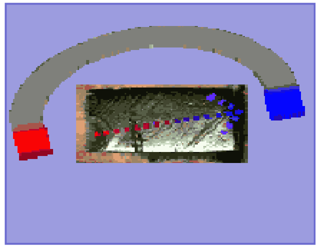
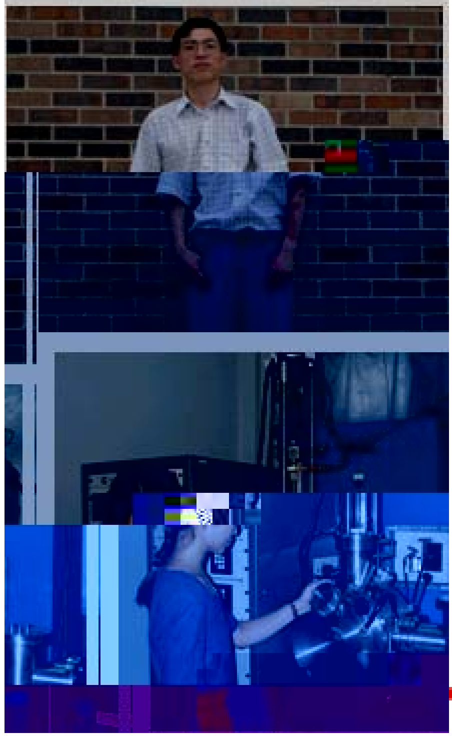


M05

2016. 10. 27

State Key Lab. of Magnetism
M
Institute of Physics, CAS
05



2

2

1

1

10

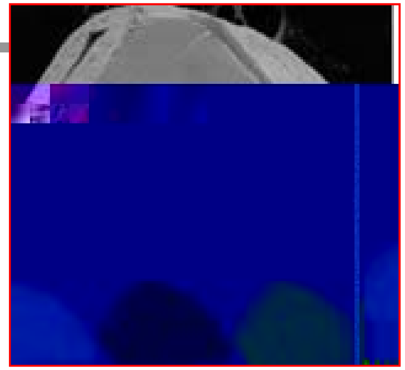
State Key Lab. of Magnetism
Institute of Physics, CAS
M 05

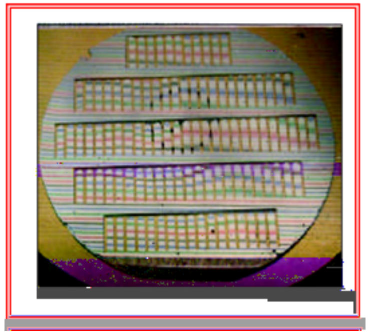
State Key Lab. of Magnetism
M
Institute of Physics, CAS
05

