Email: whw@iphy.ac.cn

http://mmp.iphy.ac.cn

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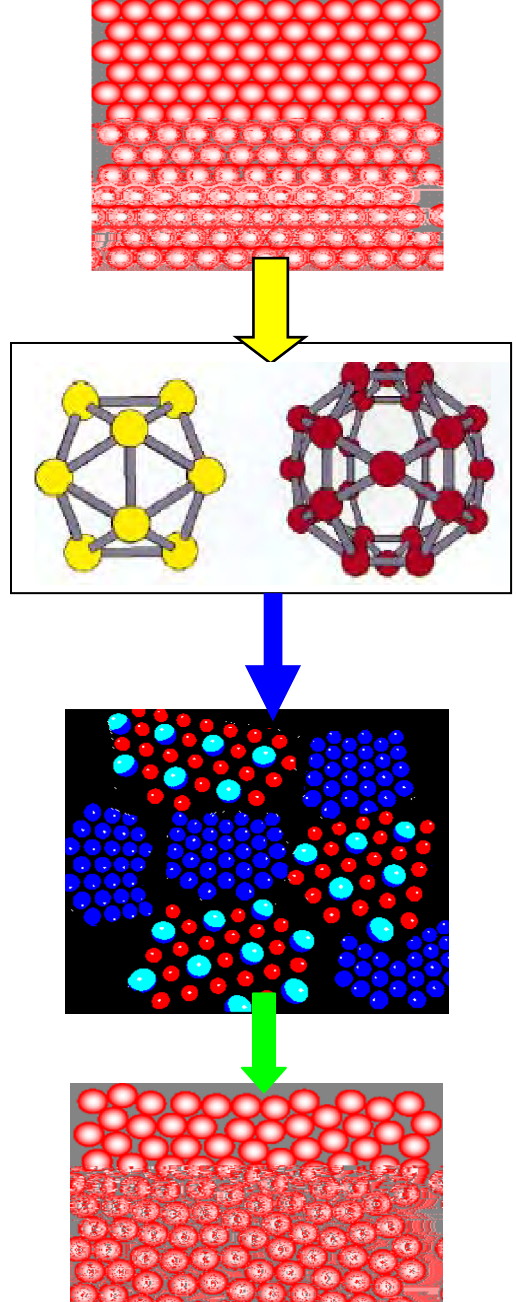
1-100 μm



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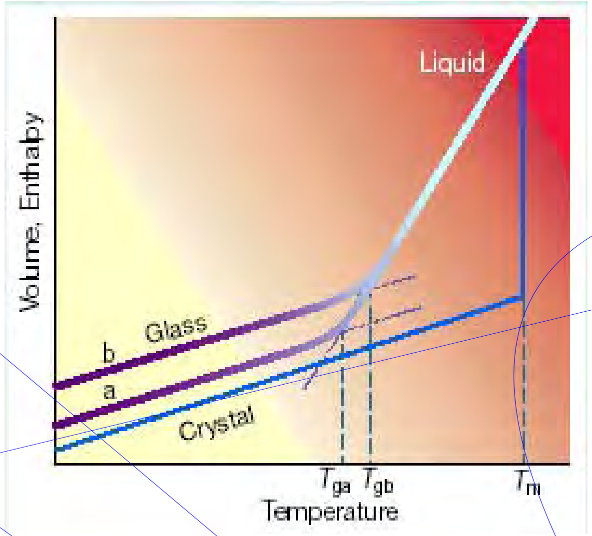

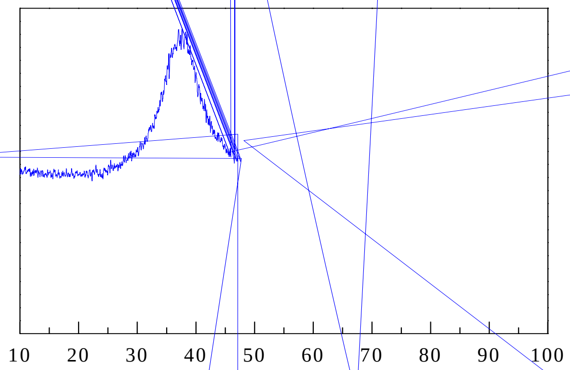

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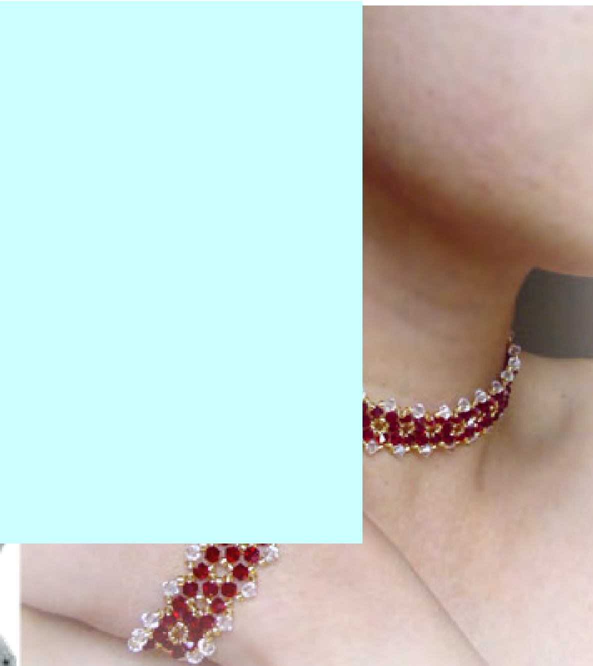

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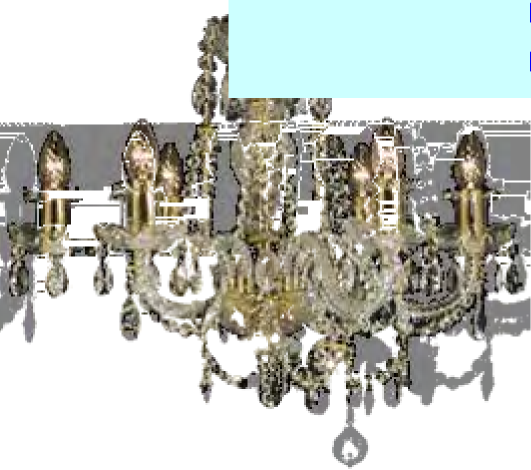

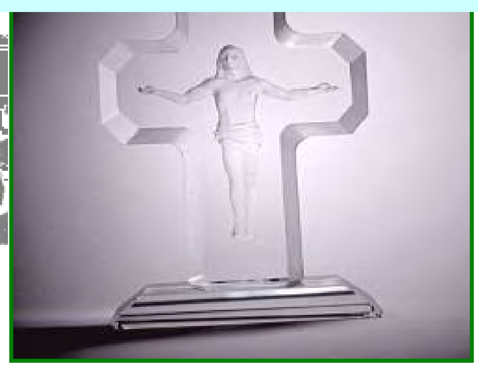


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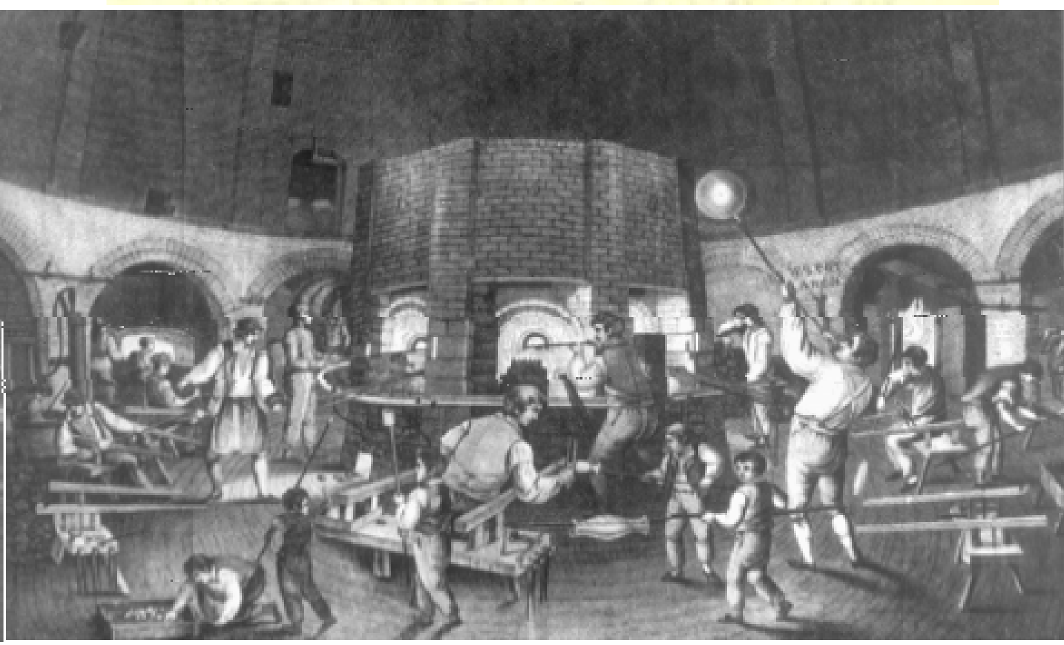

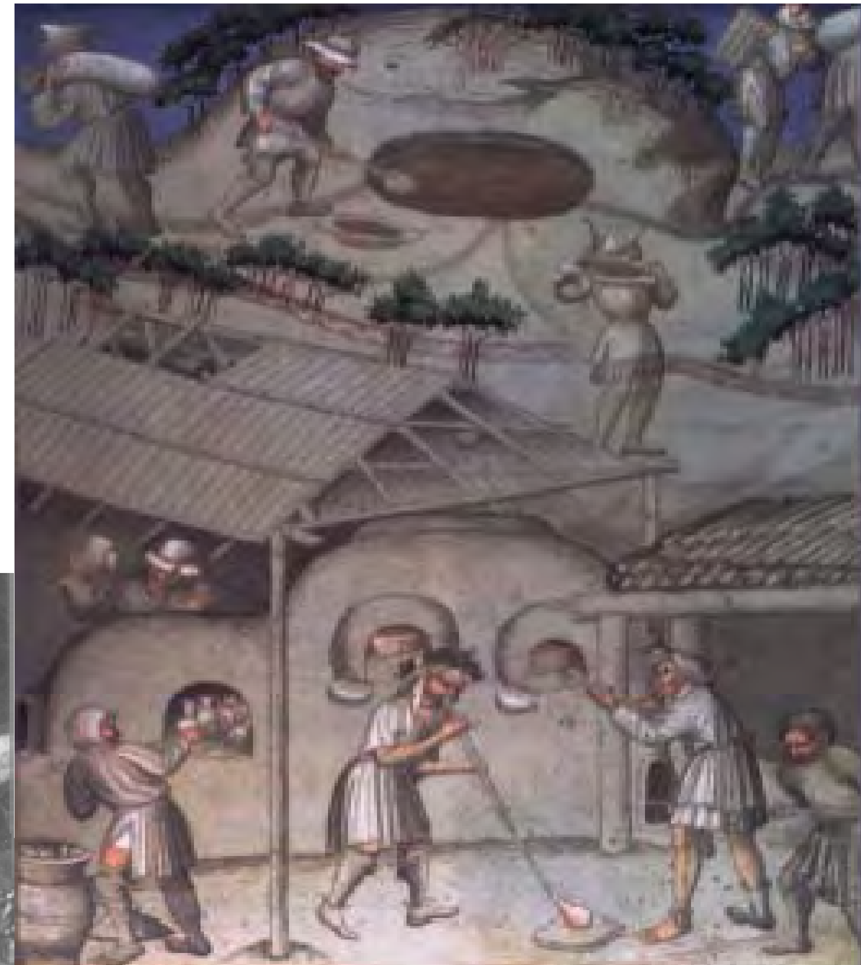

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500-600 BC

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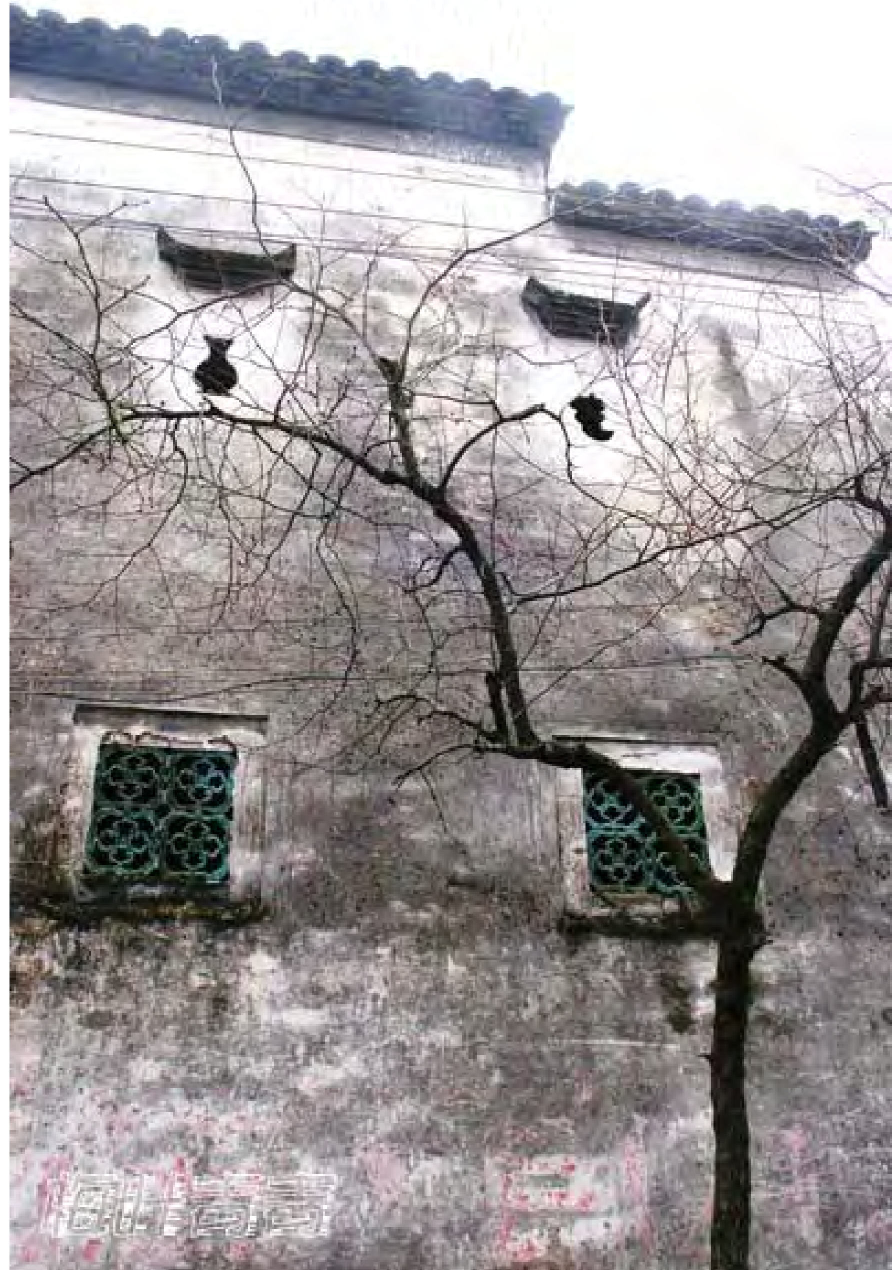

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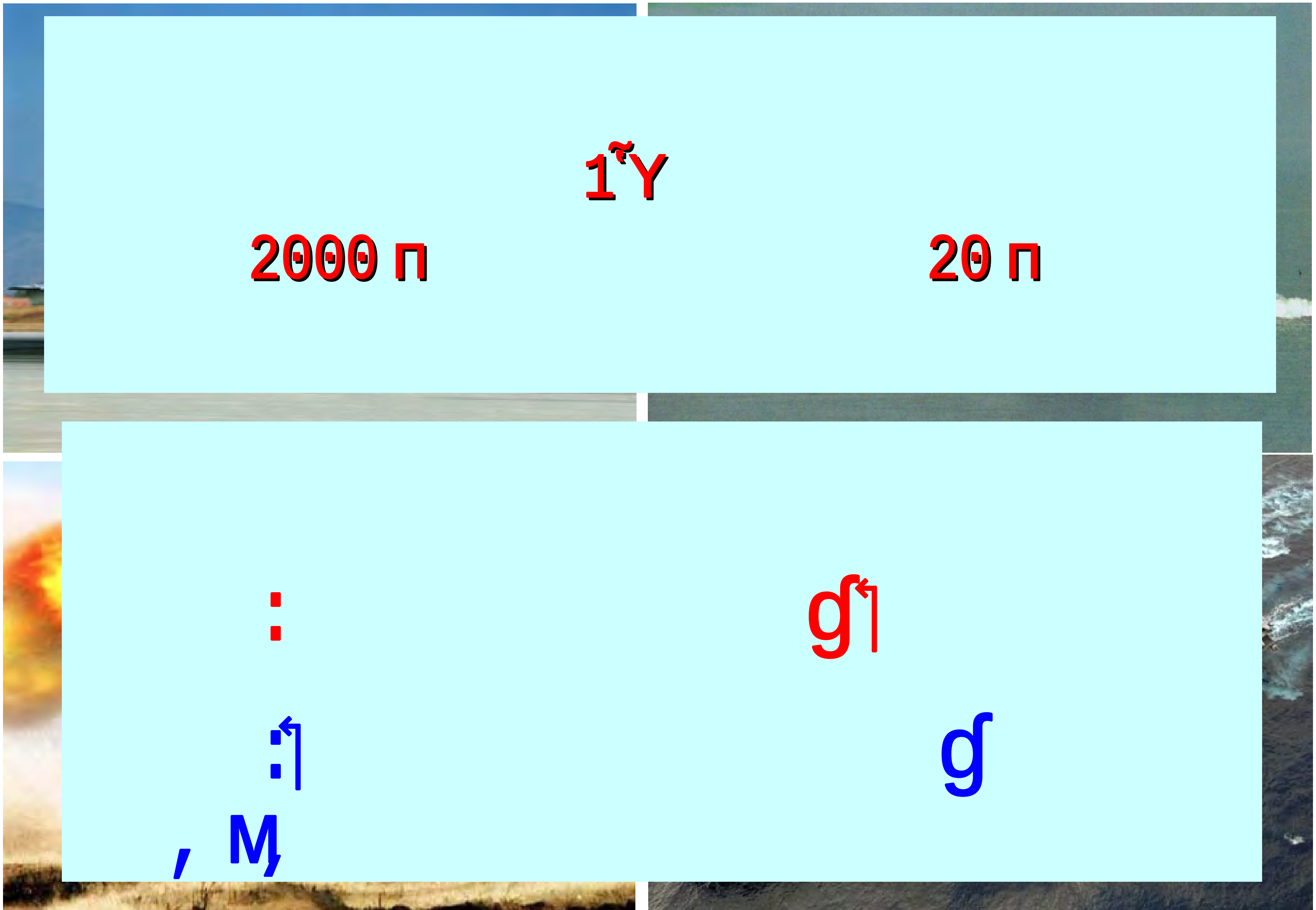

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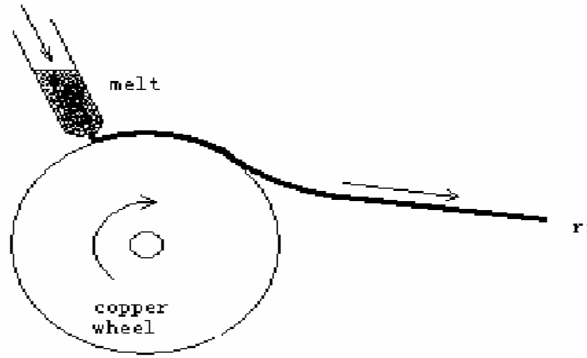

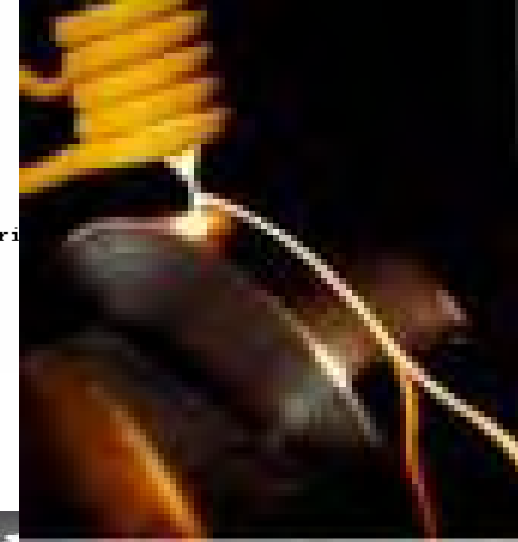

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Turnbull, P.W. Anderson,
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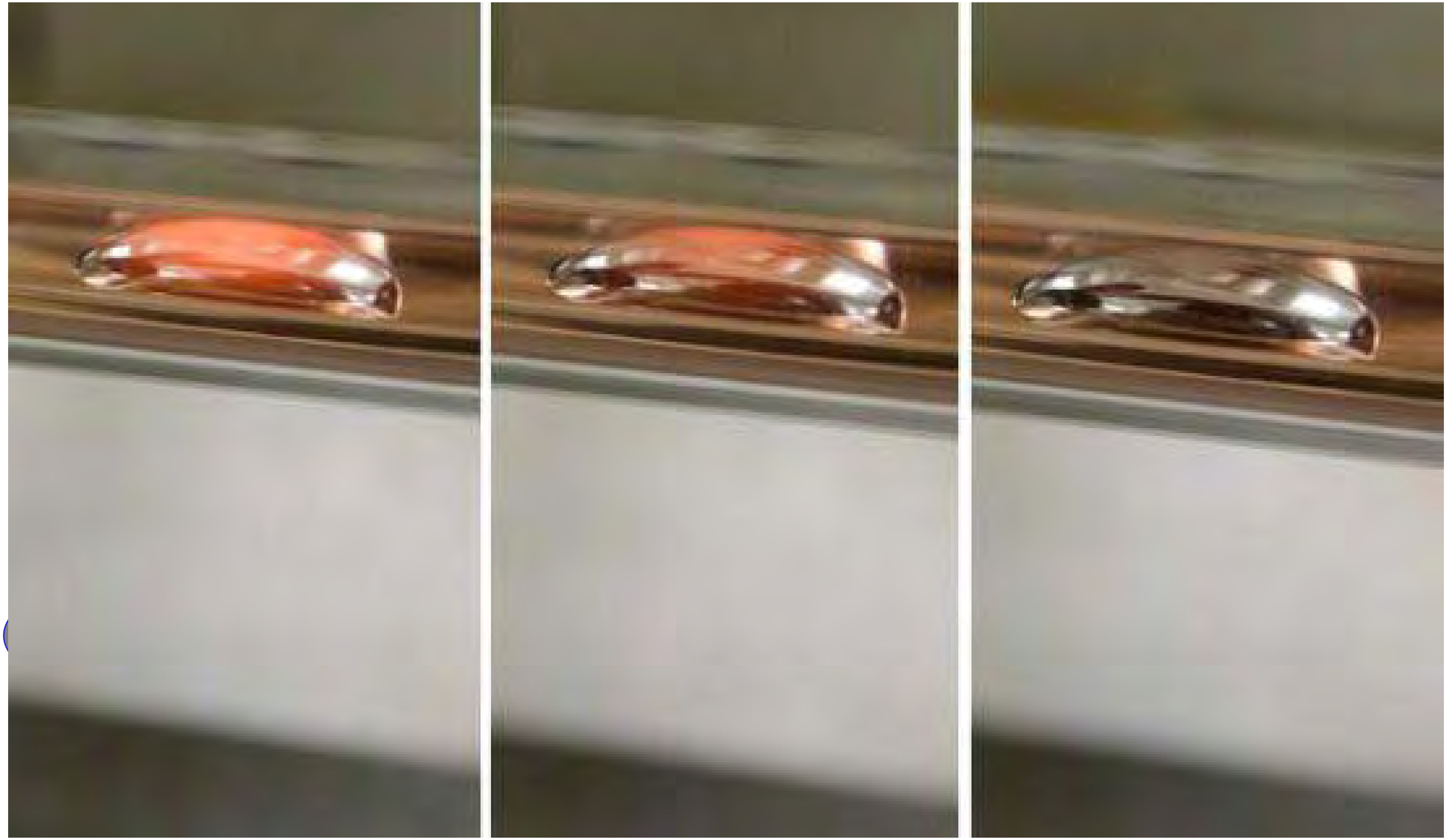

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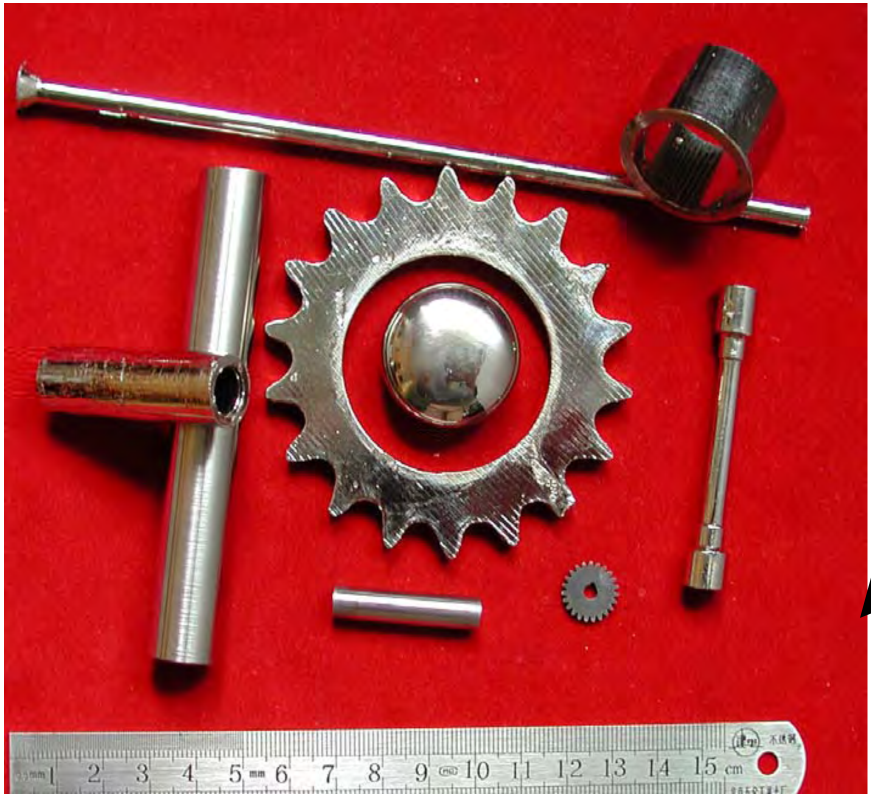
A. Inoue(K∟) W.L. Johnson (Caltech)



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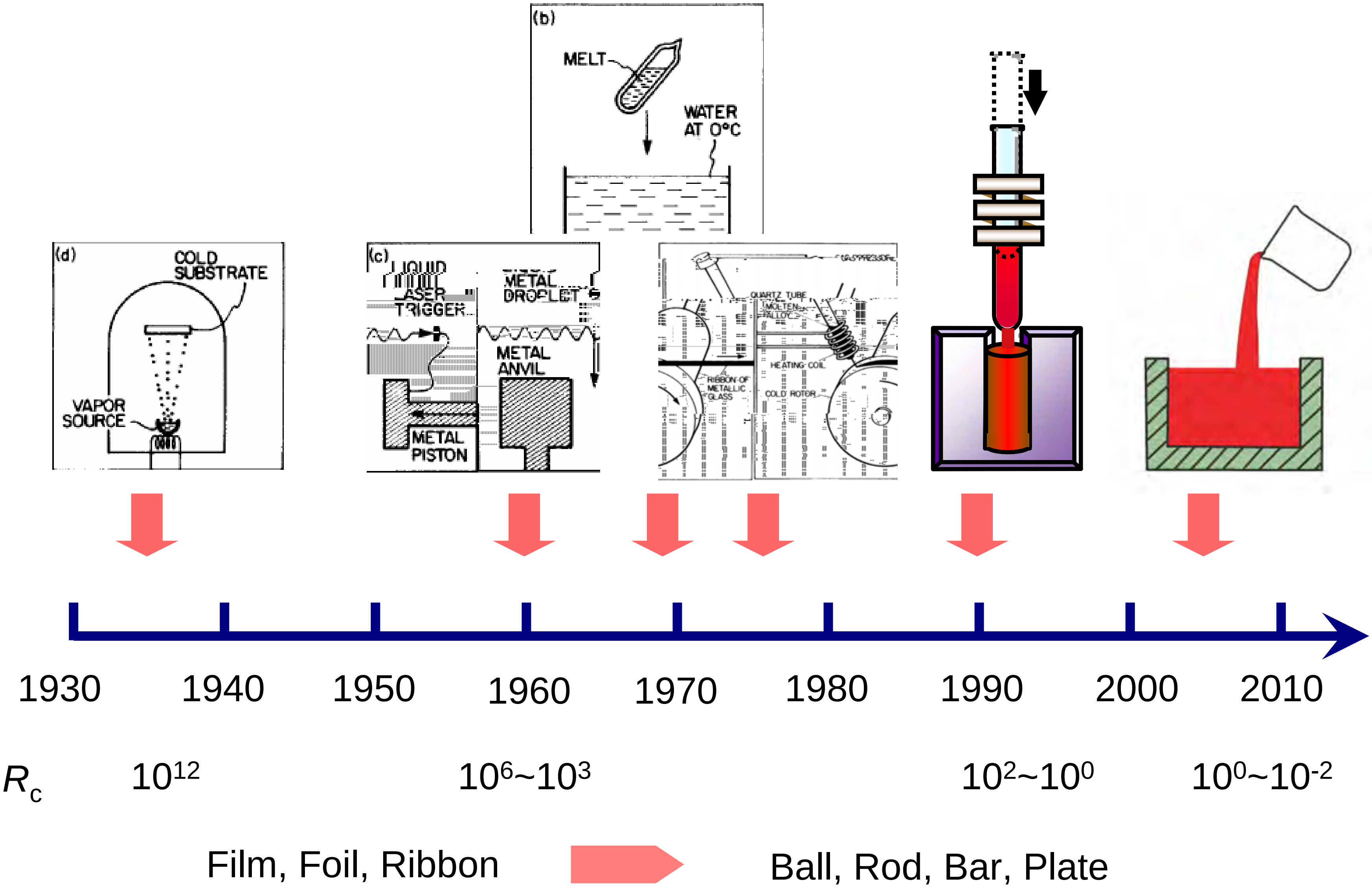
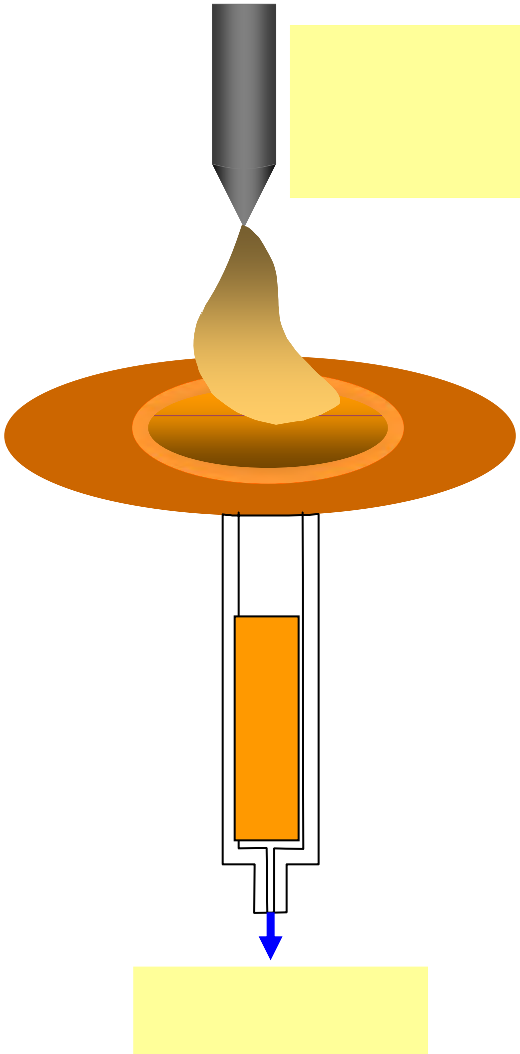
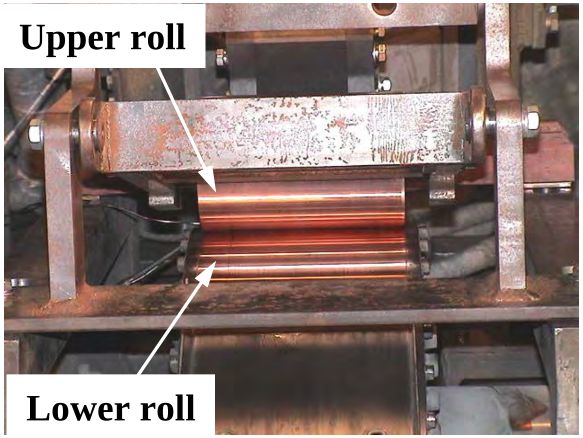

(d)
COLD SUBSTRATE
VAPOR SOURCE
(c)
LIQUID
LASER TRIGGER
METAL DROPLET
METAL ANVIL
METAL PISTON
(b)
MELT
WATER AT 0°C
QUARTZ TUBE
MOLTEN ALLOY
HEATING COIL
RIBBON OF METALLIC GLASS
COLD ROTOR
1930
1940
1950
1960
1970
1980
1990
2000
2010
R_c
10^{12}
10^6~10^3
10^2~10^0
10^0~10^{-2}
Film, Foil, Ribbon
Ball, Rod, Bar, Plate



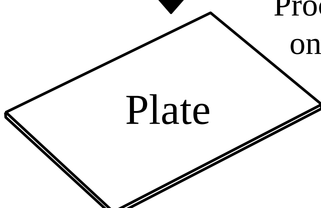
Fabrication process for large scale plates



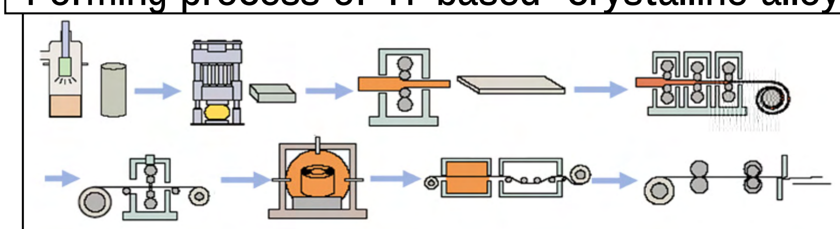
Graphite tundish

Newly developed twin-roller quenching

Process simplifying
only casting



Forming process of Ti-based crystalline alloy



Ti-based BMG large plate with width of 80 mm, length of 200 mm

80

- **Zr-, Mg-, Ti-, Fe-, Co-, Nd-, Ce- Pd-, Au-, Pt-,Ln**
- **Ḱ (CuZr) Ẳ Fe**
- **10 cm**
- **Zr Fe**
- **Zr-, Pd-, Ce-BMGs**

