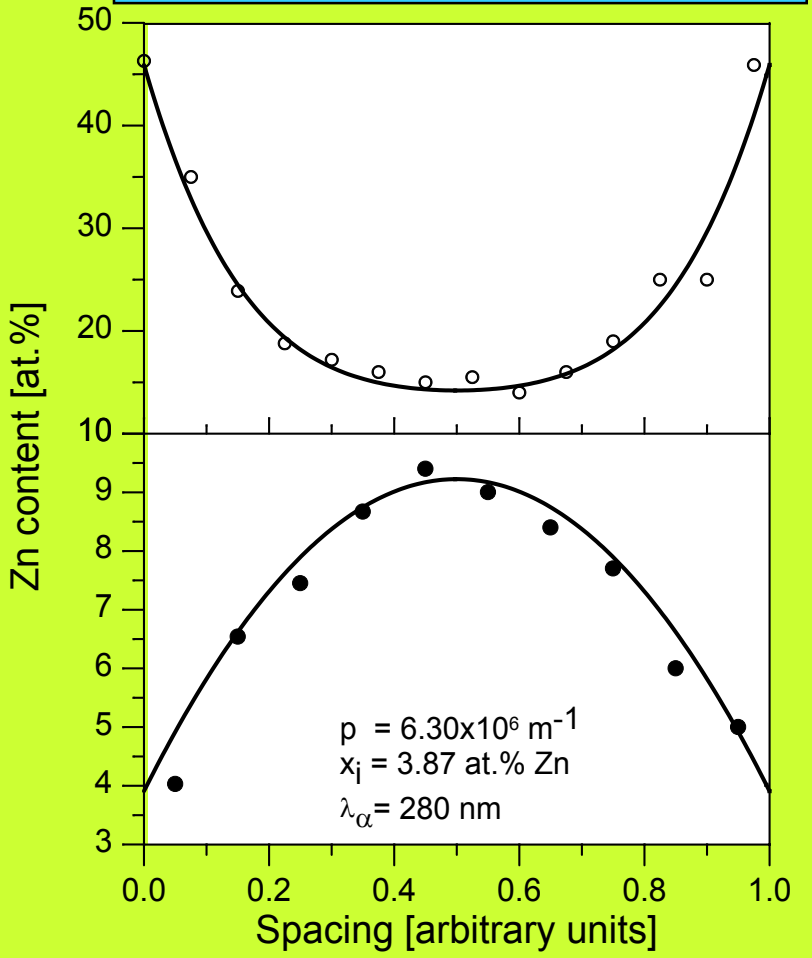
Temperature [K]		Concentration, x* [at.%]		
DD	DP	RF	OGB	IPG
560	450	46	45.2	47
570		45	44.6	45.2
580		43.5	43.1	43.3
590		43	42.8	43

DD-solute concentration profiles

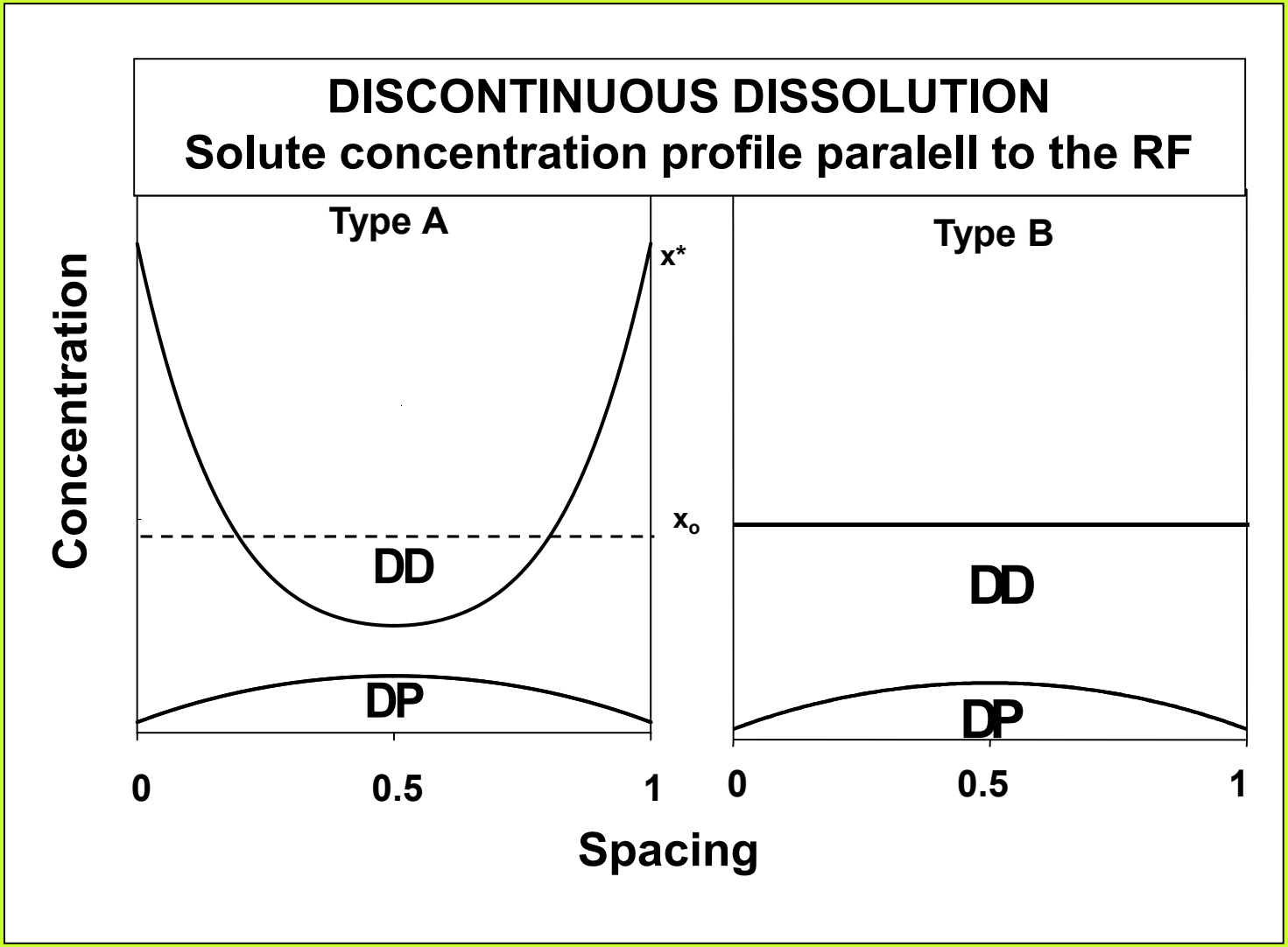
Al-22 at.% Zn aged at 400 K for 10 min.
Dissolution: 15 s at 560 K



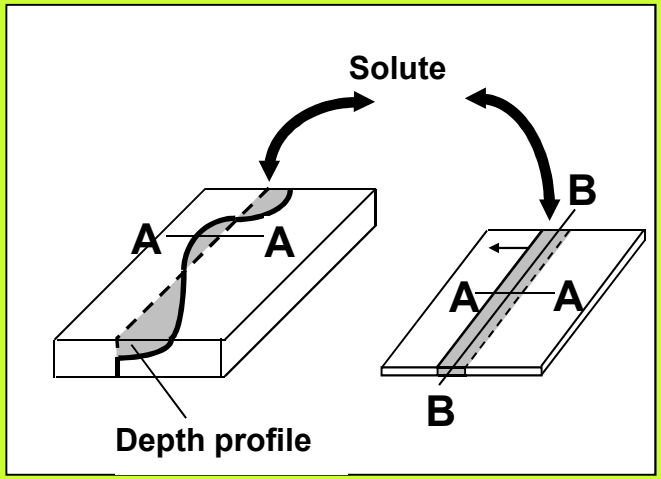
Al-22 at.% Zn aged at 450 K for 10 min.
Dissolution: 5 s at 570 K



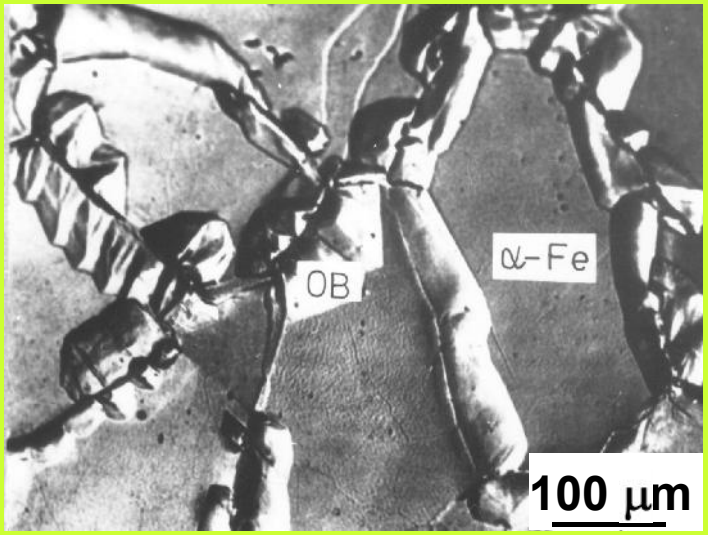
P. Zięba, W. Gust: *Interface Science* 6 (1998) 307


