2018 Spring

"Advanced Physical Metallurgy"

- Bulk Metallic Glasses -

05.23.2018

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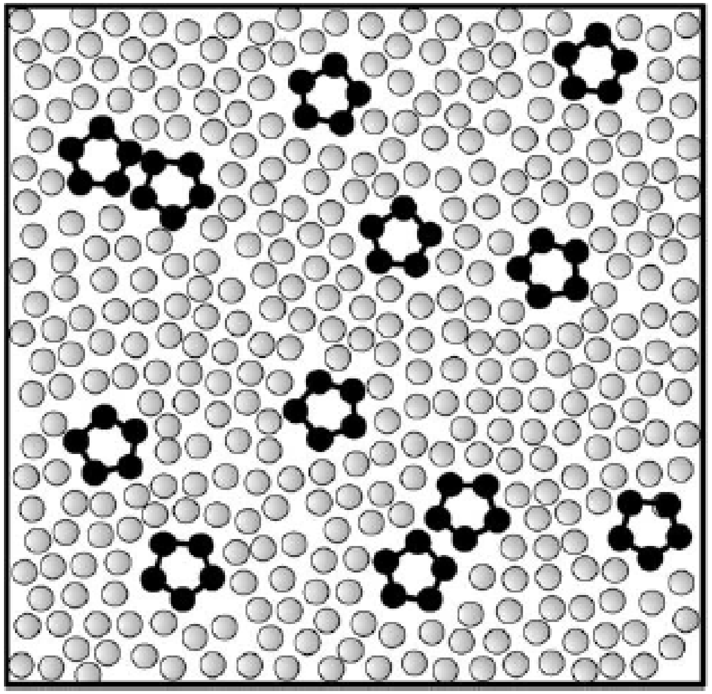
Effect of element with positive enthalpy of mixing among constituent elements

atomic scale heterogeneity



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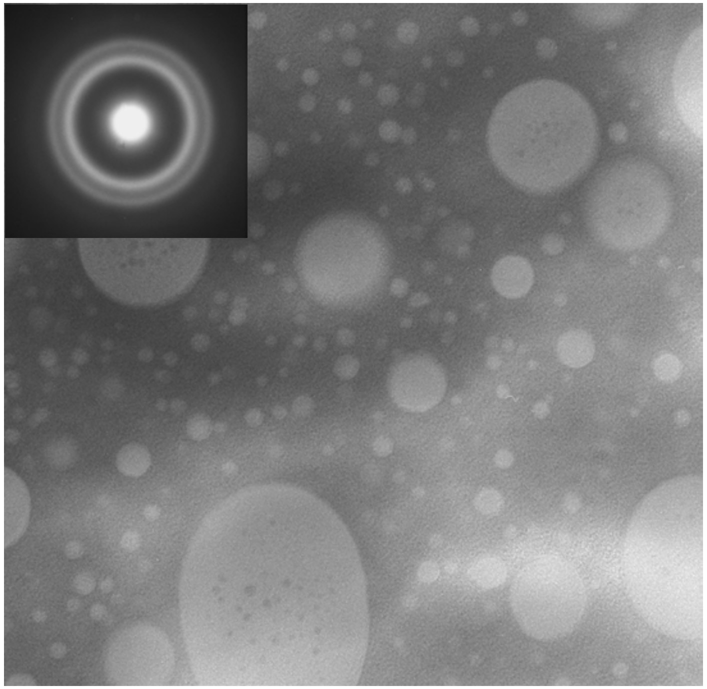
Enhancement of plasticity in BMGs

Phase separating metallic glasses



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Unique properties

Homework:

Summary (page 265 – page 360)

Chapter 6_Physical Properties & Chapter 7_Corrosion Behavior

density, thermal expansion,

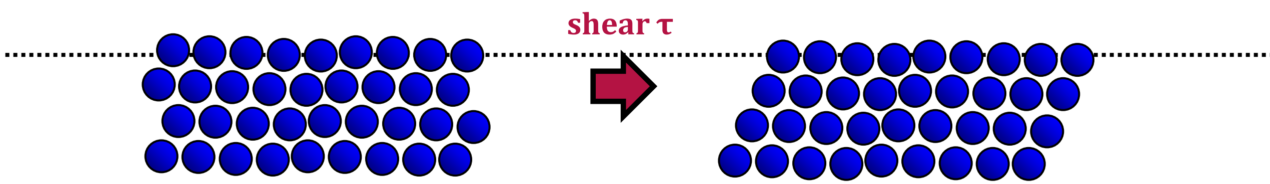
diffusion, electrical resistivity

specific heat, viscosity

You should submit your summary until 11 June. ☺

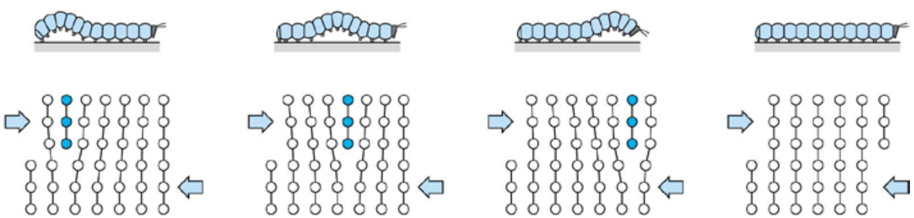
Deformation behavior: crystalline VS. amorphous

Crystalline

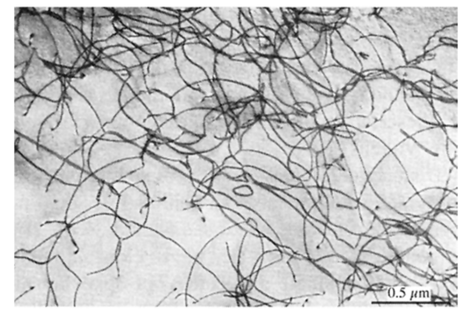


ordered structure

constant volume



Dislocation motion in crystalline metal



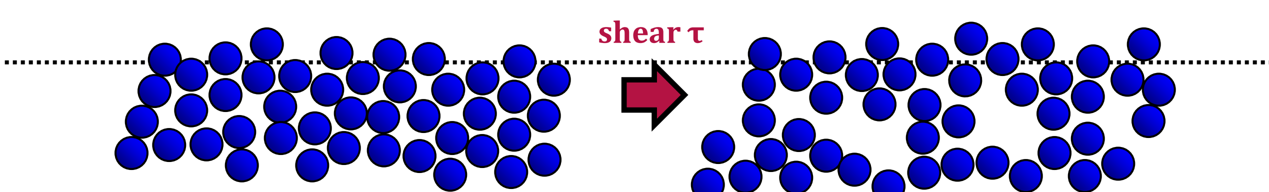
Dislocations

- "Incrementally breaking bonds"
- Has relatively low strength, performs work hardening
- Slip plane + Slip direction = Slip system
  (preferred crystallographic planes and directions)

Amorphous metal do not have slip system.

How to deform ?

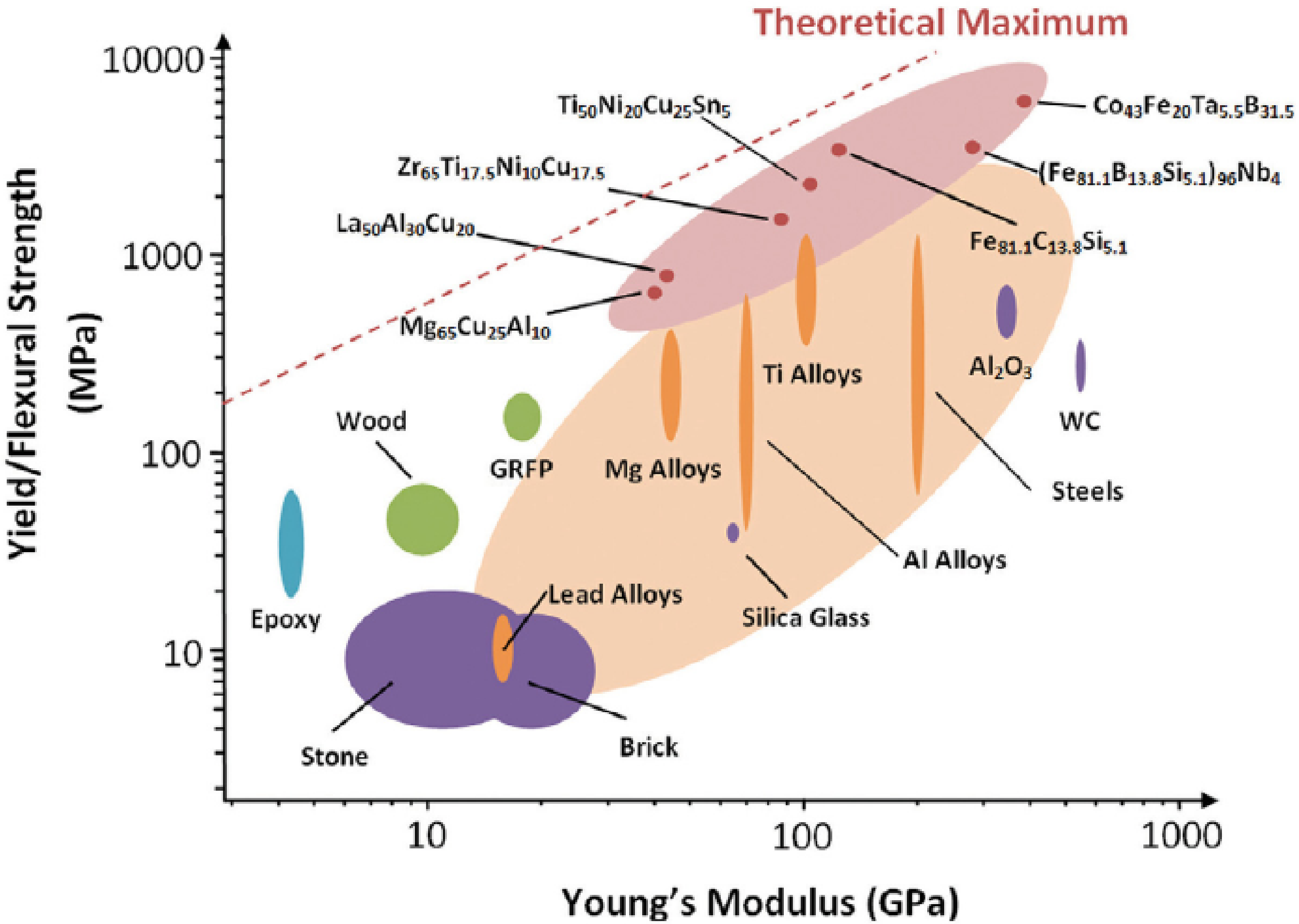
Amorphous



random structure

increase free volume (dilatation)