10

$\sigma \propto k/\sqrt{d}$, σ: d

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g M,

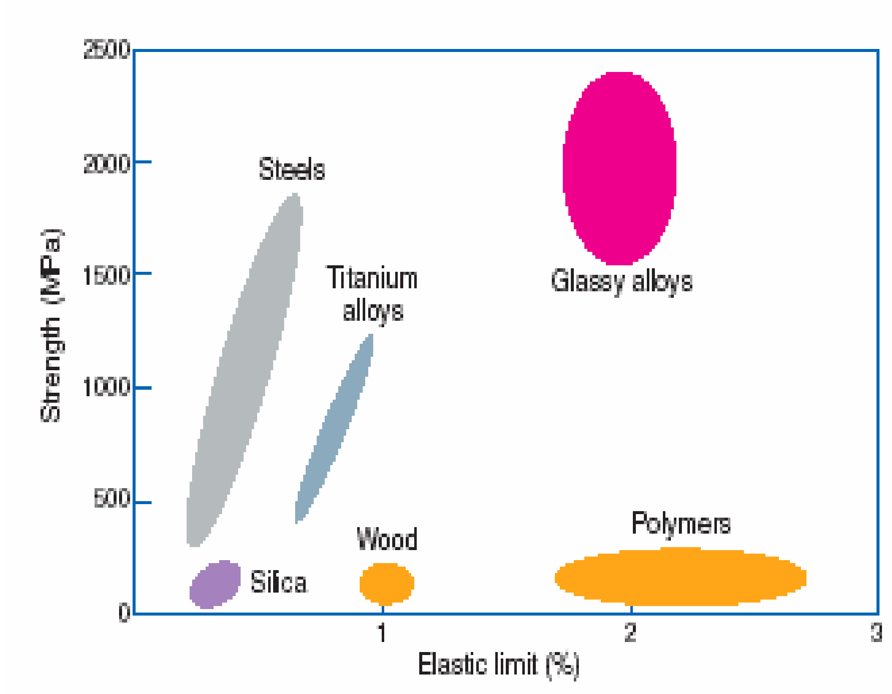
200 MPa

400 700

MPa

BMG 2000 MPa

5500 MPa



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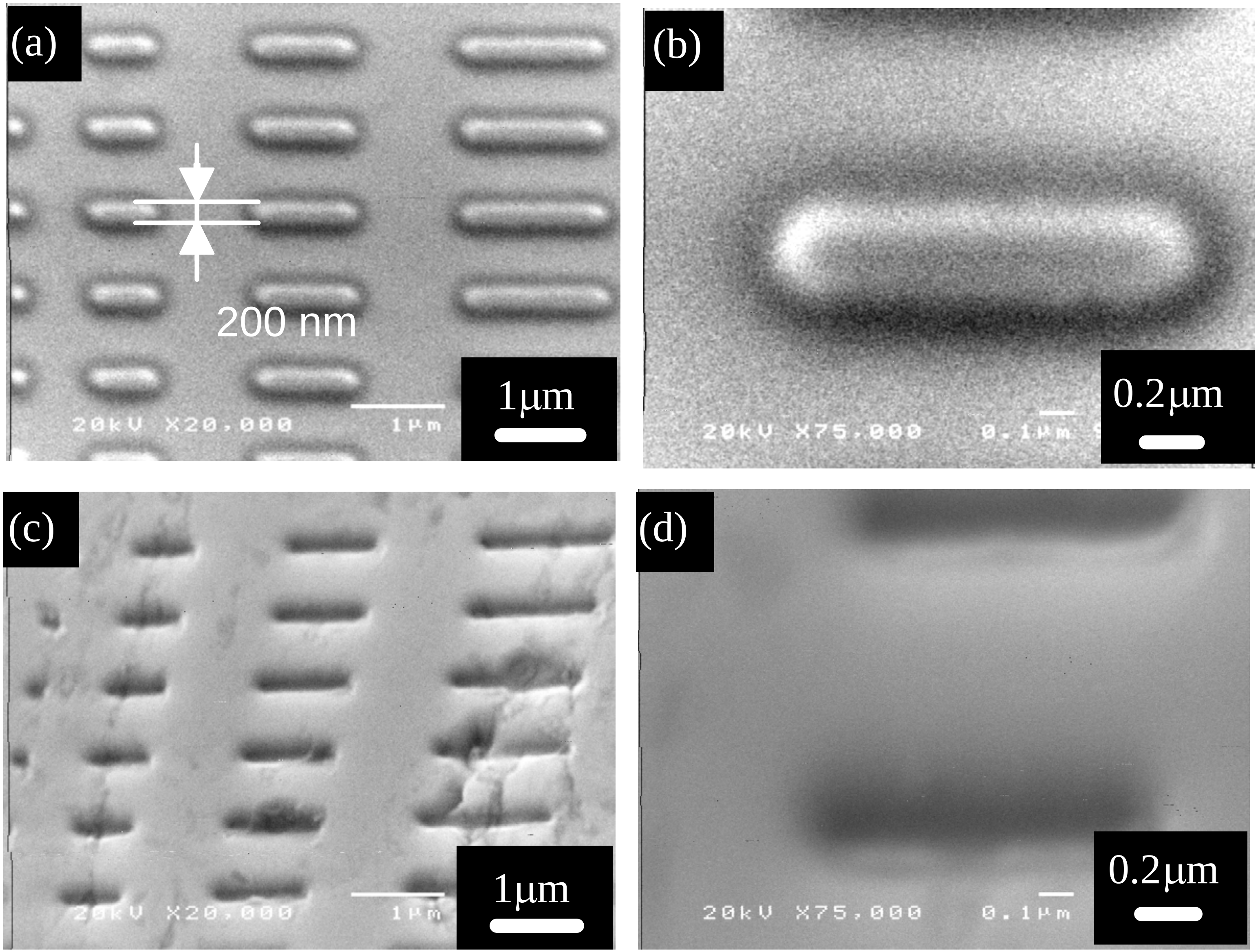
LIQUIDMETAL
PURE ENERGY TRANSFER
The unique atomic structure of Liquidmetal alloy makes it stronger than conventional metals, thus allowing Liquidmetal drivers to produce a higher launch angle and a lower backspin rate than titanium drivers with the same loft. This results in a penetrating trajectory with optimum carry and roll for more distance. (As proven in independent tests.)
Conventional Metals
LIQUIDMETAL Alloy
Titanium Driver
Liquidmetal Driver

LIQUIDMETAL

Micromachine

sma

μFR Micro flying robot
SEIKO EPSON


(a)
200 nm
1μm
20kV X20,000
1μm
(b)
0.2μm
20kV X75,000
0.1μm
(c)
1μm
20kV X20,000
1μm
(d)
0.2μm
20kV X75,000
0.1μm

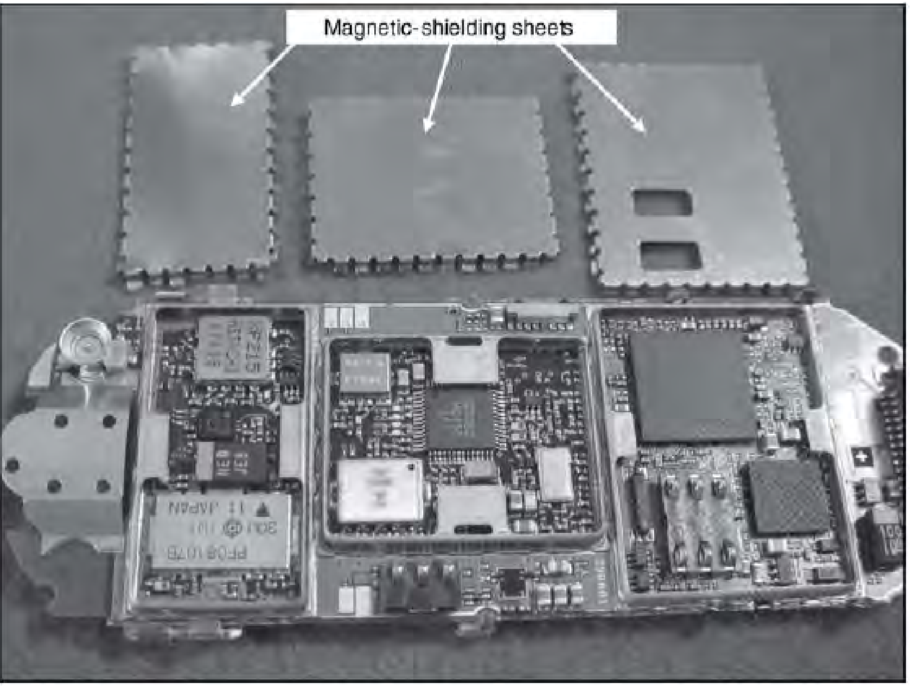
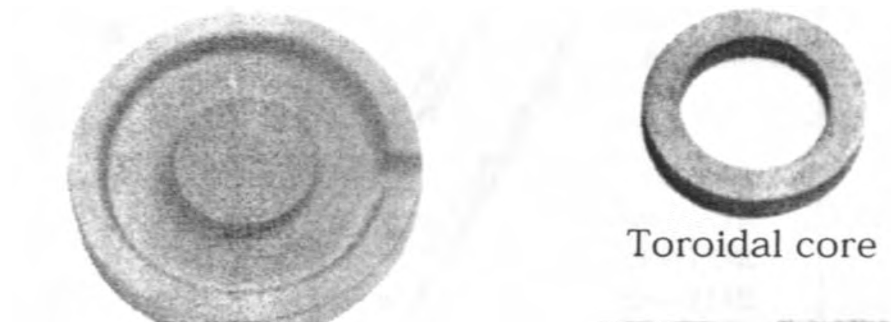
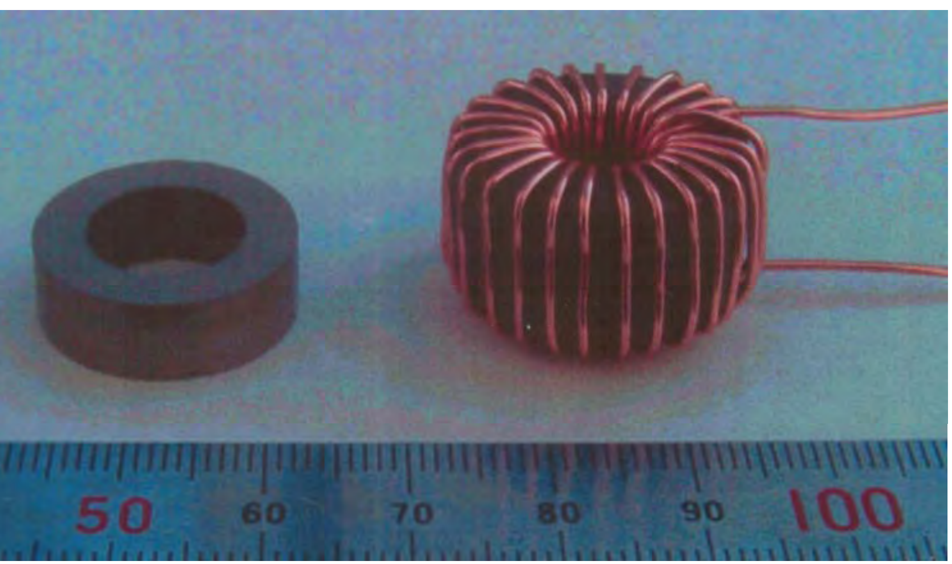
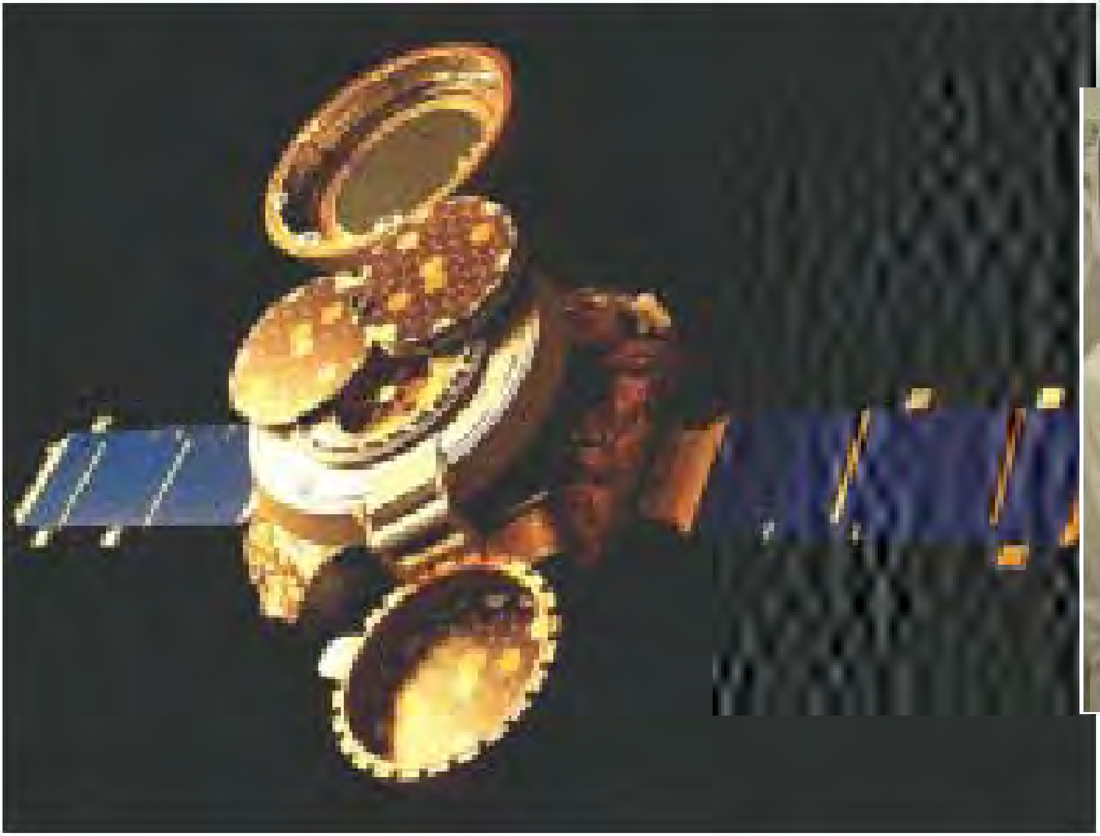


Figure 2. Bulk metallic glass magnetic-shielding sheets for laptop PCs.







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Science, 314, 1133(2006)

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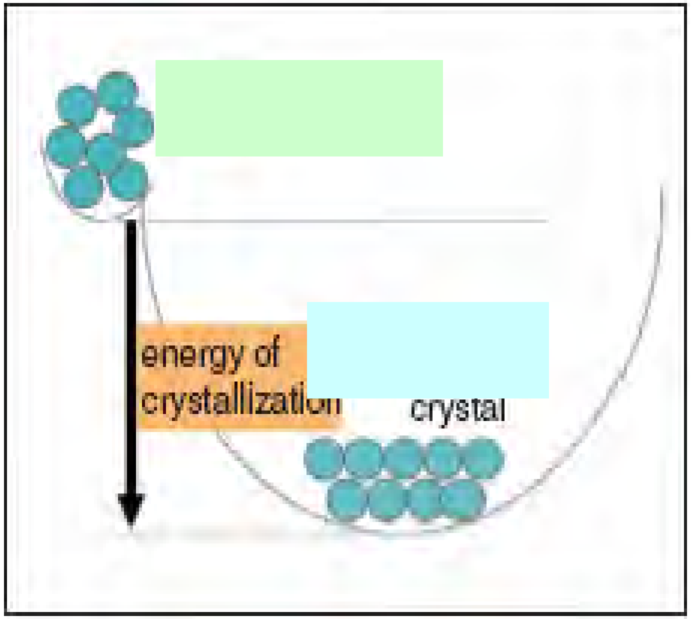

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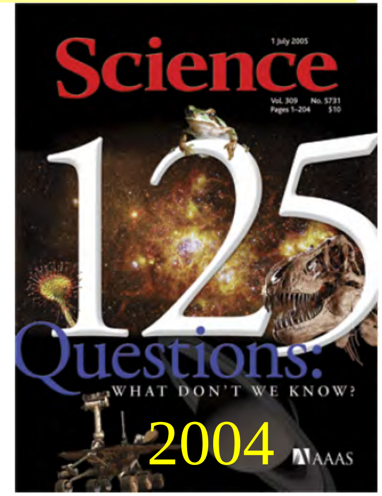

P.W. Anderson

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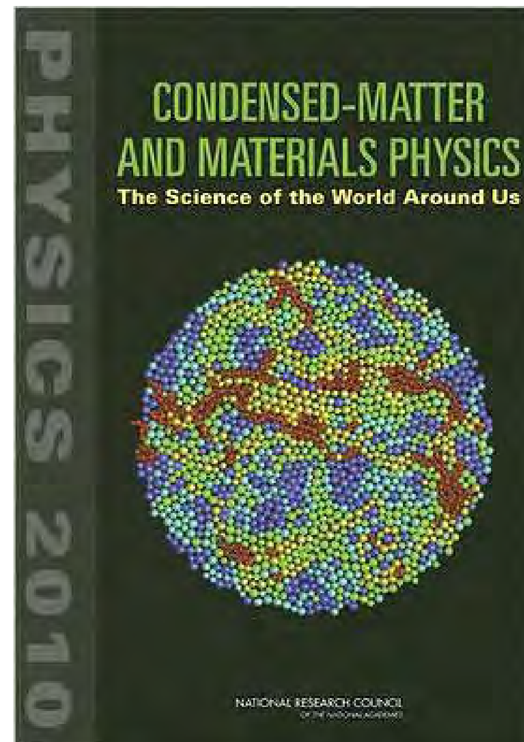
Science, 267 (1995)1615



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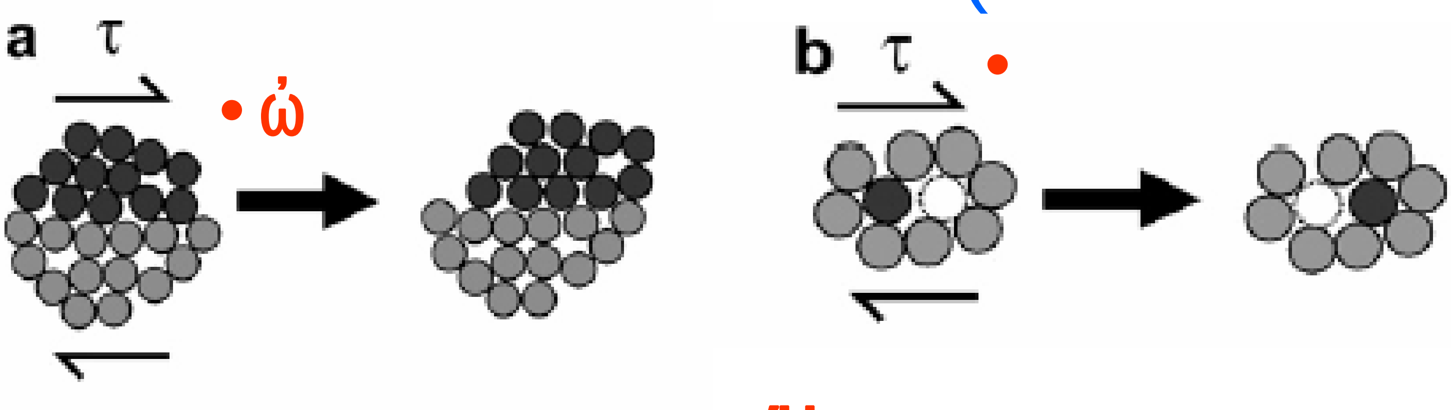

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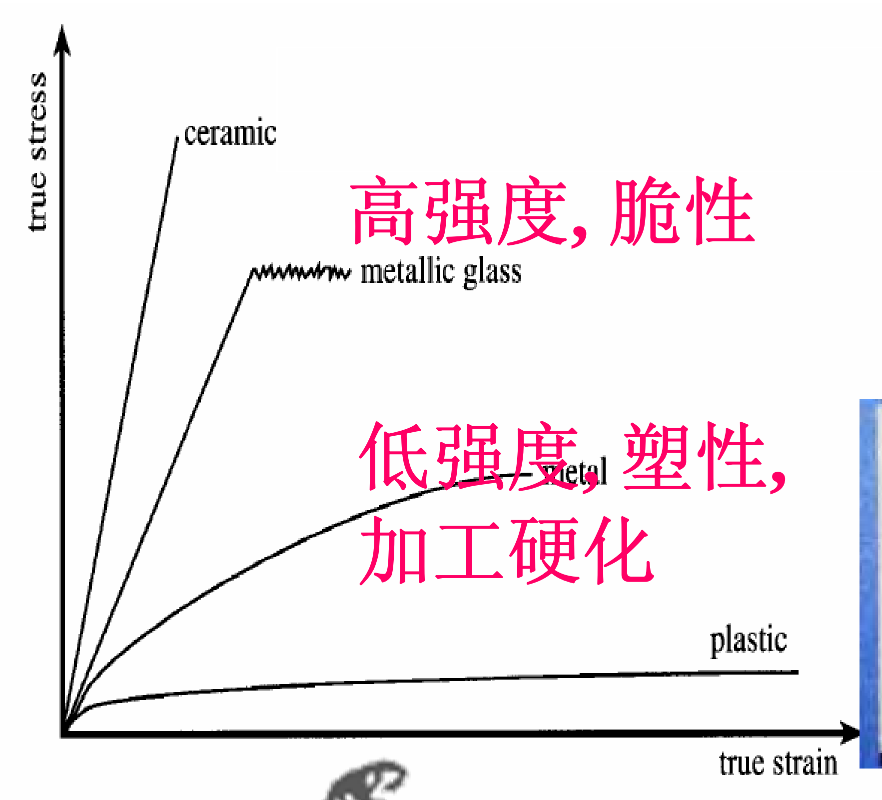

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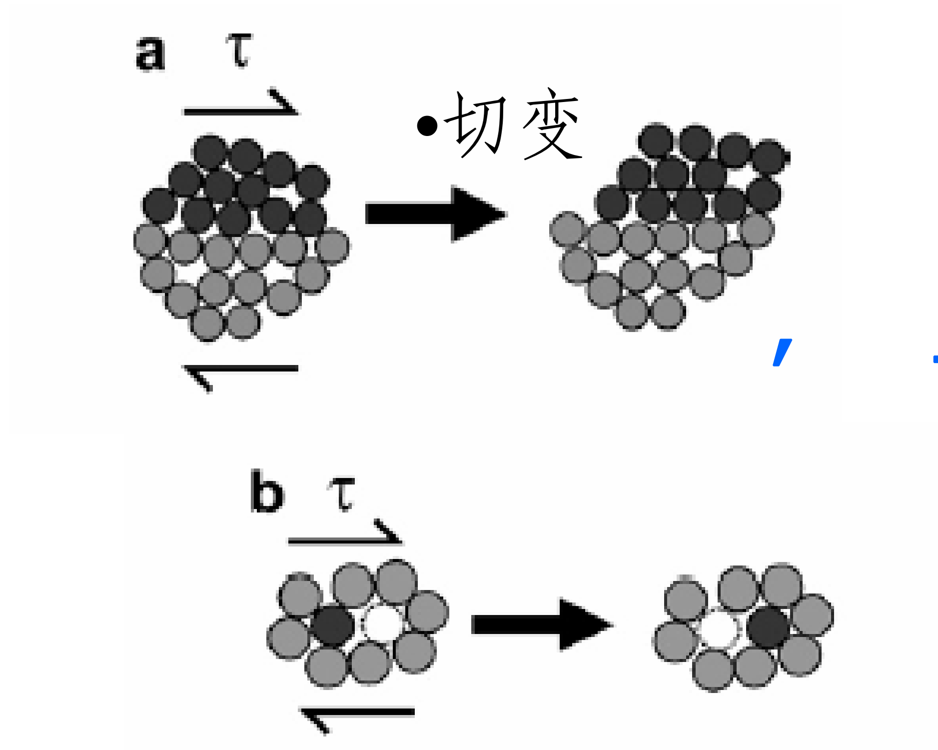

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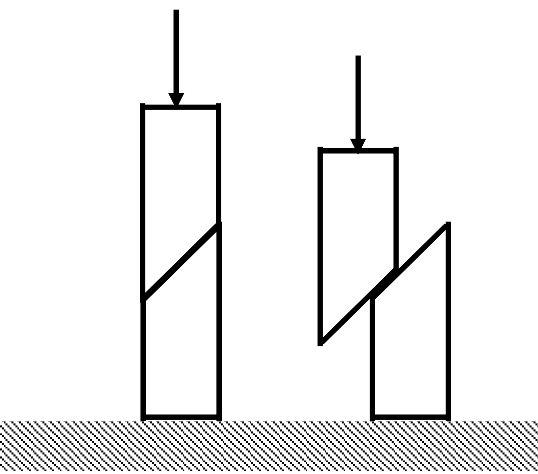

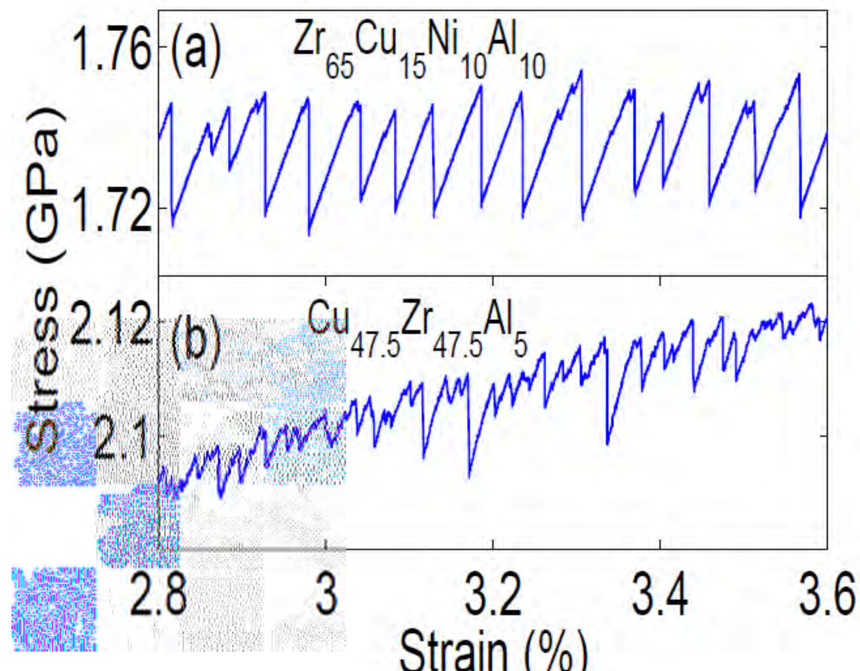

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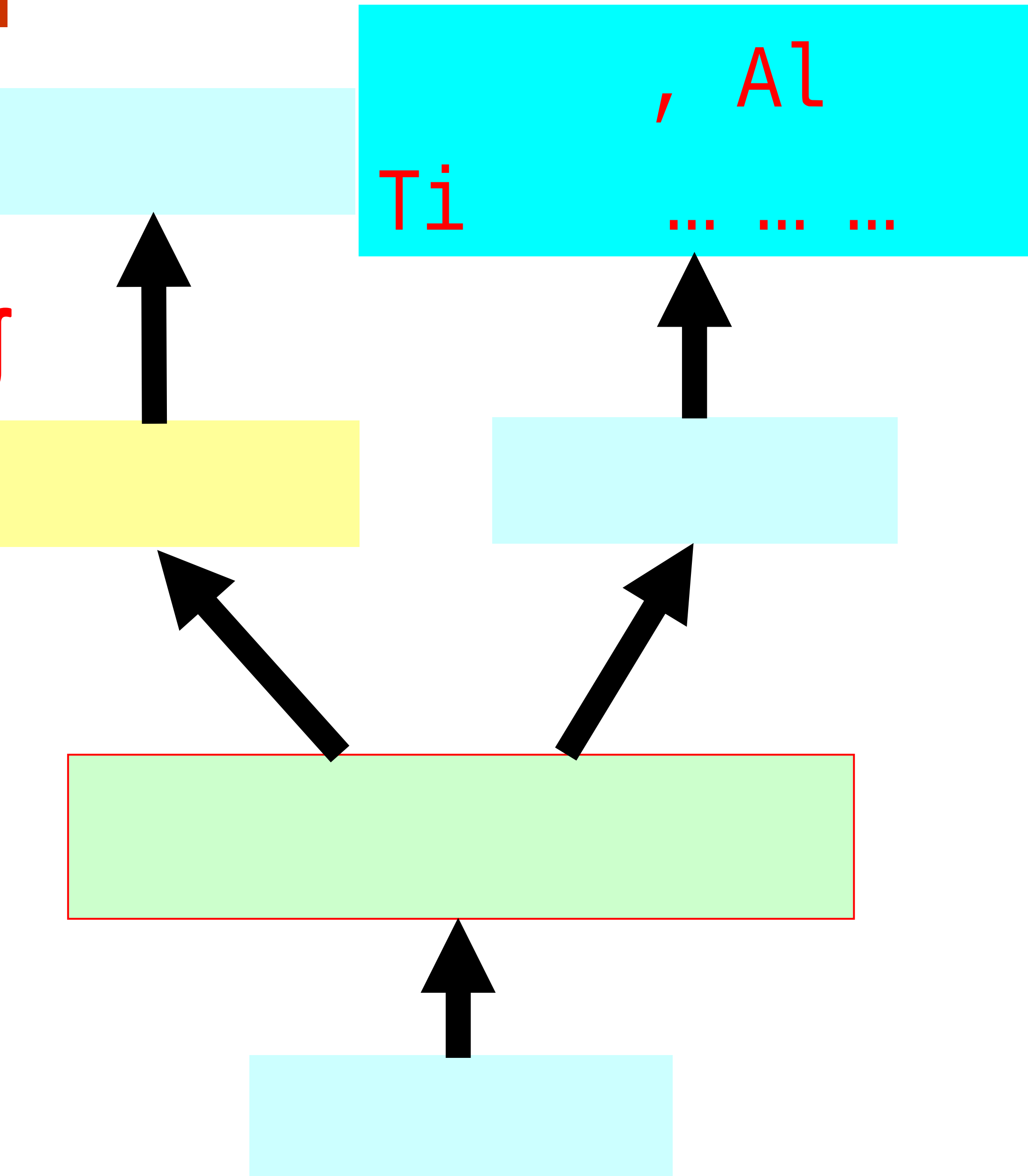

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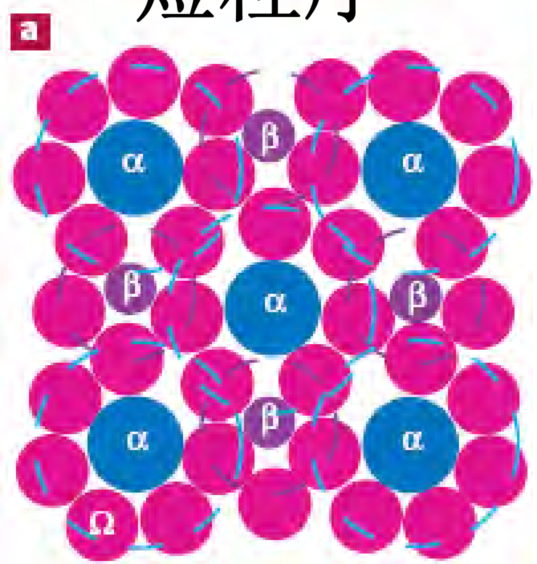

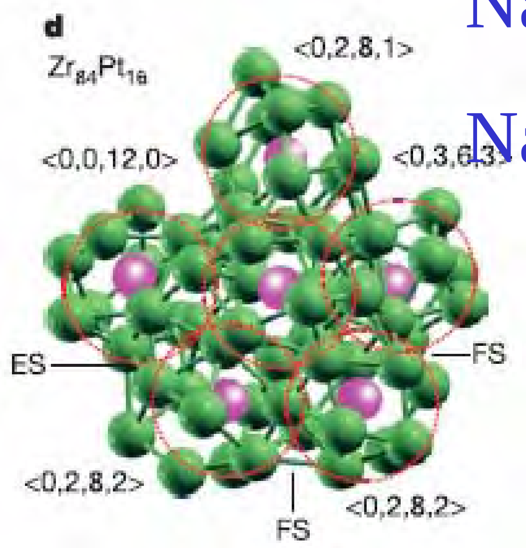

Nature Mat 3, 697 (2004)

Nature, 439, 419 (2006)

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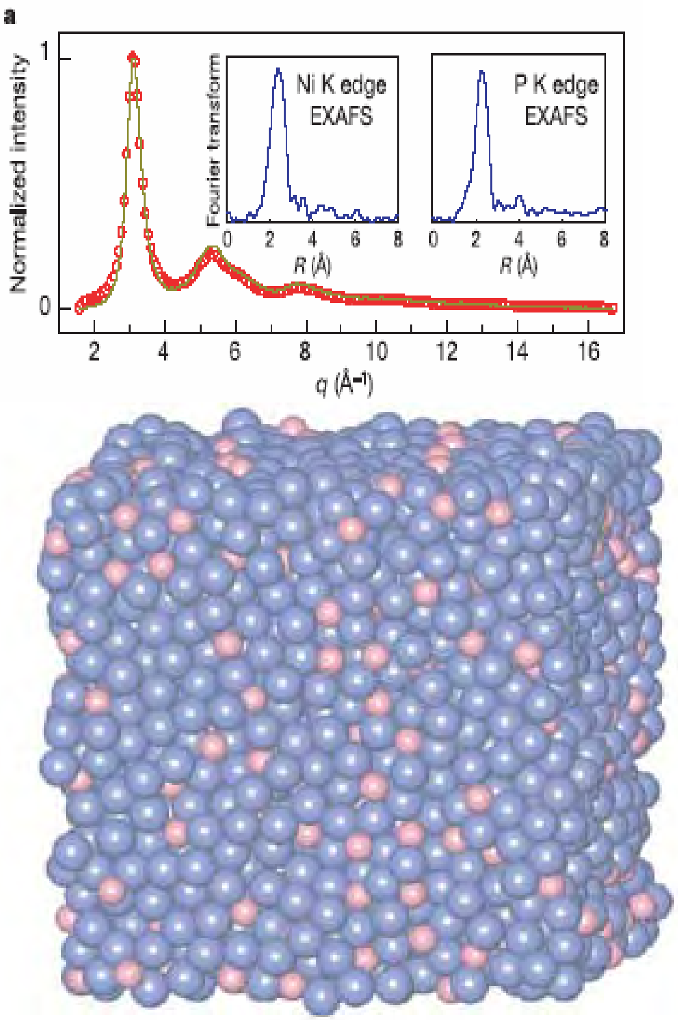
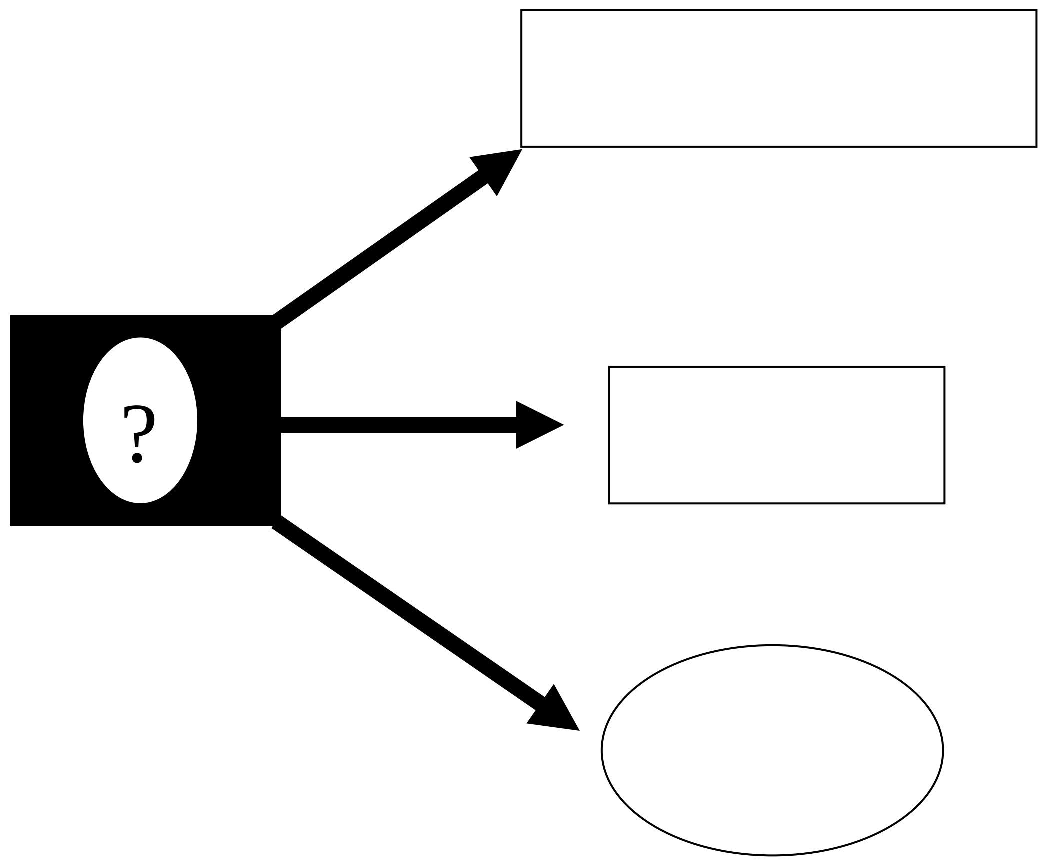


a
Normalized intensity
Fourier transform
Ni K edge
EXAFS
P K edge
EXAFS
R (Å)
q (Å⁻¹)



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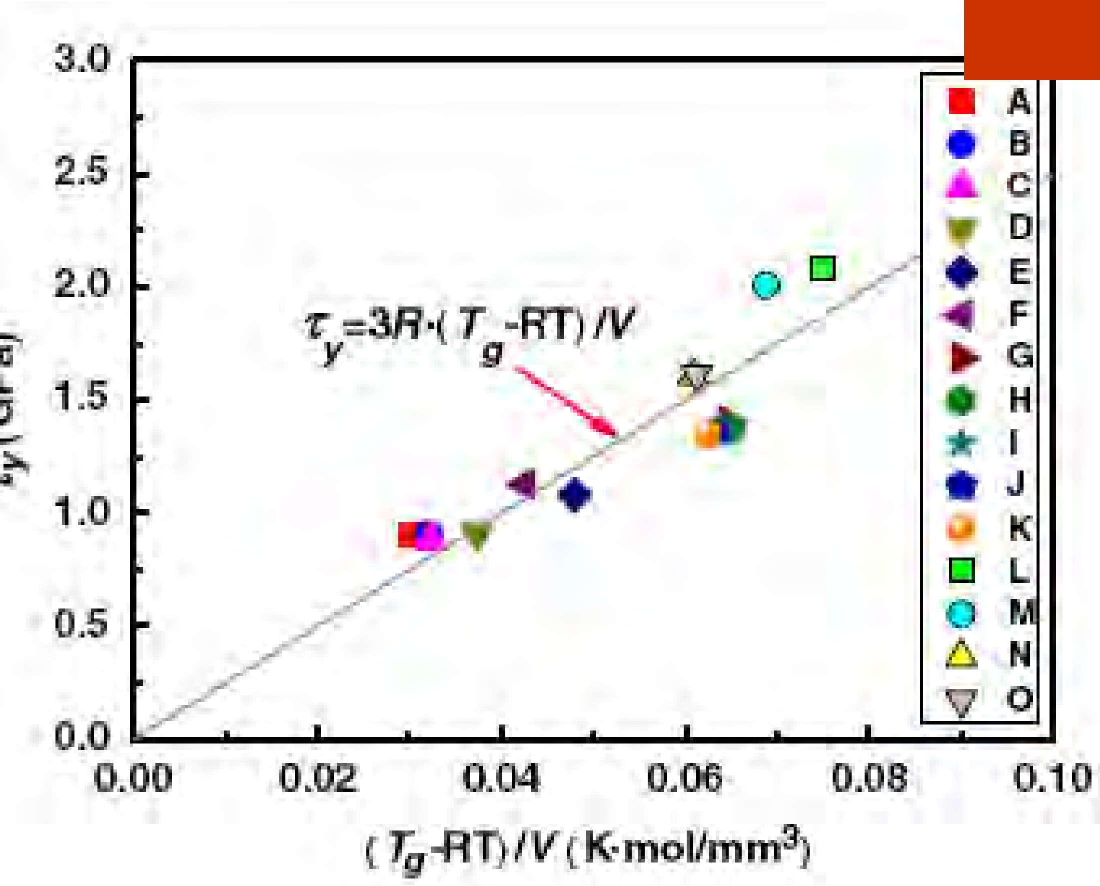

