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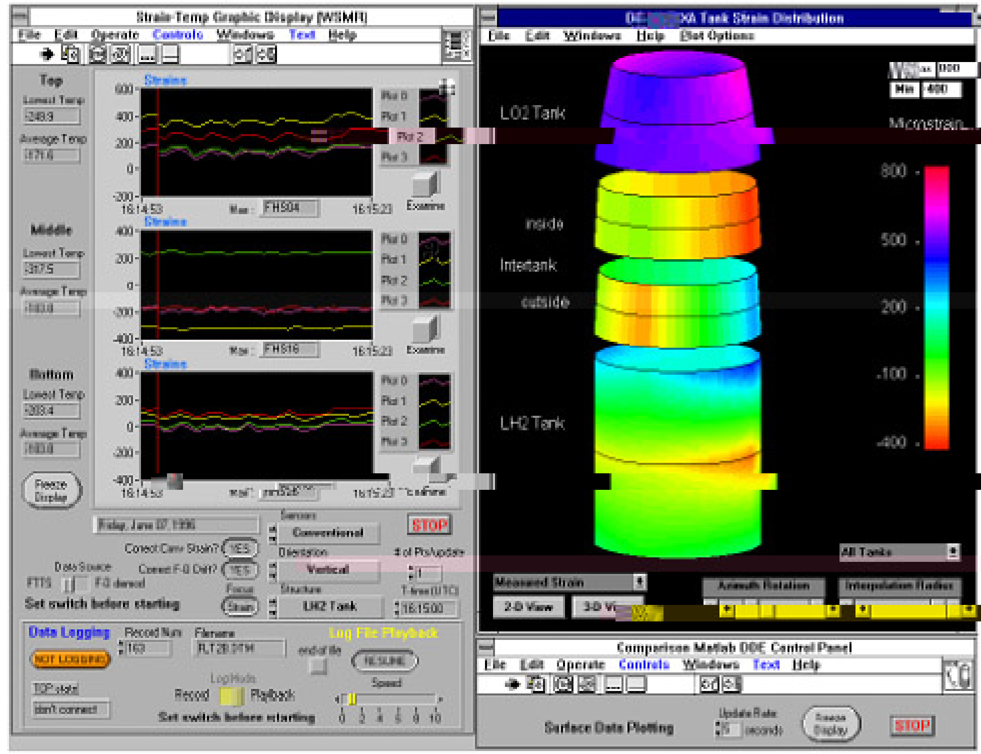
Structural Health Sensors on Composite LH_2 Tank, Intertank Structure, and LO_2 Tank

Smart Material Measuring

Strain and Temperature



Information Processing and Display

(DC-XA Flight 2 at Approx. 1 sec before lift-off, strains due to engine firing and thermal stresses)

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Photobase

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  Shape memory alloys, SMAs
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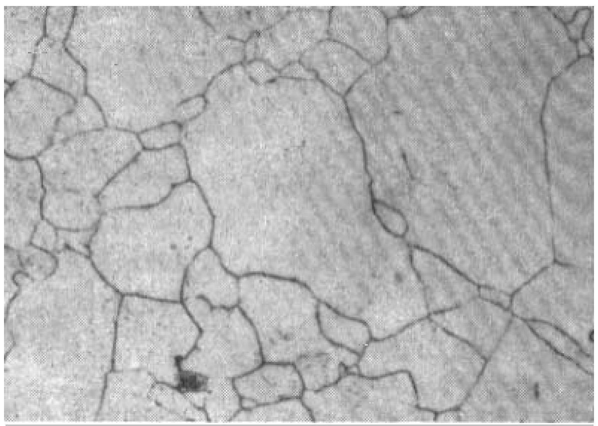
χ Є **Martensite** S ɽ

J I **Robert Austen** J ى

I پ ح χ Є **Austenite** S ɽ



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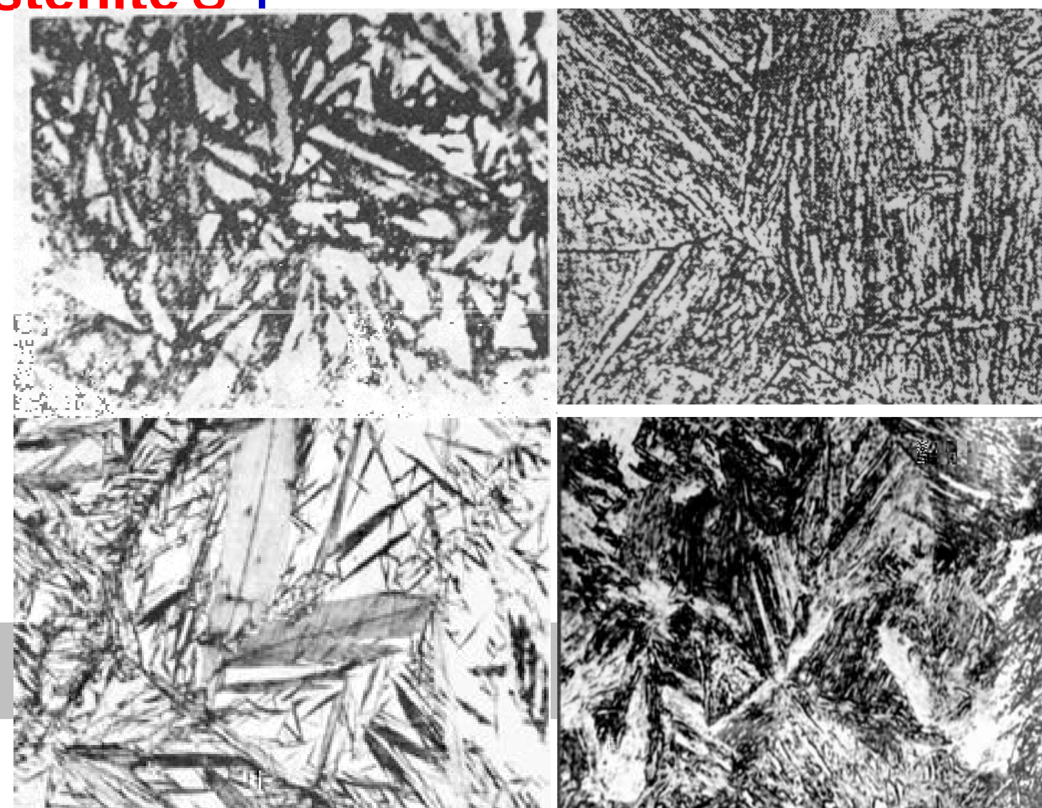

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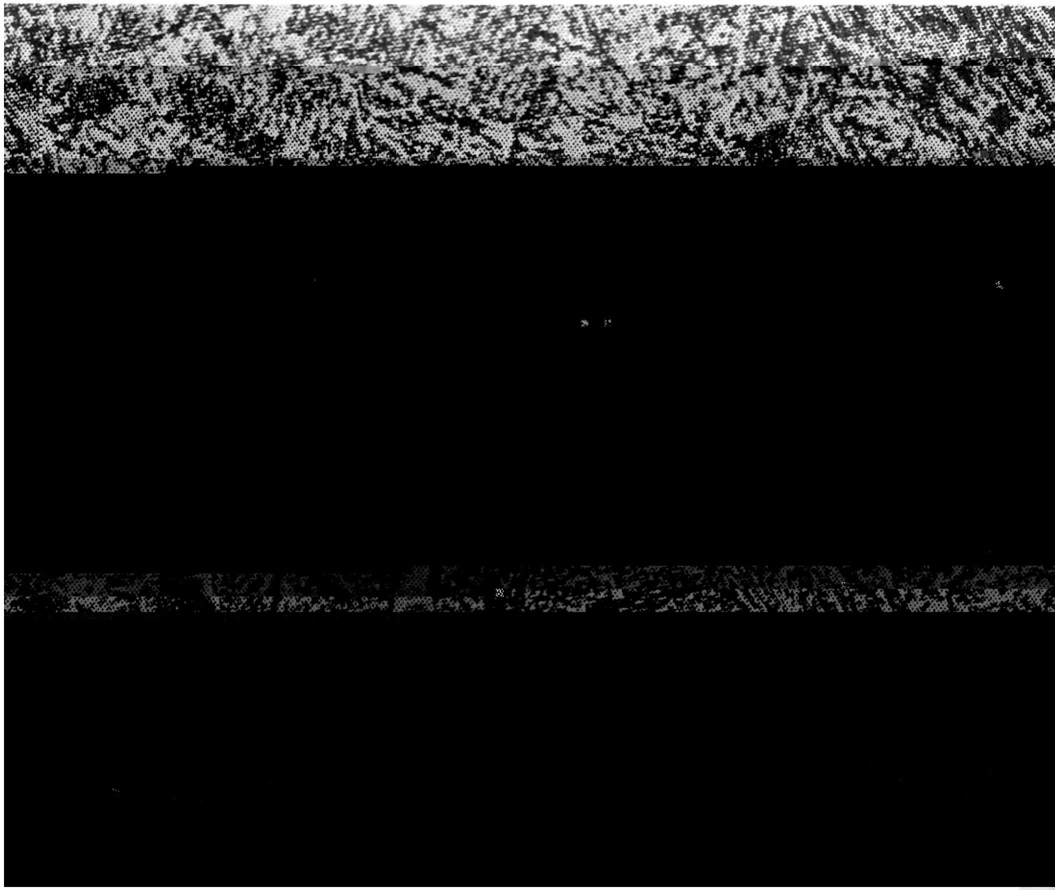
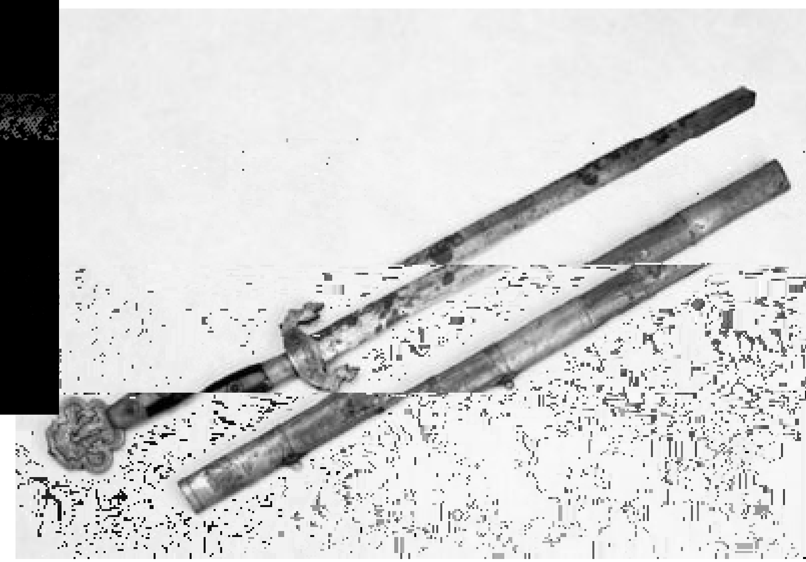


450x



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1929 J ƙ χ Є 10^5 ŏ /s S ╗ χ ɼ

1938 J Cu-Zn پ χ ˉ ͻ Q χ χ ɼ

1963 J Wolten ⅔ ZrO_2 χ

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Є International Conference on Martensitic Transformation, ICOMAT S ɽ **1976**

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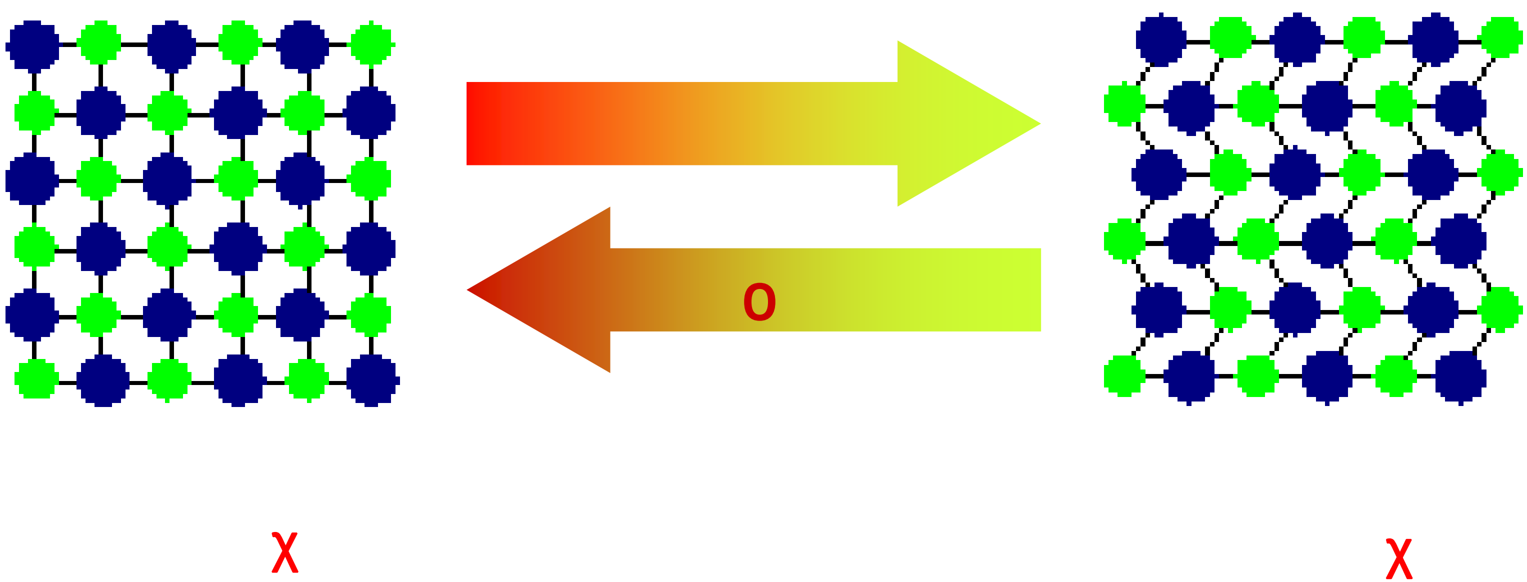

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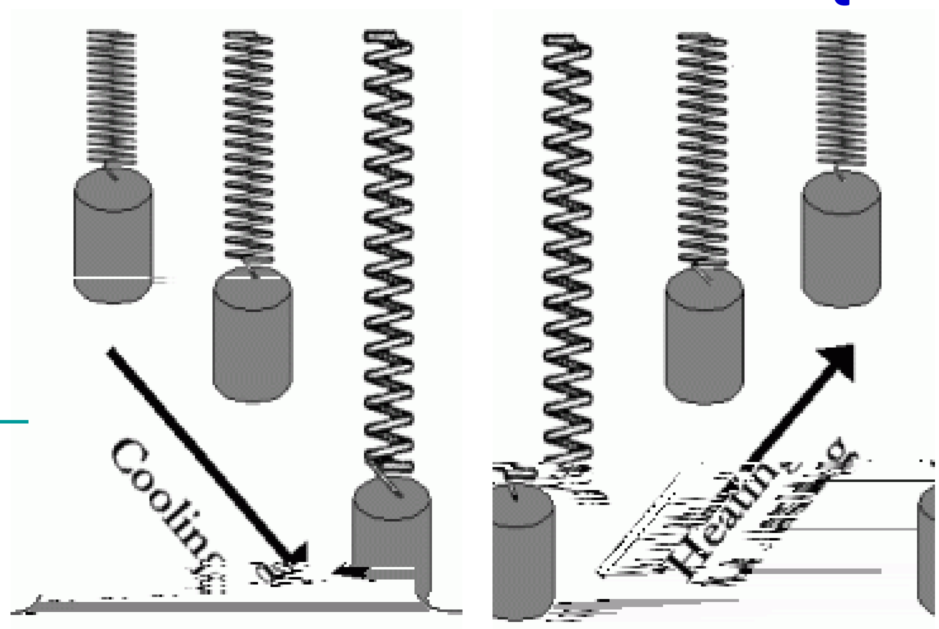

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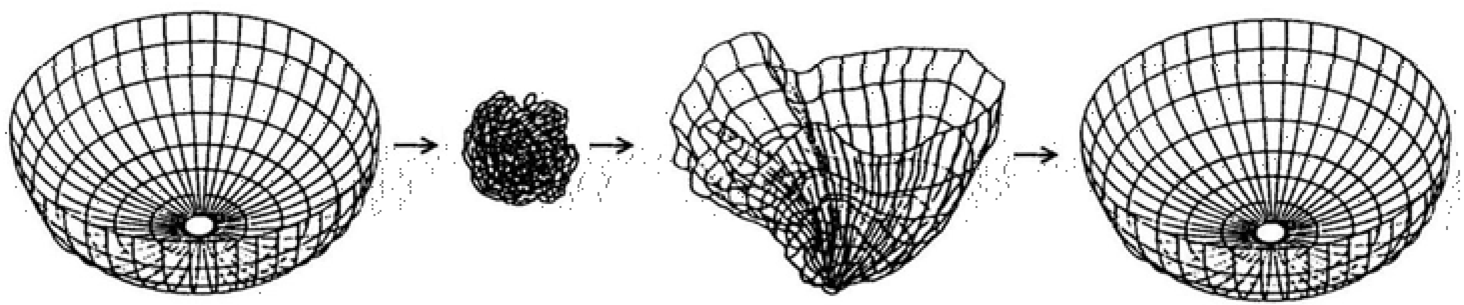

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1932 J Au-Cd پ ҳ ˊ

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1951 J Au-Cd ҳ ˊ χ ء ɽ

1953 J In-Tl پ ҳ ╗

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1963 , -

Buehler NiTi پ χ ể

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Ordnance Laboratory) ɼ

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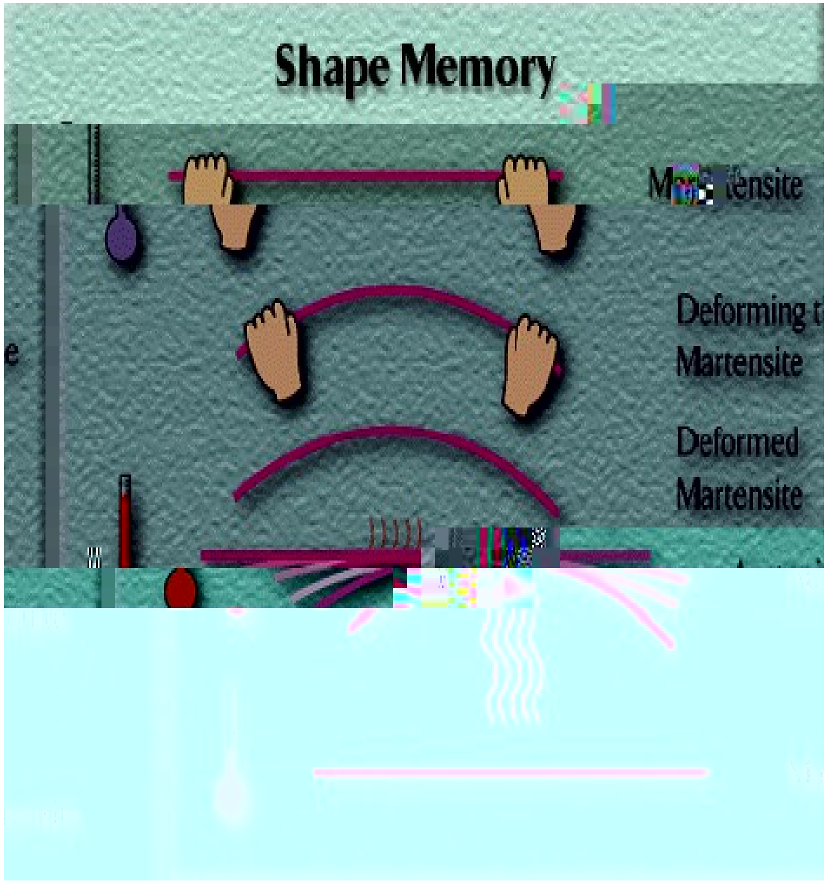

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є 1 S پ J NiTi ɼ Cu ɼ Fe پ ɼ ʹI ҳ J NiTi ▓ ‟ Ҡ и Ẇ J I پ ɼ

