

**Microstructure et texture du T40 :  
évolution au cours du laminage à froid,  
de la recristallisation,  
de la croissance de grains,  
et de la transformation  $\alpha \rightarrow \beta \rightarrow \alpha$**

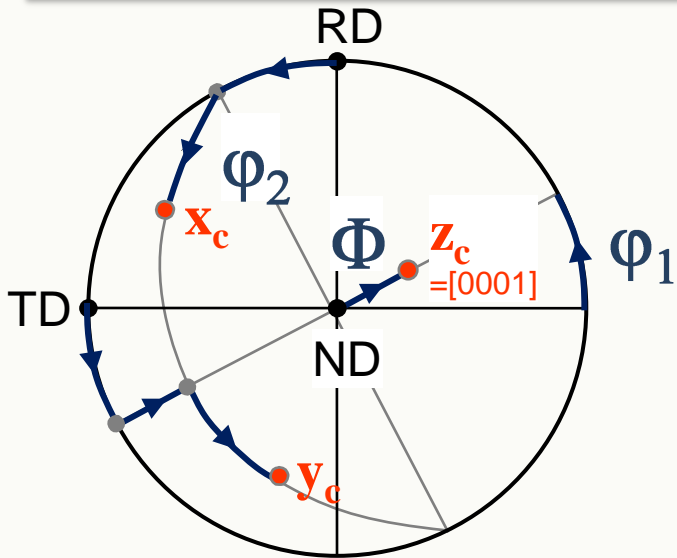


**LETAM (UMR CNRS 7078)**  
Laboratoire d'Etude des Textures et  
Application aux Matériaux

**Université Paul Verlaine - METZ**



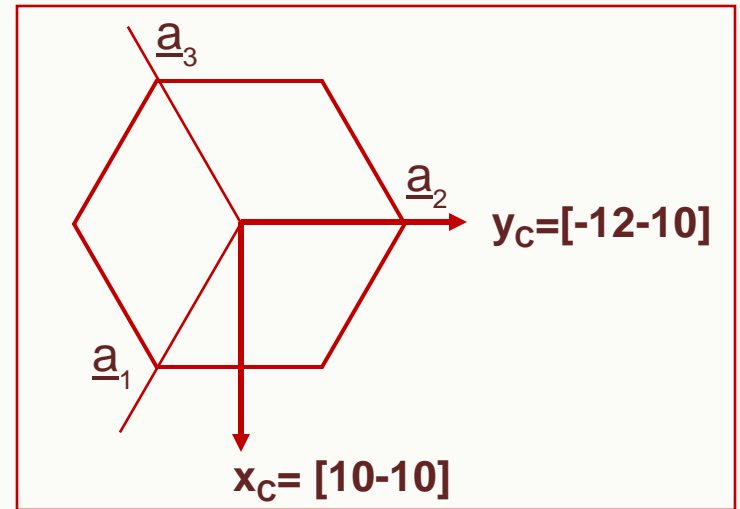
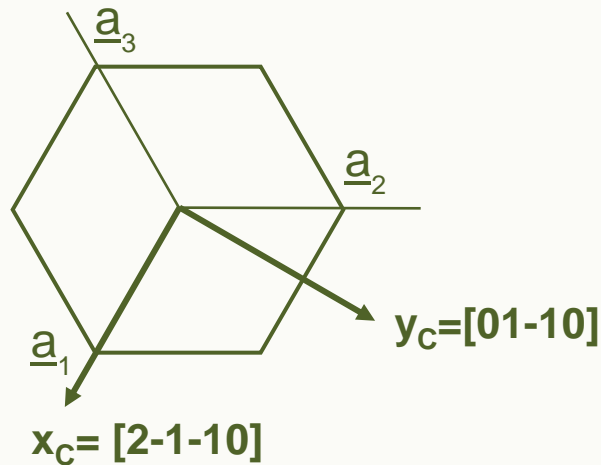
# Euler angles and cartesian system for HCP crystals



Euler angles as defined by Bunge :  
 $\varphi_1$  around Z (=ND)  
 $\Phi$  around X' (=RD')  
 $\varphi_2$  around Z''  
 to make the macroscopic system fit with the crystal system



cartesian system  
 2 conventions

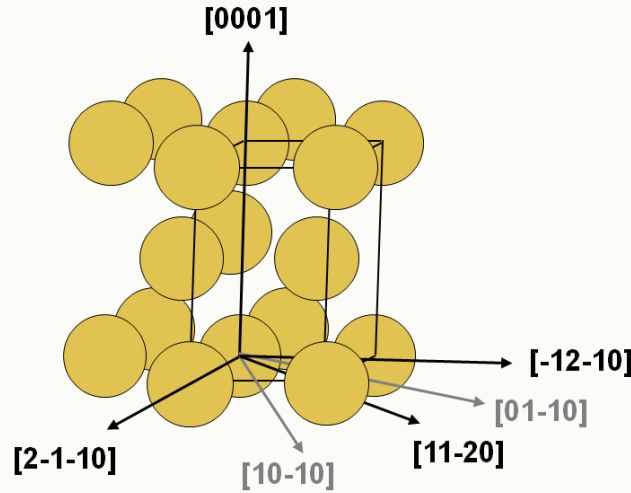
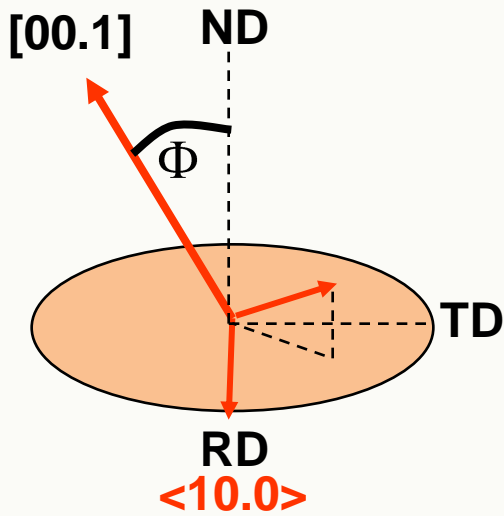


$\varphi_1, \Phi, \varphi_2 + 30^\circ$

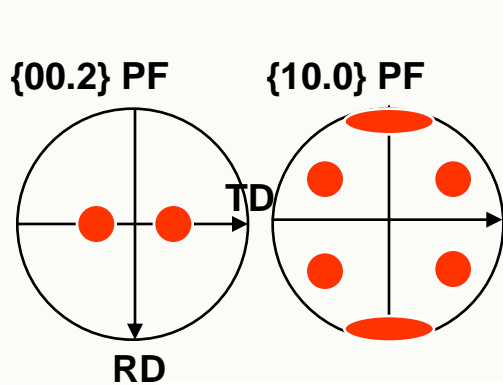
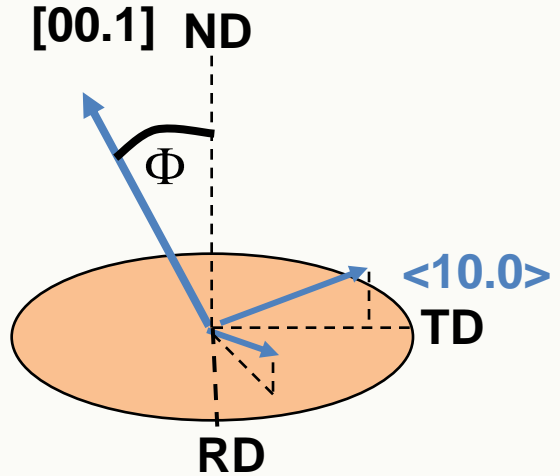