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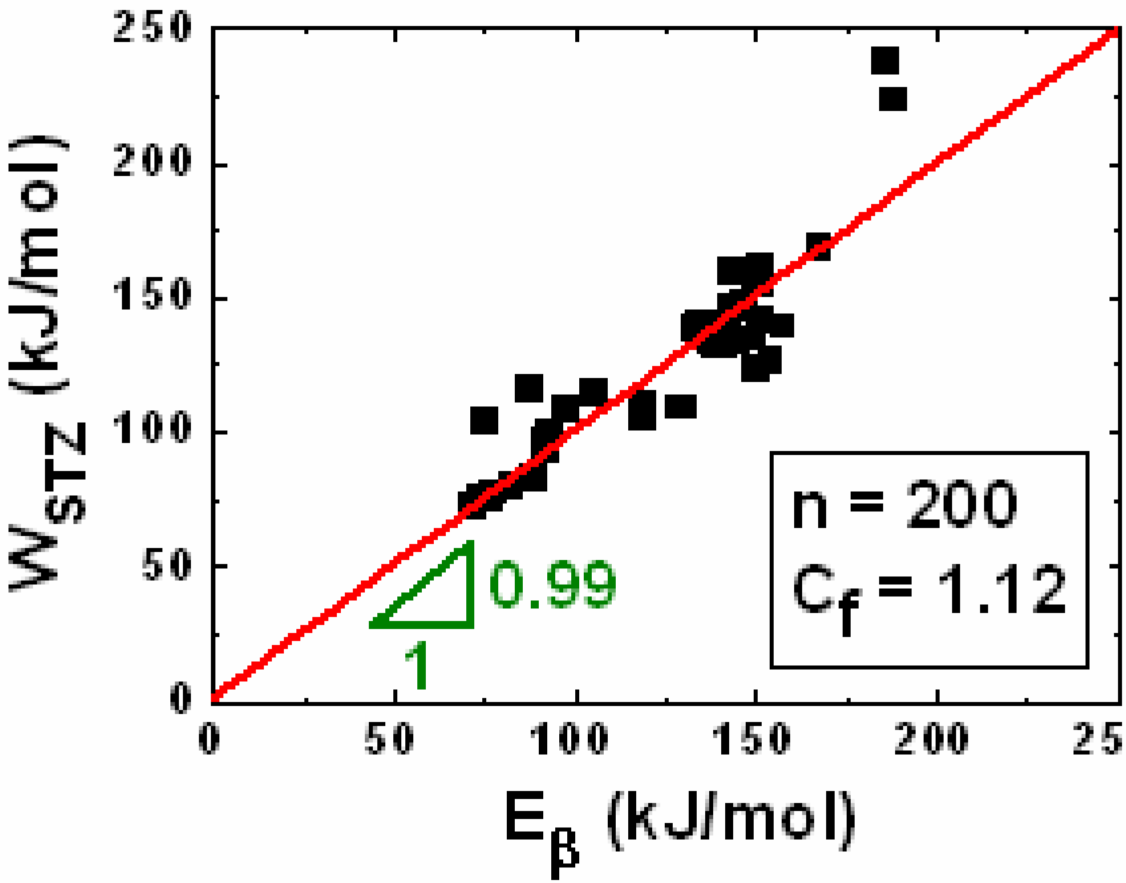
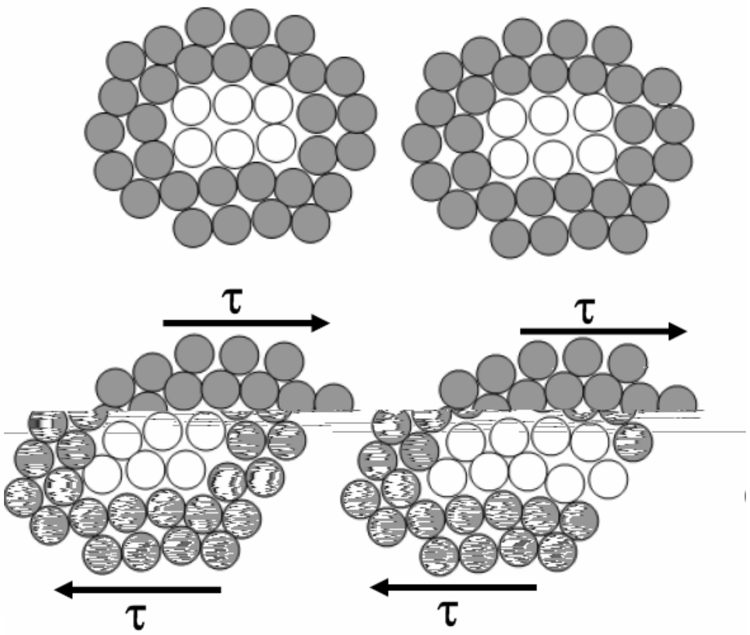
PRL 103, 065504 (2009)



$$W_{STZ} \approx E_\beta$$



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PRL， 103, 065504(2009)

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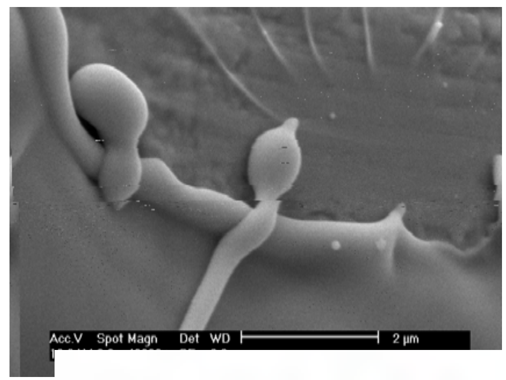
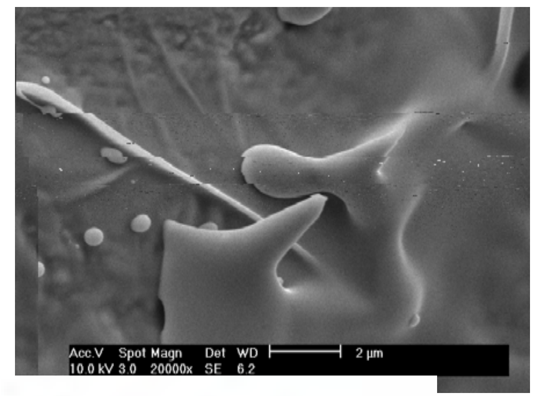
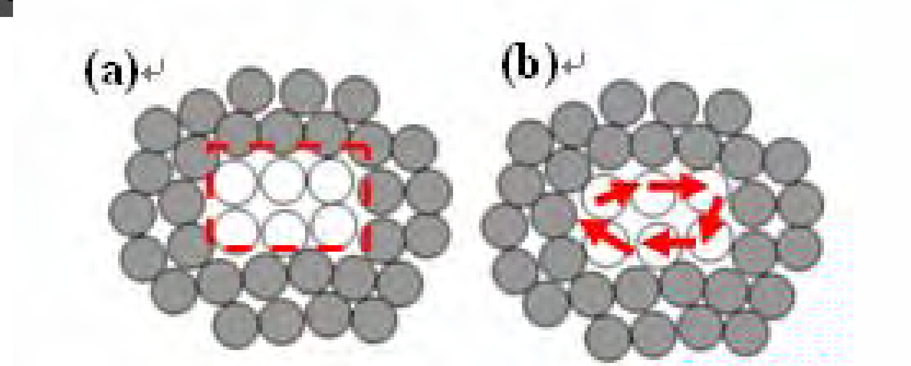

Acc.V Spot Magn Det WD 2 µm


Acc.V Spot Magn Det WD 2 µm
10.0 kV 3.0 20000x SE 6.2


(a)
(b)

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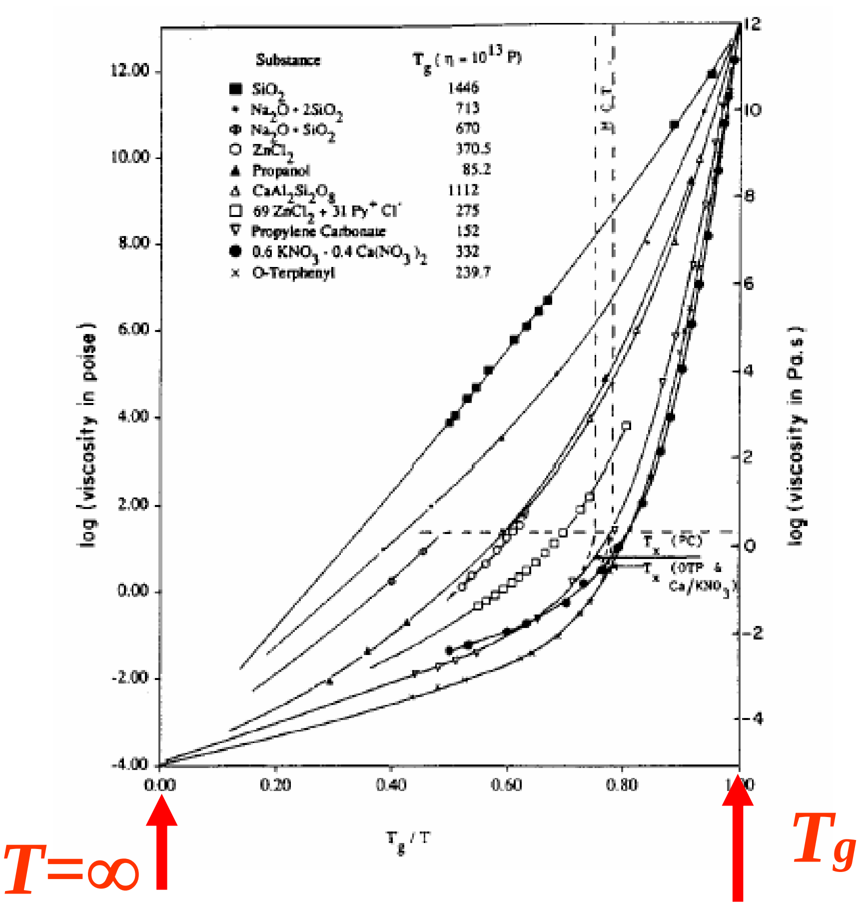
Free volume model

VFT

$$\eta = A\exp[B/(T - T_0)]$$



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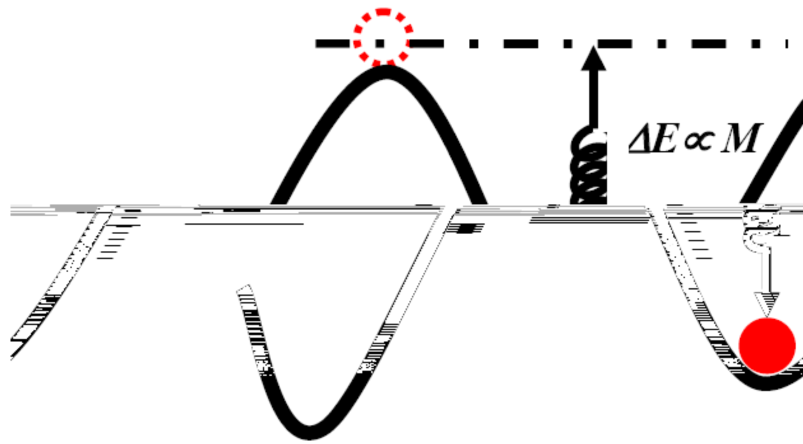
$$\eta = \eta_0 \exp[\Delta E(T)/k_B T]$$



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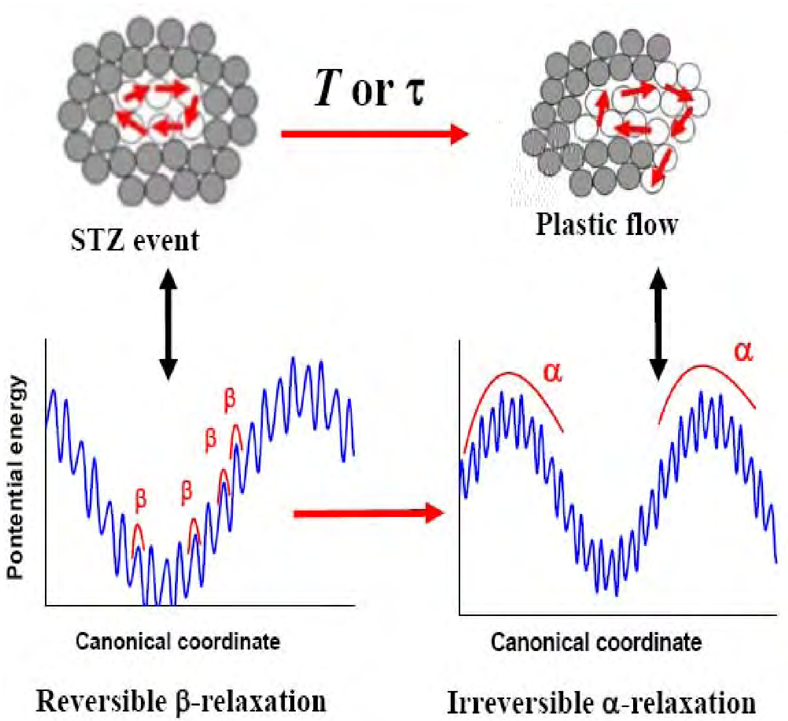

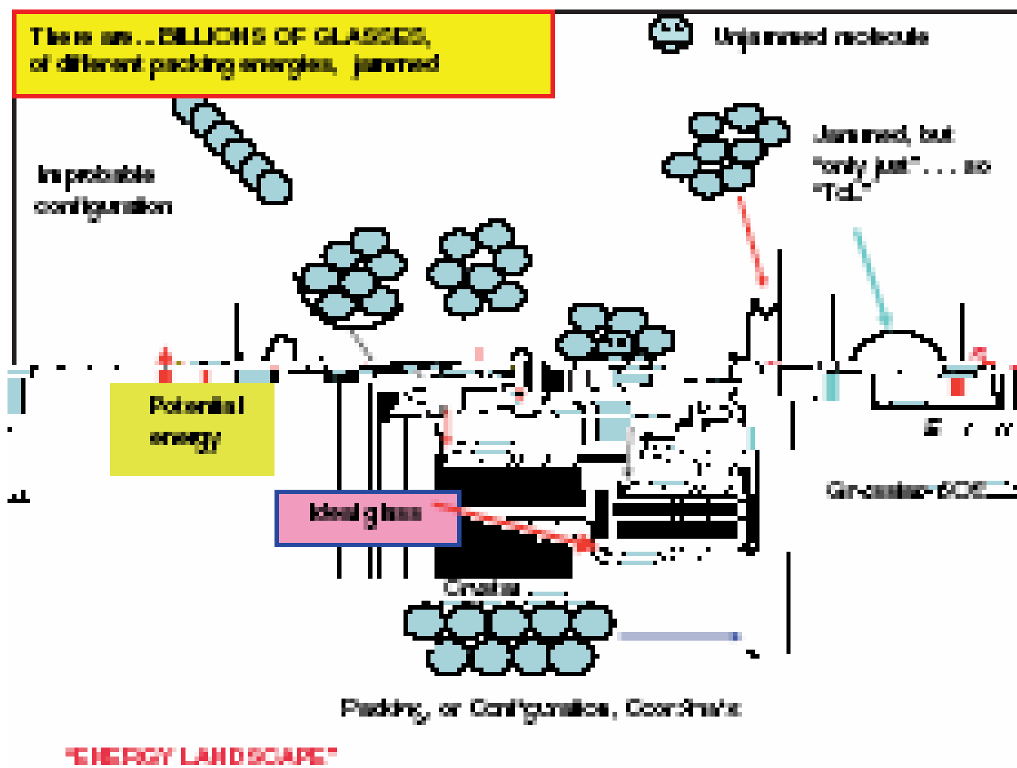

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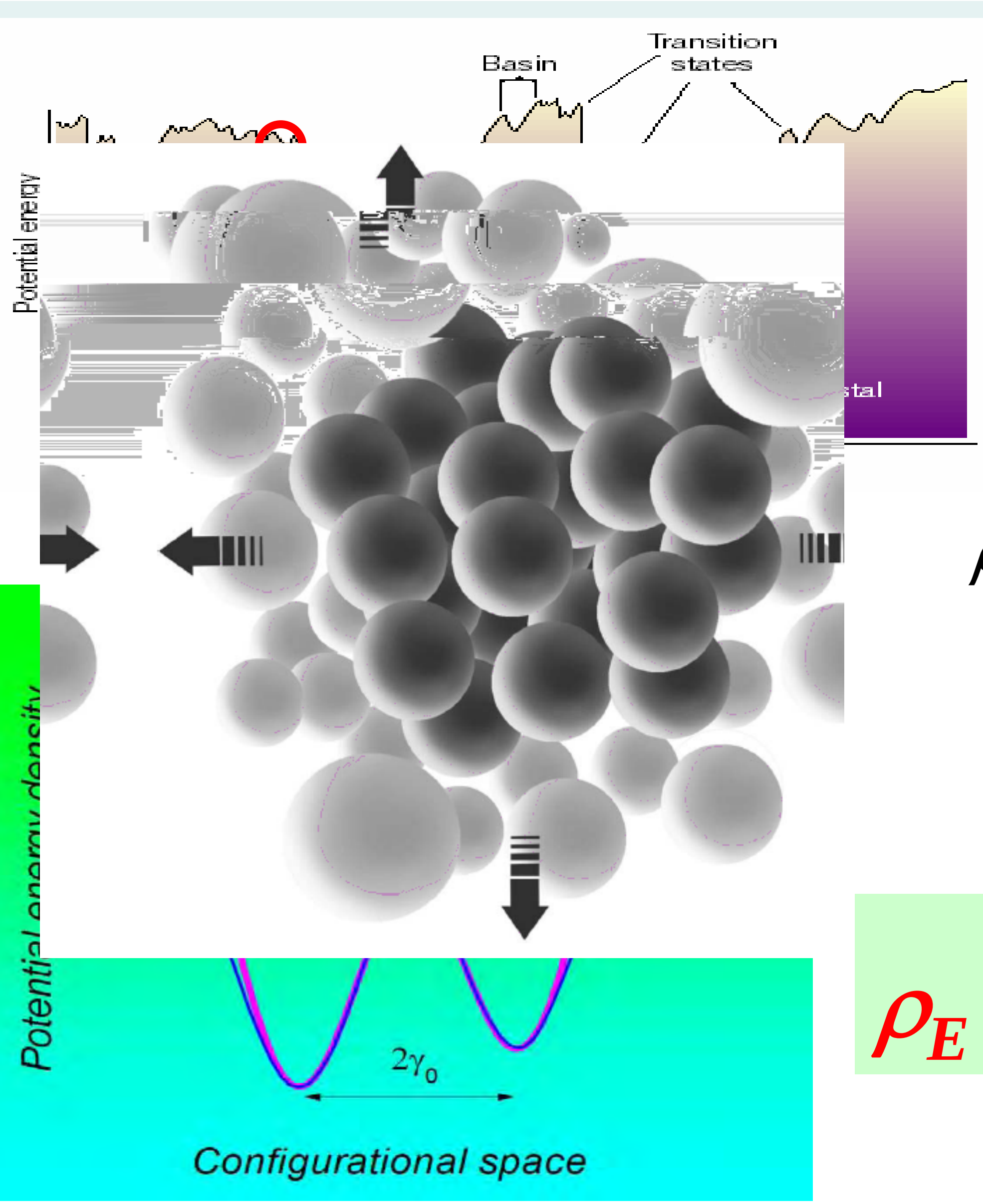

$$\rho_E = \frac{1}{2}\mathrm{M}\gamma^2$$

M—弹性模量，*γ*为一应变

$$\rho_E = \frac{1}{2}\mathrm{M}\gamma_0{}^2 = \frac{1}{2}\frac{k_B T}{\langle\gamma^2\rangle}\gamma_0{}^2 \propto \frac{k_B T}{\langle\gamma^2\rangle}$$

$$\rho_E = (1-\alpha)G + \alpha K$$

$$\boldsymbol{\rho_E = \Delta E/\mathrm{V}_{\mathrm{m}} = (10G+K)/11}$$

PRB 81, 220201 (2011)

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$$G_\infty = \rho k_B T + \frac{2\pi\rho^2}{15}\int_0^\infty \frac{d}{dr}\left[r^4 \frac{dU}{dr}\right] g(r)dr \qquad K_\infty = \frac{5}{3}G - \frac{4\pi\rho}{12}\int_0^\infty \left[r^3 U'(r)\right] g(r)dr$$

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$$\eta = \eta_0 \exp[\Delta E(T)/k_B T]$$

$\Delta E(T) \propto$

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Maxwell

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$\tau_R = \eta/G_\infty$ (1776)

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$$\eta = \eta_0 \exp[\Delta E(T)/k_B T]$$

$$\Delta E(T)/k_B T\,\big|_{T_g} = \text{常数}$$

$$\frac{\rho_E V_m}{RT_g} = \frac{(0.91G + 0.09K)V_m}{RT_g} \equiv \text{constant}$$

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$(0.91G+0.09K)\,Vm/RT_g$ ʹI

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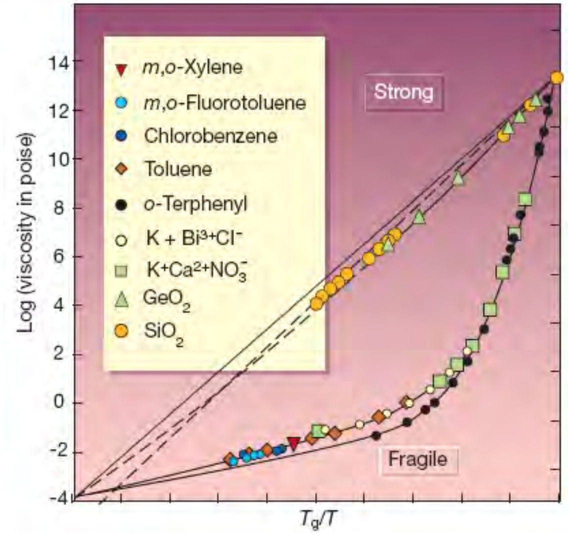
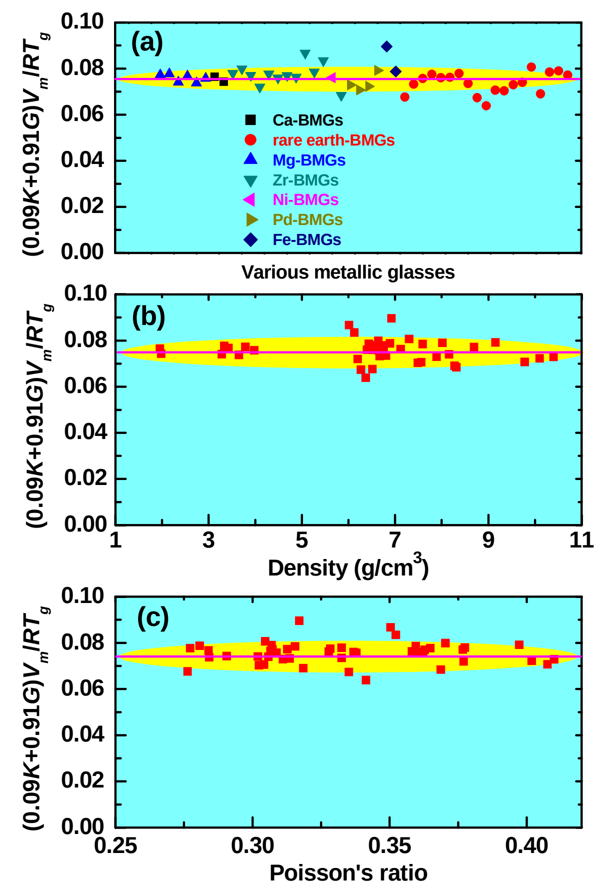
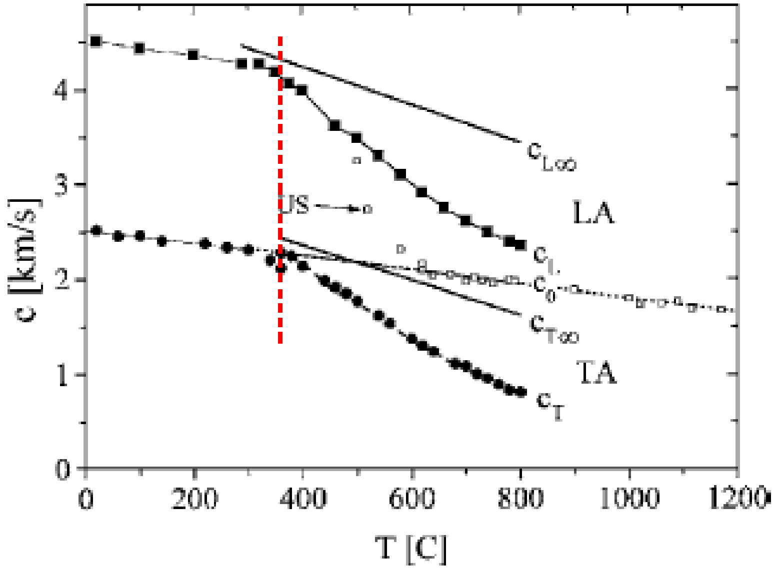
G K $\approx$10:1, ♥

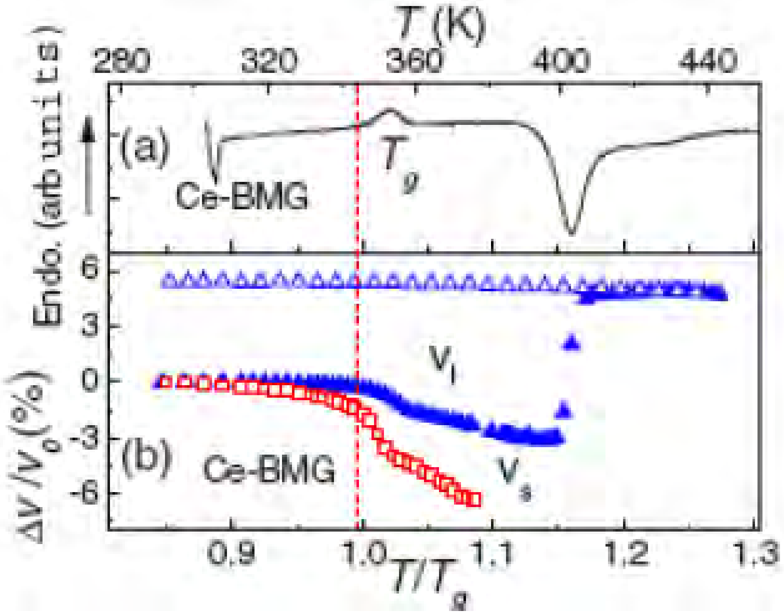
$$\rho_E = (10G+K)V_m/11$$







Rev. Mod. Phys. **78**, 953, (2006).



Phys. Rev. B **76**, 012201 (2007).

$$\frac{\Delta V_S}{V_S} : \frac{\Delta V_L}{V_L} \approx 2:1$$

$$\boldsymbol{\rho_E = (10G+K)/11}.$$

$$\left.\begin{aligned} \rho V_S^{\,2} &= G \\ \rho V_L^{\,2} - \frac{4}{3}\rho V_S^{\,2} &= K \end{aligned}\right\} \xrightarrow[V_S/V_L \approx 0.5,\ \nu \approx 0.333]{\frac{\Delta V_S}{V_S} : \frac{\Delta V_L}{V_L} \approx 2:1} \frac{\Delta G}{G} : \frac{\Delta K}{K} \approx 5:1$$

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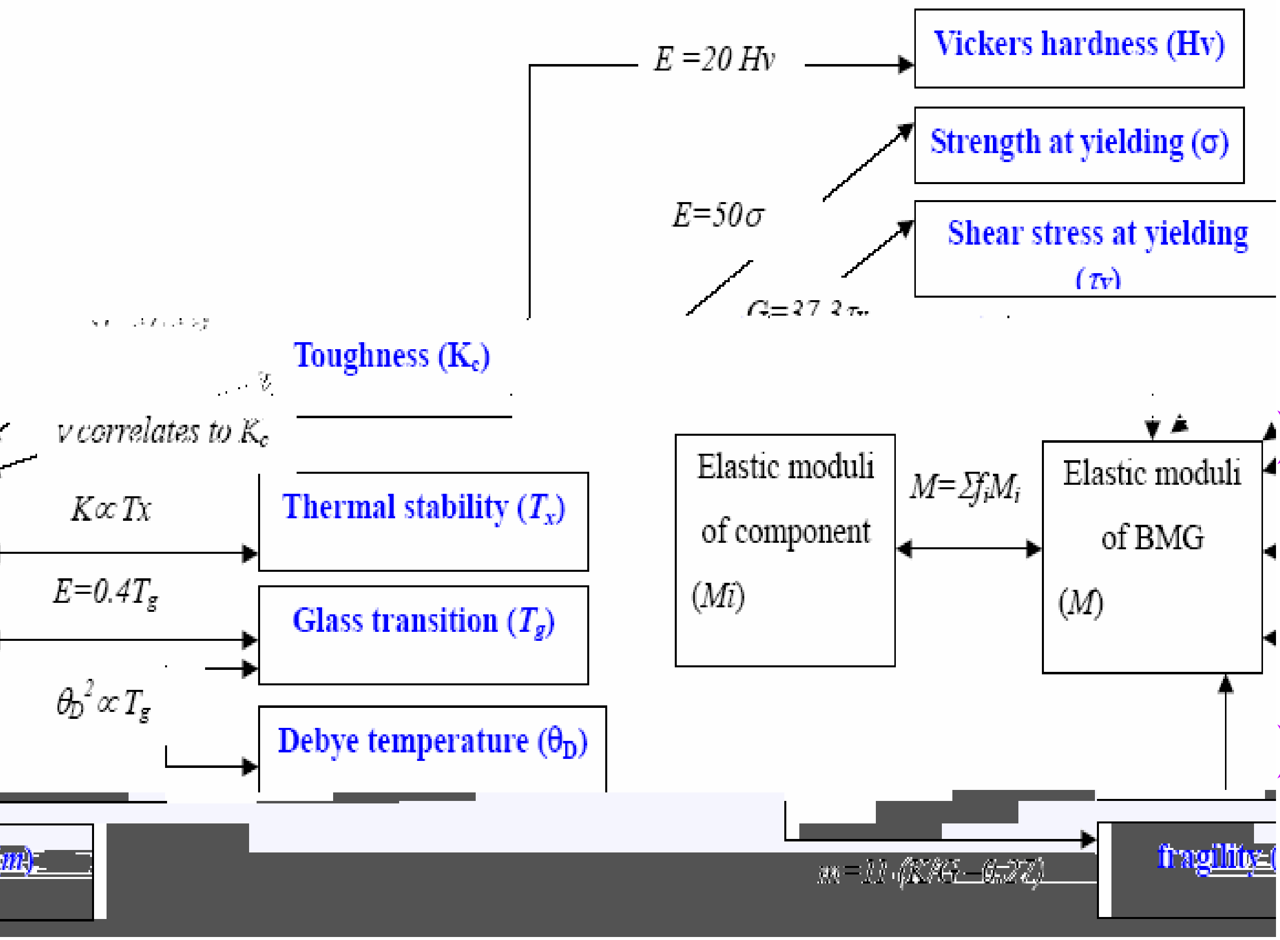

$E = 20\ Hv$
Vickers hardness (Hv)
Strength at yielding (σ)
$E = 50\sigma$
Shear stress at yielding (τ_y)
Toughness (K_c)
ν correlates to K_c
$K \propto Tx$
Thermal stability (T_x)
$E = 0.4T_g$
Glass transition (T_g)
$\theta_D^2 \propto T_g$
Debye temperature (θ_D)
Elastic moduli of component (Mi)
$M = \Sigma f_i M_i$
Elastic moduli of BMG (M)

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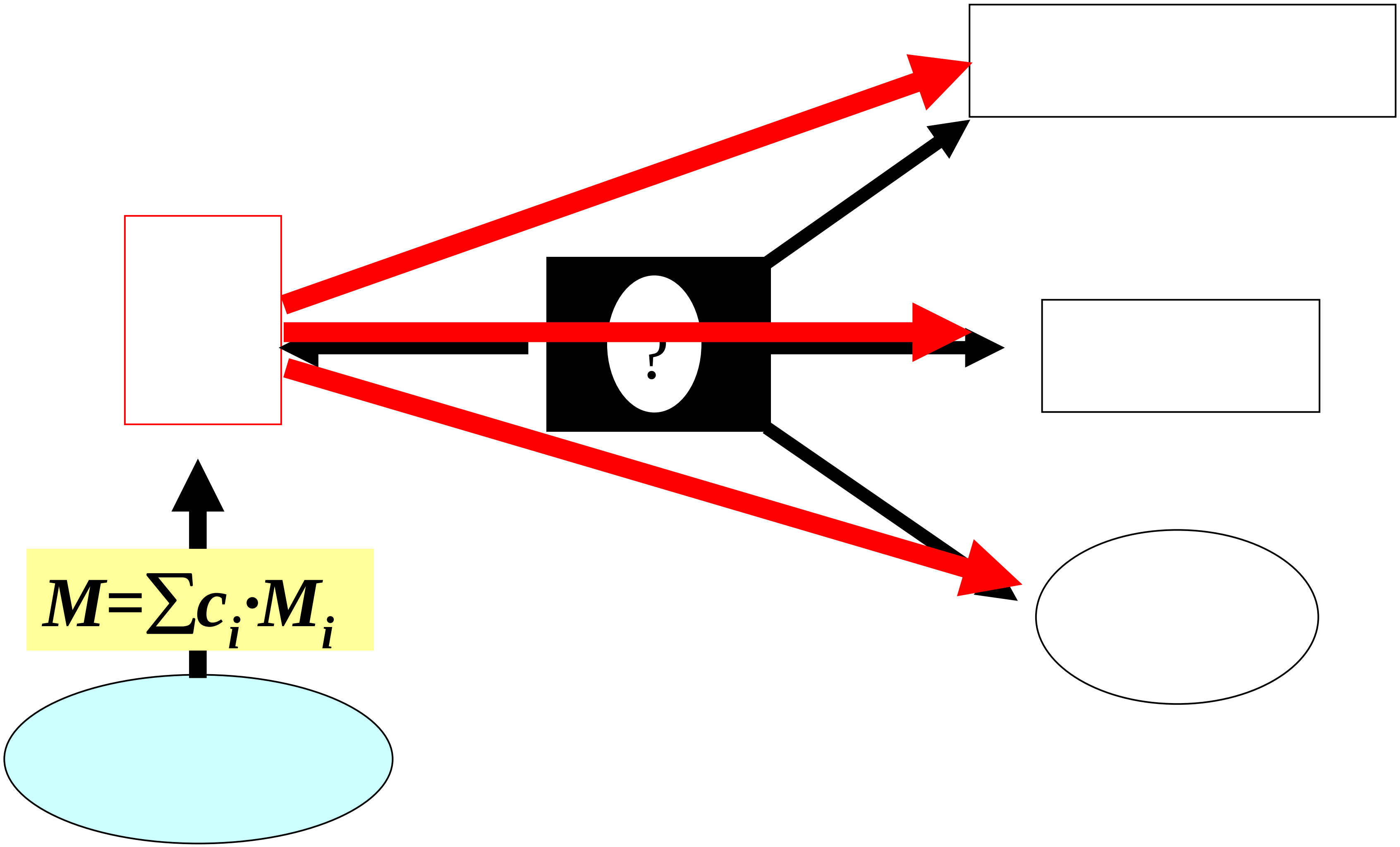
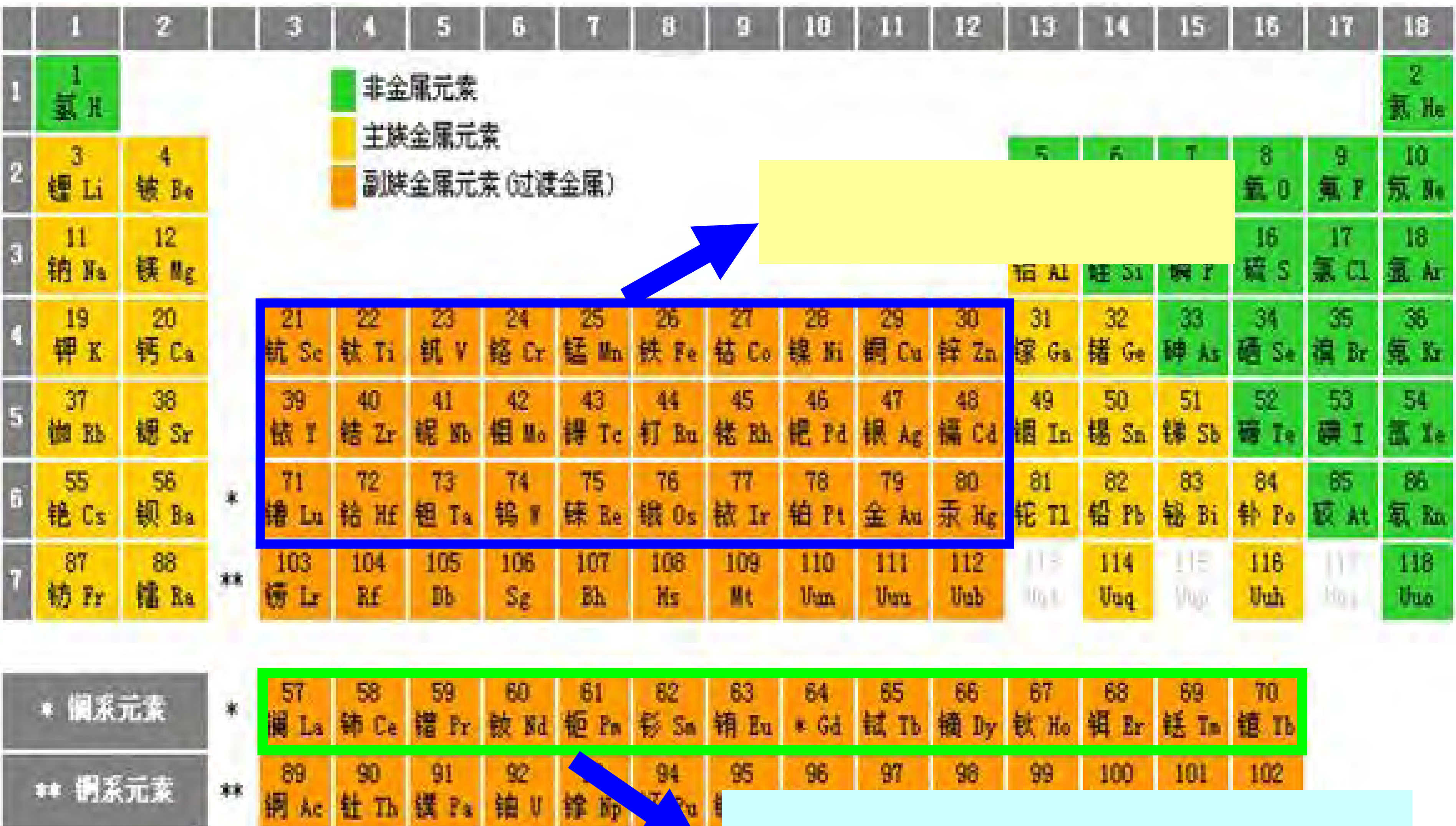