新材料

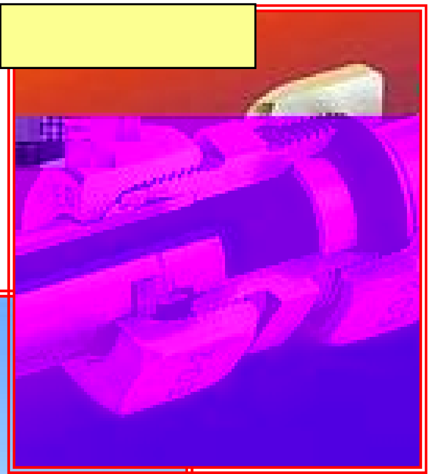
新性能

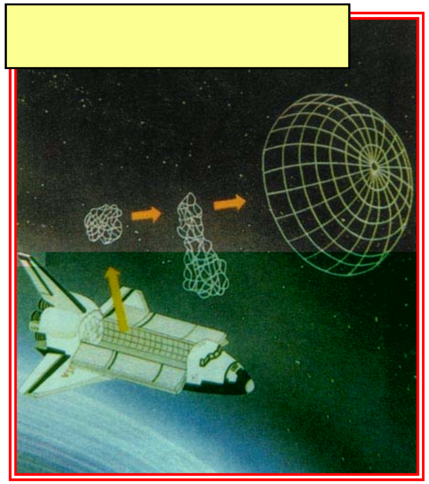
新理论

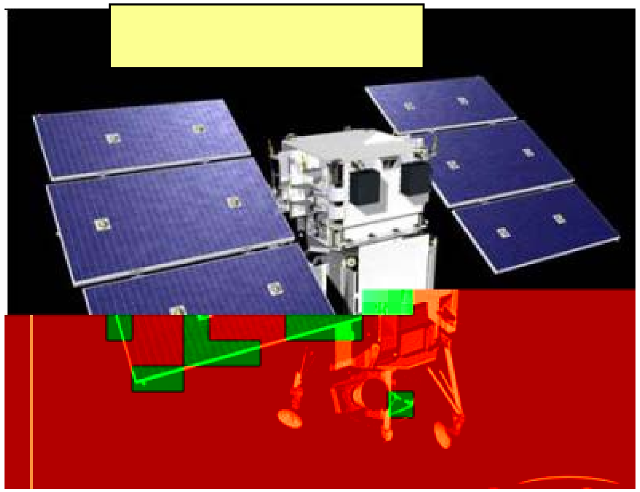




NiTi

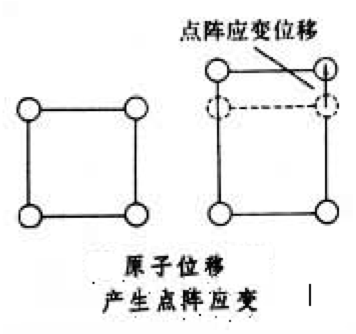


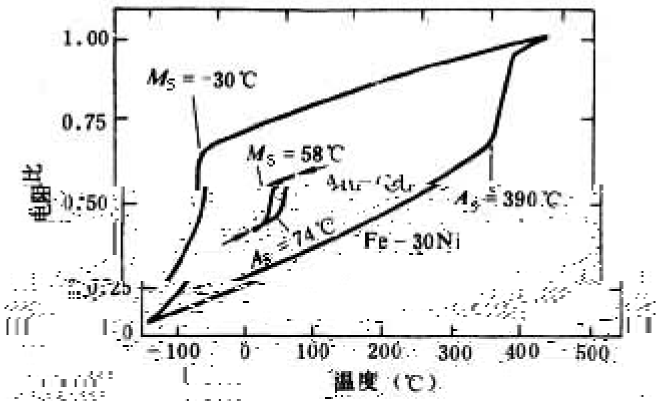




“ ”

