

Time-dependent mechanical response in Zr-based thin film metallic glasses and nanocrystalline metallic thin film

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Time-dependent mechanical behaviors

- ▶ It is a qualitative or semi-quantitative method to detect the defect activities which can not show immediately.

Anelasticity

- The **reversible** tendency of a solid material to slowly moves or deforms permanently under the influence of stresses.
- Strongly relative to defect concentration, such as point defects and dislocations.
- Sensitive to **loading history** and **temperature**.

Creep

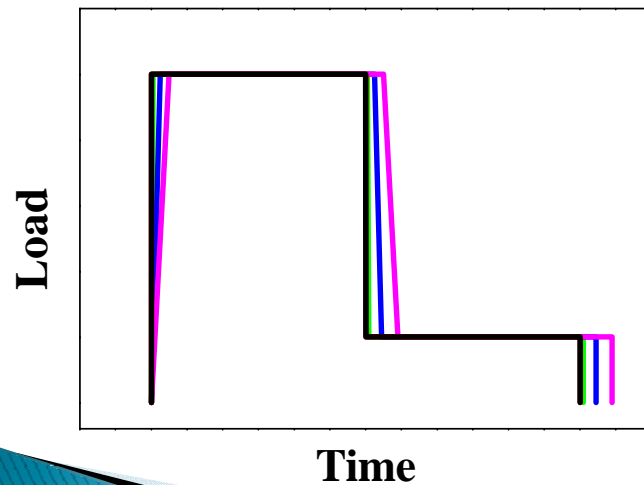
- The **irreversible** tendency of a solid material to slowly moves or deforms permanently under the influence of stresses.
- Long-term exposure to levels of stress that are **below the yield strength of the material**.
- Sensitive to **stress level, temperature, loading history** and **grain size**.

Structural effect: amorphous and crystalline structure

▶ Material:

- (a) Nanocrystalline silver with (111) preferred orientation
 - Average grain size: ~100 nm in diameter
- (b) ZrCuTiTa TFMGs

▶ Load function:



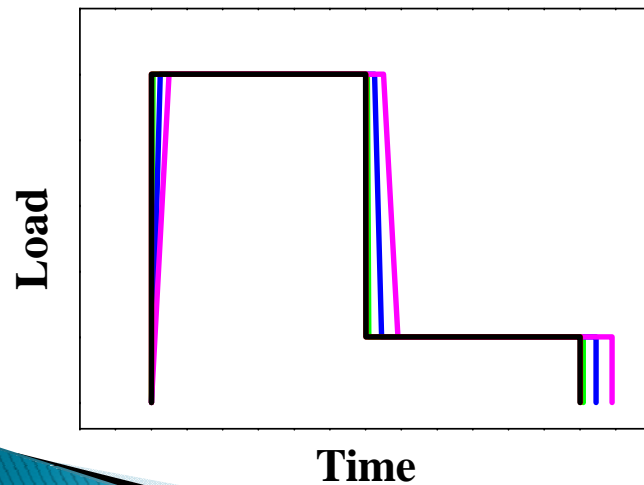
	nc silver	Zr ₄₅ Cu ₂₇ Ti ₁₅ Ta ₁₃
Load at 1 st holding	1.25 mN	5 mN
Load at 2 nd holding	0.25 mN (20% P _{max})	0.25 mN (5% P _{max})

Structural effect: amorphous and crystalline structure

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▶ Load function:



Loading rate

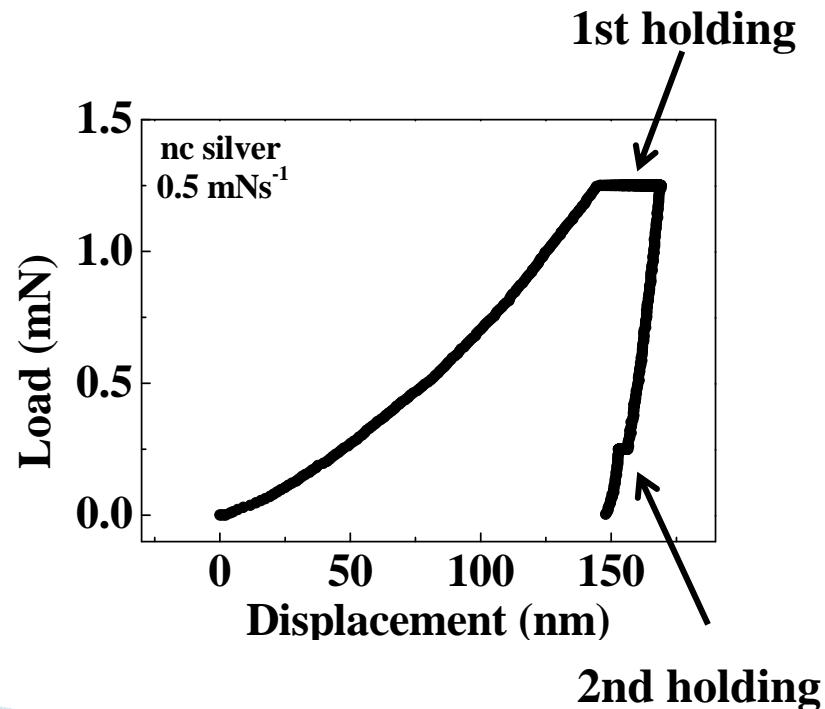
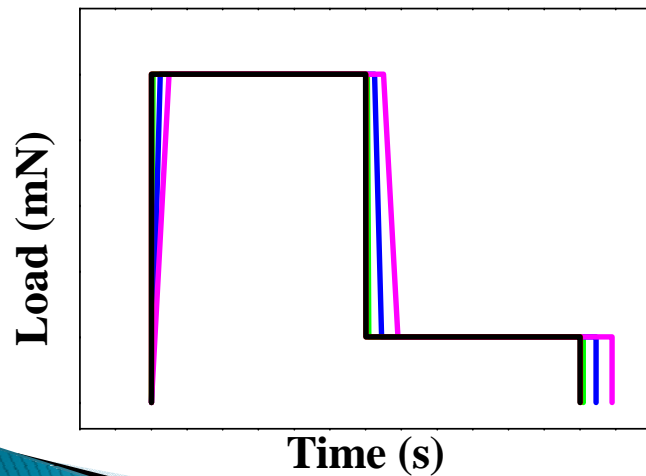
nc silver	Zr ₄₅ Cu ₂₇ Ti ₁₅ Ta ₁₃
0.05 mNs ⁻¹	0.5 mNs ⁻¹
0.25 mNs ⁻¹	1 mNs ⁻¹
0.5 mNs ⁻¹	50 mNs ⁻¹
50 mNs ⁻¹	100 mNs ⁻¹

Structural effect: amorphous and crystalline structure

▶ Material:

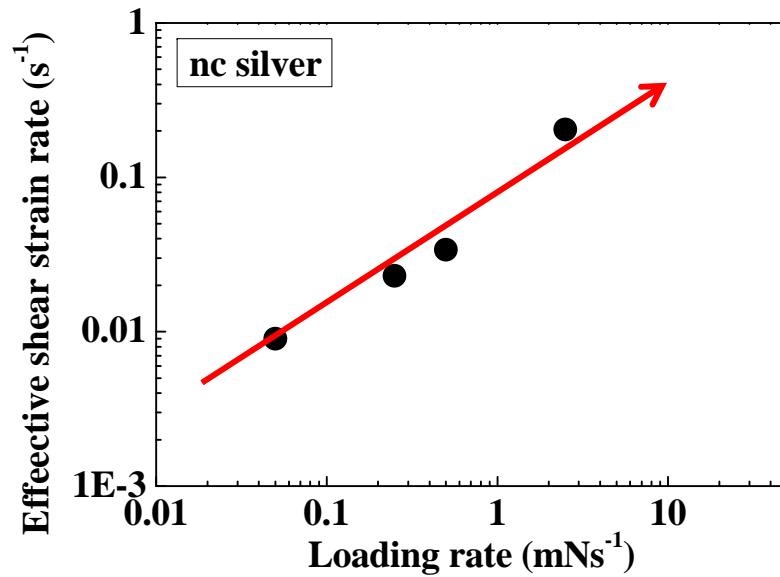
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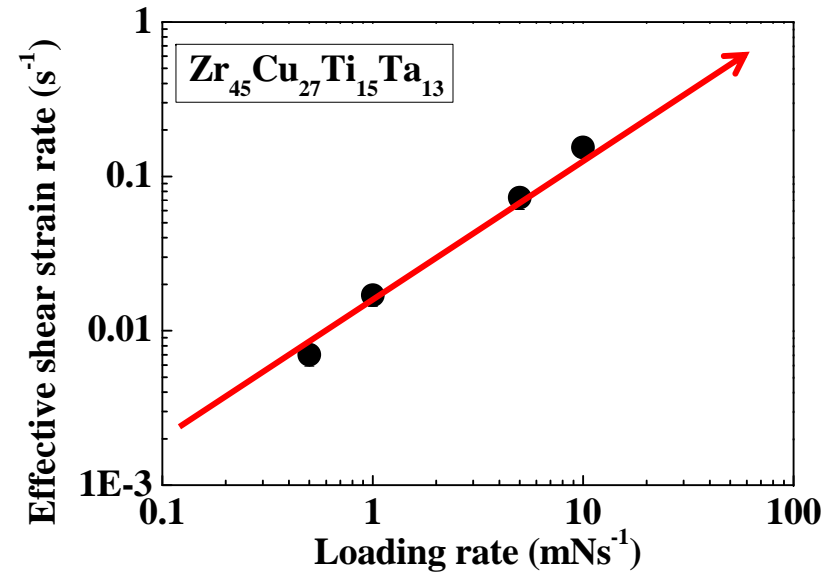