Adv Mater. 21, 4524 (2009)



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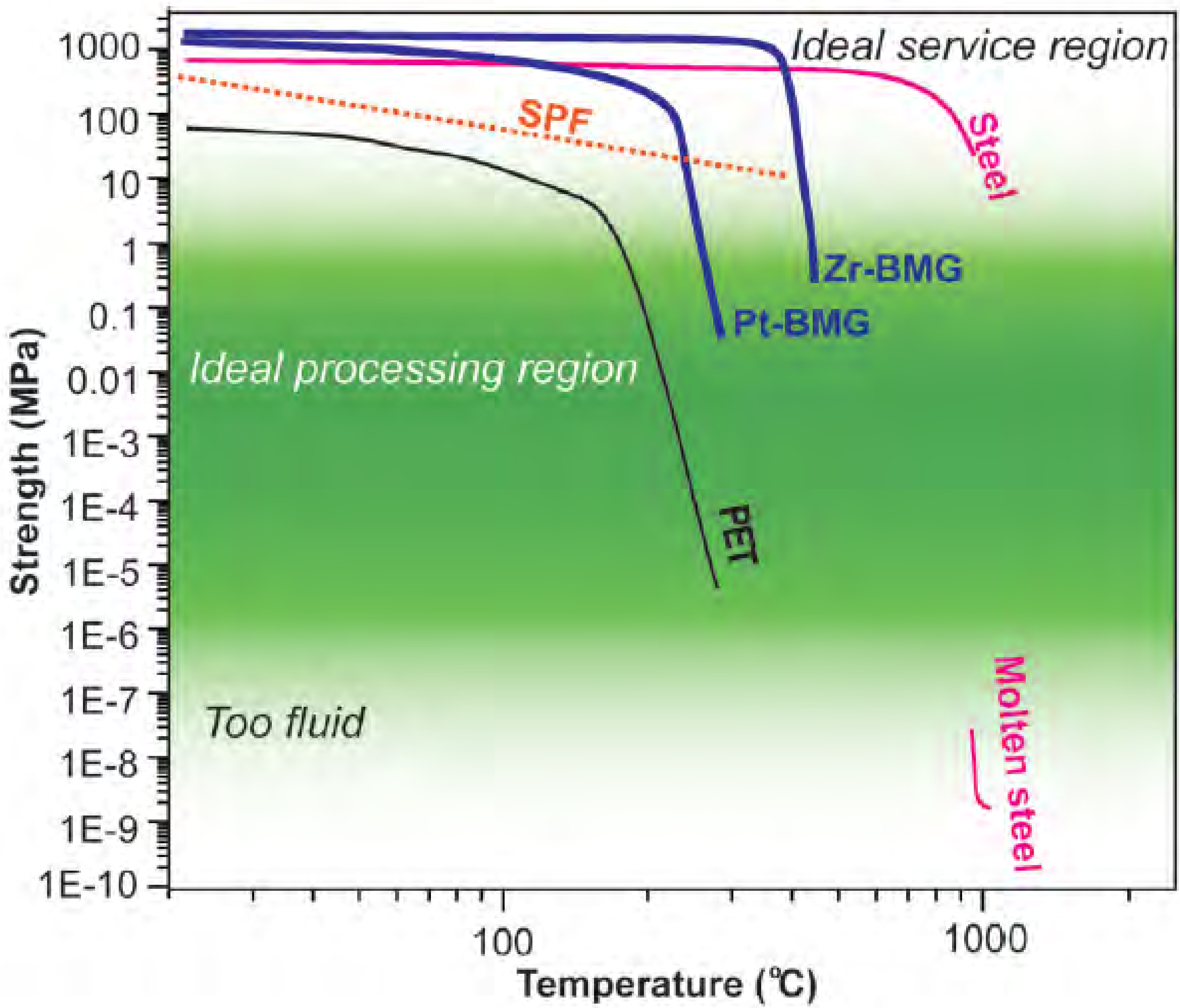
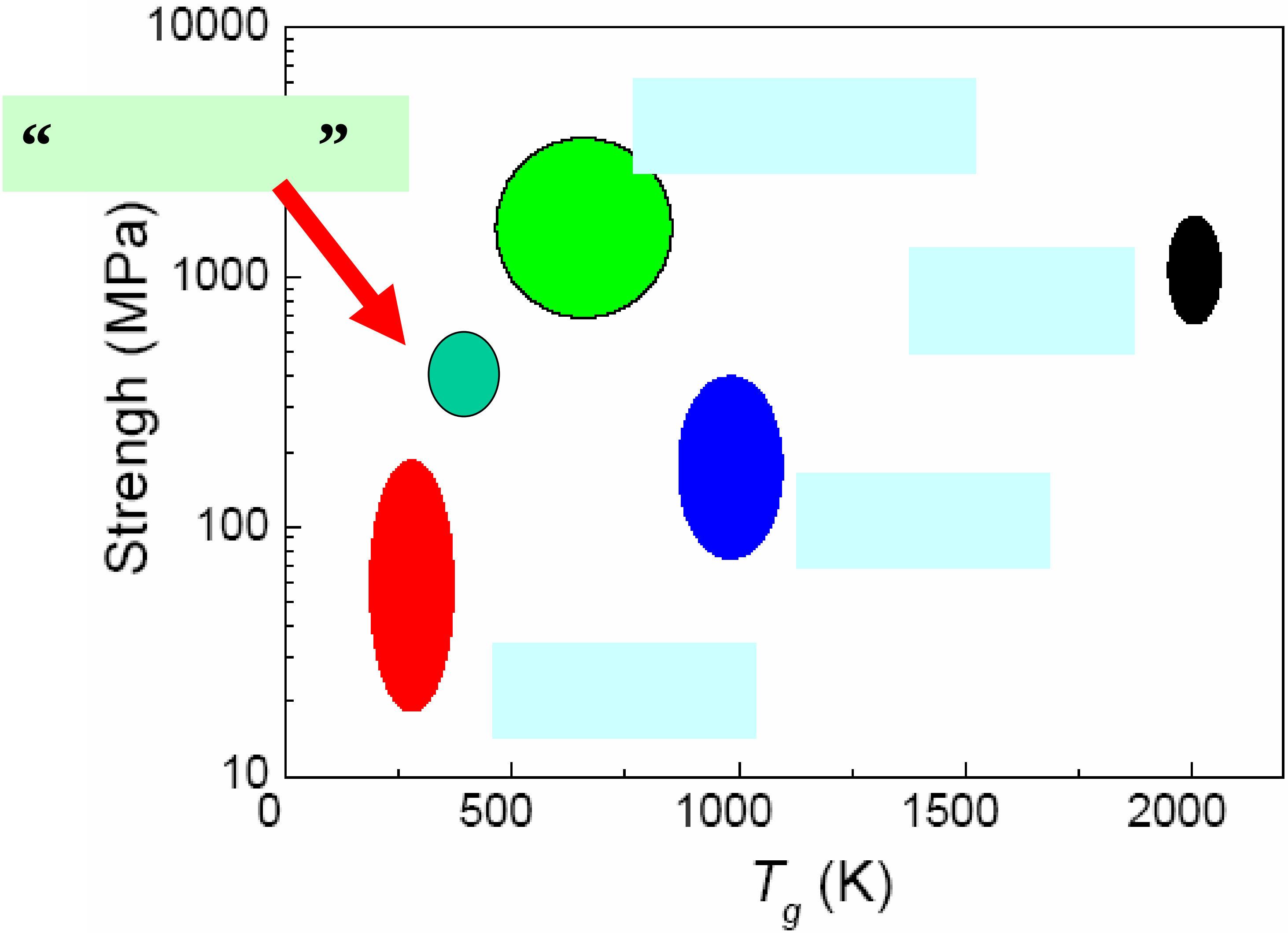


Ideal service region
SPF
Steel
Zr-BMG
Pt-BMG
Ideal processing region
PET
Too fluid
Molten steel
Strength (MPa)
Temperature (°C)
1000
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
100
1000


“ ”
10000
1000
100
10
Strengh (MPa)
0
500
1000
1500
2000
T_g (K)

???

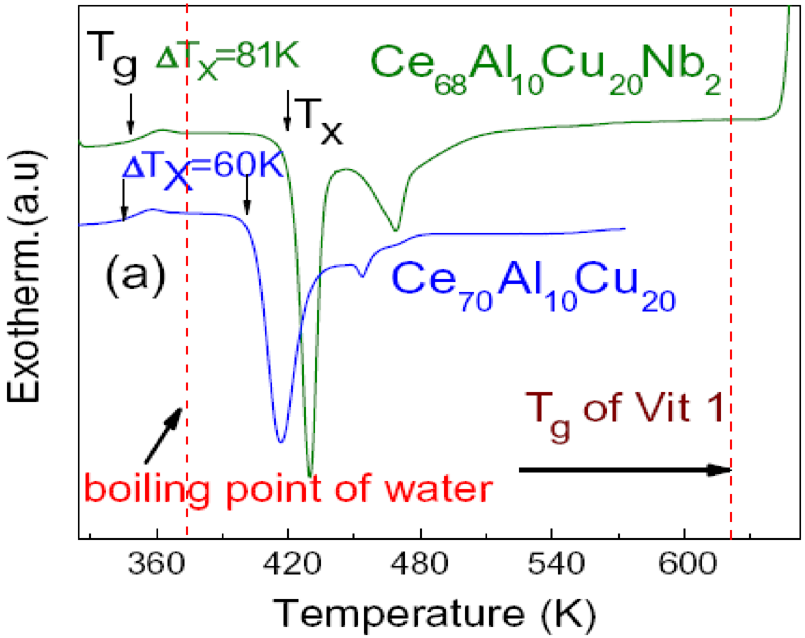
↰

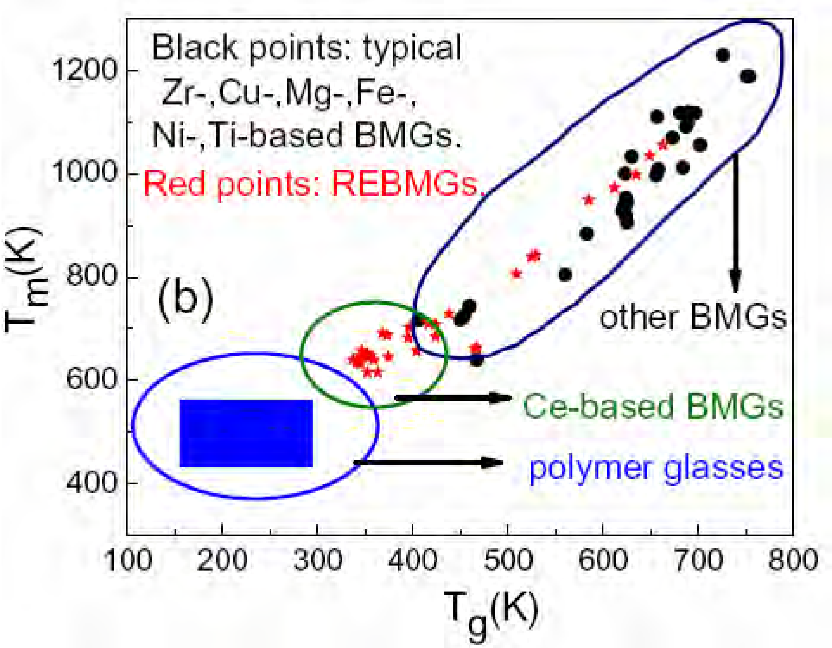
M, T_g, ,

$$E \propto T_g$$

M, T_g M,

M, Tg





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Phys Rev Lett. 94, 205502(2005)

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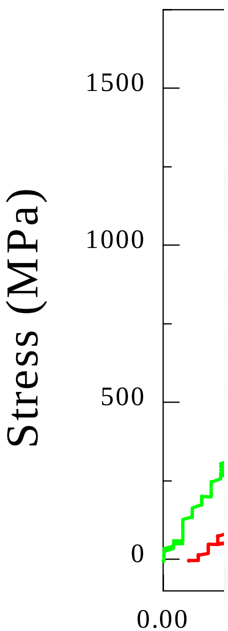
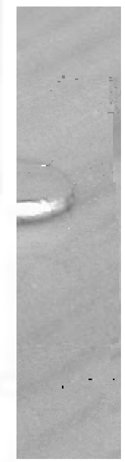
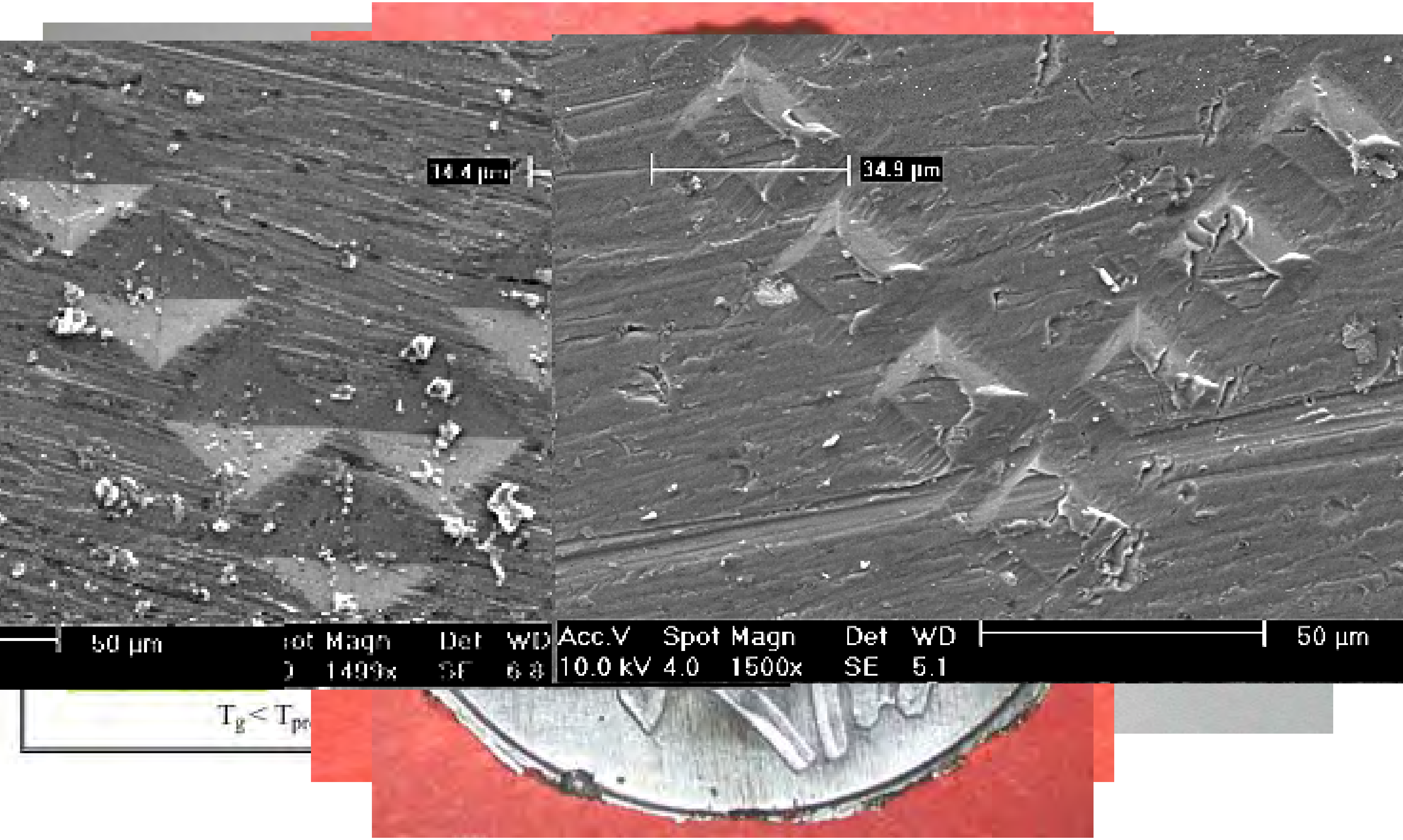
Nature, Highlight, Vol 435, pp.717, 2005



Parameter	Materials		
	Plastics	BMG	SPF alloys
Processing temperature [°C]	160-260°C	160°C (Au-based) 280°C (Pt-based) 350°C (Pd-based) 430°C (Zr-based	900°C (Ti_6Al_4)[18] 465°C (Al 2004)
Processing pressure [Pa]	1-10 x 10^5 Pa	1-4 x 10^5 Pa	1-4 x 10^5 Pa
Maximum strain	∞	~10 000%	<400%
Typical strain rate [s^{-1}]	10^{-1} -1	10^{-1}	10^{-3}
m	~1	1	0.4-0.7
$ms = \left.\frac{d\log(h/G)}{dT_g/T}\right\|_{T=T_g}$	137[20]	52 (Pt-based)[21] 70 (Zr-based)[21]	Not applicable
κ [W/mK]	0.3	10	170





PRL, 94, 205501 (2005)

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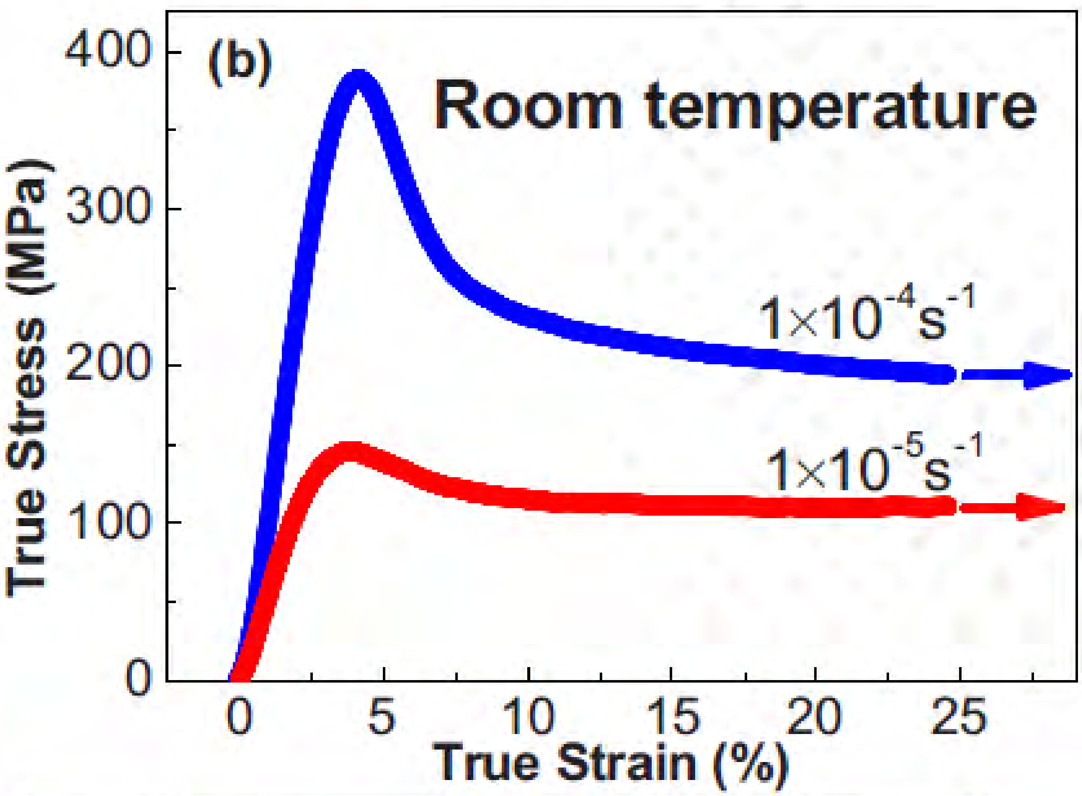
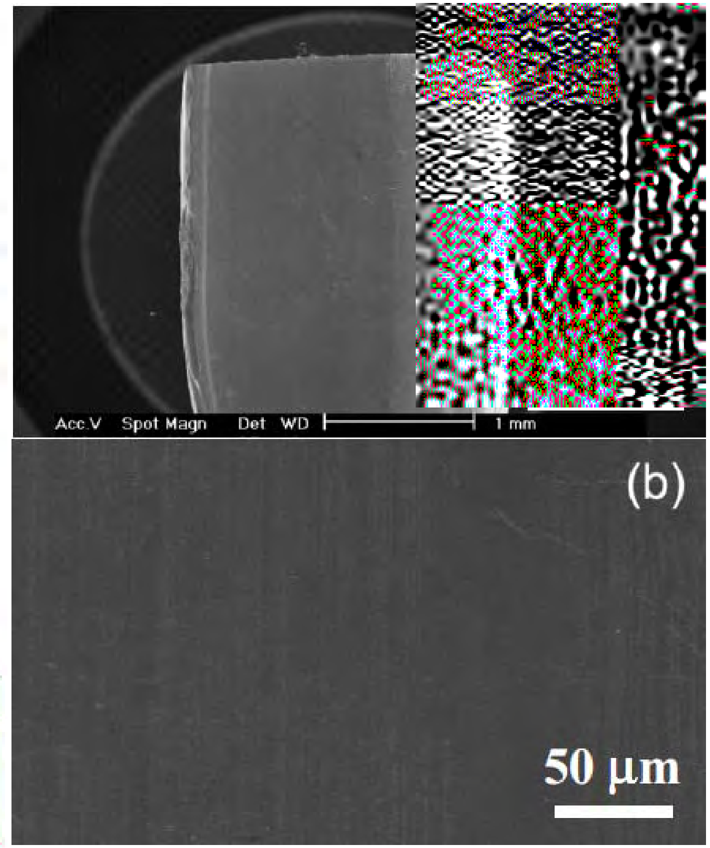
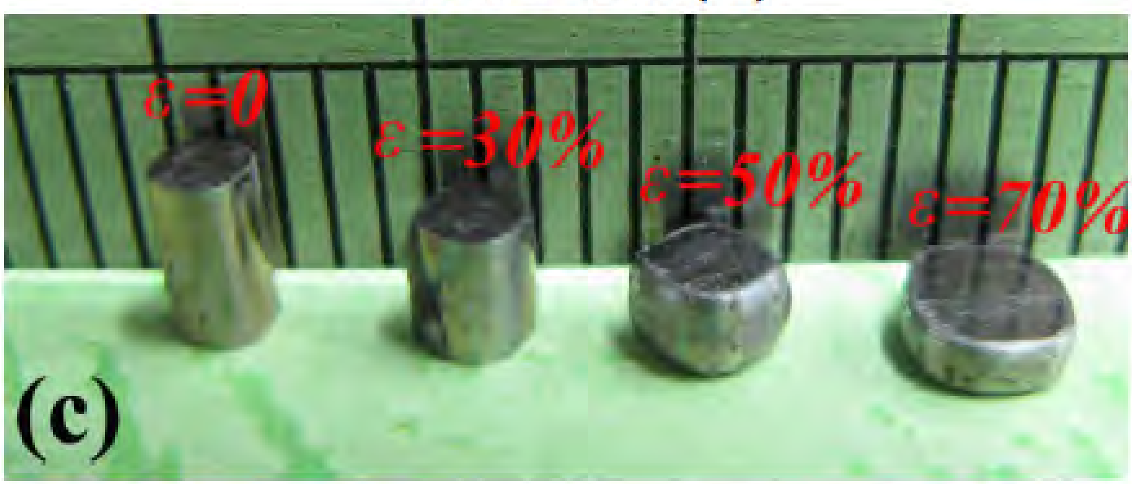
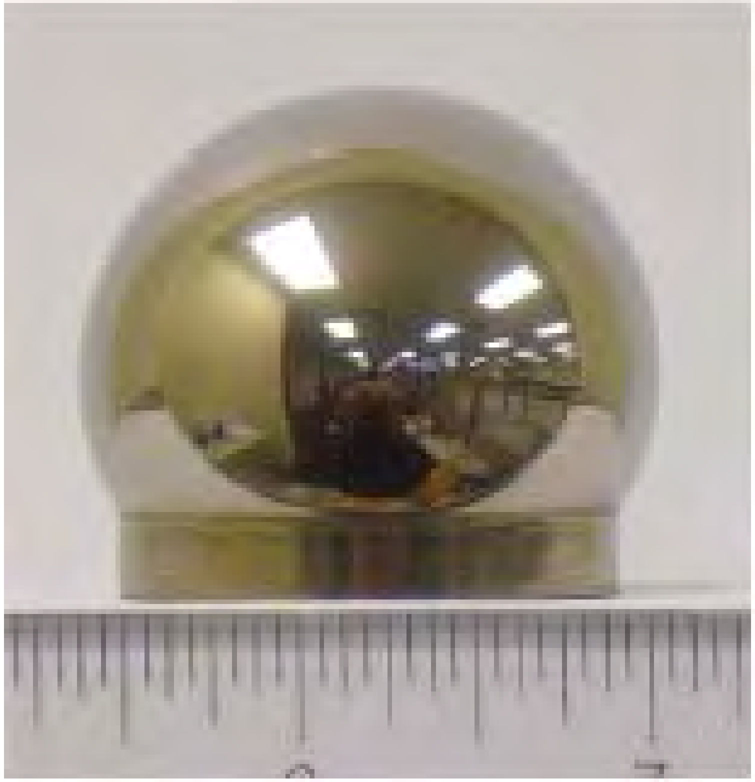






Appl Phys Lett 2011



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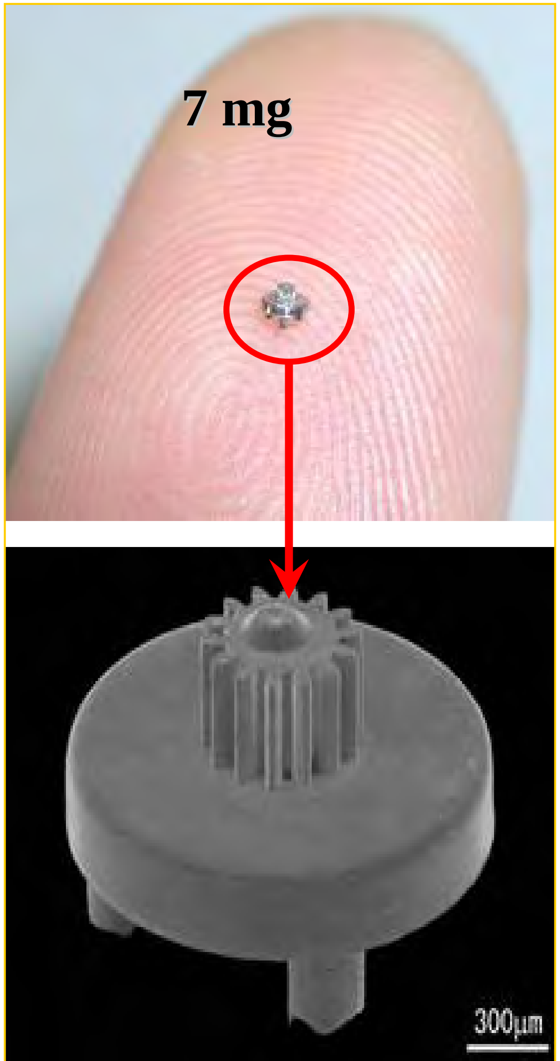
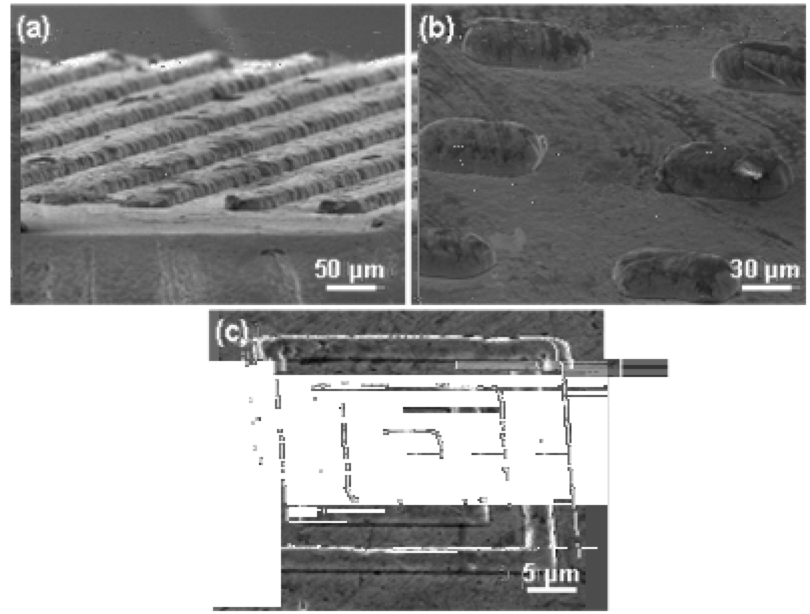
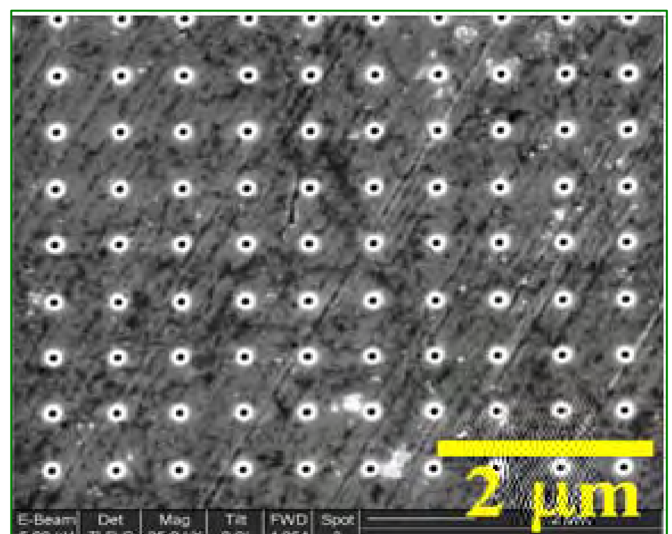
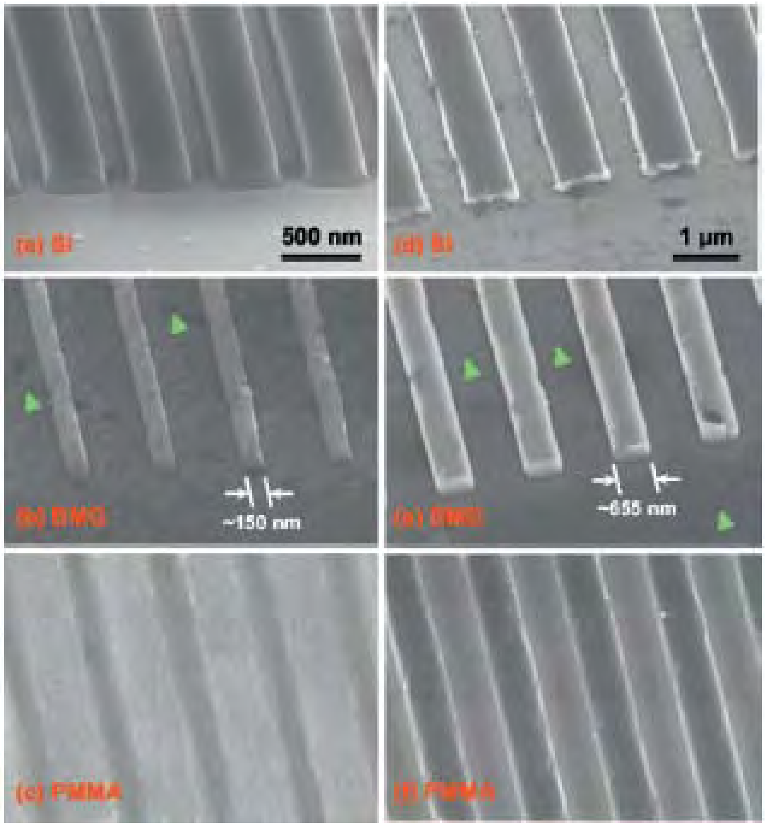
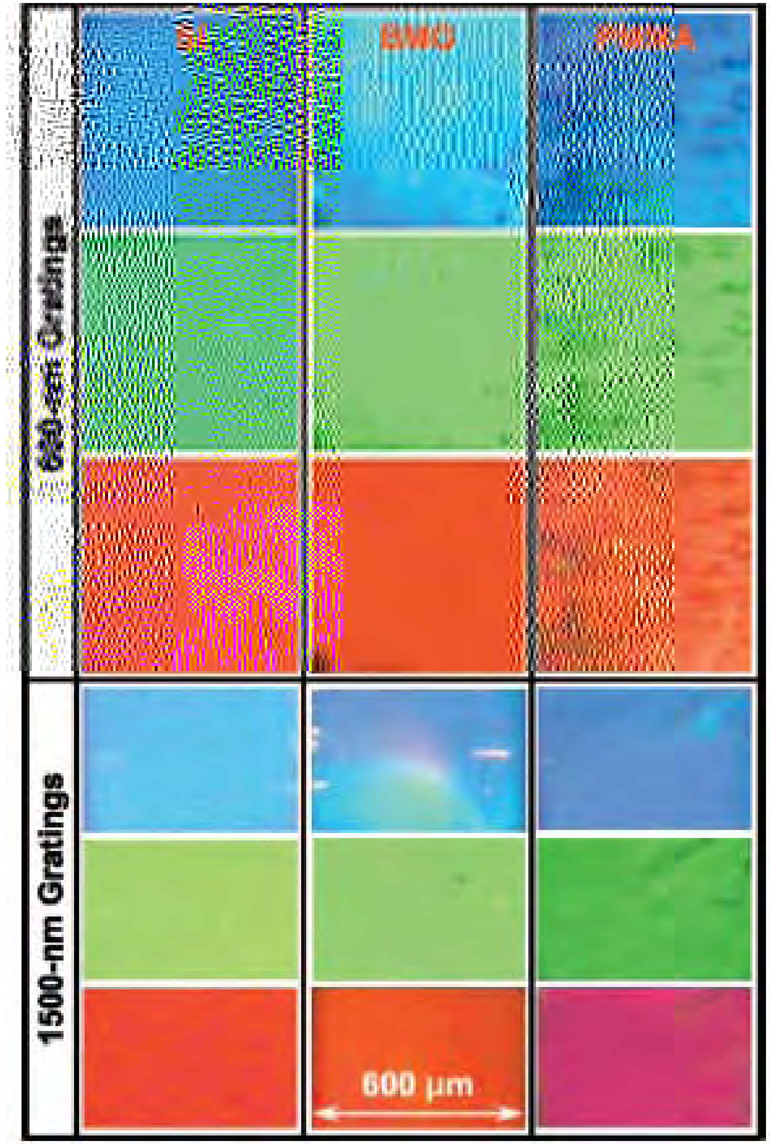