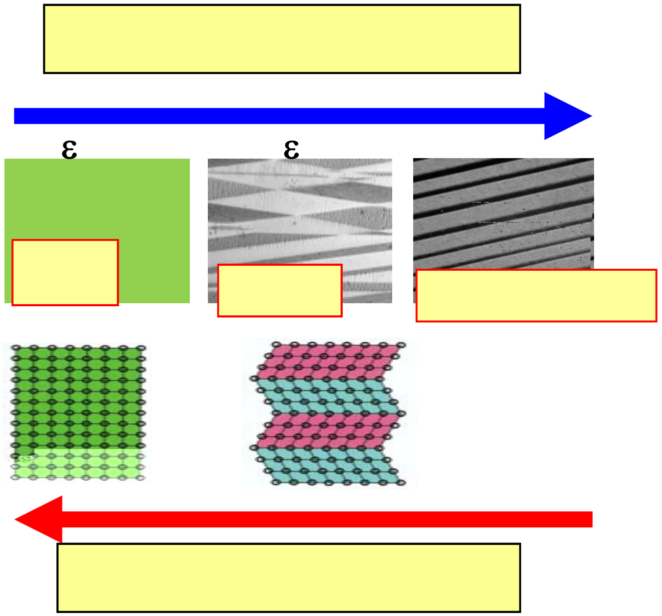
Bain →

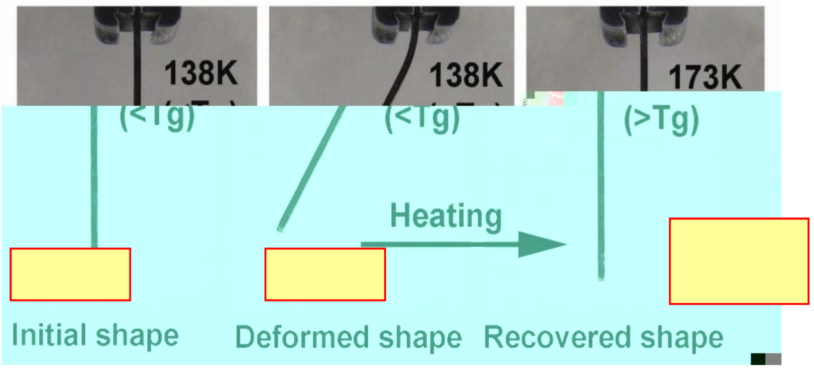


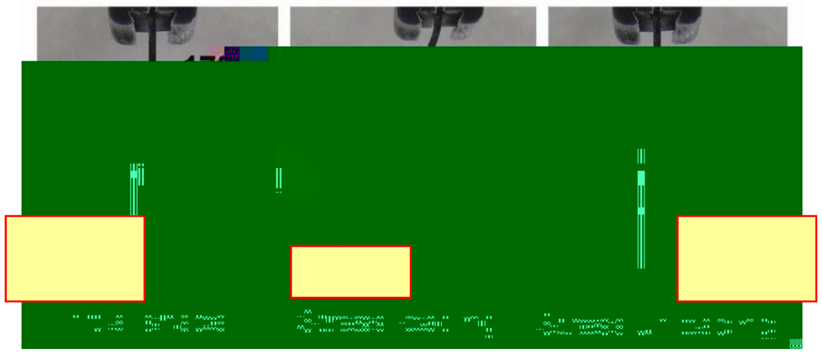


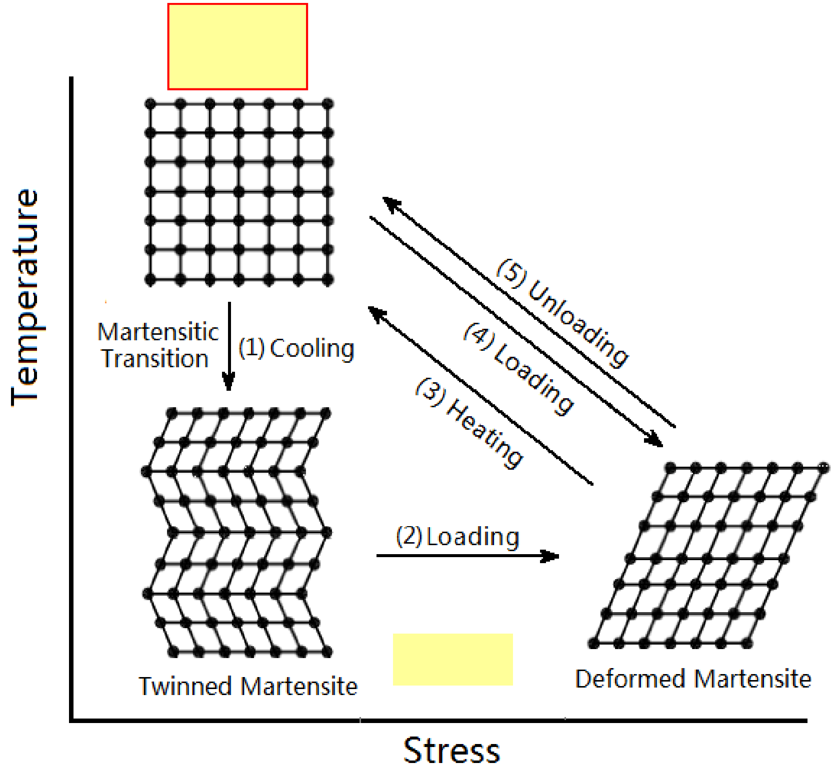
Fe-Ni 和 Au-Cd 合金的相变热滞

M_S 马氏体转变开始温度 A_s 马氏体逆变开始温度

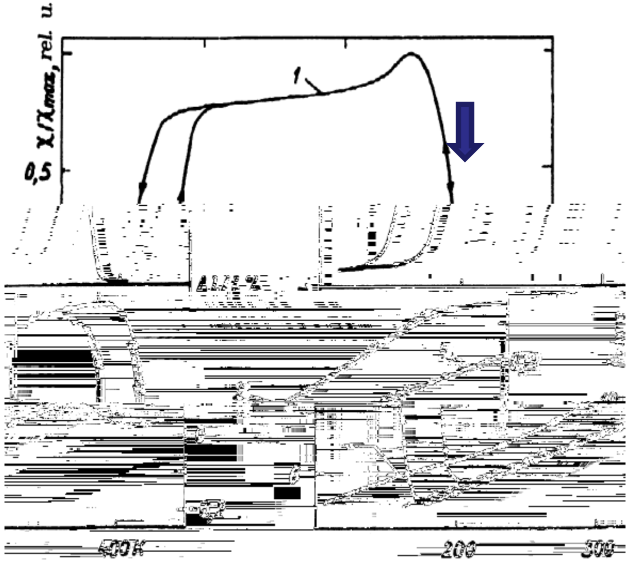



138K
(<Tg)
138K
(<Tg)
173K
(>Tg)
Heating
Initial shape
Deformed shape
Recovered shape