Relationship between loading rate and effective shear strain rate

Nanocrystalline silver



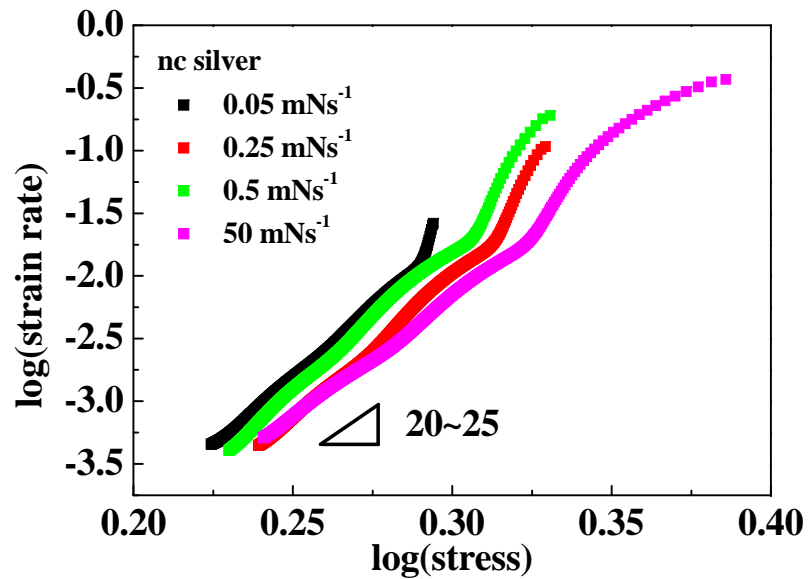
Zr₄₅Cu₂₇Ti₁₅Ta₁₃



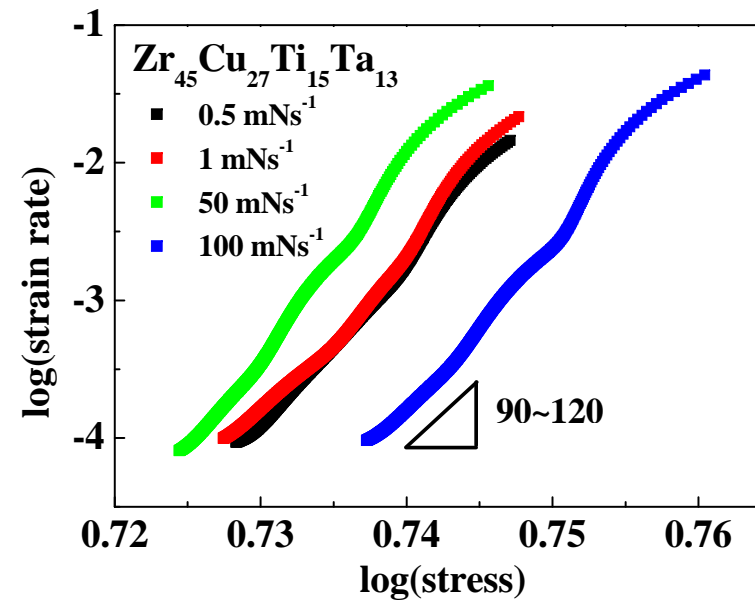
$$\dot{\gamma} = 0.16\dot{\epsilon} = 0.16 \frac{1}{h} \frac{dh}{dt}$$

