Nanoscale Twins Formed by Plastic Accommodations in Nano Bainite

Phase Transformation Group

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Hsiao-Tzu Chang
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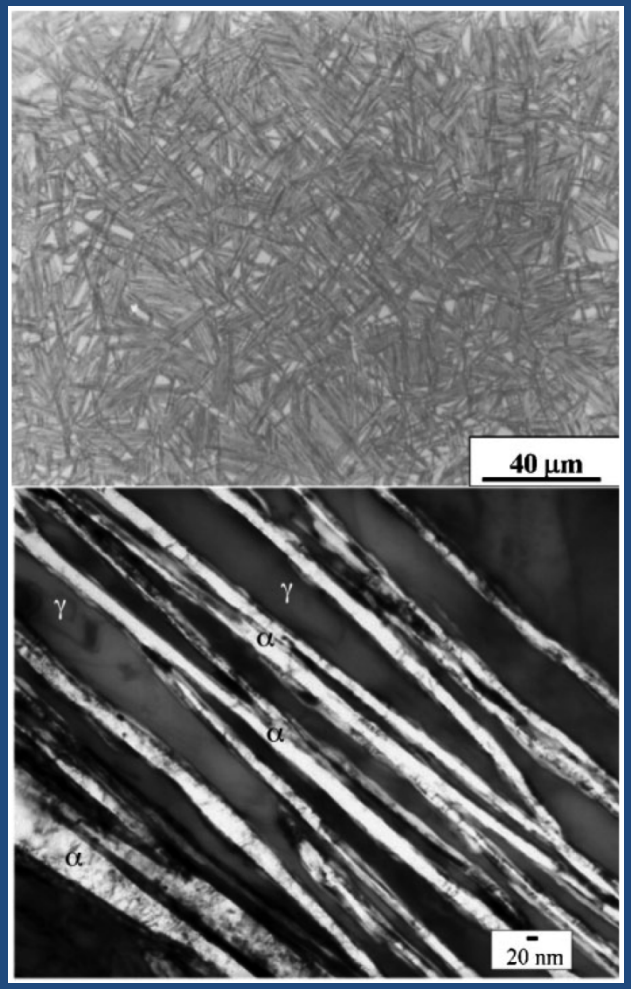
Strengthening Mechanisms in Nano Bainitic Steels



- Total strength of 2500 MPa can be achieved :

  1. about 1600 MPa by the very tiny bainite plate
  2. dislocation debris/forests
  3. solid solute strengthening

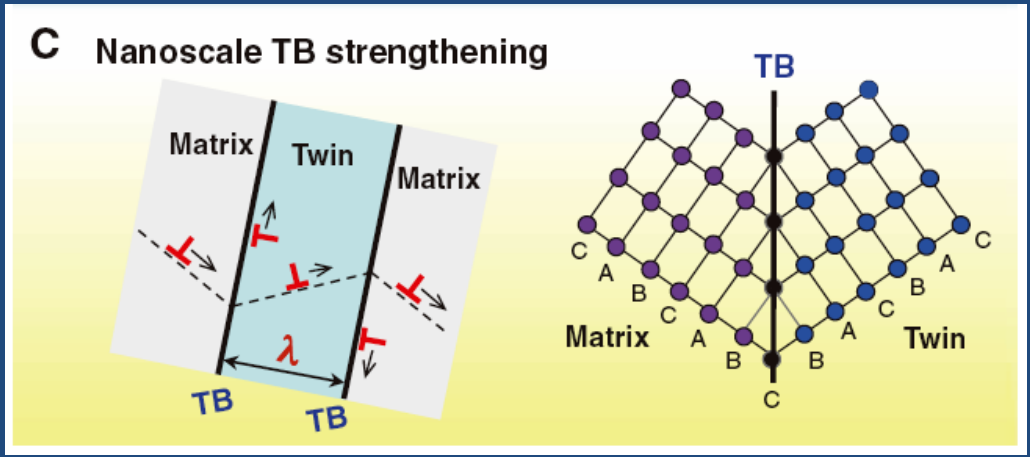
  4. coherent G.B. strengthening in retained austenite

Fe–0.98C–1.46Si–1.89Mn–0.26Mo–1.26Cr–0.09V (wt-%) transformed at 200°C for 5 days.

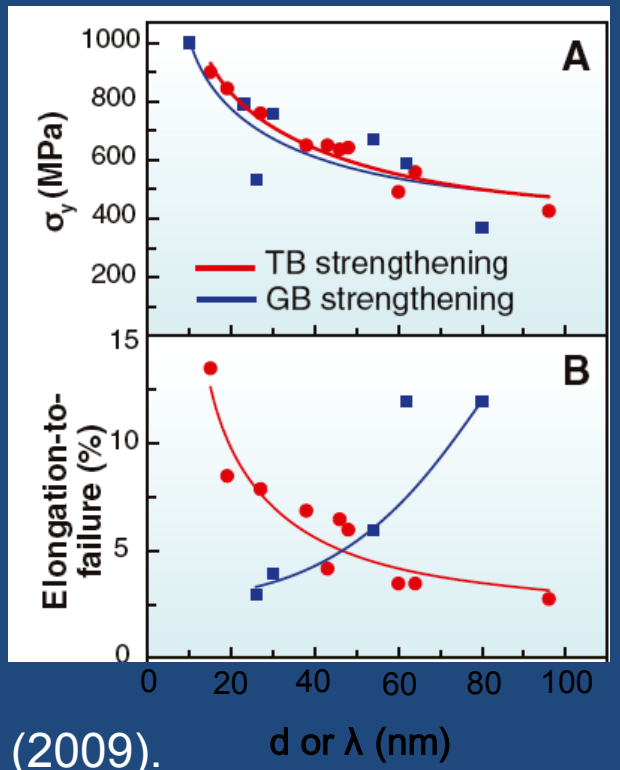
C. Garcia Mateo, F. G. Caballero and H.K.D.H. Bhadeshia: ISIJ International, Vol. 43 (2003) 1238.

Coherent TBs Strengthening Metals

- Nano Twins with coherent grain boundary has been reported as an new strengthening mechanism in FCC metals.



The challenge is the applicable of this mechanism to a variety of engineering materials.

