Reconstruction of austenite orientation map based on martensite / bainite orientation data and application to ausforming

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'10 / 6 / 4 Max Planck (Dusseldorf)

Outline

1. Introduction of ausforming
2. Measurement of orientation relationship between martensite & bainite / austenite matrix.
3. Reconstruction of austenite orientation map based on ferrite orientation map of martensite and bainite structures, and application to ausforming treatment.

Crystallographic feature of lath martensite / bainite

Lath martensite holds near K-S O.R. with γ matrix

Kurdjumov-Sachs O.R.

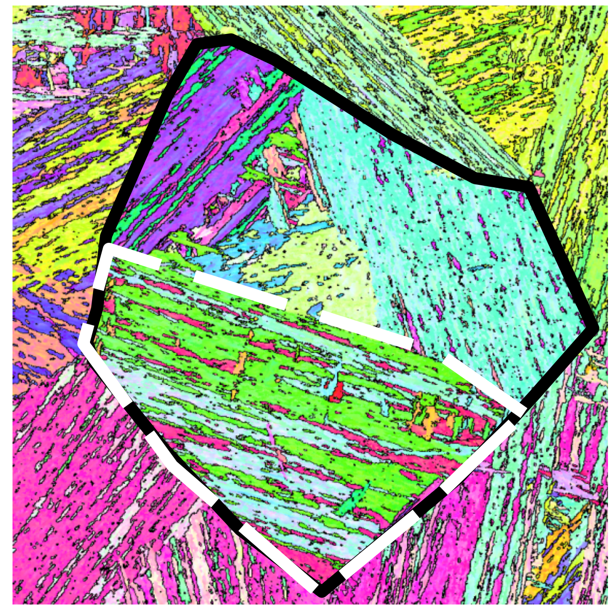
$(\underline{1}11)_{\gamma}$ // $(\underline{01}1)_{\alpha'}$: habit plane

$[101]_{\gamma}$ // $[111]_{\alpha'}$

24 equivalent variant

Refinement of substructure → Improving property

Low carbon martensite



Ausforming treatment

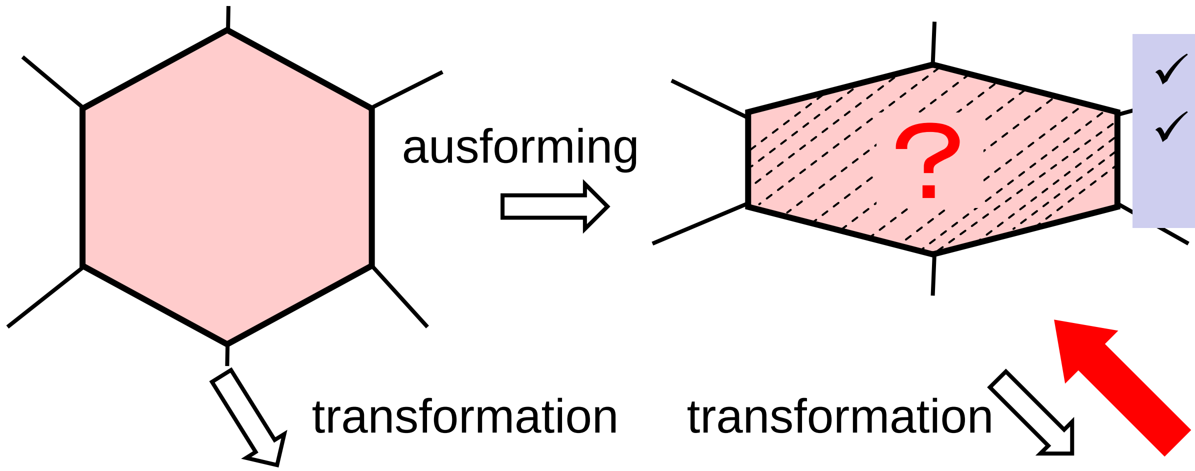
(To obtain martensite/bainite structures transformed from deformed & unrecrystallized γ) ⇨ Improvement of toughness and strength due to increasing dislocation density and refining substructure.

Effects of ausforming microstructure

H.Kawata, et al., Mater. Sci. Eng. A (2006)

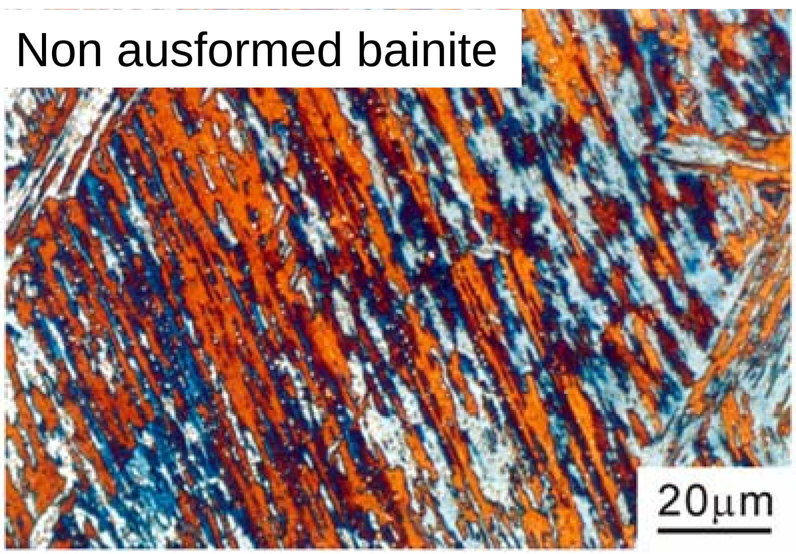
Fe-9%Ni-0.15%C alloy transformed at 623K

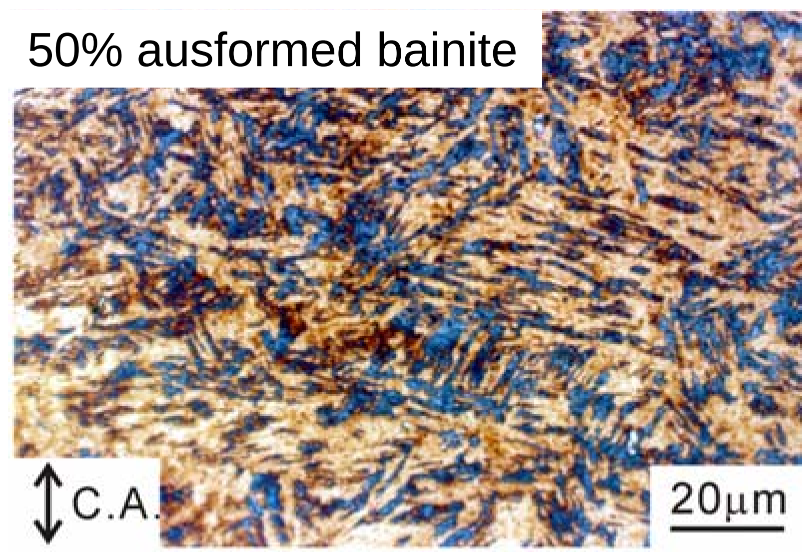
<u>non deformed γ</u>   <u>deformed γ</u>



- ✓ deformation structure in γ ?
- ✓ How it affects transformed structure？

<u>Want to reconstruct matrix structure!!</u>





Reconstruction of γ grain map

- Cayron et al., Mater. Char., **57**(2006), 386
- Morimoto et al., Tetsu to Hagane, **93**(2007), 591

① Based on averaged orientation of each ferrite grain, misorientation matrices at high angle boundary in lath martensite structure are calculated.

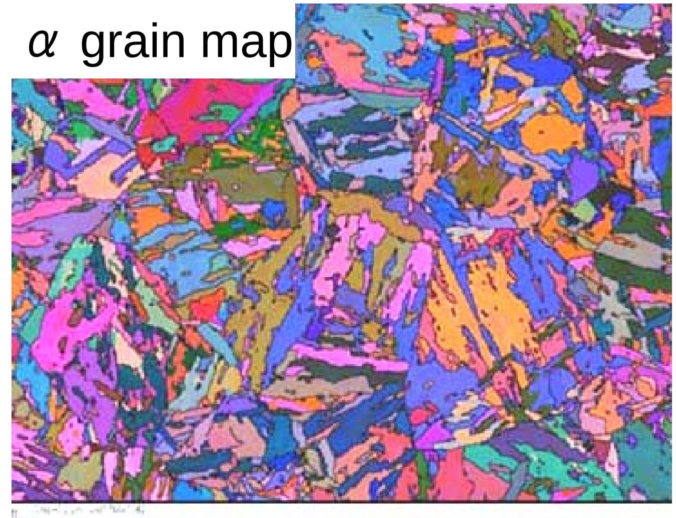
③ When the misorientation matrix coincide with that predicted by assuming K-S(N-W) O.R. within a permissible angle, ferrite grains neighboring this boundary is judged as forming from the same γ grain.

Previous reconstruction method have been applied to only non-deformed martensite.

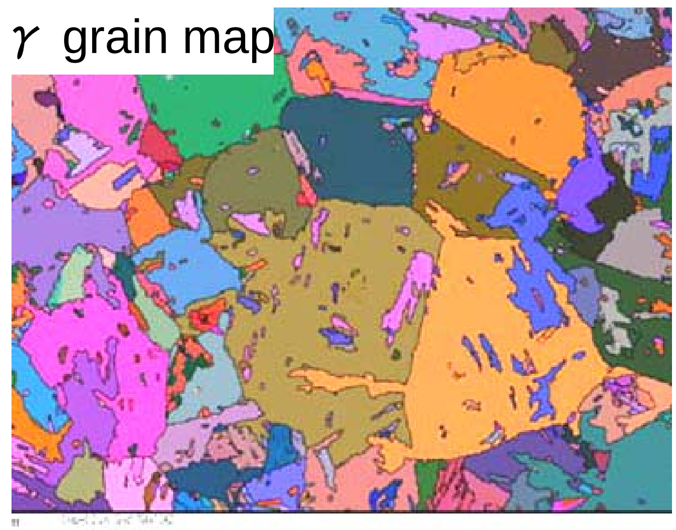
Aim
Developing new method which can reconstruct deformation structure in γ grain

C. Cayron et al.

α grain map



γ grain map



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OR between martensite(M) / γ in ferrous alloys

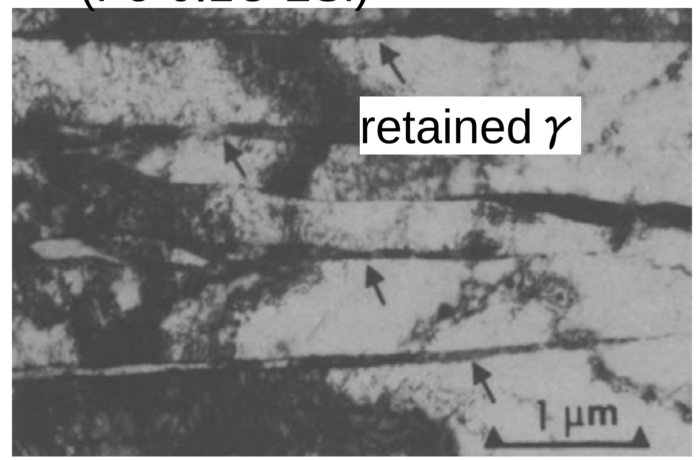
Alloy	Type of M	Angle (111)γ ~(011)α	Angle (-101)γ ~(-1-11)α	Method
Fe-3.1Cr-1.5C*1	Thinplate{225}	0.3°	2.8°	Laue（X-ray）
Fe-22Ni-0.8C*1	Thinplate	1°	2.5°	
Fe-32Ni*1	Lenticular	1°	4.3°	
Fe-20Ni-5Mn*2	lath	0°	3.9°	SADP(TEM)

*1 : C.M. Wayman, *Adv. Mater. Res*., 3(1968), 147.
*2 : B.P.J. Sandvik, C.M. Wayman, *Metall. Trans*., 14A(1983), 809.

OR between martensite(M) / γ in ferrous alloys

Alloy	Type of M	Angle $(111)\gamma \sim (011)\alpha$		
Fe-3.1Cr-1.5C[*1]	Thinplate{225}	0.3°		
Fe-22Ni-0.8C[*1]	Thinplate	1°		
Fe-32Ni[*1]	Lenticular	1°		
Fe-20Ni-5Mn[*2]	lath	0°		
Fe-0.1C-2Si[*3] Fe-0.3C-3Cr-2Mn-0.5Mo[*3]	lath	0°	2.5°	Kikuchi diffraction(TEM)

Low carbon martensite [*3]
(Fe-0.1C-2Si)



Kelly, et al, (1990)

Accurate data of OR for lath martensite in low carbon steels are few, because austenite is difficult to be retained.

*1 : C.M. Wayman, *Adv. Mater. Res*., 3(1968), 147.
*2 : B.P.J. Sandvik, C.M. Wayman, *Metall. Trans*., 14A(1983), 809.
*3 : P.M. Kelly, et al, *Acta Metall. Mater*. 38(1990), 1075.

Experimental

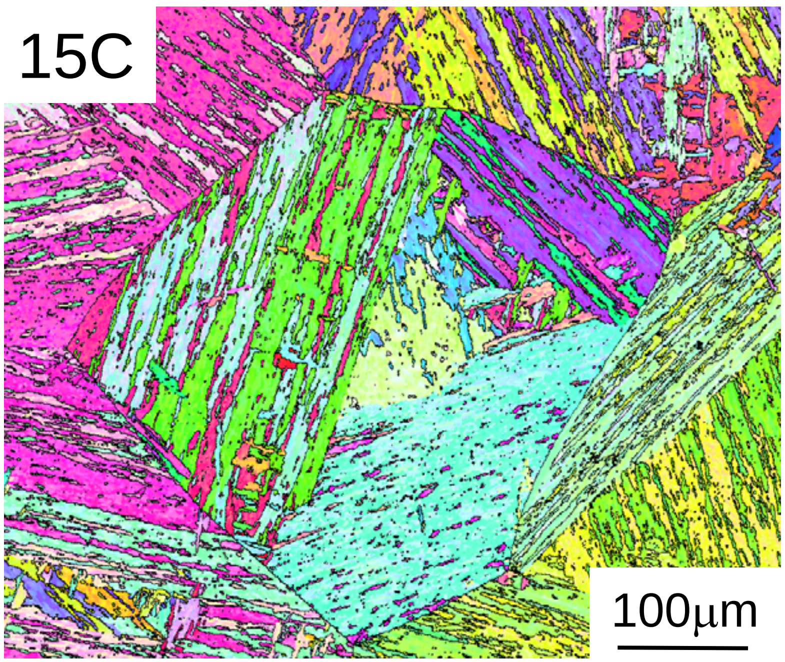
Alloy(mass%)