є 2 S پ J Ni ɼ Co ɼ Fe پ ɼ ʹI ҳ Ni_2MnGa ˉ r ʝ ╗ پ ɼ

є 3 S پ J NiTi ɼ Cu ɼ NiAl پ ɼ

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1. ڵ ء5 --

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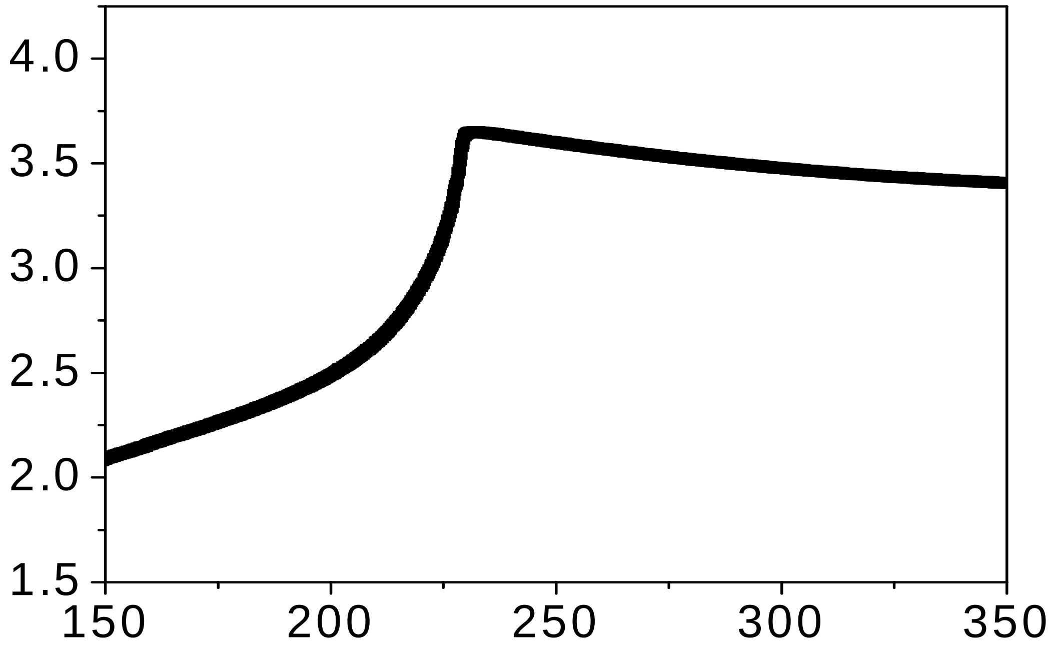
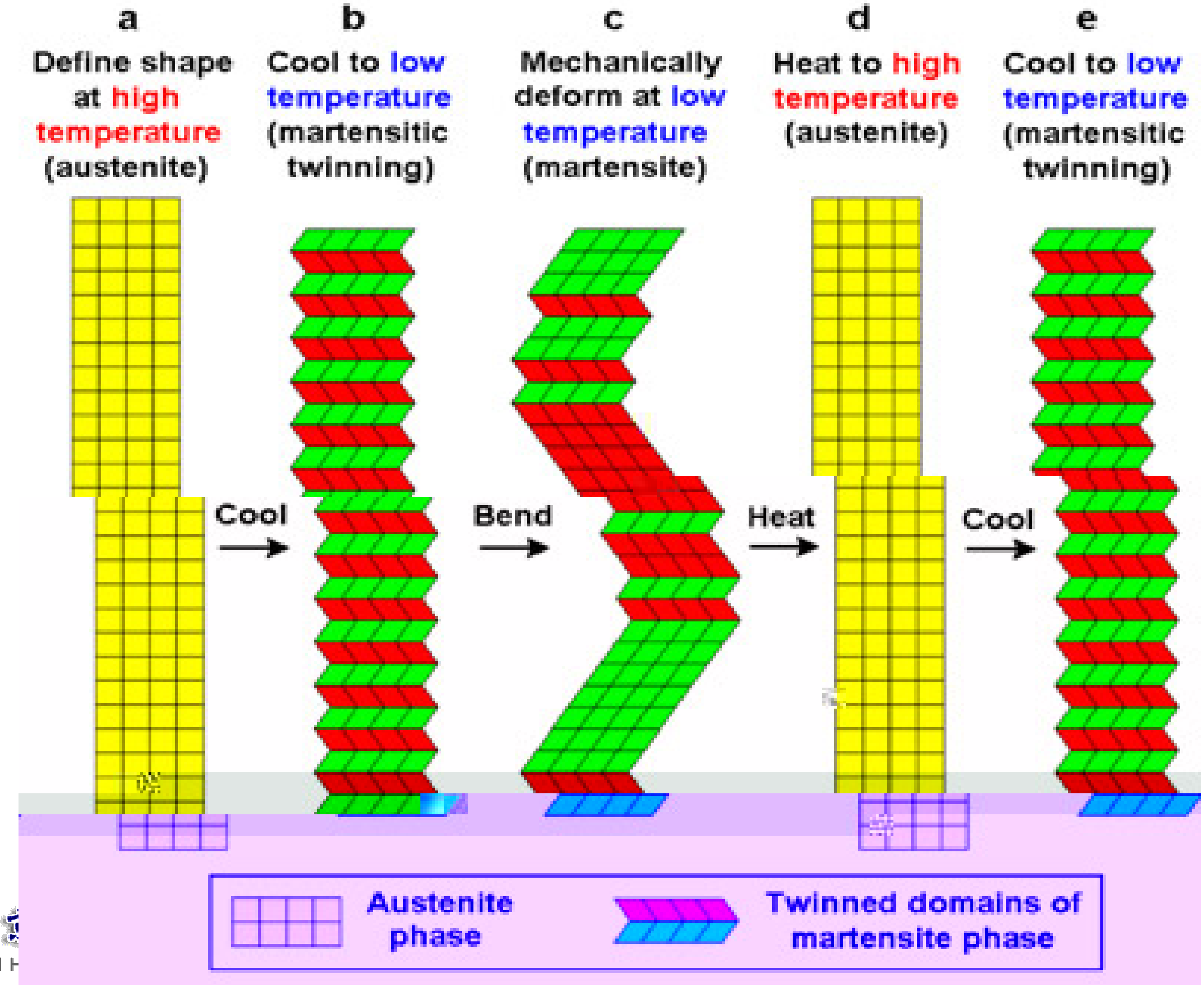
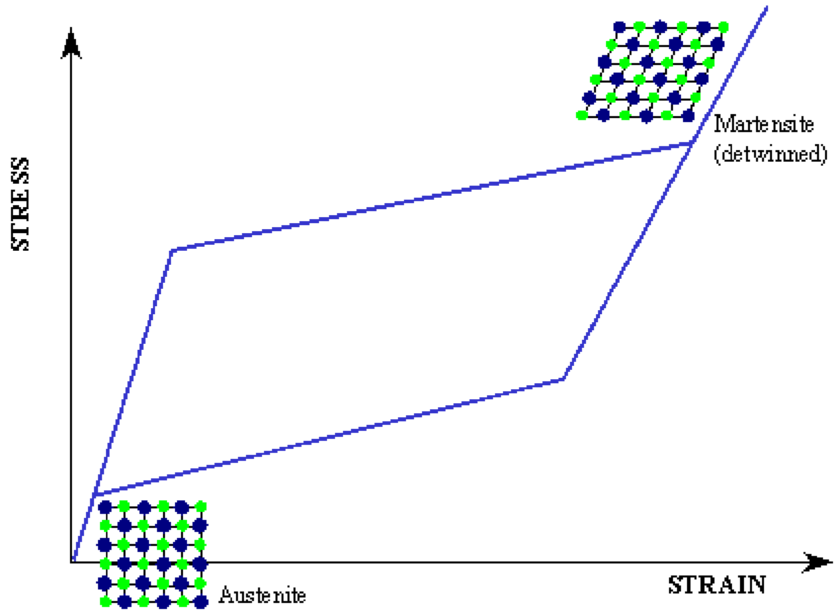
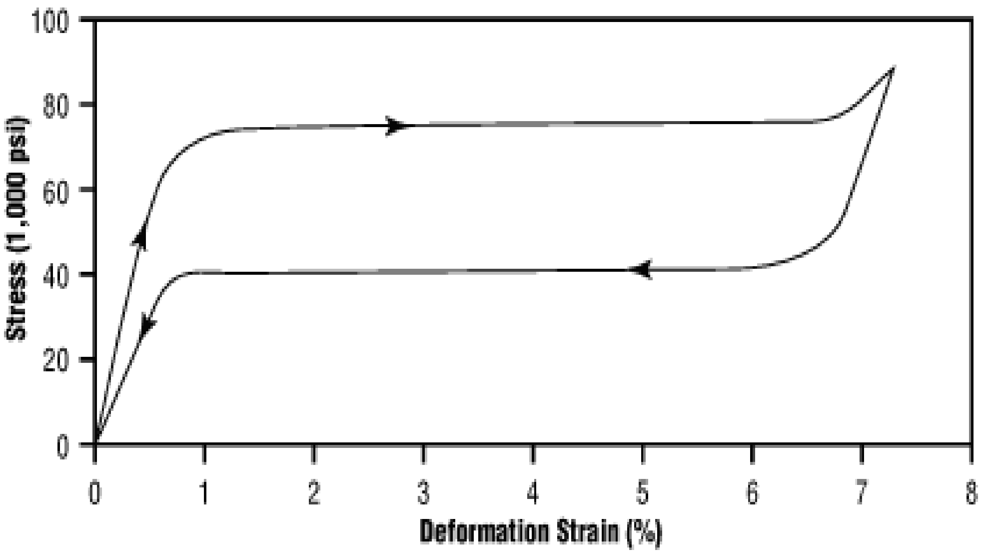

4.0
3.5
3.0
2.5
2.0
1.5
150
200
250
300
350


a
Define shape at high temperature (austenite)
b
Cool to low temperature (martensitic twinning)
c
Mechanically deform at low temperature (martensite)
d
Heat to high temperature (austenite)
e
Cool to low temperature (martensitic twinning)
Cool
Bend
Heat
Cool
Austenite phase
Twinned domains of martensite phase


STRESS
Martensite
(detwinned)
Austenite
STRAIN


100
80
60
40
20
0
Stress (1,000 psi)
0
1
2
3
4
5
6
7
8
Deformation Strain (%)

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- **NiTi** , , ,
  , , , , .
- **Cu-Al-Ni,Cu-Zn-Al** , (
  ), .
- **Fe-Mn-Si** ,
  , , .

پ Ҳ, Q Cu پ س Fe
پ پ Q NiTi پ ,
Q پ پ Ӝ ˈ NiTi
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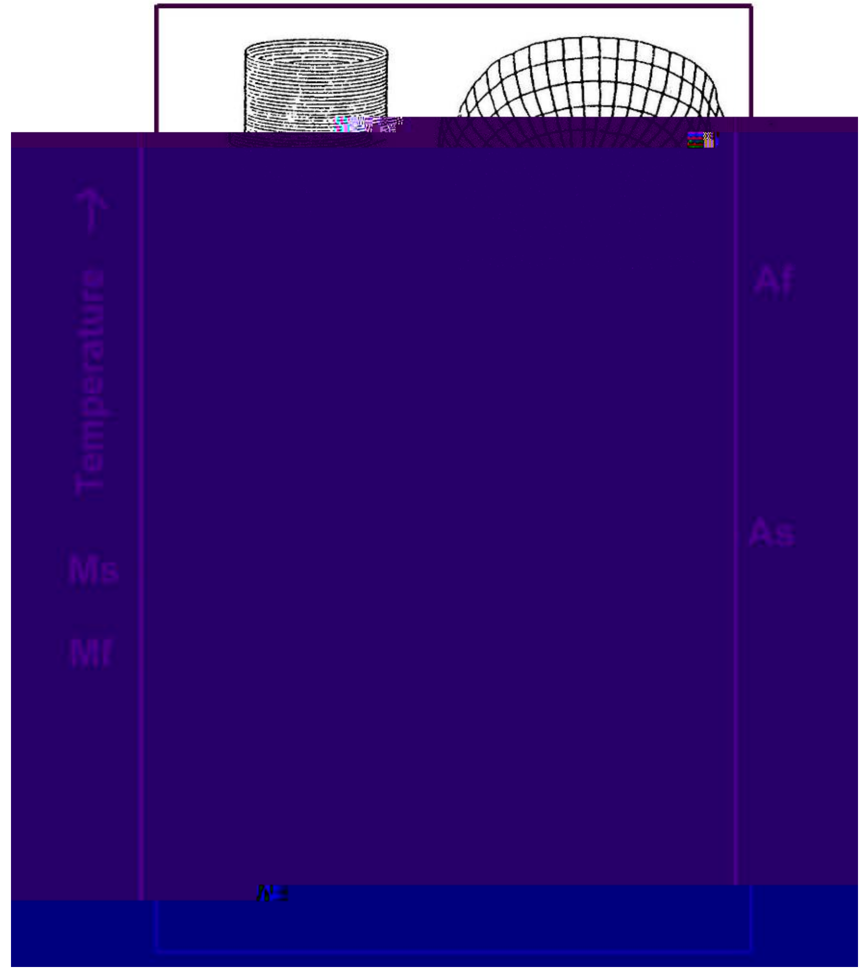

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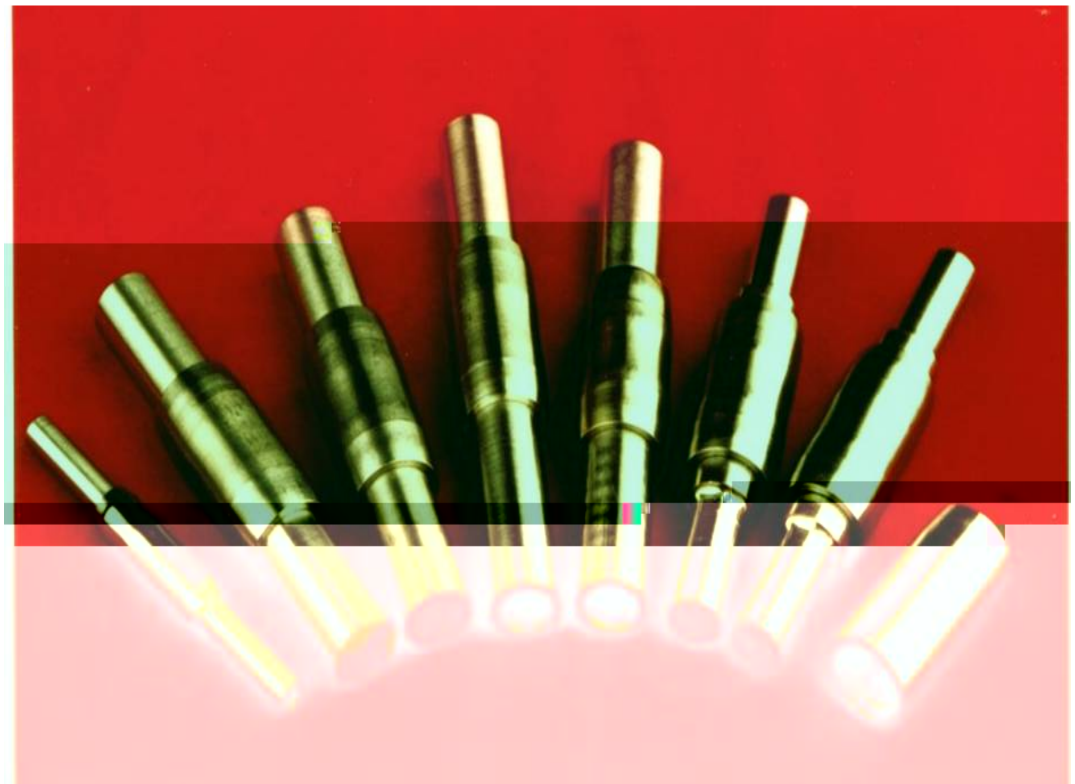

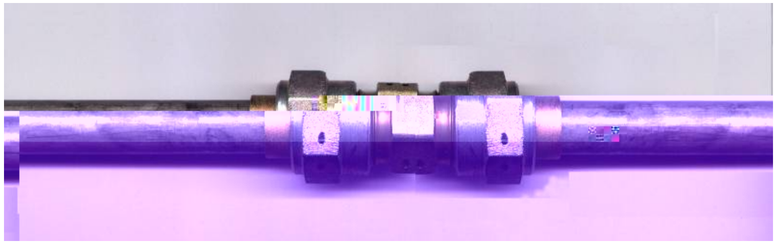

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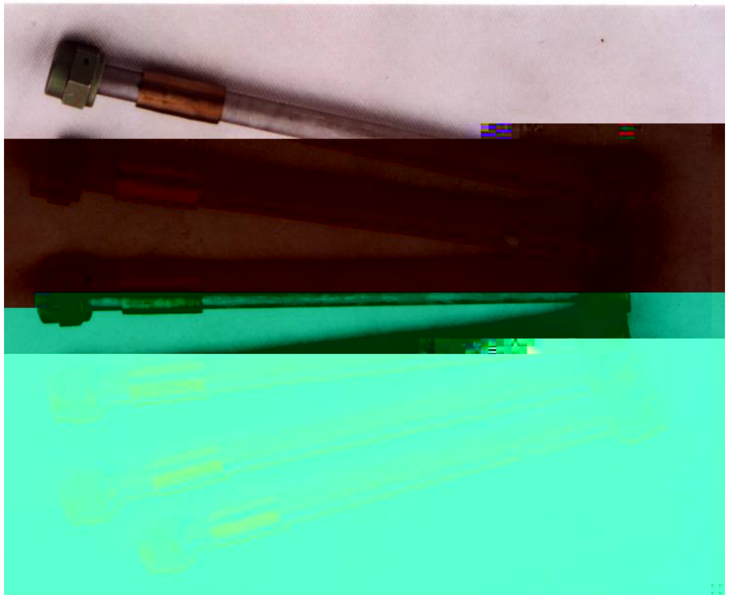