7 mg
300μm


(a)
50 μm
(b)
30 μm
(c)
5 μm


2 μm
E-Beam 5.00 kV
Det TLD-S
Mag 25.0 kX
Tilt 0.0°
FWD 4.954
Spot 3

A promising material for microdevices





microforming of
Ce glass at 420K

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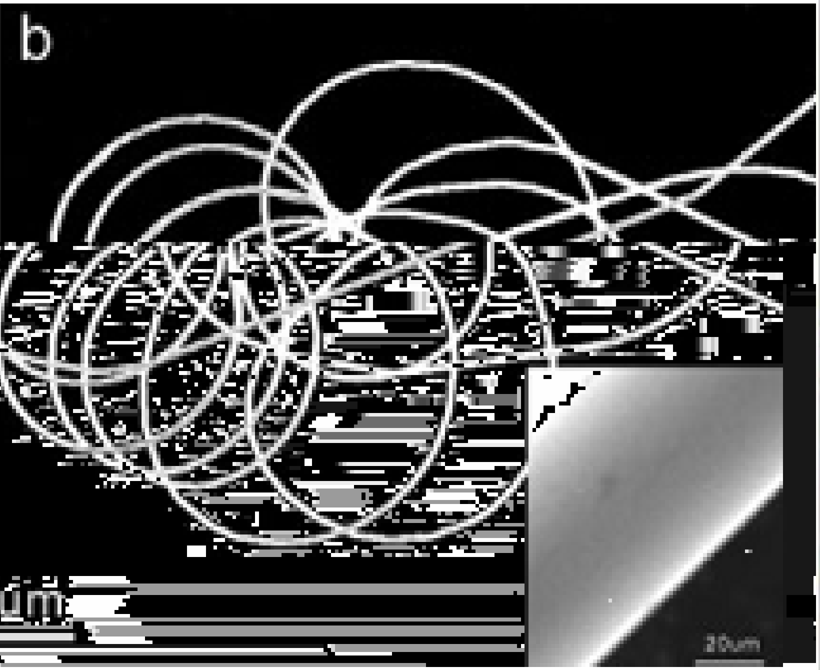

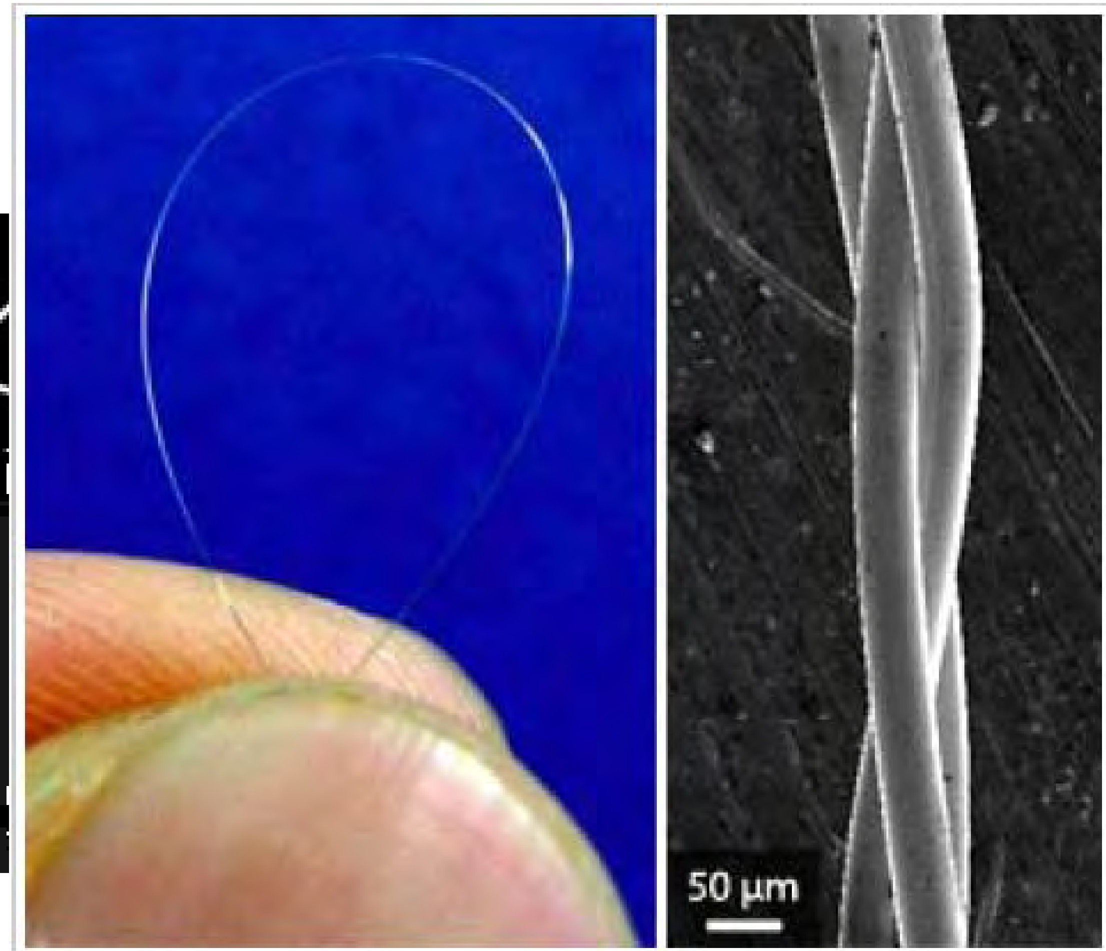

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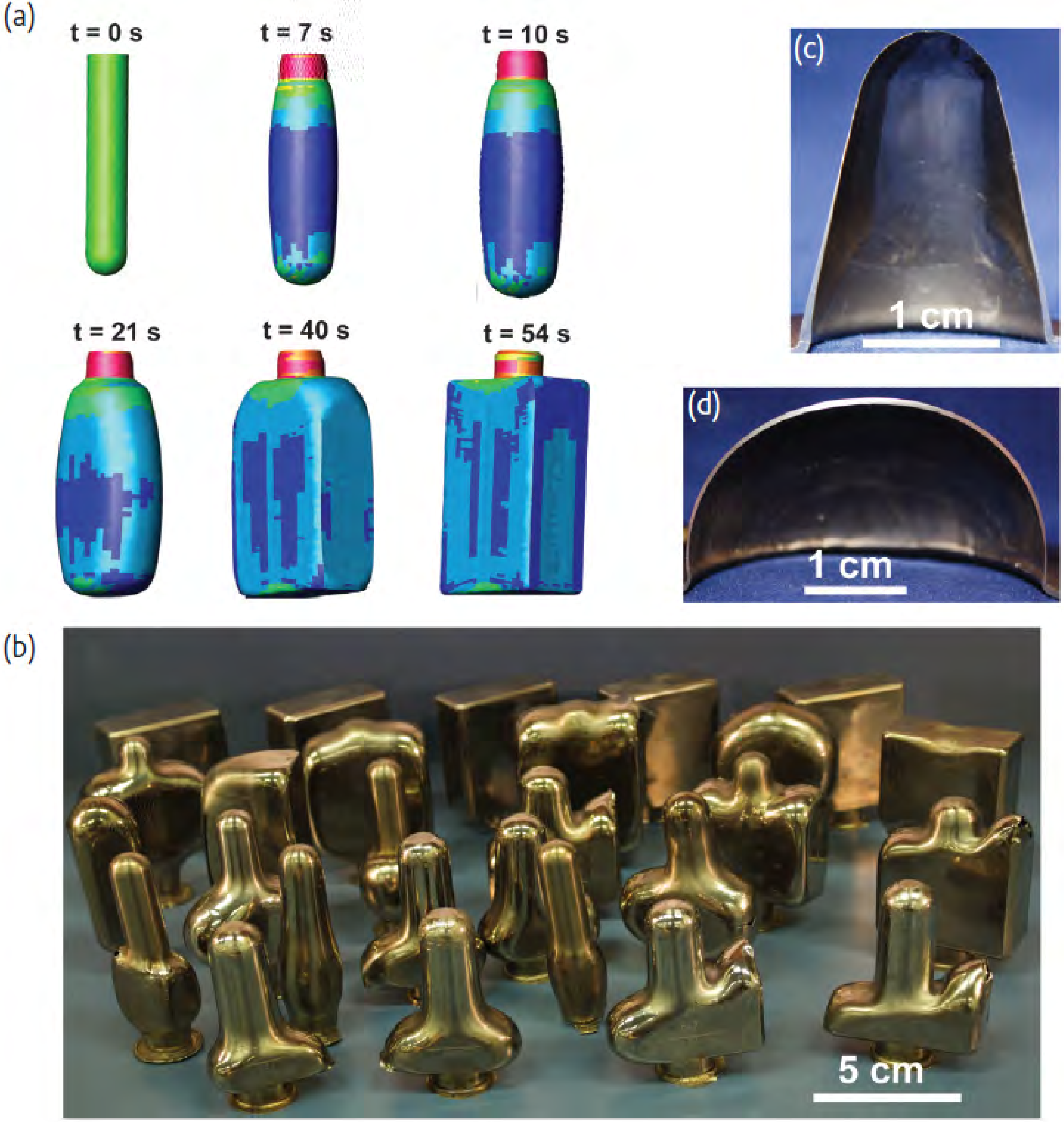
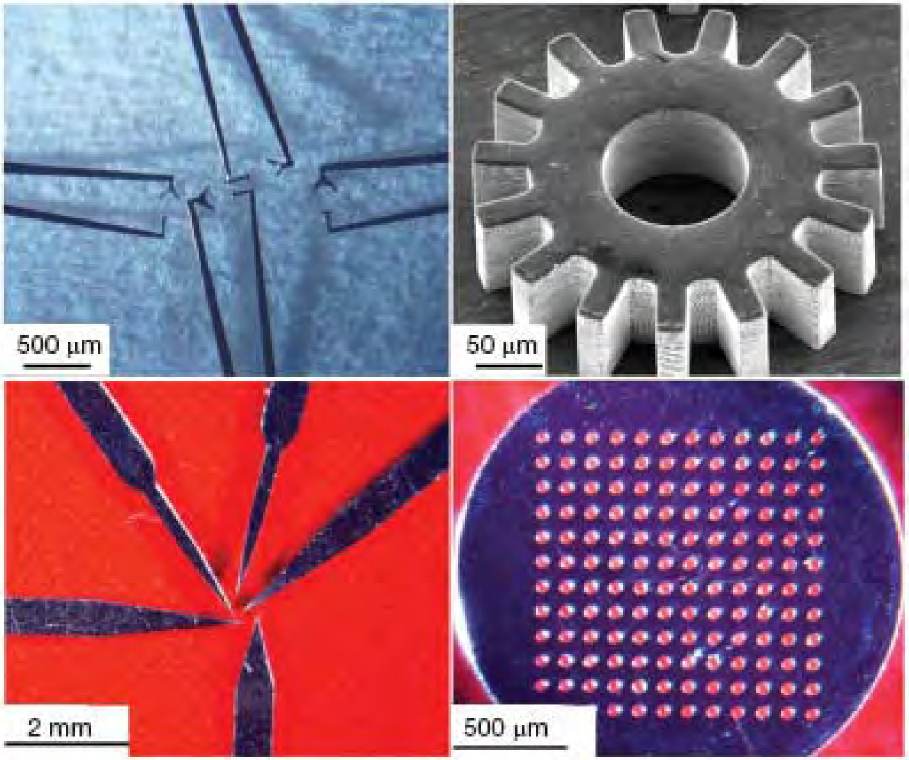
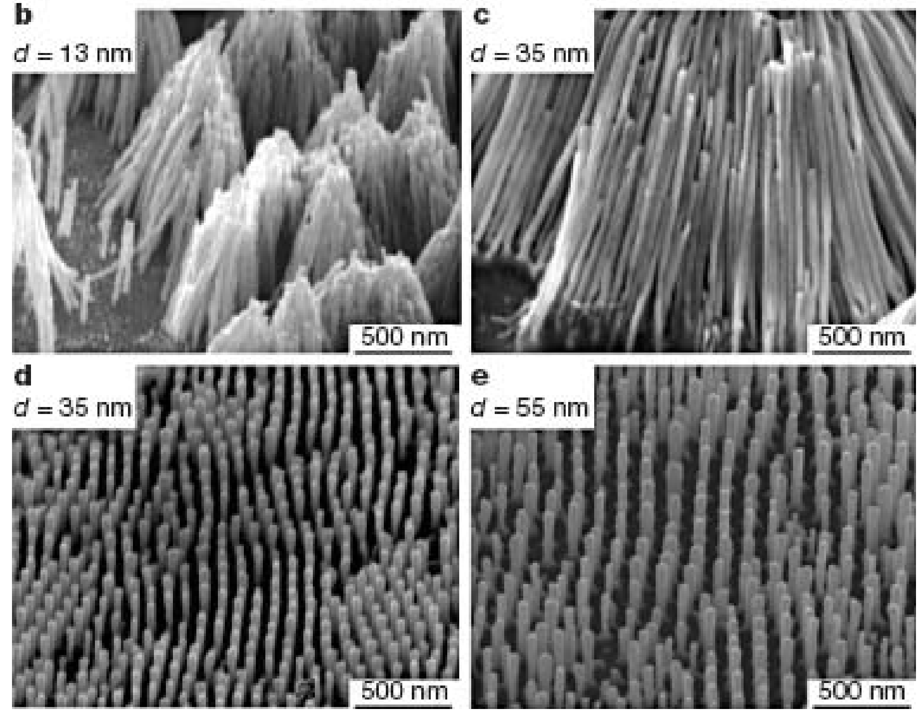
Adv Eng Mat 2010

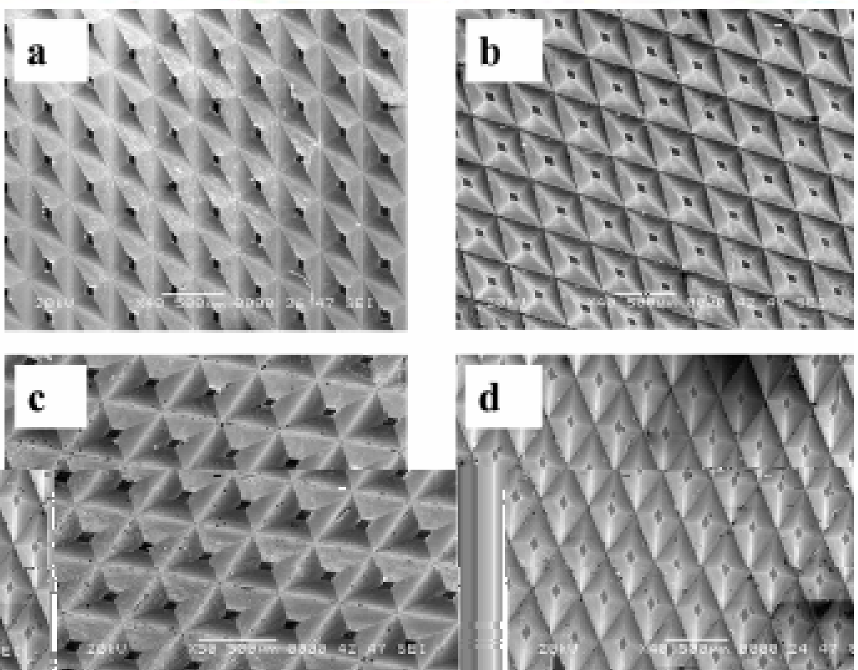

(a)
(b)
1 cm
5 mm

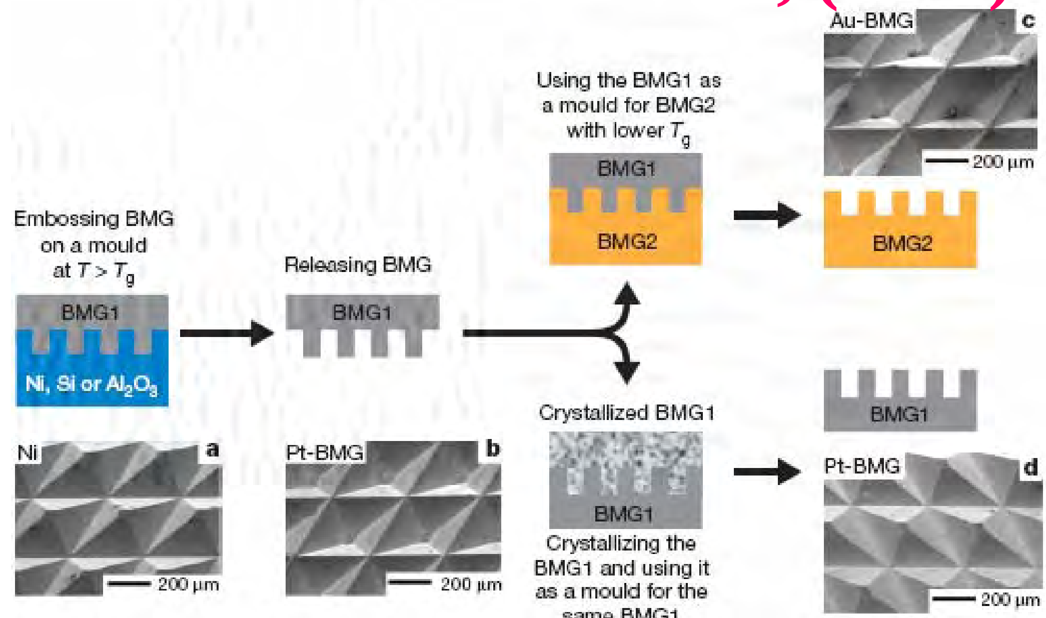

(a)
t = 0 s
t = 7 s
t = 10 s
t = 21 s
t = 40 s
t = 54 s
(b)
5 cm
(c)
1 cm
(d)
1 cm

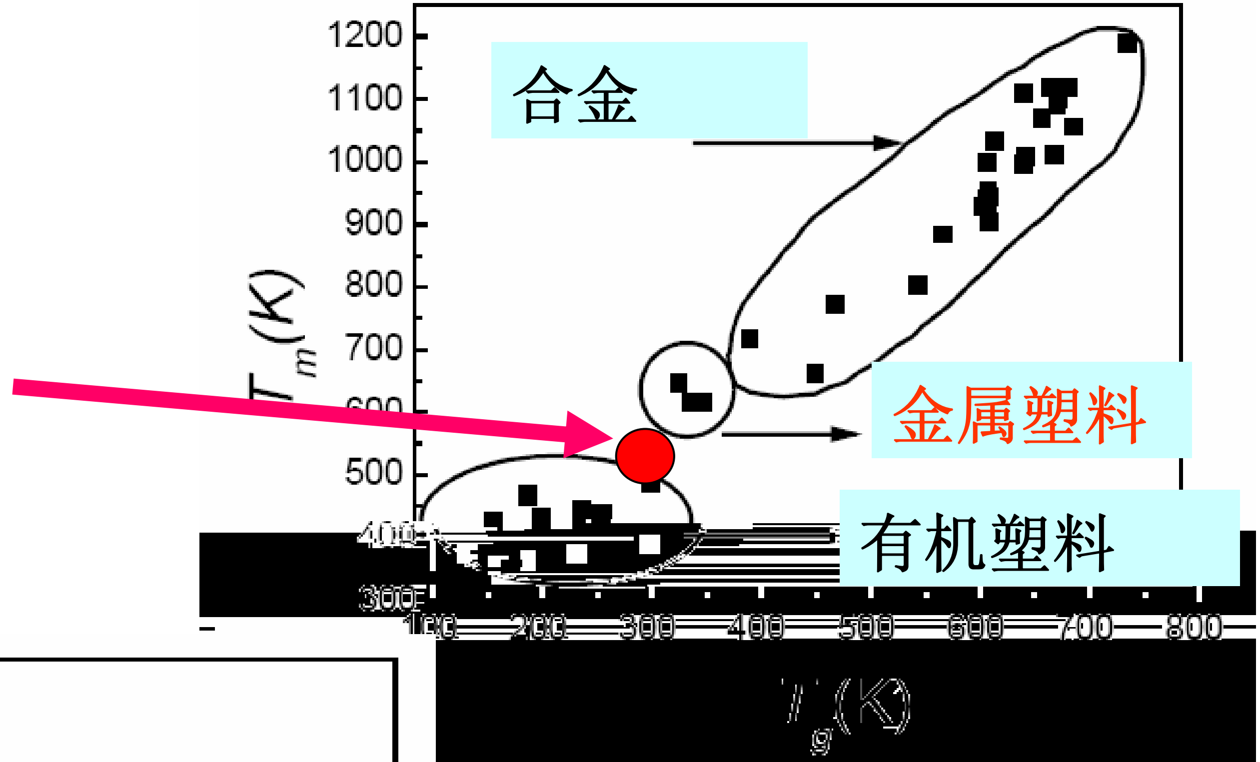




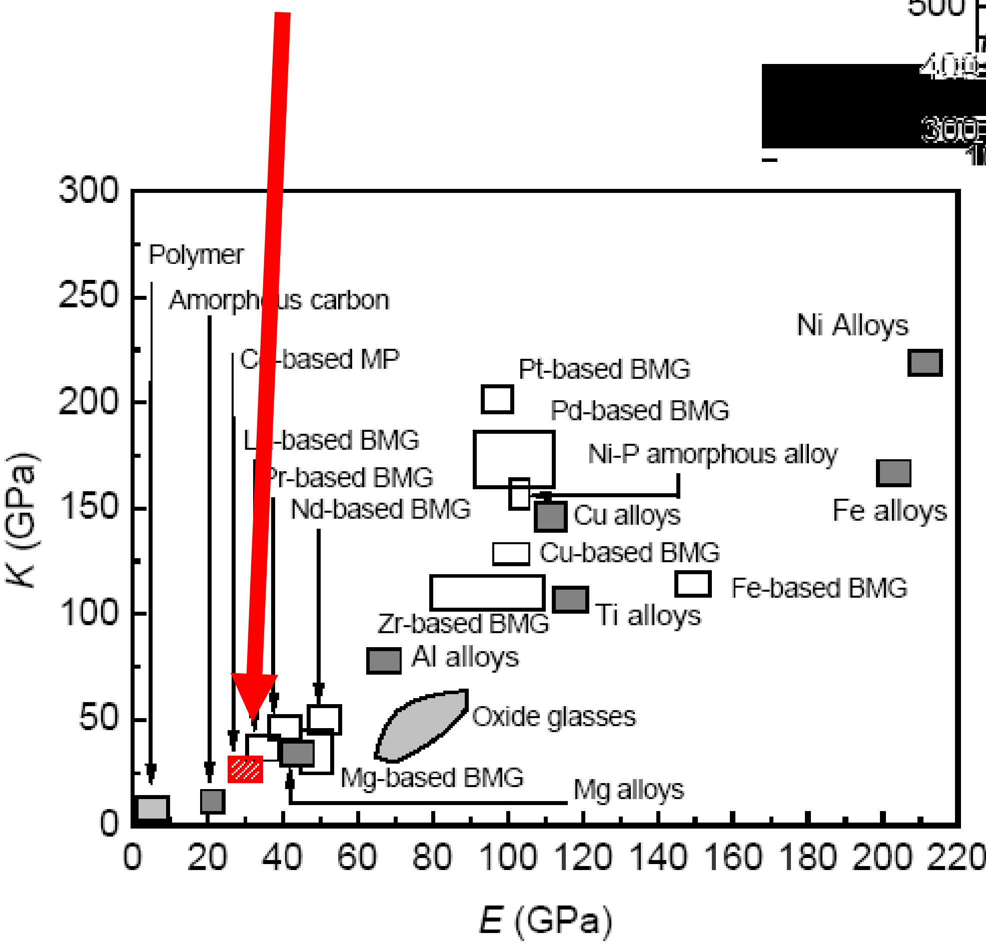
Schrores Nature 457, (2009)



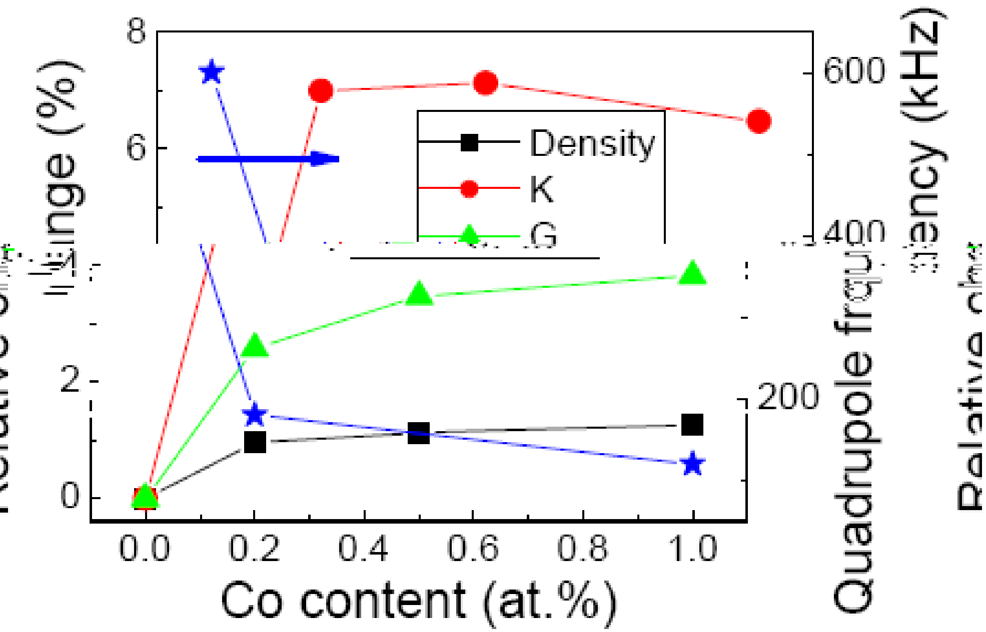


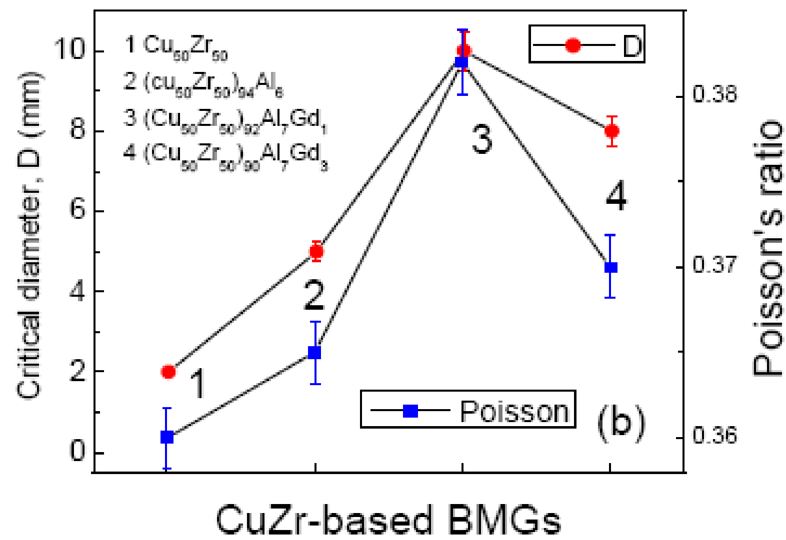


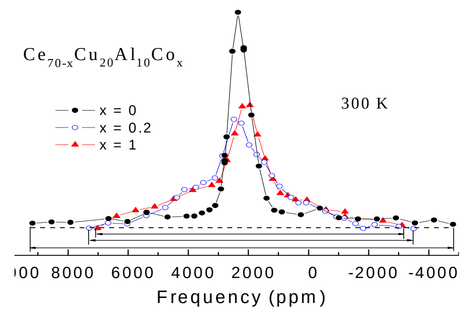
合金
金属塑料
有机塑料
1200
1100
1000
900
800
700
500
400
300
$T_m(K)$
100
200
300
400
500
600
700
800
$T_g(K)$

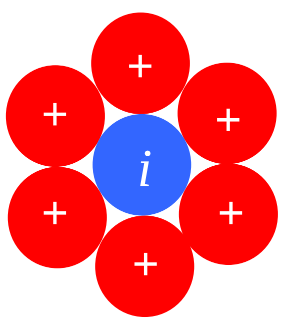


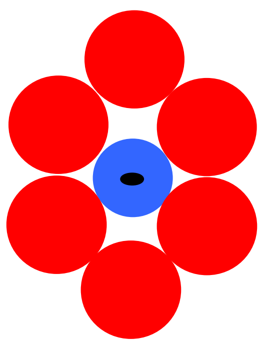
Polymer
Amorph us carbon
C -based MP
L -based BMG
Pr-based BMG
Nd-based BMG
Pt-based BMG
Pd-based BMG
Ni-P amorphous alloy
Cu alloys
Cu-based BMG
Zr-based BMG
Ti alloys
Fe-based BMG
Al alloys
Oxide glasses
Mg-based BMG
Mg alloys
Ni Alloys
Fe alloys
K (GPa)
E (GPa)
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140
160
180
200
220

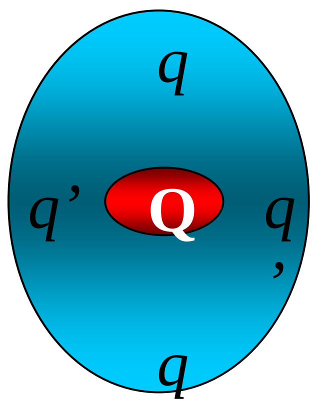










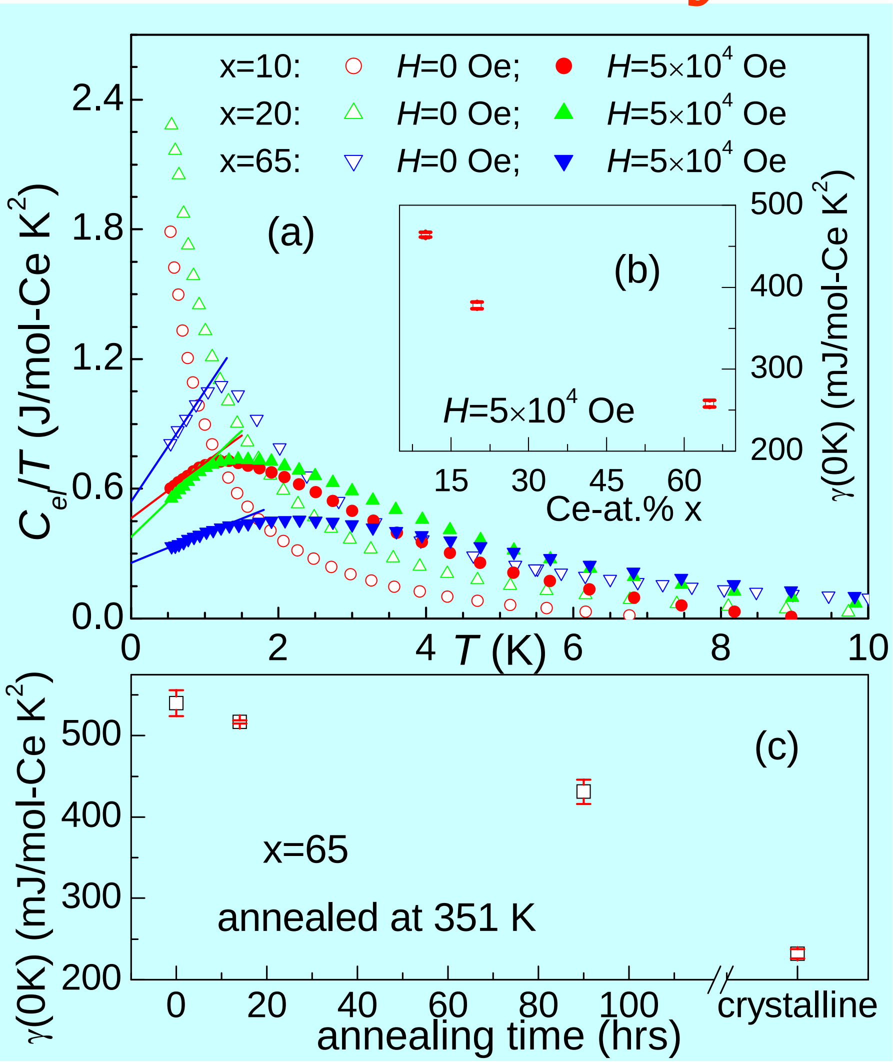


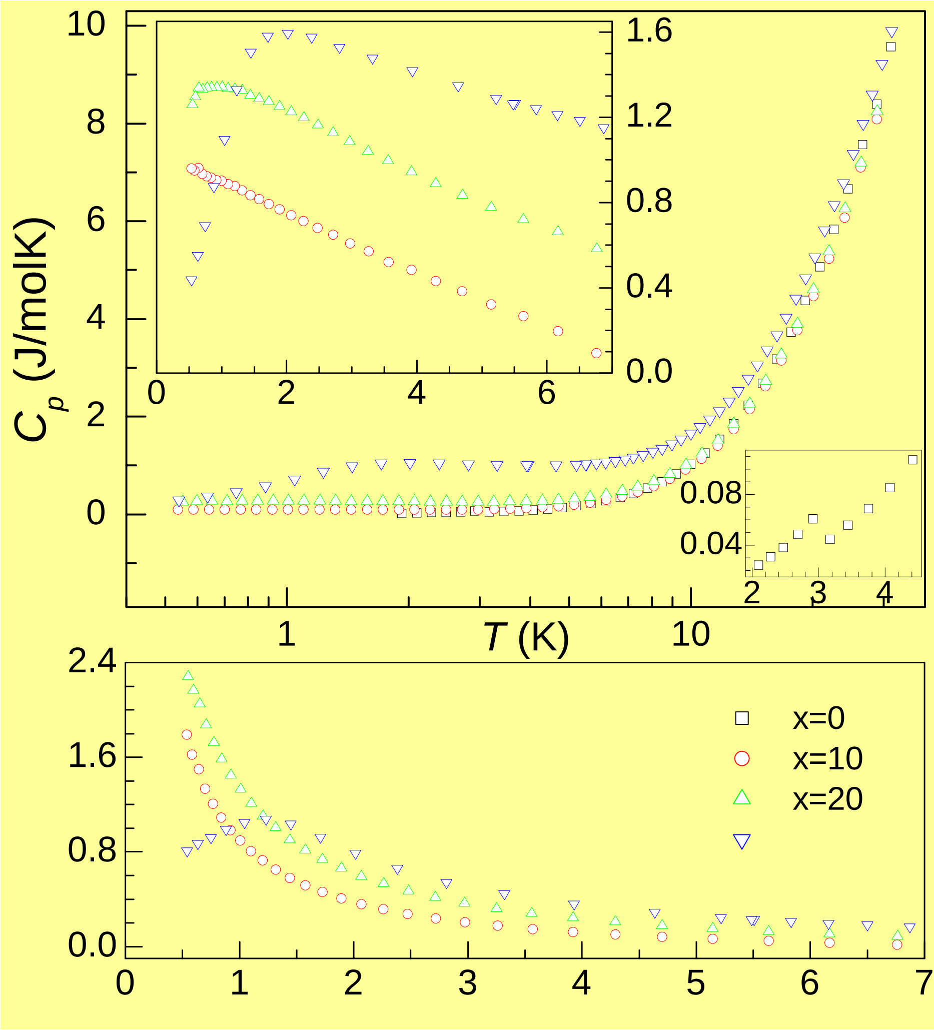
Phys. Rev. Lett. 99, 095501 (2007)