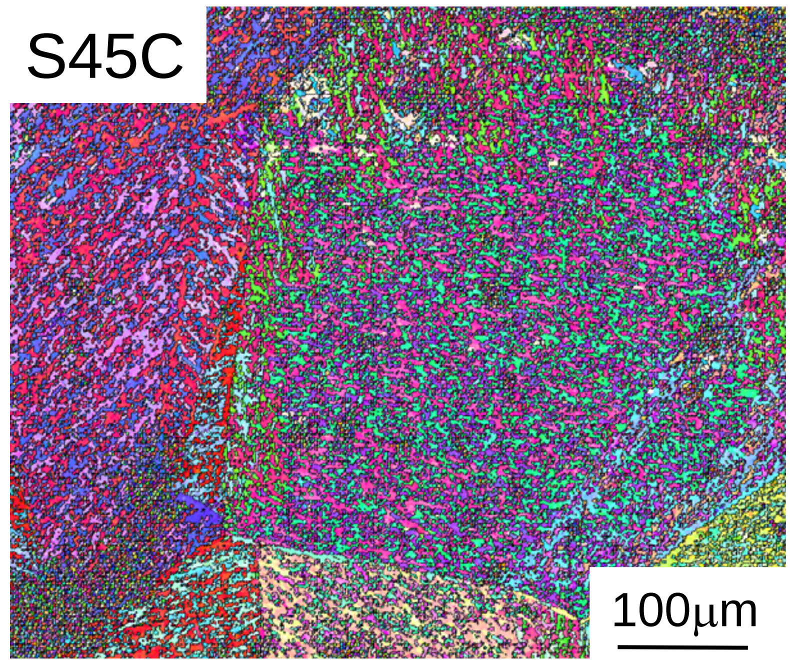
15C Fe-0.15%C -1.5%Mn-0.2 %Si-0.03%Nb

S45C Fe-0.44%C-0.86%Mn-0.26%Si

Heat treatment austenitization (1423～1473K,0.6ks) ⇨ Water quench

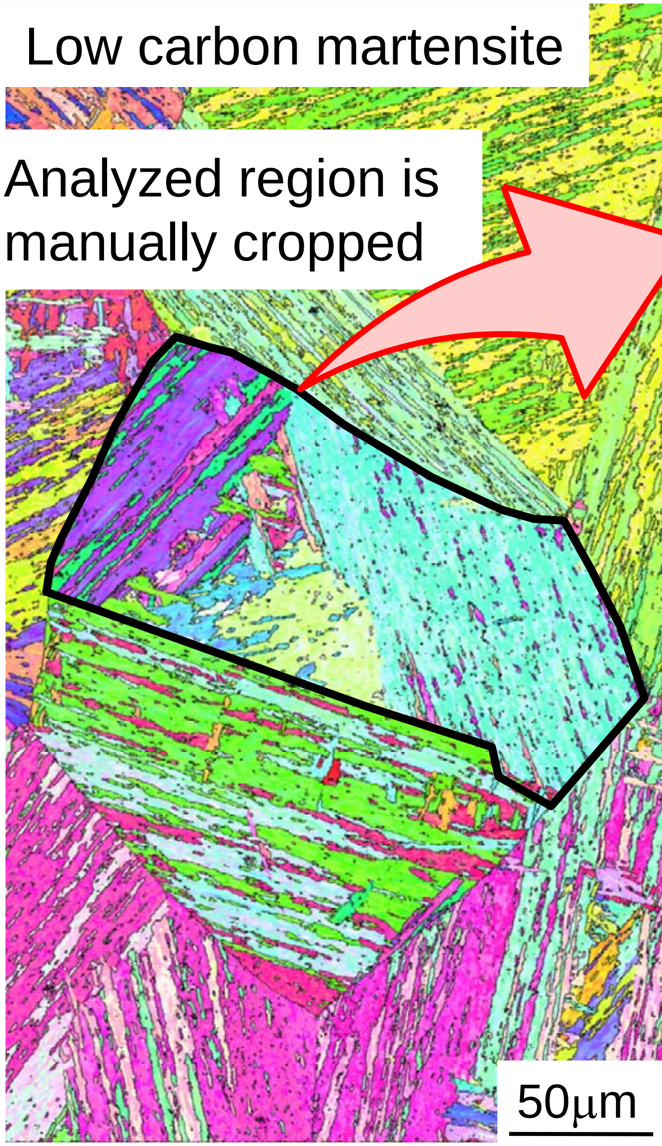
Ori. analysis SEM / EBSD



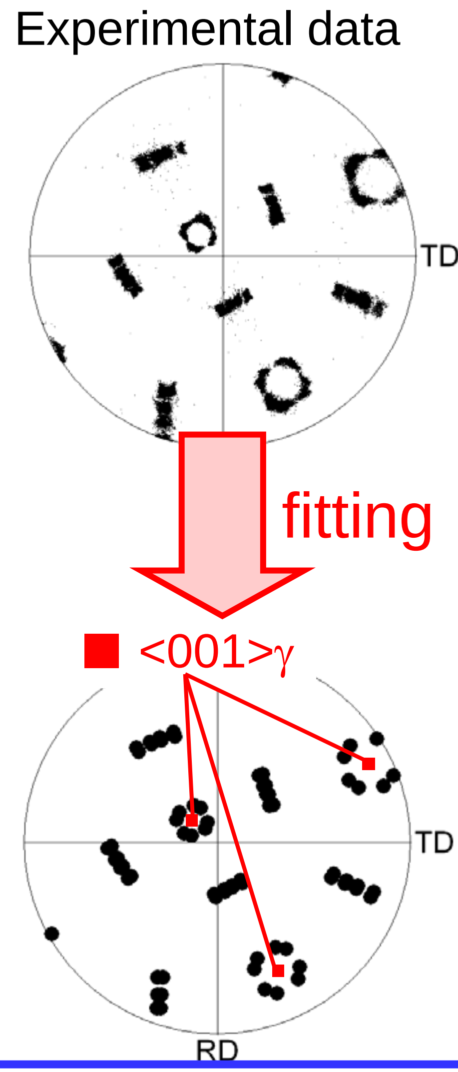


O.R. determination based on EBSD measurement

G. Miyamoto et. al, Scr. Mater. (2009)



<001>α pole figure



Fitting procedure

Orientation of M(B)(exp)

Differences are calculated.

O.R. × γ orientation

O.R. and γ orientation matrices are determined by least square fitting.

O.R. between lath M / γ (15C(M))

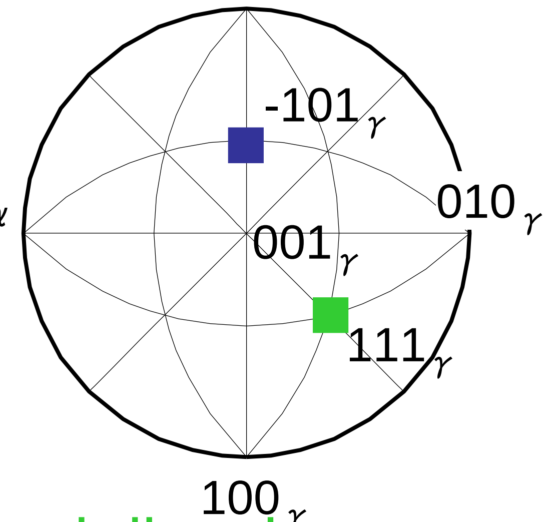
γ orientation (fitting)

M orientation (exp.)

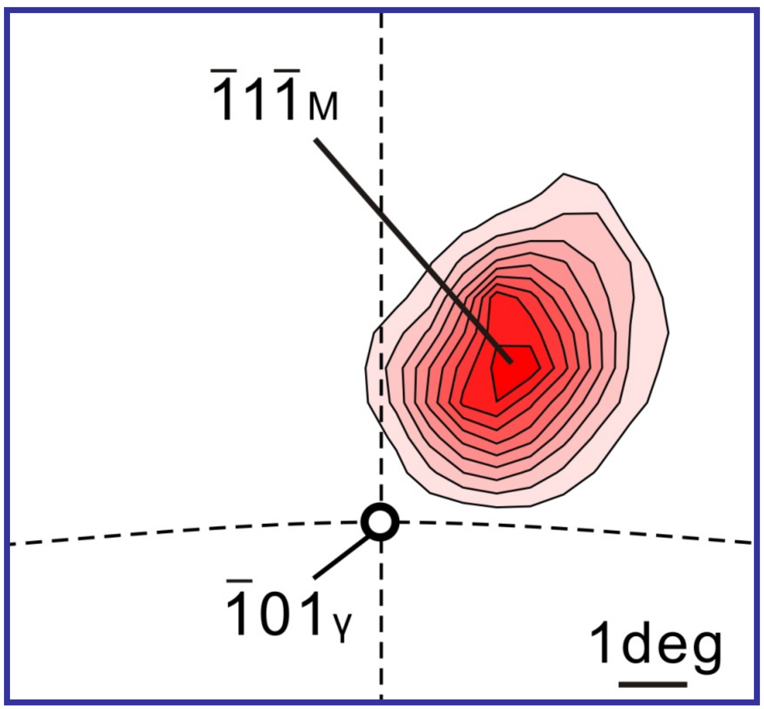
O.R. is re-indexed by considering variant

K-S O.R.
$(111)_\gamma \,//\, (011)_\alpha$
$[\bar{1}01]_\gamma \,//\, [\bar{1}\bar{1}1]_\alpha$
$[1\bar{2}1]_\gamma \,//\, [\bar{2}11]_\alpha$

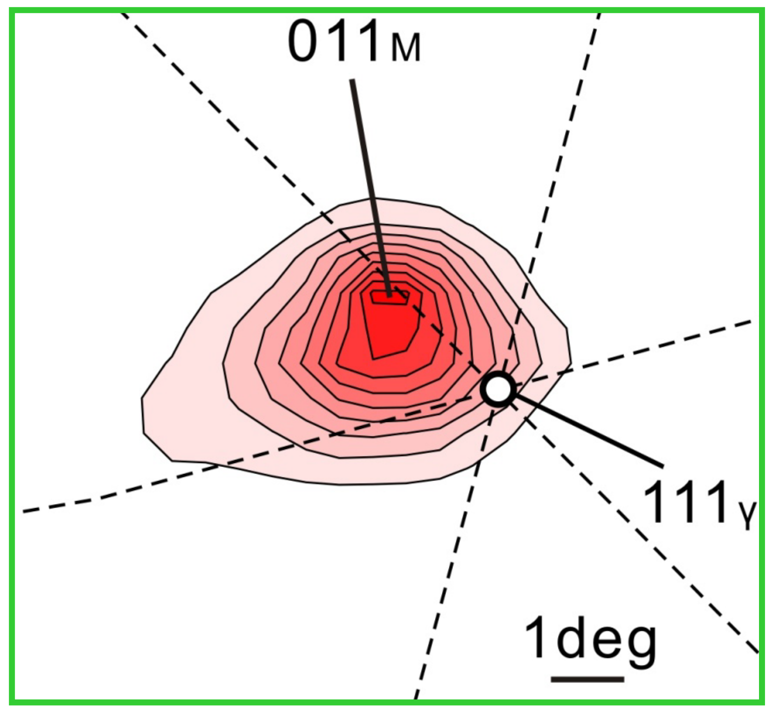
001γ stereographic projection



Close-packed plane

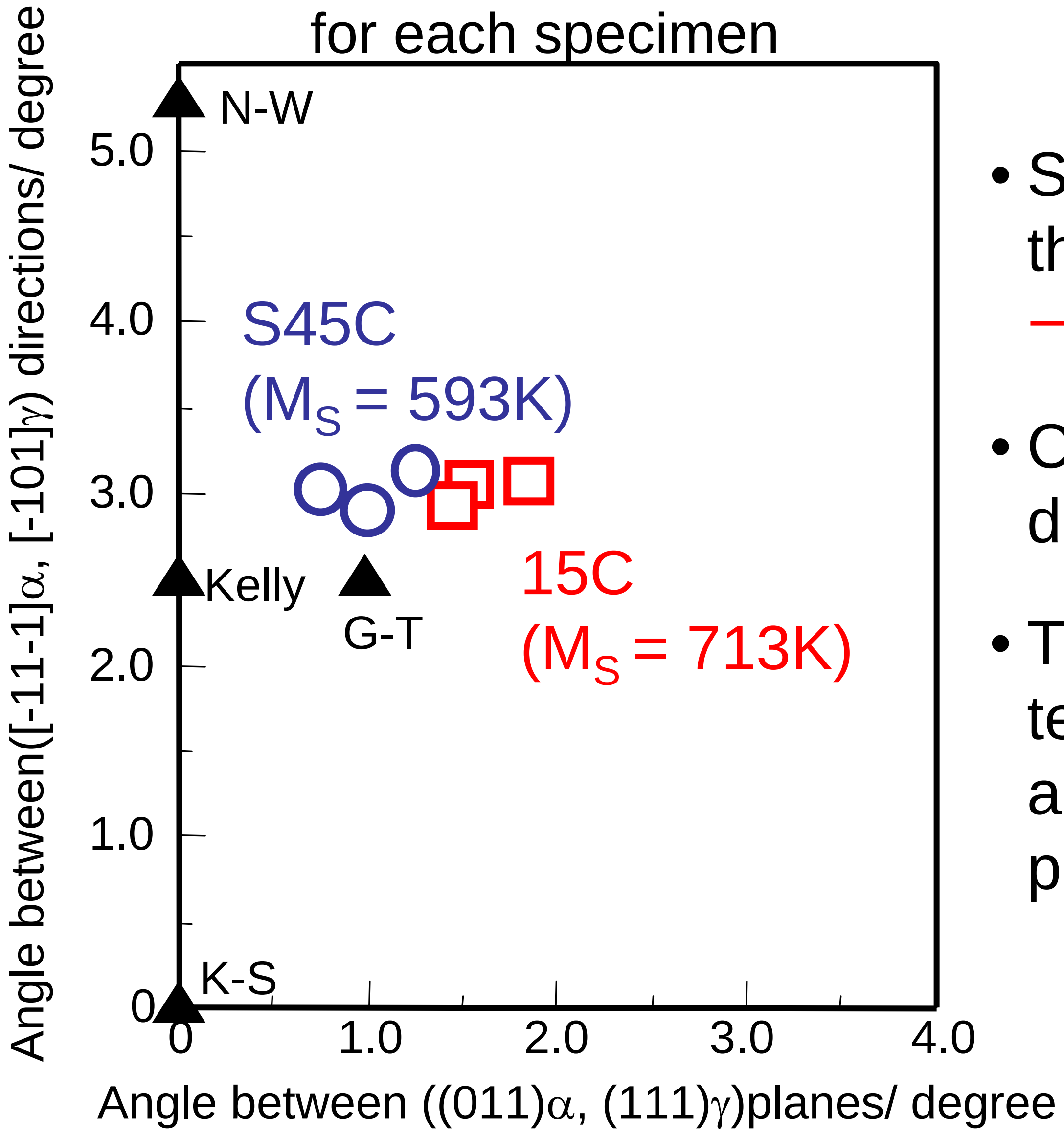


Close-packed direction



OR between lath M / γ

Measuring three different γ grains for each specimen



- Scattering in OR is less than ±0.3º in one alloy → high accuracy
- Close-packed planes and directions are not parallel.
- The higher Ms temperature, the larger angle between close packed planes.

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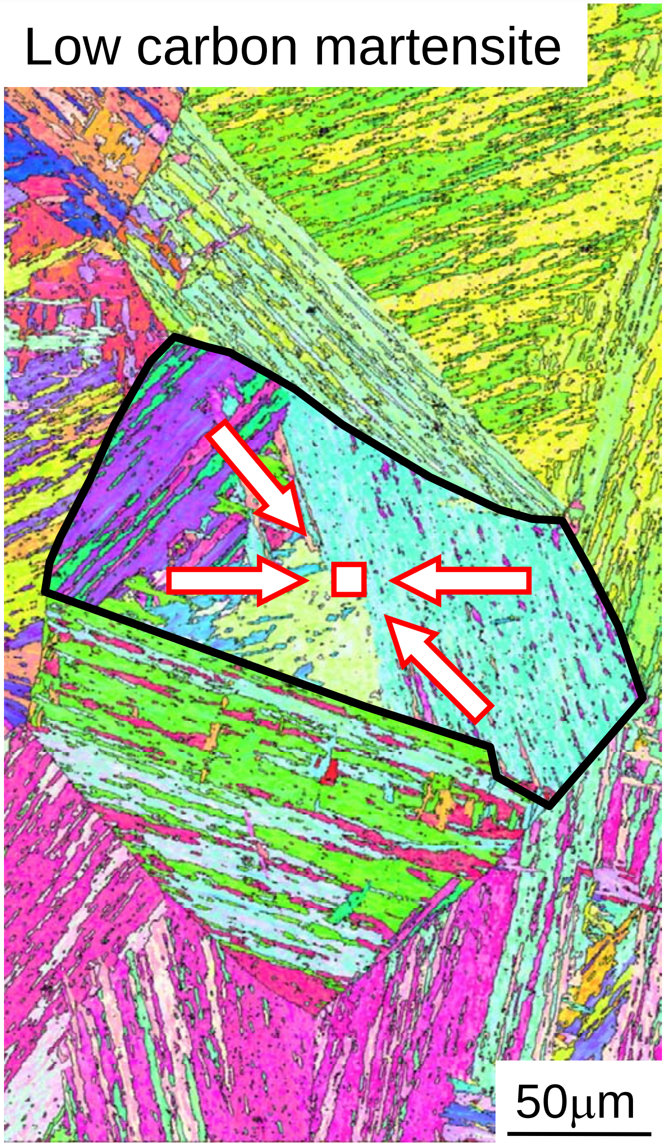
γ orientation determination based on EBSD measurement