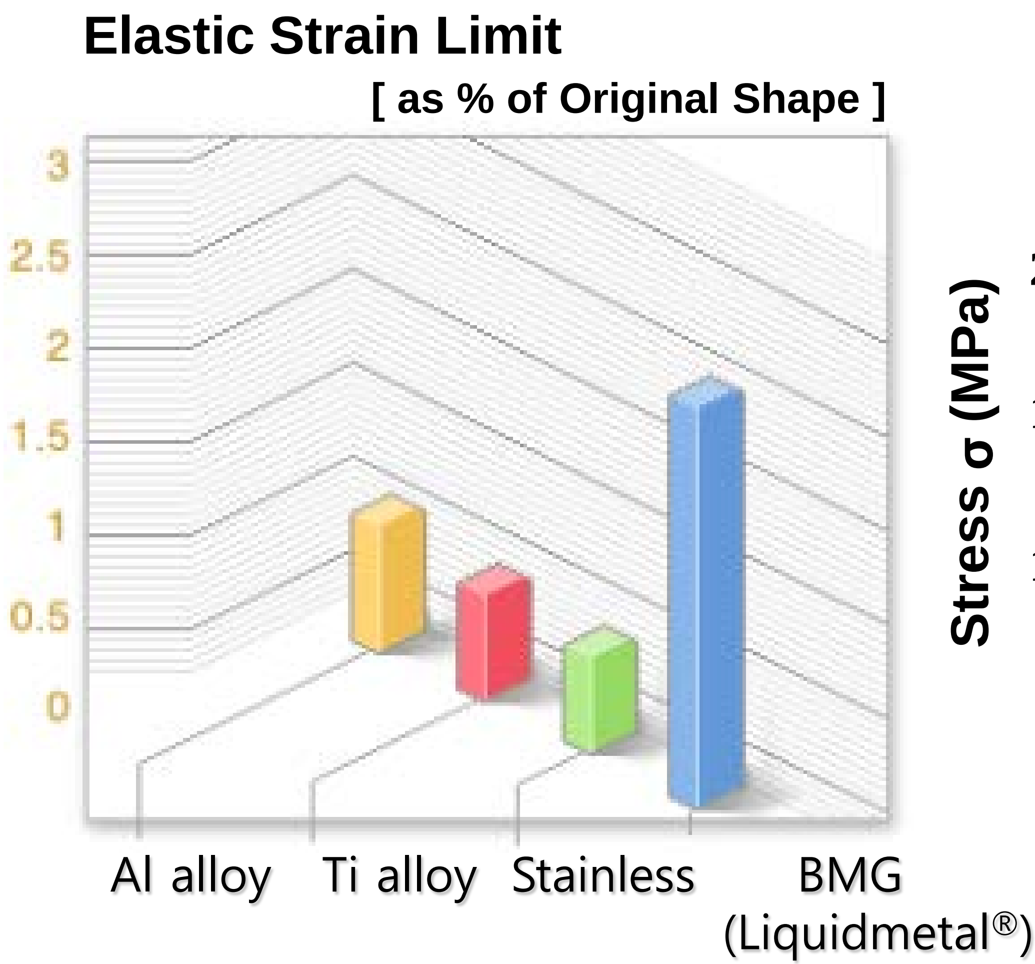
a) High strength of Bulk Metallic Glasses

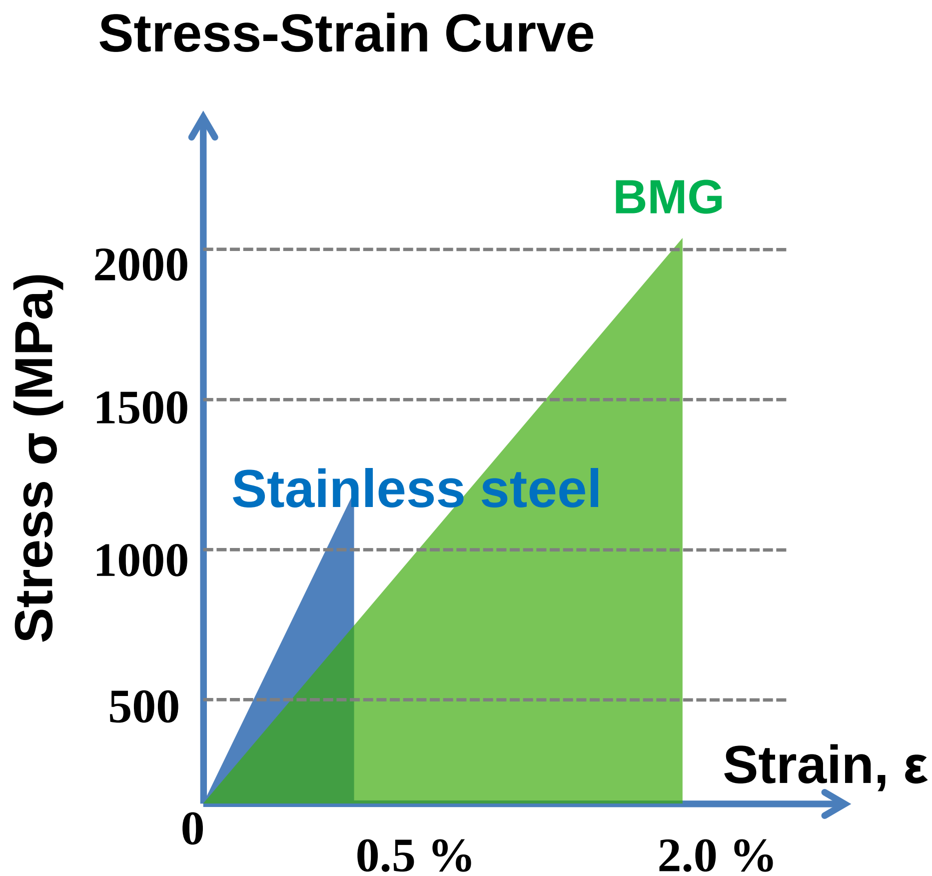


High fracture strength over 5 GPa in Fe-based BMGs

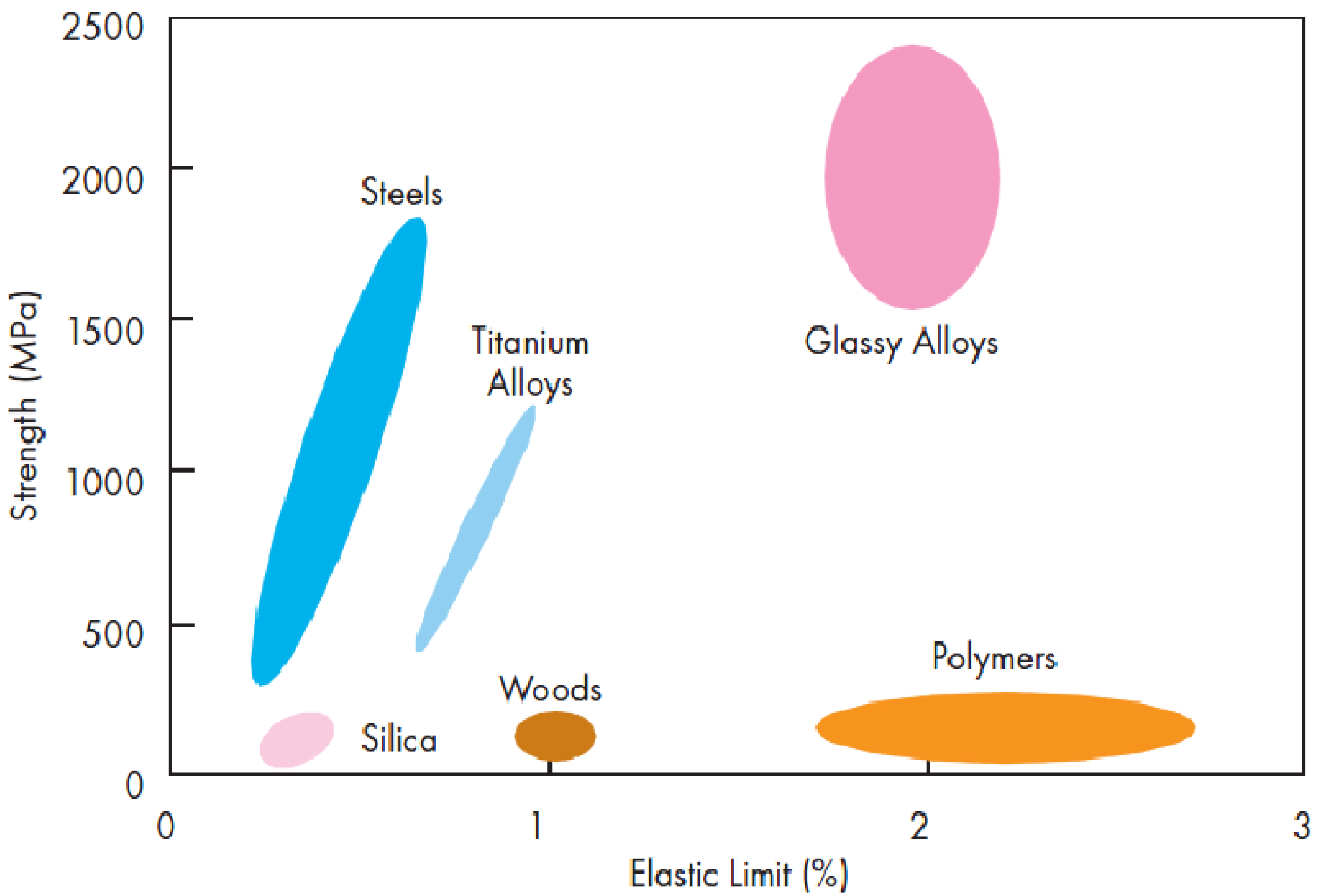
A.L. Greer, E. Ma, MRS Bulletin, 2007; 32: 612.