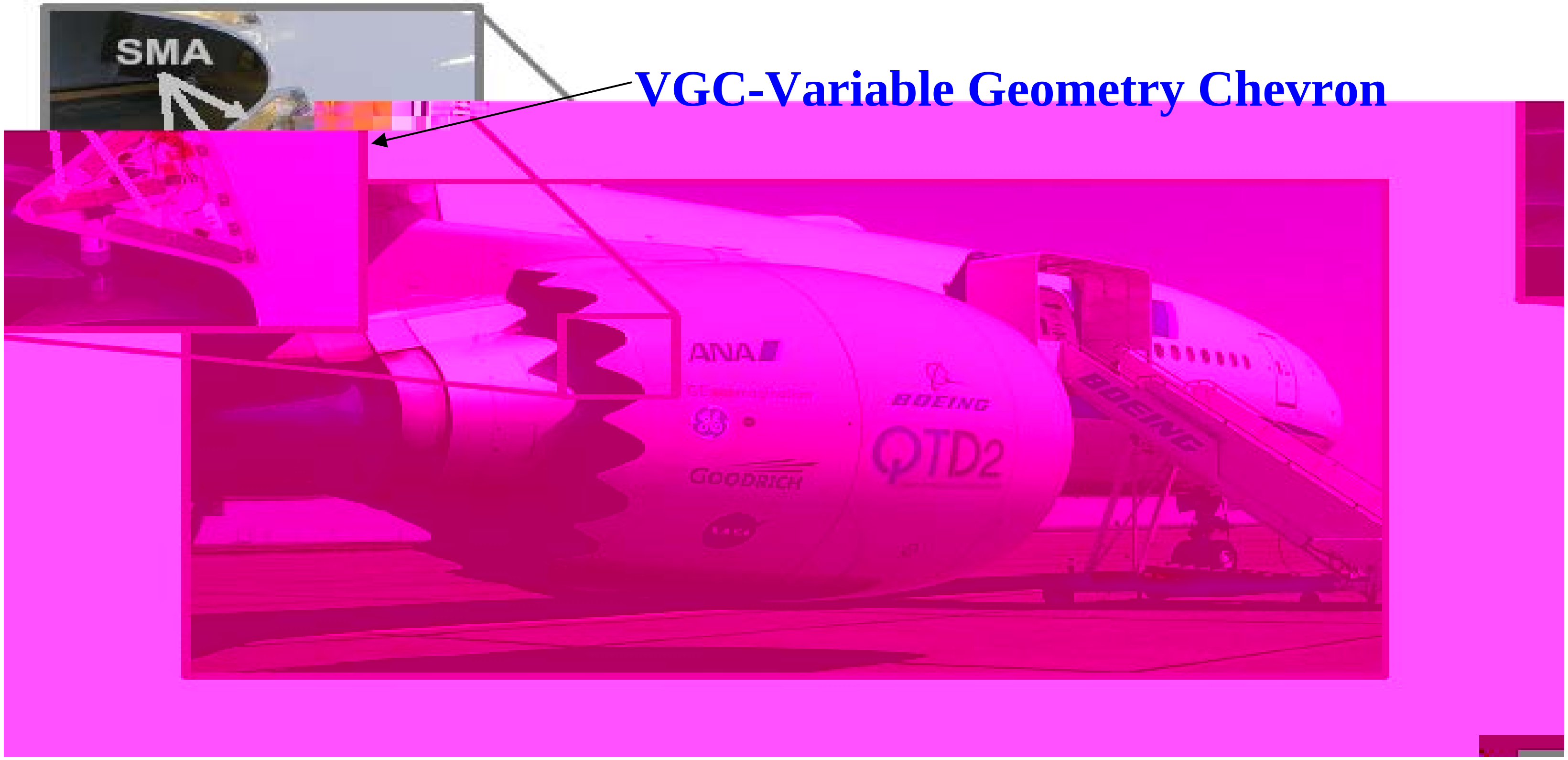

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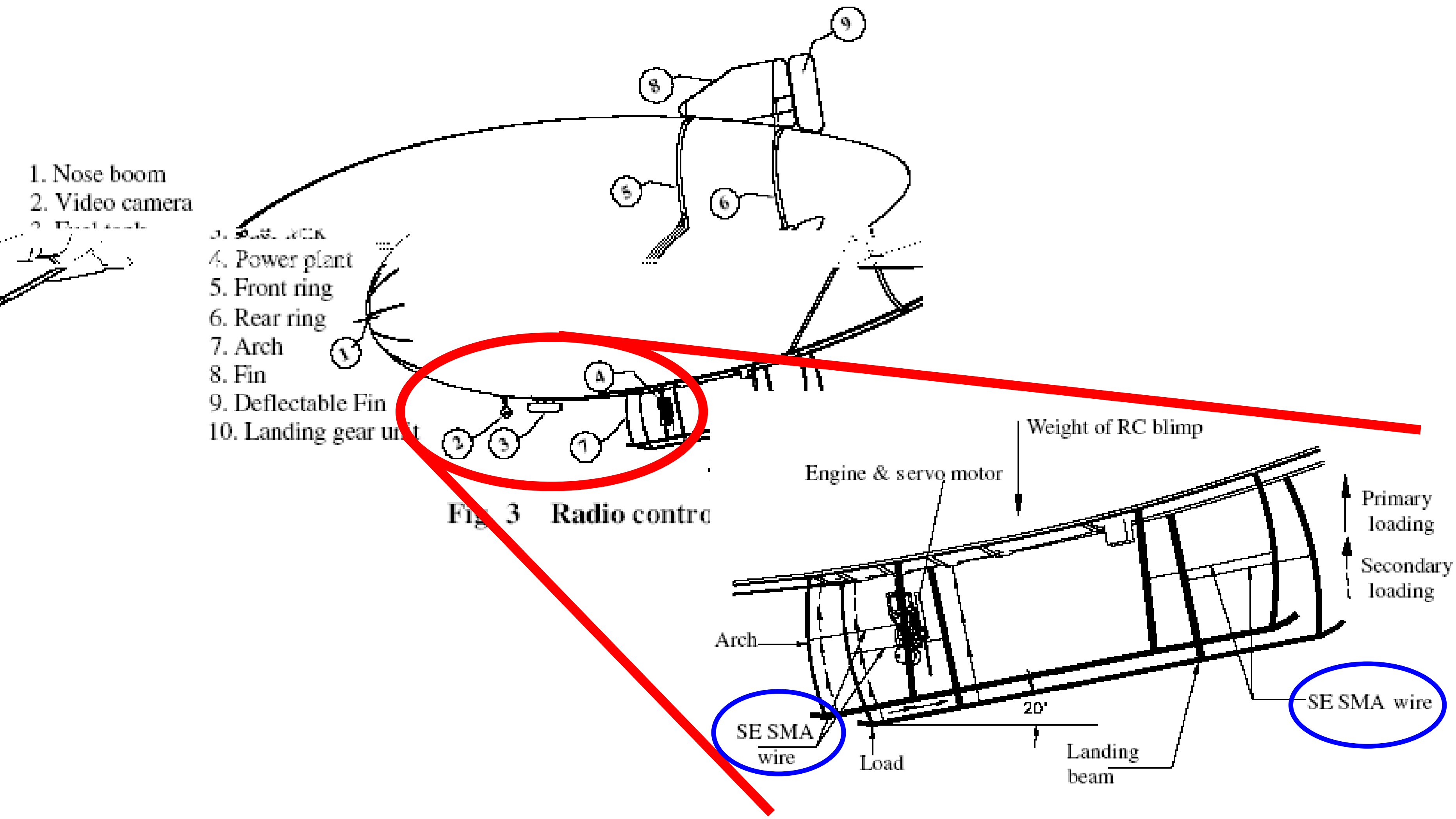

1. Nose boom
2. Video camera
4. Power plant
5. Front ring
6. Rear ring
7. Arch
8. Fin
9. Deflectable Fin
10. Landing gear unit
Fig. 3 Radio contro
Weight of RC blimp
Engine & servo motor
Primary loading
Secondary loading
Arch
SE SMA wire
20°
SE SMA wire
Load
Landing beam

NASA X J

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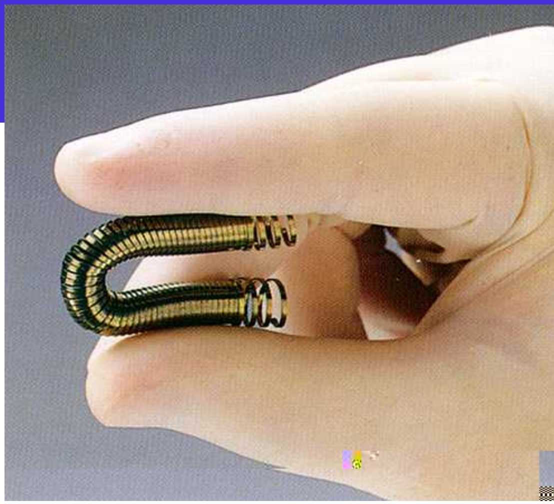

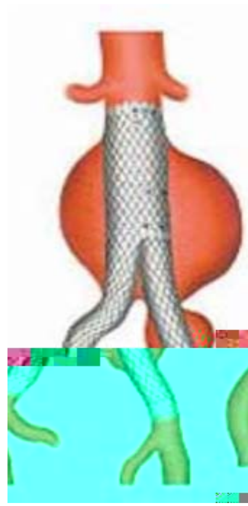

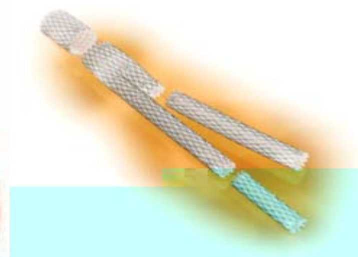

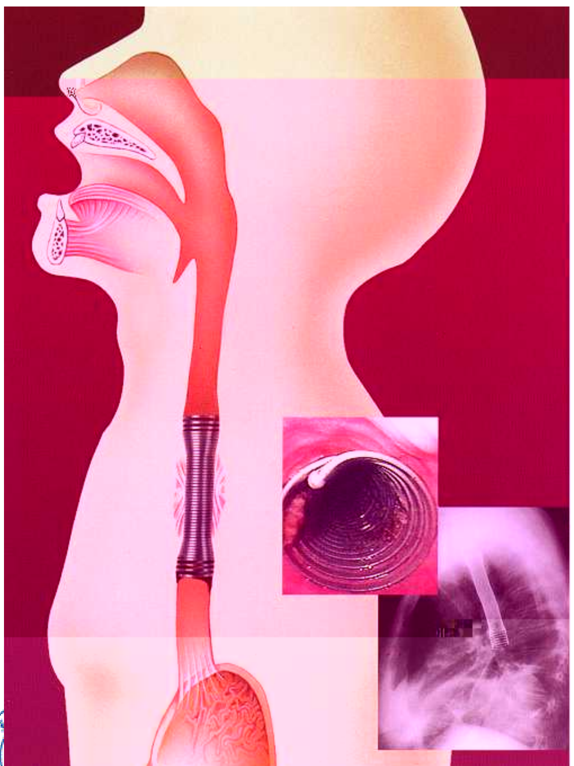

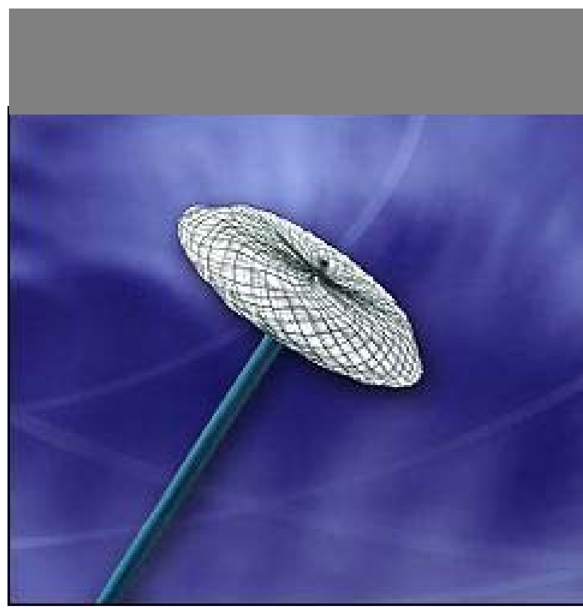

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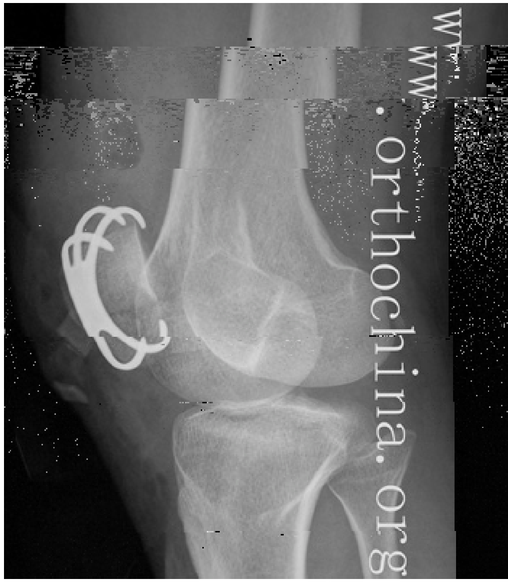

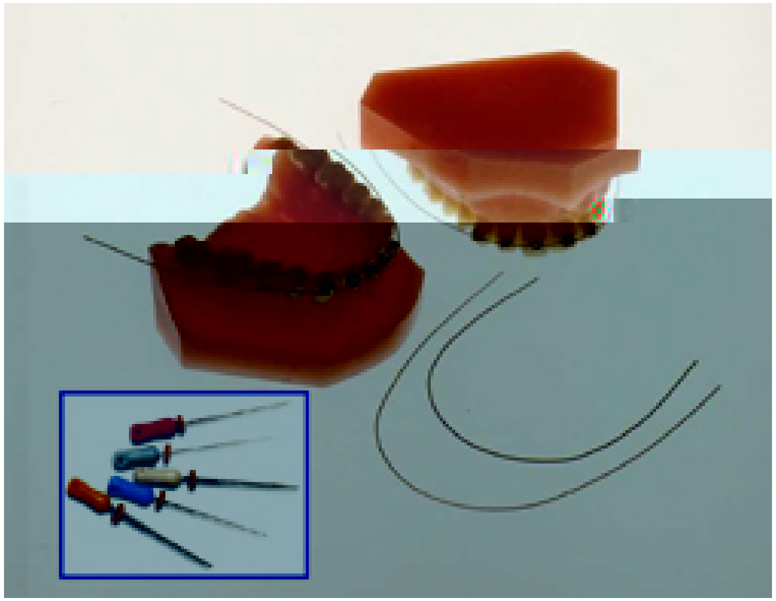

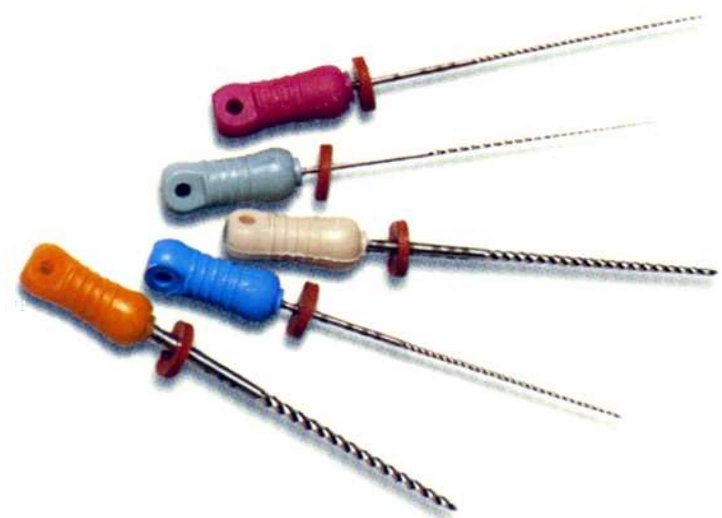

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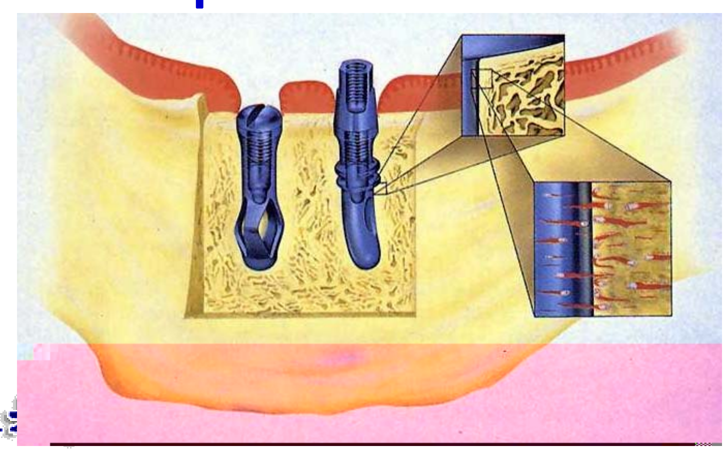

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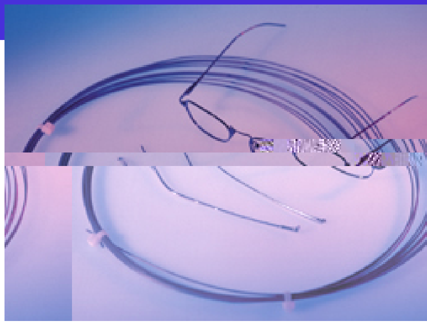

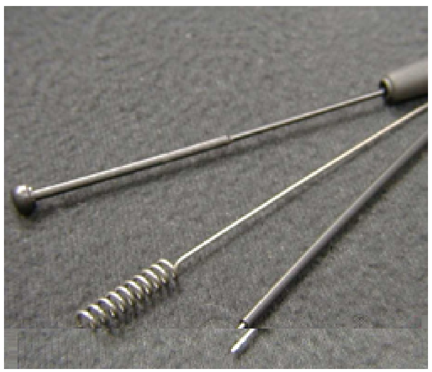

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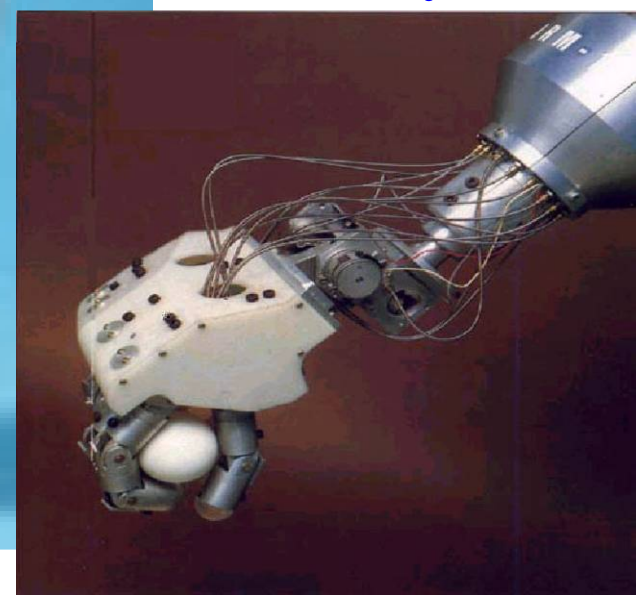

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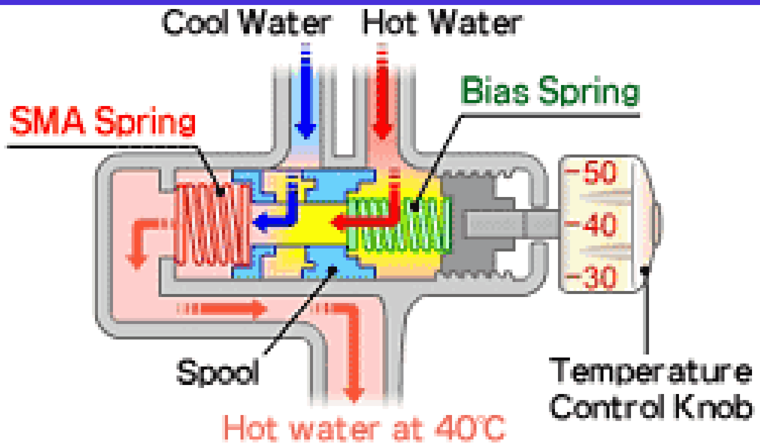
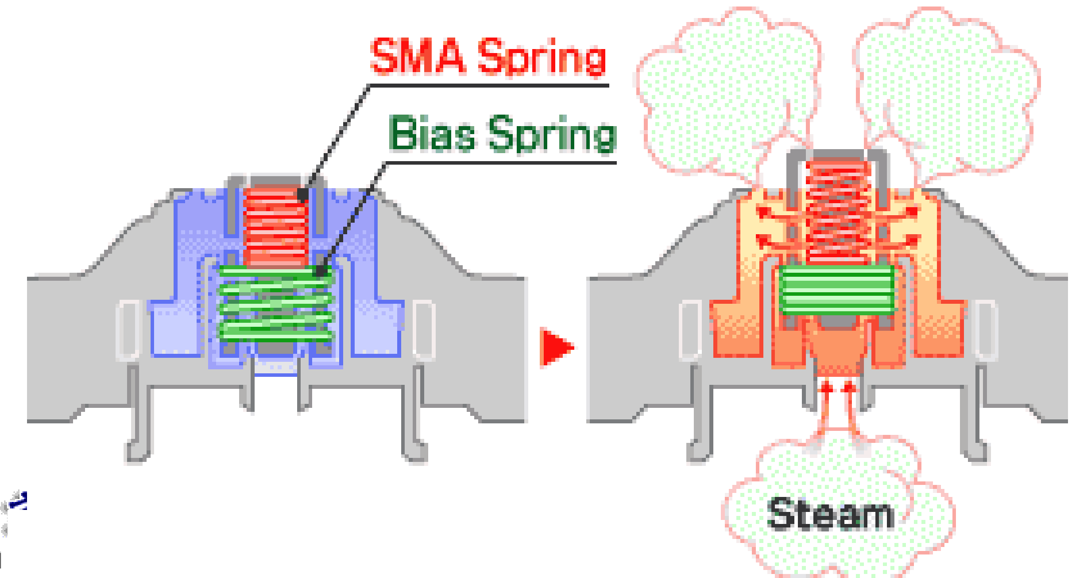


Cool Water
Hot Water
Bias Spring
SMA Spring
-50
-40
-30
Spool
Temperature
Control Knob
Hot water at 40℃



SMA Spring
Bias Spring
Steam

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- پ
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پ ⅔ ء Є 7-8% S J β ء

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ıı Ґ S J β ⅔ ء Є 0.2% S ɽ

ج ╝ ⅔ ‶ ⅔ ء Є 7-8% S J Ķ ي
Є 1000Hz ıı Ґ S إ Л

1996

G Ni_2MnGa

0.2%

6% 9.5%

0.2 0.3T J 1MPa

2006

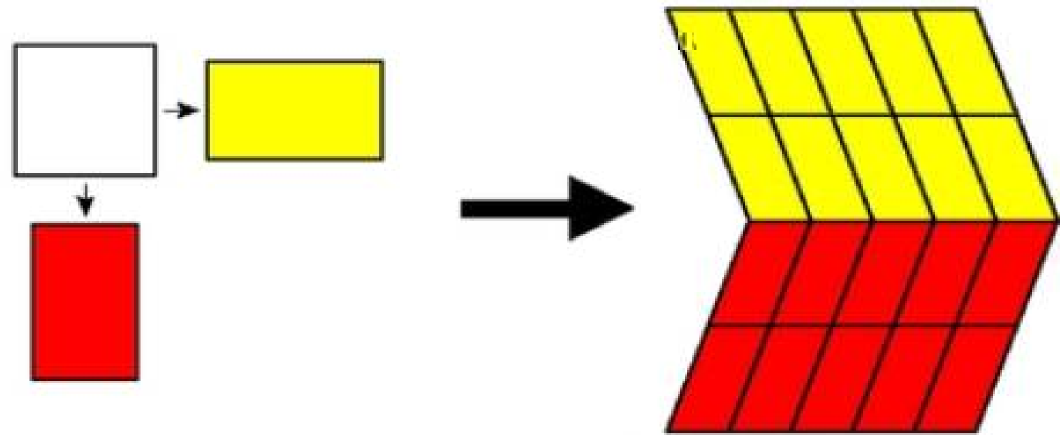
G NiCoMnIn

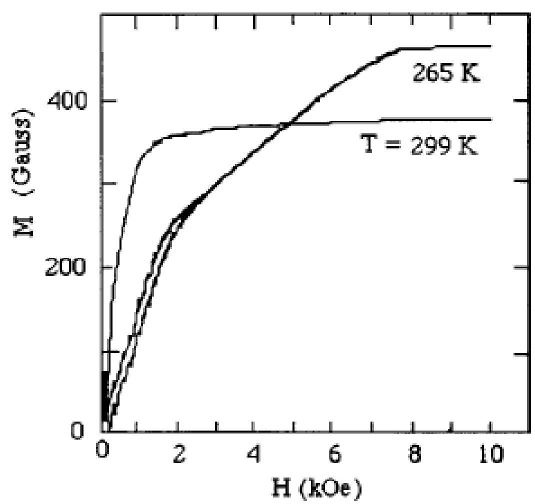
X

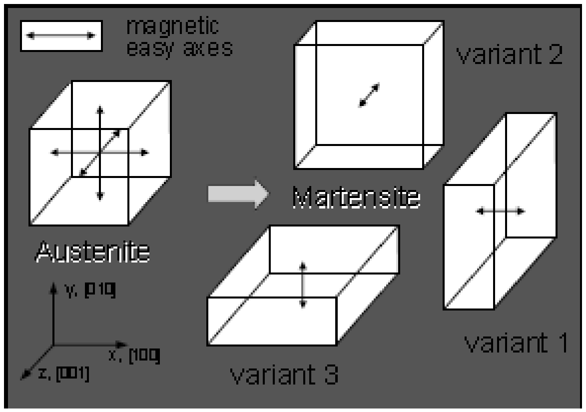
Ni(Co)MnX(X=In,Sn,Sb)