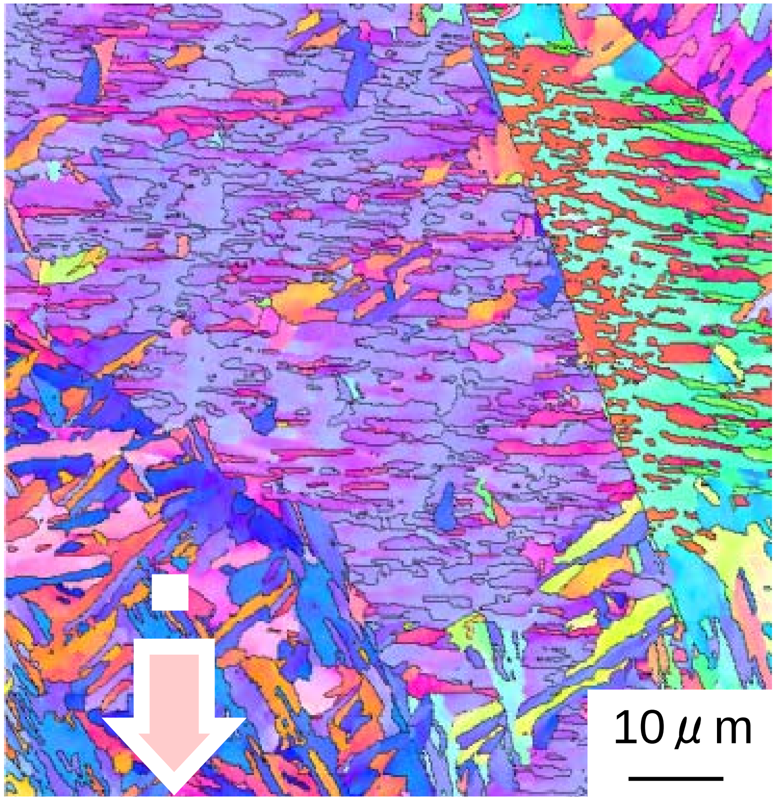
Low carbon martensite

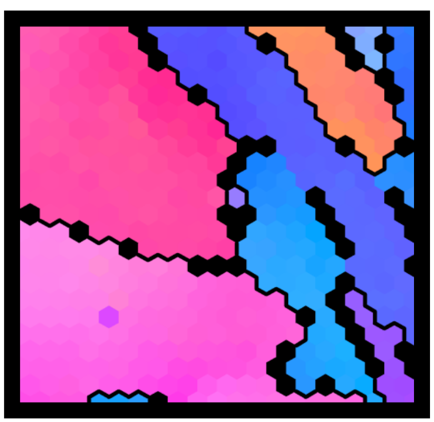


Decreasing size of cropped area
+
automatic cropping procedure

mapping of local γ orientation

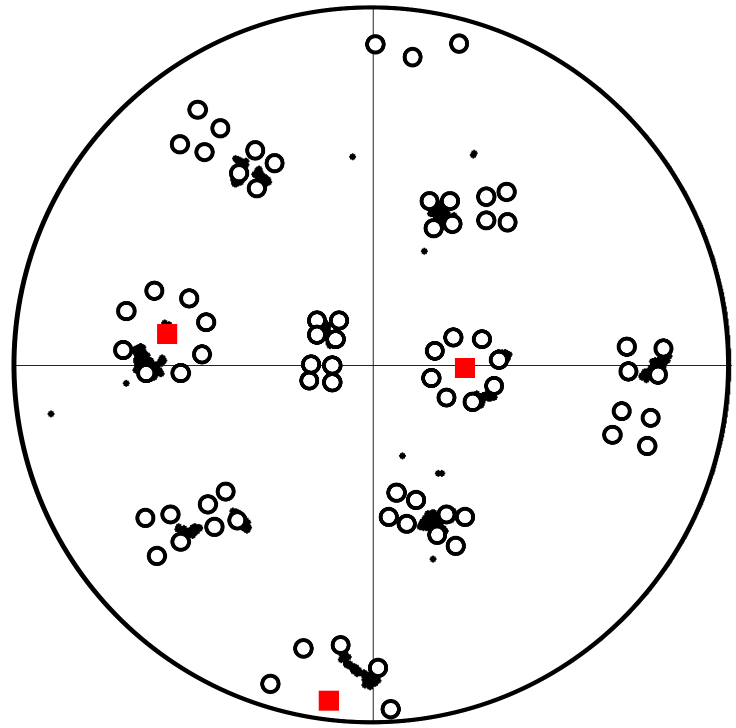
Determination of local γ orientation





i.e.
Mesh size
3 μm x 3 μm

001 α pole figure

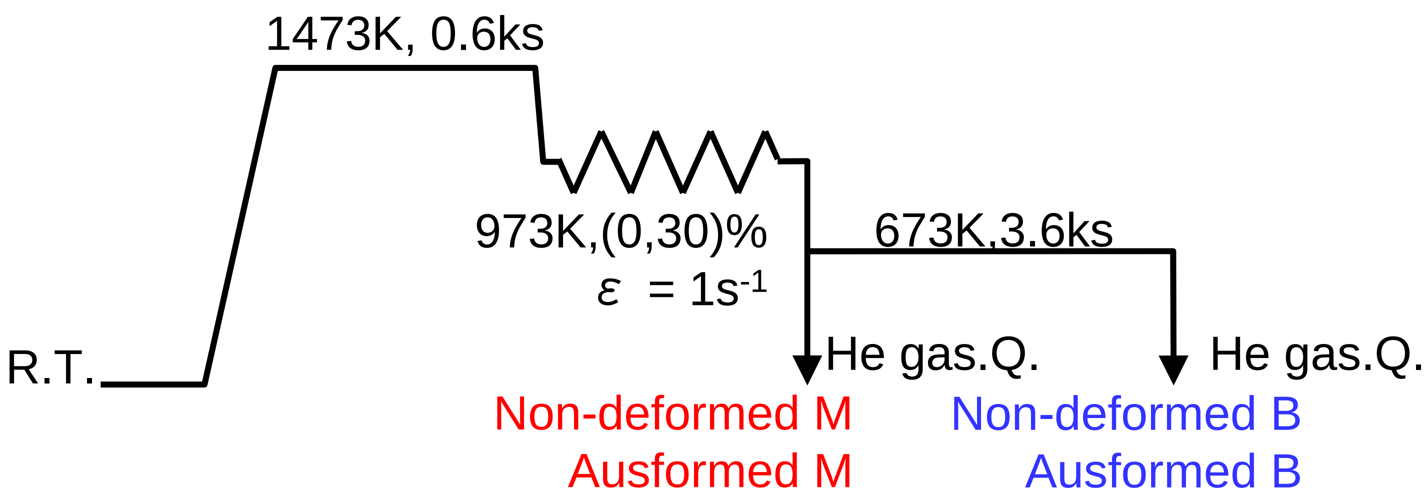


<u>parameter</u>
EBSD step size
Reconstruction
mesh & step size
γ /M(B) O.R.

Experimental procedure

Alloy Fe-0.15C-3Ni-1.5Mn-0.5Mo(mass%)

Treatment Thermecmaster Z



α orientation measurement SEM / EBSD

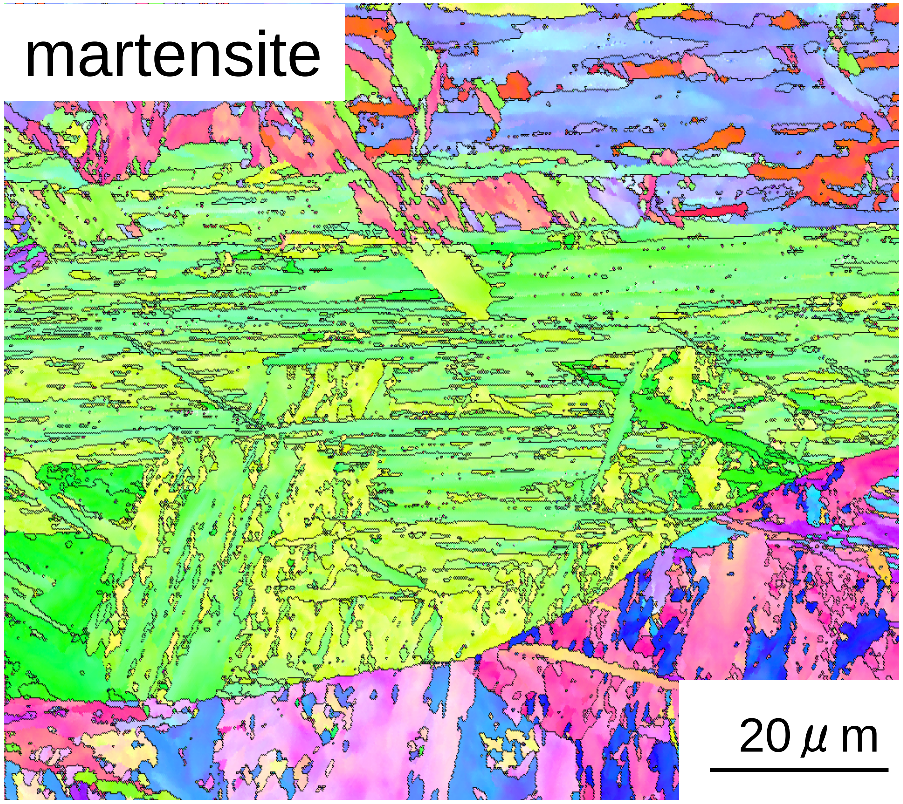
Determining γ / M(B) O.R.
(Non-deformed specimen)

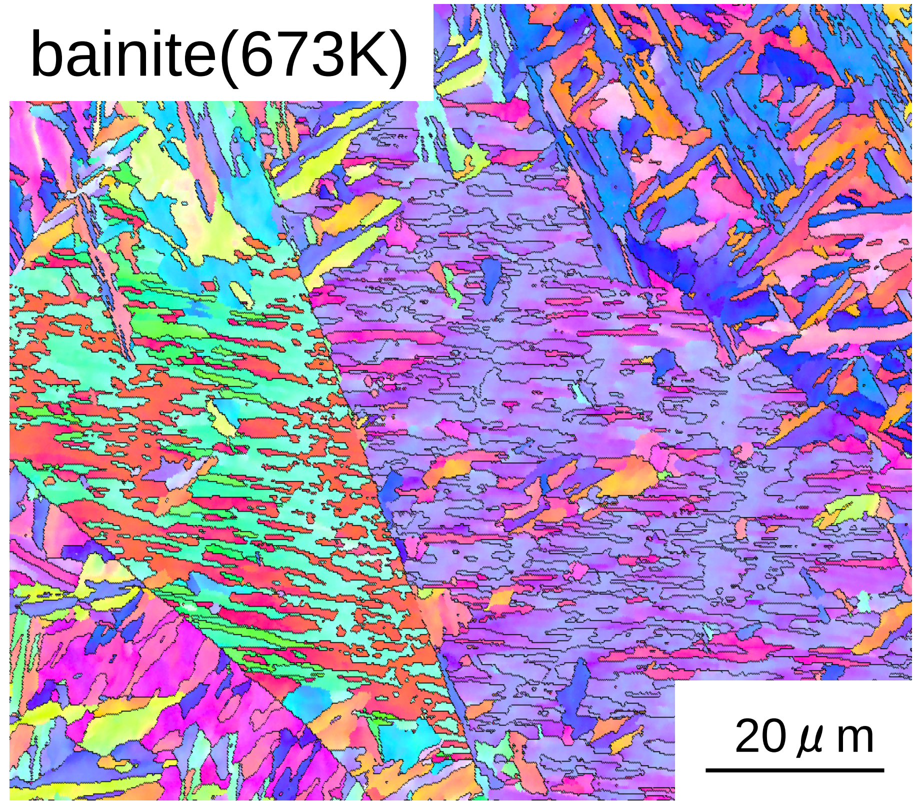
⇨

O.R. is fixed and
γ orientations are
reconstructed.

(G. Miyamoto et. al,
Scr. Mater. (2009))

α orientation map of non-deformed specimens and M,B／γ O.R.

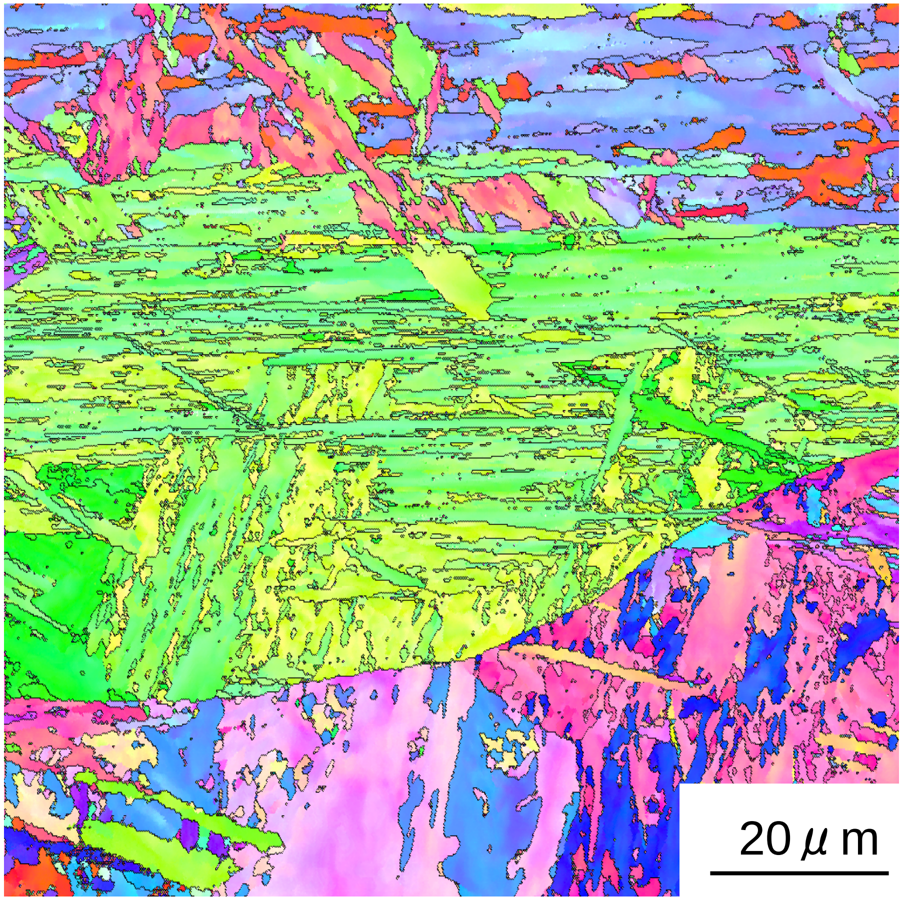




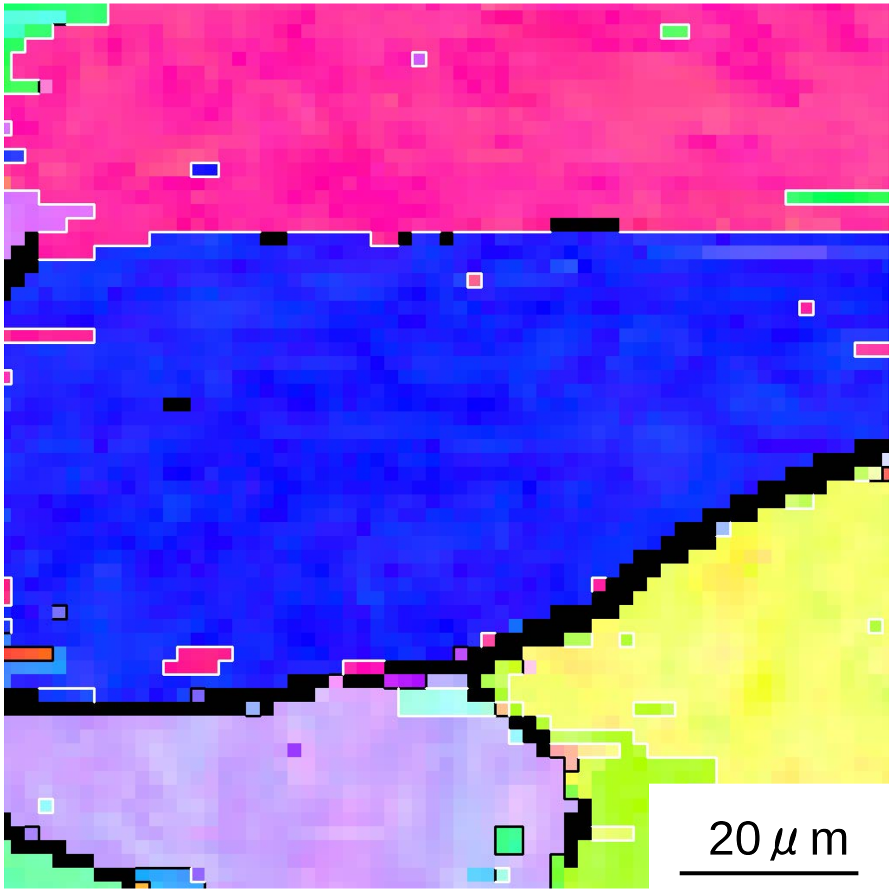
Orientation relationship	martensite	bainite
$(111)\gamma$ / $(011)\alpha$ angle ($\Delta\theta_{CPP}$)	1.5°	1.3°
$[-101]\gamma$ / $[-1-11]\alpha$ angle ($\Delta\theta_{CPD}$)	2.7°	2.9°