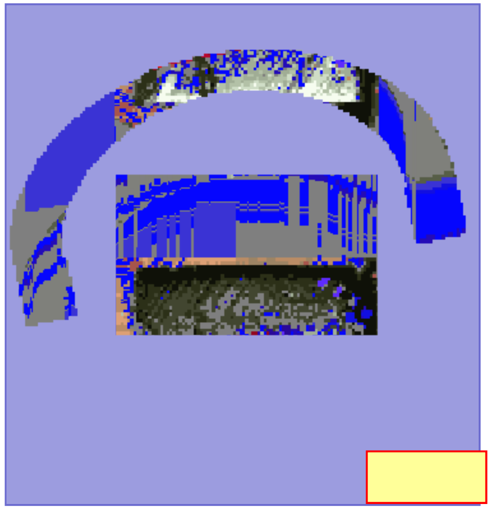


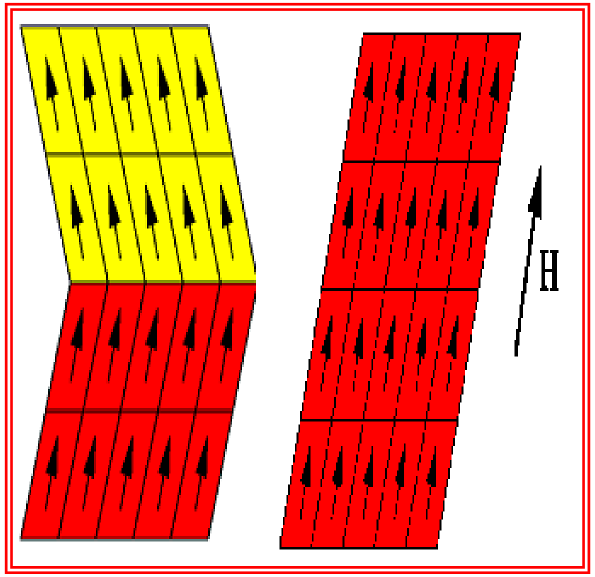

Temperature
Stress
Martensitic Transition
(1) Cooling
(2) Loading
(3) Heating
(4) Loading
(5) Unloading
Twinned Martensite
Deformed Martensite

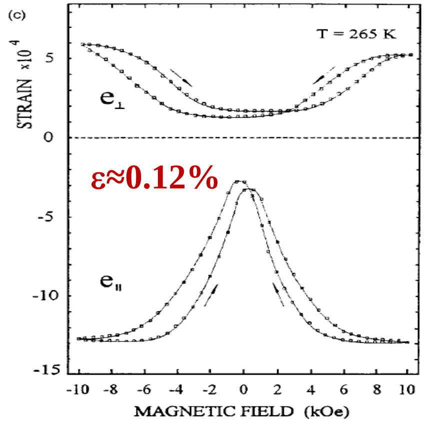
(/) FMSA

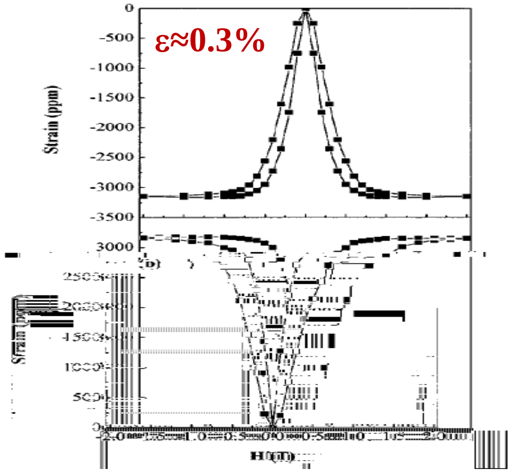


Chernenko, et al. Phys. Met. Metall. 1989.