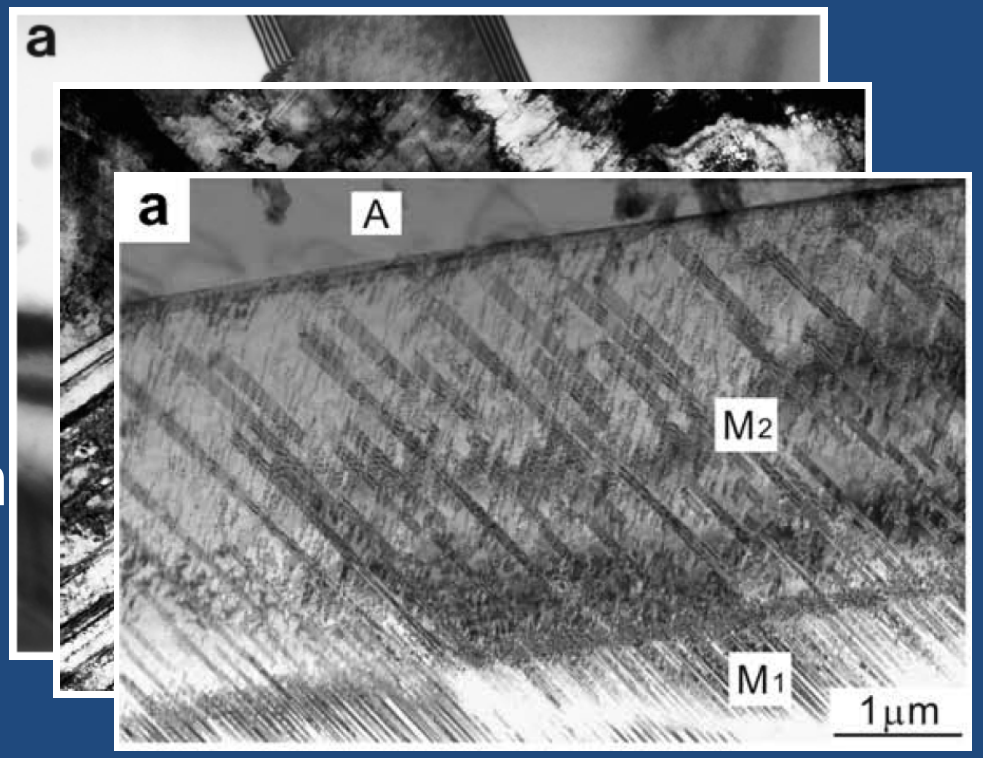


K. Lu, L. Lu, and S. Seresh: SCIENCE, Vol. 324, P. 17 (2009).

Twinning in Steels

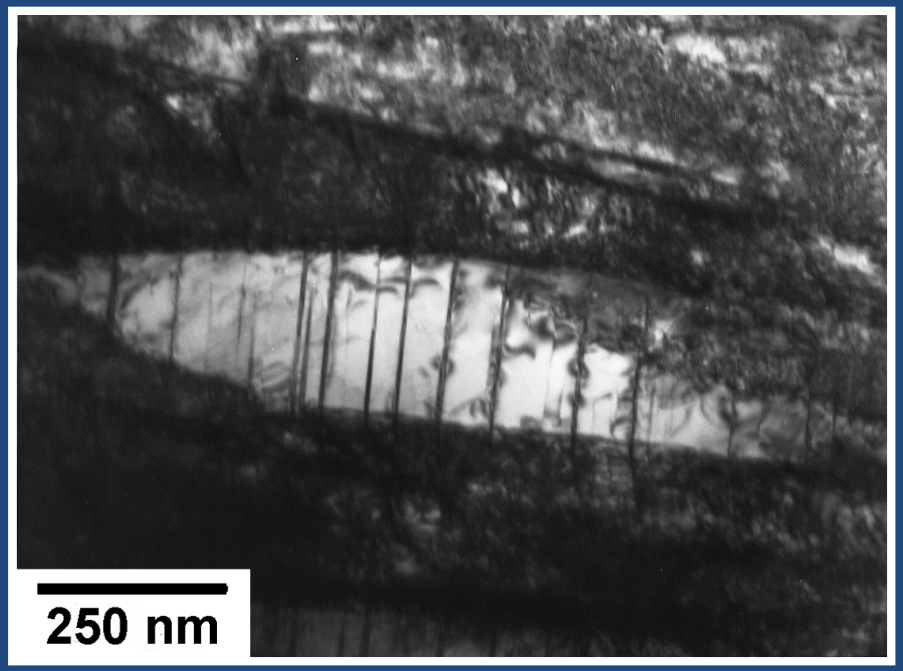
- Twinning in steels can be achieved by several different methods:

1. Annealing Twins
2. Deformation Twins
3. Transformation Twin

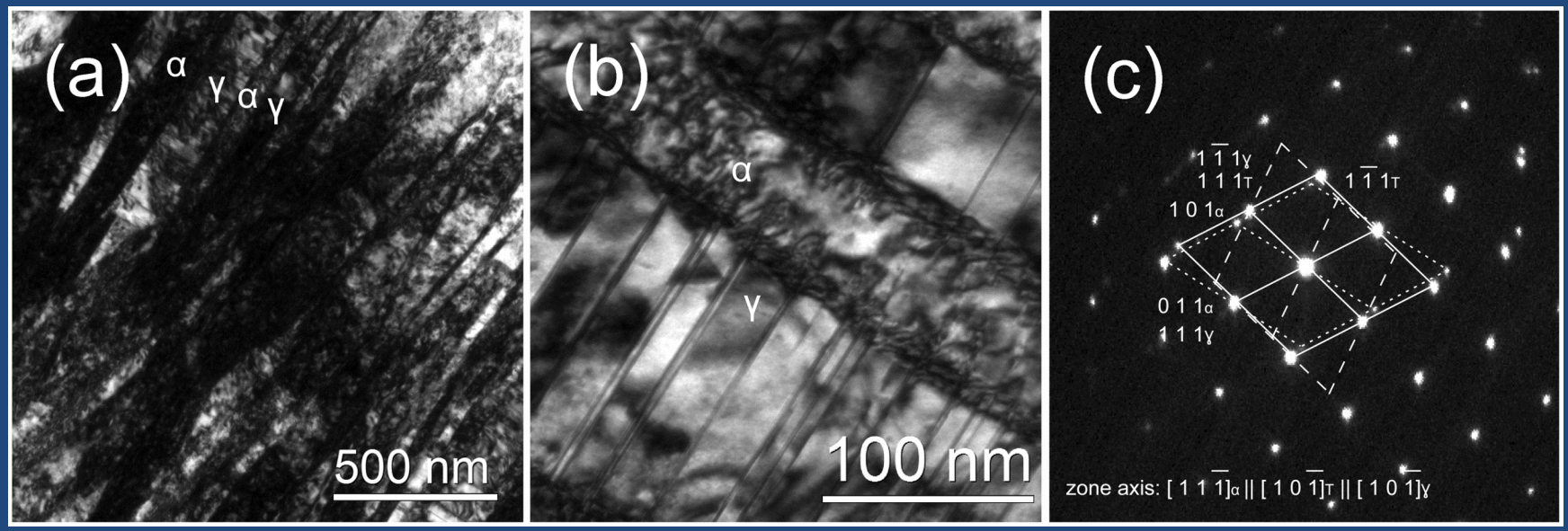


Nanoscale Twins Induced by Bainitic Transformation

- The nanoscale twins can be obtained from an Fe-0.8C-2.0Si-1.5Mn-1.0Cr-0.2Mo-0.1V (wt%) alloy isothermally heat treated at 200^{o}C.