DISCONTINUOUS DISSOLUTION
Solute concentration profile paralell to the RF
Type A
Type B
Concentration
x*
x_o
DD
DP
DD
DP
0
0.5
1
0
0.5
1
Spacing

DIFFUSION INDUCED GRAIN BOUNDARY MIGRATION



M. Hillert, G.R. Purdy,
Acta metall. 26 (1978) 333



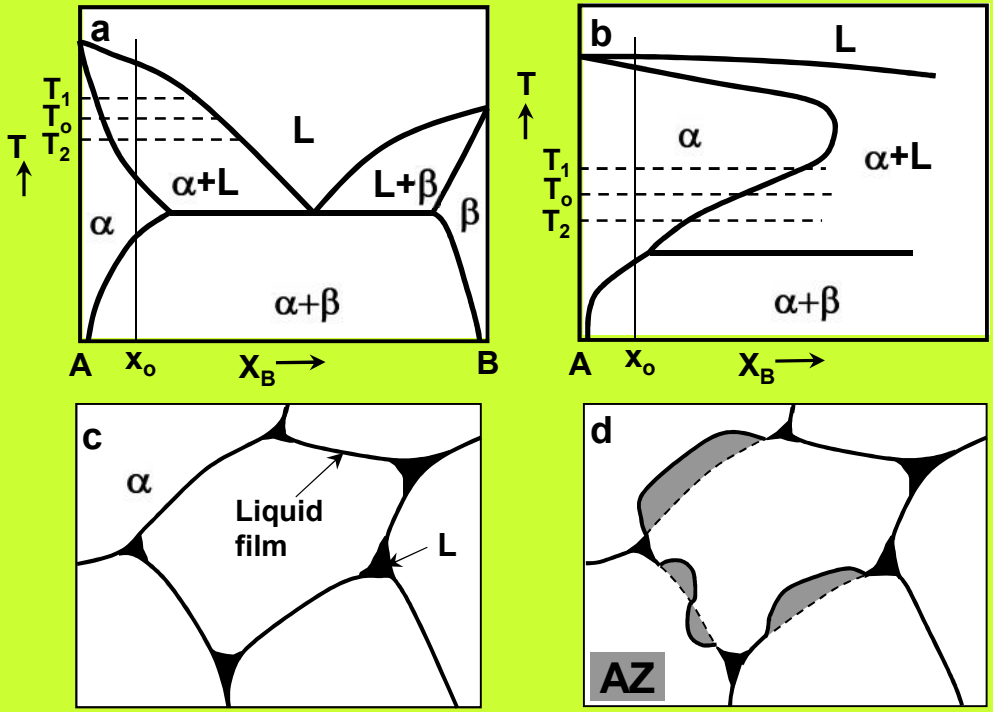
DIGM – *Diffusion induced grain boundary migration*

Phenomenon associated with the migration of a grain boundary into a pure metal or solid solution caused by the diffusion of solute atoms into or out of the material along the boundary. In a consequence, the region behind the moving boundary is enriched or depleted with solute atoms, which is manifested by an alloyed or de-alloyed zone, respectively.

CIGM – *Chemical induced grain boundary migration*

Encounters also the cases where the chemical instability leading to the grain boundary migration is induced by a temperature or atmosphere change for the internal solute sink or source.

DIGM/LFM

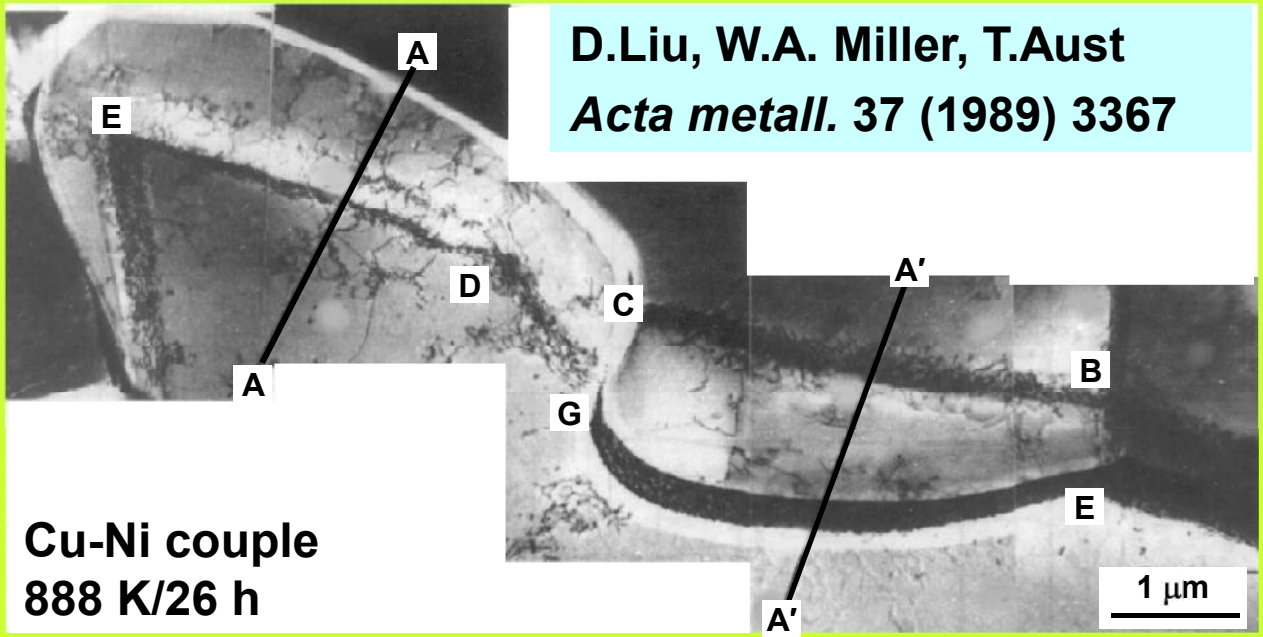


LFM – *Liquid film migration*

found in partially molten samples either when liquid is first introduced or when the chemical composition of the liquid is changed, for example, by alloying or by changing the temperature.

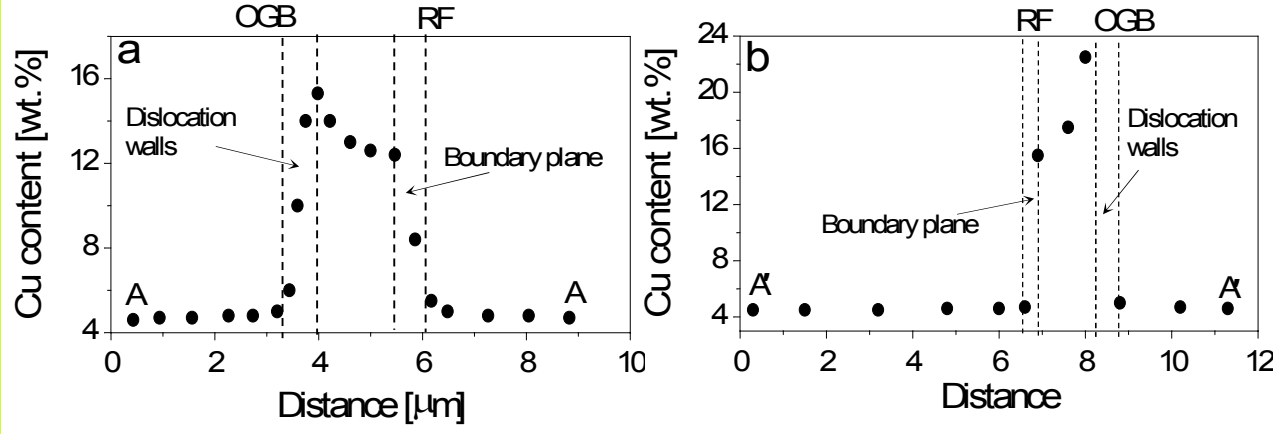
DIGM

Solute profile across RF



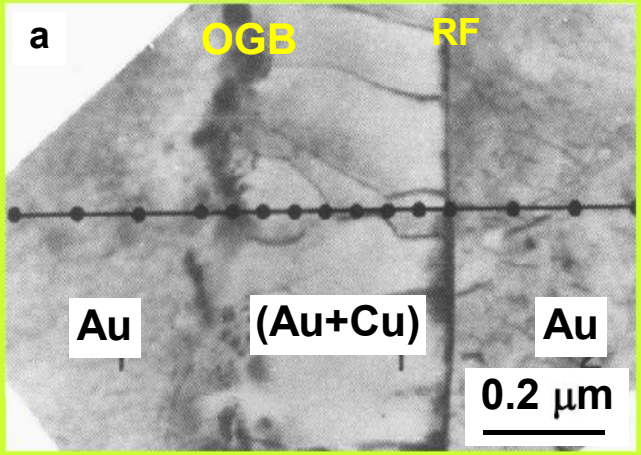
D.Liu, W.A. Miller, T.Aust
***Acta metall.* 37 (1989) 3367**