Relationship between loading rate and effective shear strain rate

Nanocrystalline silver



Zr₄₅Cu₂₇Ti₁₅Ta₁₃

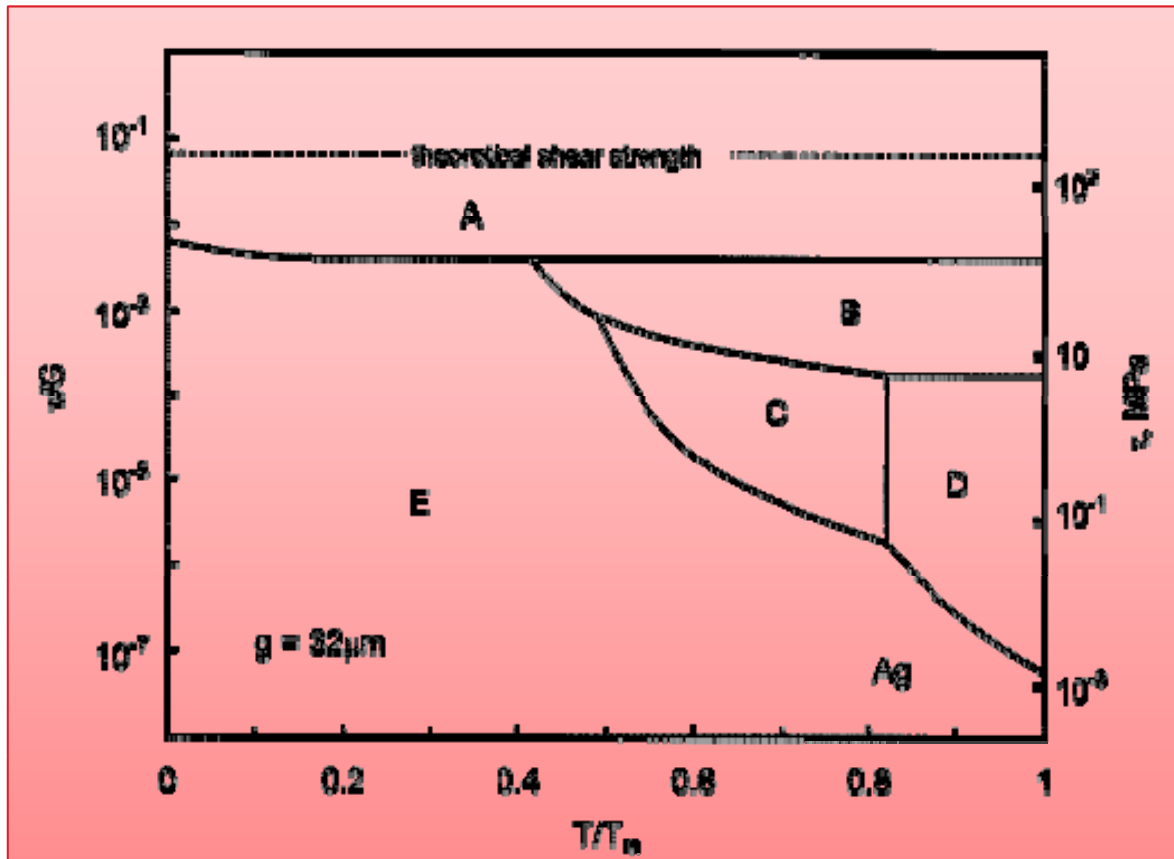


Creep

$$\dot{\varepsilon} = \frac{AGb}{kT} D_0 \exp\left(-\frac{Q_c}{RT}\right) \left(\frac{\sigma}{G}\right)^m \left(\frac{b}{d}\right)^n$$

- ▶ **Diffusion-control creep**
 - Nabarro-Herring creep (diffusion in grains)
 - Coble creep (diffusion along grain boundaries)
- ▶ **Dislocation-control creep**
 - dislocation climbing and gliding
- ▶ **Grain boundary sliding**