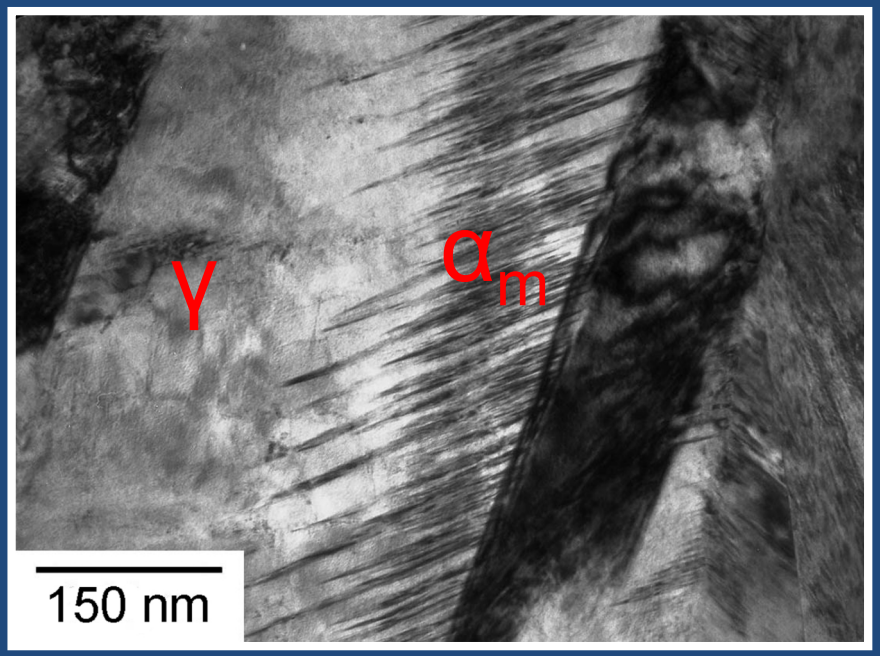


Nanoscale Twins between Nano Bainite

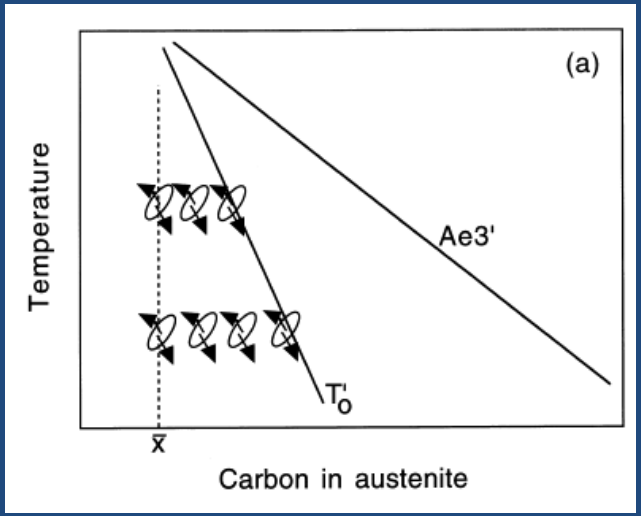


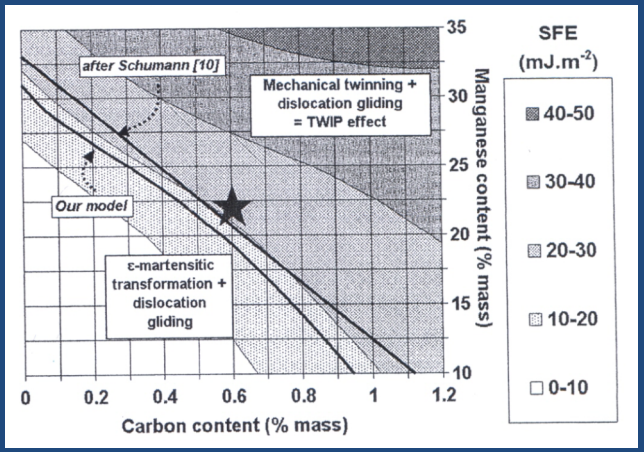
- TEM micrographs in an Fe-0.8C-2.0Si-1.5Mn-1.0Cr-0.2Mo-0.1V (wt%) steel isothermally heat treated at 200°C for 10 days.

Effect of carbon content



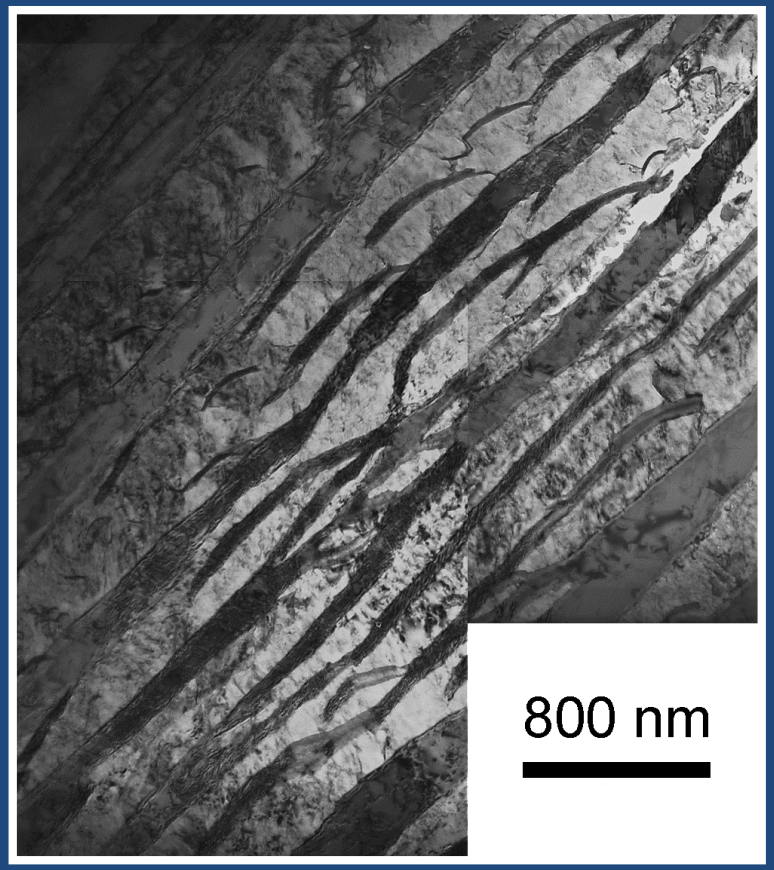
TEM micrograph of lenticular martensite in an Fe-0.8C-2.0Si-1.5Mn-1.2Cr-0.3Mo-0.1V (in wt%) steel isothermally heat treated at 200°C for 2 days after austenization.