100MPa J

1984 Heusler Ni_2MnGa

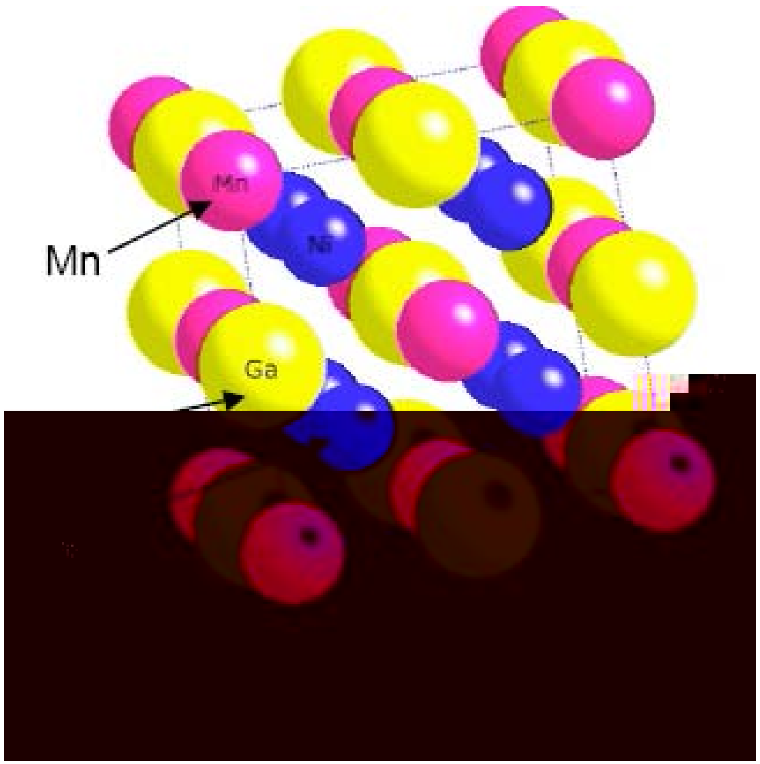


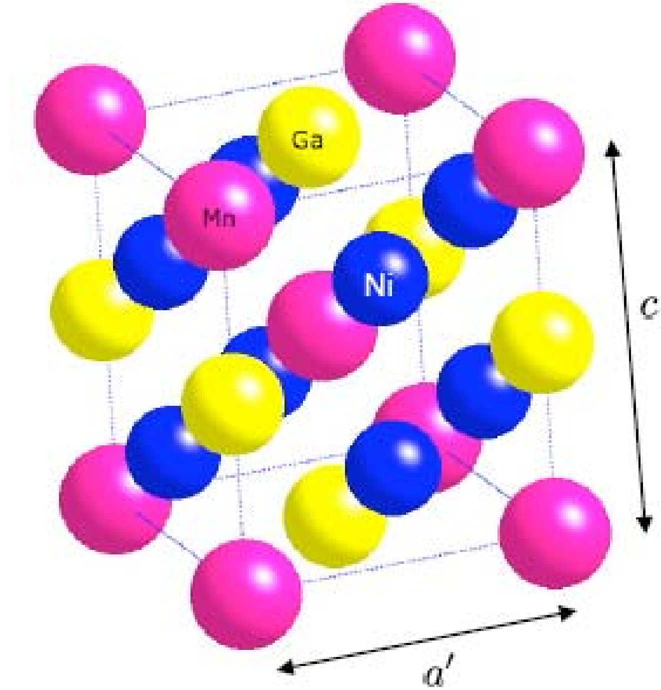




P.J. Webster, et al. *Philos Mag B* **49** (1984)295

Ni_2MnGa پ χ





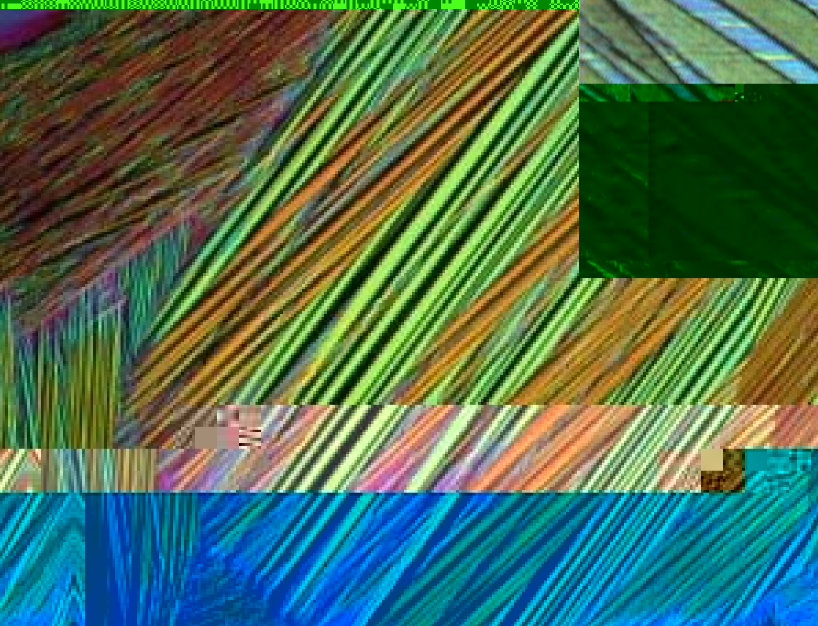
(b)

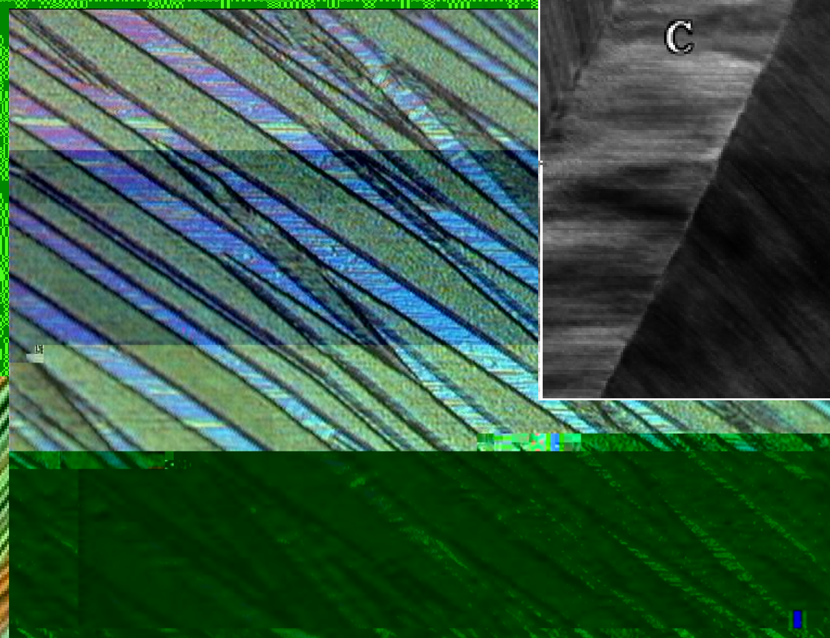
High temperature
austenite
(Cubic $L2_1$ structure)

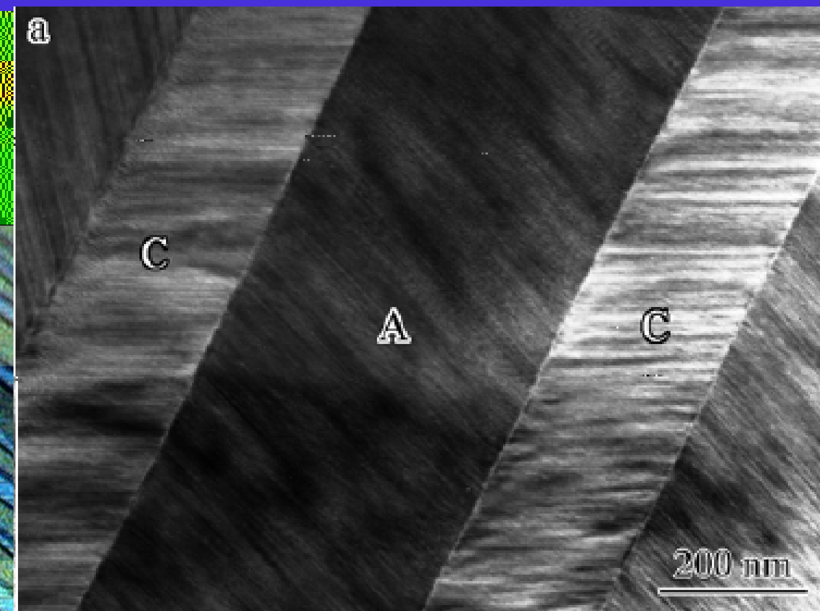
cooling
heating

Low temperature
martensite
(Tetrogonal structure)

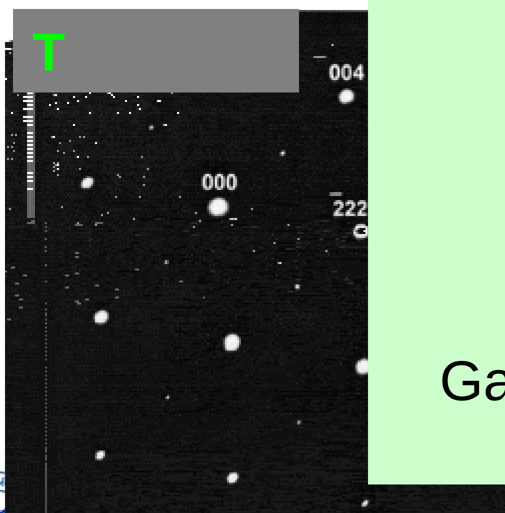
Ni_2MnGa پ χ







Ni_2MnGa پ χ



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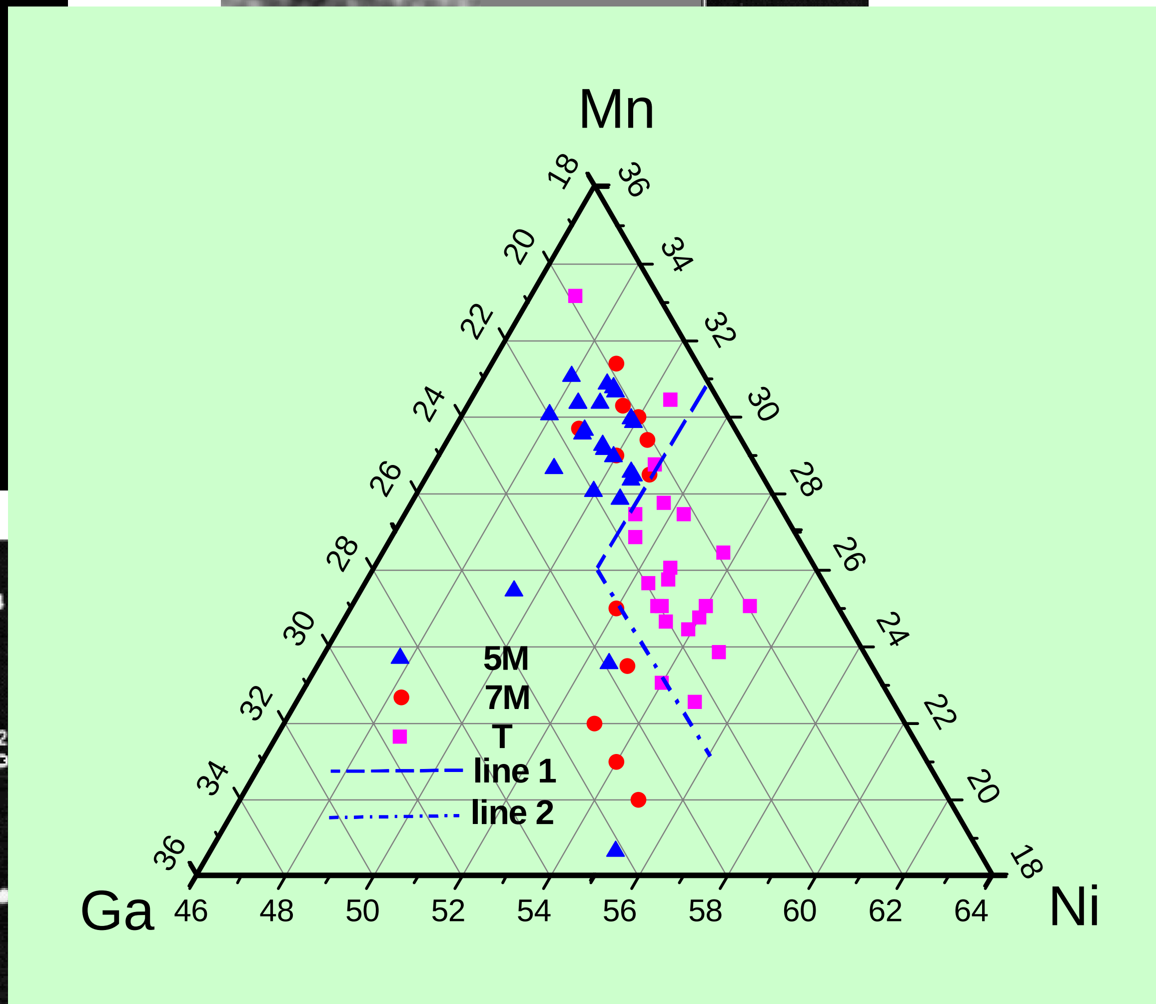

Mn
Ga
Ni
46
48
50
52
54
56
58
60
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64
18
20
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24
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28
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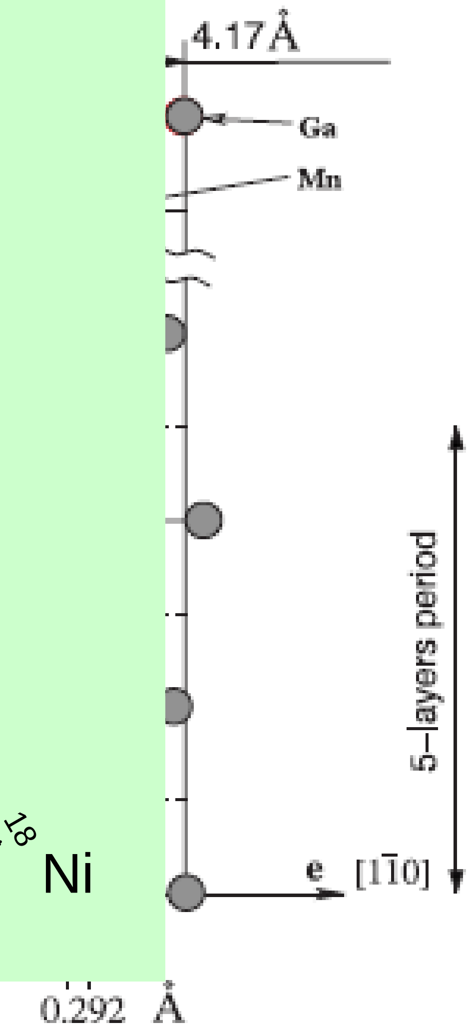
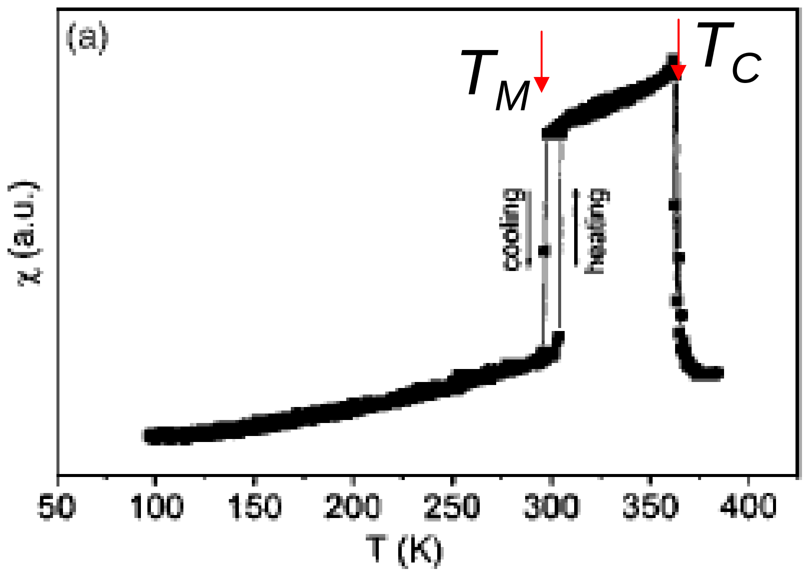
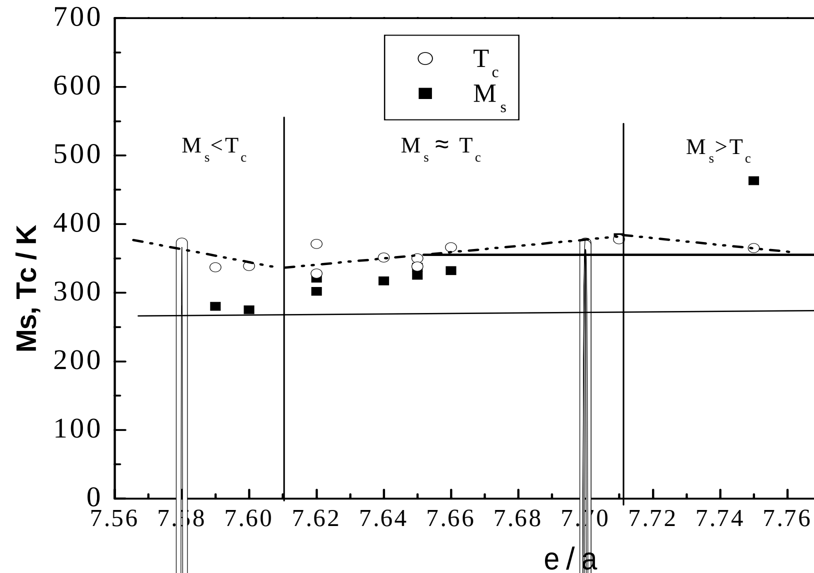
32
34
36
5M
7M
T
line 1
line 2

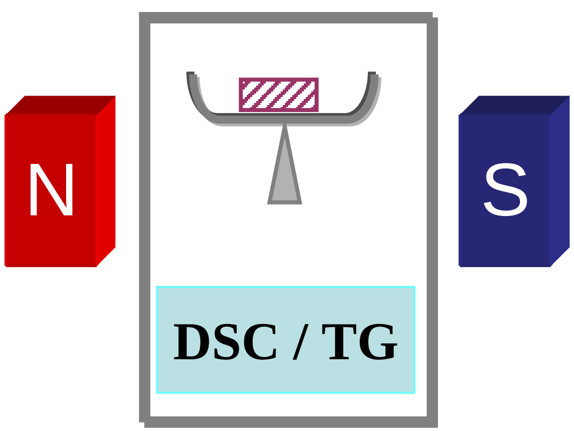


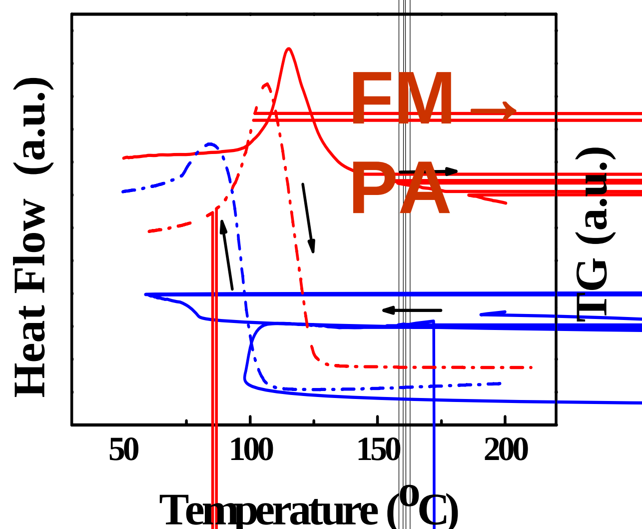
4.17Å
Ga
Mn
5–layers period
e [1$\bar{1}$0]
0.292 Å