2) Large elastic strain limit of BMGs



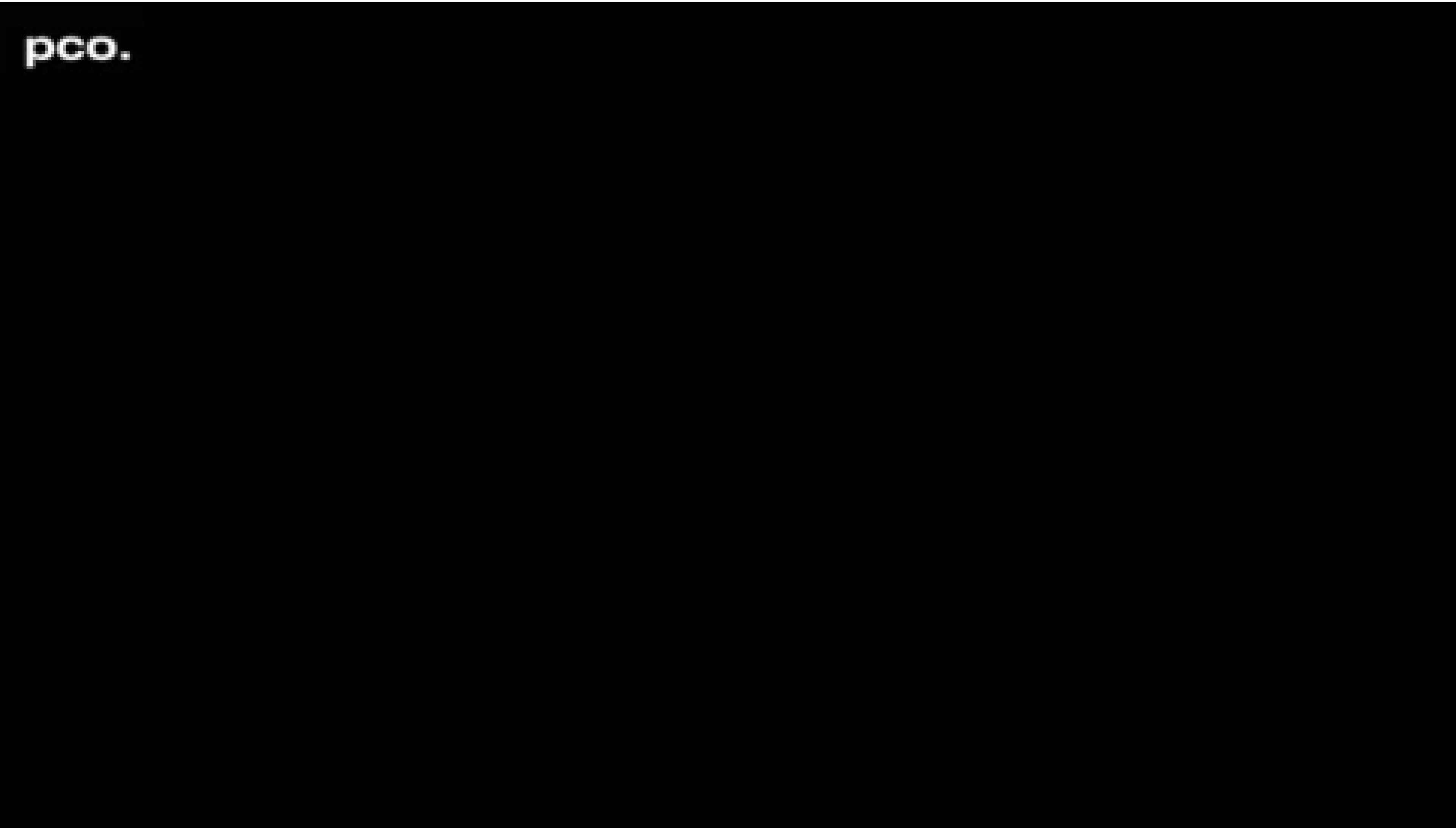


* BMGs with high strength & high elastic limit



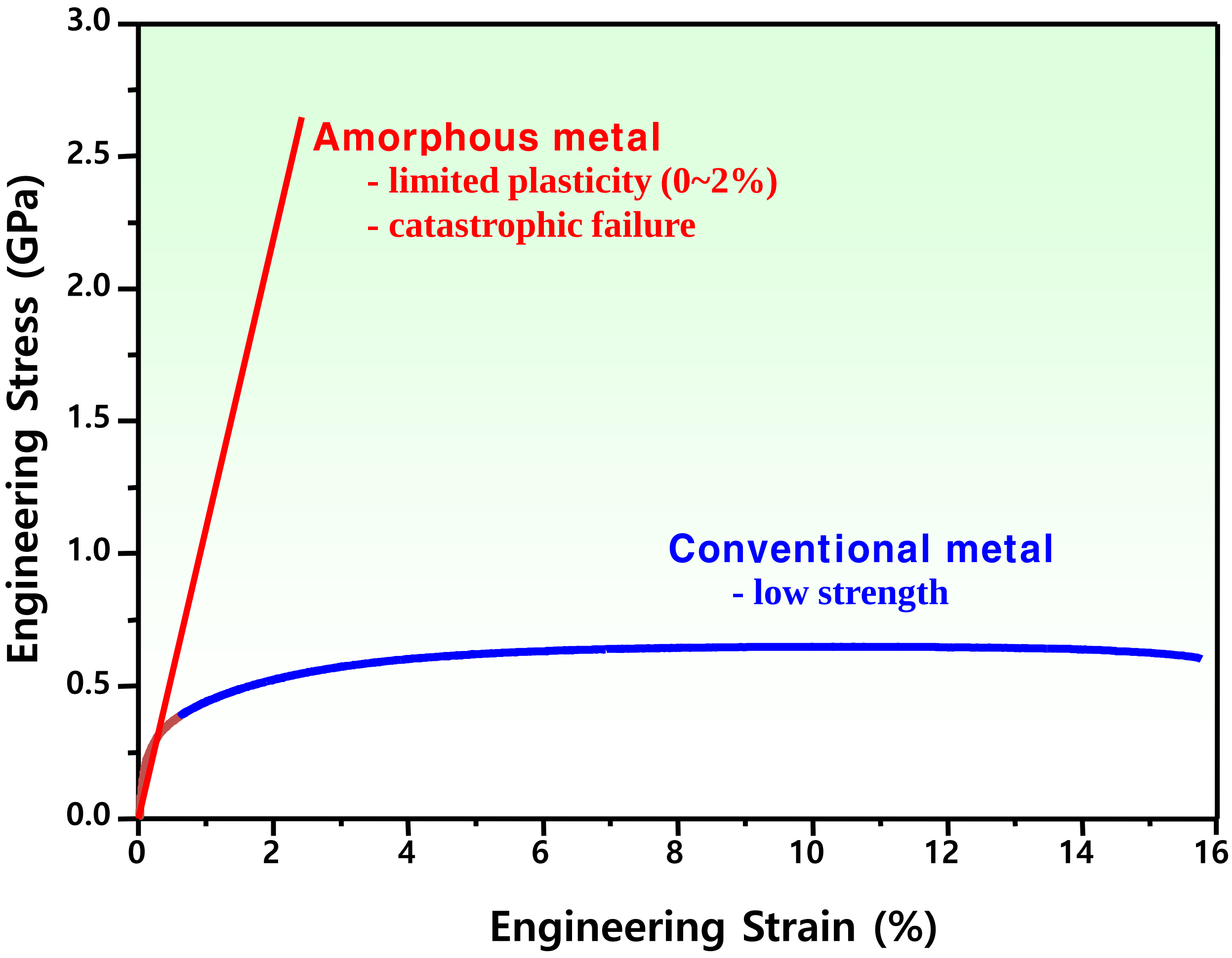
: Metallic Glasses Offer a Unique Combination of High Strength and High Elastic Limit

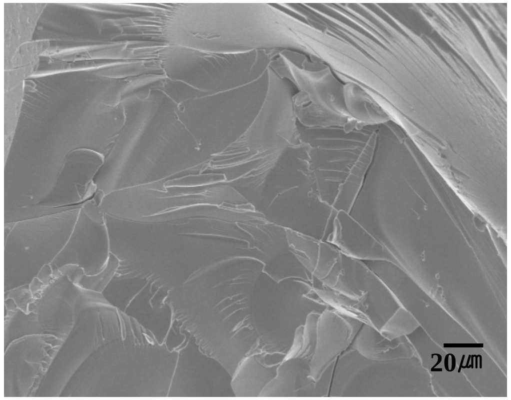
Drawback of BMGs as a Structural Materials

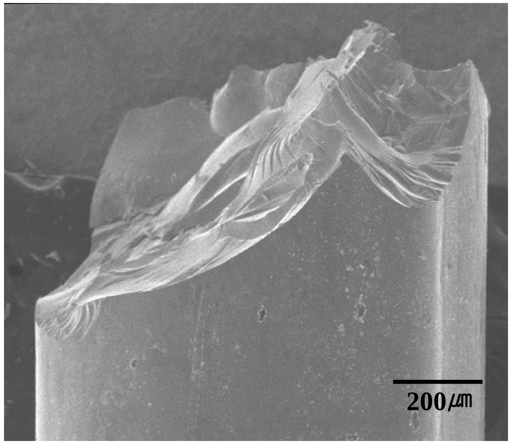


Limited plasticity by shear softening and shear band

- Microscopically brittle fracture
  - ➡ Death of a material for structural applications







8.2 Deformation Behavior

Deformation behavior of Metallic glass

8.2.2 Homogeneous Deformation

- high temp. (>0.7T_g) and in the SCLR/ high strain rate
- Viscous flow → significant plasticity

  : achieve net-shape forming capability
- Newtonian (high temp. & low stress) vs non-Newtonian (high temp. & applied stress) : associated with the precipitation of nanocrystals