γ orientation map reconstructed from non-deformed martensite

α orientation map



reconstructed γ orientaion map

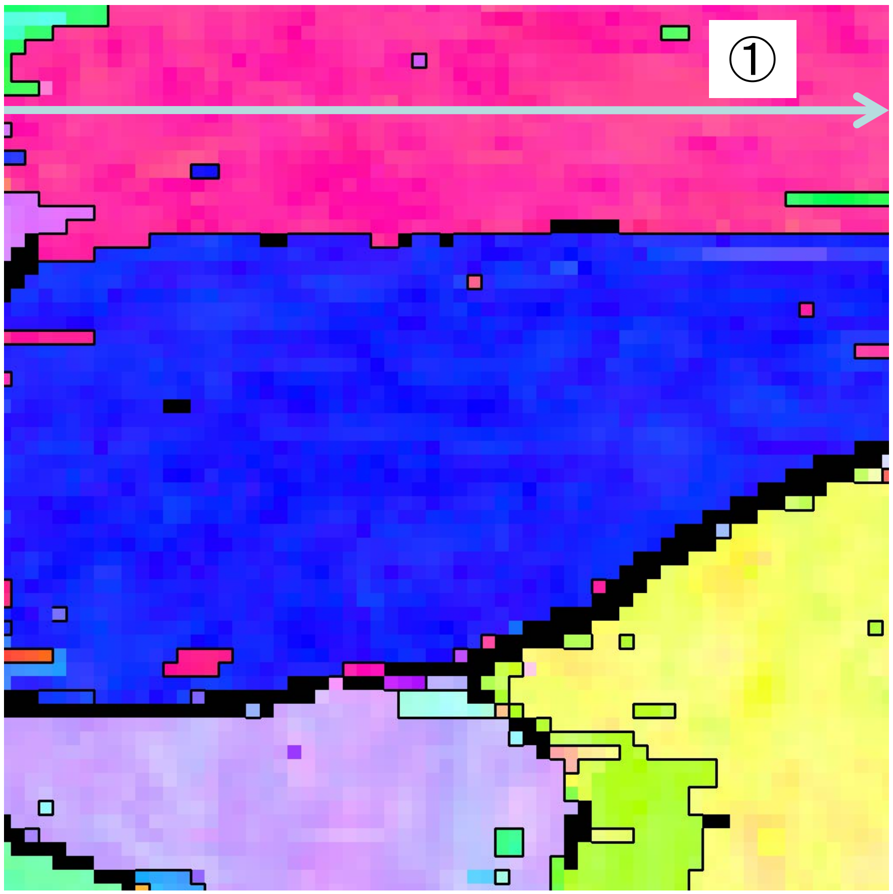


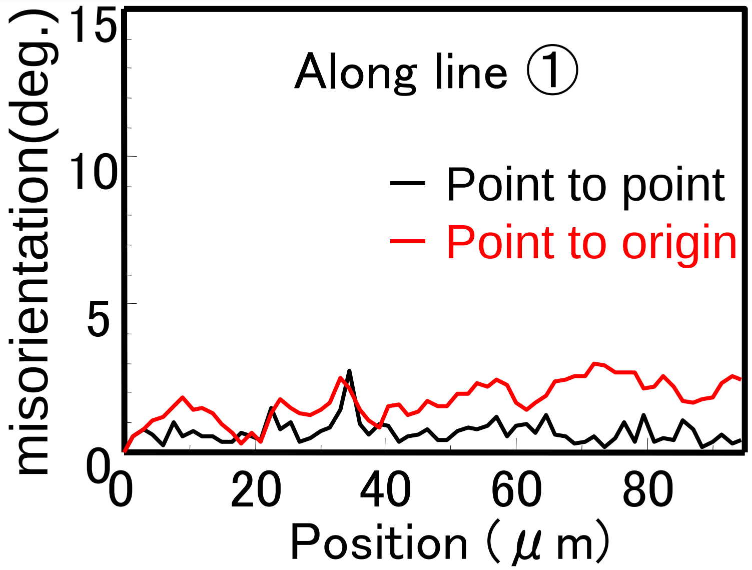
EBSD(0.2 μ m step)
Condition(3.0 μ m mesh, 1.5 μ m step)
O.R.($\Delta\theta_{CPP}$ = 1.5^o, $\Delta\theta_{CPD}$ = 2.7^o)

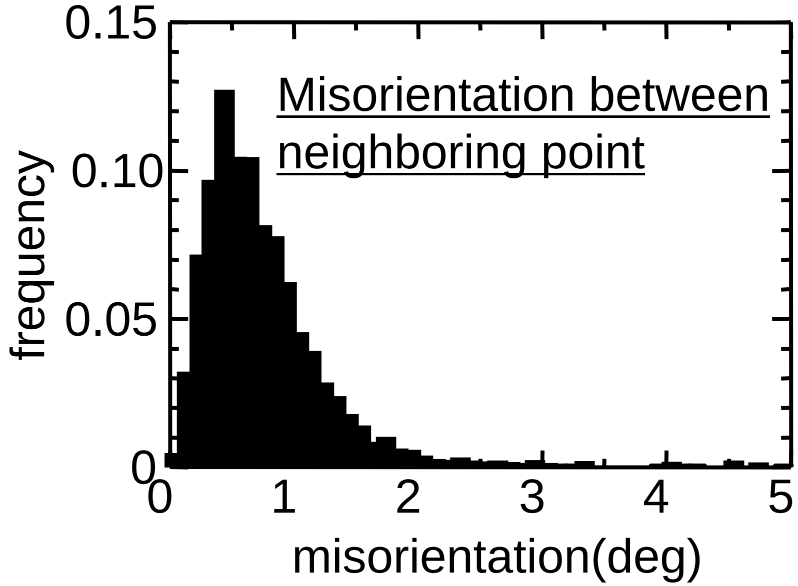
White line	twin boundary
Black line	other H.A.G.B

Scatters in reconstructed γ orientation

Non-deformed martensite

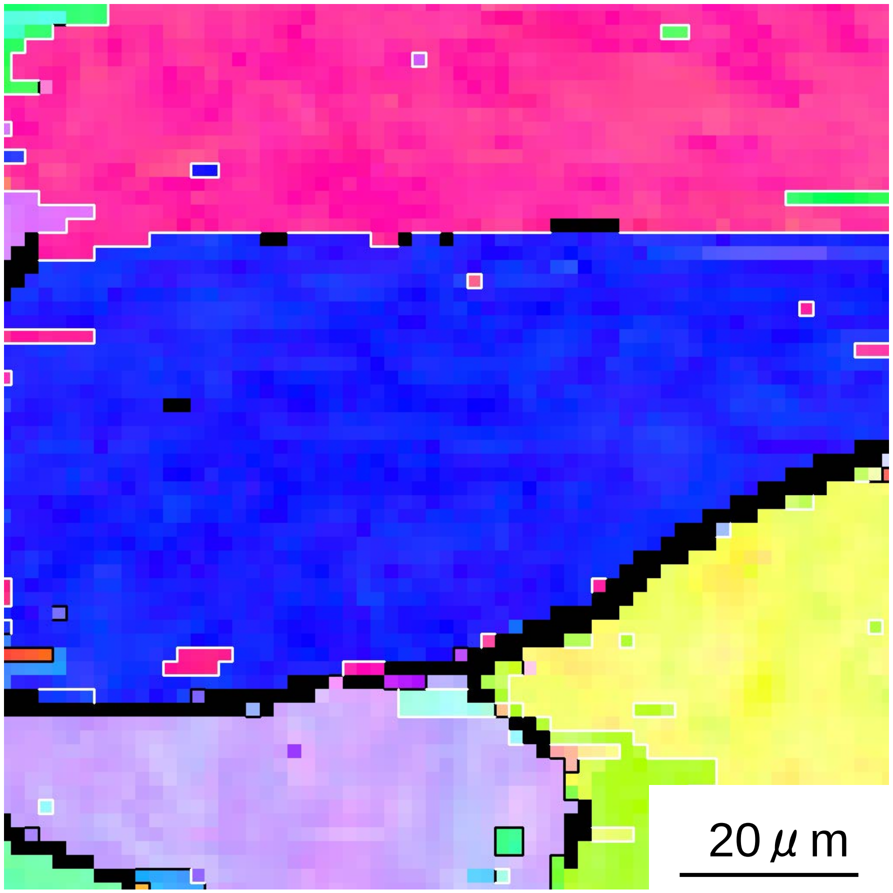




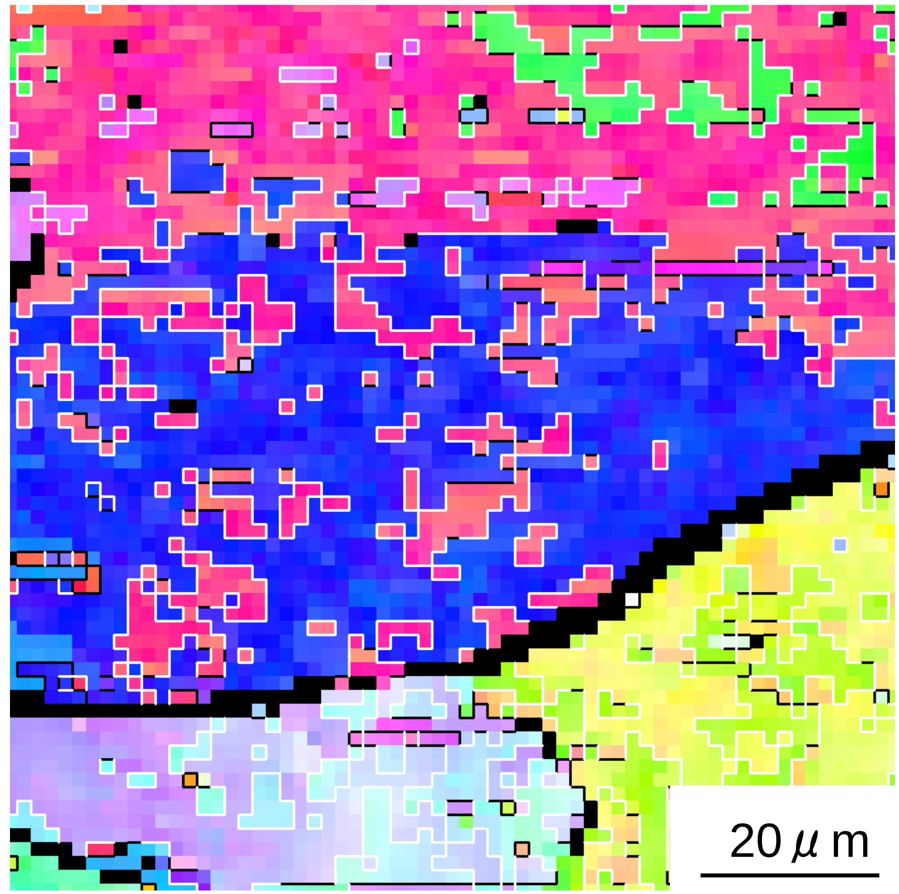


Effect of O.R. used for reconstruction

Experimentally determined O.R.
($\Delta\theta_{CPP} = 1.5^{o}$, $\Delta\theta_{CPD} = 2.7^{o}$)

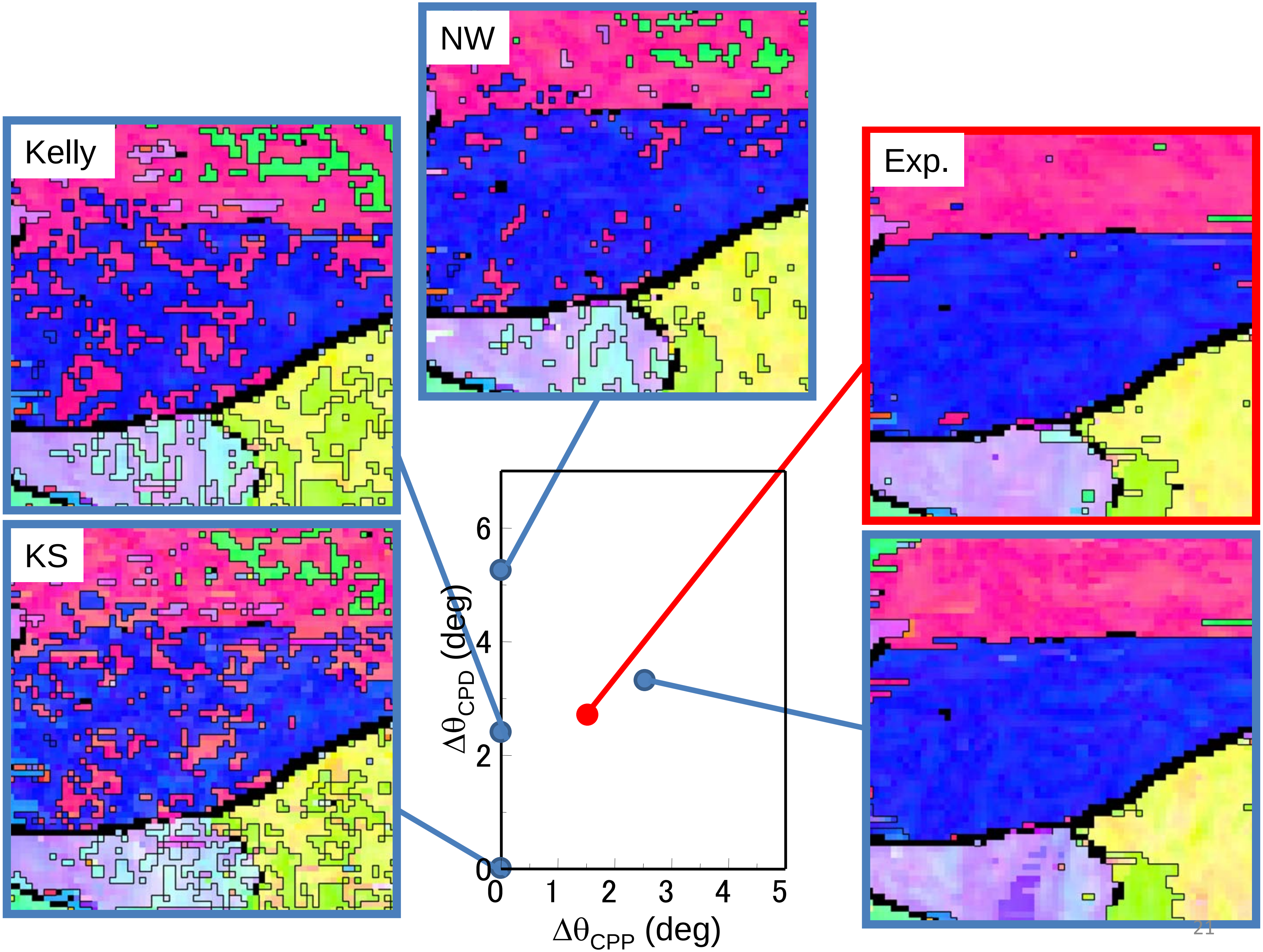


K-S O.R.
($\Delta\theta_{CPP} = 0^{o}$, $\Delta\theta_{CPD} = 0^{o}$)



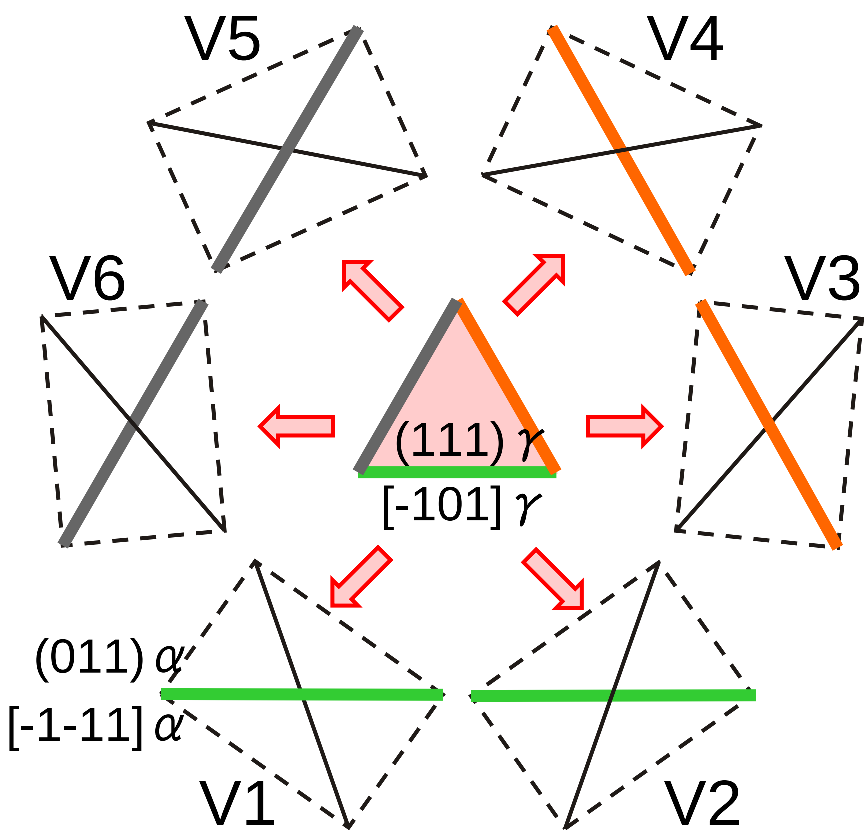
White line	twin boundary
Black line	other H.A.G.B

When K-S O.R. is used, mis-indexing as twin is frequently happened.