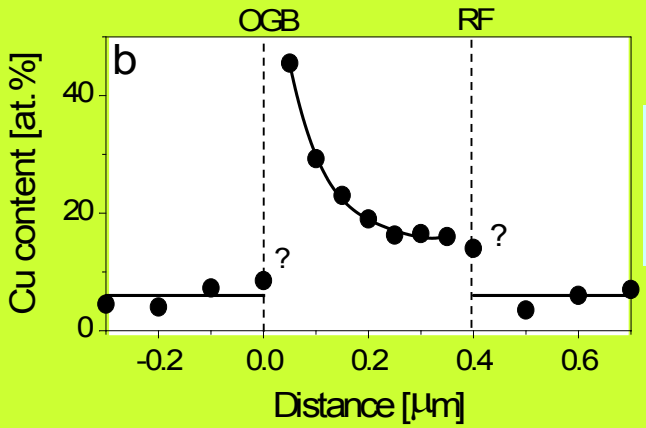
Cu-Ni couple
888 K/26 h



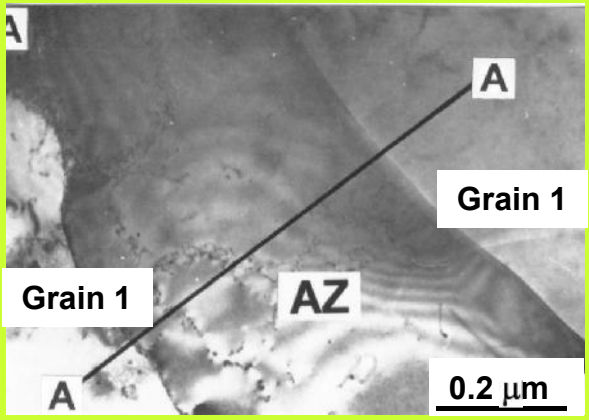
DIGM

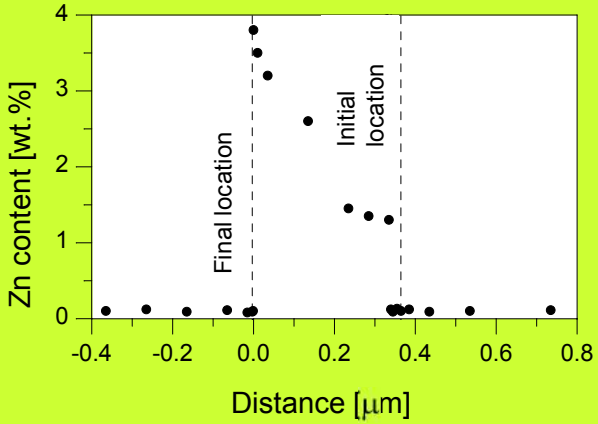
Solute profile across RF





J.W. Pan, R.W. Baluffi:
***Acta metall.* 30 (1982) 861**
Cu-Au couple: 423 K/137 h

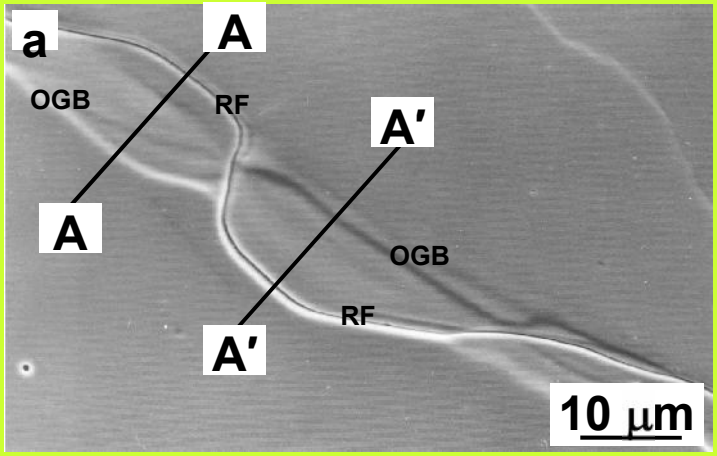


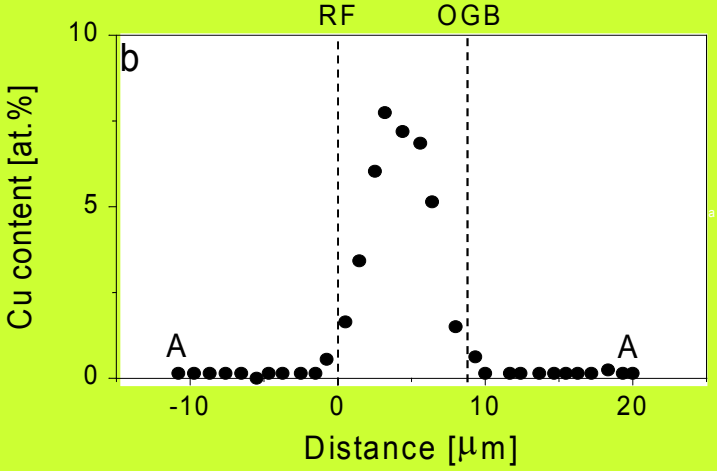


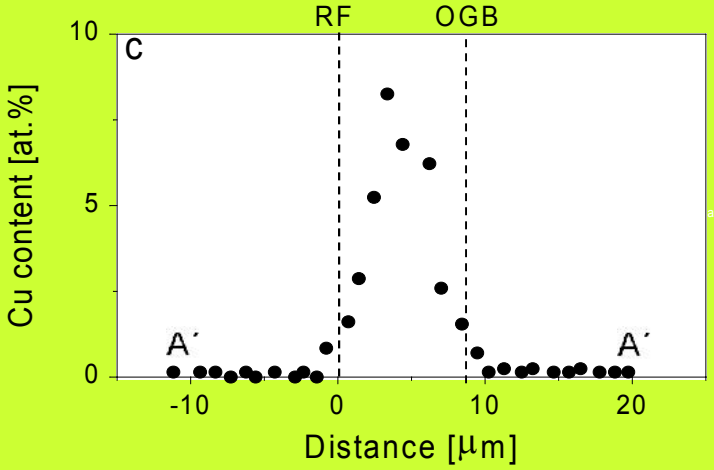
P. Zięba, A. Pawłowski:
***J. Mater. Sci.* 29 (1994) 6231**
Al-Zn couple: 455K/10 dni

DIGM

Solute profile across RF



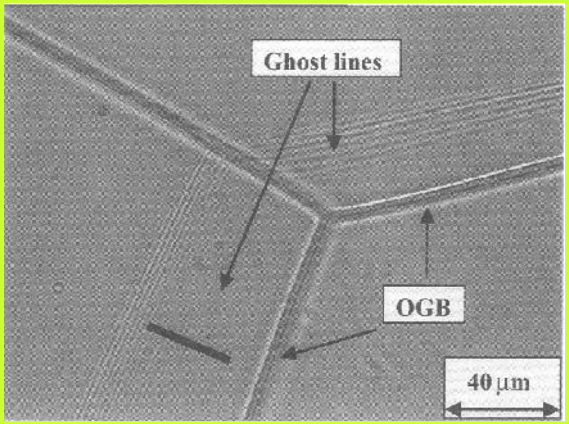




C.Y Ma, E. Rabkin, W. Gust, S.E. Hsu:
***Acta metall. mater.* 43 (1995) 3113**
Ni-Cu couple: 1023 K/6h