⇩

Homogeneous deformation

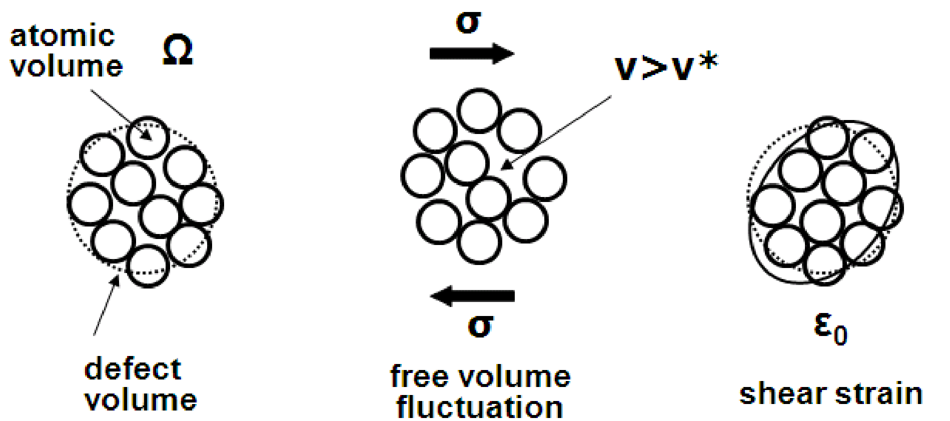
8.2.1 Inhomogeneous Deformation

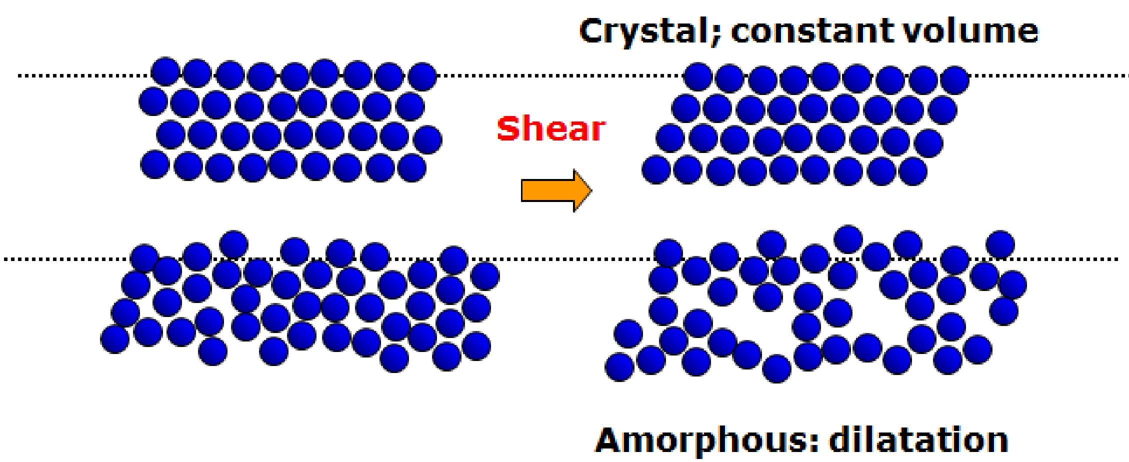
- Low temp. (<0.5T_g)/ high stress
- Localized shear band/ 45° to the loading axis
- Strain softening: deformed at lower stress and higher rate

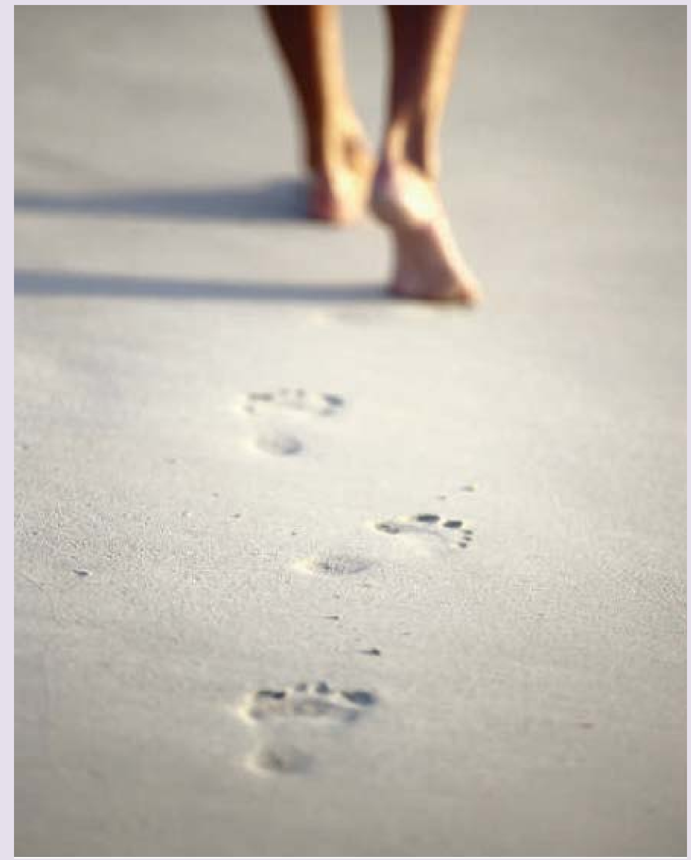
⇩

Catastrophically Failure

Elementary flow events in metallic glasses







Footprints in sand.
Water quickly disappears underneath

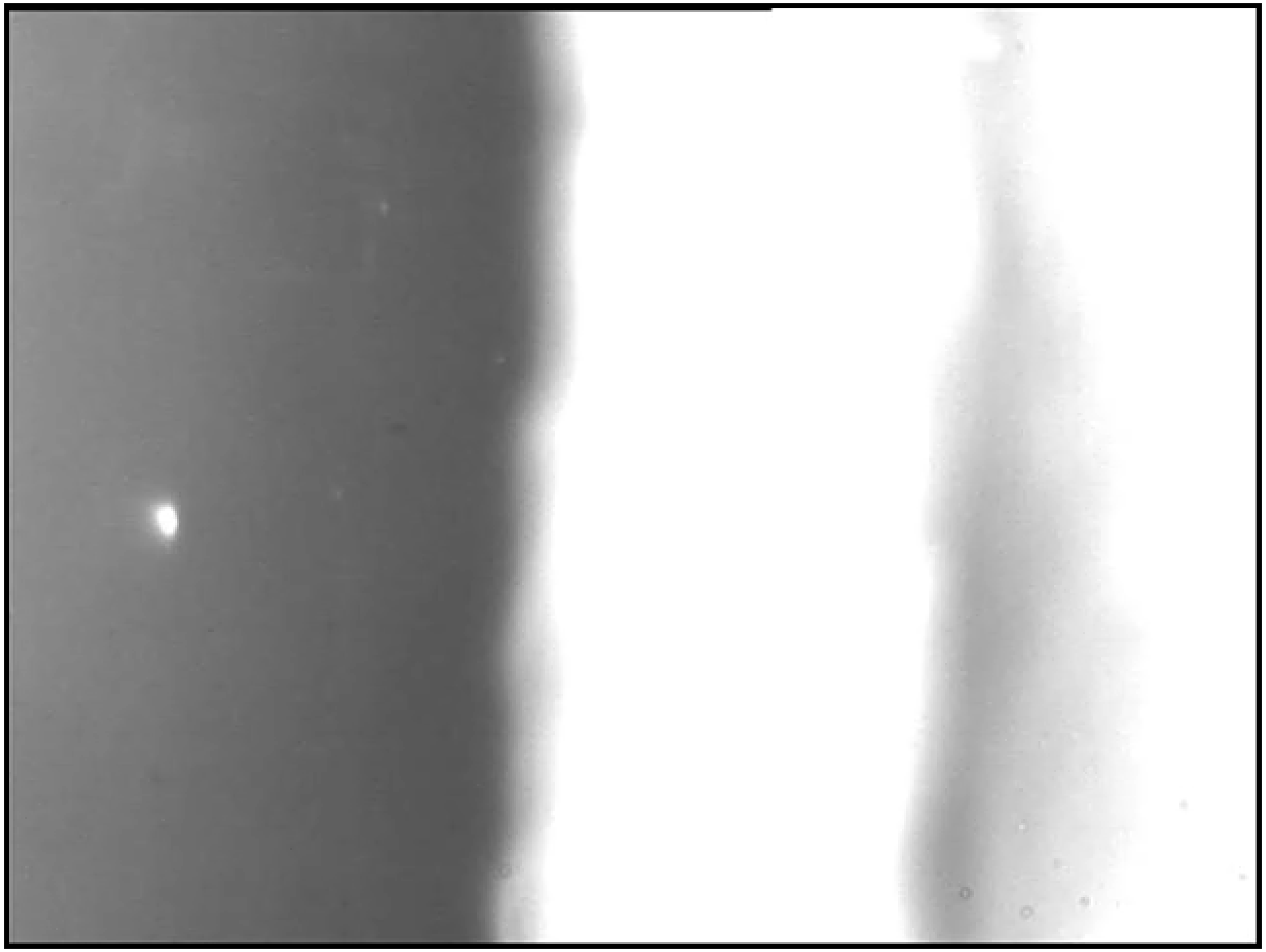
Shear bands form by accumulation of defects during deformation.

nature materials | VOL 5 | JANUARY 2006 | www.nature.com/naturematerials

Effect of local favored structure on SB nucleation

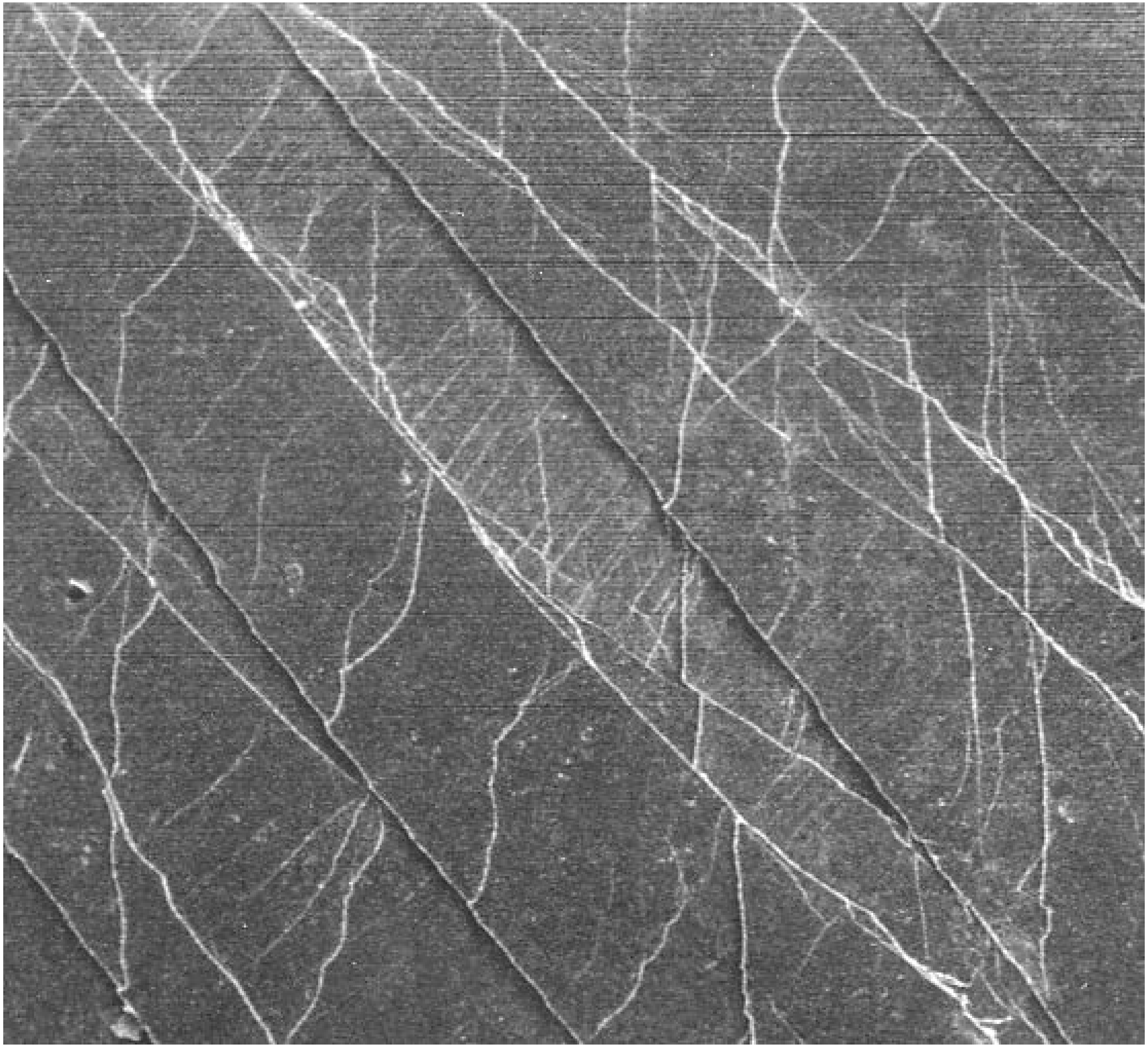
- $Ni_{60}Nb_{40}$: fully amorphous phase