$\varphi_1, \Phi, \varphi_2$

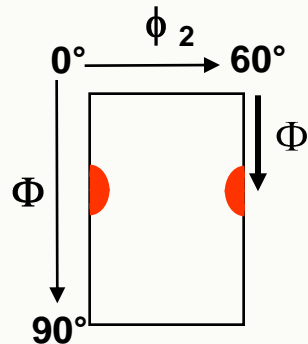
## Rolling texture



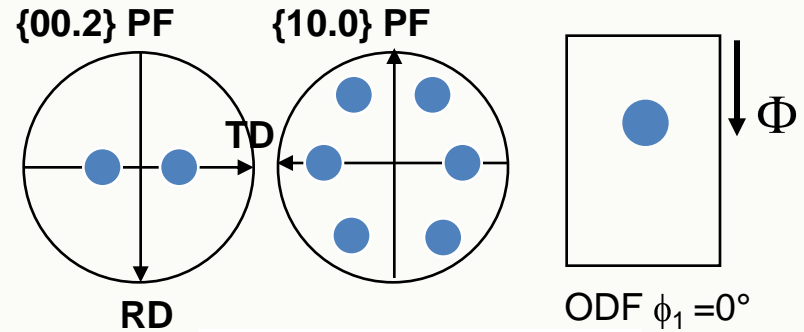
## Annealing texture



$\{\phi_1=0^\circ, \Phi, \phi_2=0^\circ\}$

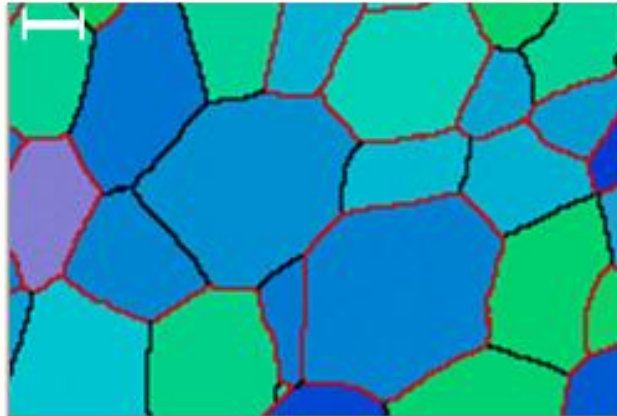


ODF  $\phi_1=0^\circ$

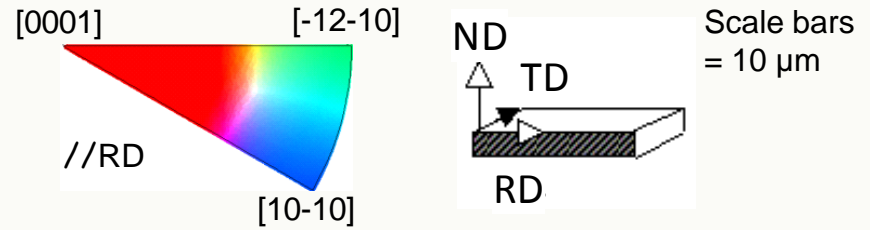


$\{\phi_1=0^\circ, \Phi, \phi_2=30^\circ\}$

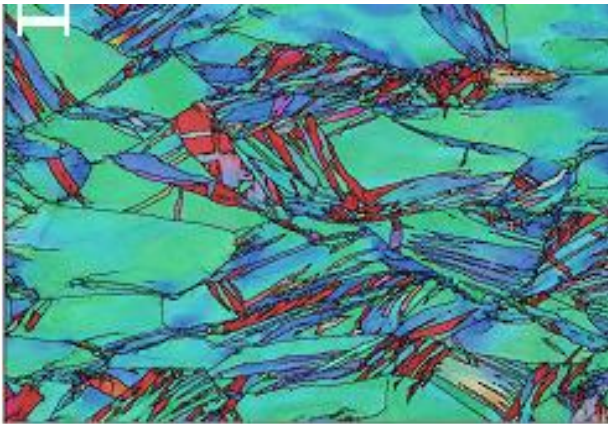
# Laminage à froid - Microstructure



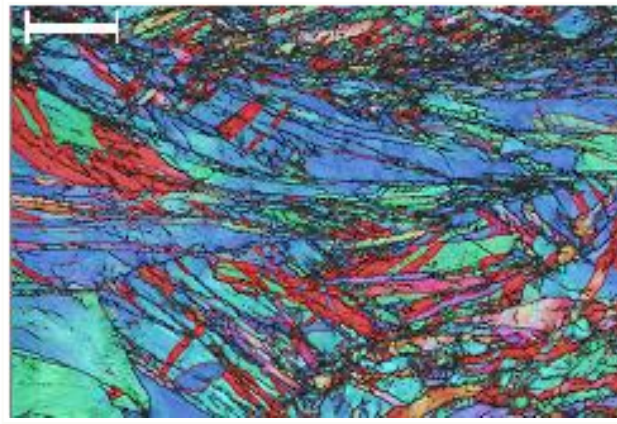
Matériau initial



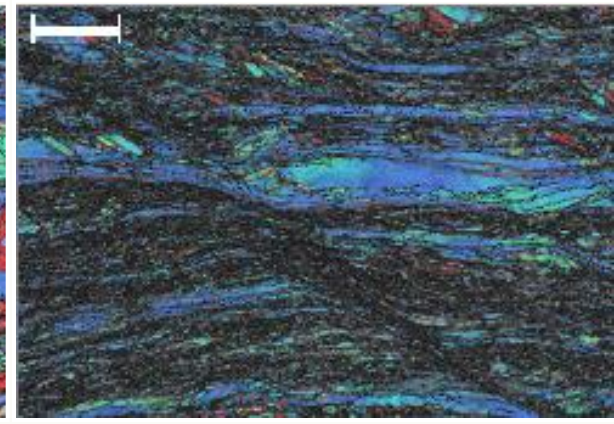
*Cartographies EBSD dans la section transverse  
 (polissage OPS puis électrolytique)*