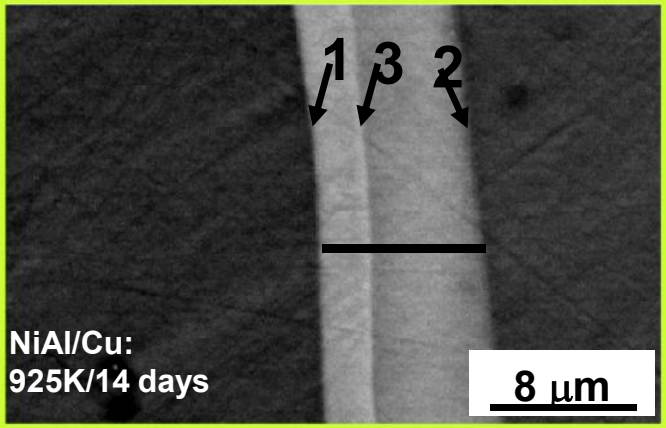
DIGM

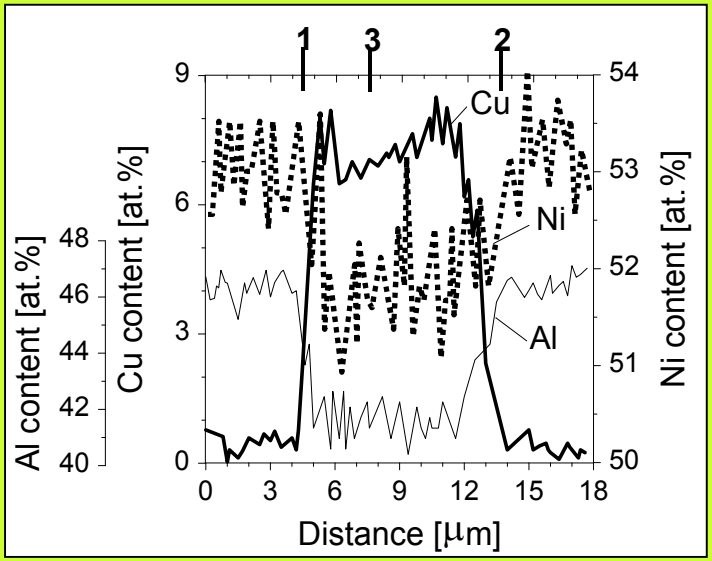
Solute profile across RF

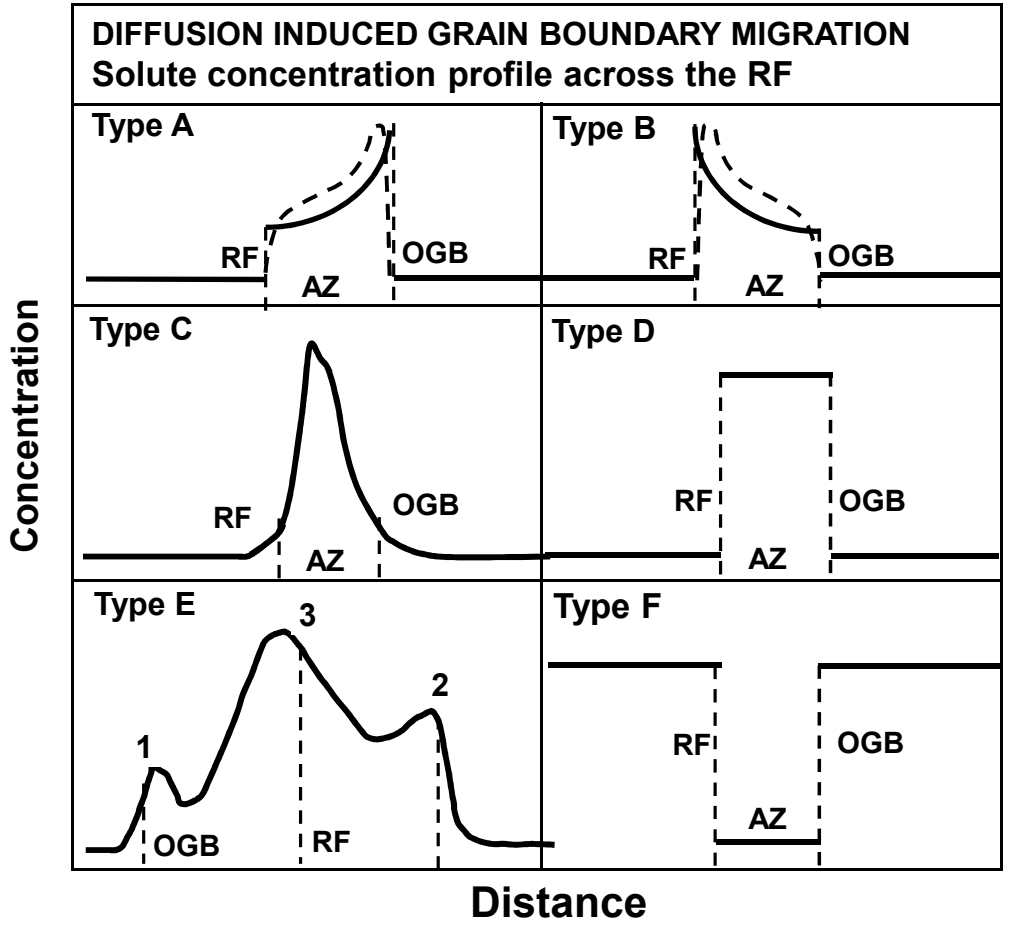


L. Chongmo, M.Hillert:
Acta metall. 29 (1981) 1949

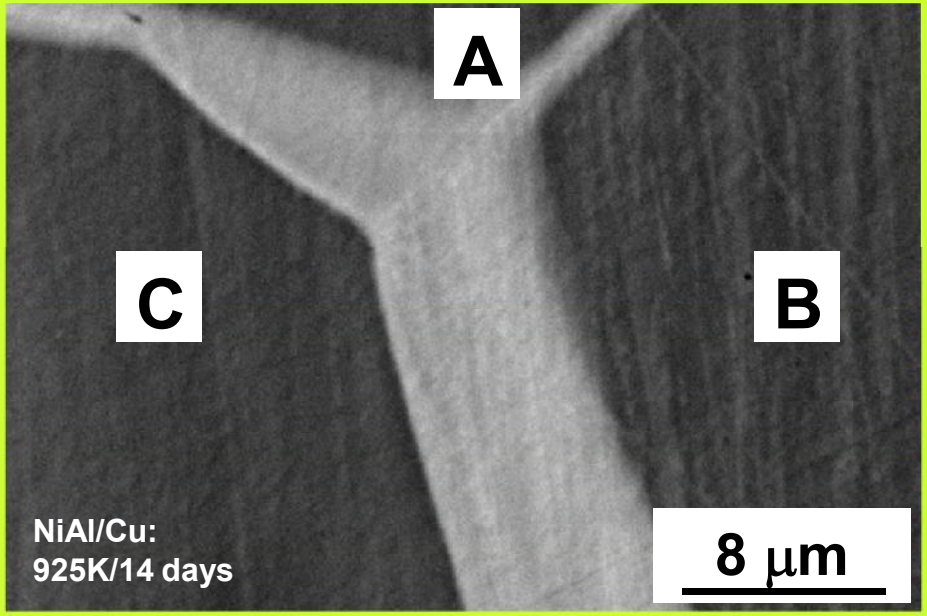
L. Chongmo, M.Hillert:
Acta metall. 29 (1981) 1949





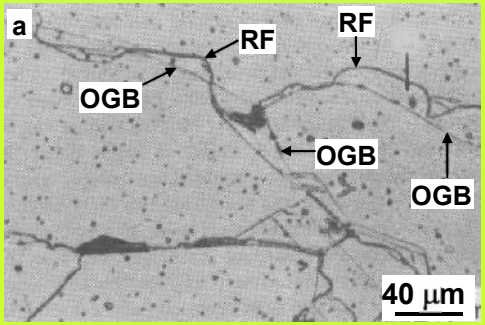

DIFFUSION INDUCED GRAIN BOUNDARY MIGRATION
Solute concentration profile across the RF
Type A
RF
AZ
OGB
Type B
RF
AZ
OGB
Type C
RF
AZ
OGB
Type D
RF
AZ
OGB
Type E
1
2
3
OGB
RF
Type F
RF
AZ
OGB
Concentration
Distance