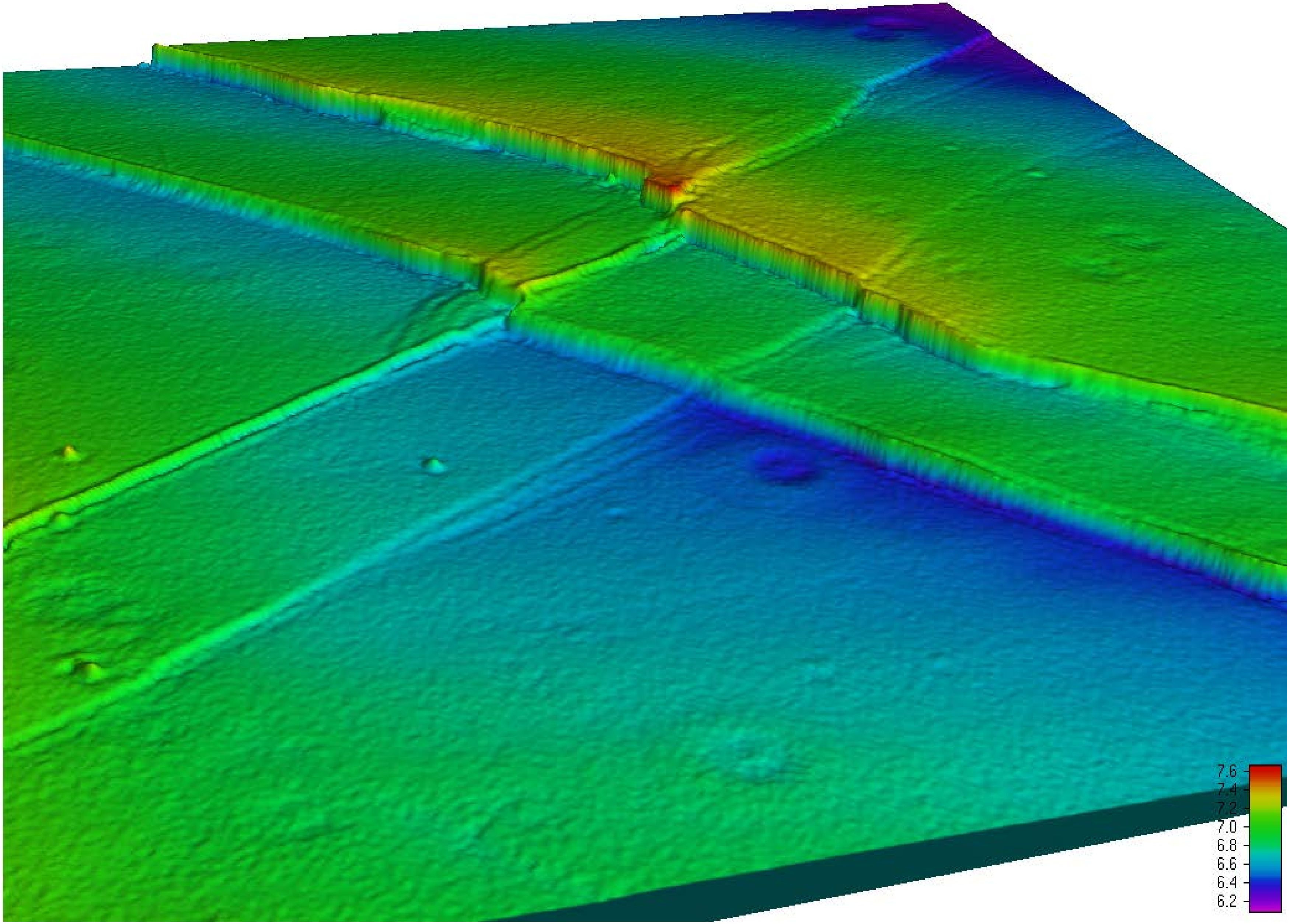
S=0.016 mm/sec



100 μm

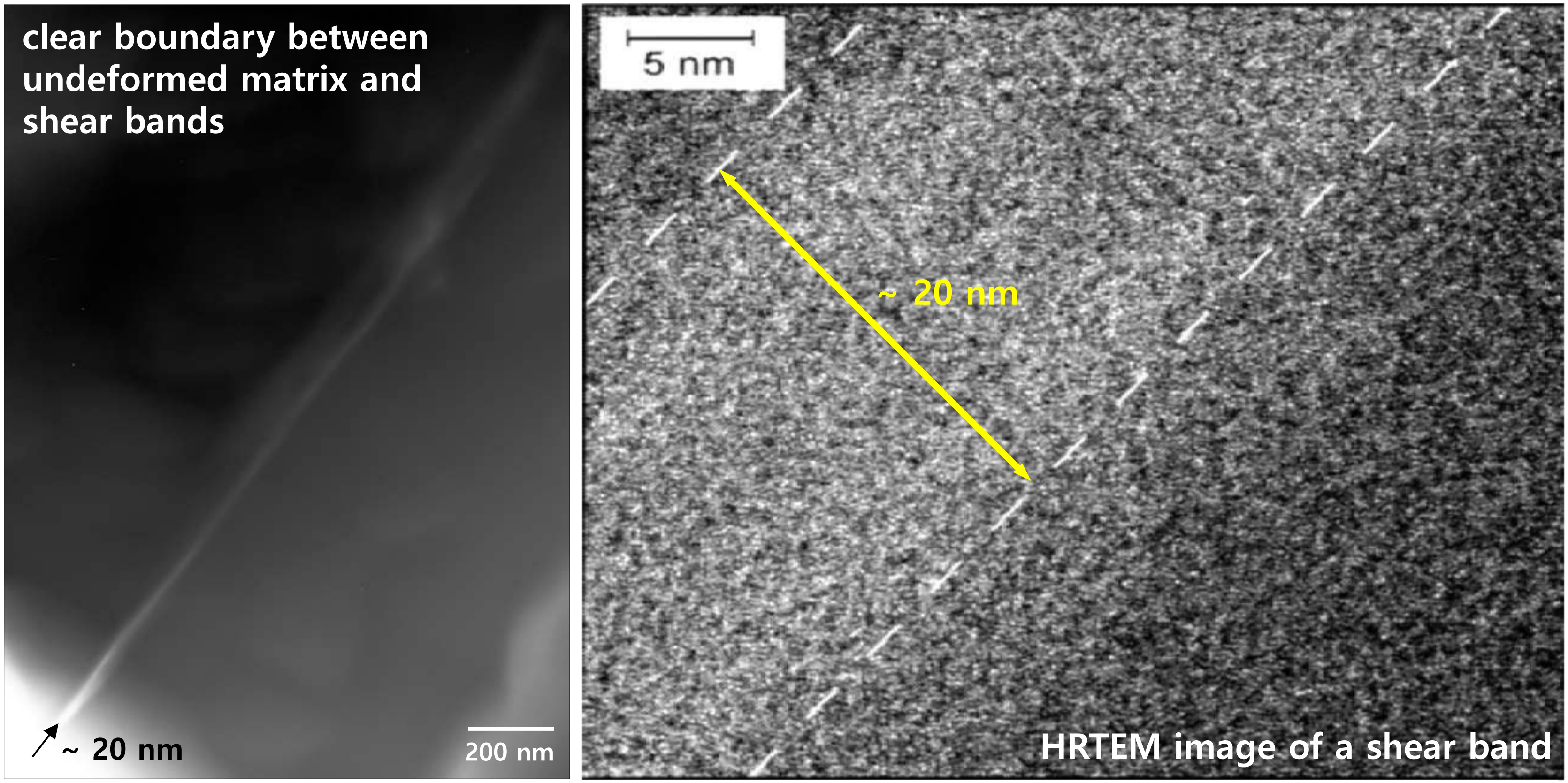
Formation of multiple shear bands during deformation




7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2

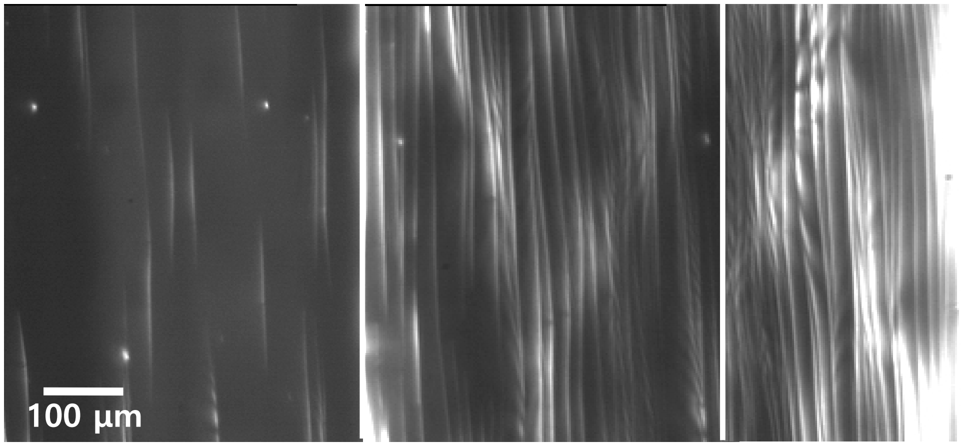
Formation of shear bands : variation of free volume

Shear bands form by accumulation of defects during deformation.