30% de réduction d'épaisseur



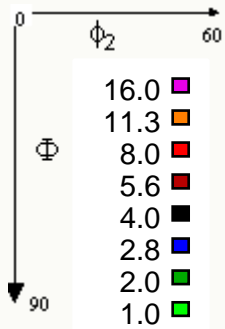
50%



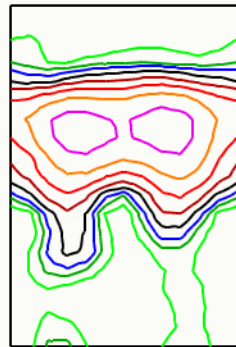
80%

# Laminage à froid - Texture

ODF sections  
 at  $\phi_1=0^\circ$

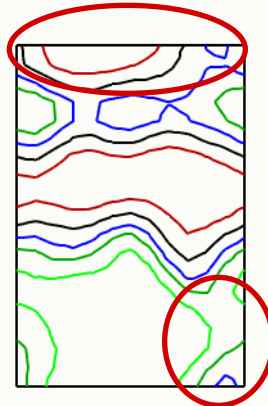


Texture  
 initiale

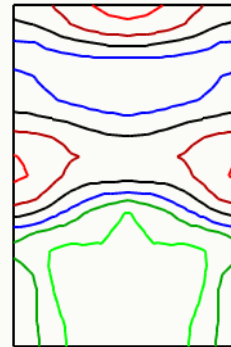


$\langle 11-20 \rangle // DL$

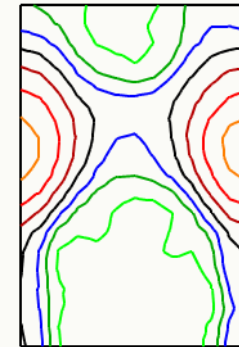
30%



50%



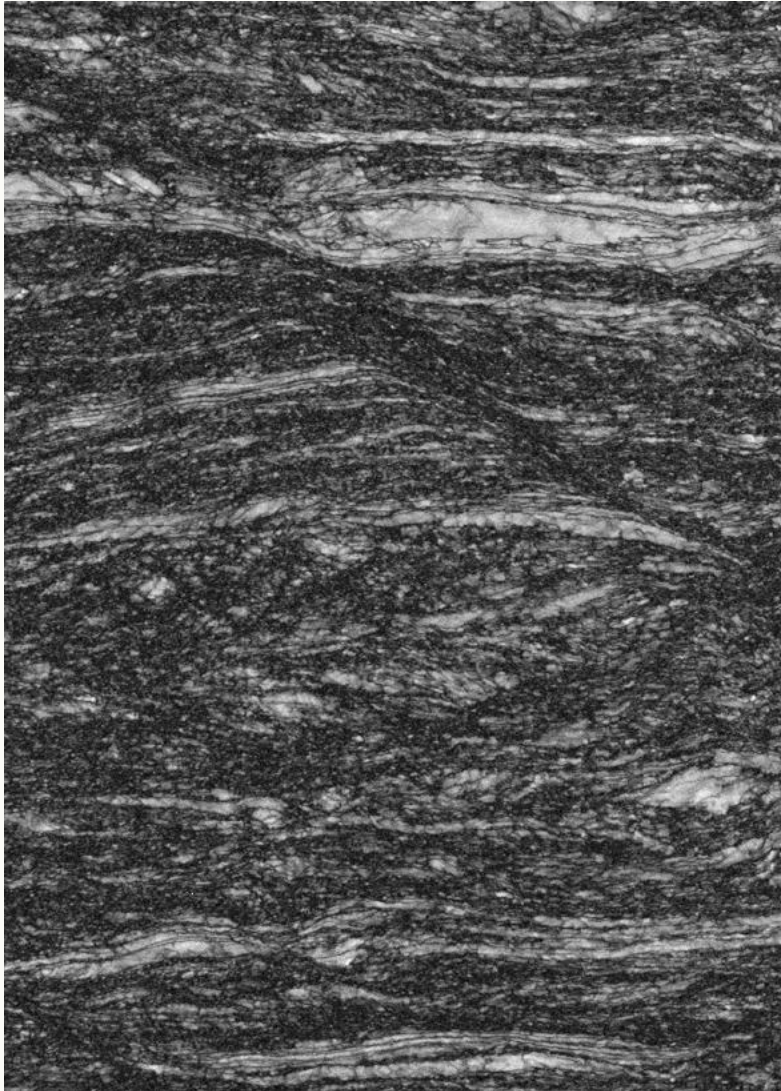
80%



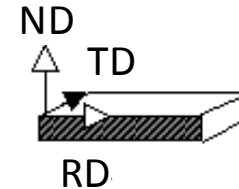
$\langle 10-10 \rangle // DL$

Composantes  
 générées par le  
 maillage  
 $\{0 ; 0 ; 30 \}$  &  $\{0 ; 90 ; 0 \}$

# Laminage à 80% - Microstructure



10  $\mu\text{m}$

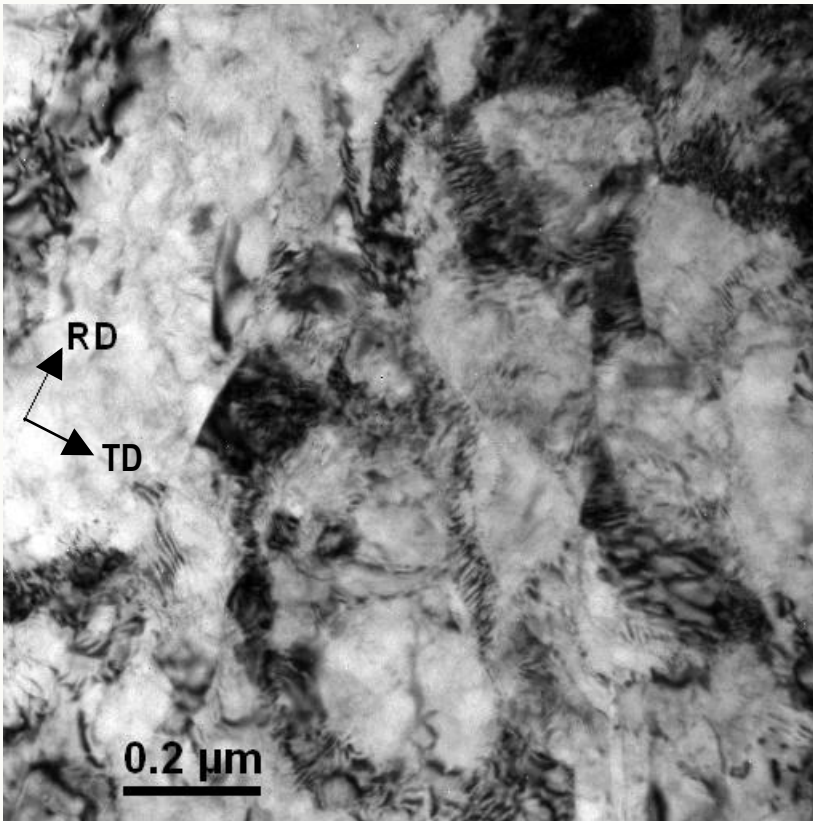


*Cartographie EBSD :*  
*Niveau de gris  $\leftrightarrow$  qualité*  
*du cliché de Kikuchi*

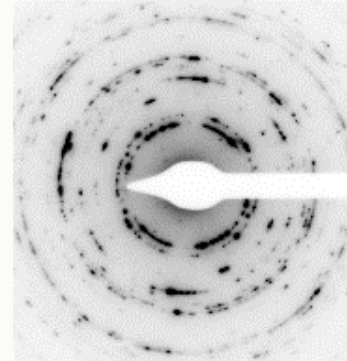
Microstructure hétérogène :  
Zones finement fragmentées  
+ zones lamellaires

# Laminage à 80% - Microstructure

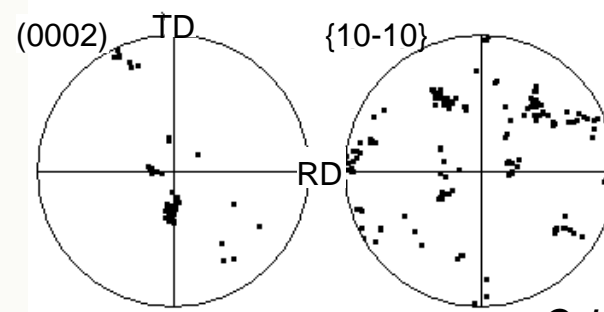
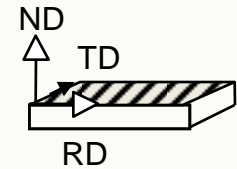
Zones finement fragmentées :



Micrographie MET



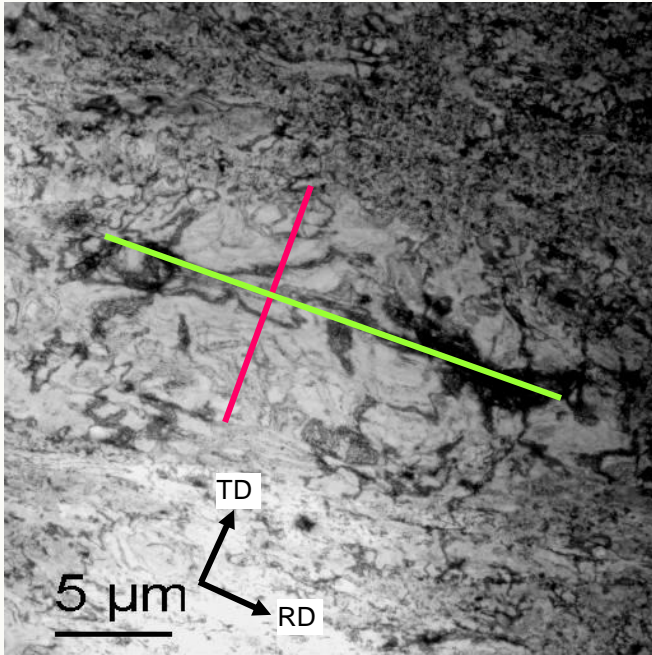
Cliché de diffraction en aire sélectionnée