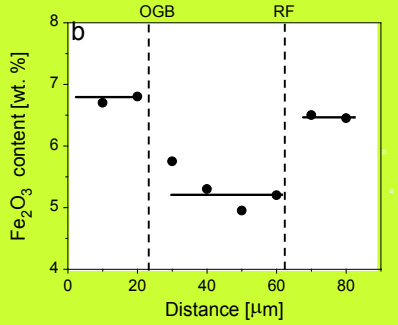
DIGM



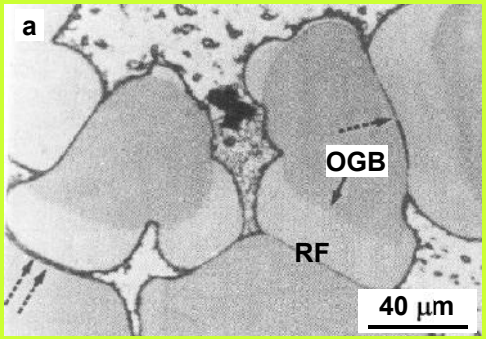
DIGM

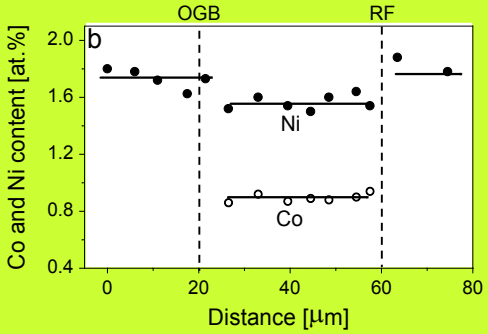
Solute concentration profile across RF



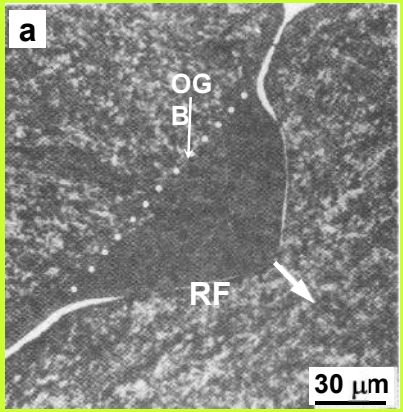


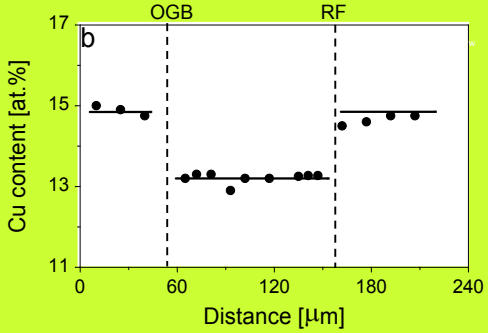
M.Y. Lee, Y.W. Rhee, S.J.L. Kang
J. Amer. Cer. Soc. 79 (1996) 1659
$93Al_2O_3$-$7Fe_2O_3$ (wt.%) sintered
1873K/2h (in air)





W.H. Rhee, D.N. Yoon
Acta metall. 37 (1989) 221
Mo-15wt.%Ni, sintering: 1733K/2h
Annealing at 1773K/1h after embedding
in molten Mo-Ni-Co20wt.%

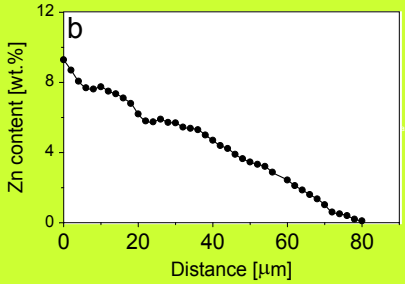




Y.J. Baik, J.K. Kim, D.Y. Yoon
Acta metall. Mater. 41 (1993) 2385
Liquid Co-20wt.%Cu sintered
1573K and annealed at 1432K/1h

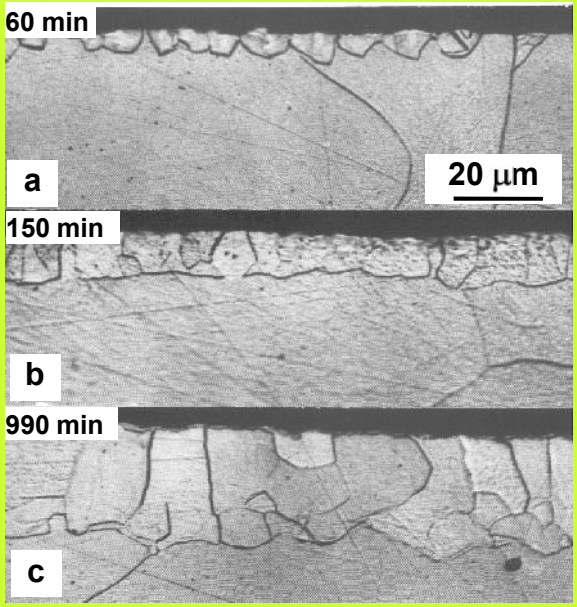
DIGM/DIR

Depth profile



P. Zięba, A. Pawłowski:
J. Mater. Sci. 29 (1994) 6231
Al-Zn couple: 455K/10 dni

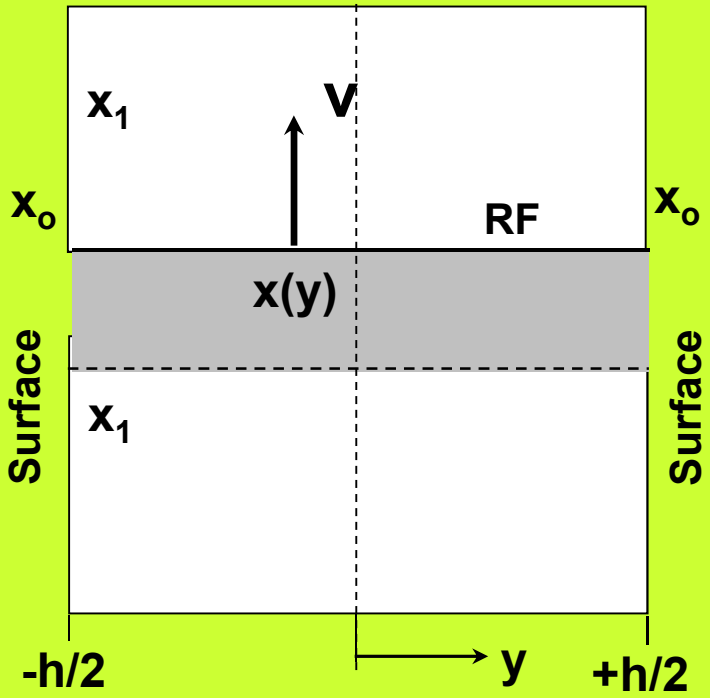
Diffusion induced recrystallization (DIR)



L. Chongmo, M.Hillert:
Acta metall. 29 (1981) 1949
Fe/Zn: 873K

Nucleation and growth of new, small grains at the surface of material with different chemical composition in comparison with material interior
DIGM: Migration + GB diffusion
DIR: Recrystallization + GB diffusion

DIGM-kinetic model



Thin foil (profile across whole sample)

$$x(y) = (x_o - x_1)\frac{\cosh\left(y\sqrt{C/h}\right)}{\cosh\left(\sqrt{C/2}\right)} + x_1 \quad gdzie \quad C = \frac{h^2 v}{s\delta D_b}$$

Pure foil

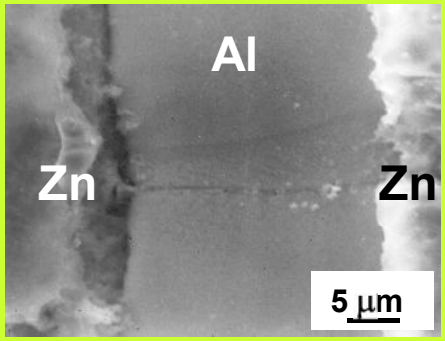
$X_1=0$

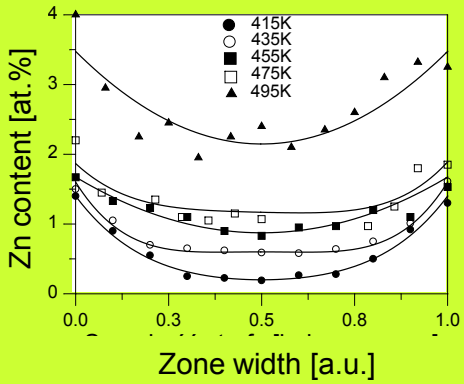
$$x(y) = (x_o)\frac{\cosh\left(y\sqrt{C/h}\right)}{\cosh\left(\sqrt{C/2}\right)}$$

Bulk sample:

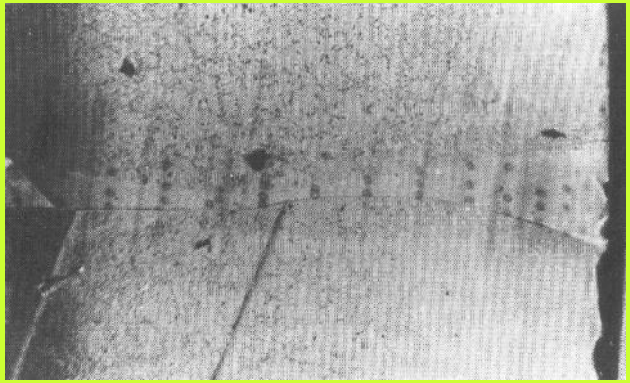
Origin of co-ordinates at the sample surface (y=h/2 instead of y=0), then h→∞