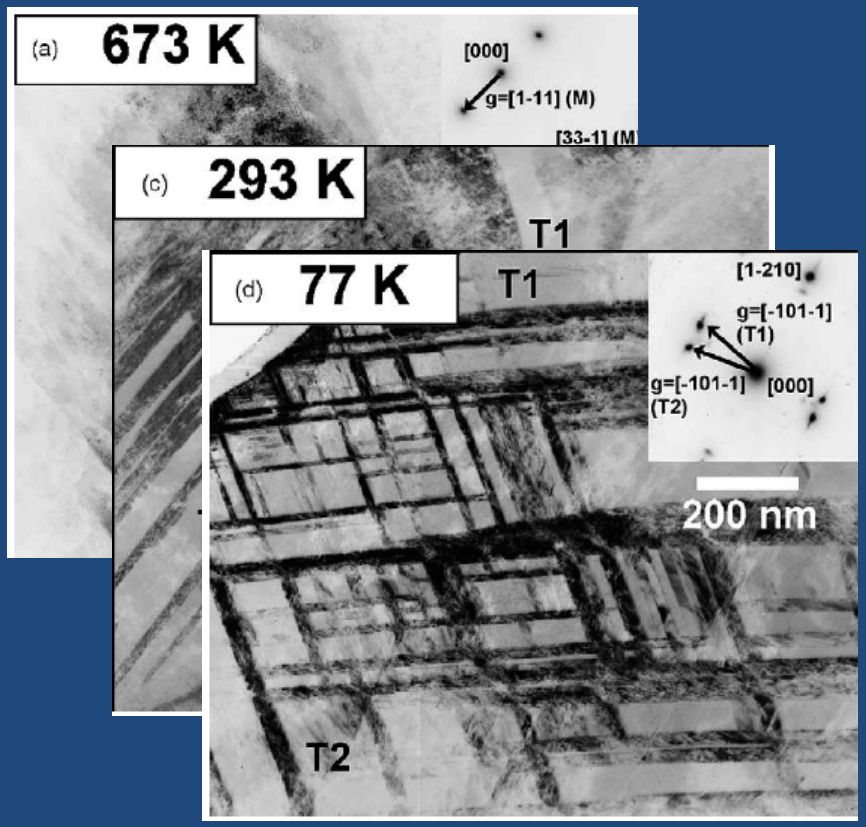


C. Scott, S. Allain, M. Faral and N. Guelton, La Revue de Metallurgie-CIT. p293 (2006).

Effect of Temperature

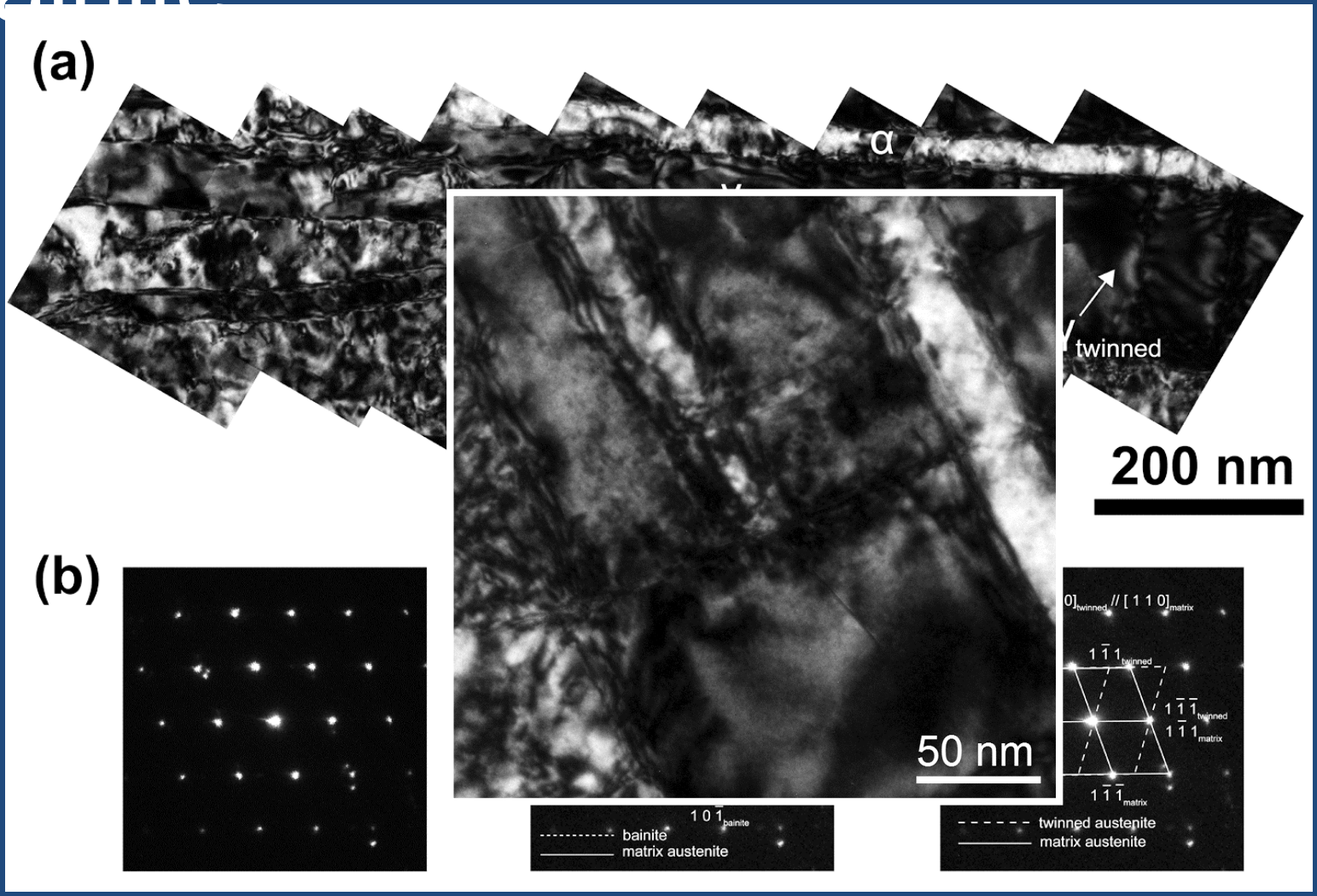


TEM micrograph of bainite in an Fe-0.8C-2.0Si-1.5Mn-1.2Cr-0.3Mo-0.1V (in wt%) steel isothermally heat treated at 300°C for 8 hours after austenization.