Ni_2MnGa پ ء









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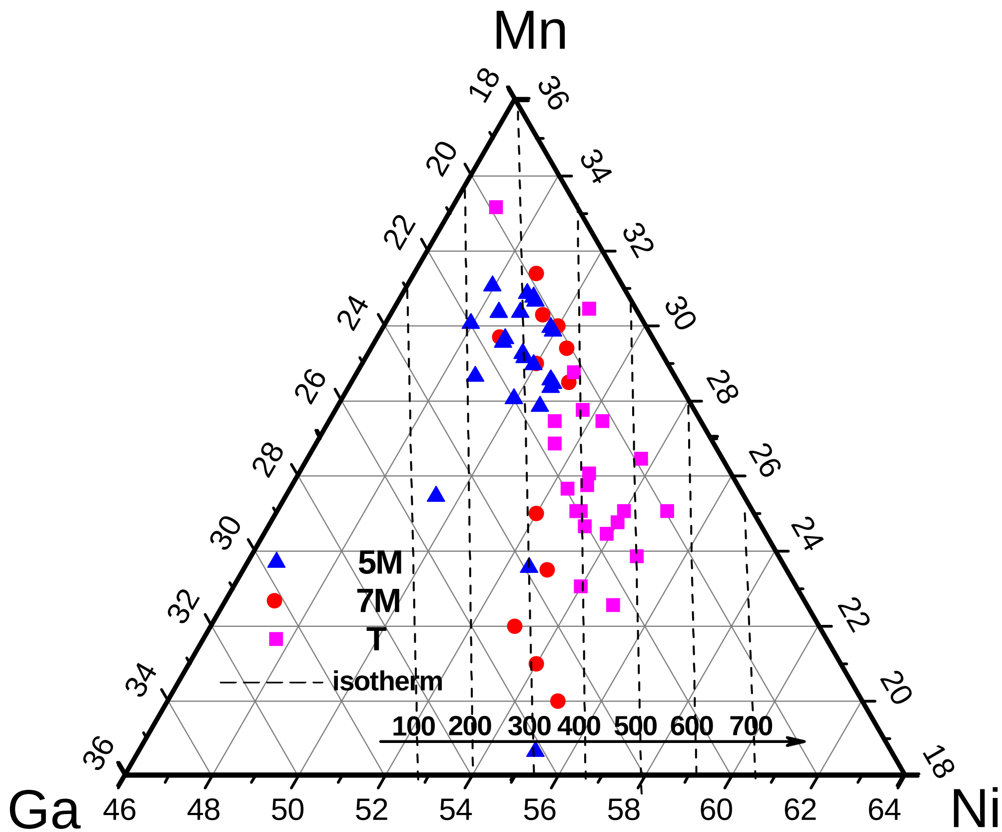
C.B. Jiang, et al. Appl. Phys. Lett. **80** (2002) 1619

Ni_2MnGa پ ء



$$Ms(K) = 74.21X_{Ni} + 40.42X_{Mn} - 4536.048$$

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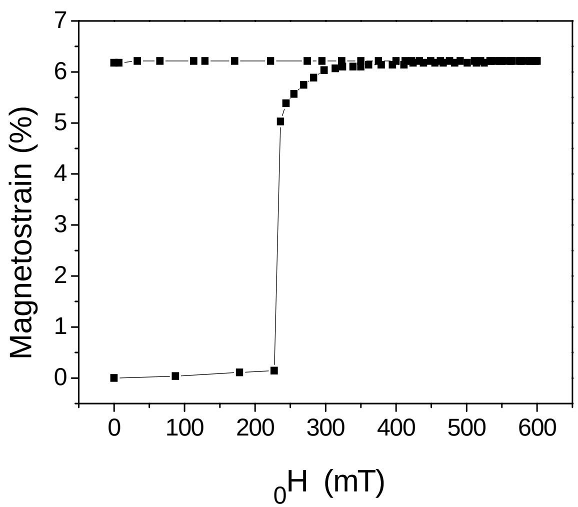
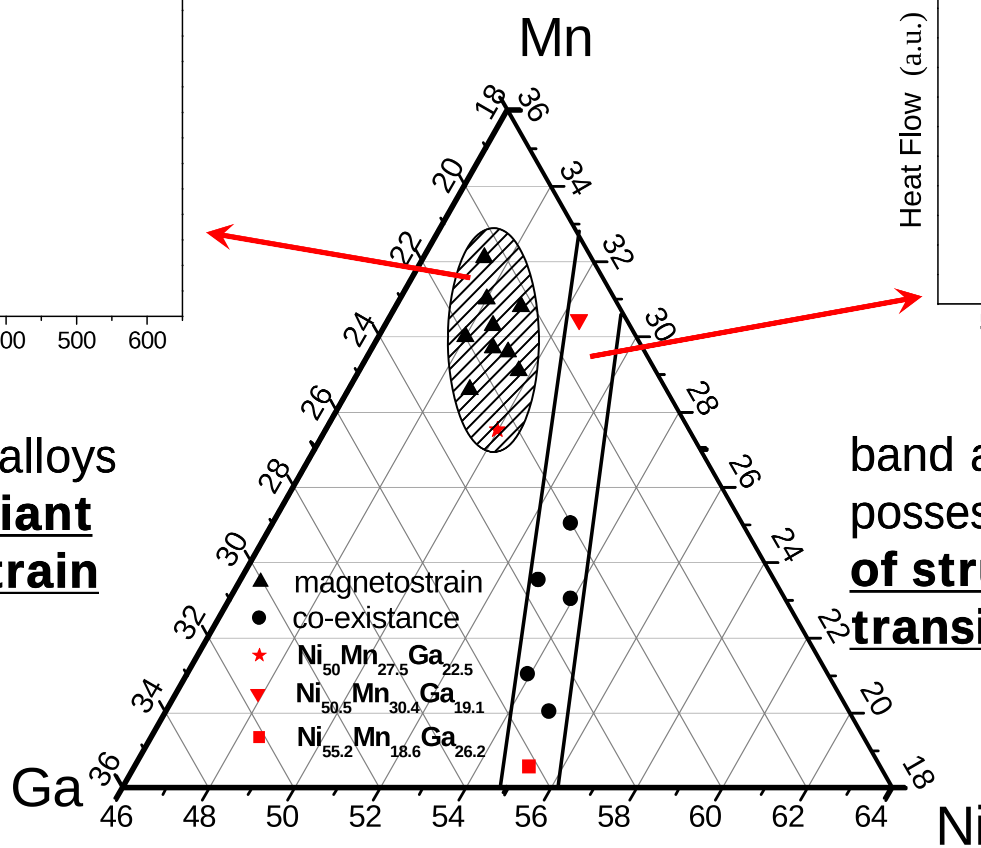
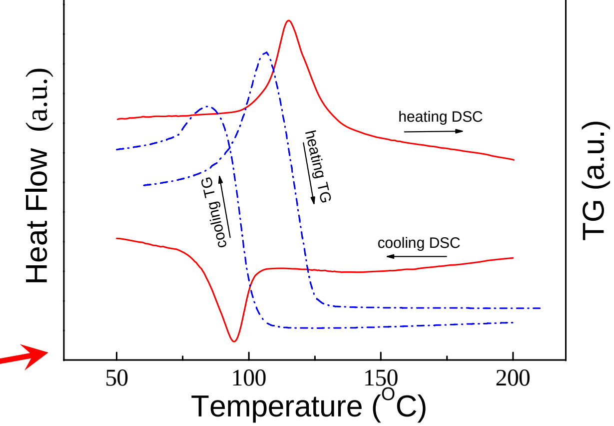
Ni$_2$MnGa پ ↨ Ĭ







circle area: alloys exhibiting **giant Magnetostrain** at RT

band area: alloys possessing **co-occurrence of structural and magnetic transitions**

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1996 G Ni_2MnGa پ χ
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MIT O'Handley

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Heusler پ Ni_2MnGa

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0.2% J β ، ـ ٫

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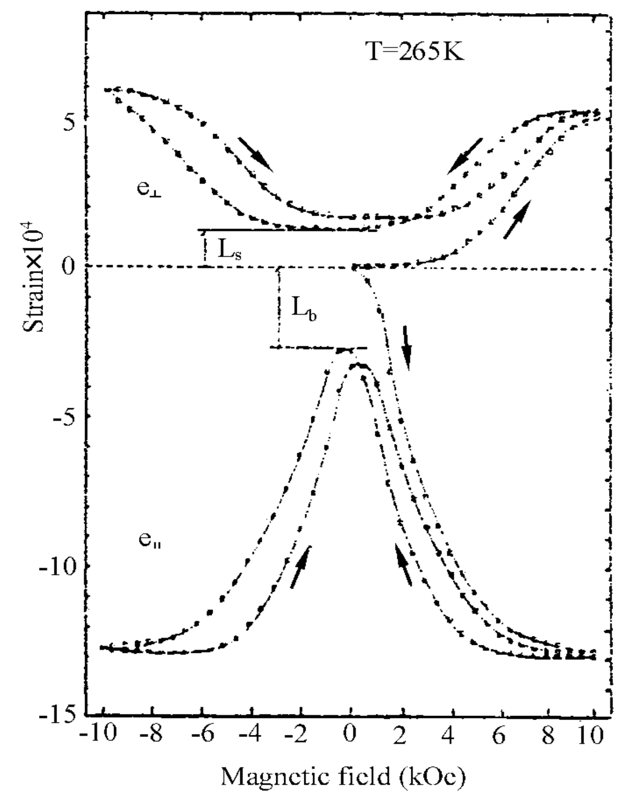

K. Ullakko, et al. *Appl. Phys. Lett.* **69** (1996)1966

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2000 J 6% ،]

2002 J 9.5%

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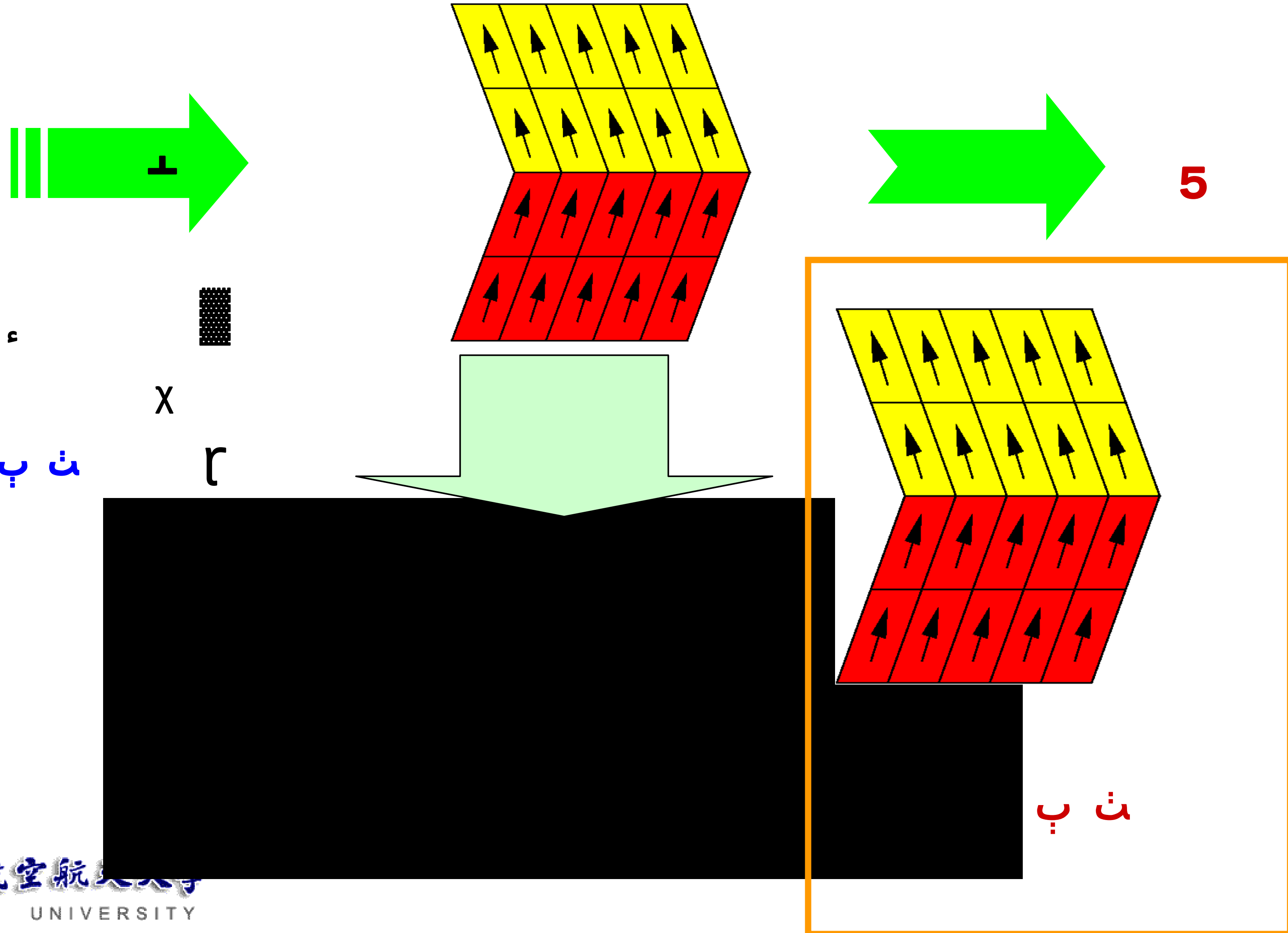

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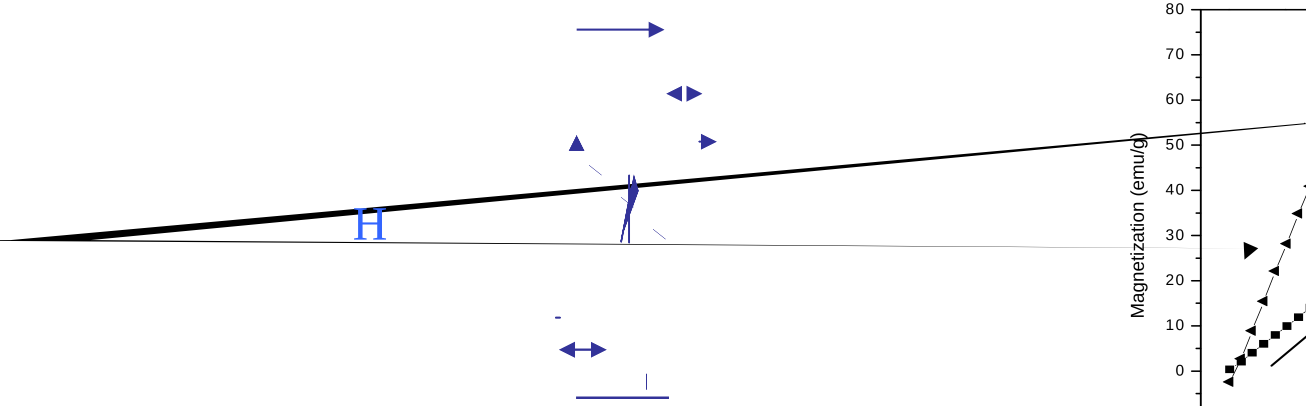
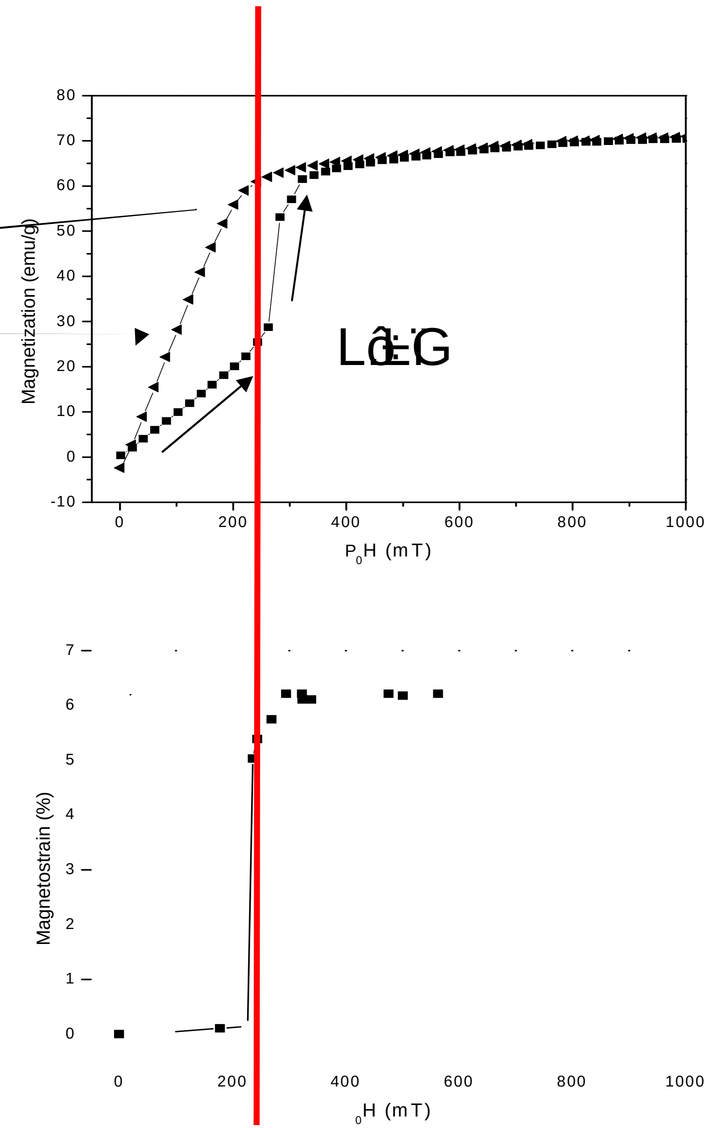
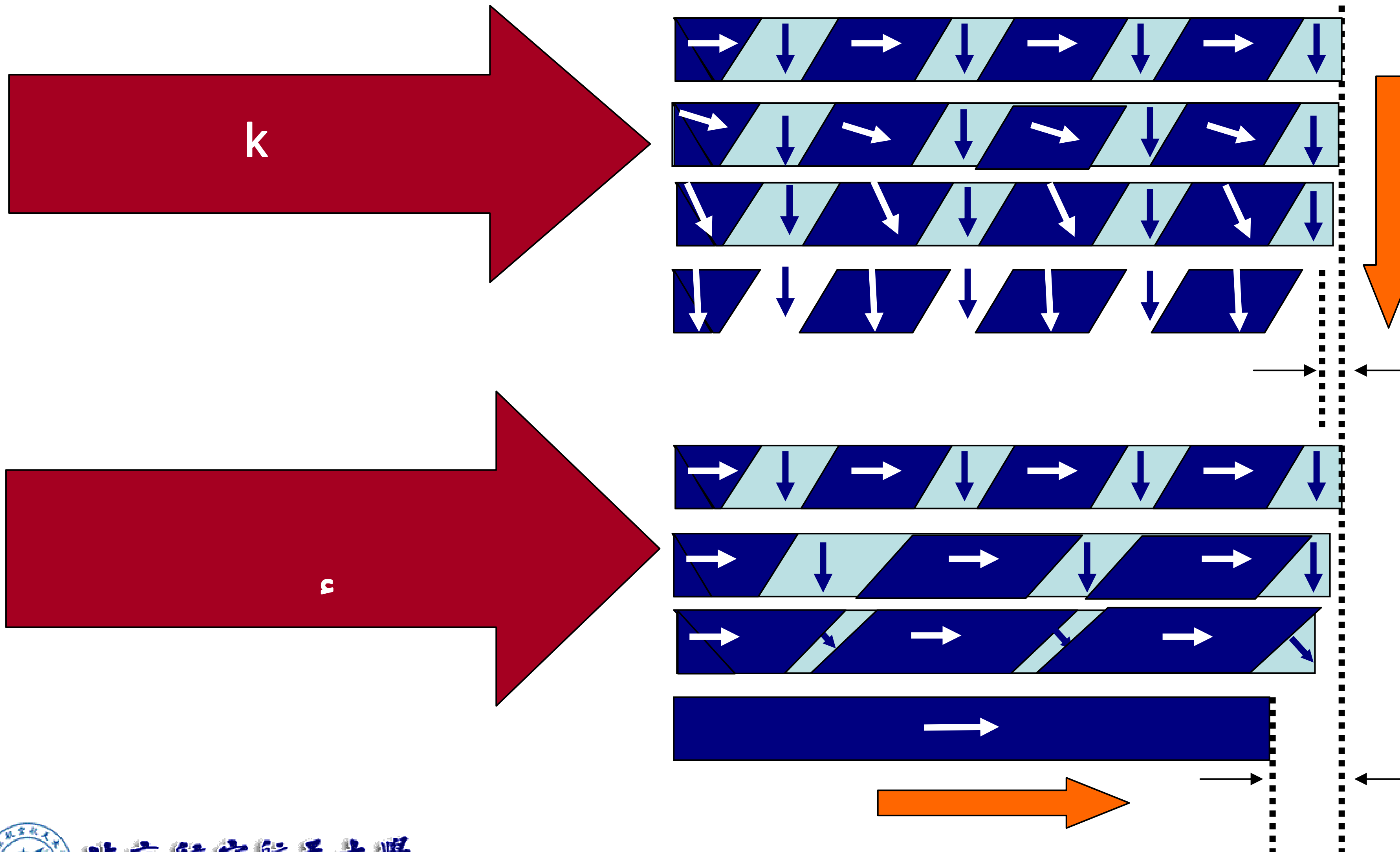
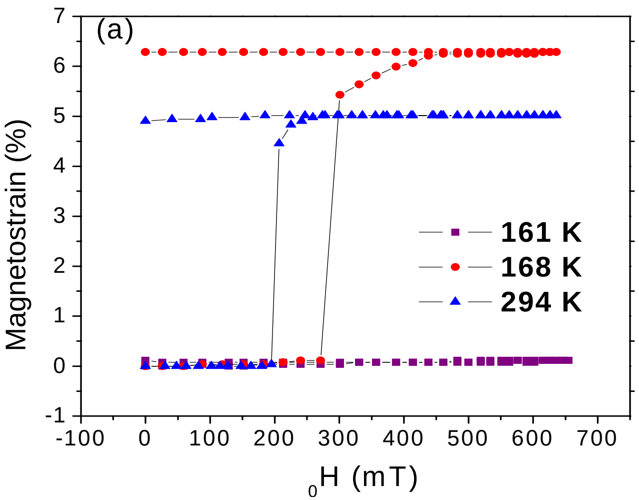