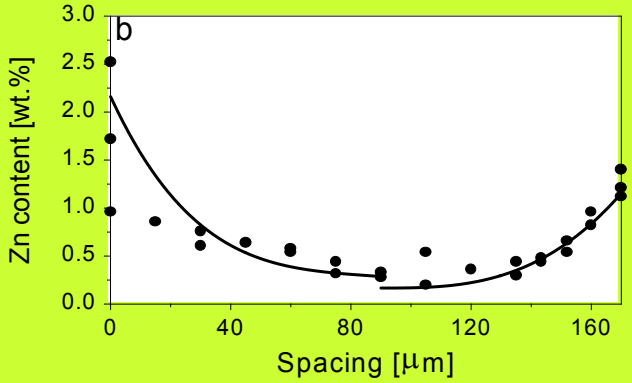
$$y(x) = x_o \exp\left(-y\left(v/s\delta D_b\right)^{0.5}\right)$$

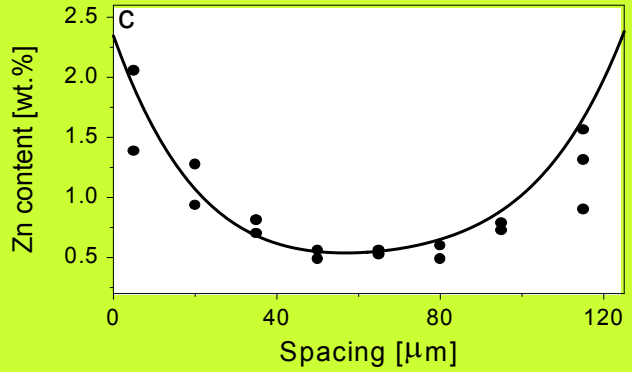




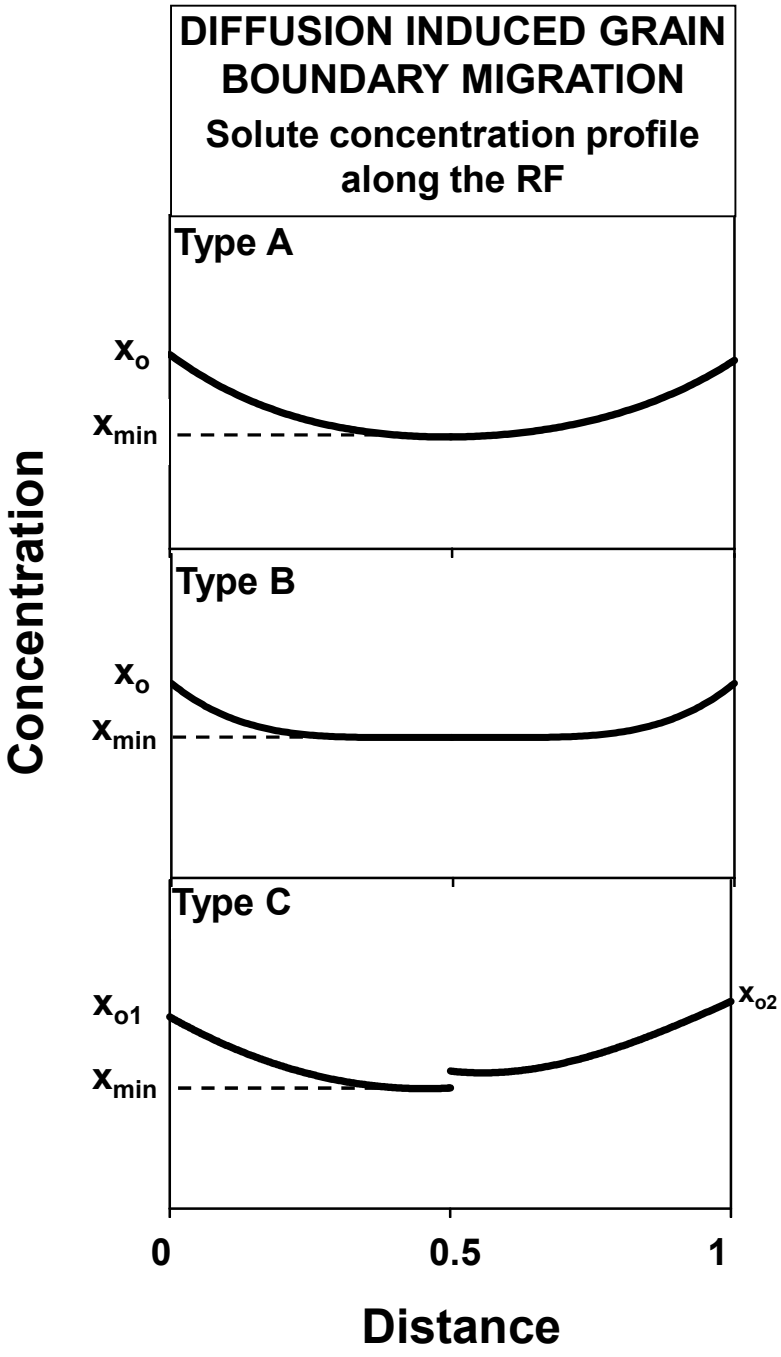
P. Zięba, A. Pawłowski: *J. Mater. Sci.* 29 (1994) 6231
Al-Zn couple: 455K/10 days





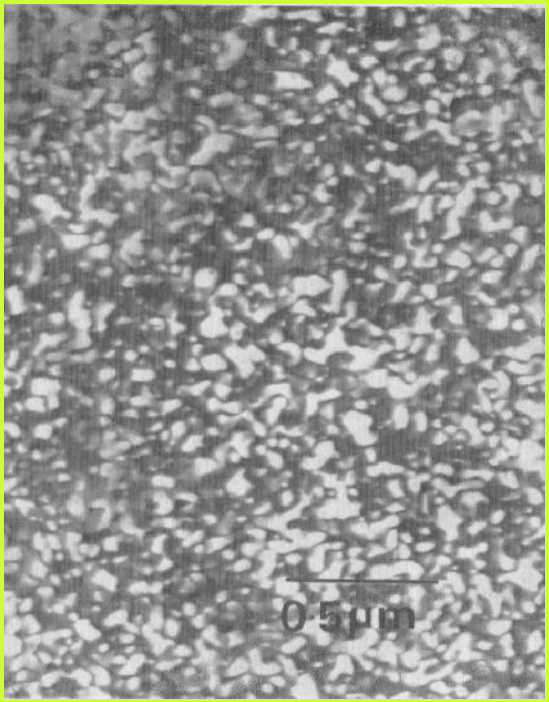


L. Chongmo, M.Hillert:
Acta metall. **30 (1982) 1133**
Cu/Cu-30.5 wt.%Zn: 623 K for 1206 h



Discontinuous ordering (DO)

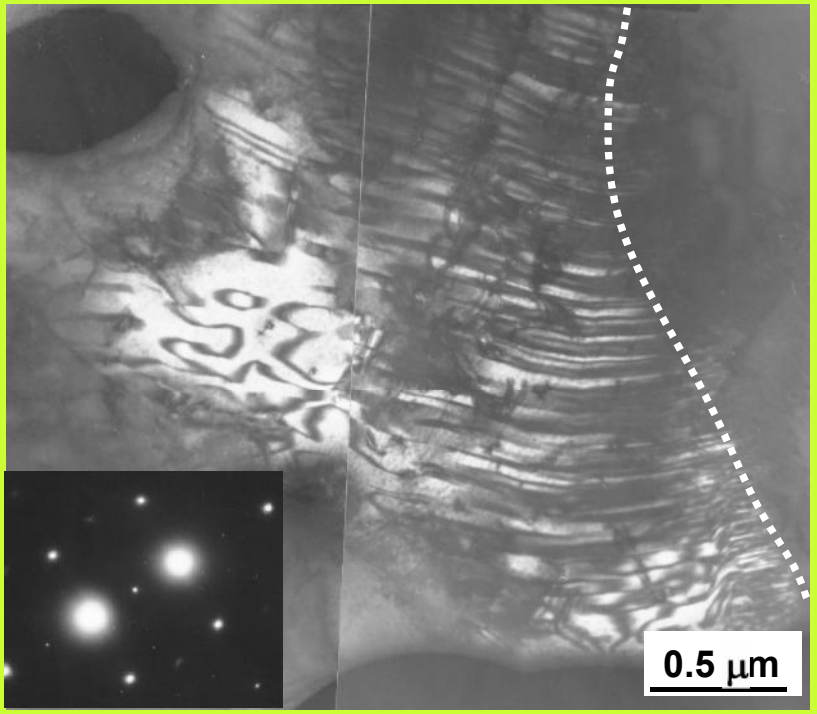
Nucleation of ordering phase at the GB and subsequently its growth to the grain interior due to GB migration.