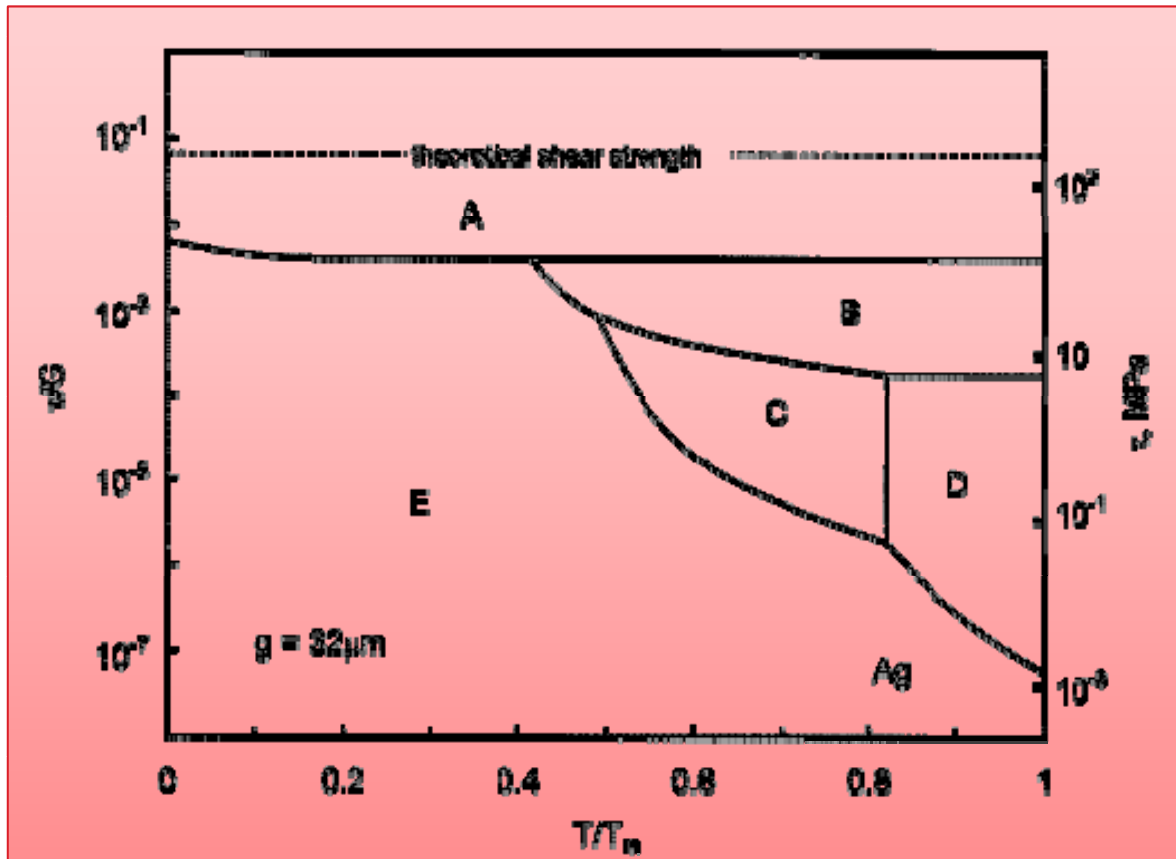
Deformation map of polycrystalline silver in creep



- A: Dislocation glide**
- B: five-power-law creep**
- C: coble creep**
- D: Nabarro-Herring Creep**
- E: Elastic deformation**