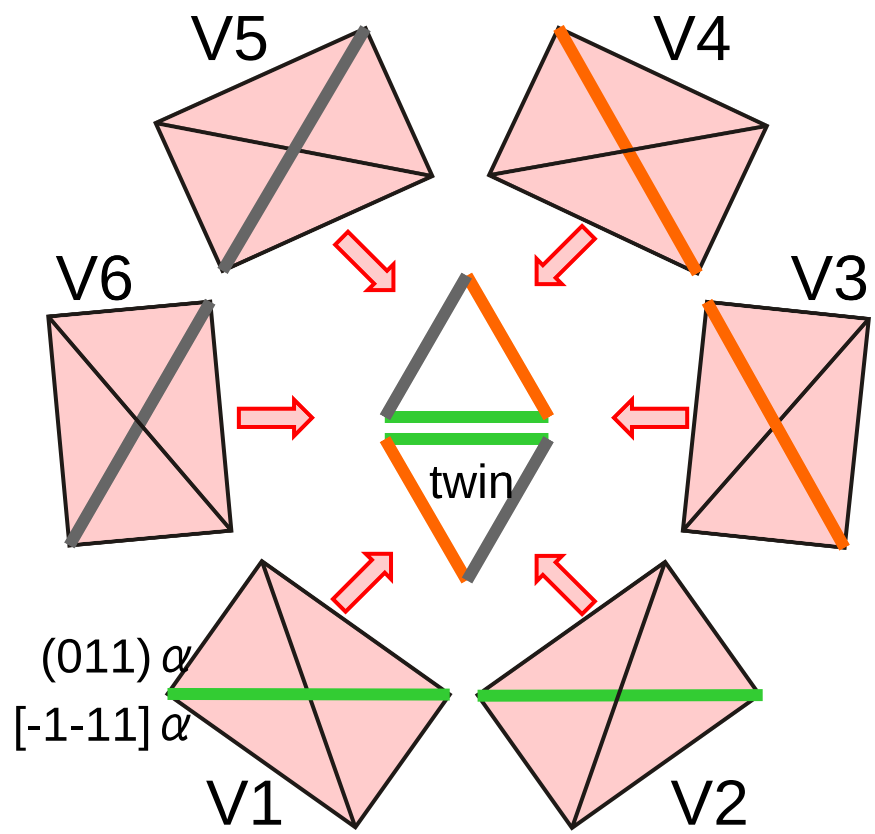

NW
Kelly
Exp.
KS
6
4
2
0
0 1 2 3 4 5
$\Delta\theta_{CPD}$ (deg)
$\Delta\theta_{CPP}$ (deg)

Reason for mix-indexing of twin orientation

fcc → bcc transformation

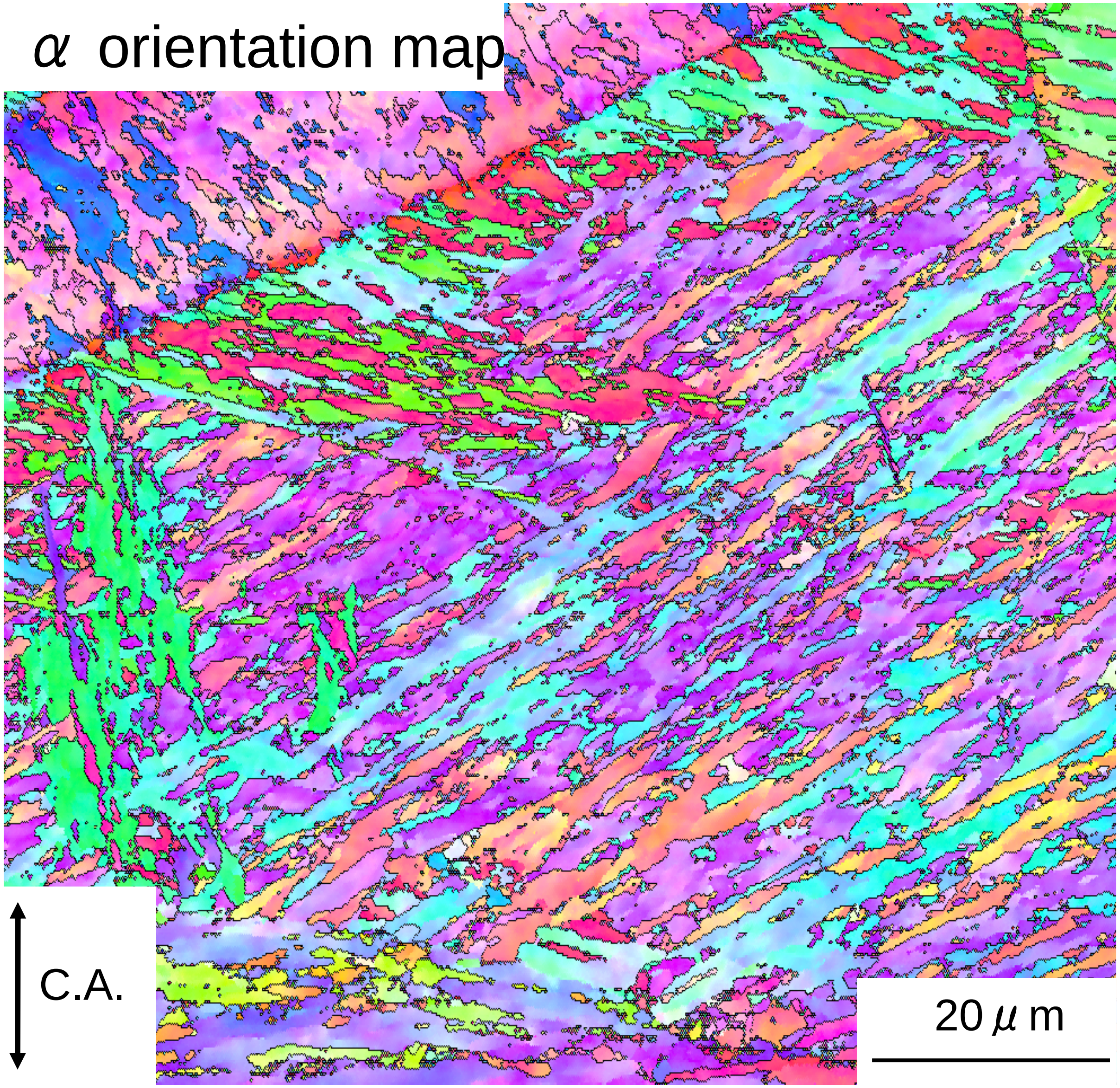


bcc → fcc reconstruction



Non-parallel relation between close-packed planes loses twin symmetry?

Reconstruction of γ orientation map from 30% ausformed martensite



EBSD

0.2 μm step

Condition

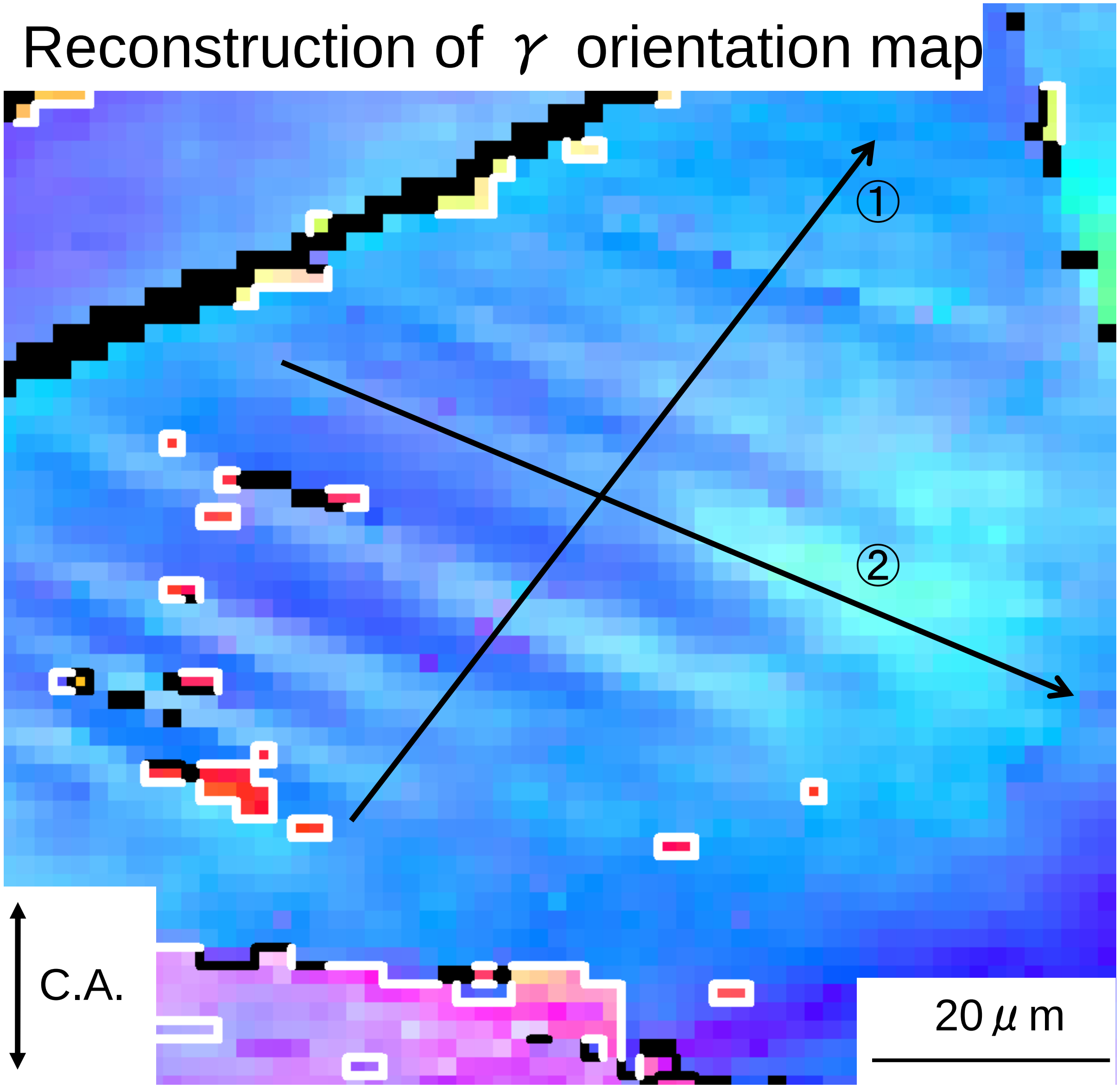
2.0 μm mesh & step

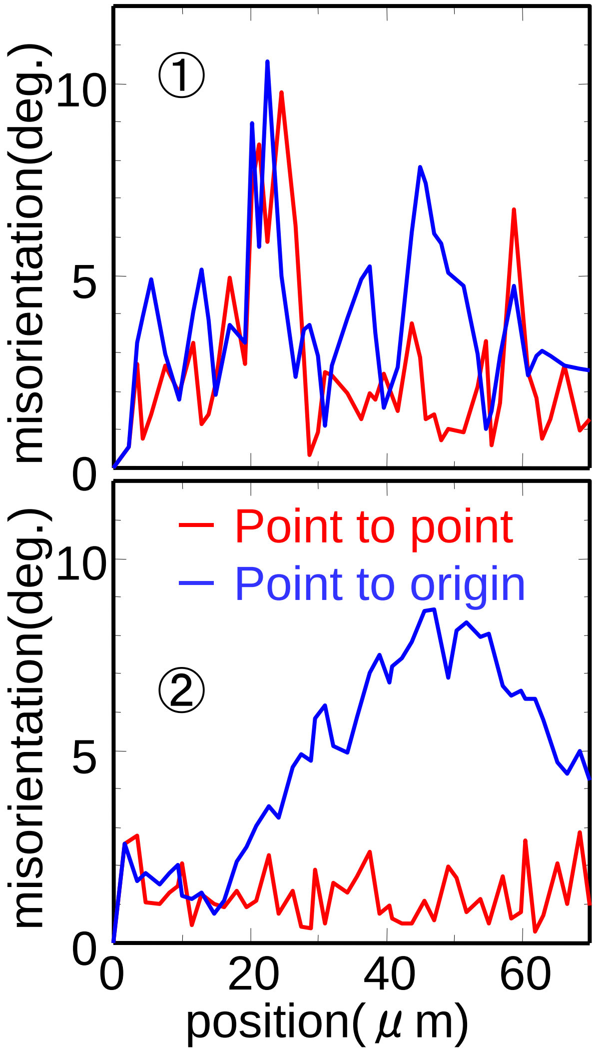
O.R.