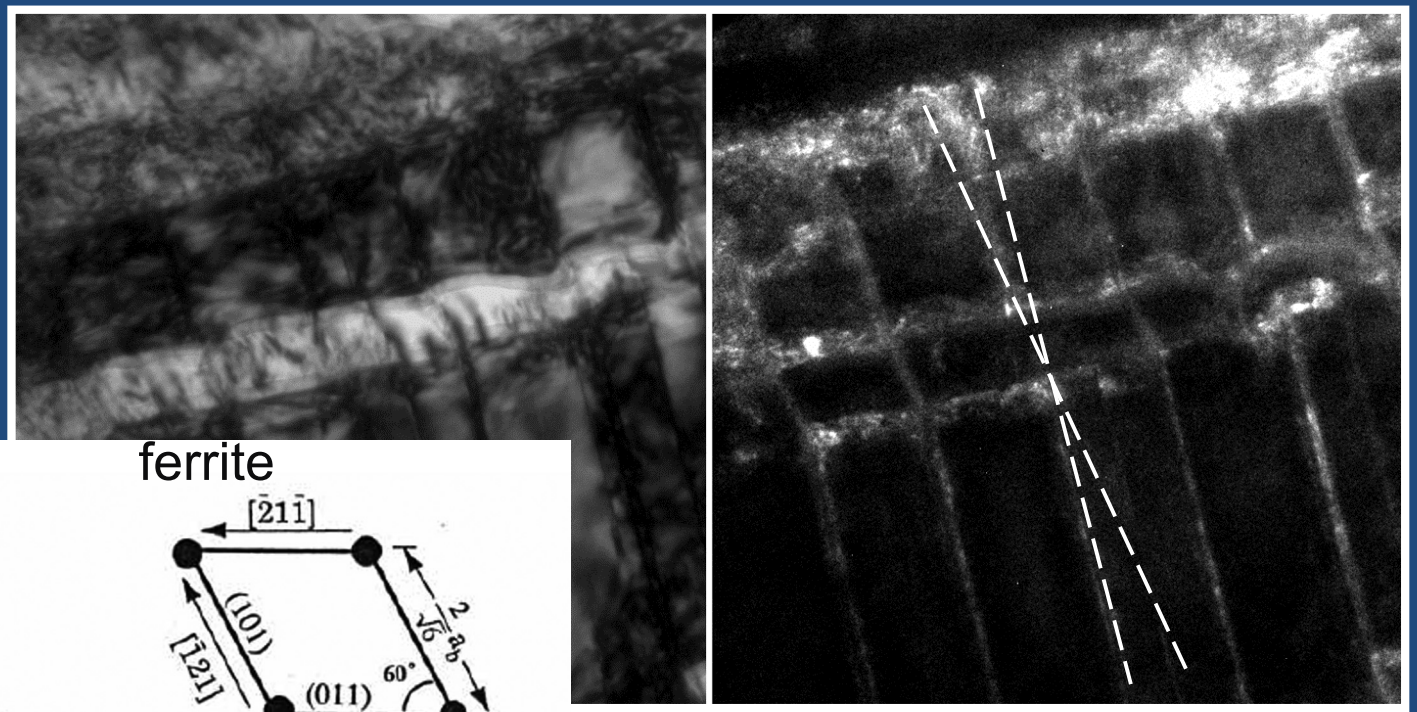
Temperature effect on deformed structure in an Fe-22Mn-0.6C (wt%) alloy.