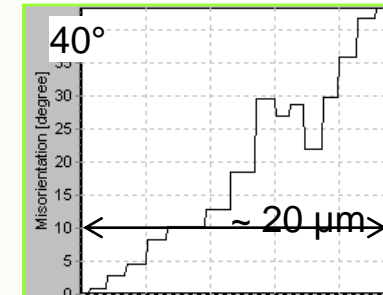
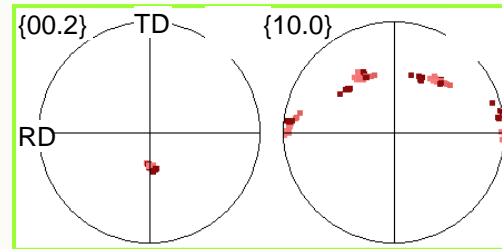
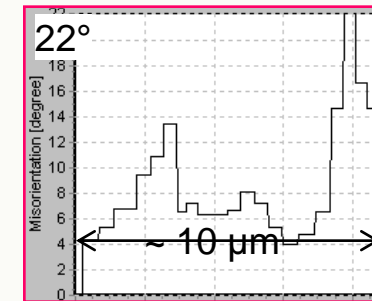
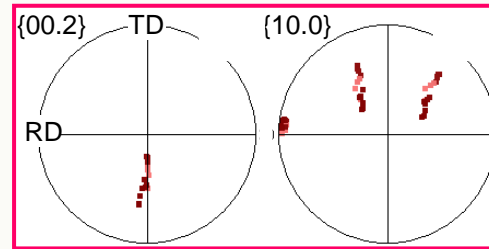
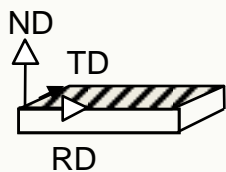
Orientations locales mesurées par diffraction en faisceau convergent

# Laminage à 80% - Microstructure

Zones lamellaires :