$\Delta\theta_{CPP} = 1.5^o$

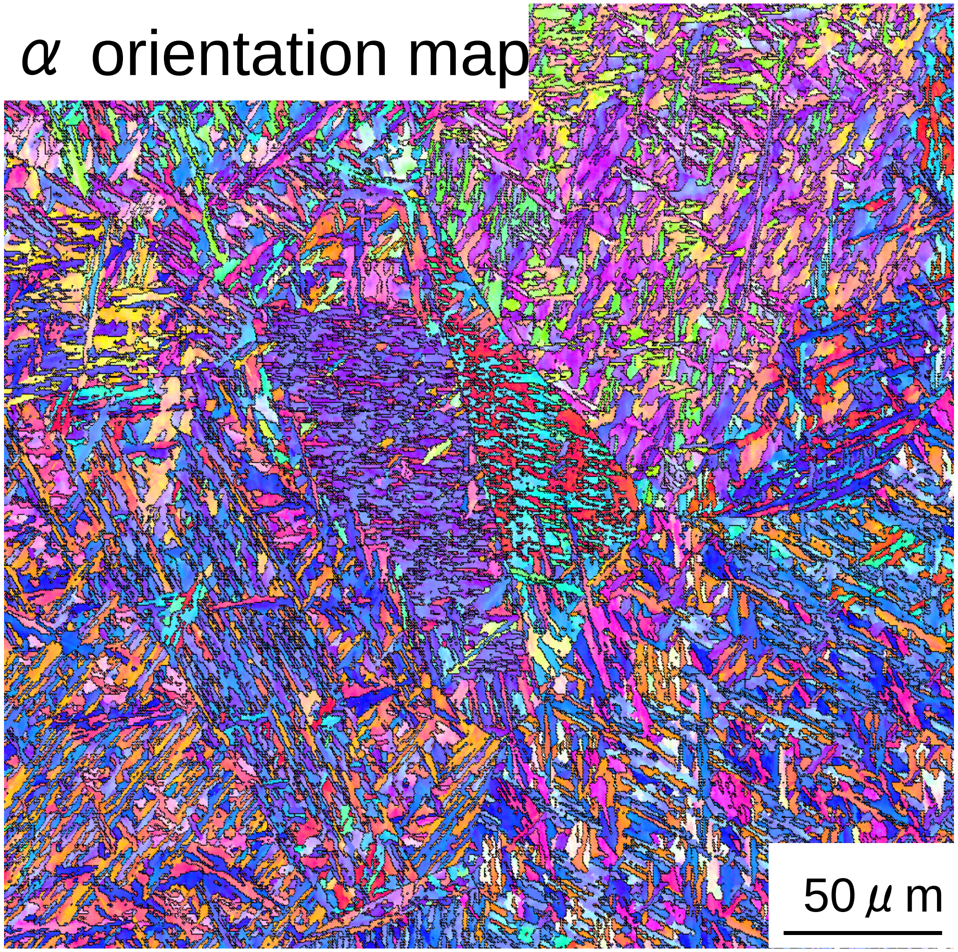
$\Delta\theta_{CPD} = 2.7^o$

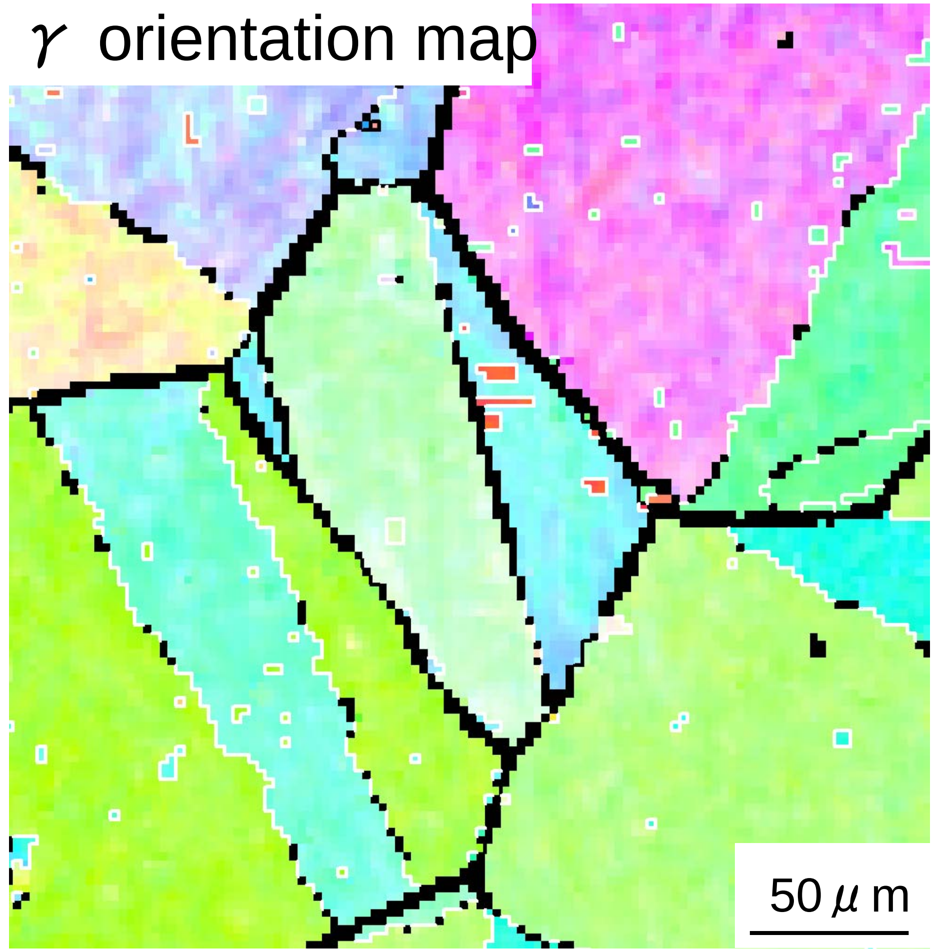
Reconstruction of γ orientation map from 30% ausformed martensite





Reconstruction of γ orientation map from non deformed bainite



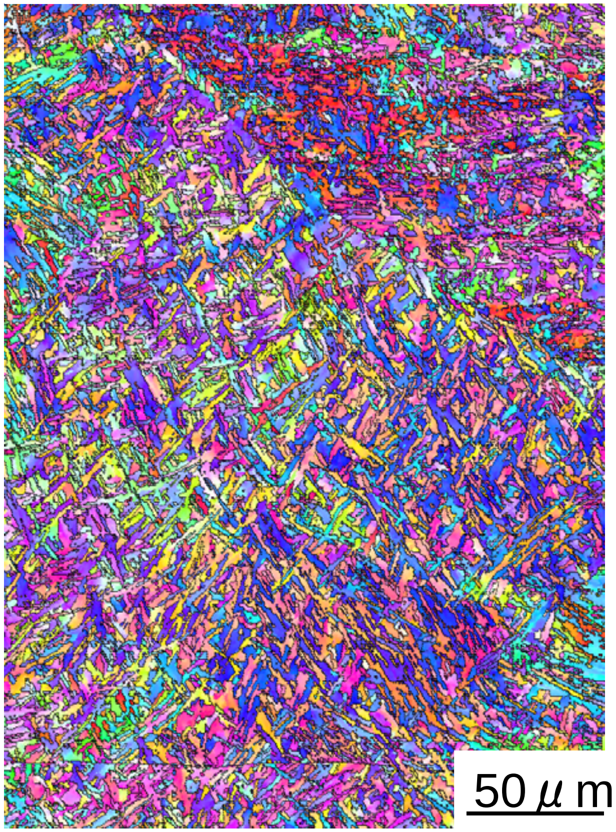


EBSD(0.5 μm step)
Condition(5.0 μm mesh, 2.5 μm step)
O.R.($\Delta\theta_{CPP}$ = 1.3°, $\Delta\theta_{CPD}$ = 2.9°)

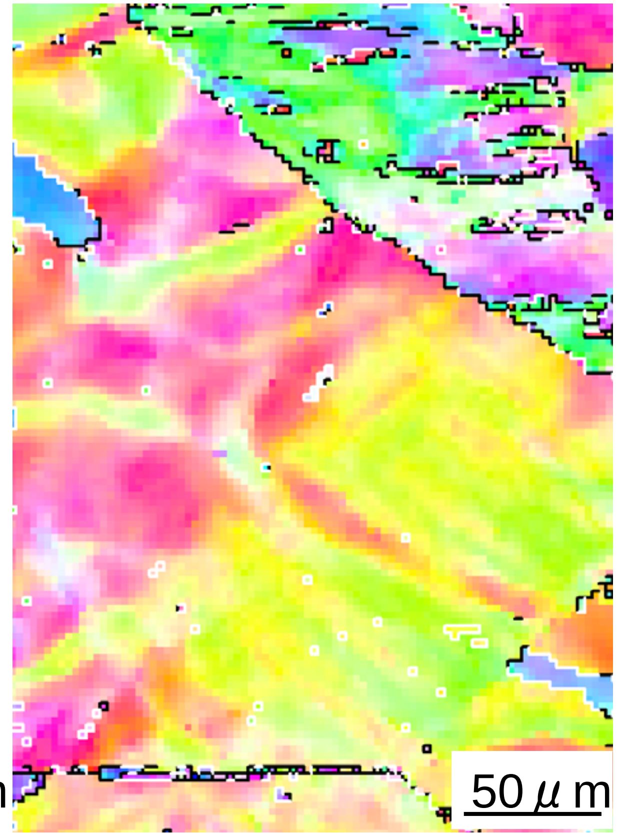
White line	twin boundary
Black line	other H.A.G.B

Reconstruction of γ orientation map from 30% ausformed bainite

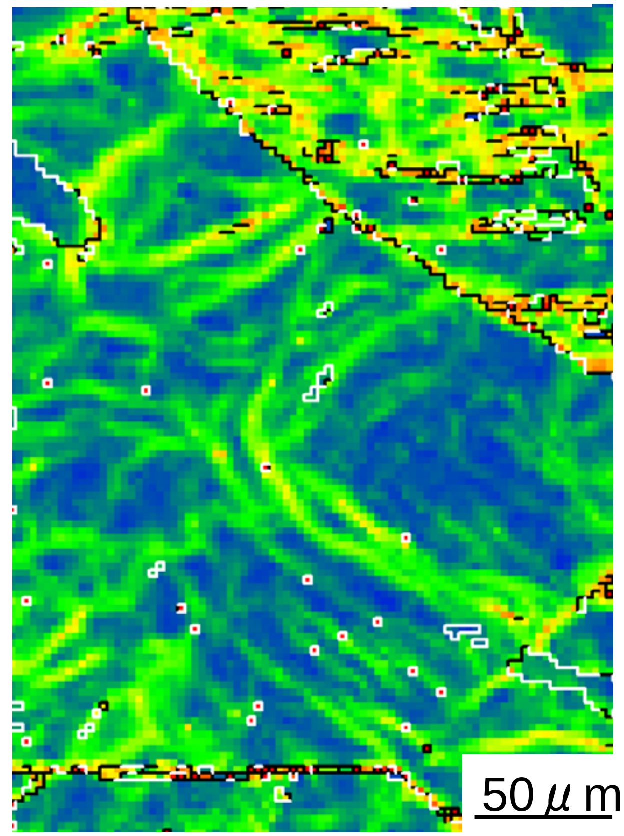
α orientation map



γ orientation map



γ-KAM map($\Delta\theta$=15°)



<u>EBSD</u>(0.5 μm step)
<u>Condition</u>(5.0 μm mesh, 2.5 μm step)
O.R.($\Delta\theta_{CPP}$ = 1.3°, $\Delta\theta_{CPD}$ = 2.9°)

White line	twin boundary
Black line	other H.A.G.B

Summary

New methods determining M･B/γ O.R. and reconstructing γ orientation are developed.

O.R. measurement

•Orientation relationship between M / γ and B / γ can be determined precisely within an error of 0.5degrees based on EBSD measurement without retained austenite.

•Close-packed planes and directions of martensite and bainite are not parallel. Angular deviation between close-packed planes decreases with an decrease in Ms temperature.

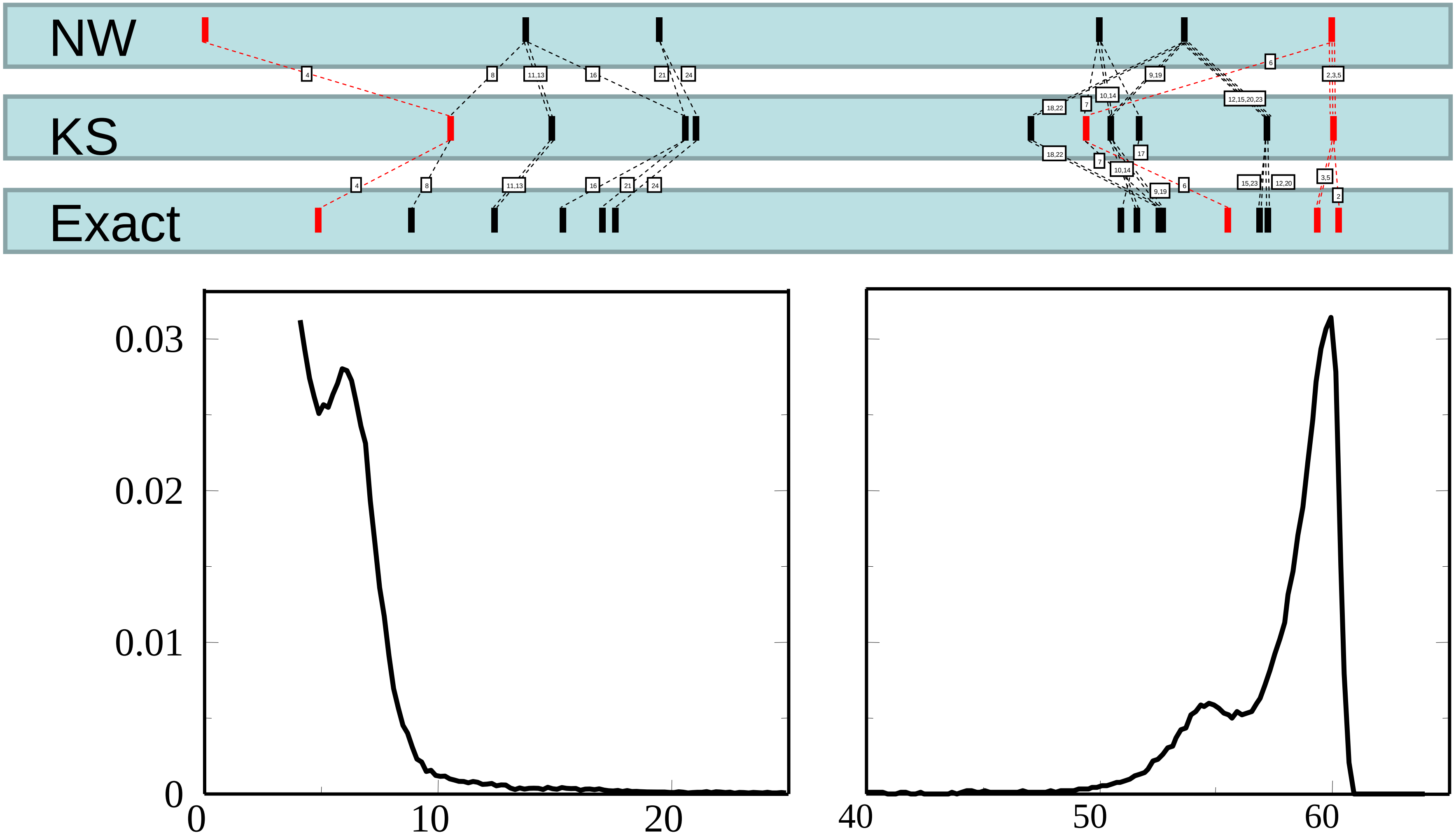
γ orientation reconstruction

•Mis-indexing of twin orientation frequently happens when K-S or N-W O.R. are used for reconstruction possibly because of mirror symmetry of 111γ // 011α relation. By using experimentally determined O.R., frequency of the mis-indexing is reduced largely.

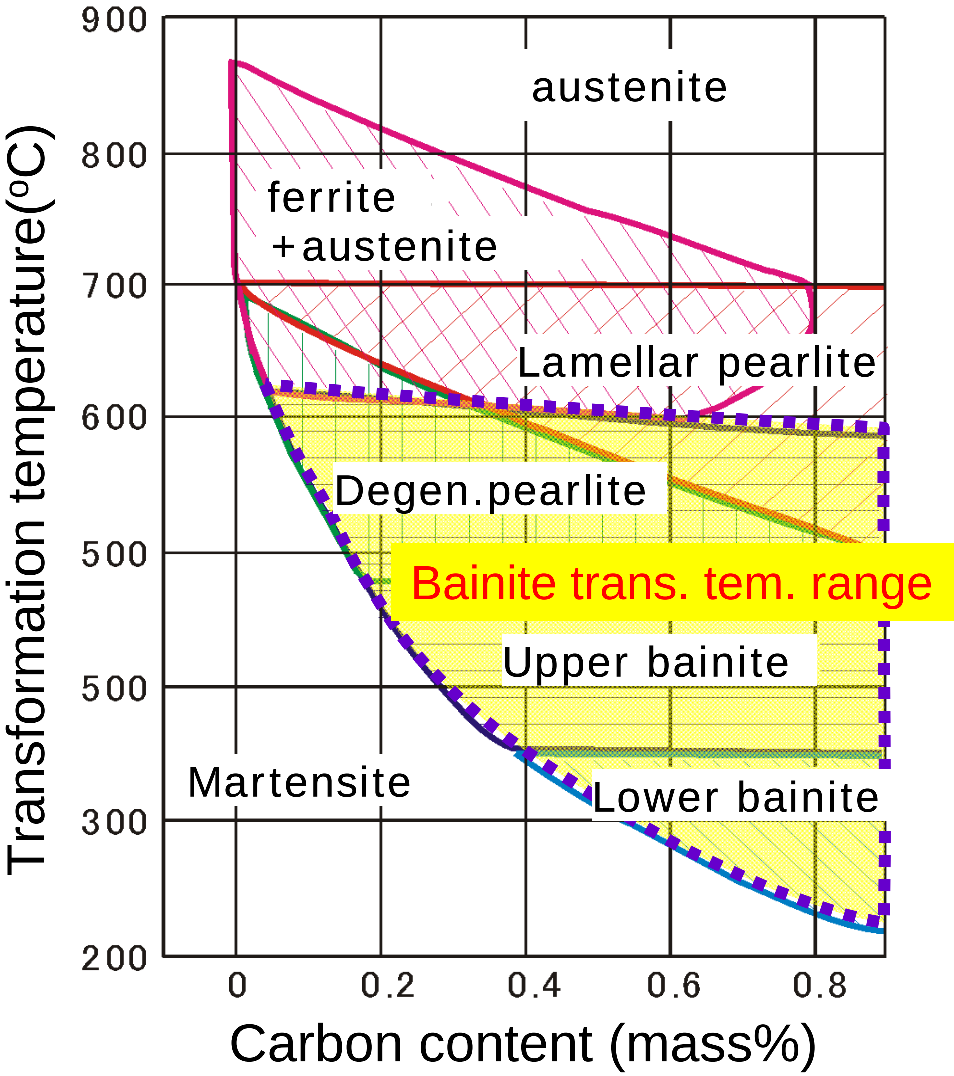
•Deformation structure in γ can be reconstructed successfully and be analyzed misorientation profile or KAM analysis.