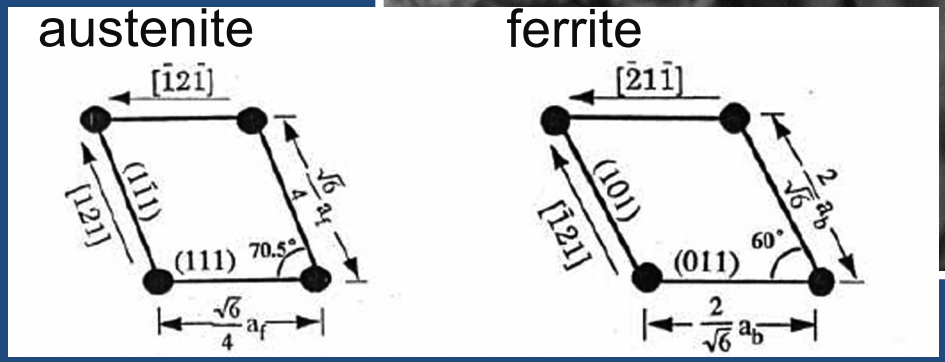
The Microstructure of Nano Bainite



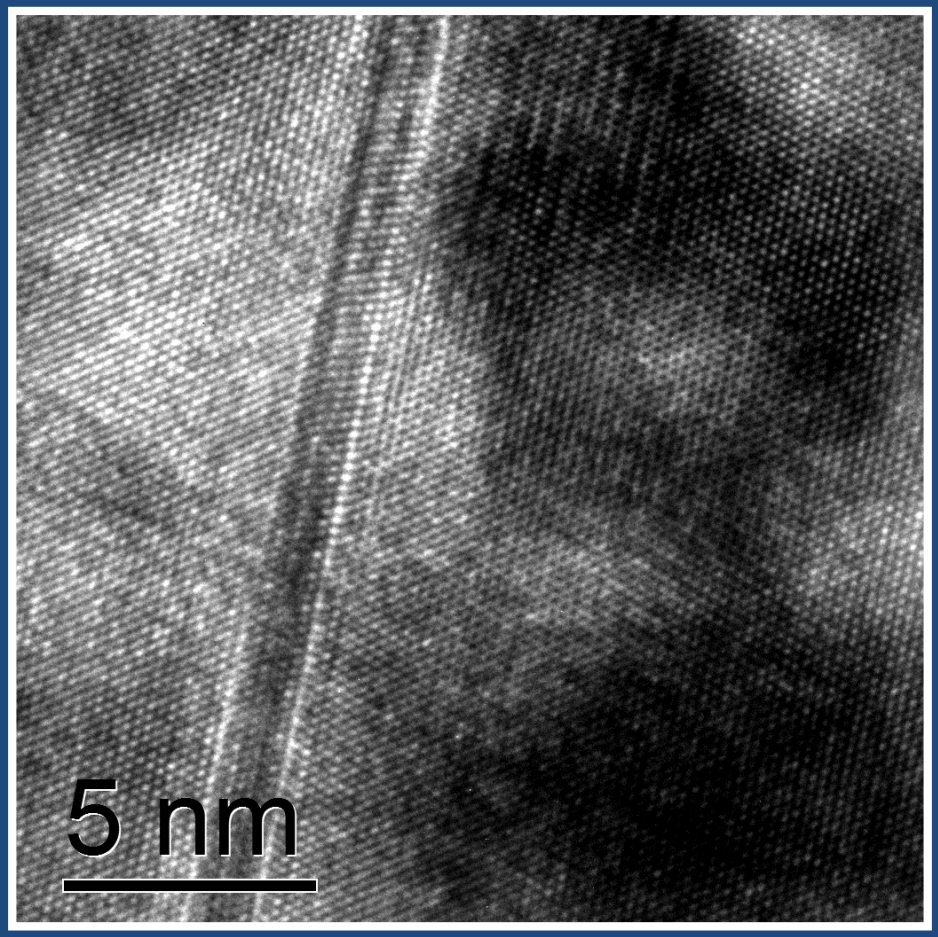
The Microstructure of Nano Bainite

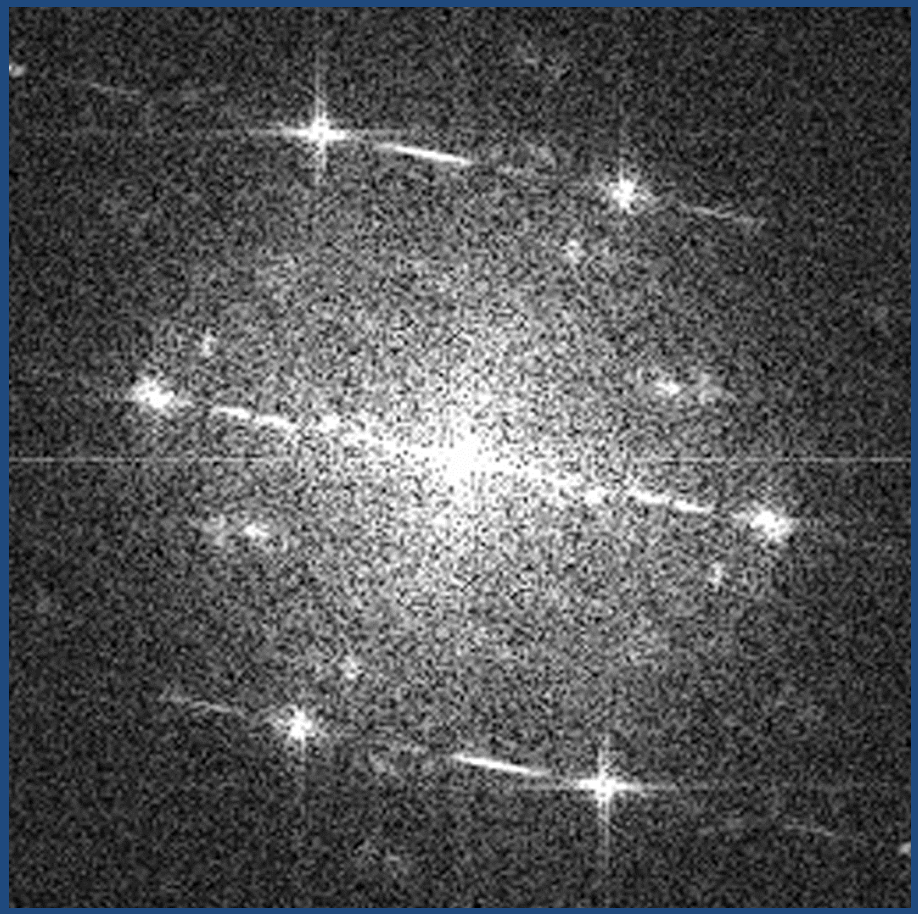
- The induced nanoscale twins could be bent by latter transformaed bainite due to the transformation strain.