PNAS 2007

Nature Mater 2007

Heavy electron





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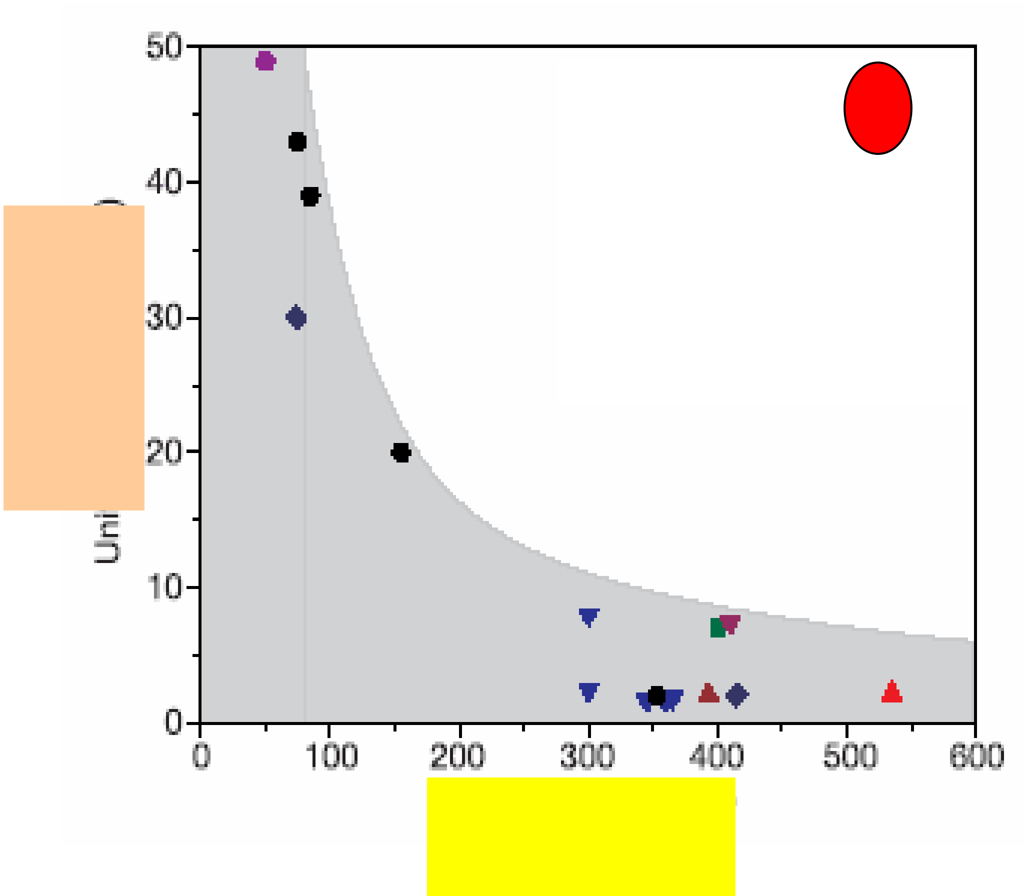

: 5%,

↰ 1%,

300 п US$

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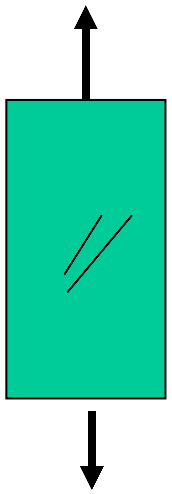

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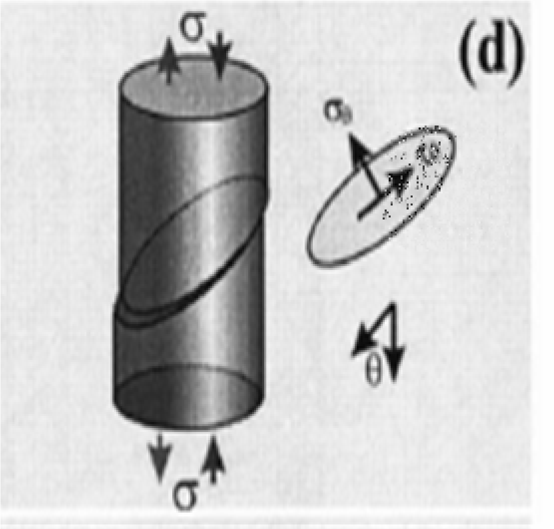

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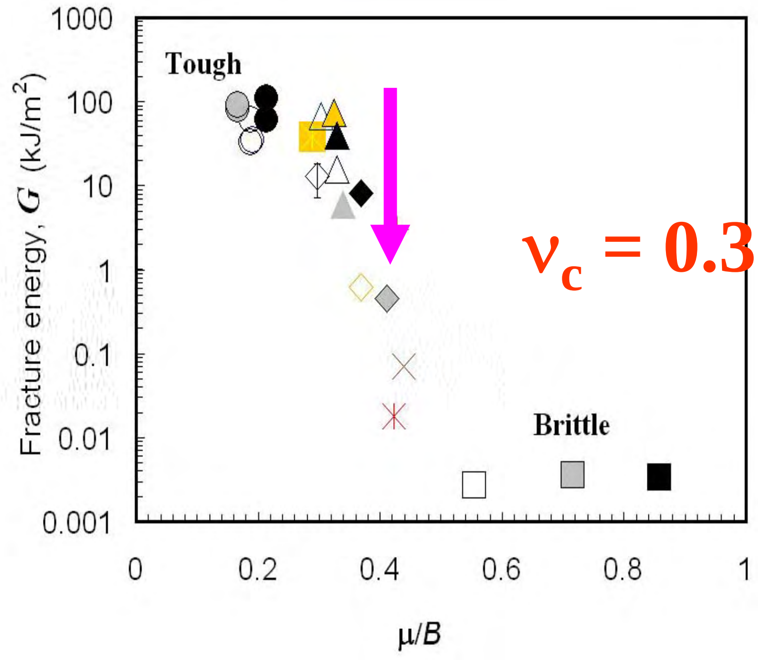

$\nu_c = 0.32–0.33$

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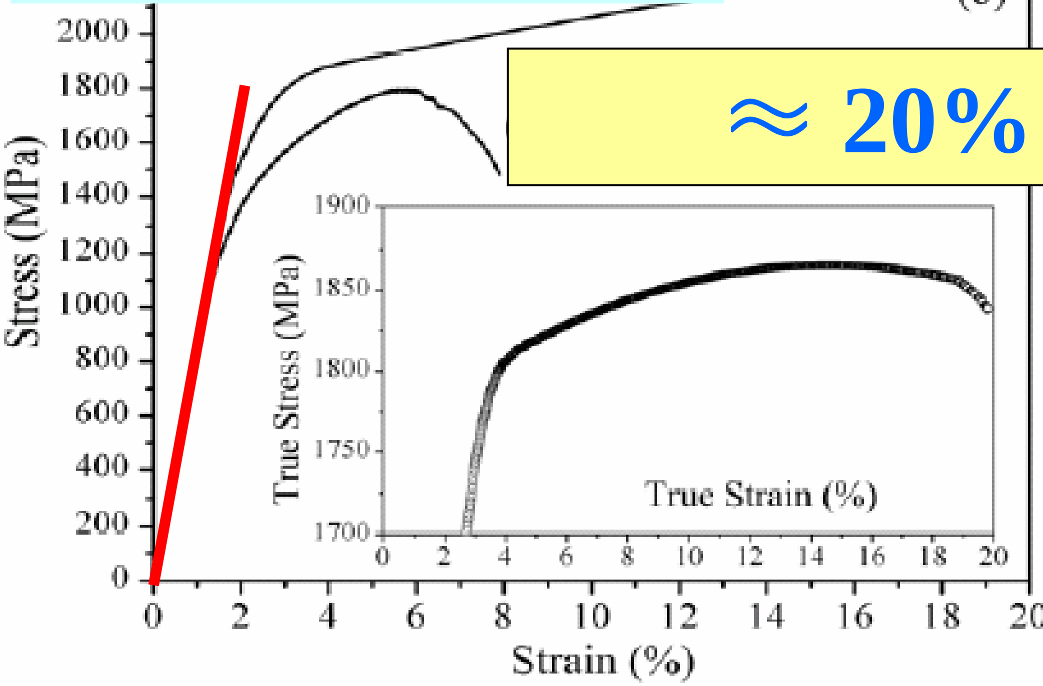
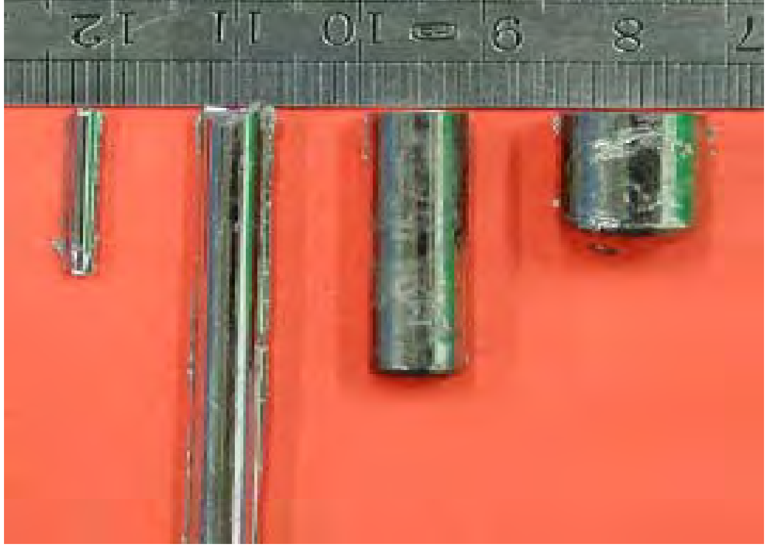
Philo Mag Let 85,77(2005) Nature Mat 5, 857(2006)

CuZrAl



≈ 20%

2.23 GPa




Physical Review Focus

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Phys. Rev. Lett. **94**, 205501
(issue of 27 May 2005)
Phys. Rev. Lett. **94**, 205502
(issue of 27 May 2005)
Titles and Authors

9 June 2005

Glass-Like Metal Performs Better Under Stress

- Phys Rev. Lett. 2005, 94, 205501 (2005) Chin Phys. Lett (2004) 901
- PRL Focus

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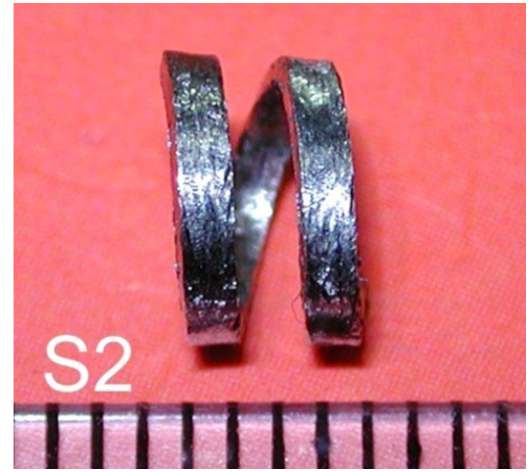

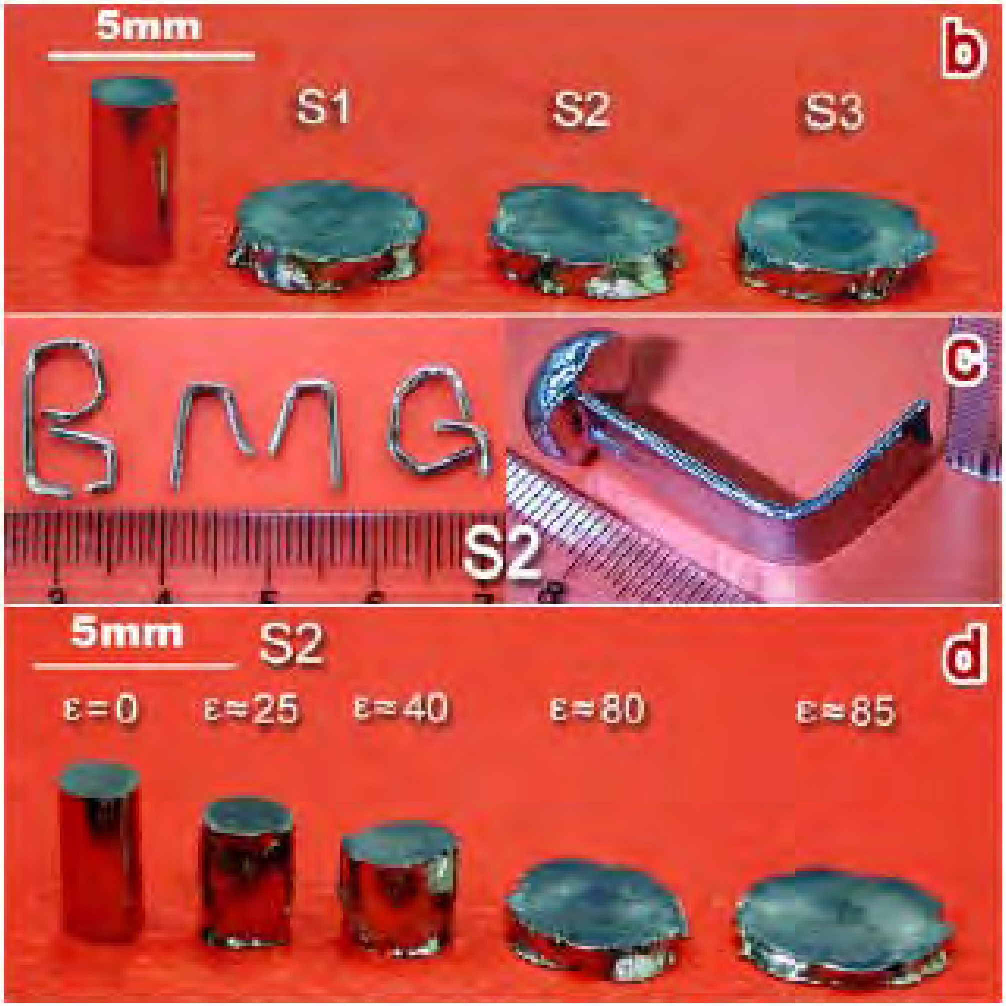

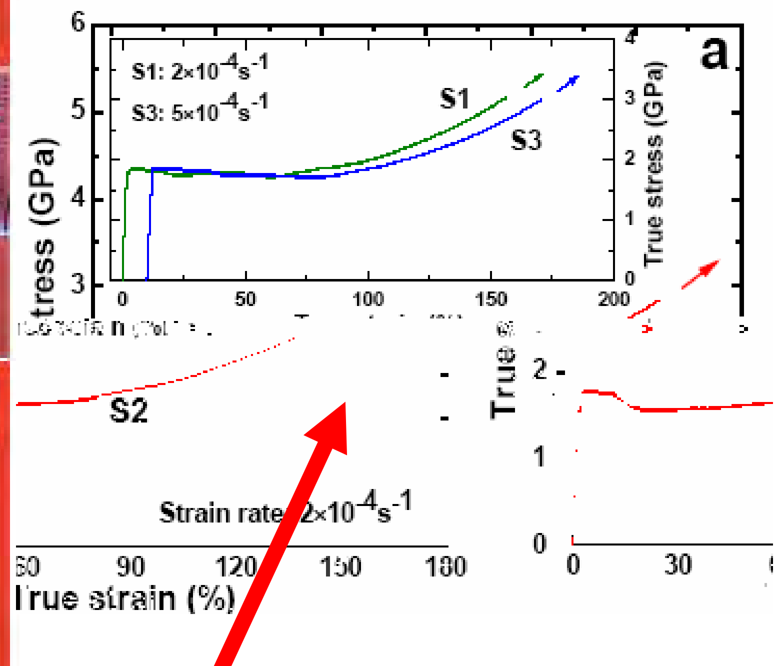

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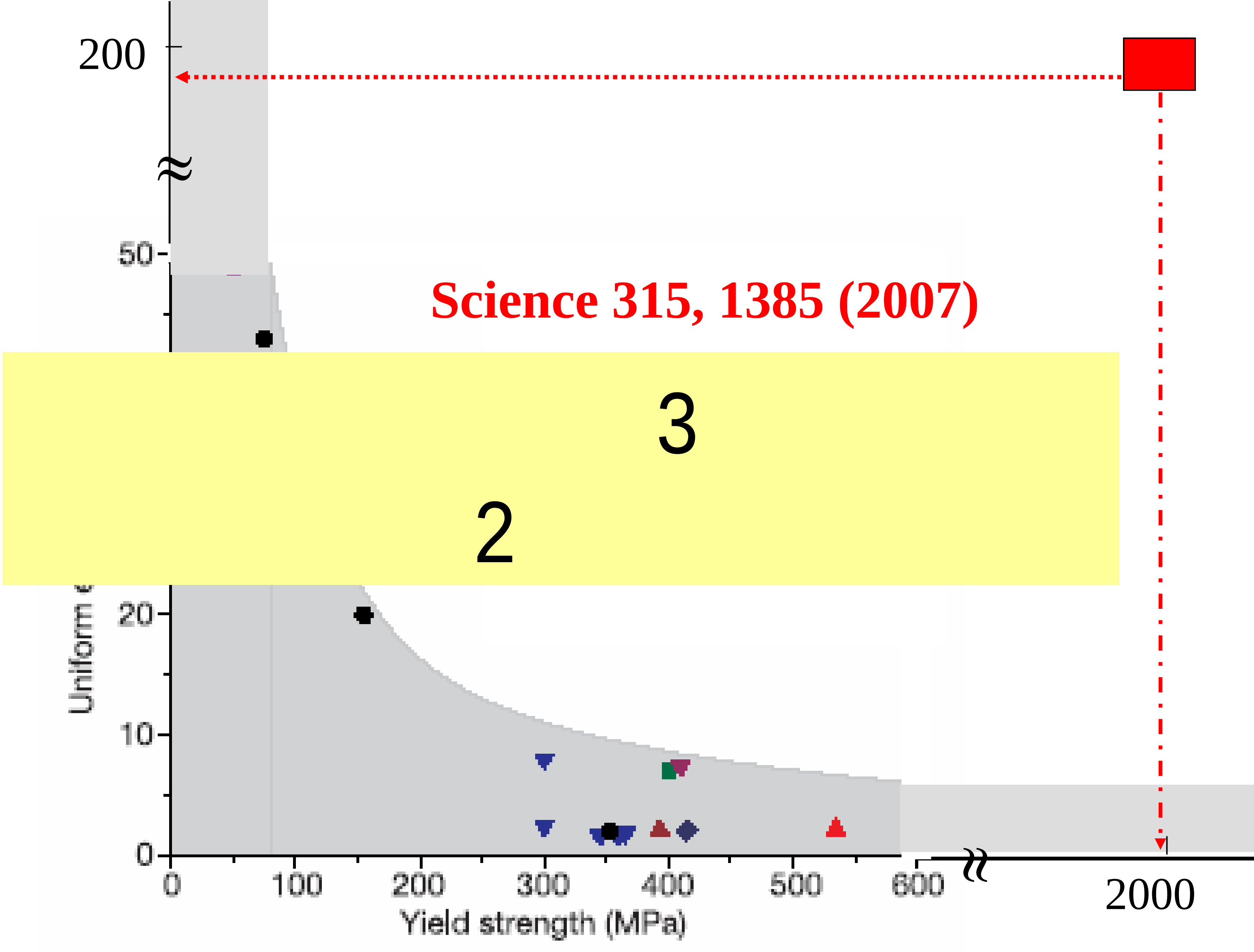
Science 315, 1385(2007)



200
Science 315, 1385 (2007)
3
2
50
20
10
0
Uniform
0
100
200
300
400
500
600
2000
Yield strength (MPa)

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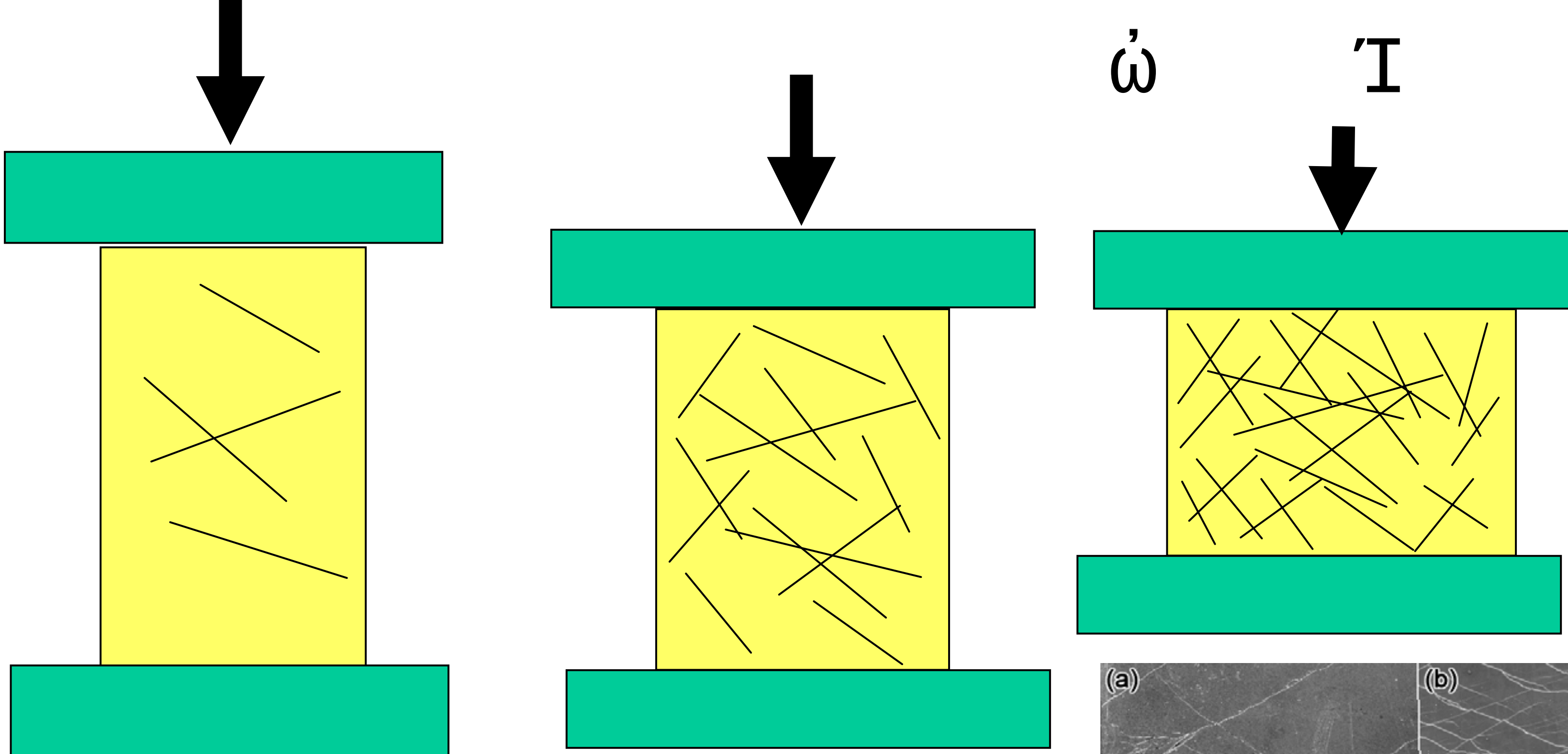
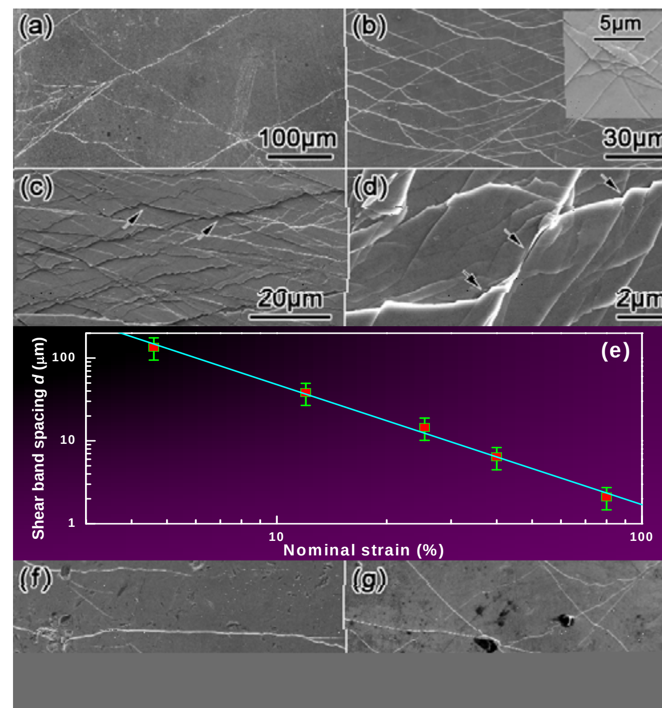


$$d = A\,\varepsilon^{-B}$$

B=1.45

ε (%)	Shear band spacing d (μm)
4.6	135
12	38.2
25.4	14.5
40	6.4
80	2.1



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Science 315, 1385 (2007)

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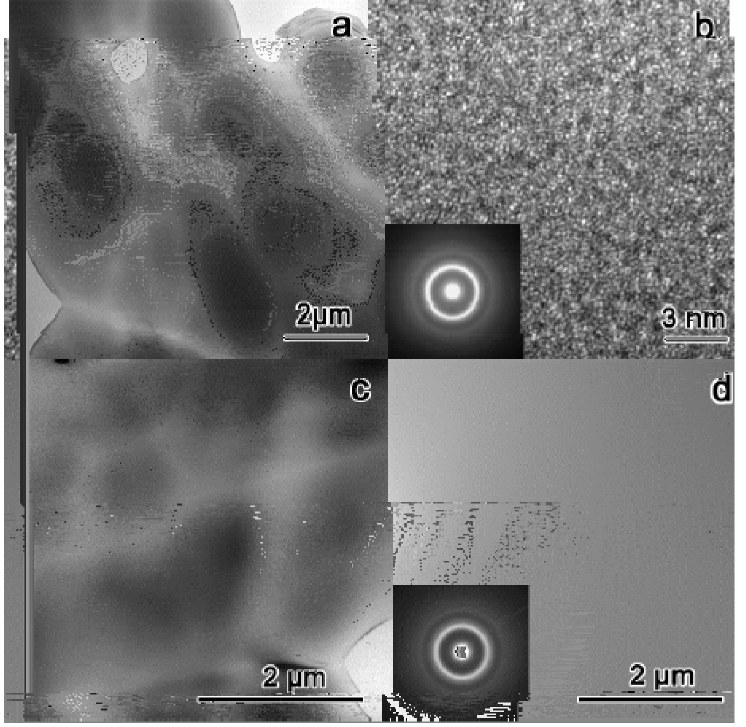
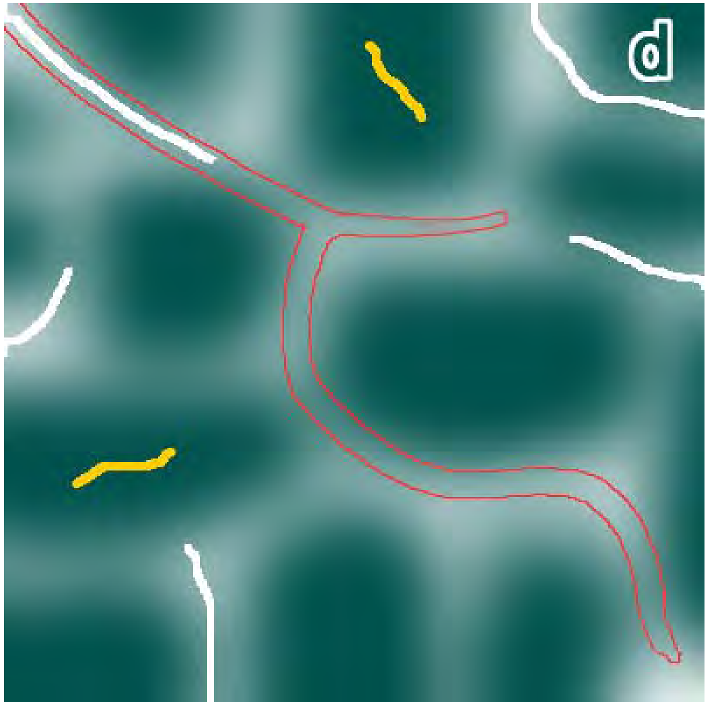


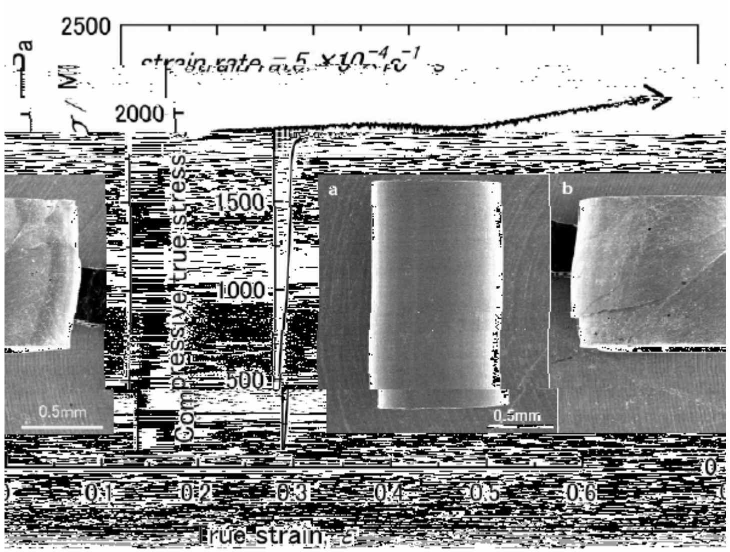


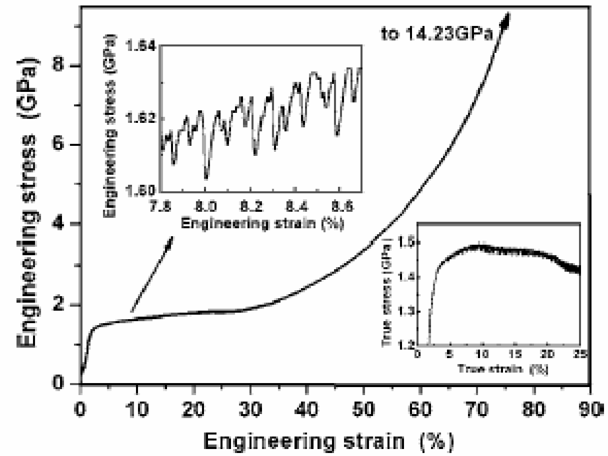
Cu50Zr50

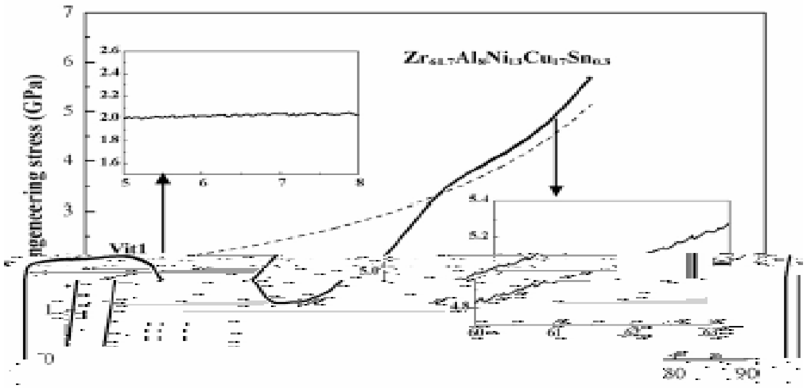
PdSi

CuZrAl

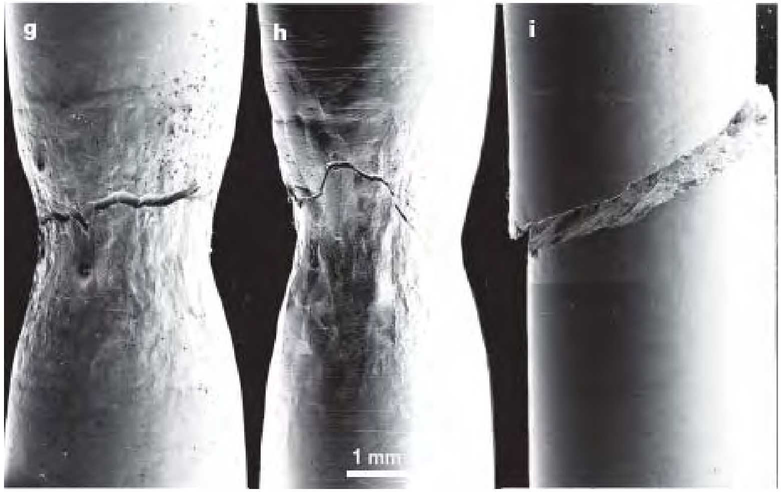
CuZrAlNiSn







$Zr_{61.7}Al_8Ni_{13}Cu_{17}Sn_{0.3}$



Johnson, Nature, 451, 1085 (2008)

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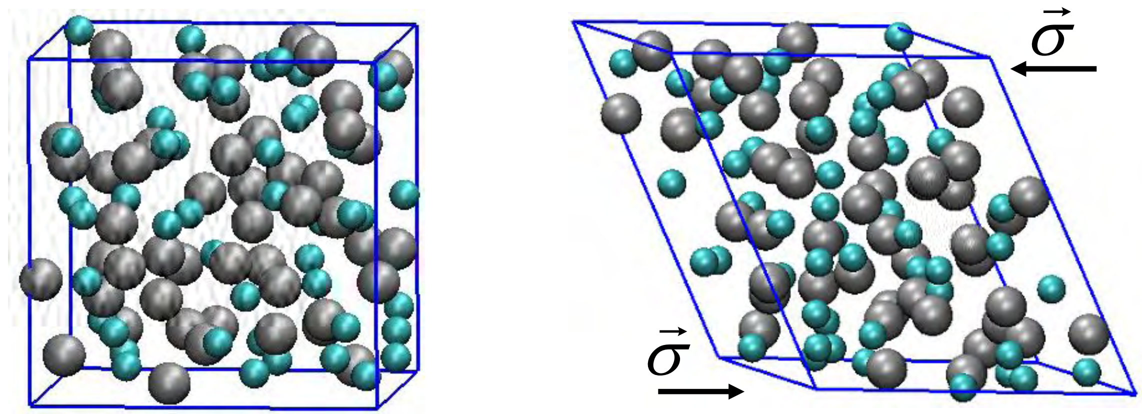
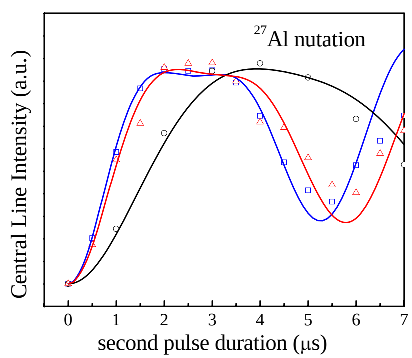
Metallic glasses with large plasticity
Open a window for understand the intrinsic mechanism of structural deformation in glass.