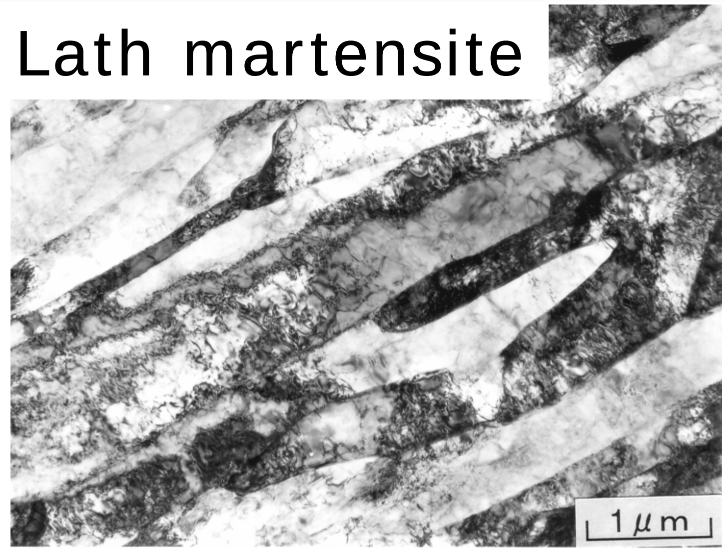
Misorientation profile of lath martensite

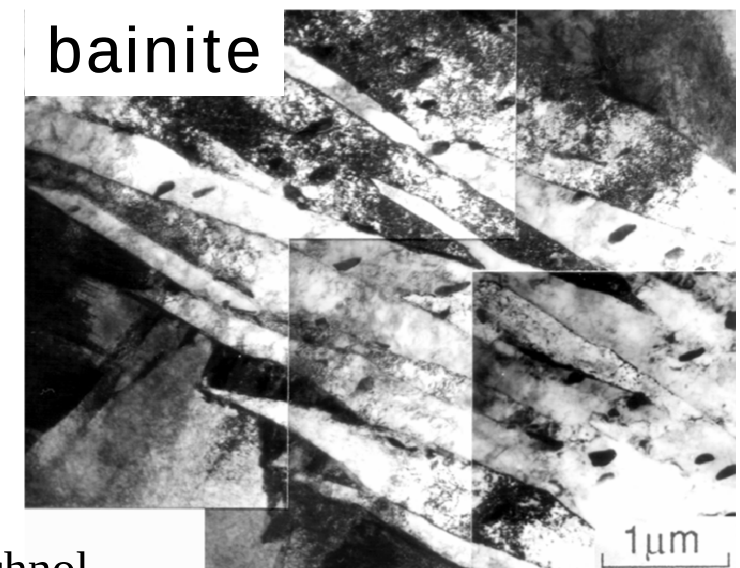
V1/V2,3,4,5,6



Martensite and bainite structures





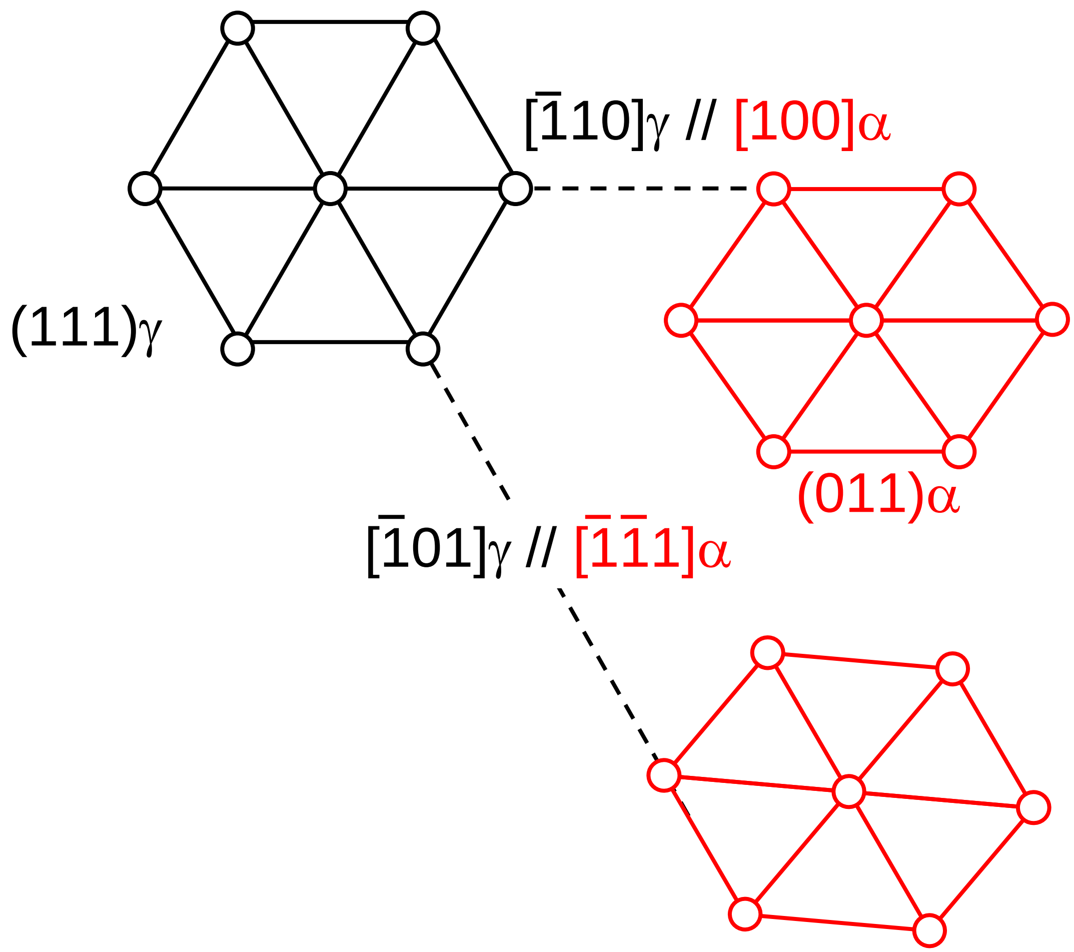


Ohmori, Honeycombe: Proc. Int. Conf. Sci. & Technol. of Iron and Steels, Suppl. Trans. ISIJ, 11 (1971), 1160.

Simple orientation relationship in fcc → bcc transformation

FCC（γ：austenite）

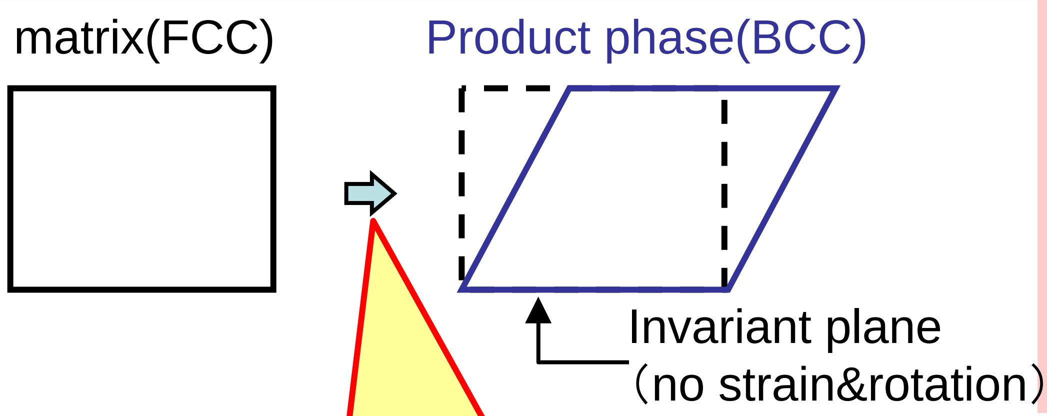
BCC（α：ferrite, martensite, bainitic ferrite･･･）

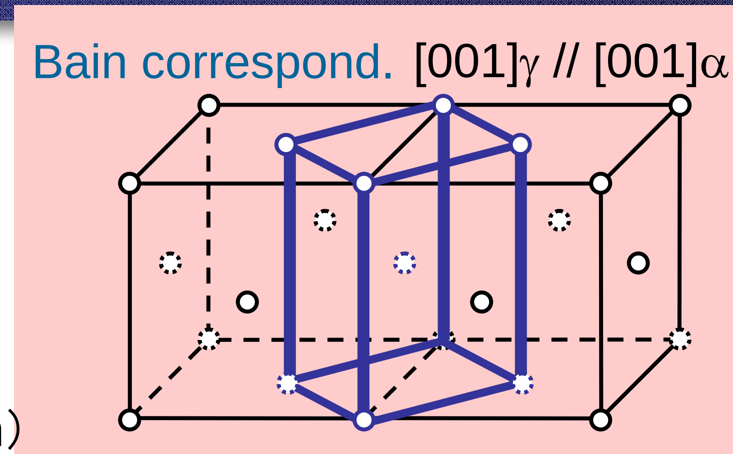


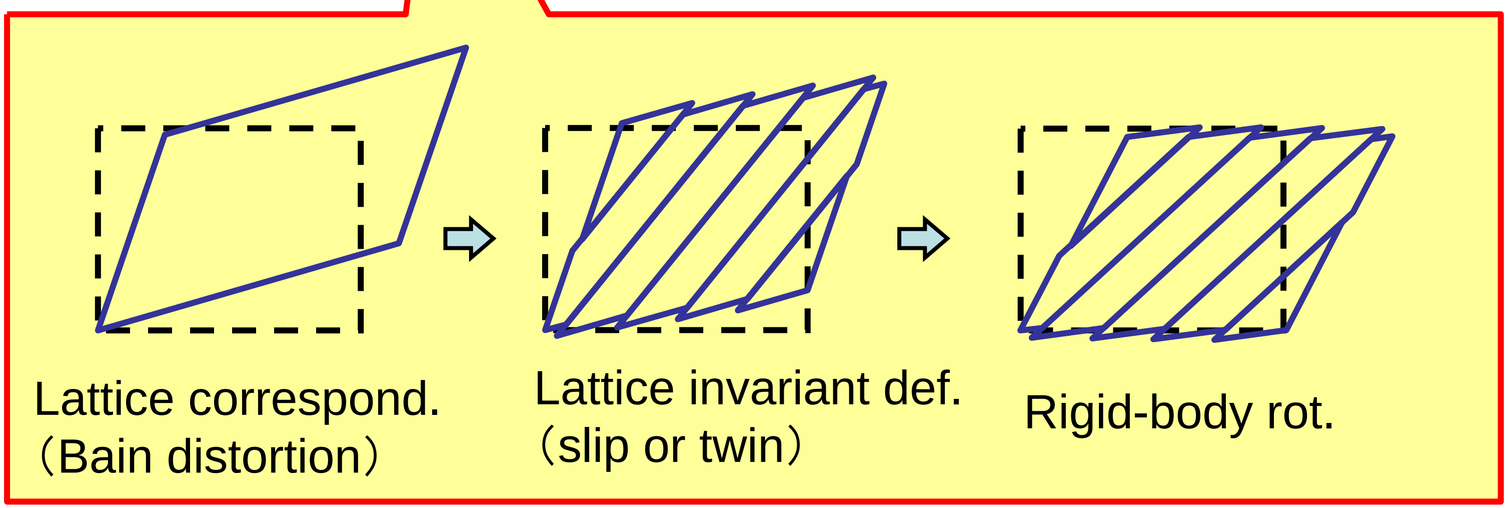
Nishiyama-Wassermann(NW)
(111)γ // (011)α
$[\bar{1}10]\gamma$ // $[100]\alpha$

Kurdjumov-Sachs（KS)
(111)γ // (011)α
$[\bar{1}01]\gamma$ // $[\bar{1}\bar{1}1]\alpha$

FCC → BCC shear transformation



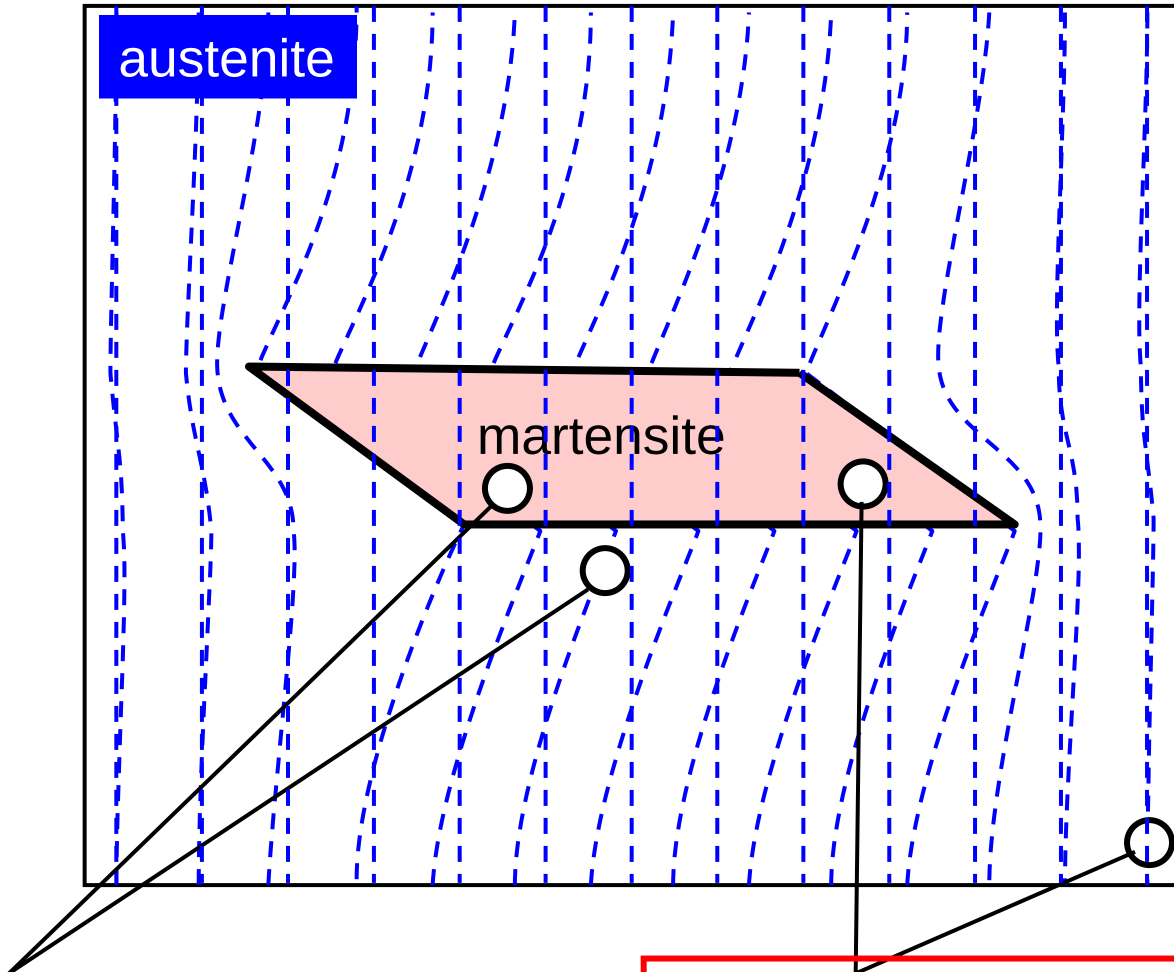




F(shape change) = **R**(Rigid-body rot.) · **B**(Bain distortion) · **P**(lattice invariant def.)