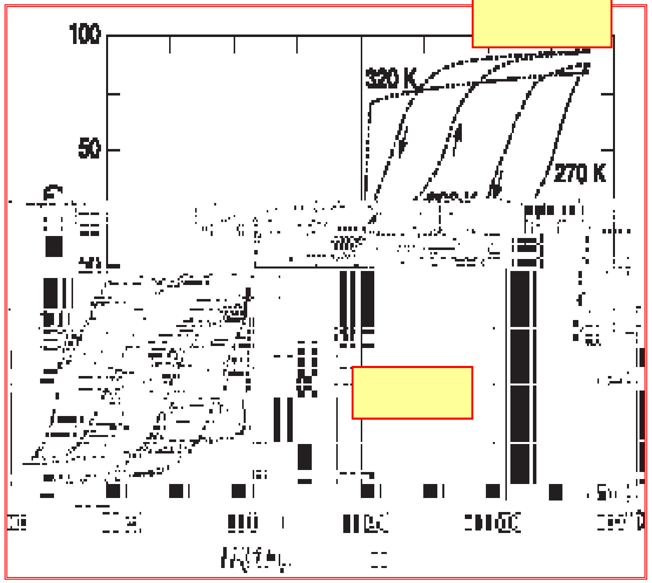

H

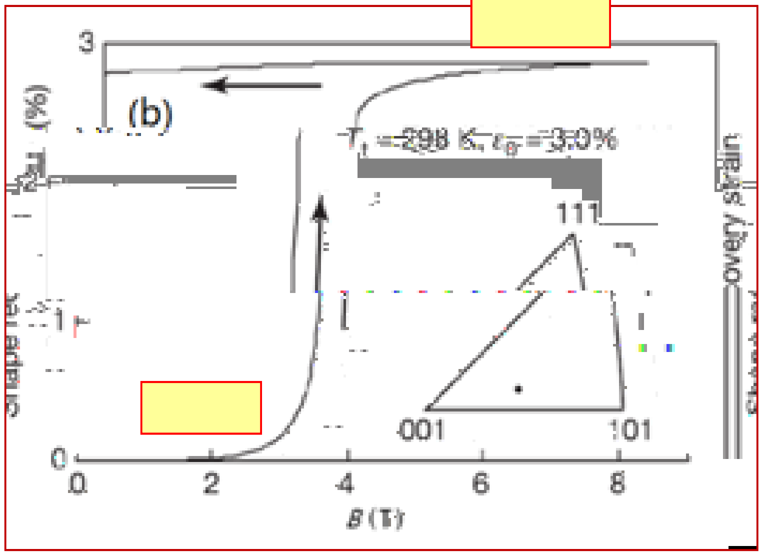

(c)
T = 265 K
STRAIN ×10^-4
ε≈0.12%
MAGNETIC FIELD (kOe)


ε≈0.3%
Strain (ppm)

Heusler alloys

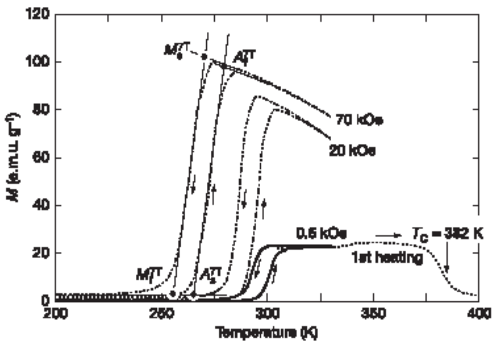
- ◆NiMnIn:Co
- ◆ 2006 Kainuma



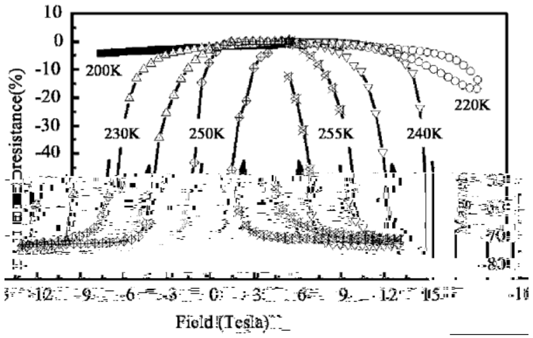


Heusler alloys

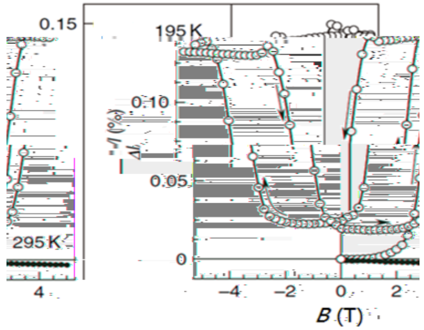
R. Kainuma, *et al.* Nature, 2006.