M.E. Kassner and M.-T. PeArez-Prado, Prog. Mater. Sci., **45**, (2000), 1

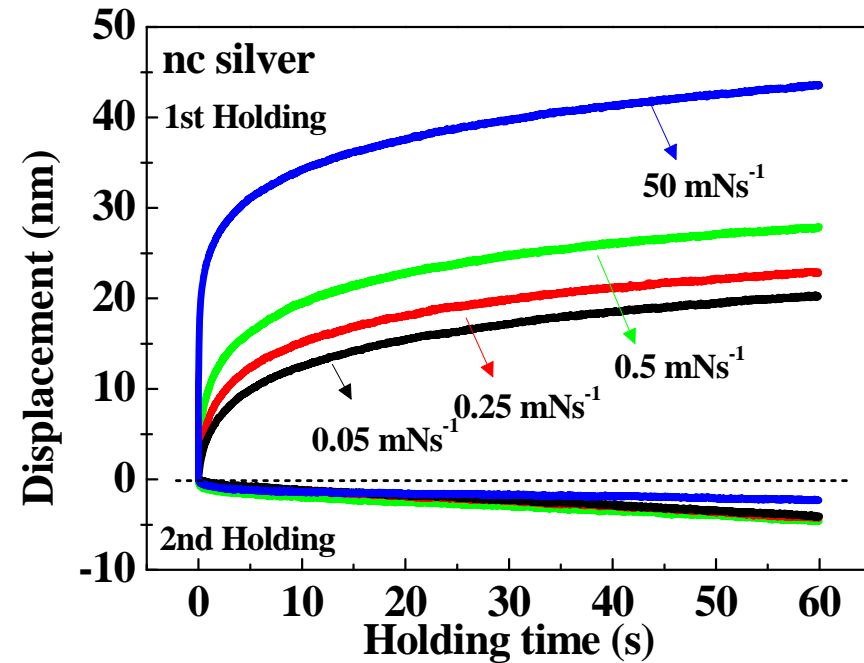
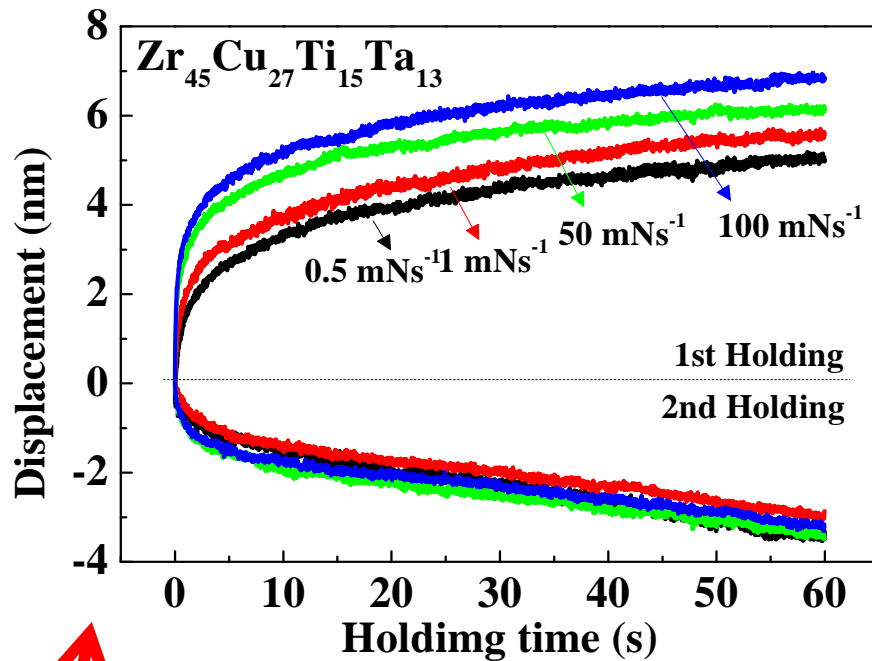
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Time-dependent mechanical behavior



$$h = h_e + \sum_n J_n \left(1 - \exp\left(-\frac{t}{\tau_n}\right)\right) + kt$$