→ Determine O.R.

Notice:OR determined in this method



OR-type1

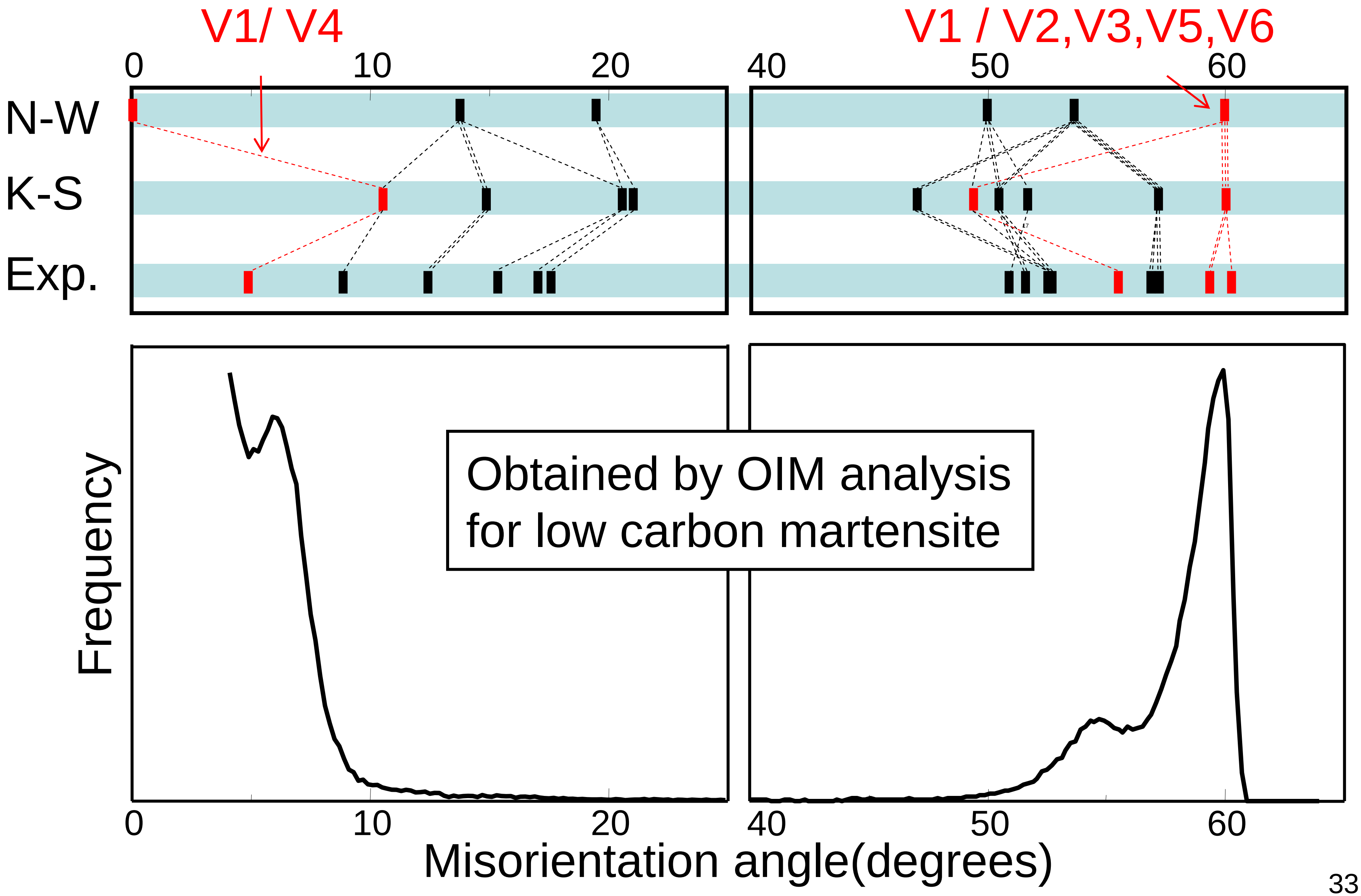
OR with respect to γ orientation deformed for accommodation.
(TEM/Kikuchi analysis)

OR- type 2

OR with respect to initial γ orientation
(X-ray analysis)

OR in present study
→OR2

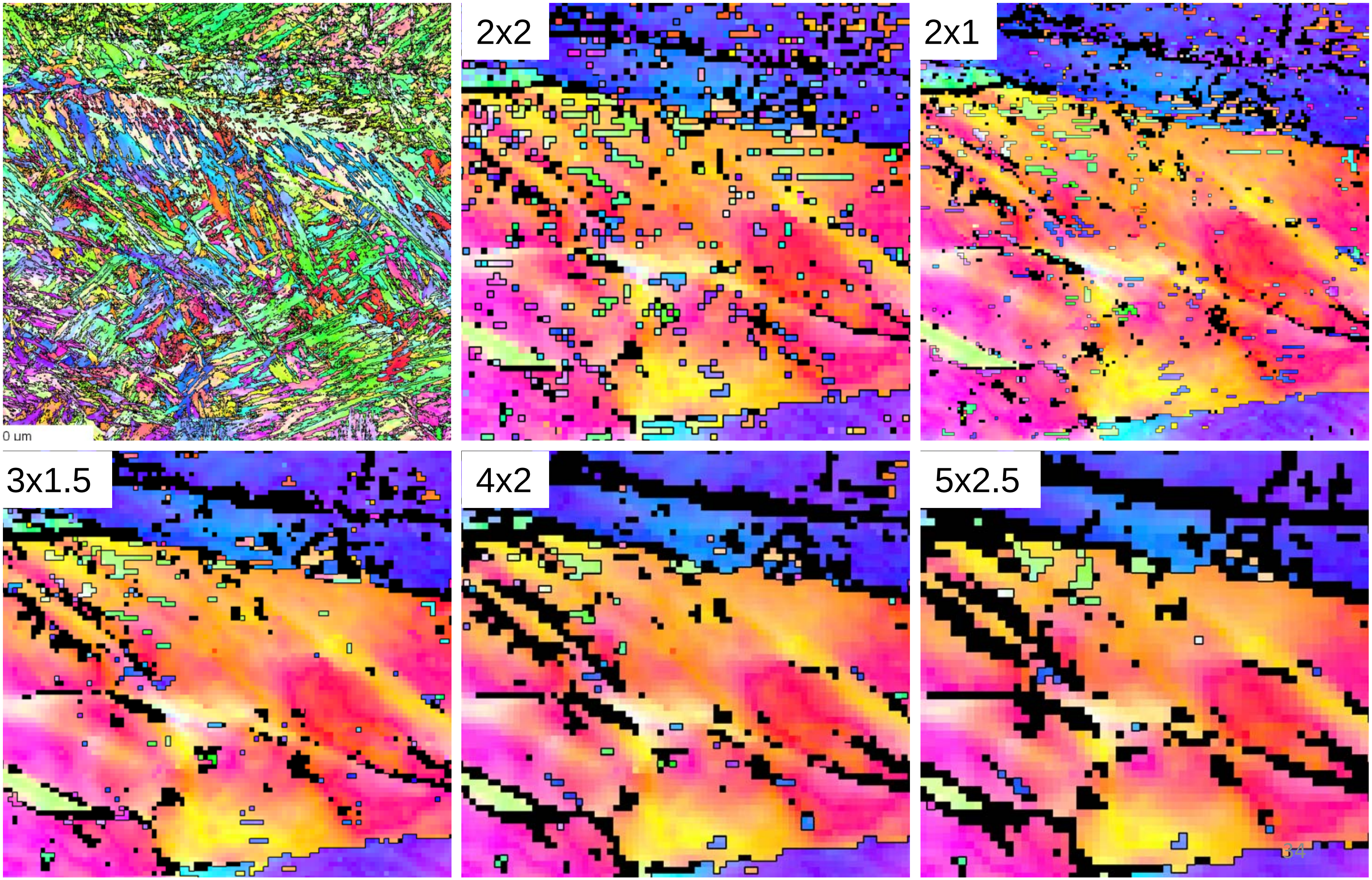
Misorientation profile of lath martensite



Obtained by OIM analysis
for low carbon martensite

再構築結果に及ぼすメッシュ、ステップサイズの影響(30%加工変態途中B)

Mesh-step

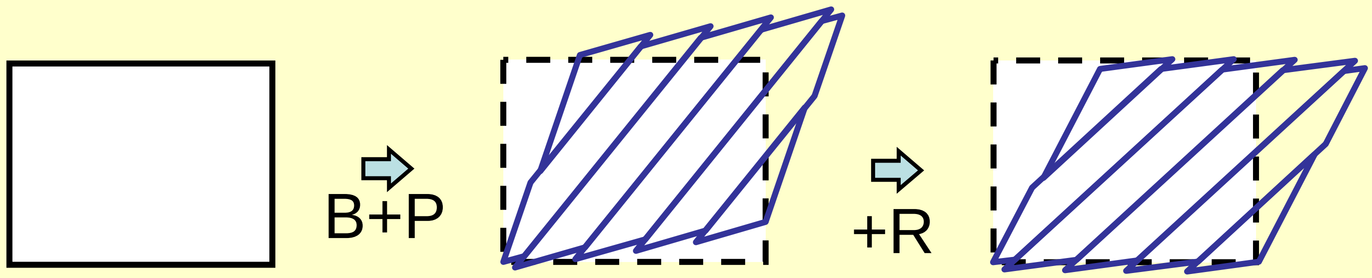


変態温度による方位関係の変化

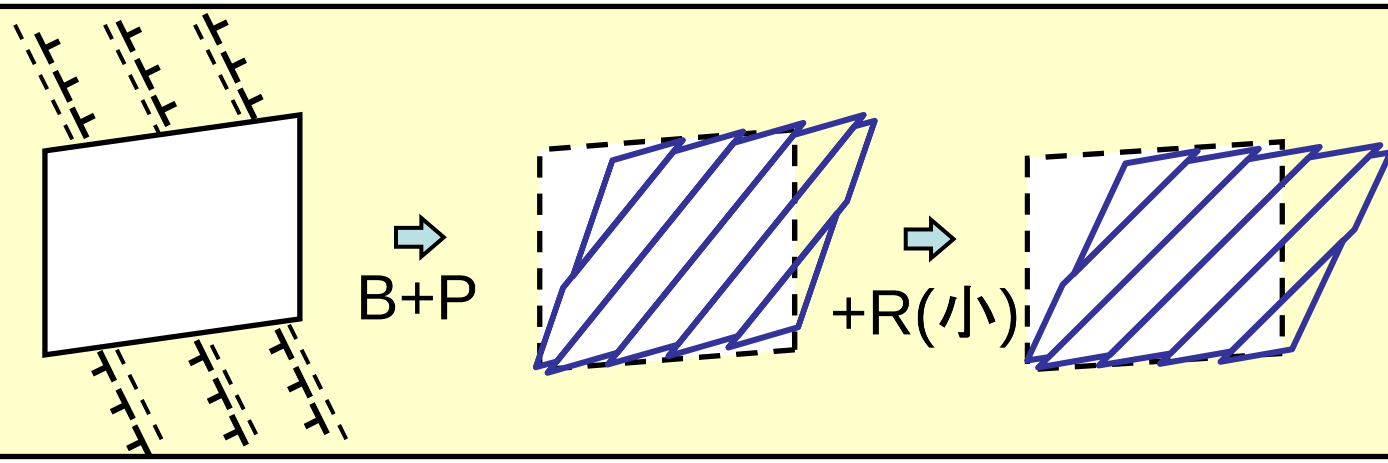
F(外形変化) = **R**(剛体回転)・**B**(ベイン変形)・**P**(格子不変変形)

→ 方位関係を決める

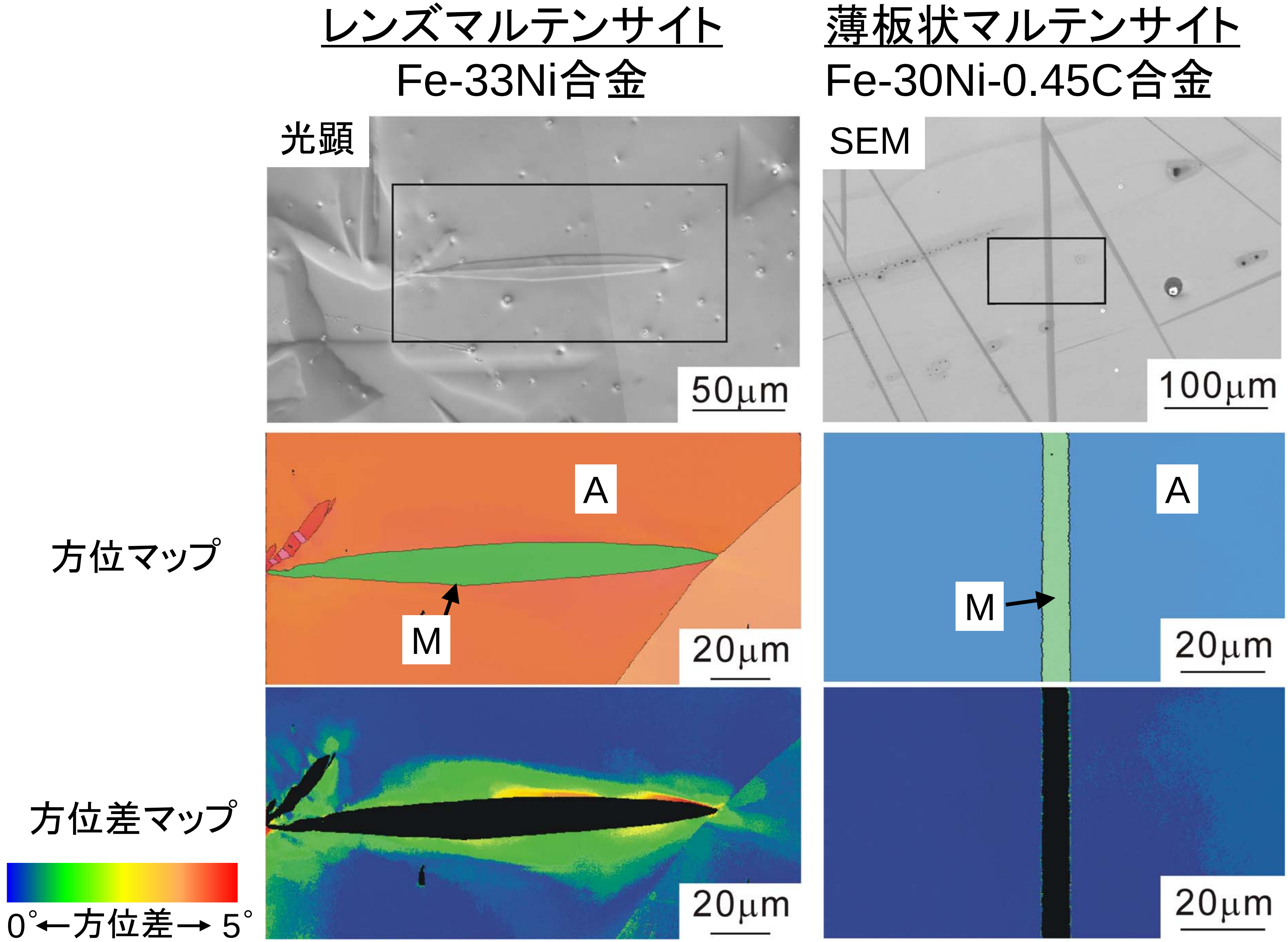
<u>Low Temp.</u>
(less plastic accommodation)



<u>High Temp.</u>
(more plastic accommodation)



More plastic accommodation leads to approaching Bain O.R.



レンズマルテンサイト
Fe-33Ni合金
薄板状マルテンサイト
Fe-30Ni-0.45C合金
光顕
50μm
SEM
100μm
方位マップ
A
M
20μm
A
M
20μm
方位差マップ
0°←方位差→ 5°
20μm
20μm

ラスマルテンサイト(Fe-20Ni-5Mn合金)