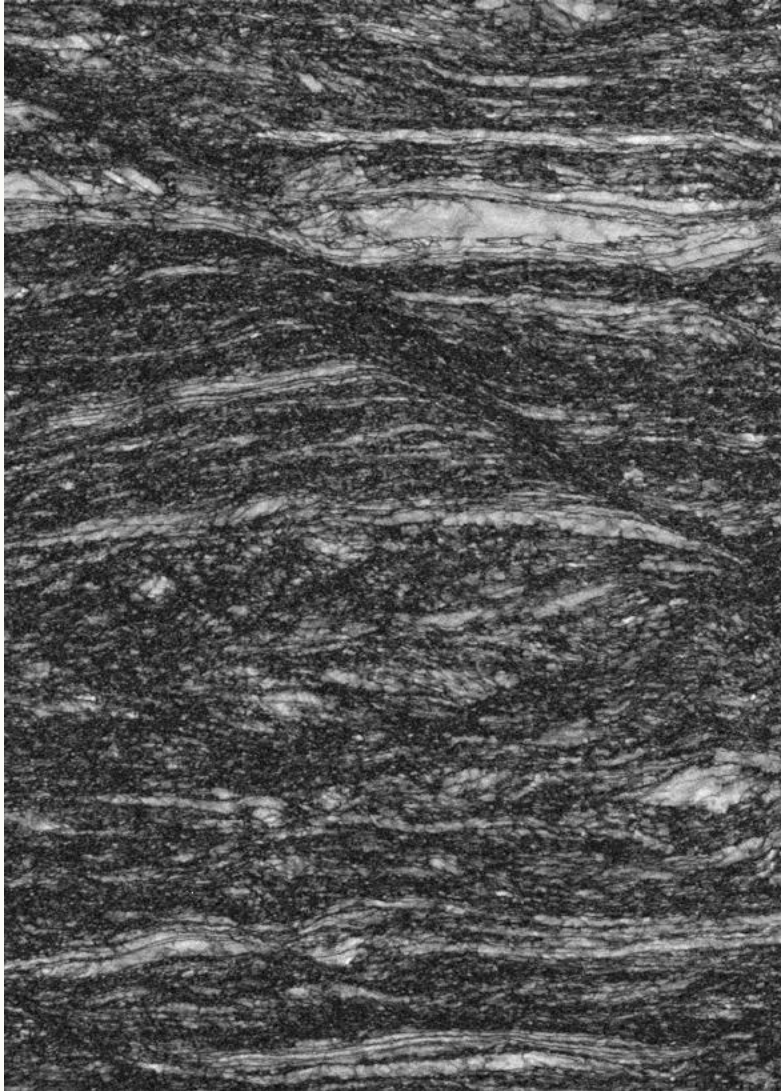


Micrographie MET

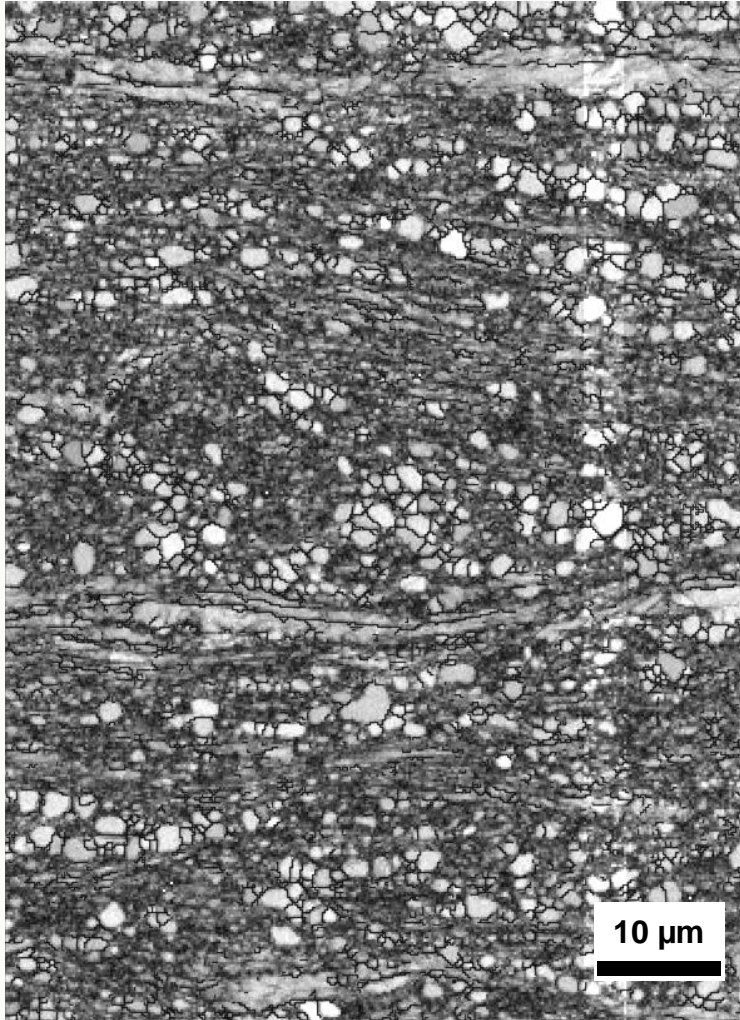


Orientations locales  
 mesurées par  
 diffraction en  
 faisceau convergent

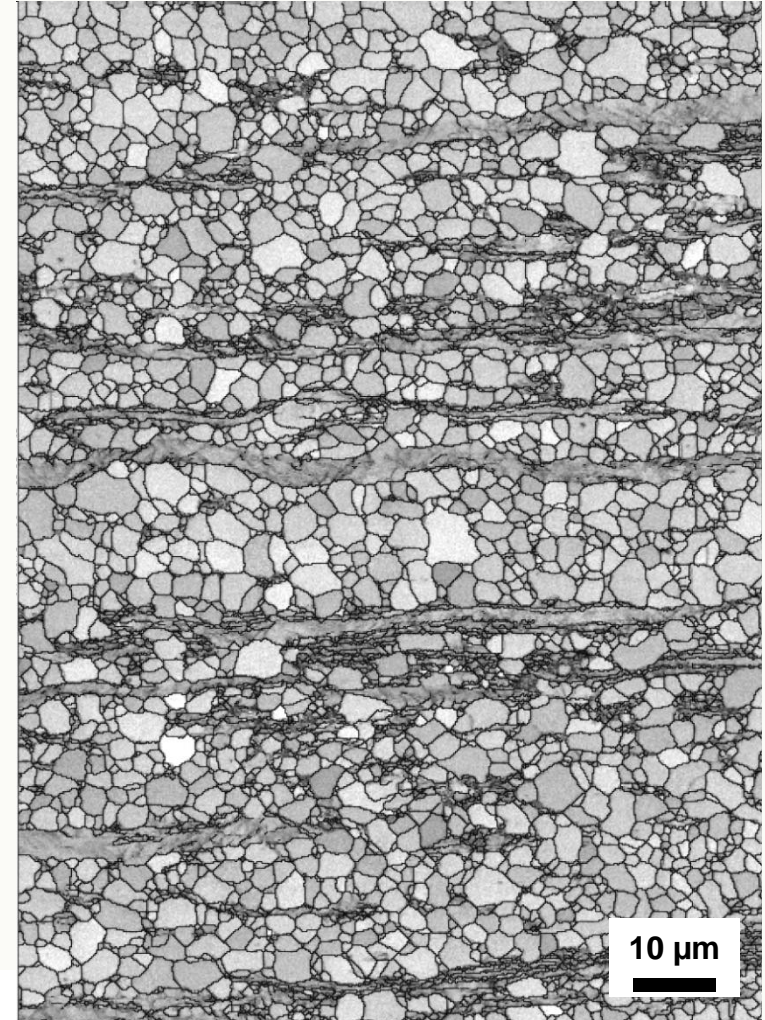
Profils de  
 désorientation  
 correspondants



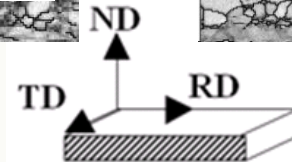
**Recristallisation de  
la microstructure  
laminée à 80% ...**



Laminé 80% puis  
recuit 5' à 500 C



Laminé 80% puis  
recuit 60' à 500 C



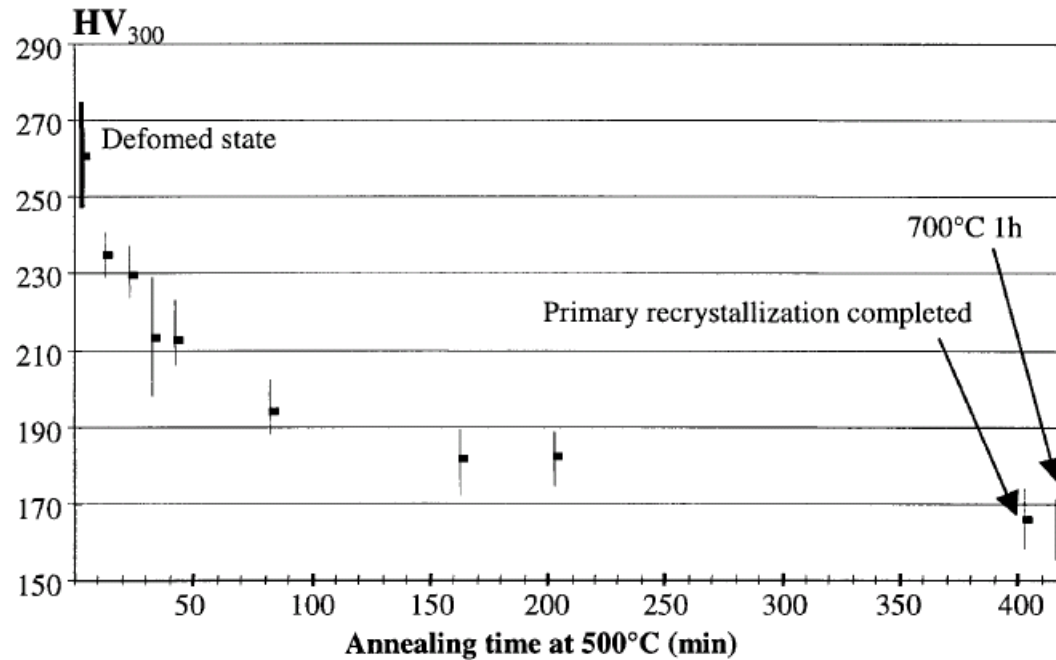
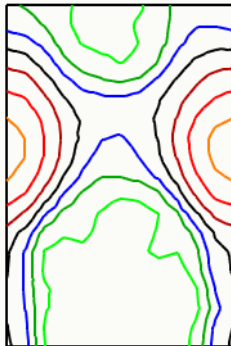
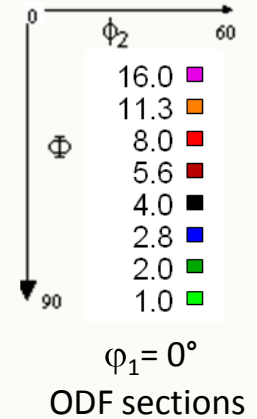
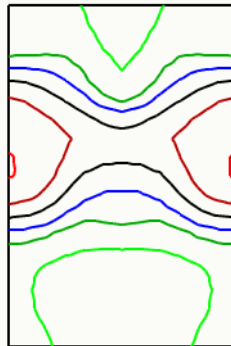


Fig. 1. Evolution of the Vickers microhardness with time for annealing at 500°C. The microhardness of a sample recrystallized at 700°C for 1 h is also given for reference. Bars indicate the dispersion of measurements (min/max).