h_t

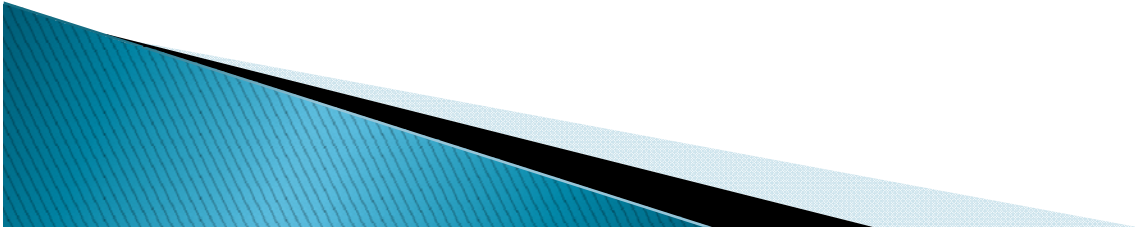
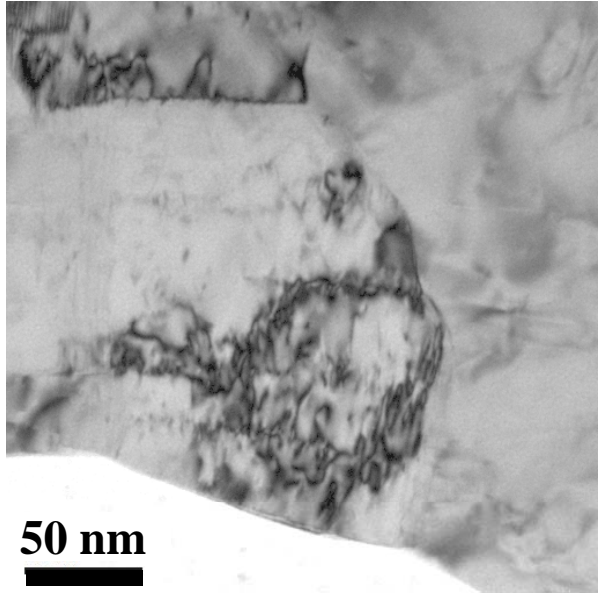
h_l

Why crystalline material does not show the anelastic characteristics?

Creep
Local structural relaxation

→ Thermo-activated process

Dislocation movement
Local structural relaxation



Conclusion

- ▶ As we know, time-dependent mechanical behaviors are strongly related to the **stress level**, **strain rate** and **material characteristic**.
- ▶ Through the second holding, the difference of the recovery characteristics implies the plastic deformation in the loading segments is intrinsic different.
- ▶ No obvious anelasticity is found in nanocrystalline because of **the competition between dislocation movement and local structural relaxation**

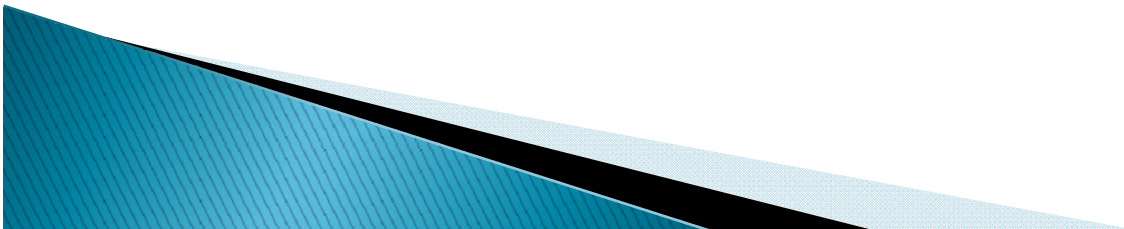
Static time-dependent mechanical analysis via nanoindentation

▶ Advantages:

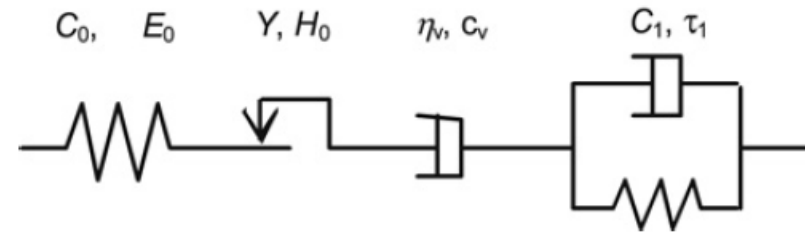
- Easy to measure

▶ Disadvantages:

- Complex two-dimension stress state
- Need a good accuracy of displacement and load.
- Necessary to correct the **loading history** (time delay)



Viscoelastic analysis



Loading segment

$$h^2(t) = \frac{\pi P_{\max}}{8 \tan(\alpha)} J(t) = K_c P_{\max} J(t)$$

Elasticity Creep Anelasticity
Plasticity

Holding segment

$$h^2(t) = K_c P_{\max} \left(C_0 - \sum_3 C_i \exp(-t / \tau_i) RCF_i \right) + \frac{C_v}{2} (t - t_r)$$

C_0, C_i : Creep compliance



Elastic modulus

Thanks for your attention