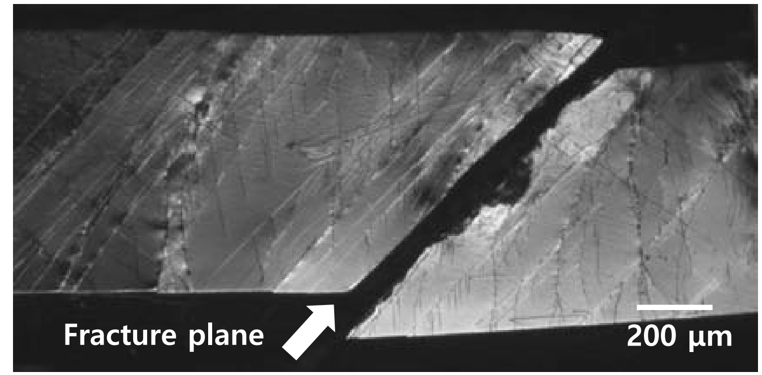


Shear deformed areas with the same composition & different density of free volume

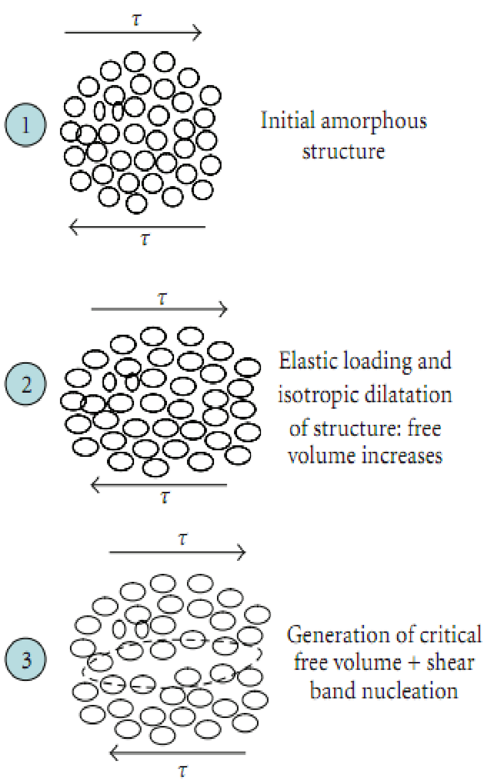
Shear band nucleation and propagation: strain softening



Shear band formation and propagation in the ribbon bending test



Formation of multiple shear bands in an $Ni_{50}Pd_{30}P_{20}$ BMG specimen subjected to compression testing.
K. Wang et al. / *Acta Mater.* ***56*** *(2008)* 2834.



Plastic deformation of metallic glass

controlled by shear band behavior **Nucleation & Propagation**

Excess volume → **Connect to form a shear band**

Plastic strain localized into these shear bands ▶ **Catastrophic failure**

Elastic energy rises local temperature

Decrease in the viscosity → **Shear softening**

Enhancement of ductility ····· **Increase of the shear band density**

SB nucleation and propagation : Multiple serrations, observed only at slow strain rates → temperature rise

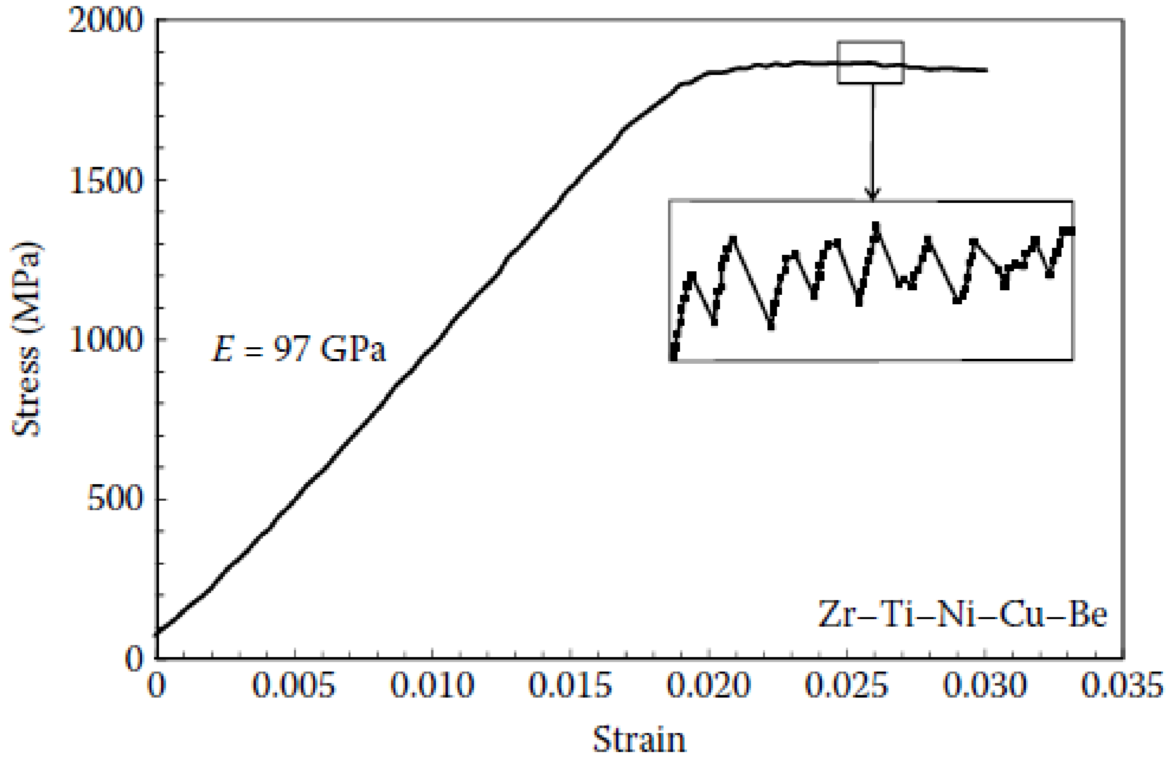


FIGURE 8.1
Compressive stress–strain curve for $Zr_{40}Ti_{14}Ni_{10}Cu_{12}Be_{24}$ BMG alloy tested at a strain rate of $1 \times 10^{-4}\,s^{-1}$. (Reprinted from Wright, W.J. et al., *Mater. Trans.*, 42, 642, 2001. With permission.)

SB nucleation and propagation : Multiple serrations
→ temperature rise

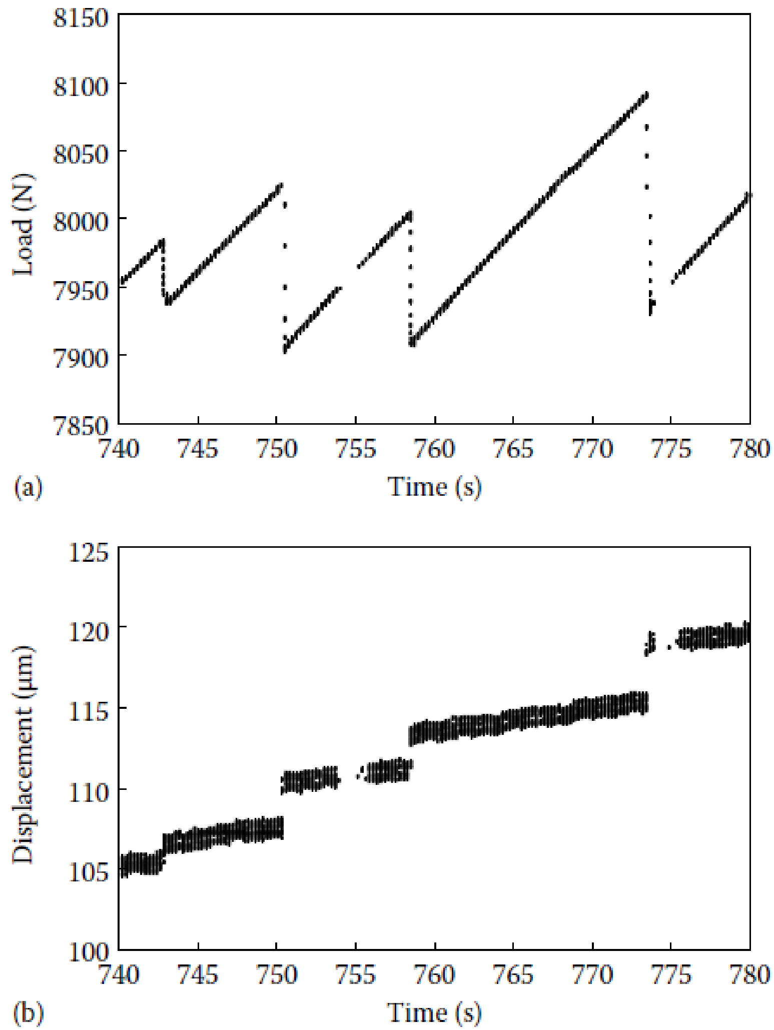


FIGURE 8.2
(a) Load as a function of time and (b) total displacement as a function of time in the serrated flow region of the $Zr_{40}Ti_{14}Ni_{10}Cu_{12}Be_{24}$ BMG alloy tested in uniaxial compression. (Reprinted from Wright, W.J. et al., *Mater. Trans.*, 42, 642, 2001. With permission.)

Serrated flow is also observed during nano-indentation,

but only at "slow loading rates". Activation of each individual shear band is associated with the occurrence of a discrete "pop-in" event (sudden rise in load).