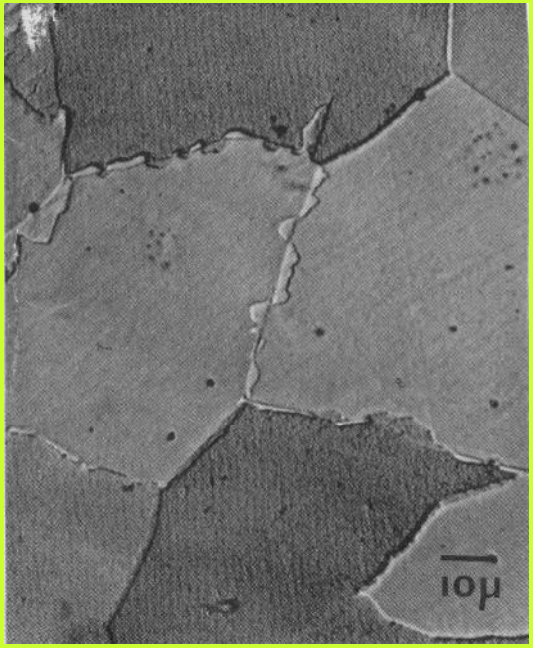
FeCo-2V saturated at 1073 K, annealed at 723 K for 5 hours

M. Tajkovic, R.A. Buckley, *Metal Science* 21, (1981) 21-29

DO appears in Ni_2V (described for the first time by L.E. Tanner in 1972), Cu-Pt and Fe-Co alloys

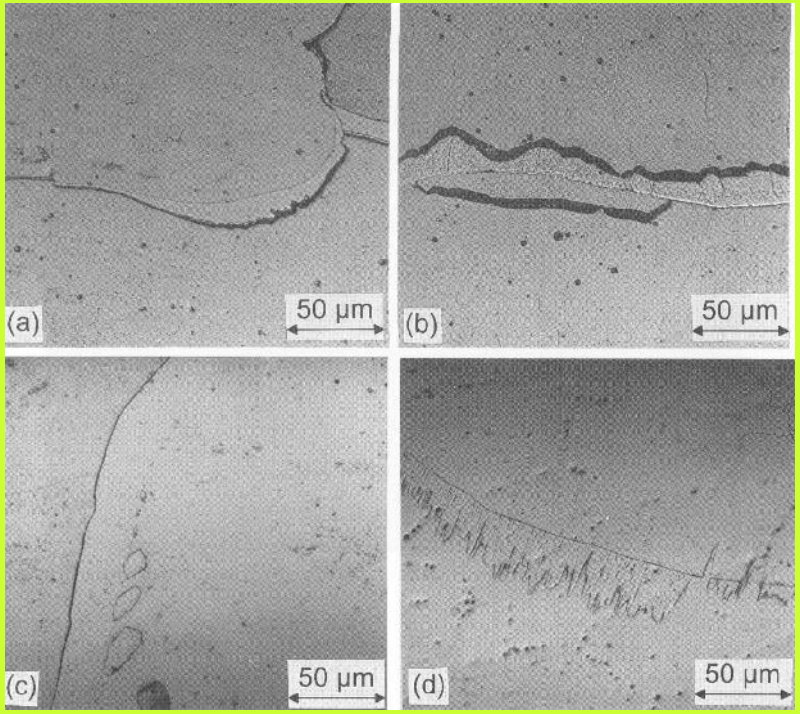


Discontinuous ordering



Fe-50 at.%Co saturated at 1073 K, annealed at 673 K for 2 hours

M. Tajkovic, R.A. Buckley,
***Metal Science* 21, (1981) 21-29**

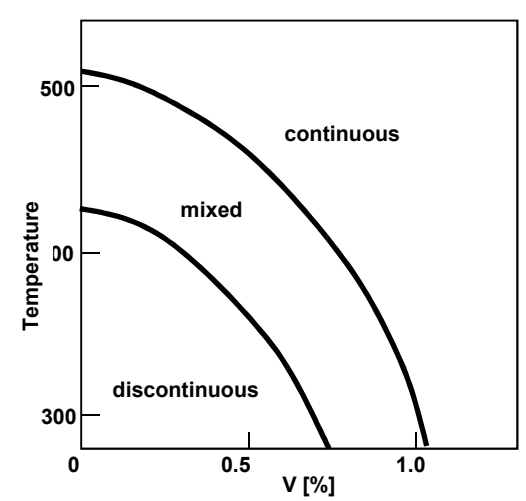


Fe-50 at.% Co: saturation at and annealing: 643K/8h (a) i (b), 643K/14h (c), 613K/14h (d)

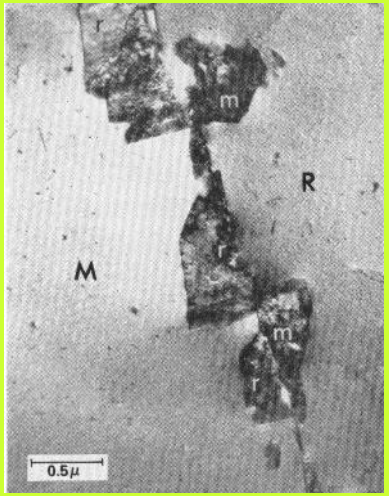
V.Semenov, E. Rabkin, E. Bischoff, W. Gust

Acta mater. 46, (1998) 2289-2298

Discontinuous ordering

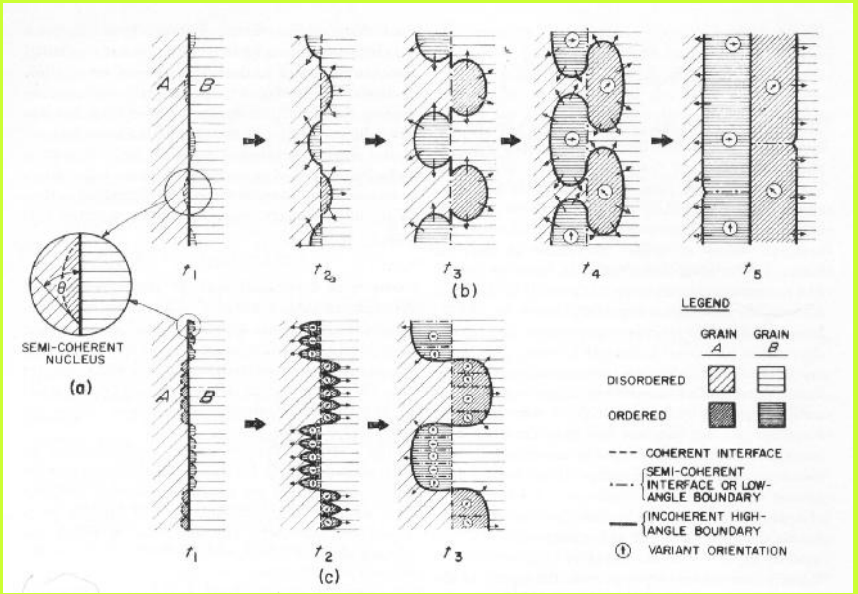


M. Tajkovic, R.A. Buckley,
Metal Science 21, (1981) 21-29

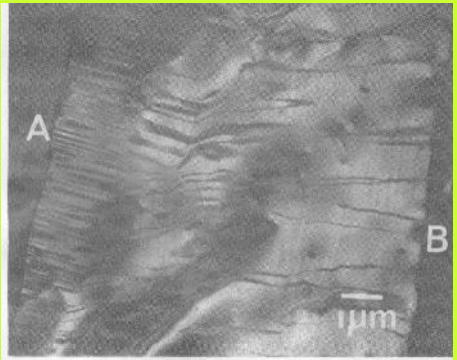


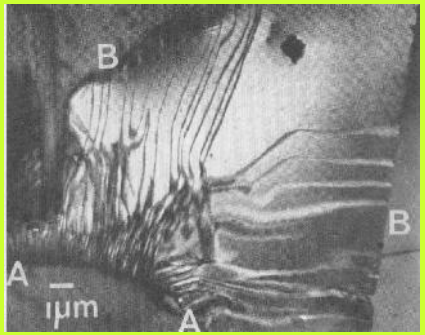
Ni_2V annealed at873 K for 2 min

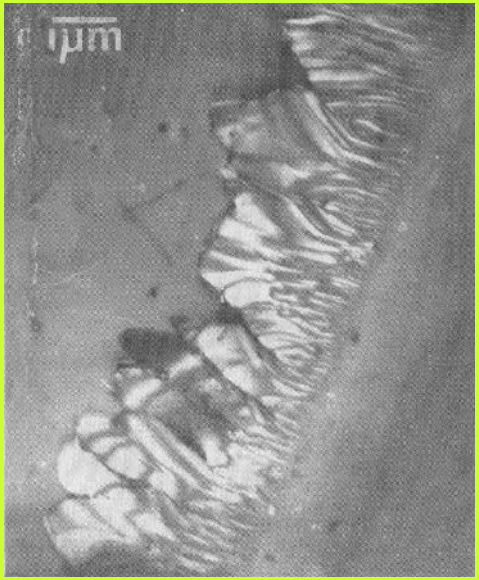
L.E. Tanner, *Acta metall 20*, (1972) 1197-1227