ZrCuNiAl



What is the length scale of plastic deformation?
NMR: local, short range
Neutron: intermediate range
TEM: microstructure

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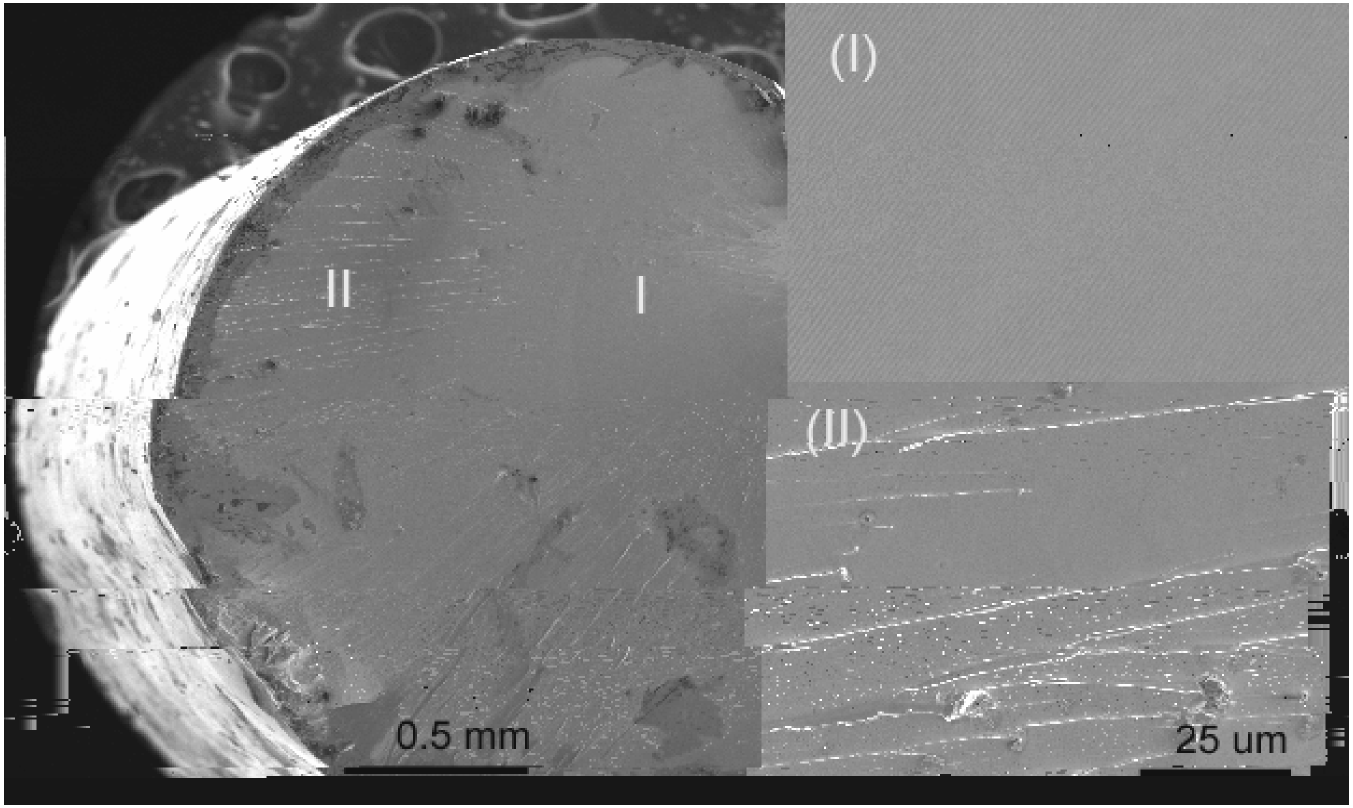
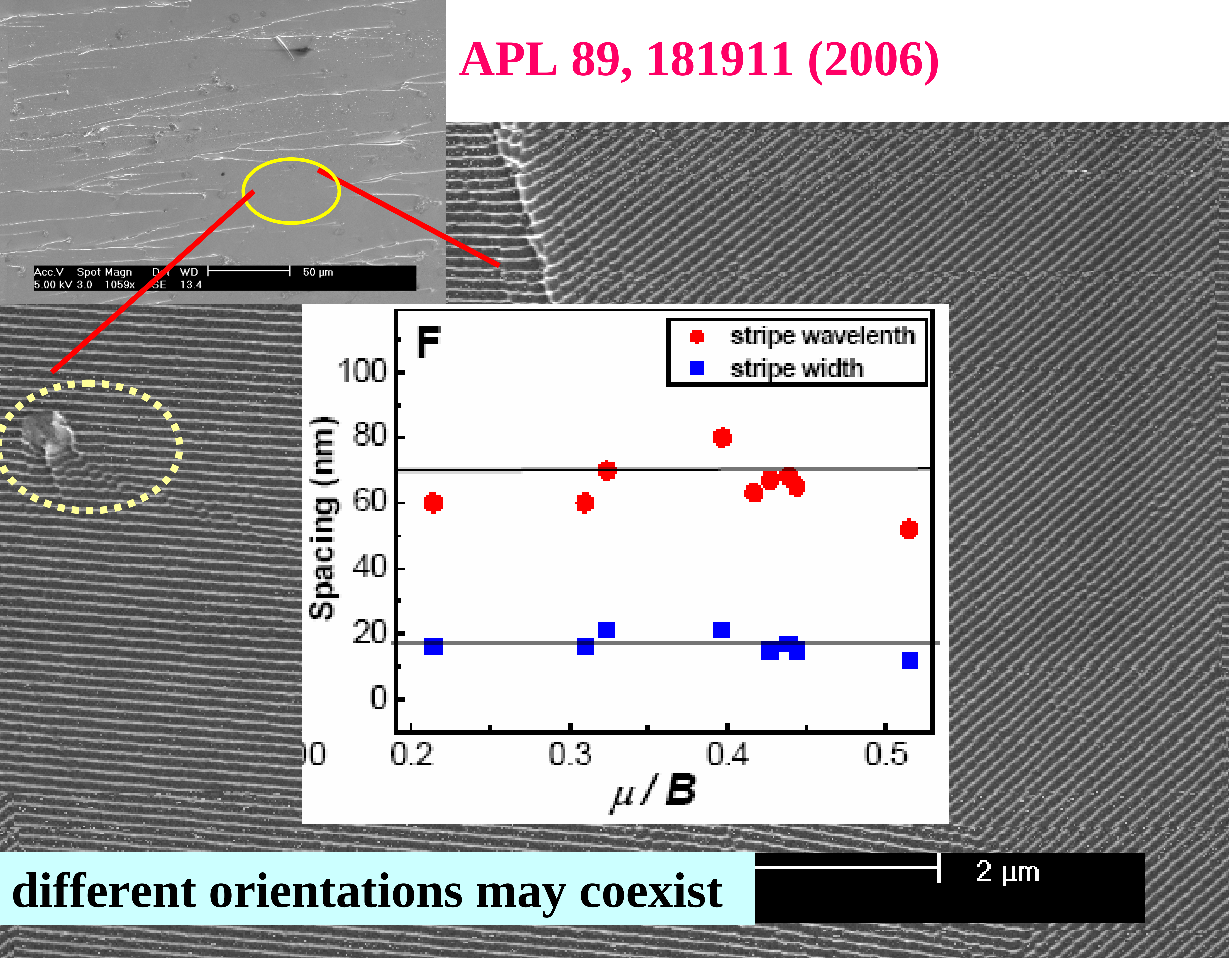


Flat shine fracture surface like silicate glasses

The brittle BMGs close to ideal brittle fracture

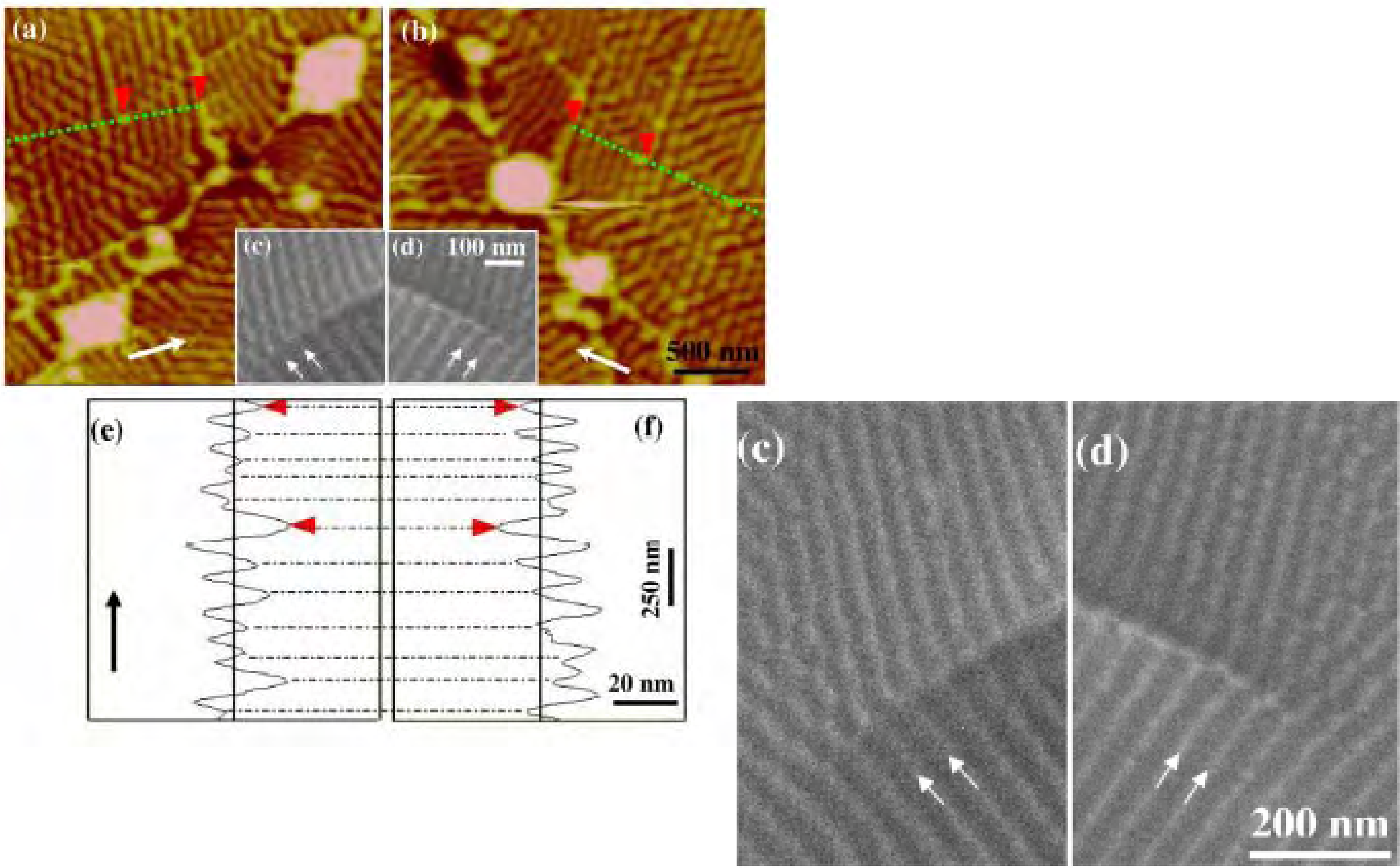
BMG exhibits two distinct zones: flat mirror zone and mist zone consisting of massive river patterns

APL 89, 181911 (2006)

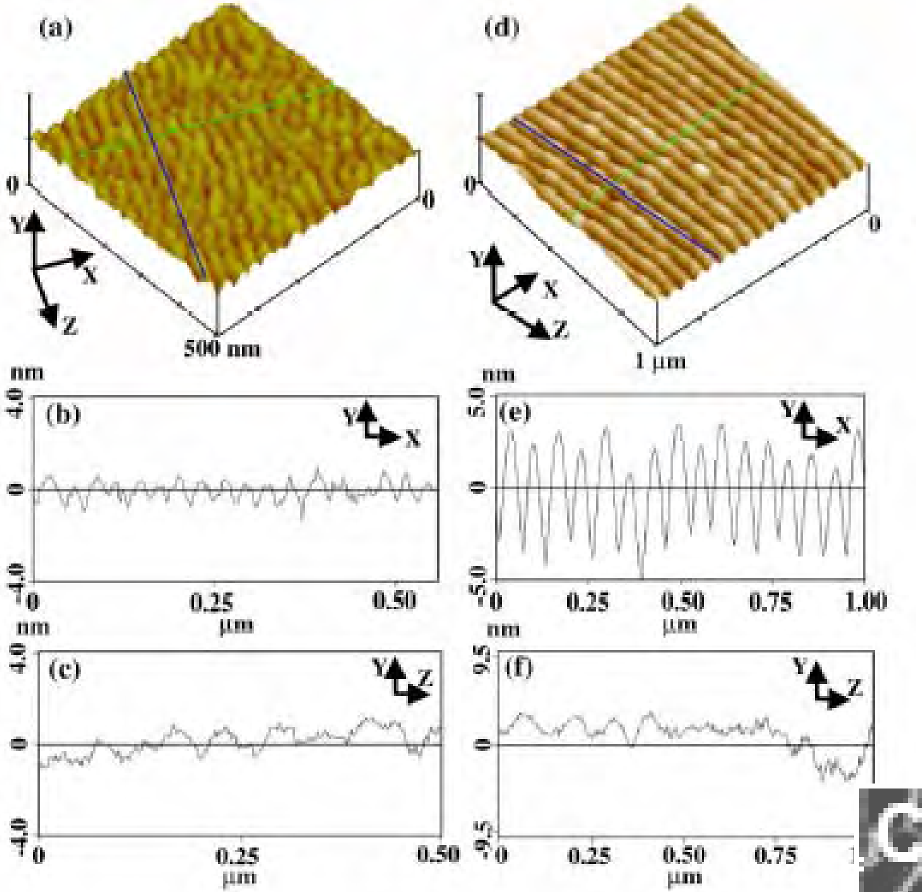


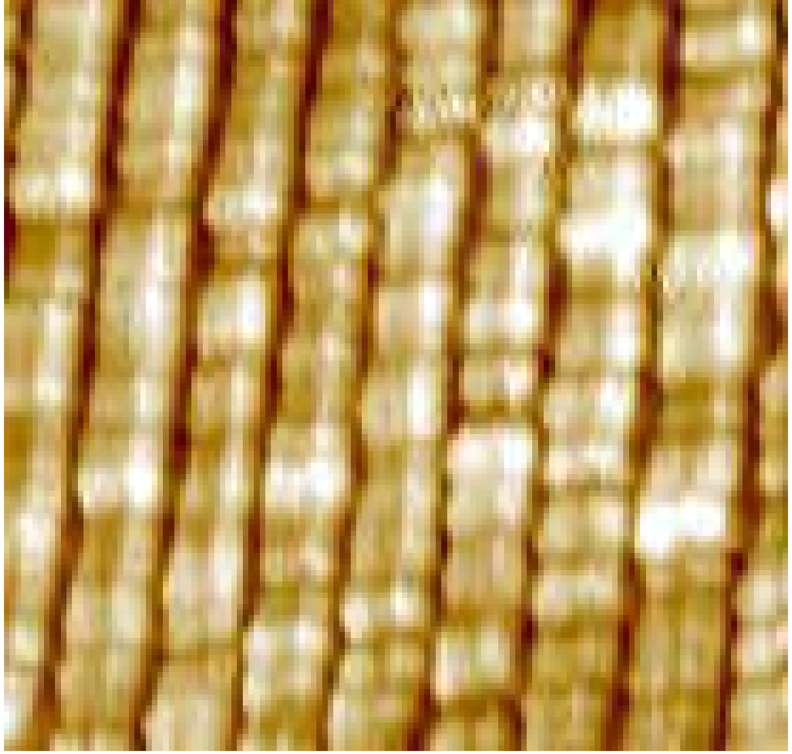
different orientations may coexist

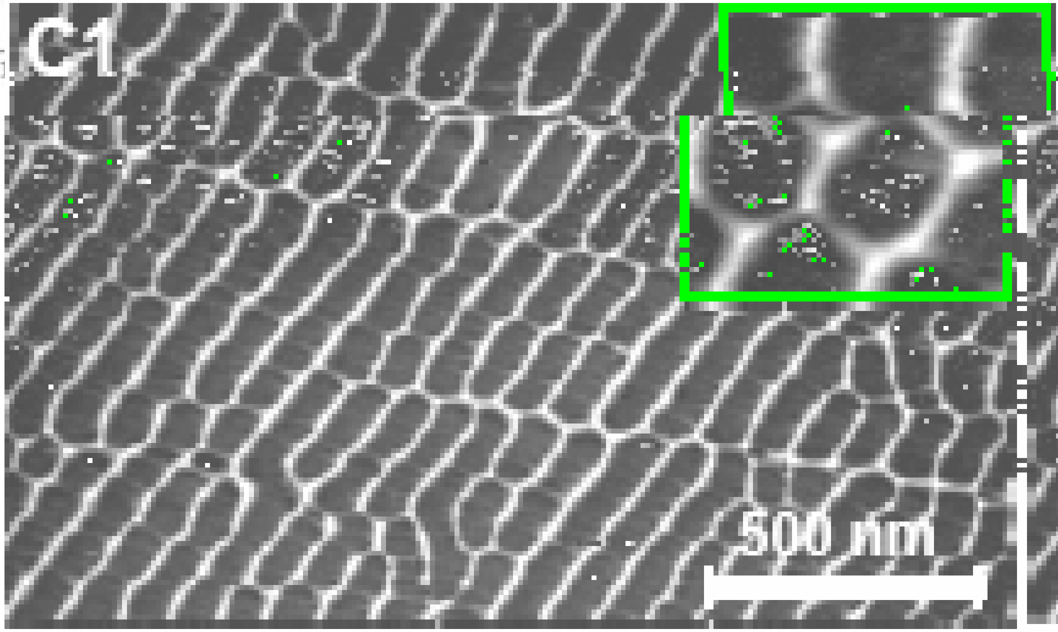
Peak to peak and valley to valley



Phys Rev Lett 98, 235501 (2007)

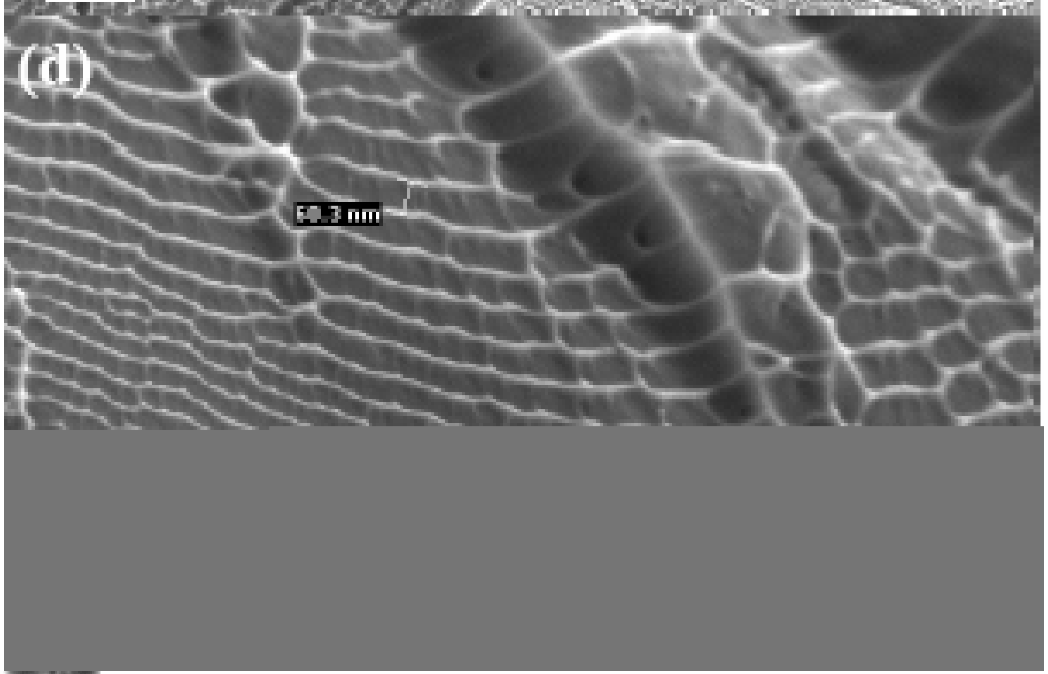


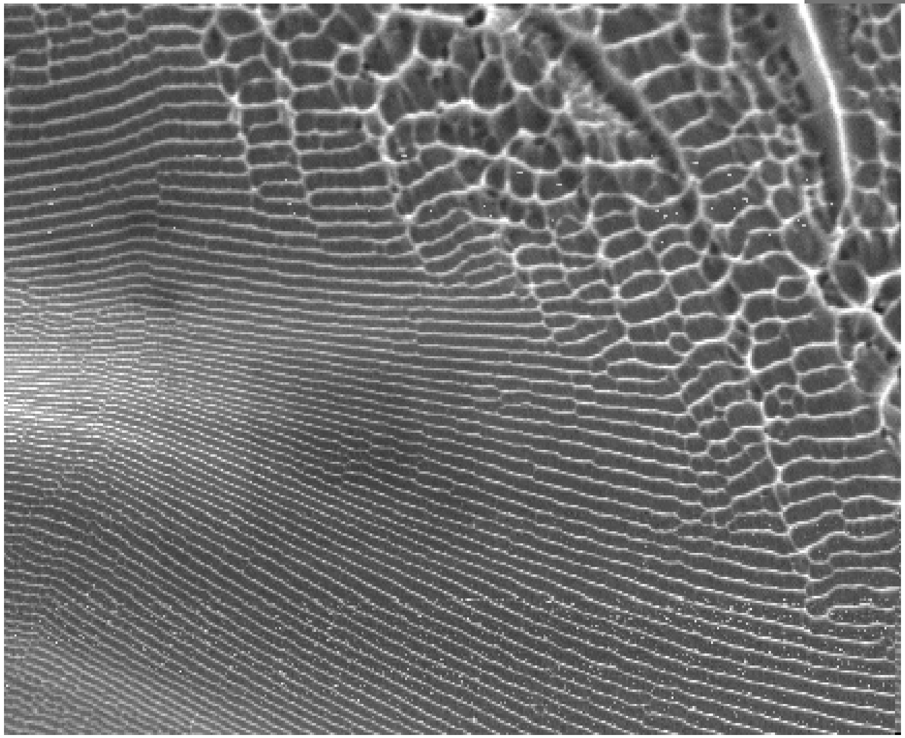




The stripes consist of the hexagonal closed-packing ordered dimples

The transition from dimple to periodic corrugation

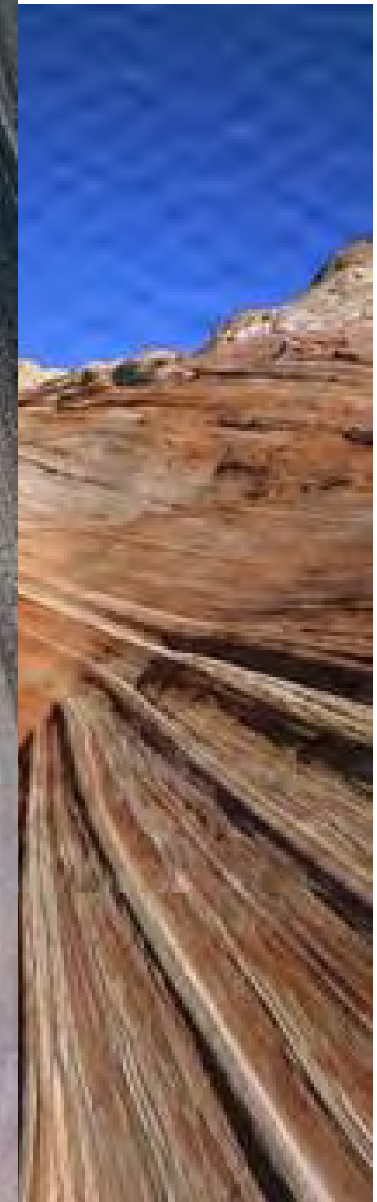


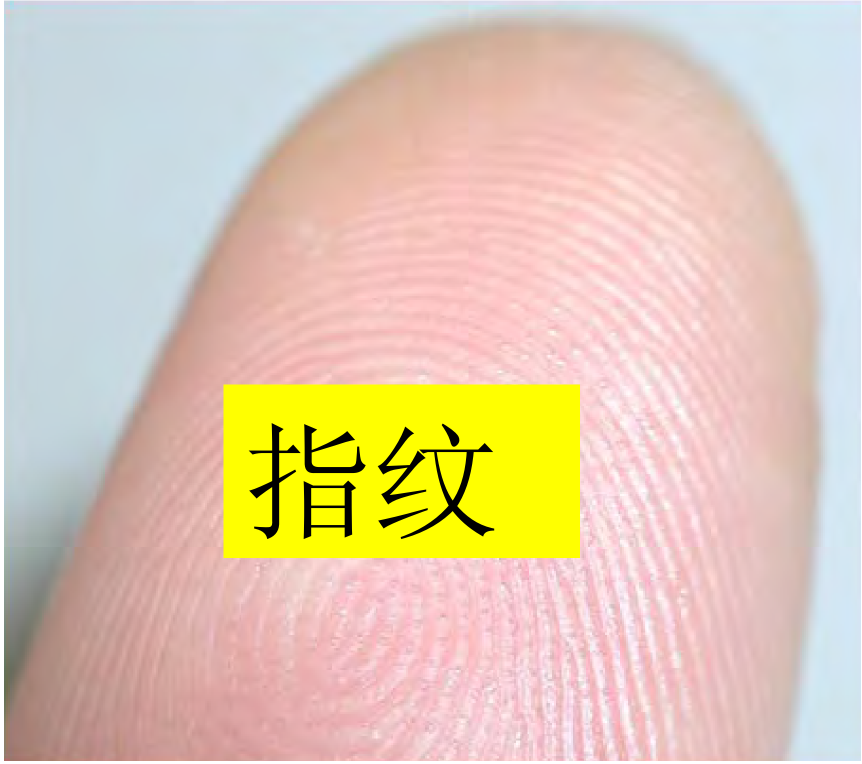


a certain dimple density and velocity are required to form a periodic corrugation pattern

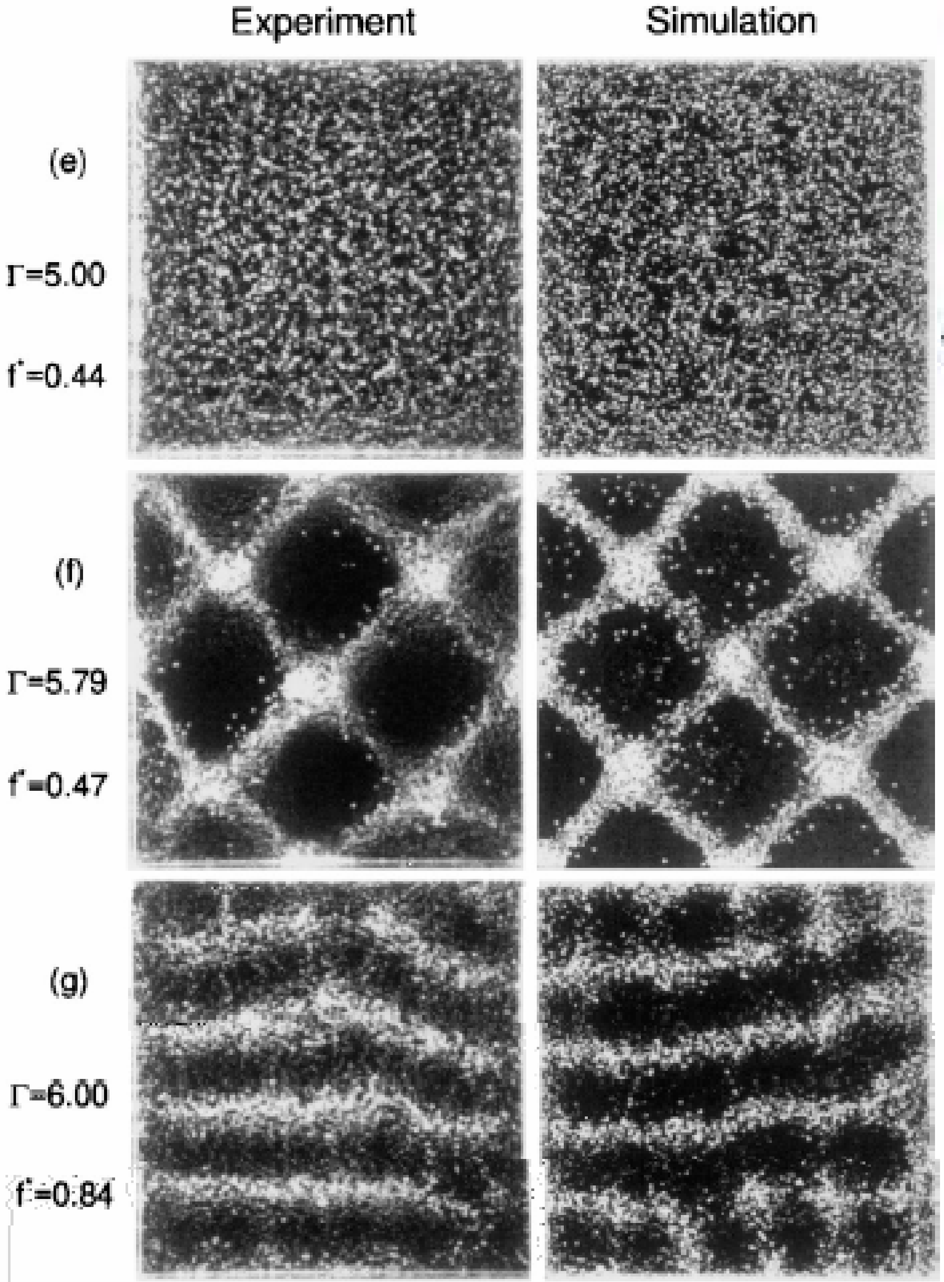
APL 89, 121909 (2006)



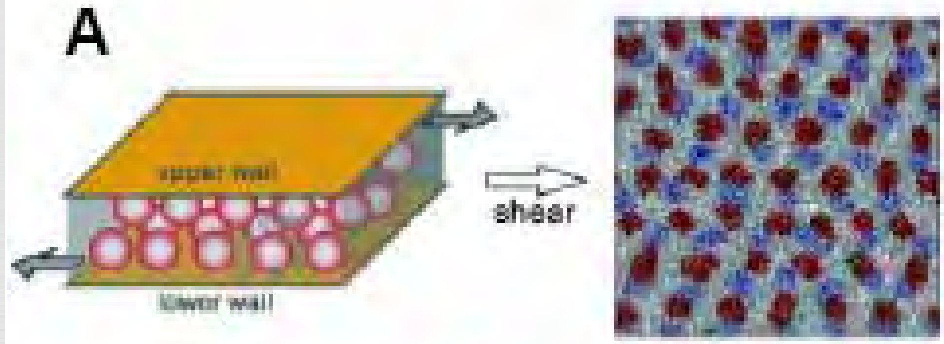


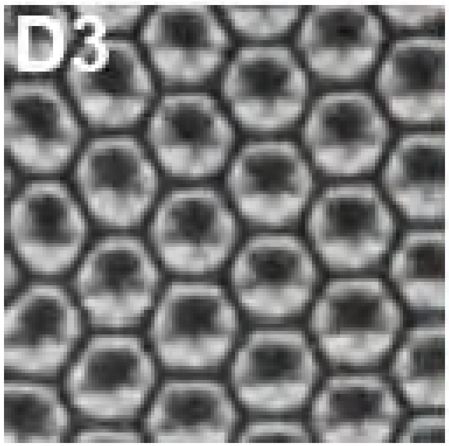


沙丘上的波纹

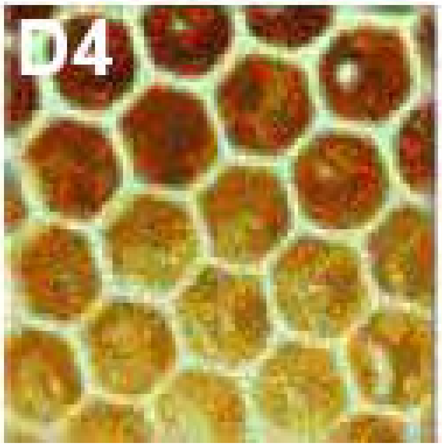


In granular system



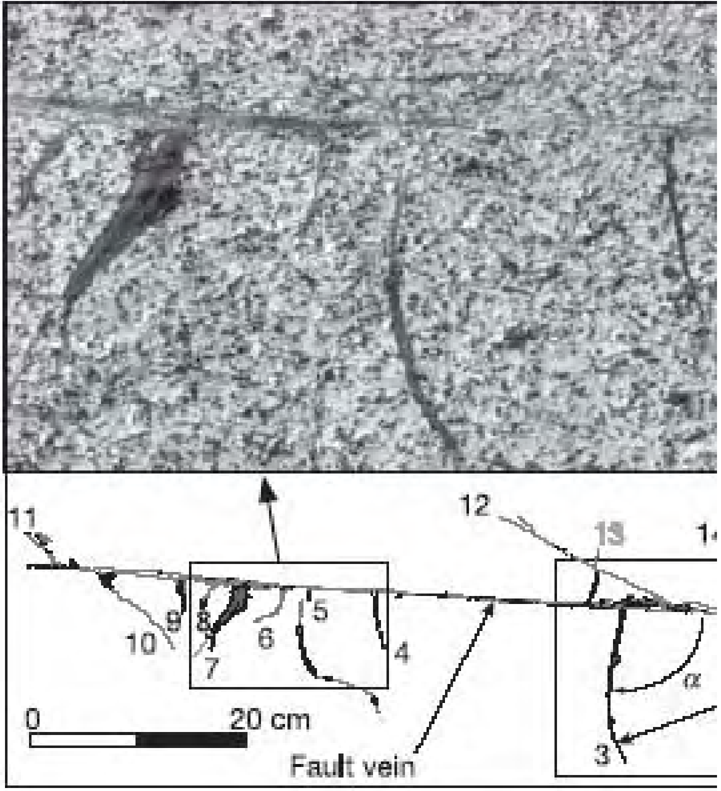


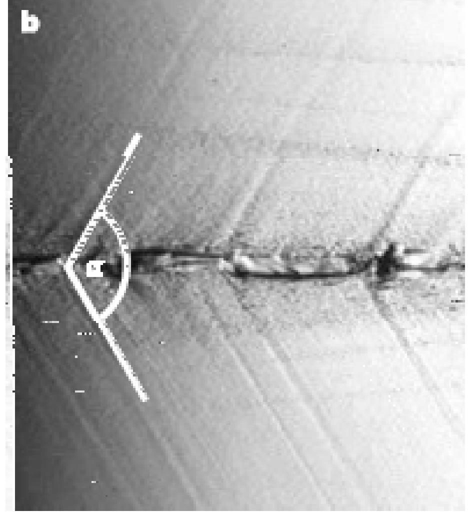
Si oil 表面对流



honeycomb

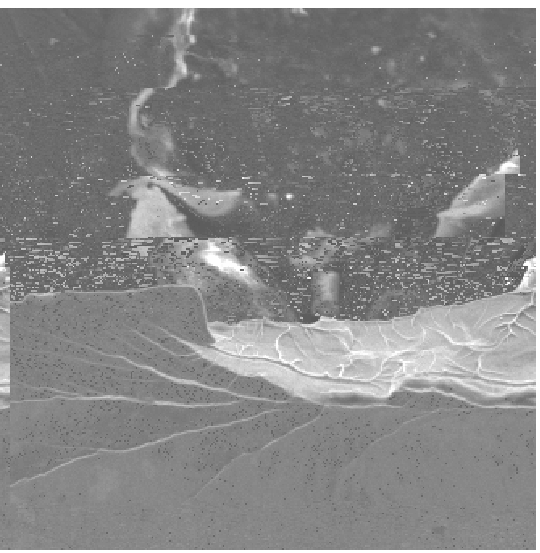
bubble bath

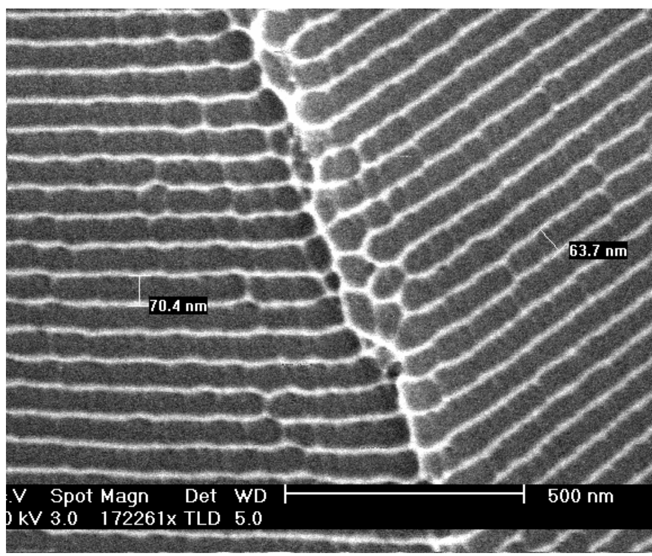


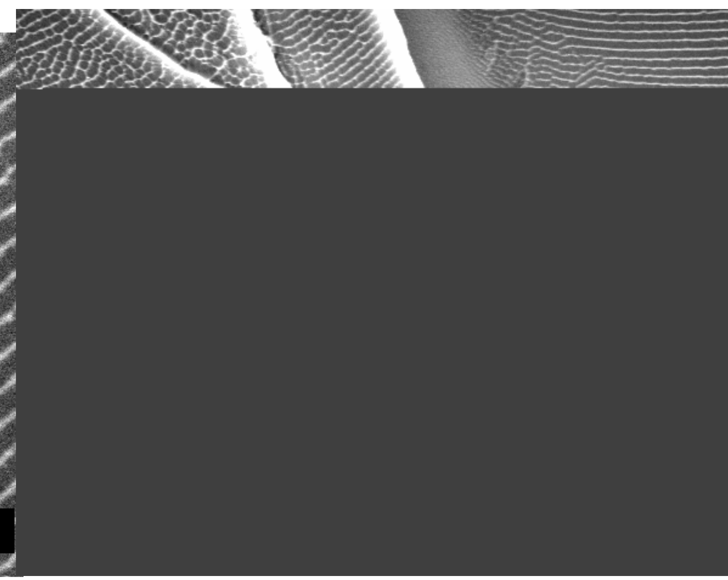


Nature 436, 1008 (2005)

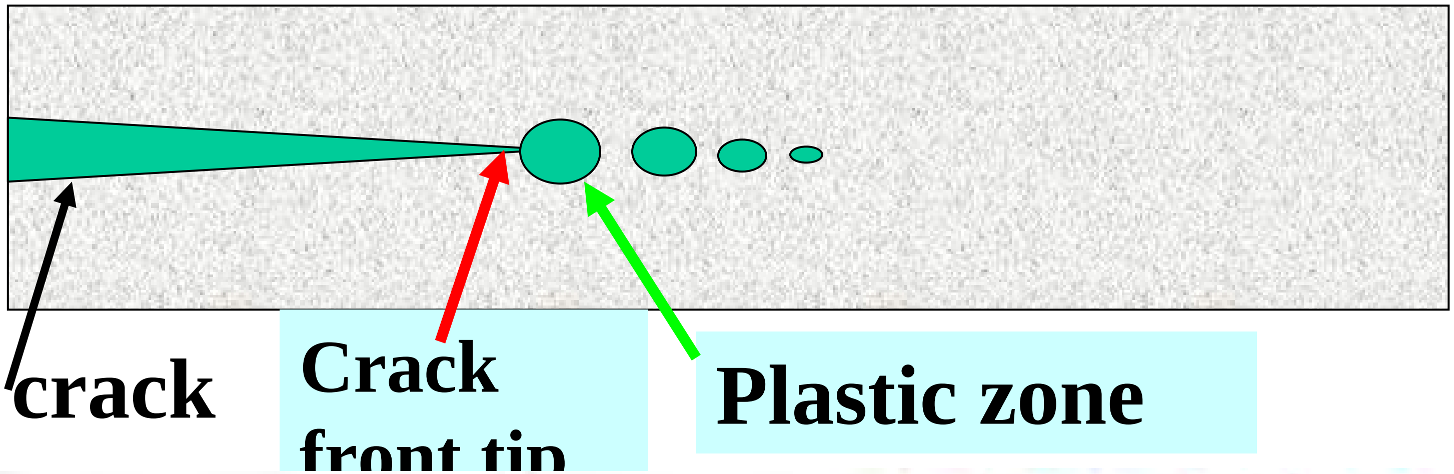
Nature 418, 310 (2002)