High loading rate → multiple shear bands → smooth load-displacement curve

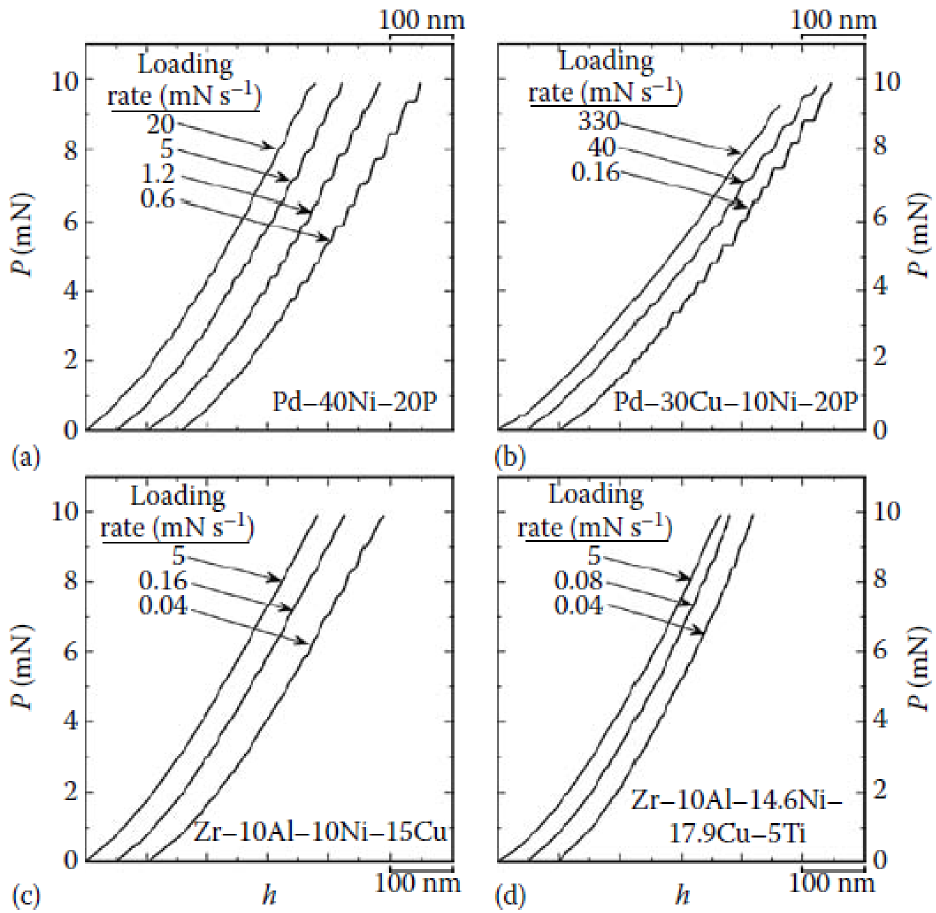


FIGURE 8.3
Typical load–displacement (*P*–*h*) curves measured on the loading portion of nanoindentation experiments, for four different BMGs investigated. (a) $Pd_{40}Ni_{40}P_{20}$, (b) $Pd_{40}Cu_{30}Ni_{10}P_{20}$, (c) $Zr_{65}Al_{10}Ni_{10}Cu_{15}$, and (d) $Zr_{52.5}Al_{10}Ni_{14.6}Cu_{17.9}Ti_5$. Curves are offset from the origin for clear viewing, and the rate of indentation loading is specified in each graph. (Reprinted from Schuh, C.A. and Nieh, T.G., *Acta Mater.*, 51, 87, 2003. With permission.)

8.4 Temperature rise at shear bands

Most of the plastic strain is localized in narrow shear bands, which form approximately on the planes of maximum resolved shear stress. The inhomogeneous flow in metallic glasses appears to be related to a local decrease in the viscosity in shear bands. One of the reasons suggested for this was the local adiabatic heating that could lead to a substantial increase in the temperature.

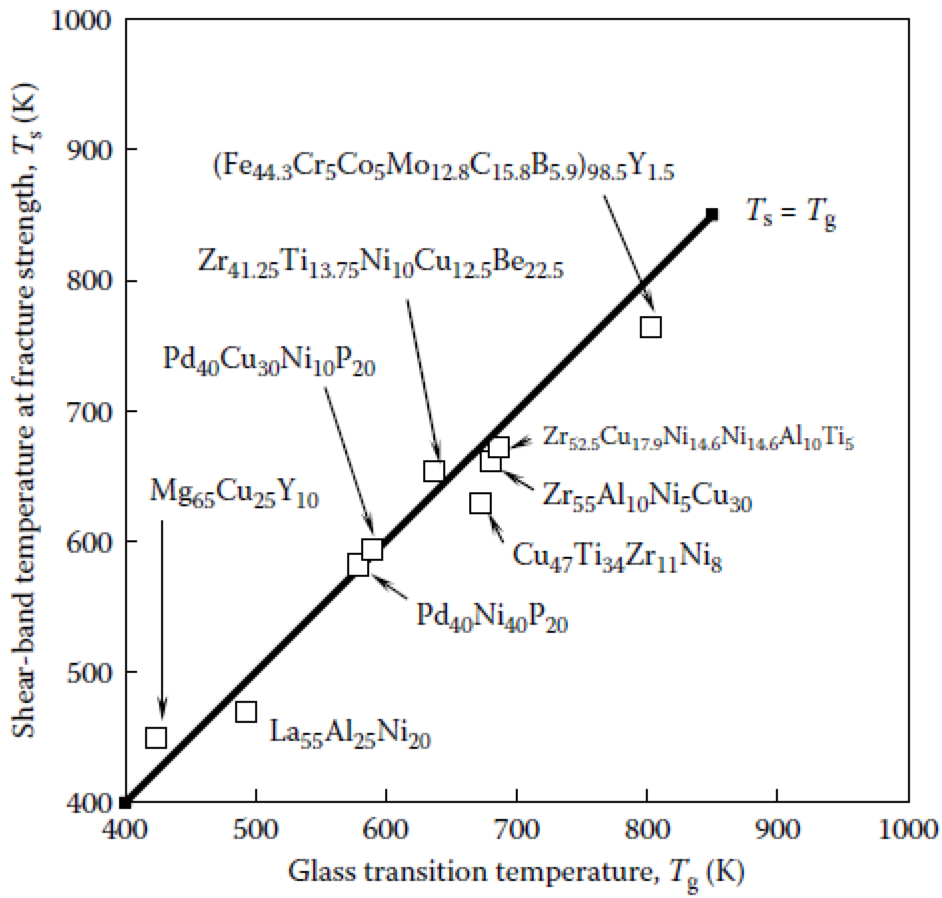


FIGURE 8.8
Temperature rise, ΔT in the shear bands at the time of fracture for different BMG alloys plotted against the glass transition temperature, T_g. (Reprinted from Yang, B. et al., *J. Mater. Res.*, 21, 915, 2006. With permission.)

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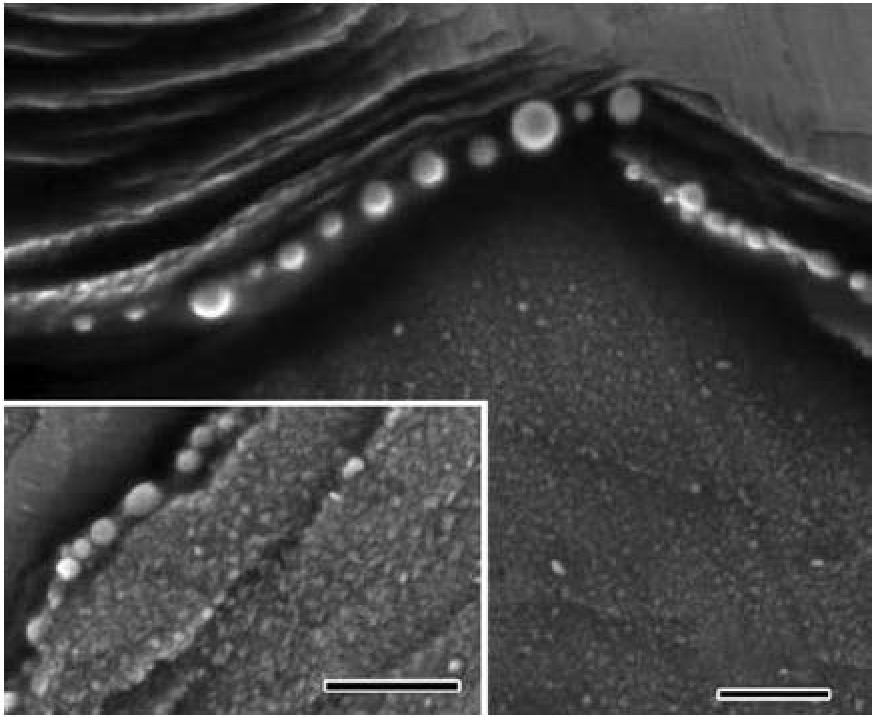
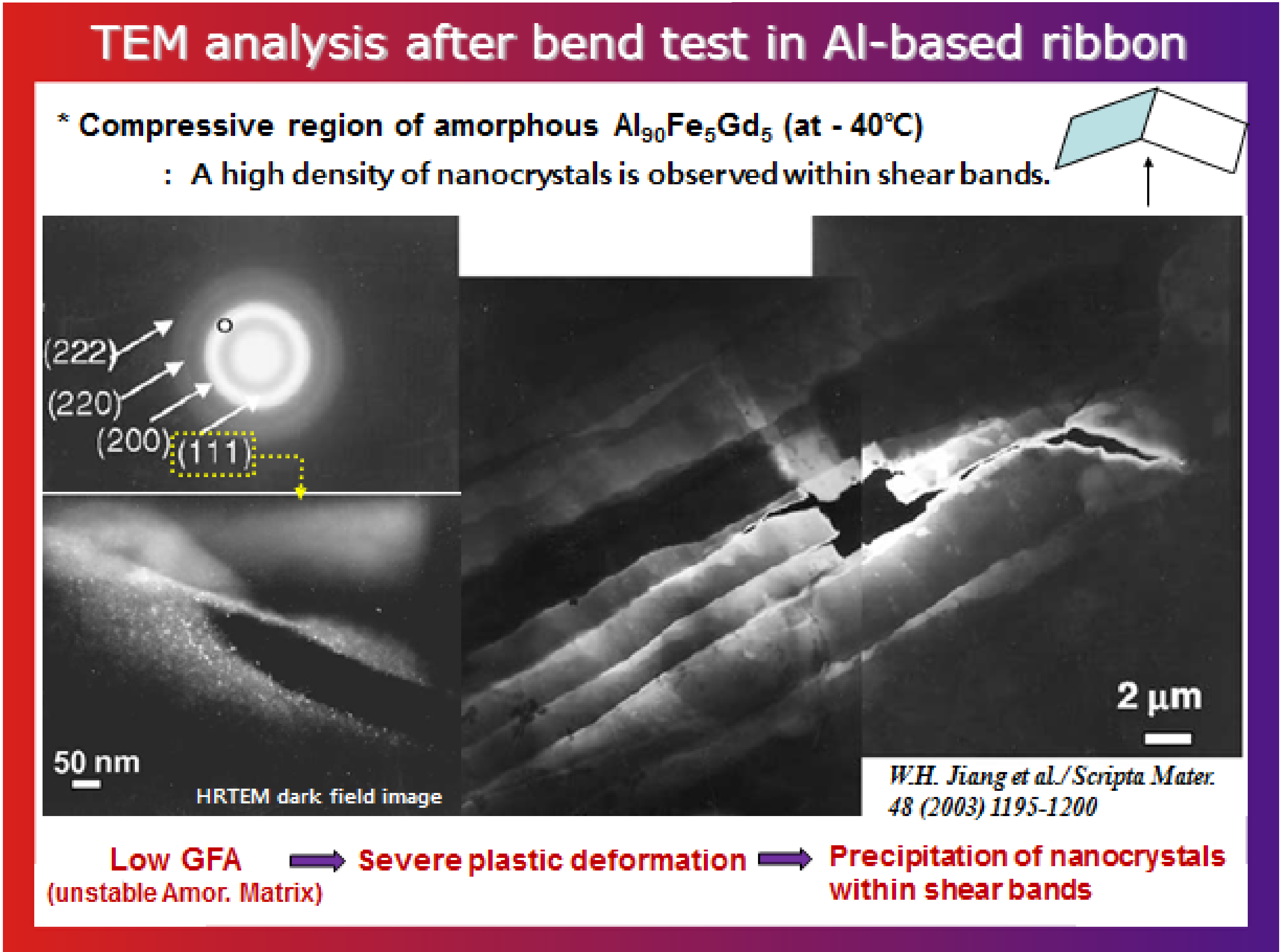