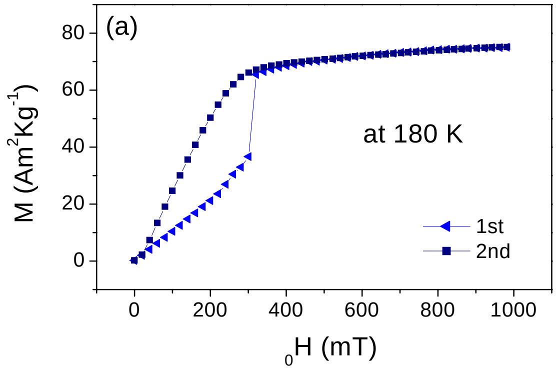


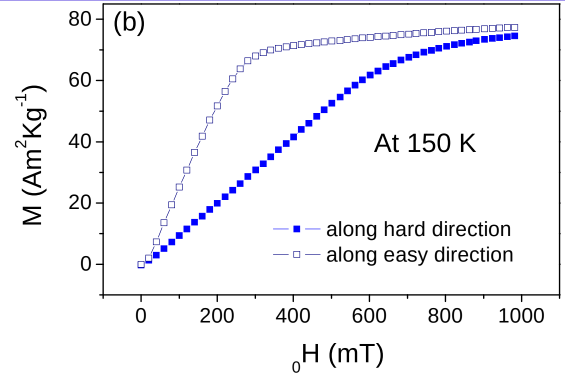
Magnetization (T)

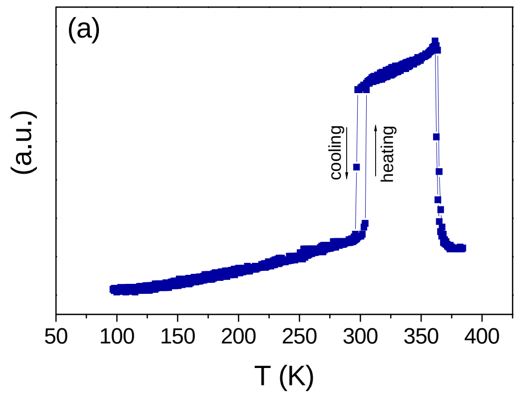
Field (kA/m)

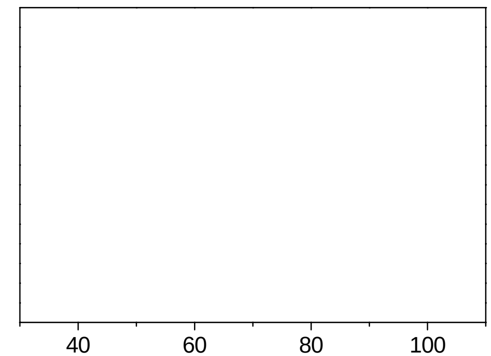


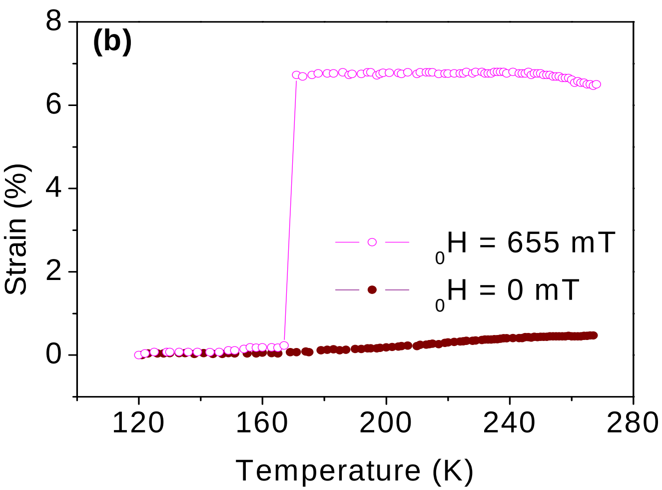

(a)
Magnetostrain (%)
$_0$H (mT)
161 K
168 K
294 K


(a)
M (Am^{2}Kg^{-1})
$_0$H (mT)
at 180 K
1st
2nd


(b)
M (Am^{2}Kg^{-1})
$_0$H (mT)
At 150 K
along hard direction
along easy direction


(a)
(a.u.)
T (K)
cooling
heating




(b)
Strain (%)
Temperature (K)
$_0$H = 655 mT
$_0$H = 0 mT

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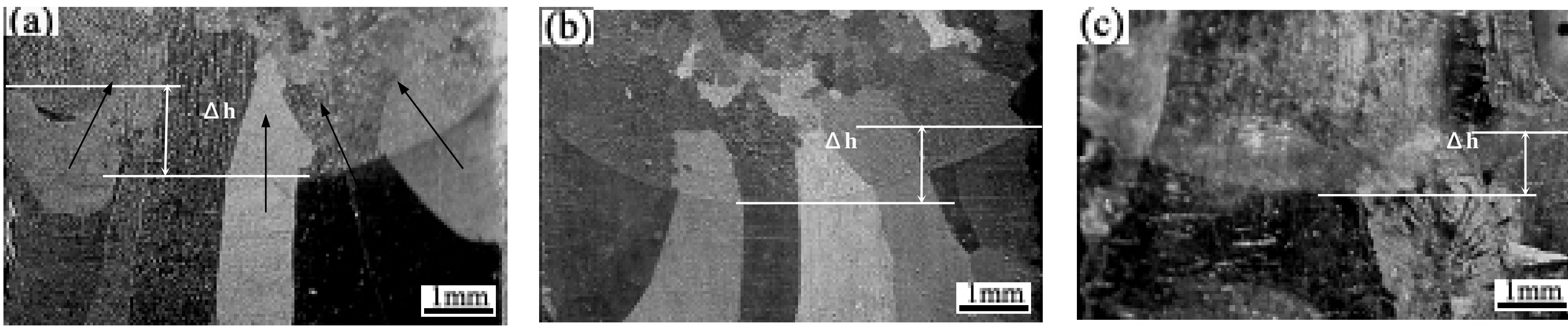
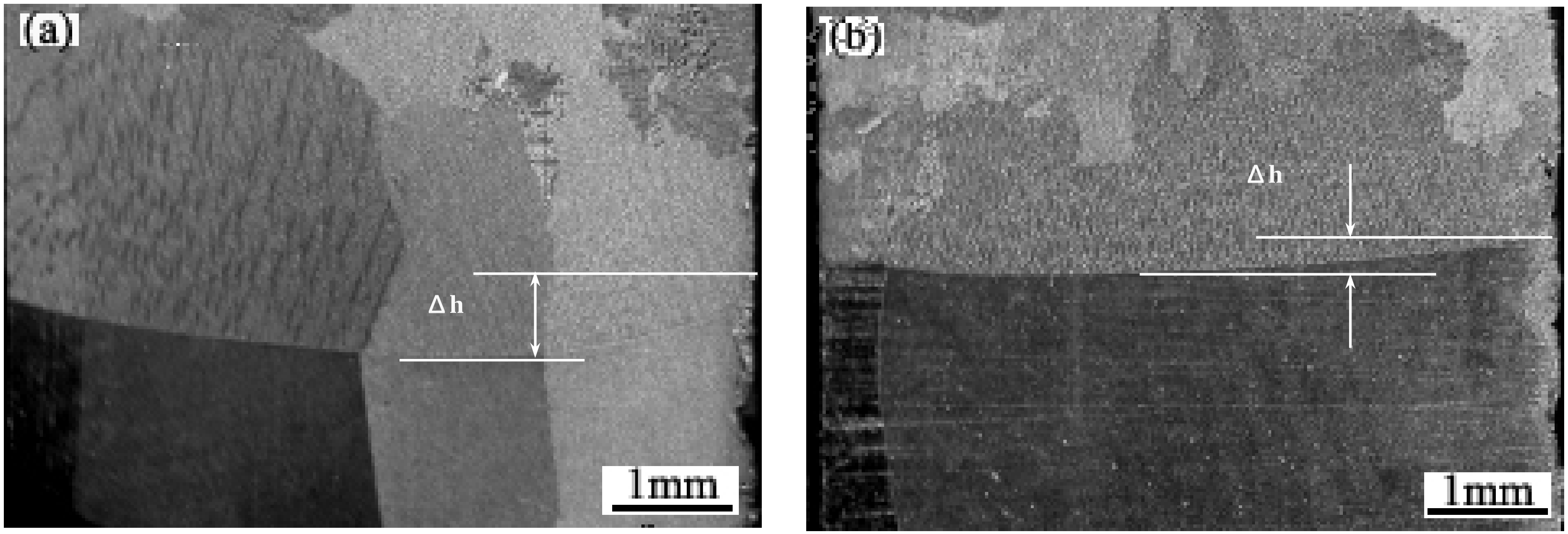


Unidirectionally solidified samples grown under $G_L \approx 500K/cm$ and V=10mm/h with different melting zone length L and interface concave height Δh **(a)** L = 6mm Δh=1.65mm, **(b)** L = 11mm Δh=1.34mm, **(c)** L = 19mm, Δh =1.04mm.



Unidirectionally solidified samples grown under **$G_L \approx 1200K/cm$** and **V=10mm/h** with different melting zone length L and interface concave height Δh **(a)** L = 8mm   Δh=0.65mm, **(b)** L = 10mm   Δh=0.27mm.

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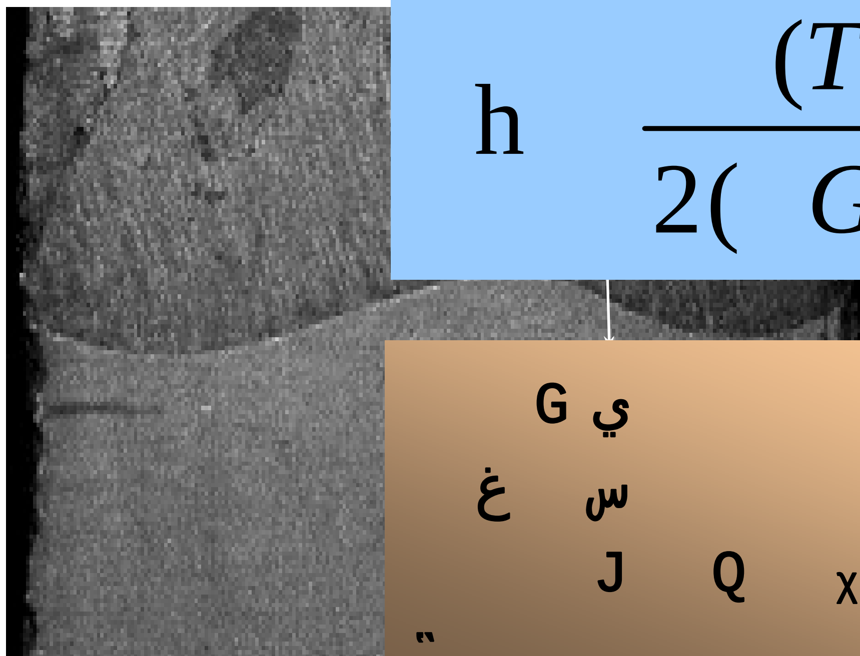

$$h \quad \frac{(T_m^4 \quad T_0^4)R}{2(\quad G_L \qquad LV)}$$

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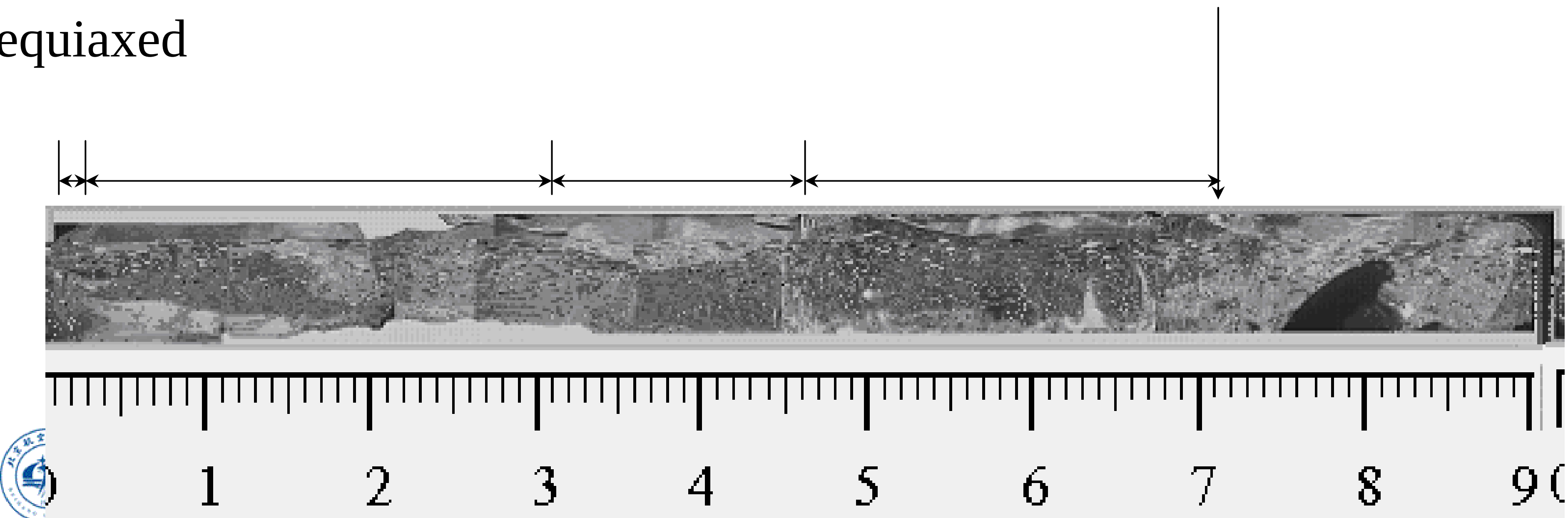
Single crystal grown under <u>$G_L \approx$ 1500K/cm</u> and <u>V=10mm/h</u>, the melting zone length L=17mm, and the interface concave height Δh=-0.48mm.


equiaxed
1
2
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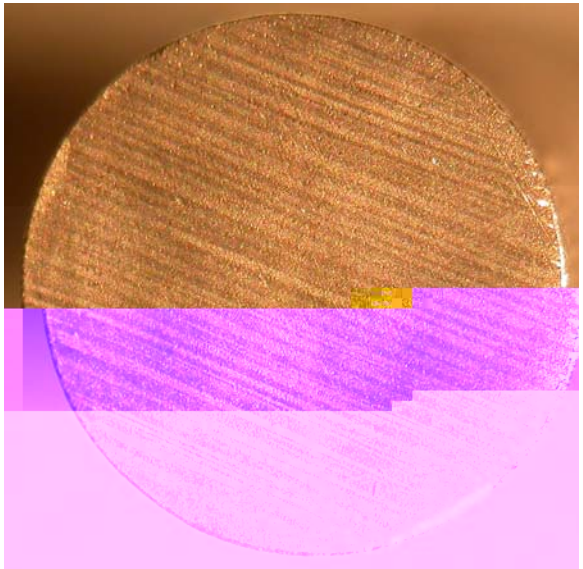
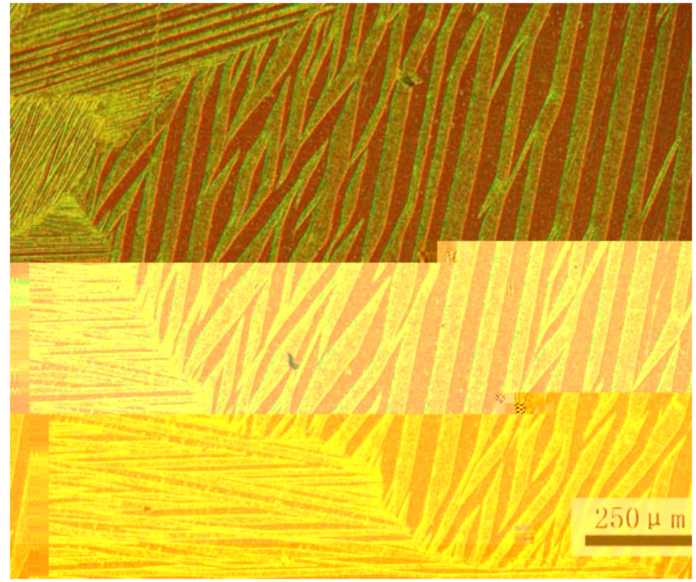
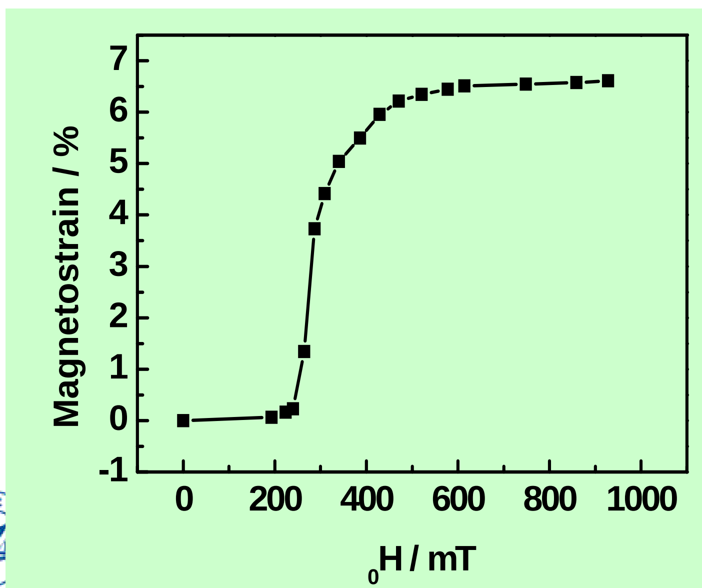
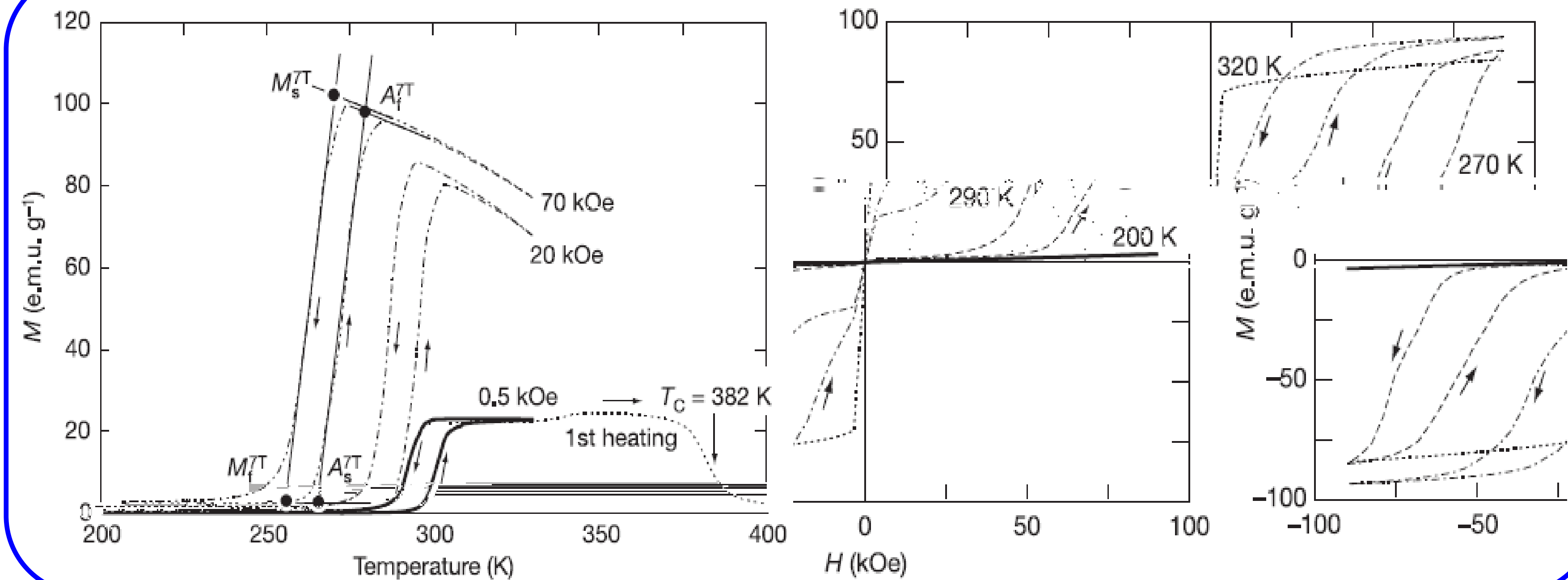
4
5
6
7
8
9