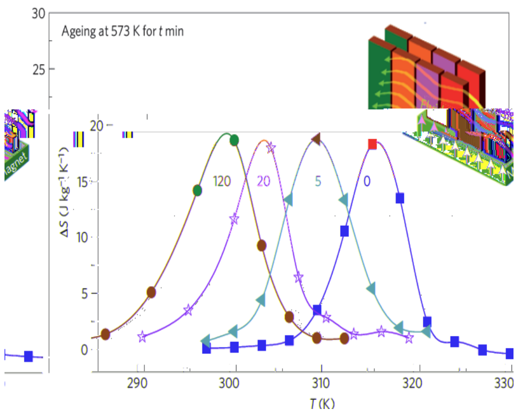
et al. APL, 2007



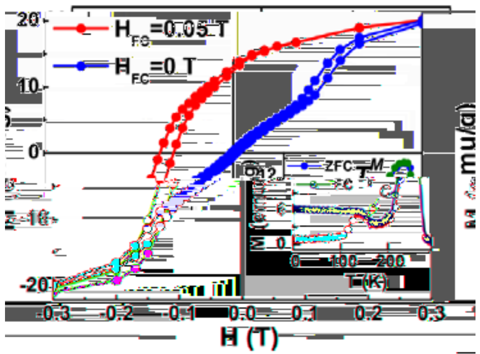
T. Krenke, et al. PRB, 2006



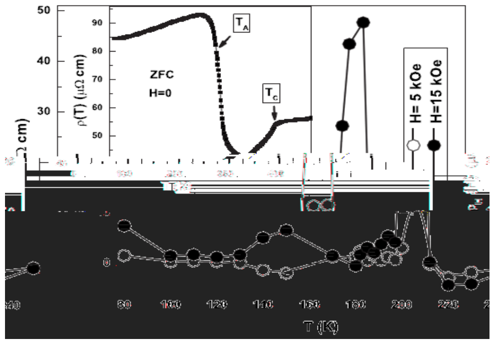
et al. NM, 2013



et al. APL, 2011

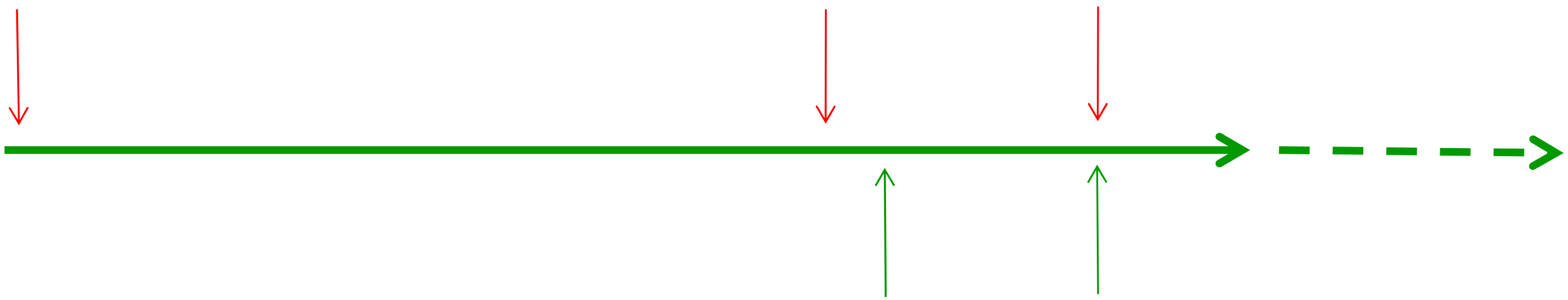


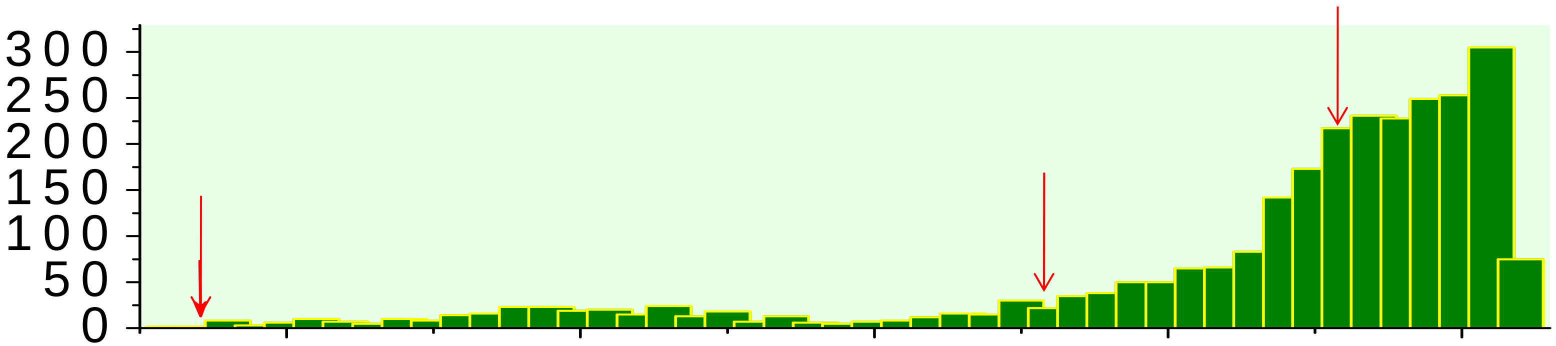
I. Dubenko, *et al.* PRB, 2009

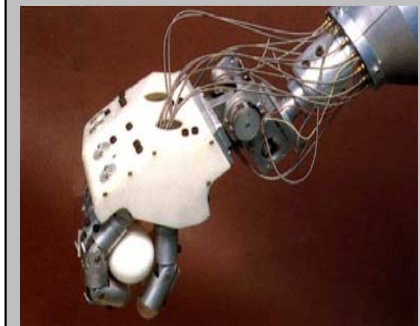


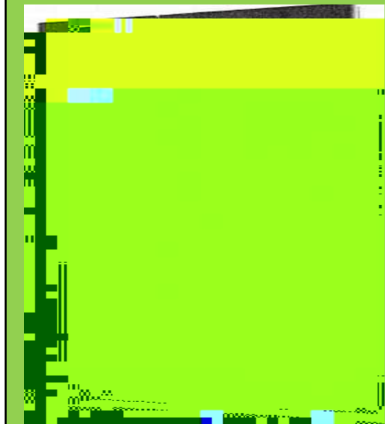
6

Heusler alloys)