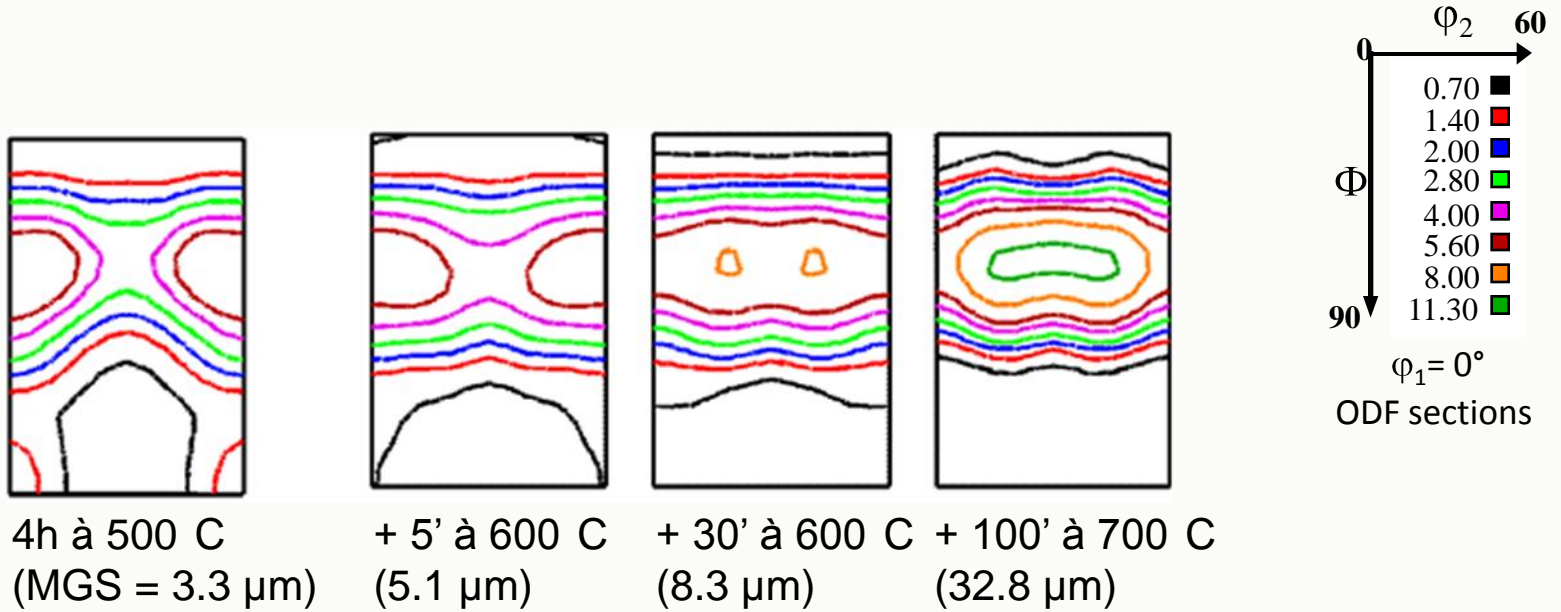
T40 laminé  
 à 80%



Fin de  
 recristallisation  
 primaire  
 (4h at 500 C)

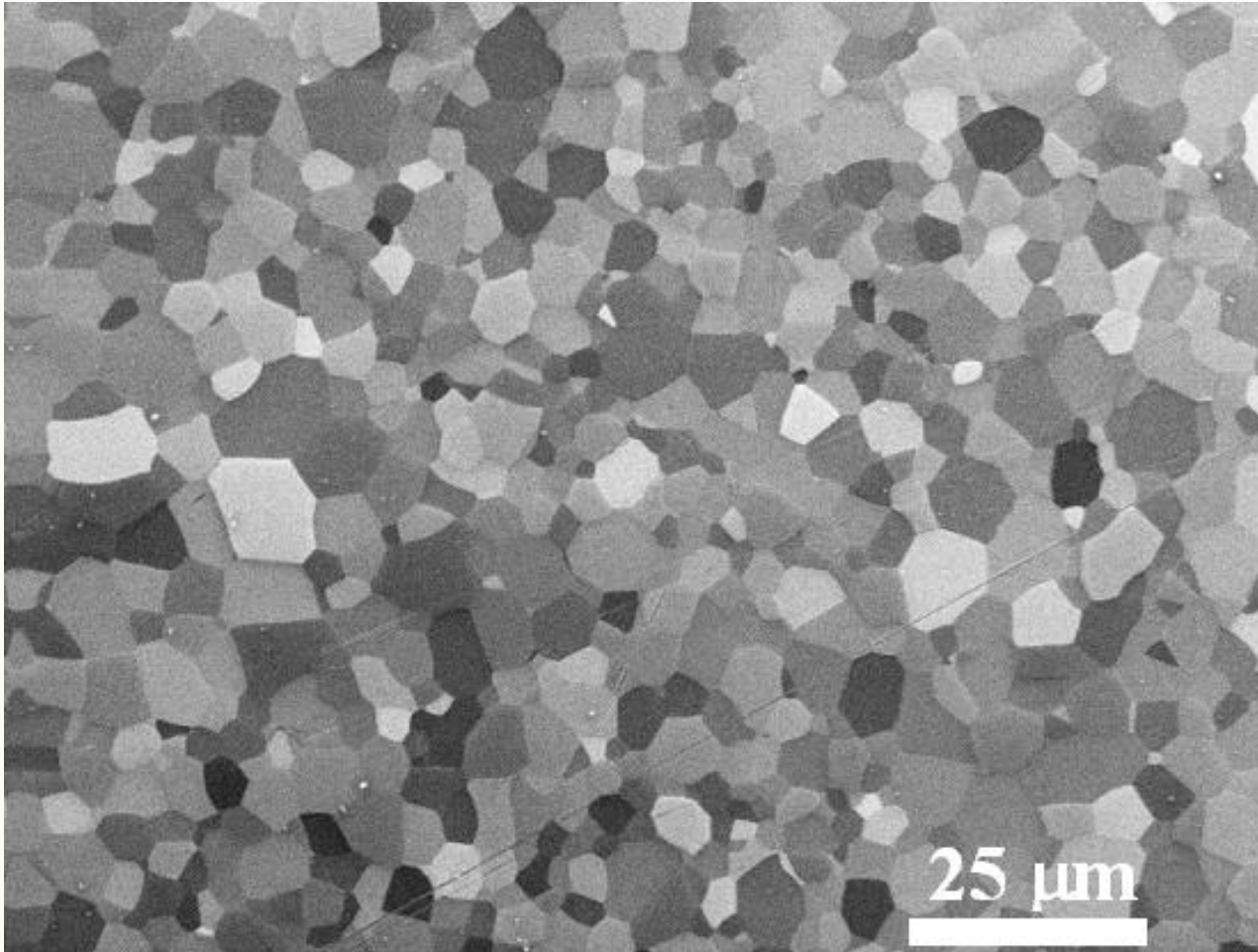


La recristallisation primaire conserve la  
 composante de texture majoritaire de  
 la texture de déformation ( $\langle 10\text{-}10 \rangle // \text{DL}$ )



$\langle 10\text{-}10 \rangle // \text{DL}$   
 $\{ 0 ; 40 ; 0 \}$ 

**Changement de texture  
 "rotation 30 [0001]"**
→
 $\langle 11\text{-}20 \rangle // \text{DL}$   
 $\{ 0 ; 30 ; 30 \}$



30 min at 600°C  
MGS = 8.3 μm

*BSE-SEM micrograph  
OPS polishing*

**Croissance de grains normale**

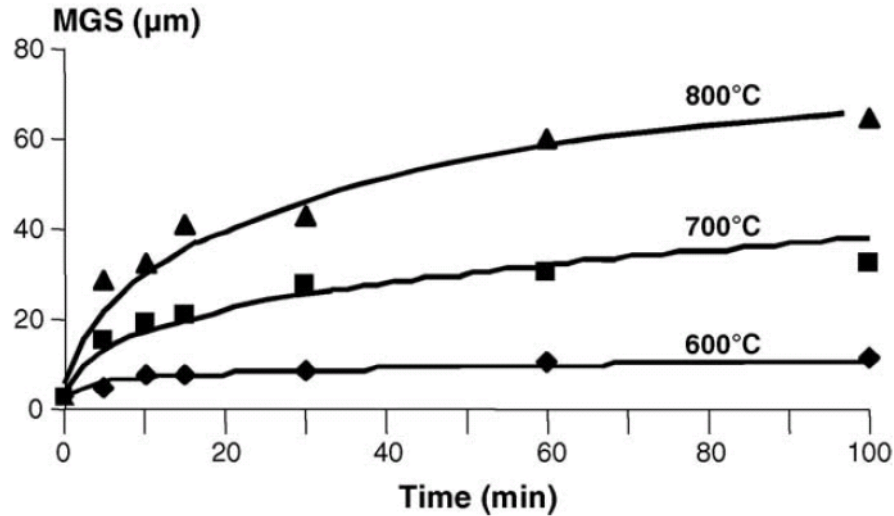
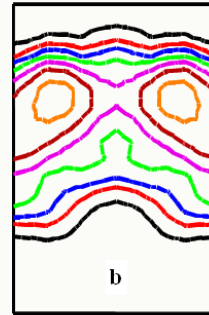
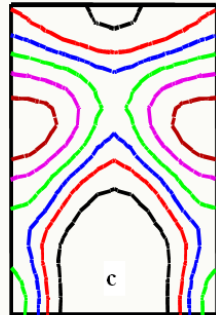
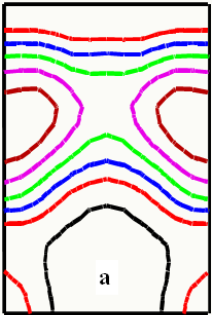


Fig. 2. Evolution of the grain size as a function of annealing time for different temperatures (the initial grain size obtained after primary recrystallization was 3.3 μm).