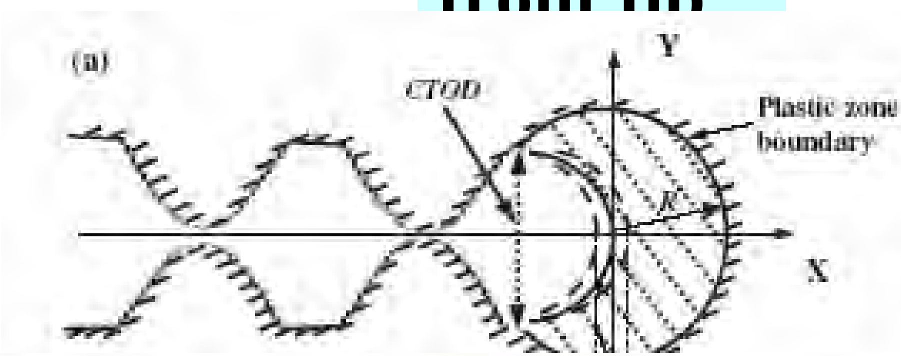


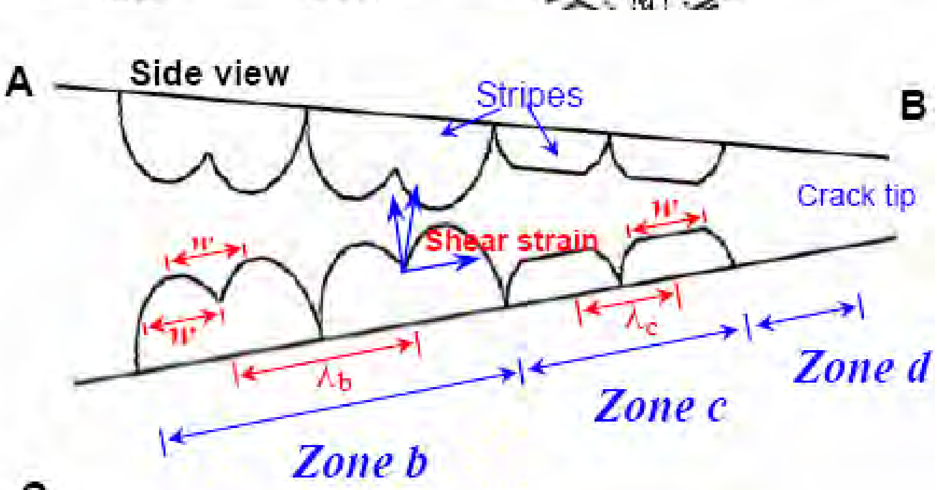


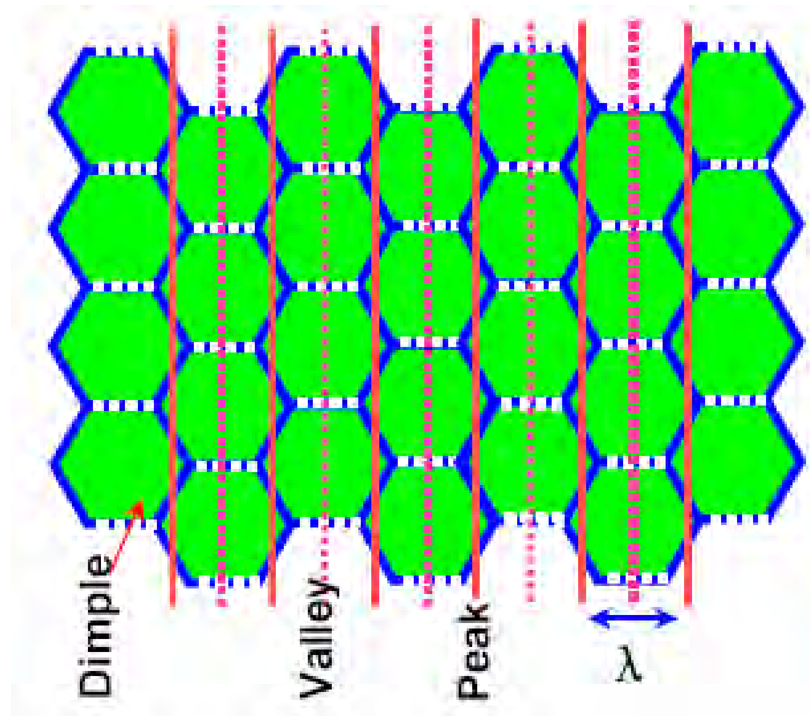


Damage cavities assembly model

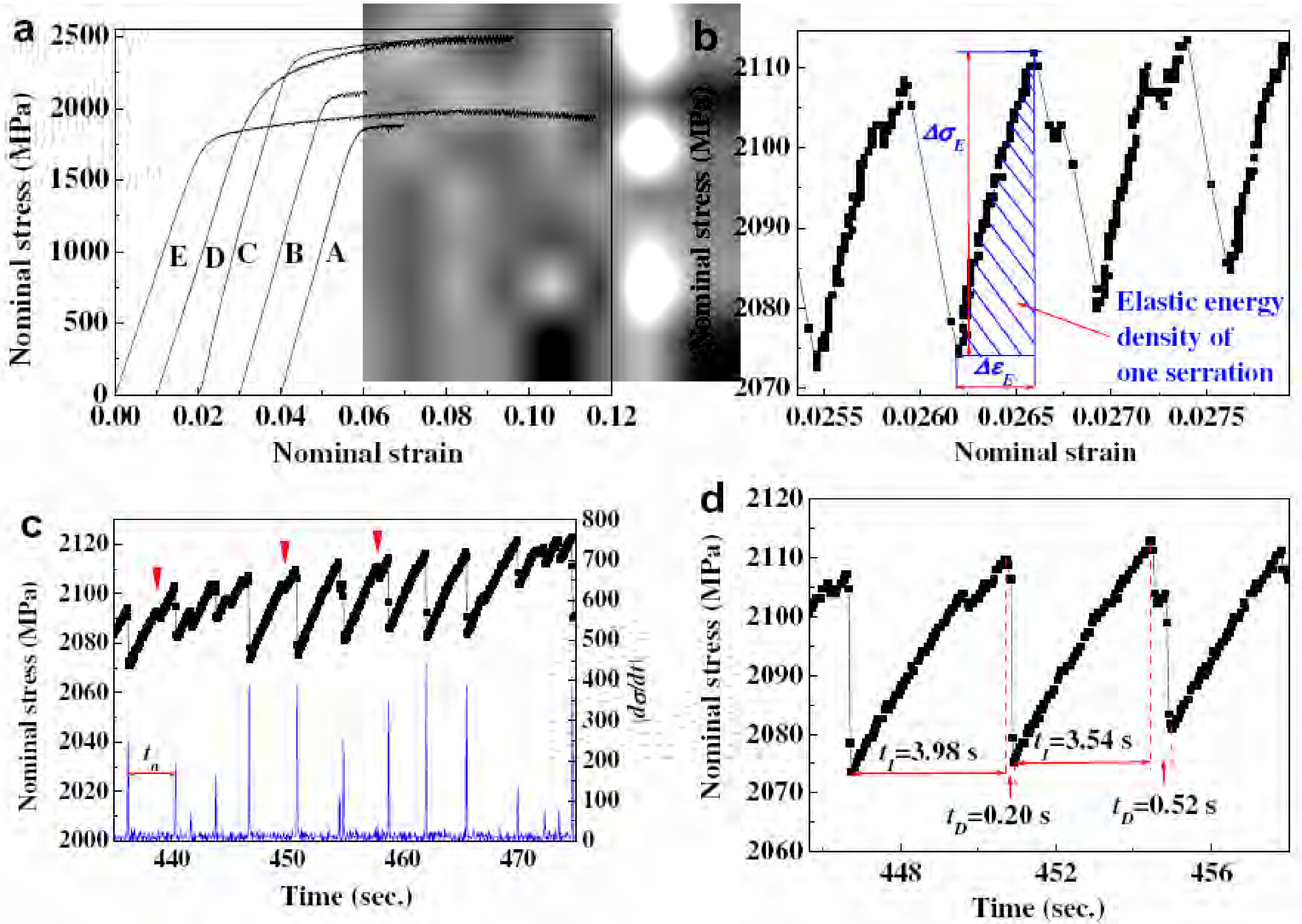






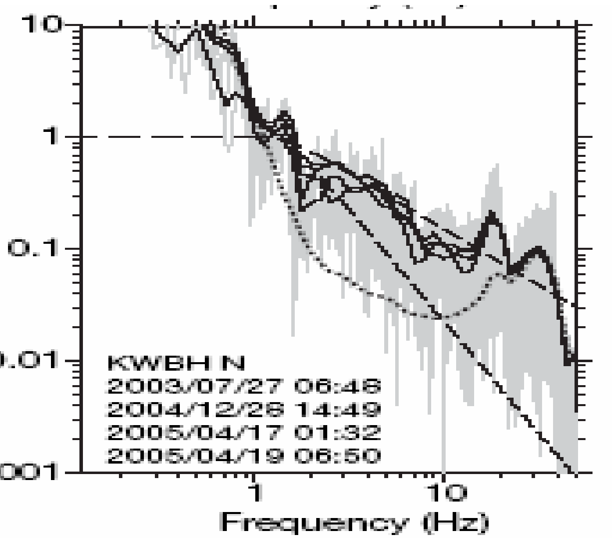


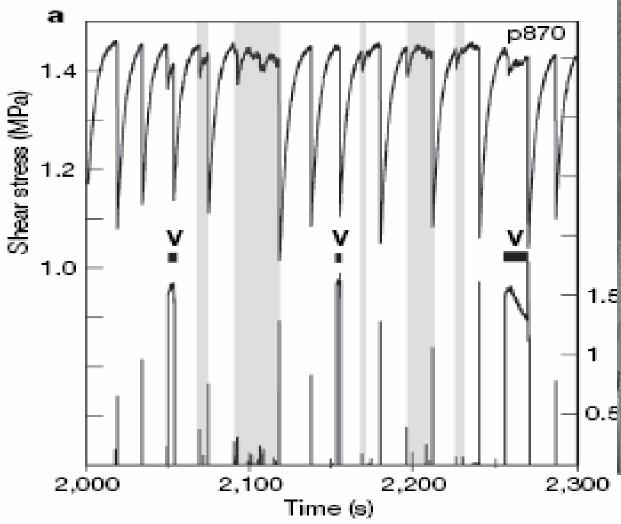
PRL 98, 235501 (2007)

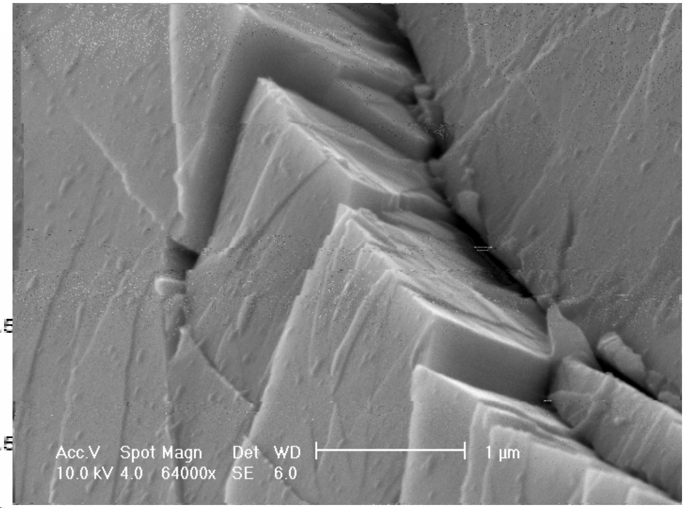


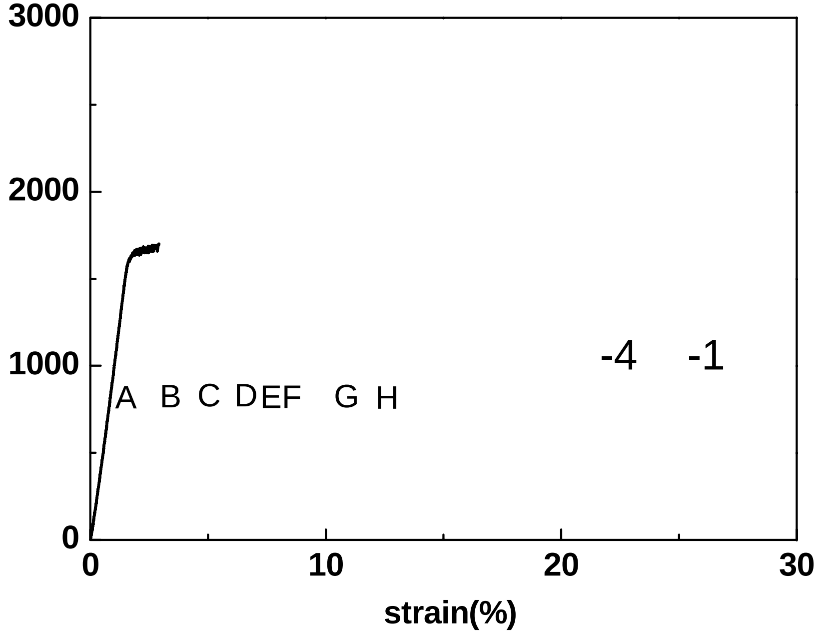
a
Nominal stress (MPa)
Nominal strain
E D C B A
b
Nominal stress (MPa)
Nominal strain
$\Delta\sigma_E$
$\Delta\varepsilon_E$
Elastic energy density of one serration
c
Nominal stress (MPa)
$|d\sigma/dt|$
t_a
Time (sec.)
d
Nominal stress (MPa)
t_I=3.98 s
t_I=3.54 s
t_D=0.20 s
t_D=0.52 s
Time (sec.)

Similar deformation morphology









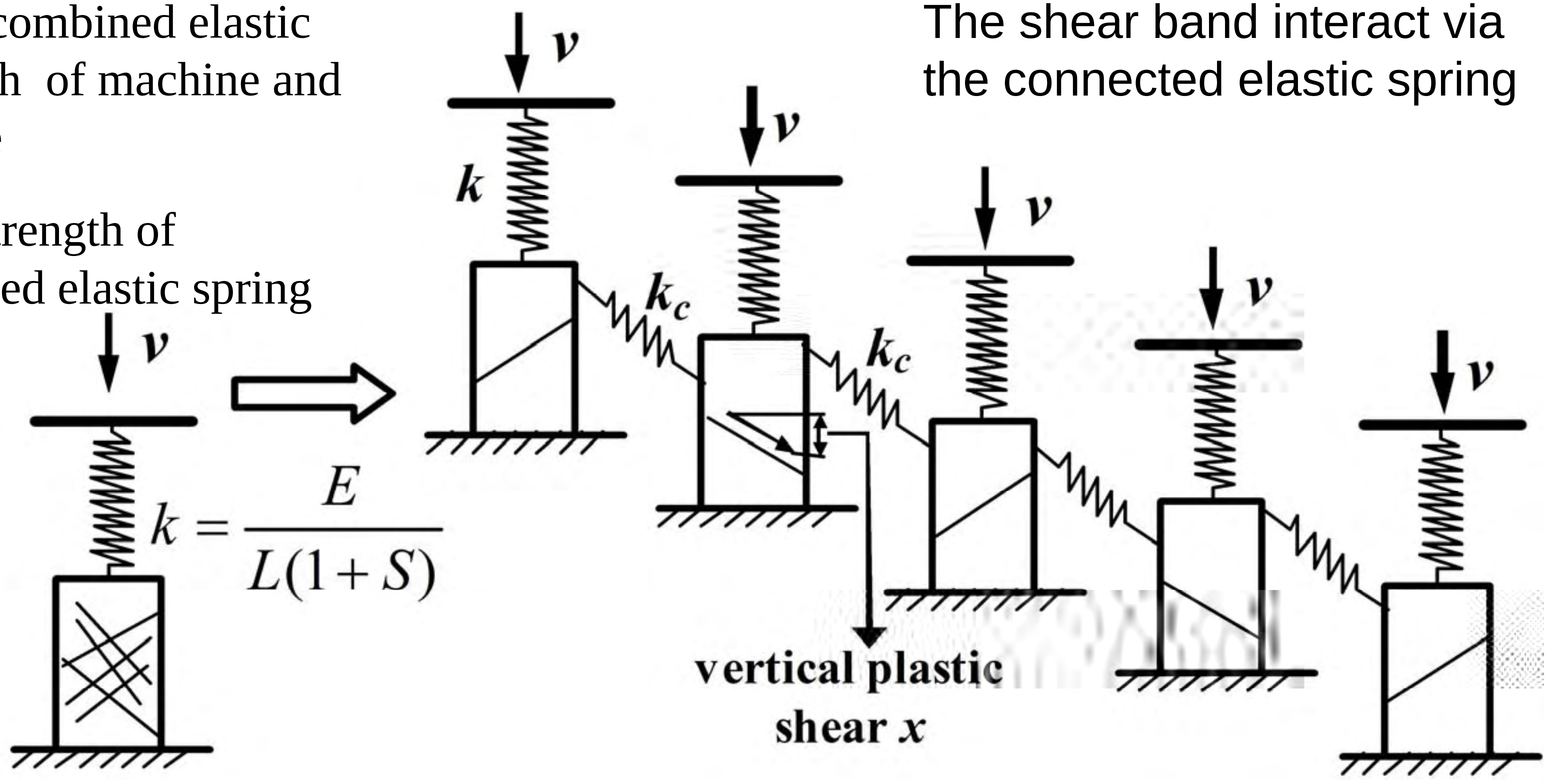
$$D(s) \sim s$$

Our model considering the interaction of multiple shear bands

k: the combined elastic strength of machine and sample

k_c the strength of connected elastic spring

The shear band interact via the connected elastic spring

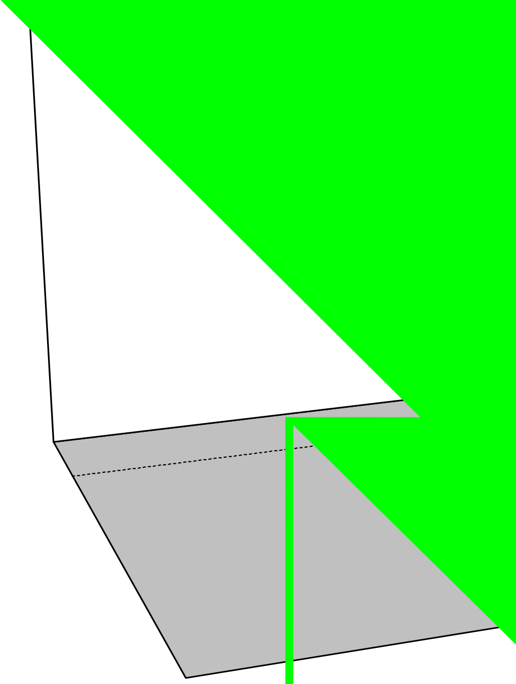


The kinetic equation for the system:

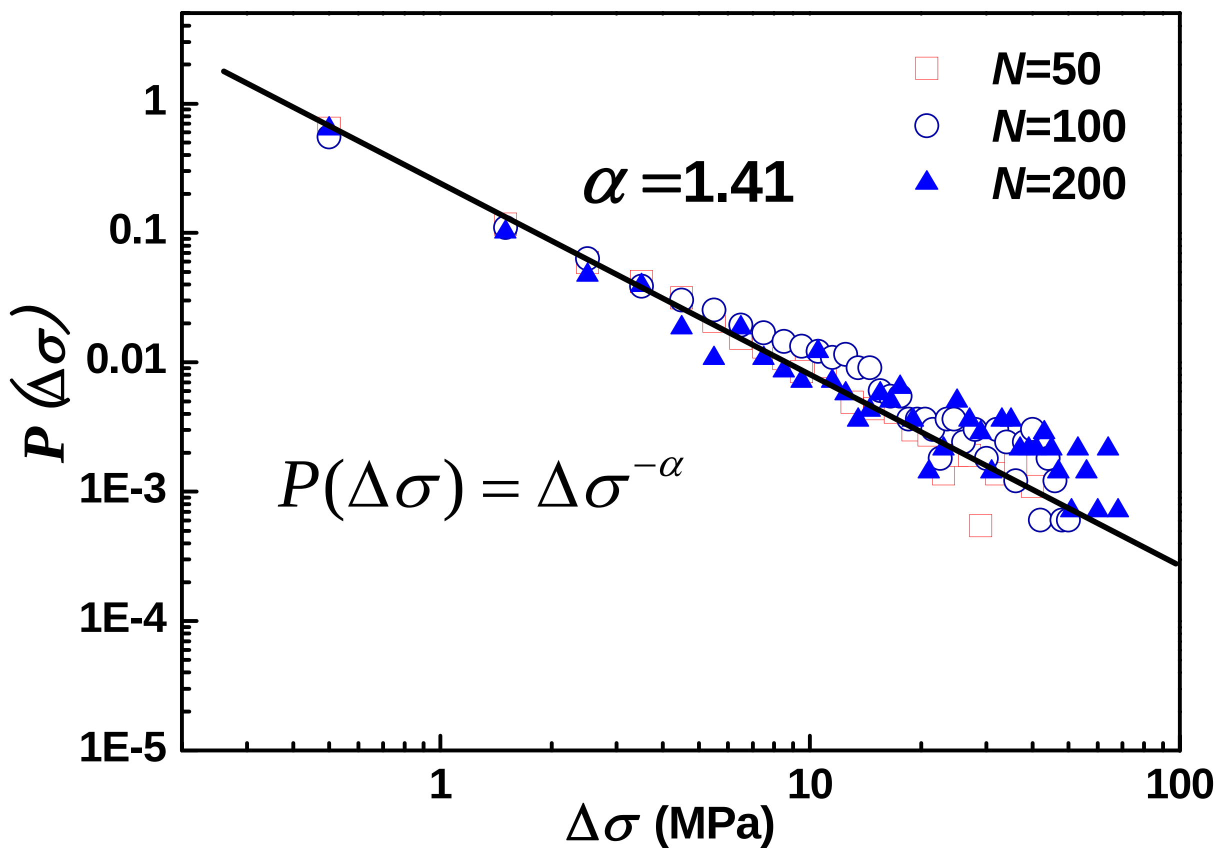
$$[k(vt - x_i) + k_c(x_{i+1} + x_{i-1} - 2x_i) - \boxed{\sigma_f(\dot{x}_i)}]\frac{\pi d^2}{4} = M\ddot{x}_i$$

$$\sigma(x) = \sigma_{ys} - E\frac{x_s}{L} = \sigma_{ys} - \frac{E}{L}\frac{\kappa_M}{(\kappa_S + \kappa_M)}x = \sigma_{ys} - \frac{Ex}{L(1+S)}$$

Shear resistance of material



The calculated stress drop probability distribution can be well fitted by a power law distribution, reproduce the experimental observation



PRL 105 (2010) 035501

Science 319, 1655 (2008)

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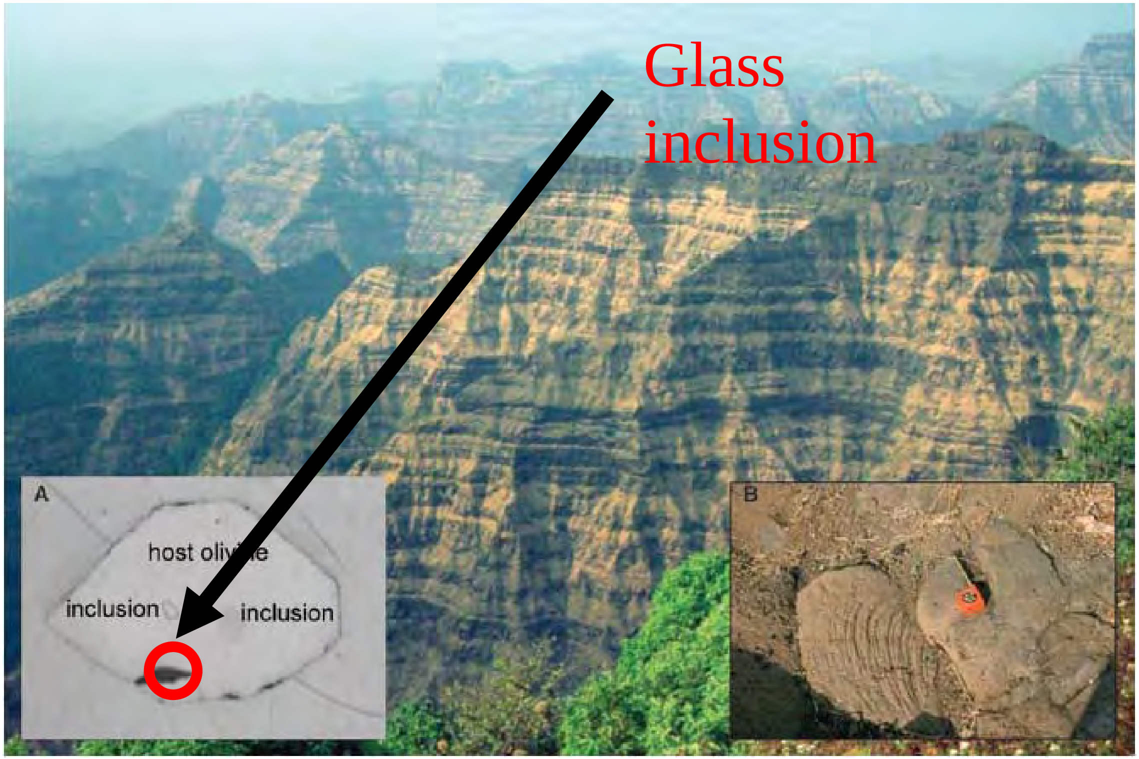

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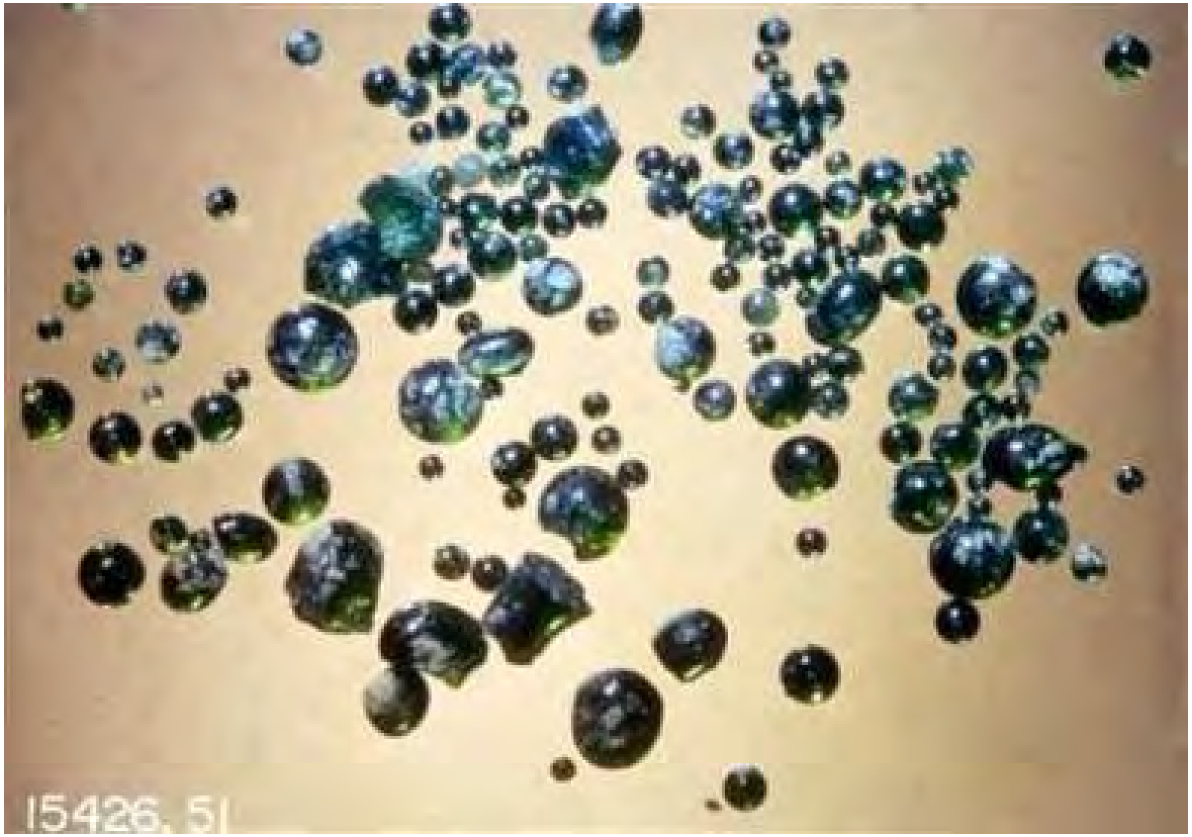


Nature 454, 192 (2008)

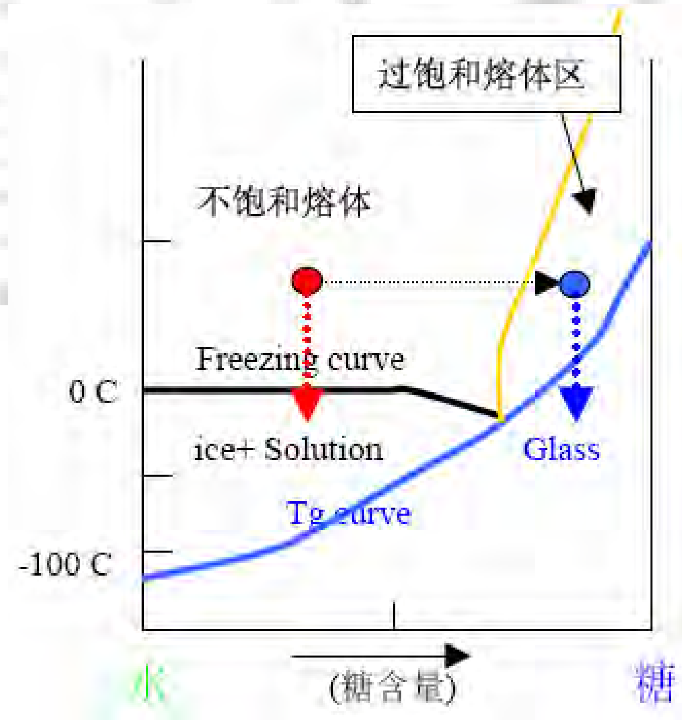
The volatile budget of the lunar mantle can, at present, only be reconstructed from the record preserved in the mare basalts and the lunar volcanic glasses, the most primitive basalts from the Moon.

Northern Wood Frog

Rana sylvatica

— the only frog found north of the Arctic circle

— when frozen, the frog's breathing, blood flow and heartbeat stop



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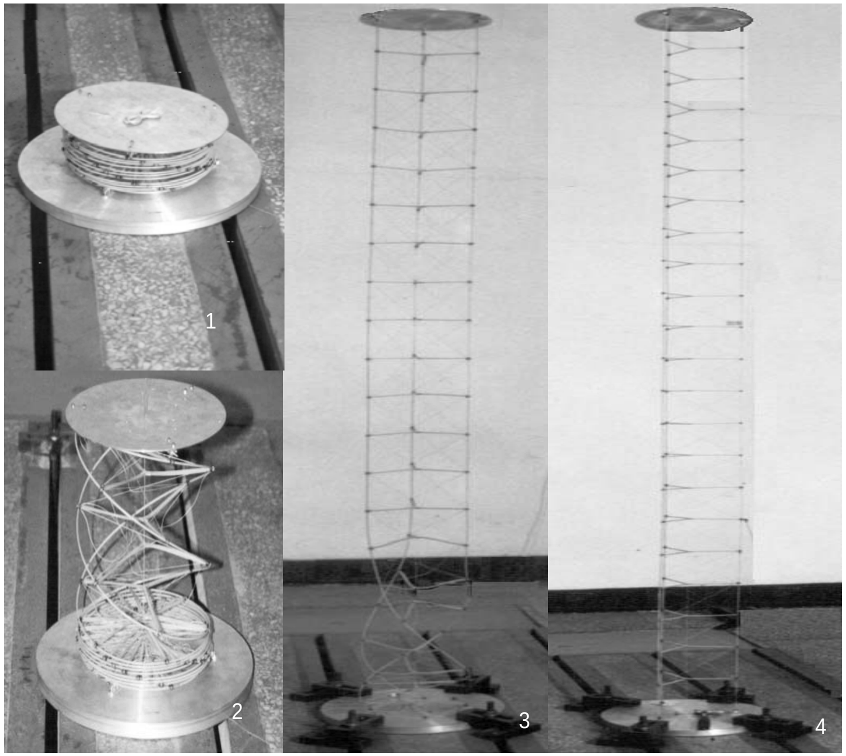
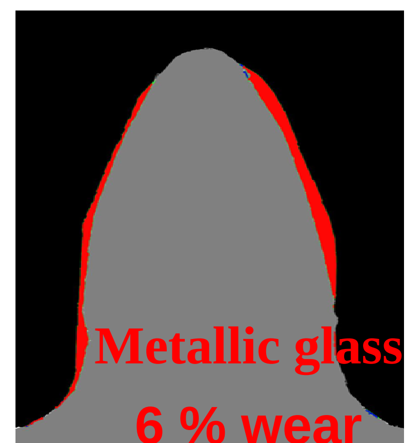


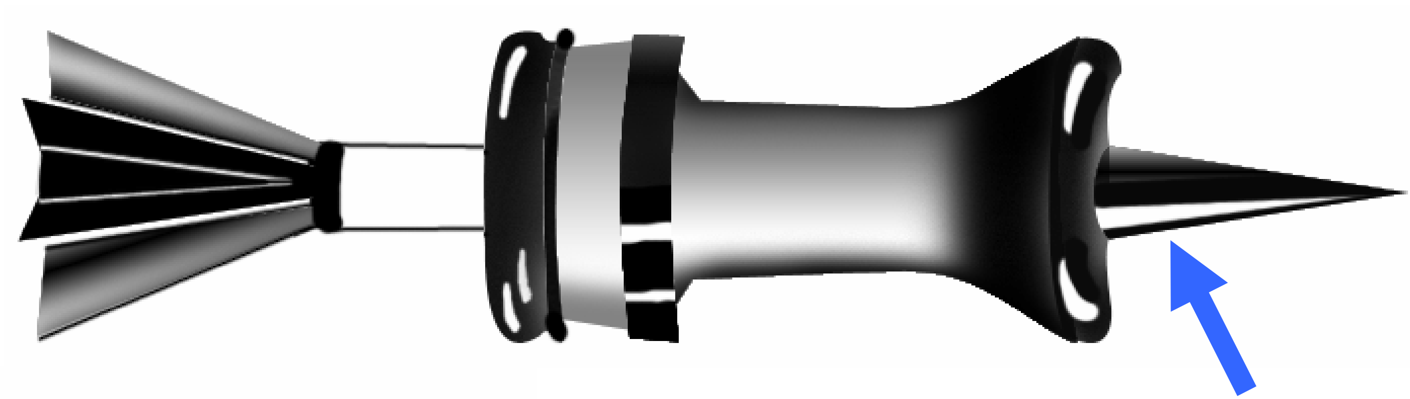

inner ring

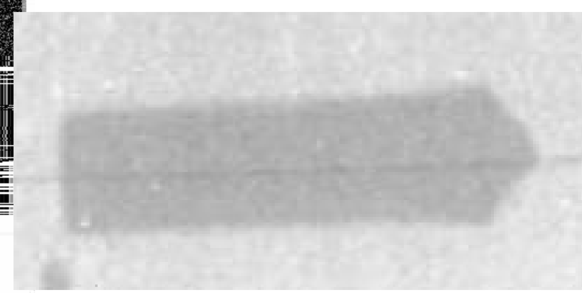

(a)

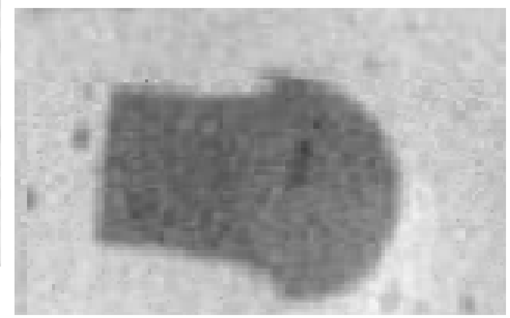

(b)
GCr15


Steel
22 % wear

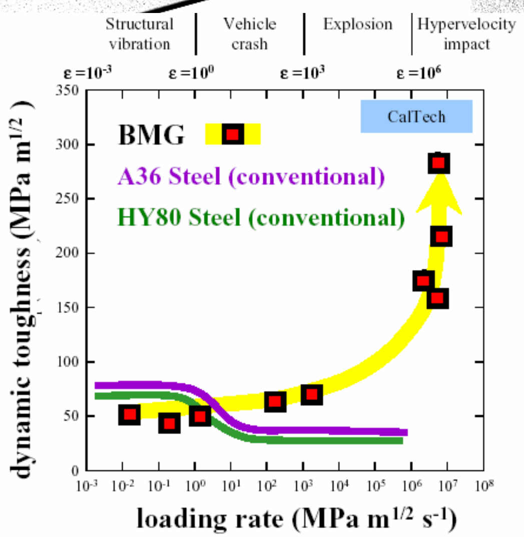

Metallic glass
6 % wear







W alloy



高动态断裂韧性及自锐性


VERTU
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