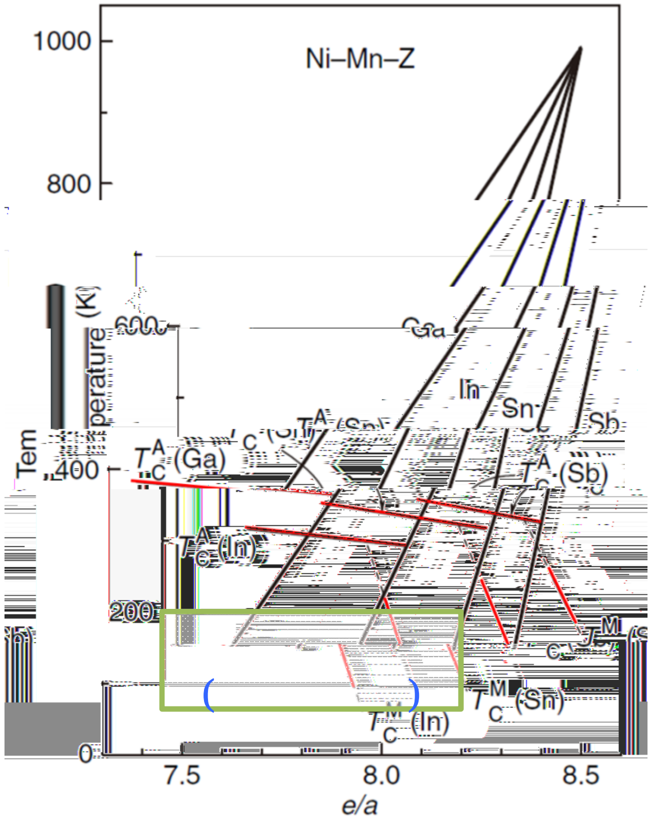




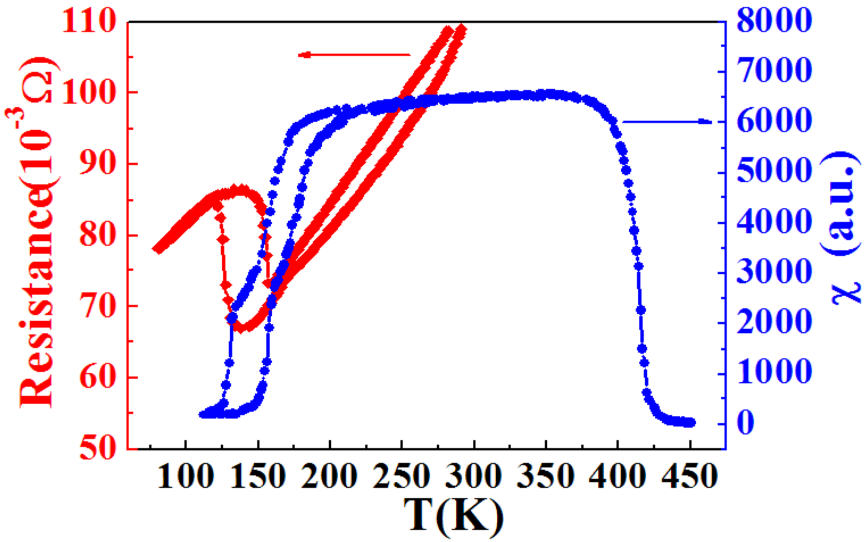


Heusler alloys

( )



Aksoy, S., et al. Phil. Mag. 2009, 89: 2093.