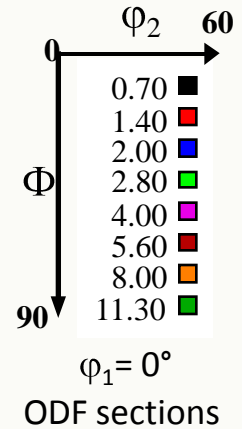
$$D^n - D_0^n = \left[ A_0 \exp \left( \frac{-Q}{RT} \right) \right] t \quad (1)$$

The activation energy for grain boundary migration ( $Q$ ) obtained from this formula was 204 kJ mol<sup>-1</sup>.

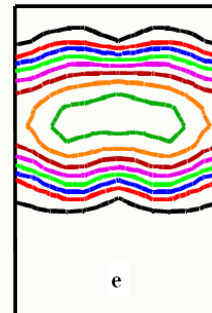
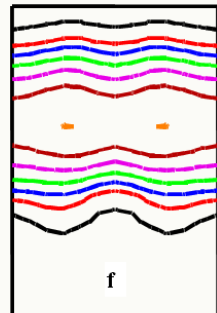
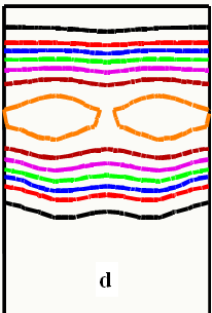
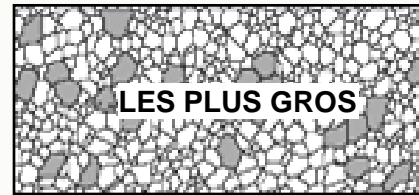
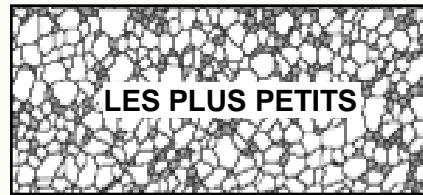
$\langle 10-10 \rangle // DL$



Etat de fin de recristallisation primaire  
 (TGM = 3  $\mu\text{m}$ )

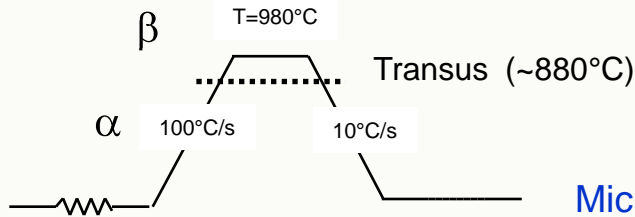


TOUS LES GRAINS



+ recuit 100 min à 600 C  
 (TGM = 10.4  $\mu\text{m}$ )

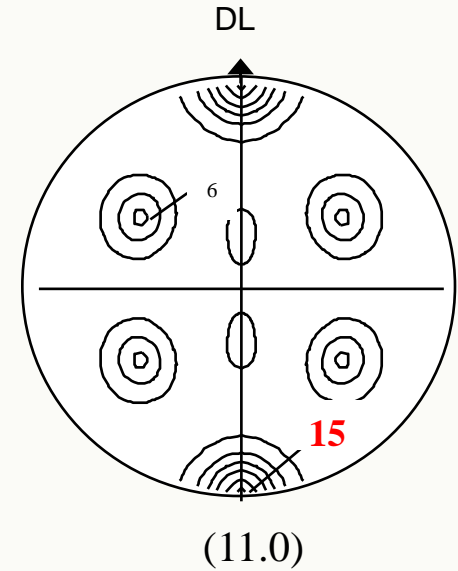
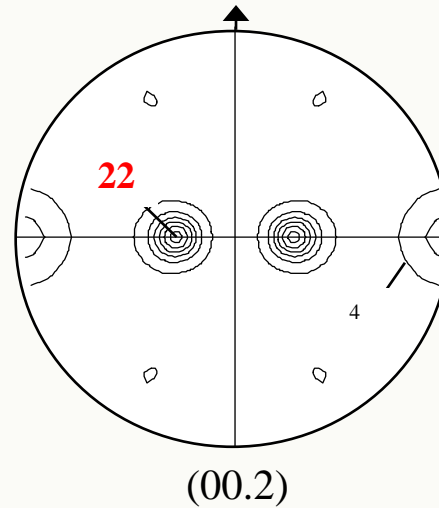
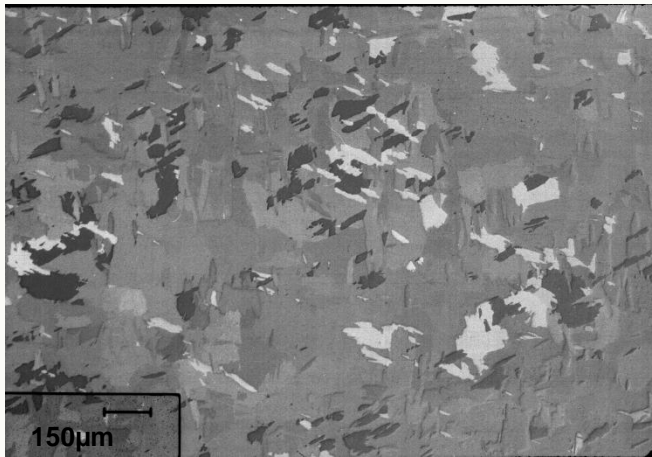
$\langle 11-20 \rangle // DL$



Phase  $\alpha$  héritée à température ambiante :

Microstructure

Texture globale



Après double transformation  $\alpha \rightarrow \beta \rightarrow \alpha$  :

$$(1\bar{1}0)_\beta // (00.2)_\alpha$$

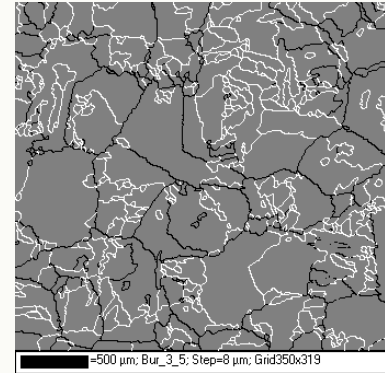
$$\parallel 11\bar{1}_\beta // \parallel 1\bar{2}0_\alpha$$

$$\alpha \xrightarrow{6OI_\beta} \beta \xrightarrow{12OI_\alpha} \alpha$$

-Texture de transformation très marquée  
 (Indice de texture = 12)

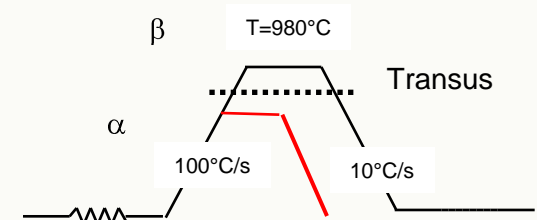
- Composante majoritaire :  $\{0, \pm 30^\circ, 30^\circ\}$  avec  $\langle 11-20 \rangle // DL$