FIGURE 8.9
Scanning electron micrograph of the surface of $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$ BMG, which was originally coated with a tin coating. During deformation, the "fusible coating" had melted near the shear bands. The round shape of the tin beads clearly suggests that the coating had melted due to the temperature rise as a result of deformation and had resolidified. The bar in the micrographs corresponds to 1 μm. (Reprinted from Lewandowski, J.J. and Greer, A.L., *Nat. Mater.*, 5, 15, 2006. With permission.)

8.4.1 Nanocrystallization near Shear Bands

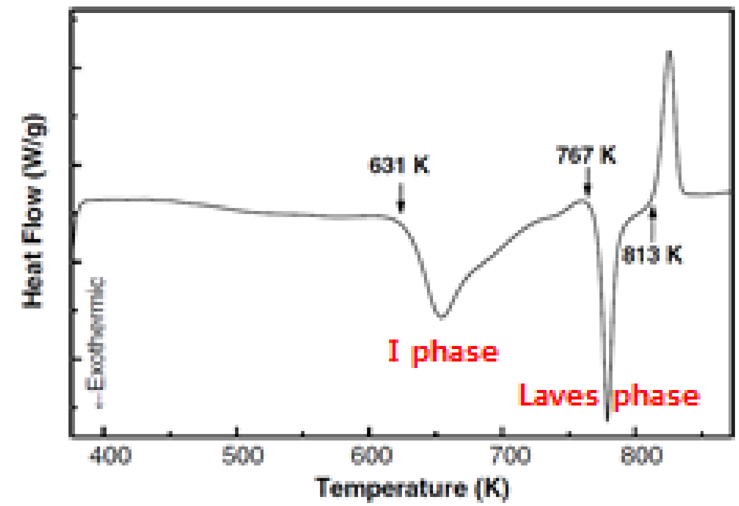


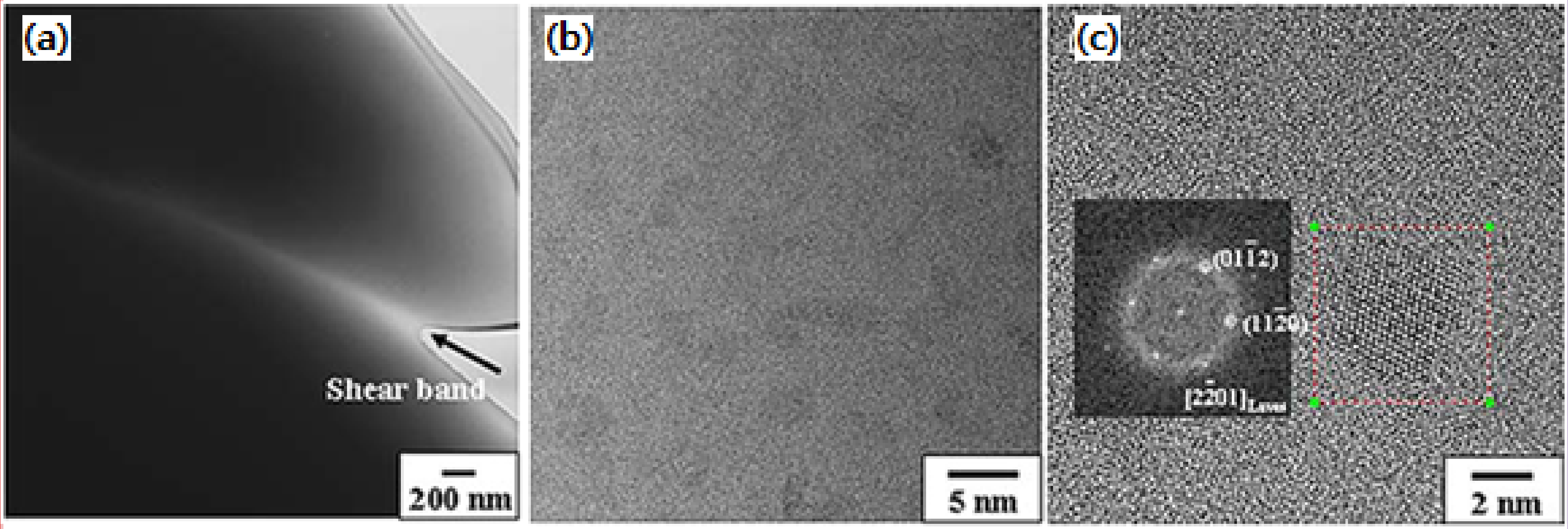
TEM analysis after severe compressive loading

* Quasi-forming $Ti_{40}Zr_{29}Cu_9Ni_8Be_{14}$ BMG exhibits large plastic strain.

: nanocrystals is observed within shear bands.

H.J. Chang et al./ Scripta Mater. 55 (2006) 509-512

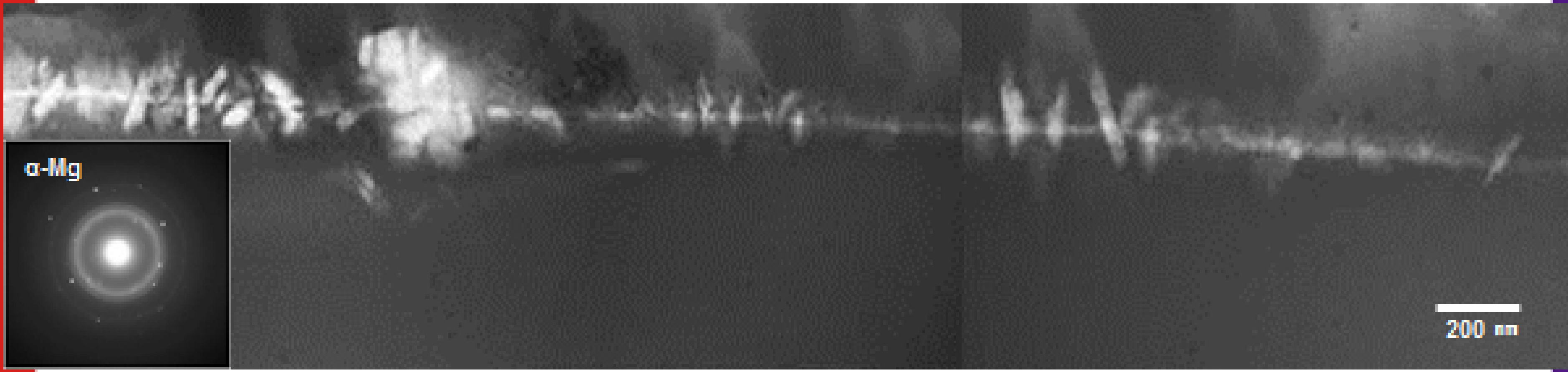


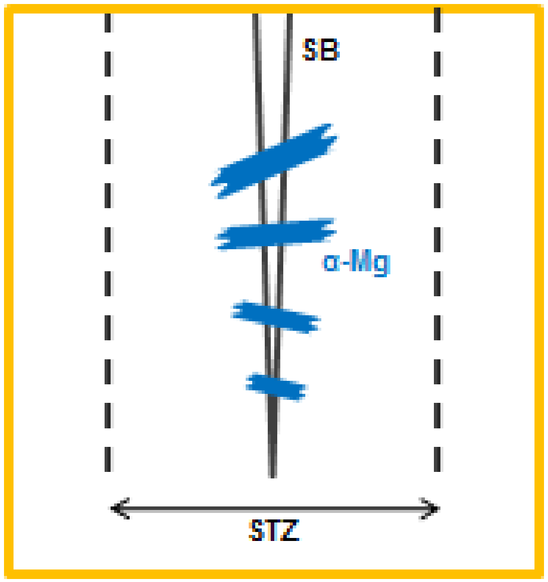


Unstable Amor. Matrix ➡ Severe plastic deformation ➡ Precipitation of nanocrystals within shear bands

TEM analysis after severe compressive loading

* Mg-rich $Mg_{80}Cu_{15}Gd_5$ BMGC ~ large plastic strain





Precipitation of several hundreds nm scale α-Mg in SB & STZ region occurs during the severe compressive deformation, which is related to relatively low T_g (or T_x) value as well as unstable amorphous matrix in Mg-rich BMGC.

J.I. Lee will present the detail at July 8 (11: 45, room E7)

Unstable Amor. Matrix & relatively low T_g (or T_x) ➡ Severe plastic deformation ➡ Precipitation of nanocrystals in SB and STZ region