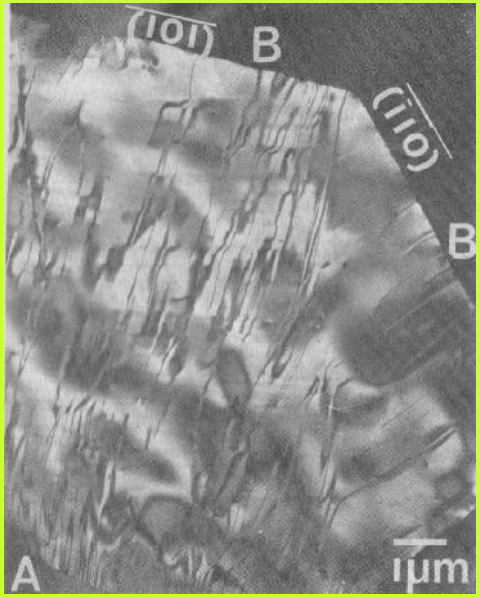


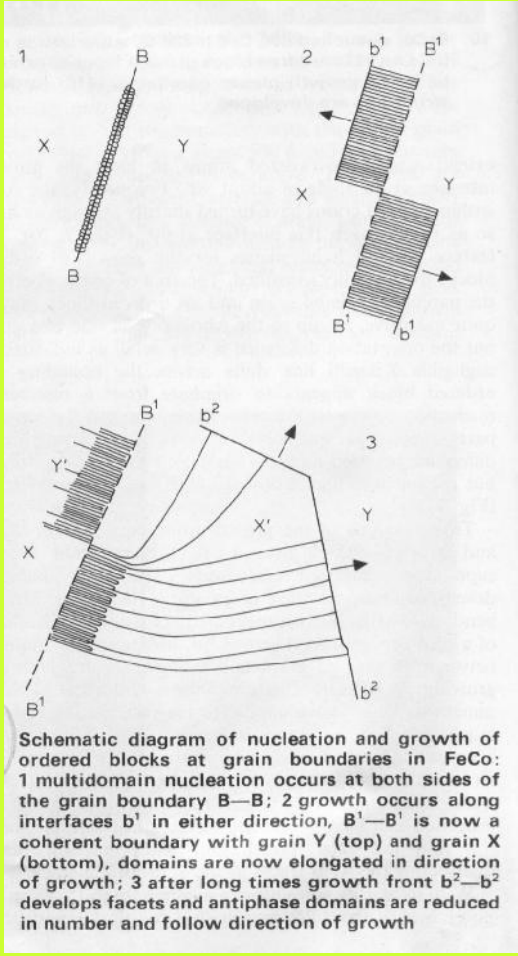
Discontinuous ordering







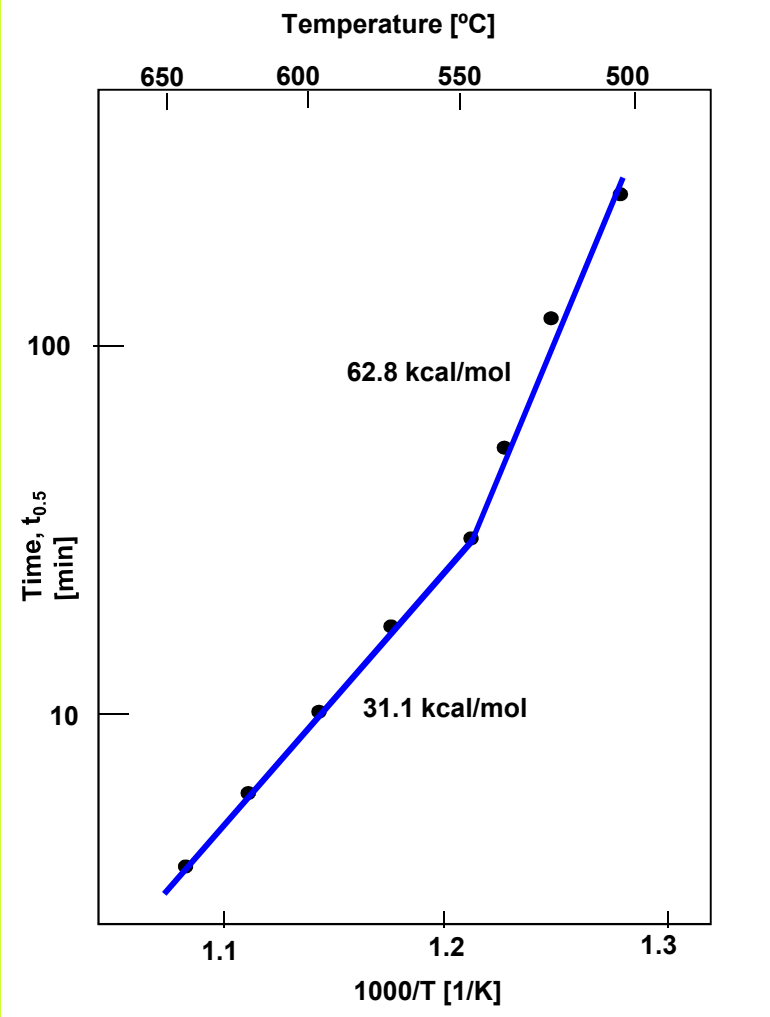




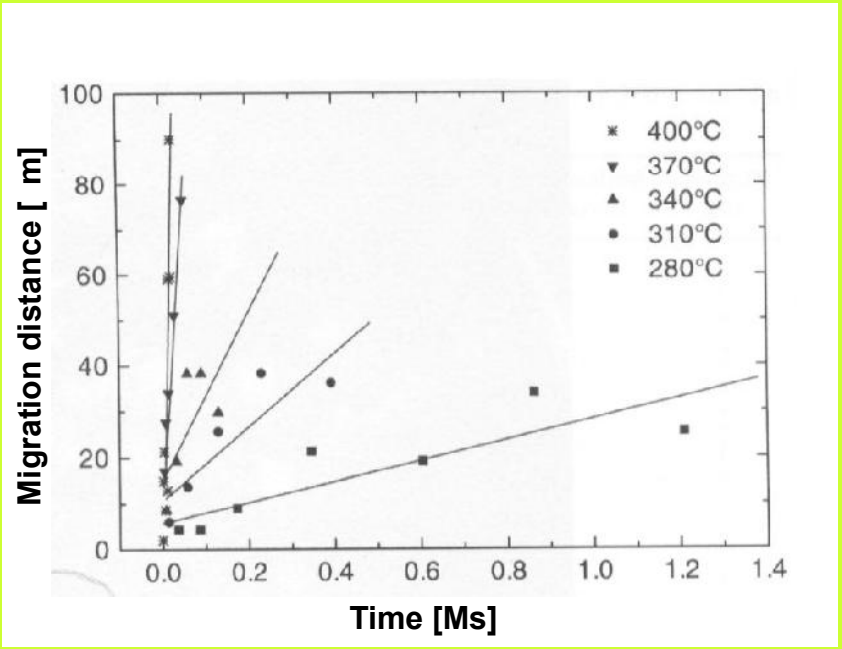
Schematic diagram of nucleation and growth of ordered blocks at grain boundaries in FeCo: 1 multidomain nucleation occurs at both sides of the grain boundary B—B; 2 growth occurs along interfaces b^1 in either direction, B^1—B^1 is now a coherent boundary with grain Y (top) and grain X (bottom), domains are now elongated in direction of growth; 3 after long times growth front b^2—b^2 develops facets and antiphase domains are reduced in number and follow direction of growth

M. Tajkovic, R.A. Buckley,
***Metal Science* 21, (1981) 21-29**

Discontinuous ordering



L.E. Tanner, *Acta metall 20*, (1972) 1197-1227



Fe-50 at.% Co:
V.Semenov, E. Rabkin, E. Bischoff, W. Gust
Acta mater. 46, (1998) 2289-2298