**Composante  
 de croissance de grains**



## Analyse EBSD des microtextures de transformation

## Analyse de la microstructure et texture avant transformation $\alpha \rightarrow \beta$



## Evaluation des microtextures $\beta$ haute température – (1) (2)

[\(1\) Specific analysis of EBSD data to study the texture inheritance due to the  \$\beta \rightarrow \alpha\$  phase transformation](#)

N. Gey, M. Humbert - *Journal of Materials Science* 38 (2003)- 1289-1294

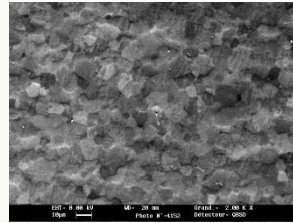
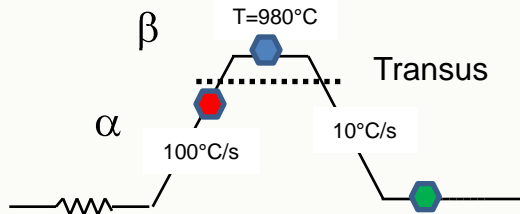
[\(2\) Reliability of reconstructed  \$\beta\$ -orientation maps in titanium alloys](#)

L. Germain, N. Gey, M. Humbert - *Ultramicroscopy*, Volume 107, Issue 12, November 2007, Pages 1129-1135

## Mesure de texture in situ en diffraction des neutrons – (3)

[\(3\) In situ observation of texture evolution during  \$\alpha \rightarrow \beta\$  and  \$\beta \rightarrow \alpha\$  phase transformations in titanium alloys investigated by neutron diffraction](#)

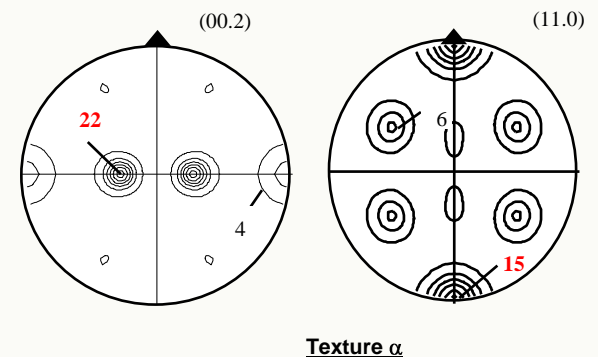
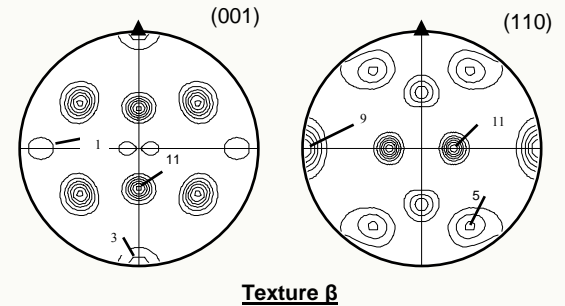
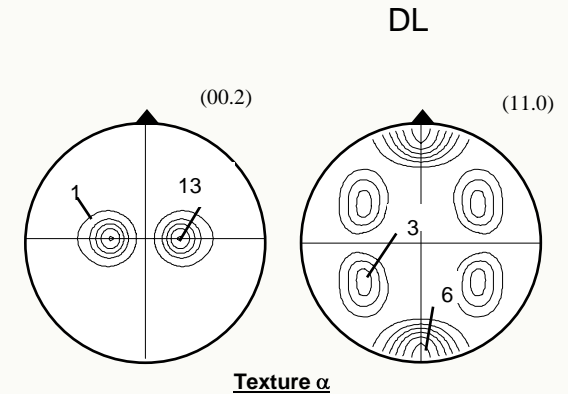
I. Lonardelli, N. Gey, H.-R. Wenk, M. Humbert, S.C. Vogel, L. Lutterotti  
*Acta Materialia*, Volume 55, Issue 17, October 2007, Pages 5718-5727



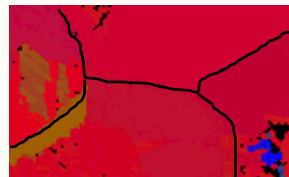
● **Avant transformation  $\alpha \rightarrow \beta$  : 800°C-15s**  
 microstructure recristallisée  
 taille de grains moyenne :  $\Phi$  20 $\mu$ m  
 texture :  $\{0, \pm 30^\circ, 30^\circ\}$  avec  $\langle 11-20 \rangle // DL$

● **Transformation  $\alpha \rightarrow \beta$  : 980°C- 30s**  
 transformation  $\alpha \rightarrow \beta$  des orientations  $\{0^\circ, \pm 30^\circ, 30^\circ\}$   
 croissance rapide des grains  $\beta$  -  $\Phi$  500 $\mu$ m  
 texture  $\beta$  très marquée  $\{001\} \langle 100 \rangle$  &  $\{112\} \langle 111 \rangle$

● **Transformation  $\beta \rightarrow \alpha$  :**  
 renforcement de la composante  $\{0^\circ, \pm 30^\circ, 30^\circ\}$   
 transformation  $\beta \rightarrow \alpha$  avec forte sélection de variantes



**Variantes  $\alpha$  préférentiellement sélectionnées :**  
 Celles qui peuvent être mis en commun entre les grains  $\beta$  voisins



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Laboratoire d'Etude des Textures et  
Application aux Matériaux

**Université Paul Verlaine - METZ**



# Références bibliographiques

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## *Articles de journaux*

- F. Wagner, N. Bozzolo, O. Van Landuyt, T. Grosdidier "Evolution of recrystallization texture and microstructure in low alloyed titanium sheets" *Acta Materialia*, vol. 50, (2002), 1245-1259
- N. Bozzolo, N. Dewobroto, T. Grosdidier, F. Wagner "Texture evolution during grain growth in recrystallized commercially pure titanium" *Materials Science and Engineering A*, vol. 397, (2005), 346-355
- N. Bozzolo, N. Dewobroto, H.-R. Wenk, F. Wagner "Microstructure and microtexture of cold-rolled commercially-pure titanium" *Journal of Materials Science*, vol. 42, (2007), 2405-2416
- N. Gey, M. Humbert "Characterization of the variant selection occurring during the  $\alpha \rightarrow \beta \rightarrow \alpha$  phase transformations of a cold rolled titanium sheet" , *Acta Materialia*, 50, (2002), 277-287
- N. Gey, M. Humbert "Specific analysis of EBSD data to study the texture inheritance due to the  $\beta \rightarrow \alpha$  phase transformation" *J. of Materials Science*, 38, (2003), 1289-1294
- L. Germain, N. Gey, M. Humbert "Reliability of reconstructed  $\beta$ -orientation maps in titanium alloys" *Ultramicroscopy*, 107, (2007), 1129-1135
- I. Lonardelli, N. Gey, H.-R. Wenk, M. Humbert, S.C. Vogel, L. Lutterotti "In situ observation of texture evolution during  $\alpha \rightarrow \beta$  and  $\beta \rightarrow \alpha$  phase transformations in titanium alloys investigated by neutron diffraction" *Acta Materialia*, 55, (2007), 5718-5727

## Références bibliographiques (suite)

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- N. Dewobroto, N. Bozzolo, T. Grosdidier, F. Wagner « Texture and microstructure evolution during recrystallization of cold-rolled titanium » Proc. Titanium 2003, Ti-2003 Science and Technology vol. II, (2004), 1211-1218, eds G. Lütjering and J. Albrecht (Wiley-vch)
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