250 μ m


Magnetostrain / %
7
6
5
4
3
2
1
0
-1
0
200
400
600
800
1000
$_0$H / mT



2006 J **R. Kainuma** **Nature**

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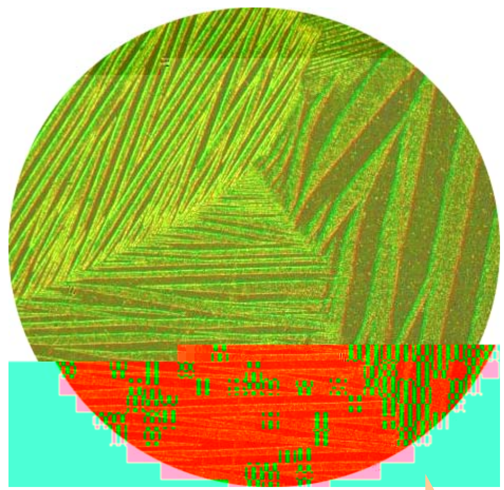
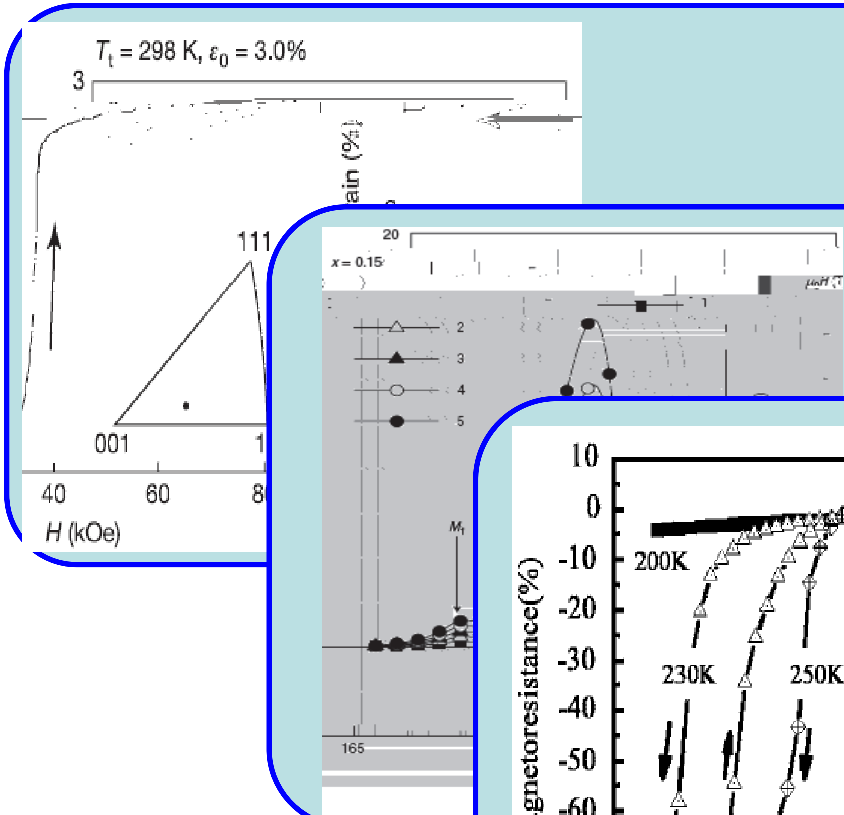
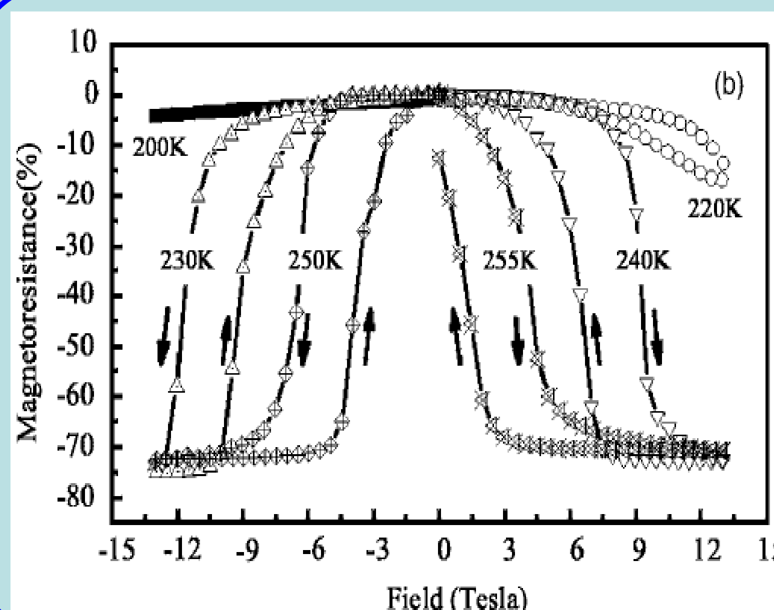
R. Kainuma, et al. *Nature* **439** (2006) 957

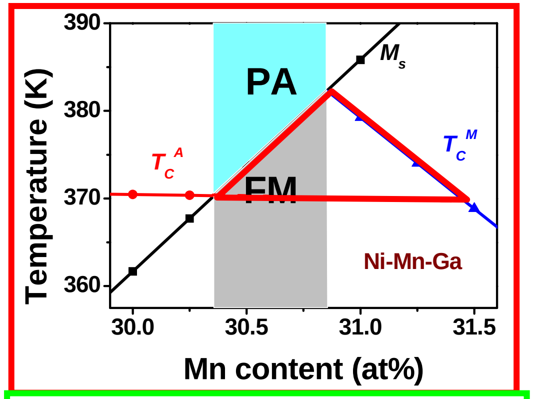


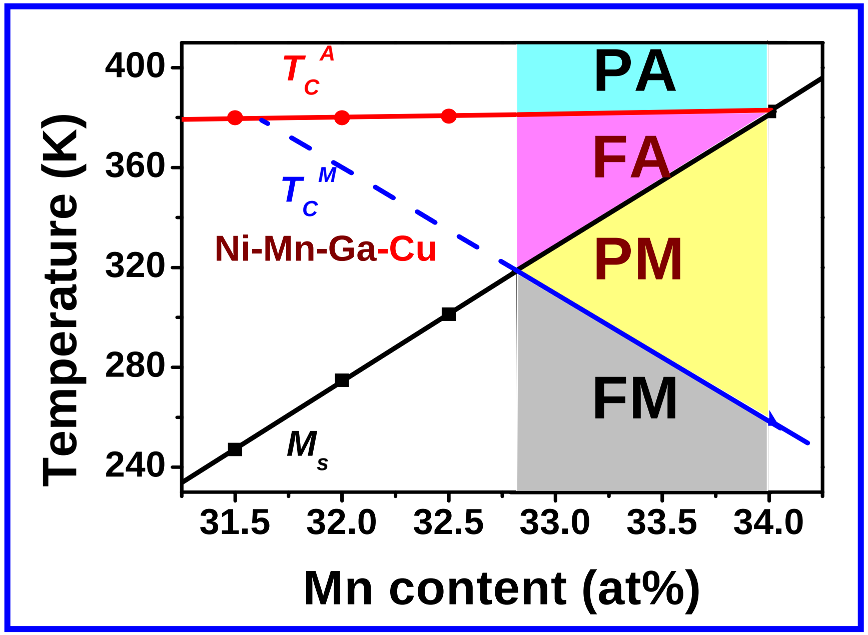




APL 90, 242501, 2007

NiMnGaCu پ ´ ء





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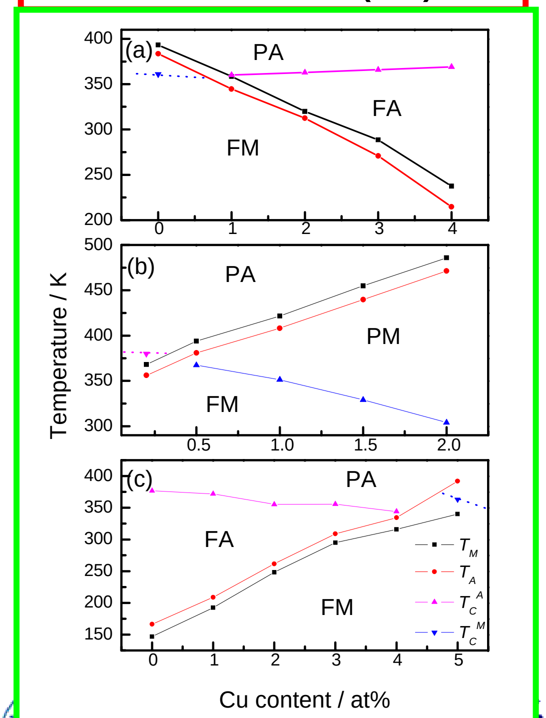

T_M (K) = $40.25X_{Ni}-14.9X_{Mn}-58.15X_{Ga}-55.775$

T_C^M (K) = $7.71X_{Ni}+11.49X_{Mn}+46.068X_{Ga}-1232.76$

T_C^A (K) = $-3X_{Ni}+5.388X_{Mn}+8.652X_{Ga}+176.59$

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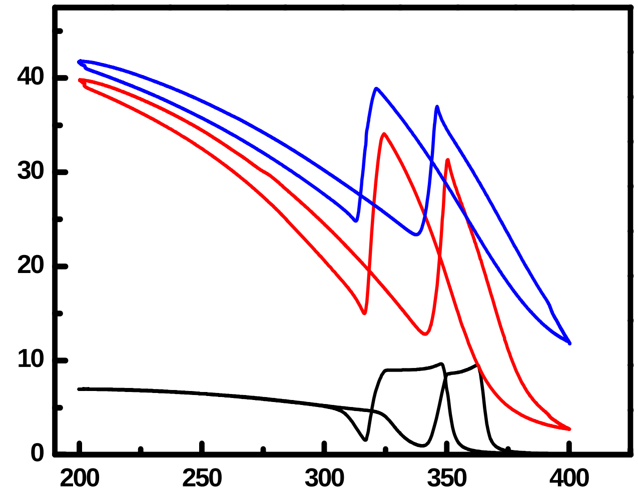
C.B. Jiang, et al. Appl. Phys. Lett. **95** (2009)252501

[redacted]



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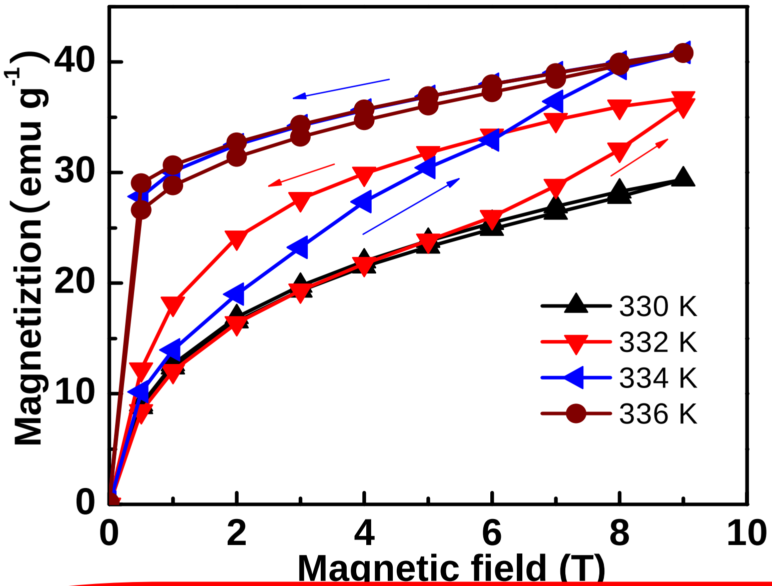
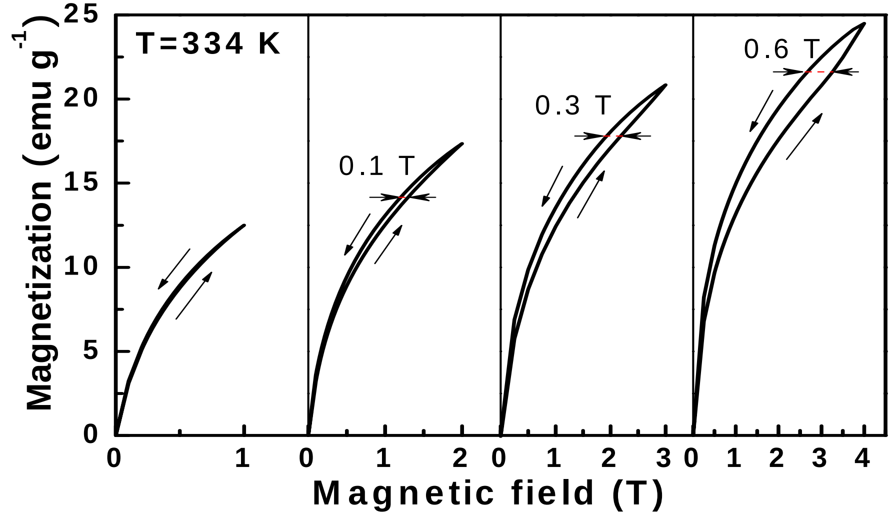
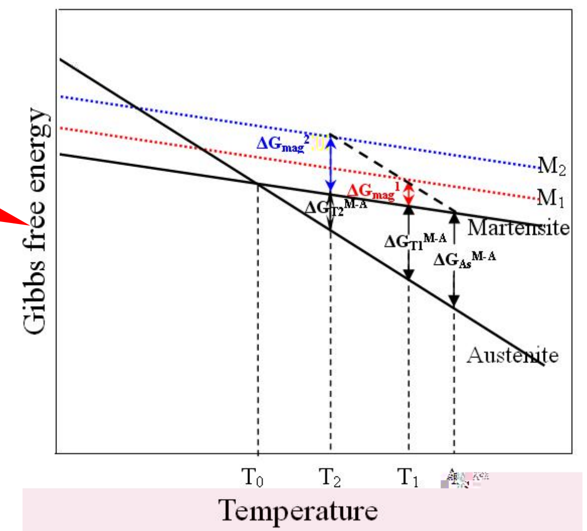




$$G^{M\ \ A}\quad G_{ch}^{M\ \ A}\quad G_{el}^{M\ \ A}\quad E_{irr}^{M\ \ A}$$

$$G^{M\ \ A}\quad G_{ch}^{M\ \ A}\quad G_{el}^{M\ \ A}\quad E_{irr}^{M\ \ A}\quad G_{mag}^{M\ \ A}$$



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P.P. Li, et al. Appl. Phys. Lett. submitted

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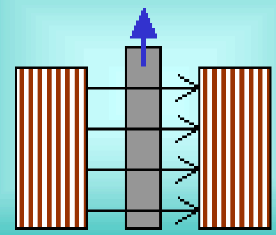
Actuator



Couplers

- Fasteners
- Brakes and clamps
- Automatic assembly

Vibrators

- Shakers
- Sonar transducers
- Loudspeakers
- Drills
- Vibration damping

Fluidics

- Valves
- Pumps
- Injectors
- Ink-jets
- Drug delivery

Positioning devices

- Robots
- Manipulators
- Linear drives
- Switches

Sensors and generators

- Force/position sensors
- Vibration monitoring
- Joysticks
- Power generators

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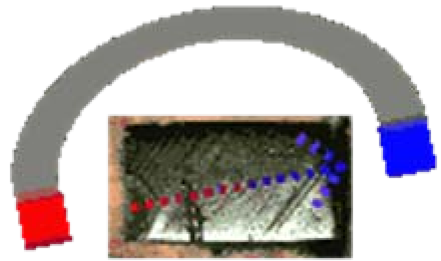
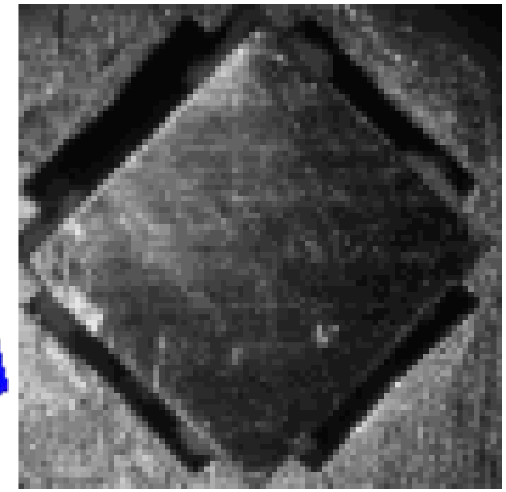
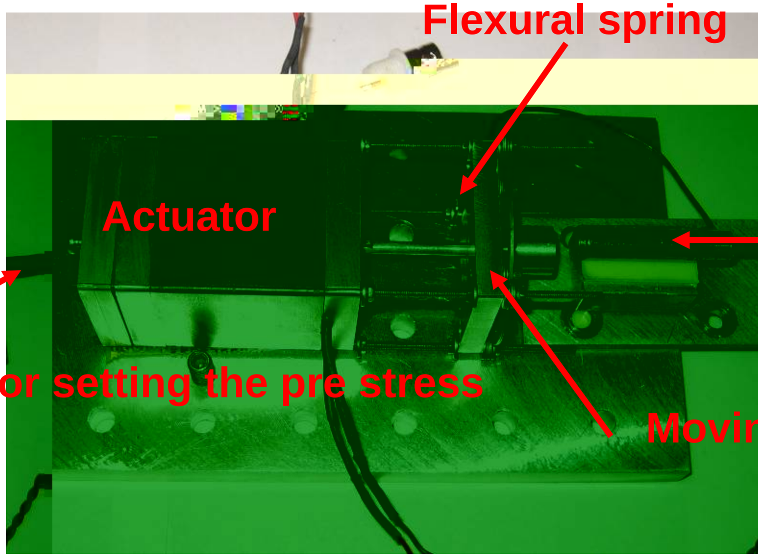
Actuators

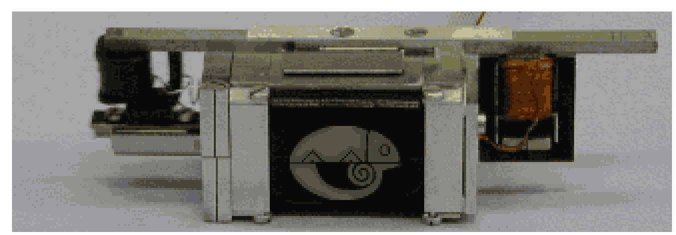




Bump valve



Transducer



Linear motor

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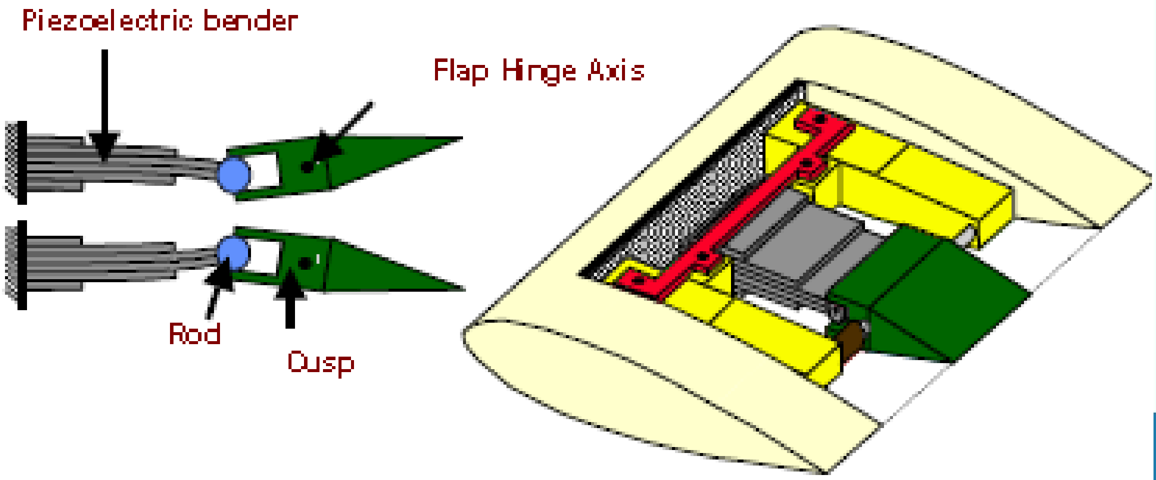
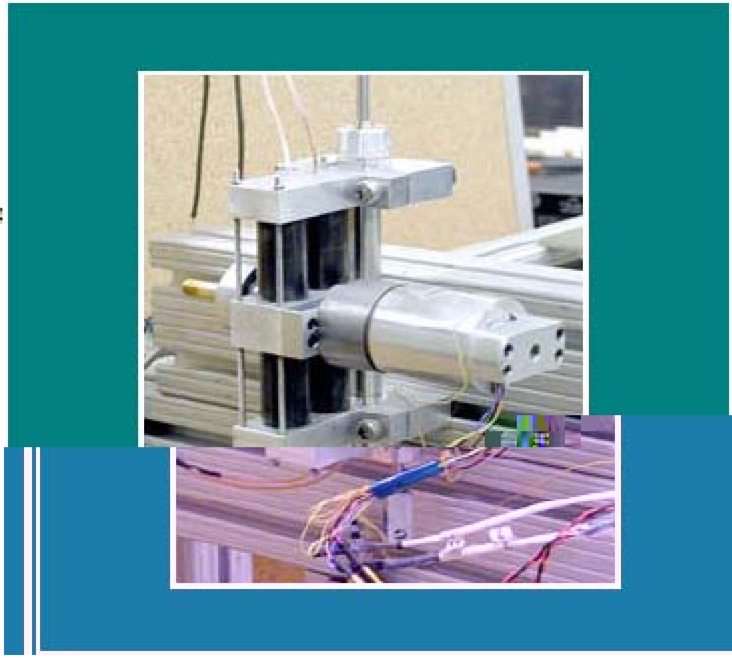


Stroke Amplification

Actuator-Flap Assembly



helicopters. The project, performed in collaboration with the Alfred Gessow Rotorcraft Center at the University of Maryland, [illegible] exploiting Magnetic Shape Memory Alloy materials f[illegible] primary rotor control.