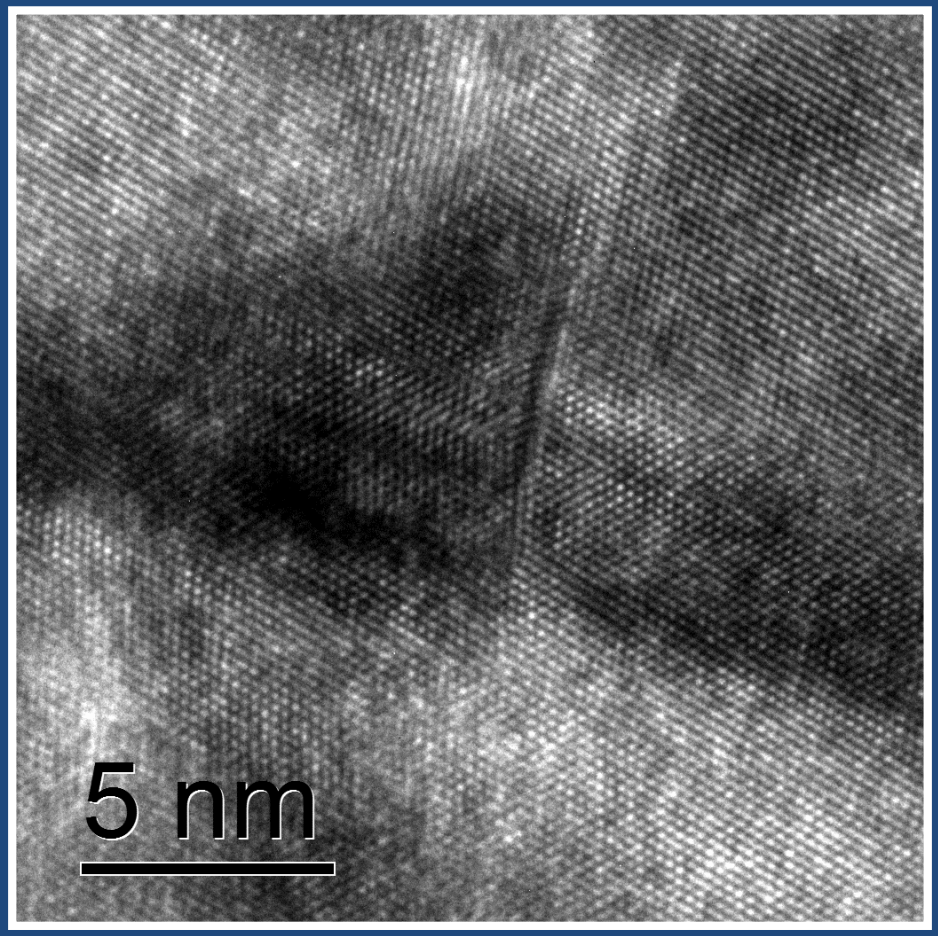


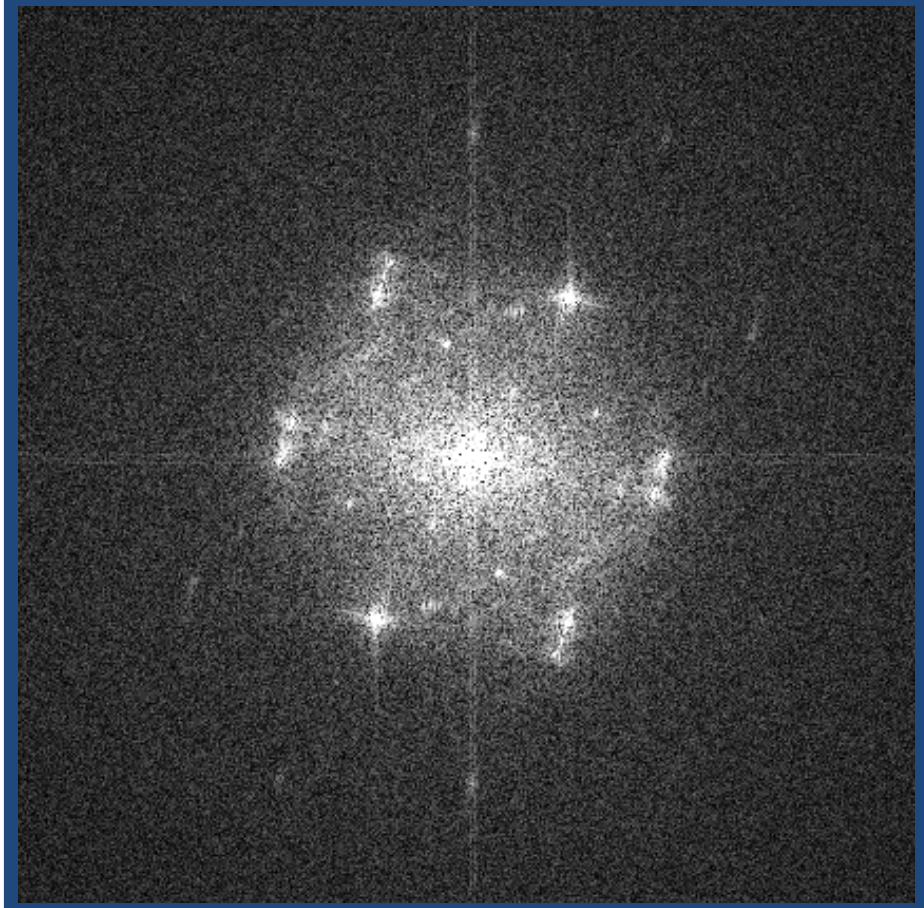
HRTEM Image of Nano Twin



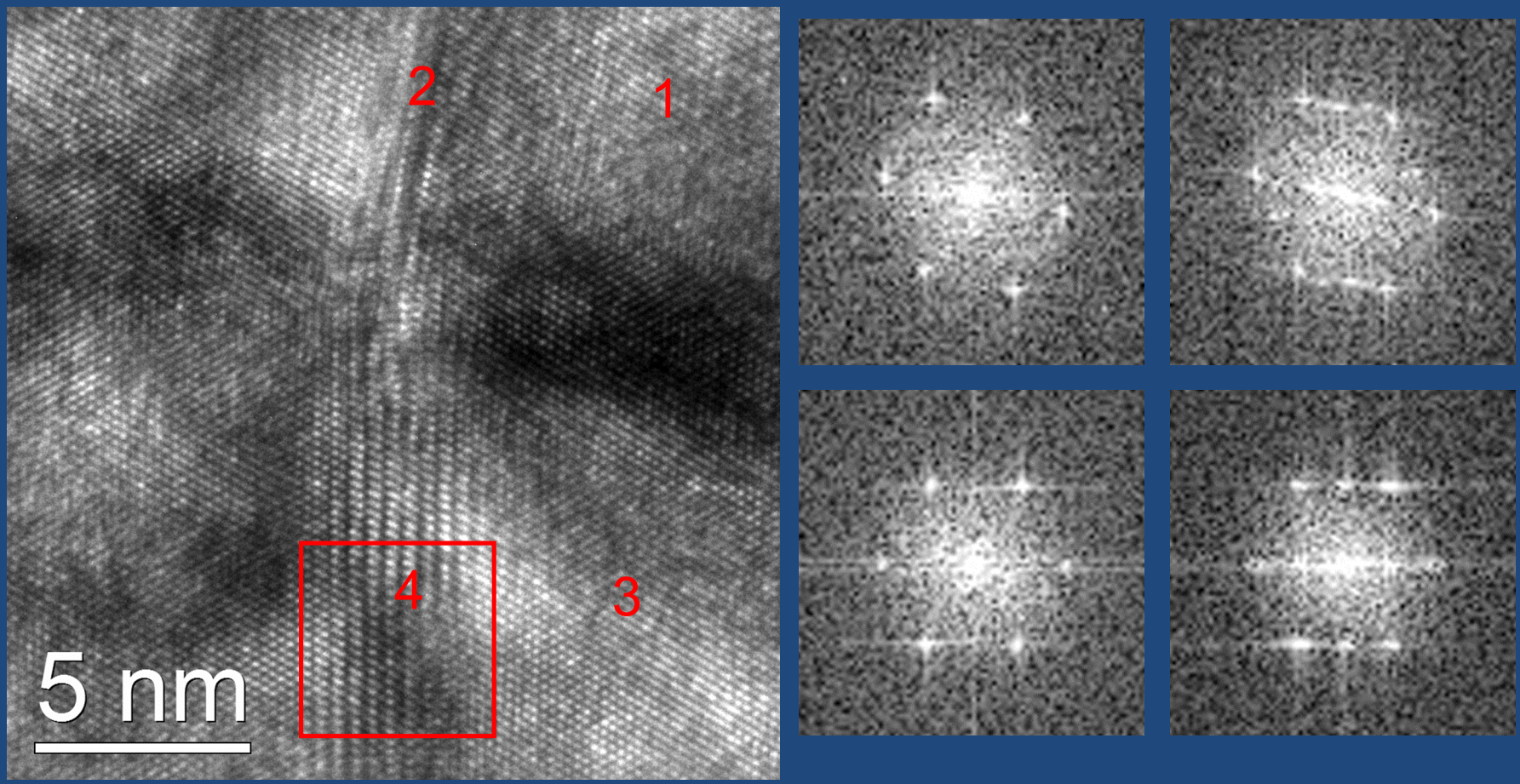


HRTEM Images of Nano Twin

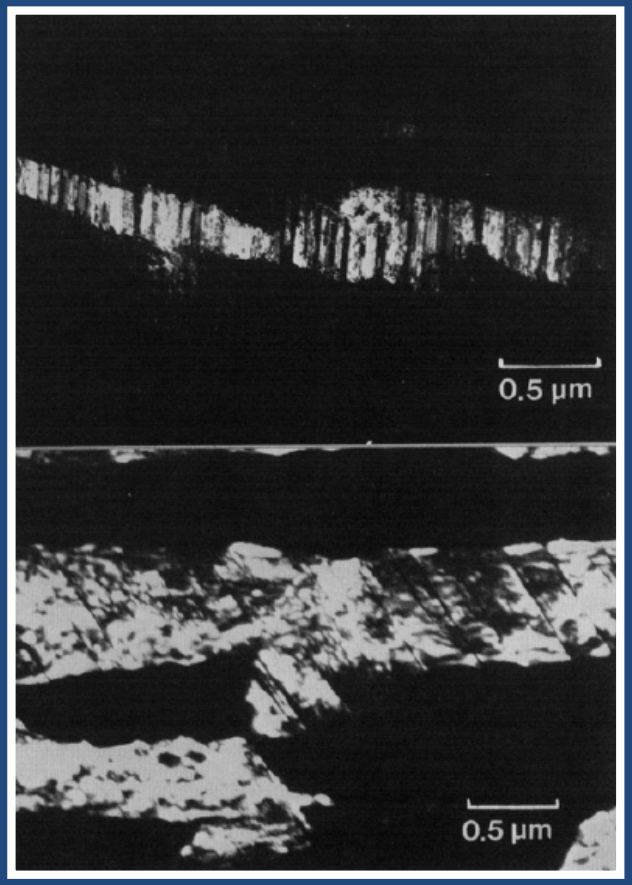




Bent Feature of Nano Twin

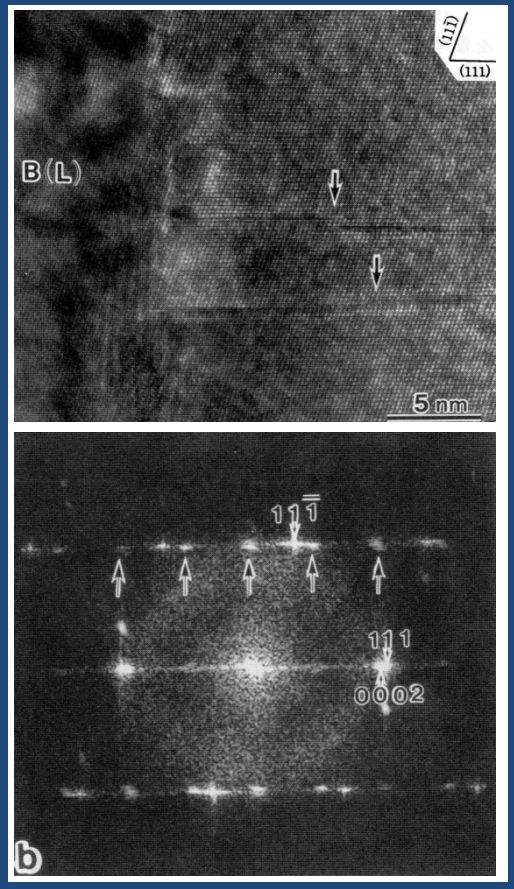


$(1\bar{1}1)[121]$ Defects



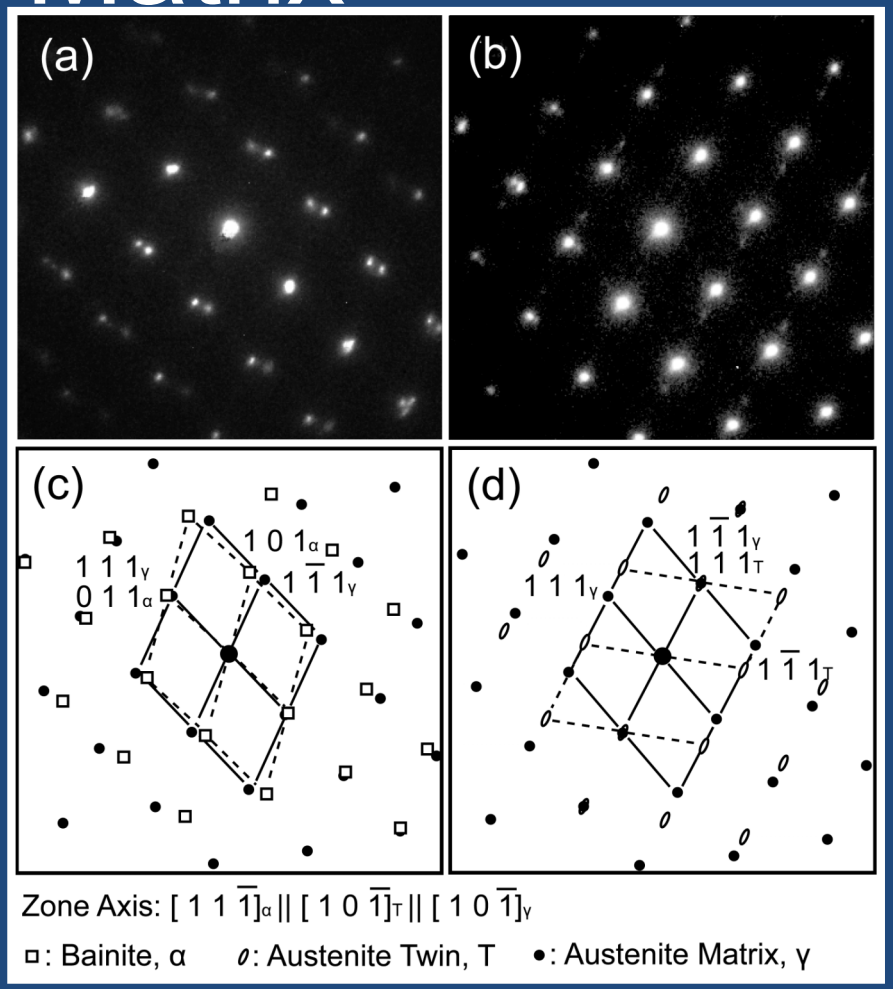
Slip steps
by Bhadeshia and Edmonds

Twins
by Sandvik and Wayman



Epsilon martensite
by Ogawa

The OR and Transformation Matrix



- Approximate K-S OR
  $a_\gamma / a_\alpha = 1.253$

$$(\alpha J\gamma) = \begin{matrix} 0.9289 & -0.8351 & -0.0938 \\ 0.8140 & 0.9289 & -0.2088 \\ 0.2088 & 0.0938 & 1.2315 \end{matrix}$$

$$(\alpha C\gamma) = (\alpha \quad \gamma)(\gamma \quad \gamma)^{-1}$$

$$(\gamma S\gamma) = \begin{matrix} 1.1108 & -0.0732 & 0.1330 \\ 0.0598 & 1.1242 & 0.0598 \\ -0.1929 & -0.0732 & 0.7849 \end{matrix}$$

Phenomenological Theory

$(\gamma_{SPQ})_{IB} = (\gamma \quad \gamma)(\gamma \quad \gamma) = (\gamma \quad \gamma)(\gamma \quad \gamma)$

The invariant line (-0.7544 0.0480 0.6547)

Twinning shear:

$1(1\bar{1}1)[2\ 1\ ]s = 2^{-1/2}$

However, the invariant line of (γS γ) doesn't lie on the $(1\ 1\ \bar{1})$. That means the twinning shear can not be the lattice invariant strain. In present case, the twinning accommodation was proposed to be resulted from the shape deformation.

Summary

- Nanoscale twins can be formed during the bainitic transformation at low temperature.
- The thickness of nanoscale twin is range from several atomic layer to 10nm.
- The features of nano twins could be the evidence that the transformation occurs by the displacive mechanism.
- The twins are induced by the displacive transformation due to the shape deformation.
- The occurrence of twinning relies on the carbon concentration in the austenite and the transformation temperature.

Acknowledgements

- Our gratitude goes first to Prof. Bhadeshia for providing the steels.
- We thank for tons of idea from Prof. Caballero and Prof. Garcia Mateo.
- The research funding is supported by National Science Council, Taiwan, ROC.

Thank you for your Attentions.

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