The TSi Smart Flap system utilizes single crystal, martensite, NiMnGa materials with superior force, stroke and frequency response properties to actuate on-blade trailing-edge flaps. "The use of Smart Flaps has the potential to reduce helicopter control complexity, cost, and maintenance requirements," says Chen.

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■ NiTi, CuZnAl, Fe: u <120 Ņ

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- **Ni-Ti-Pd** پ J ج Ή ء 5.5Ë
  И
- **Ni-Al** 5 J χ ء
  J ء F
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- **Ni-Ti-Hf/Zr** v
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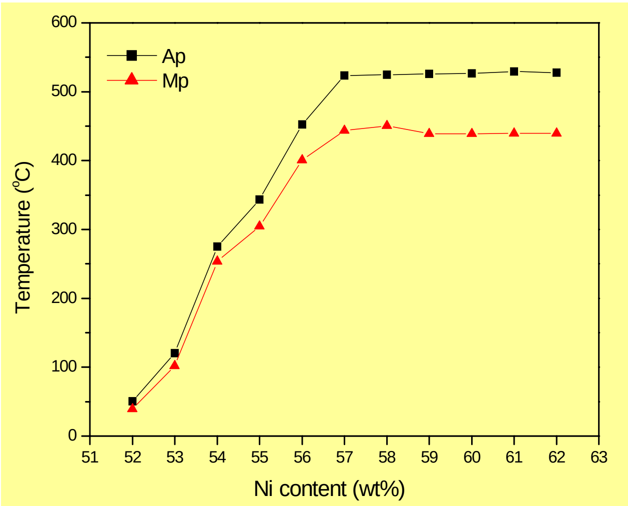
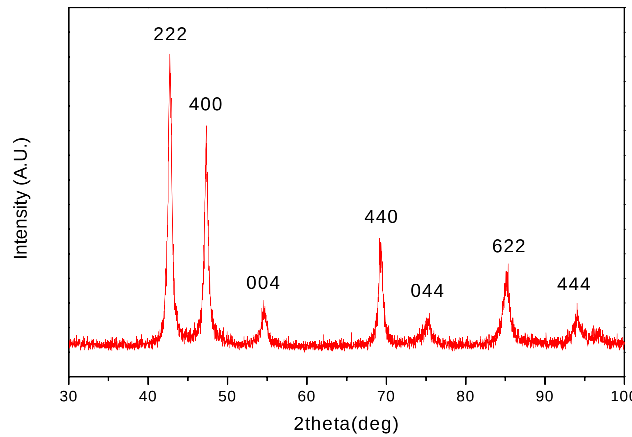
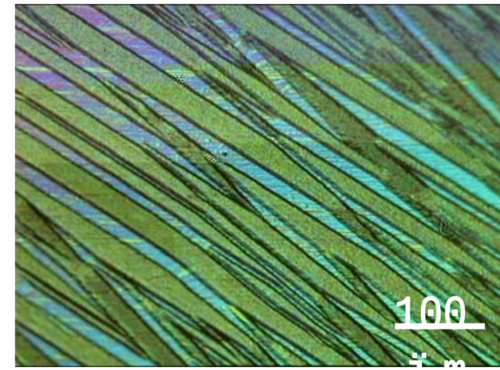
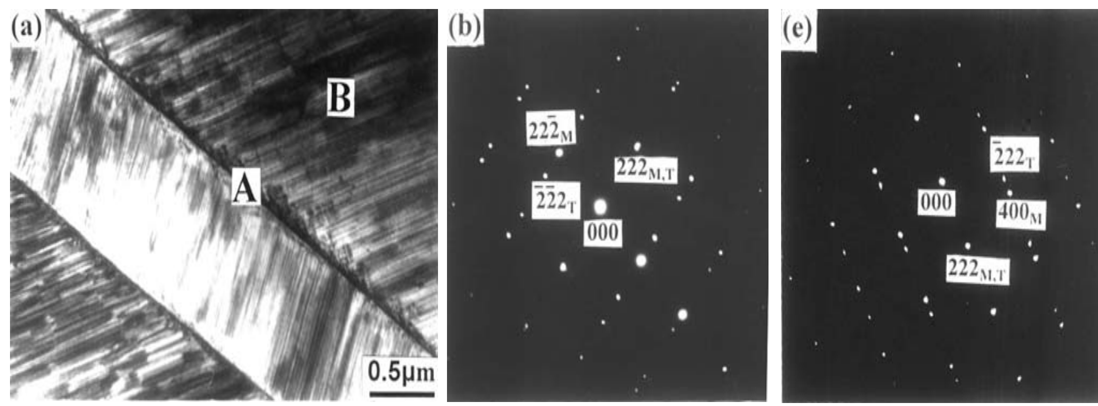
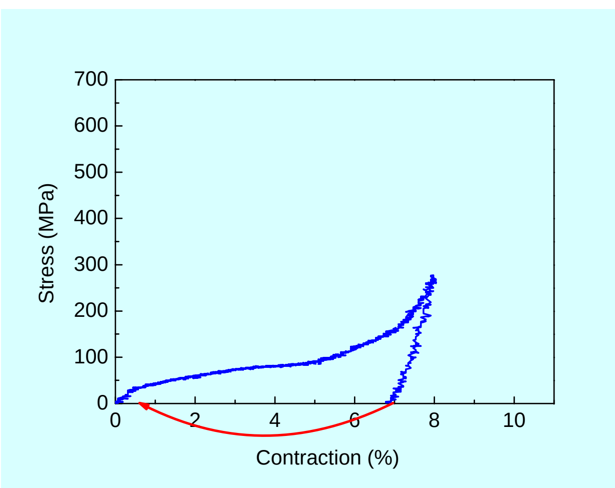
NiMnGa











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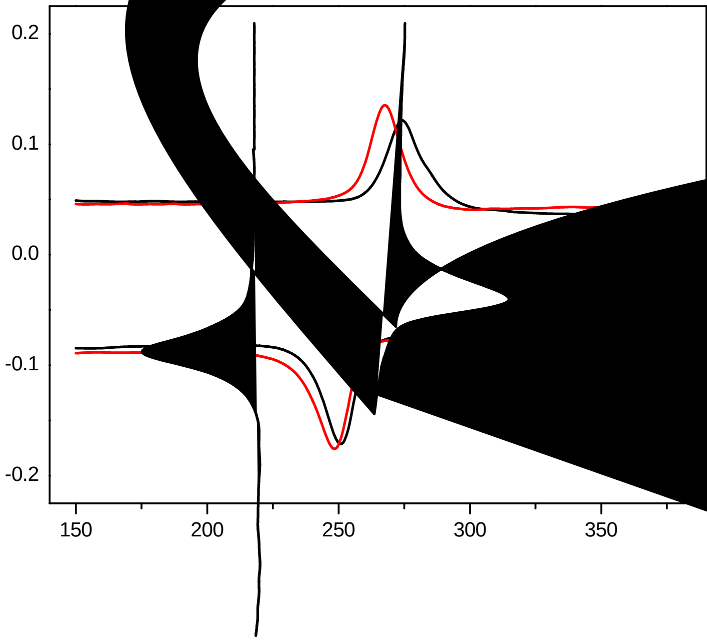
Appl. Phys. Lett. **82** 2003 3206-3208


0.2
0.1
0.0
-0.1
-0.2
150
200
250
300
350

NiMnGa پ Ↄ Ꞙ k Ↄ
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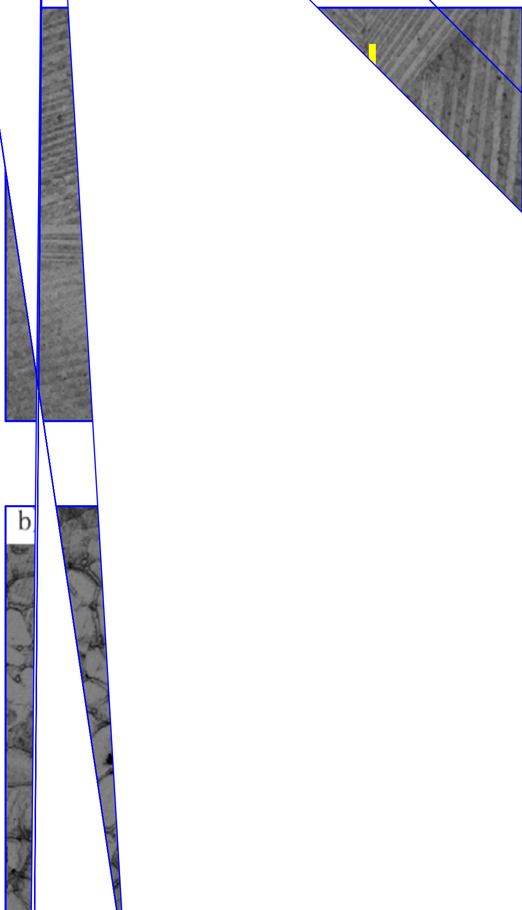
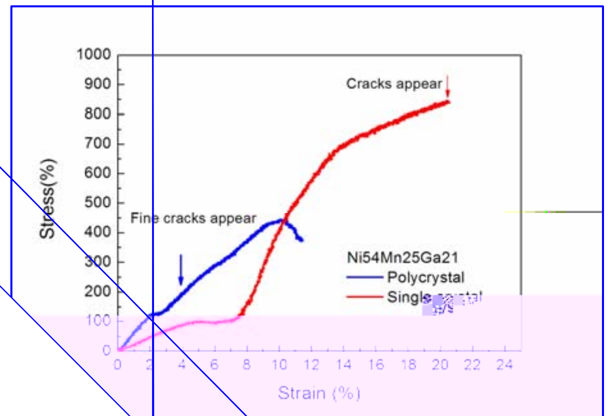
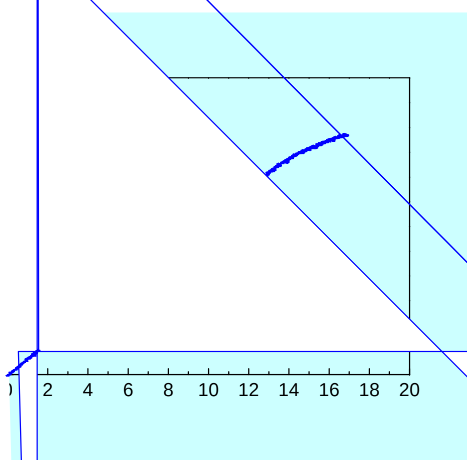
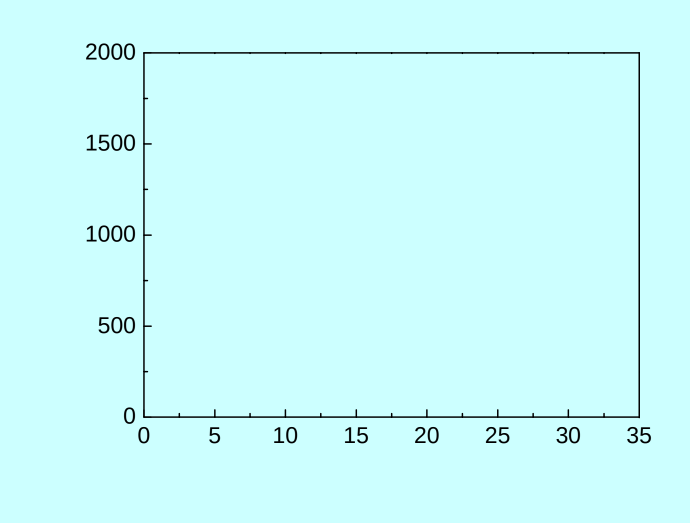
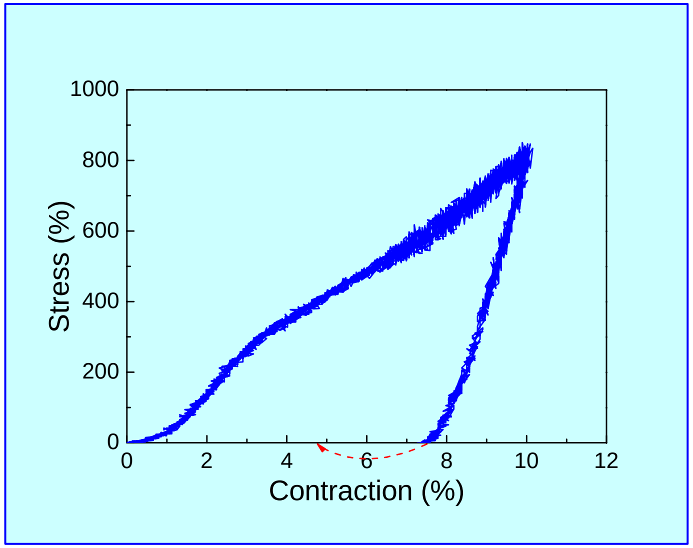






ATER 51(2004): 849-852





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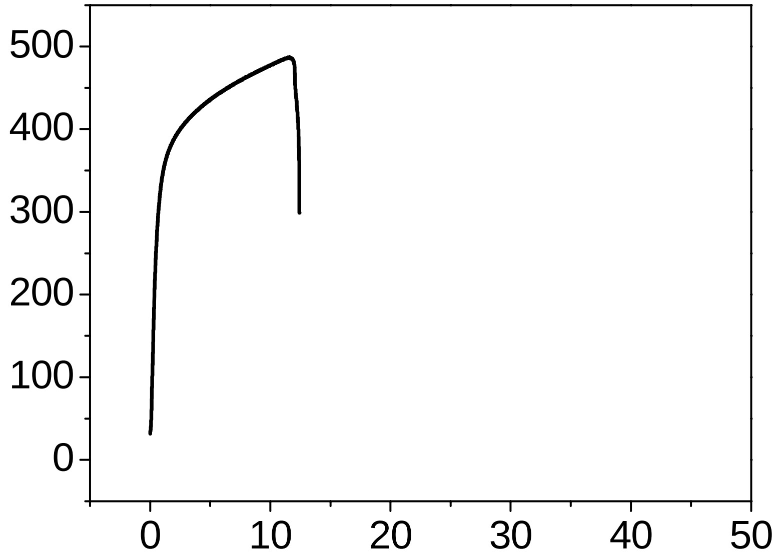
Cu ῴ א ’ fl



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NiMnGaCu پ
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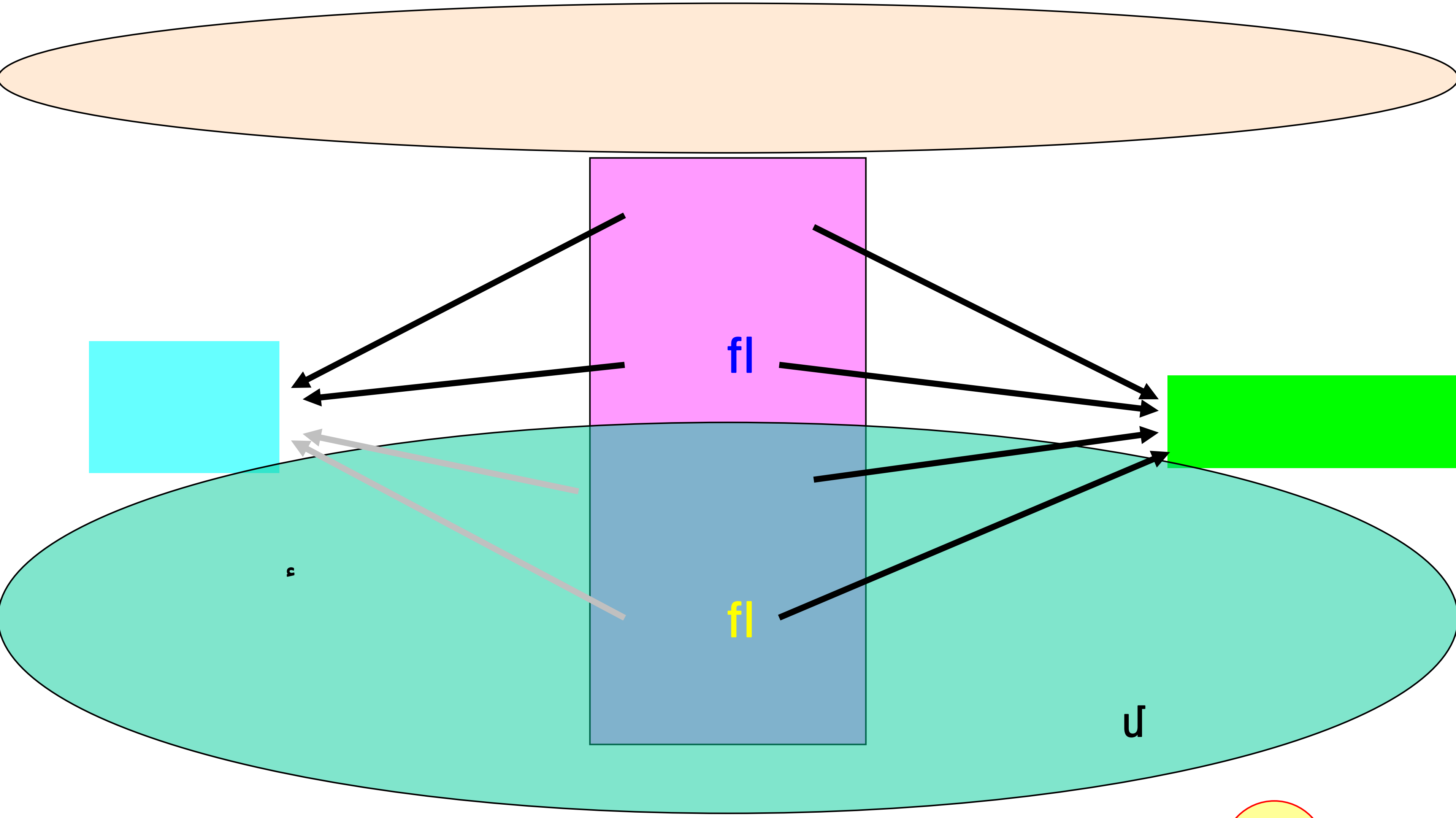
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