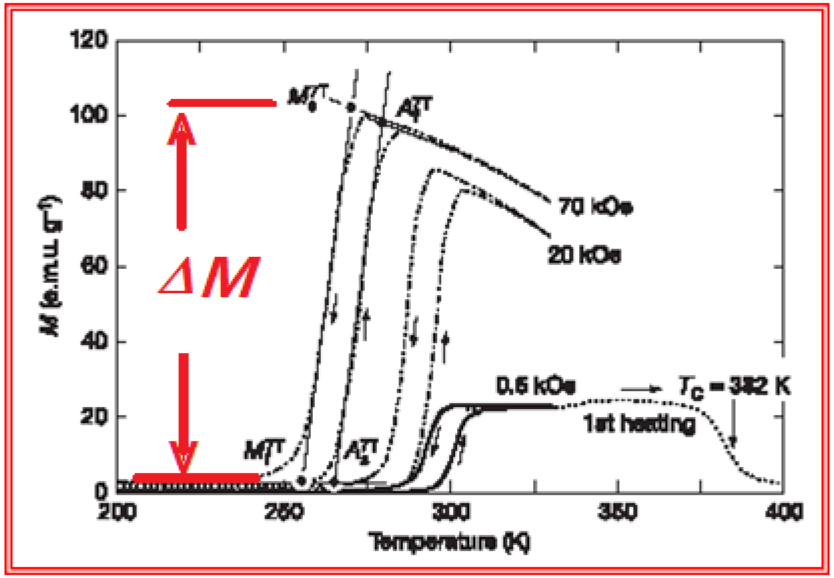


Heusler alloys

Δ

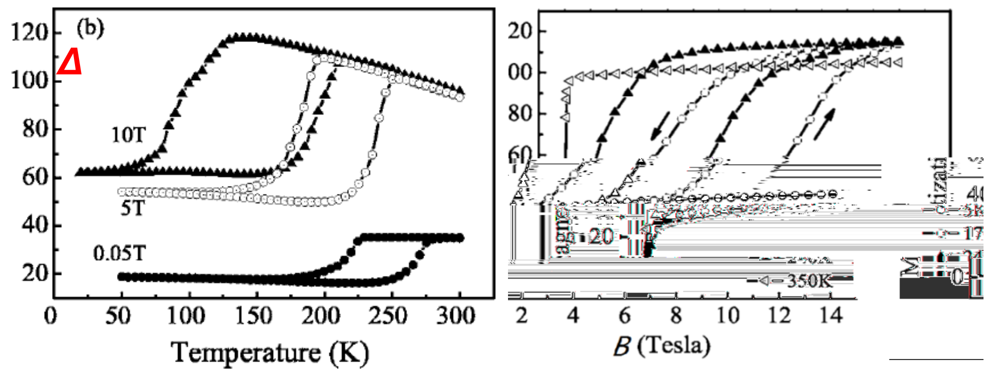
$$\frac{\Delta T}{\Delta H} = -\frac{\Delta M}{\Delta S}$$

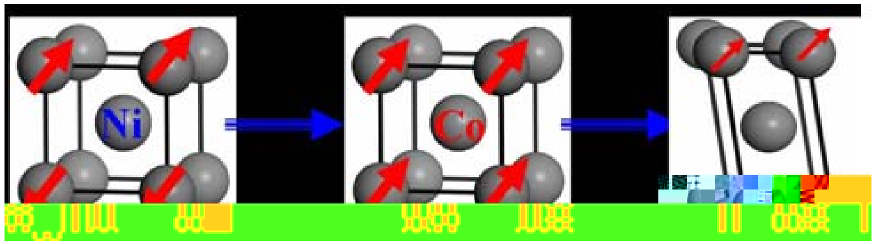
R. Kainuma, *et al*. Nature, 2006.

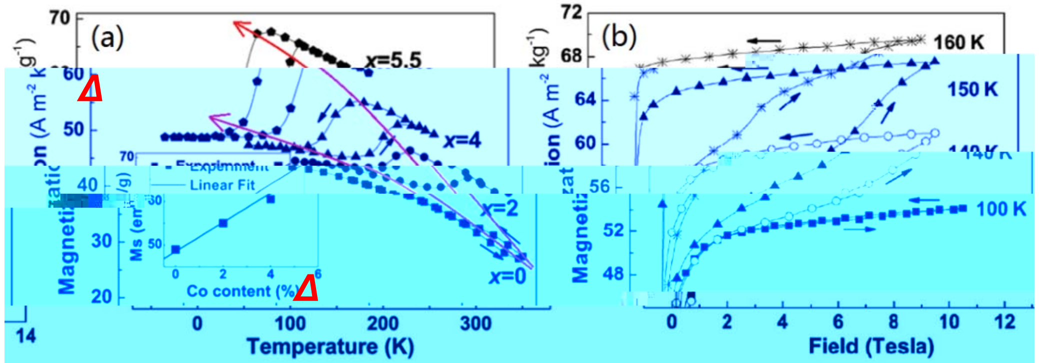


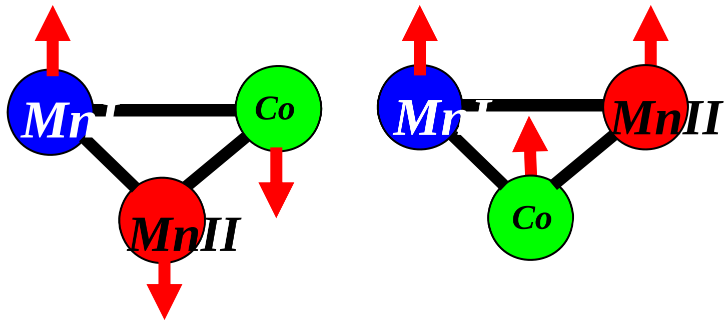
Δ

Co （Heusler alloys)









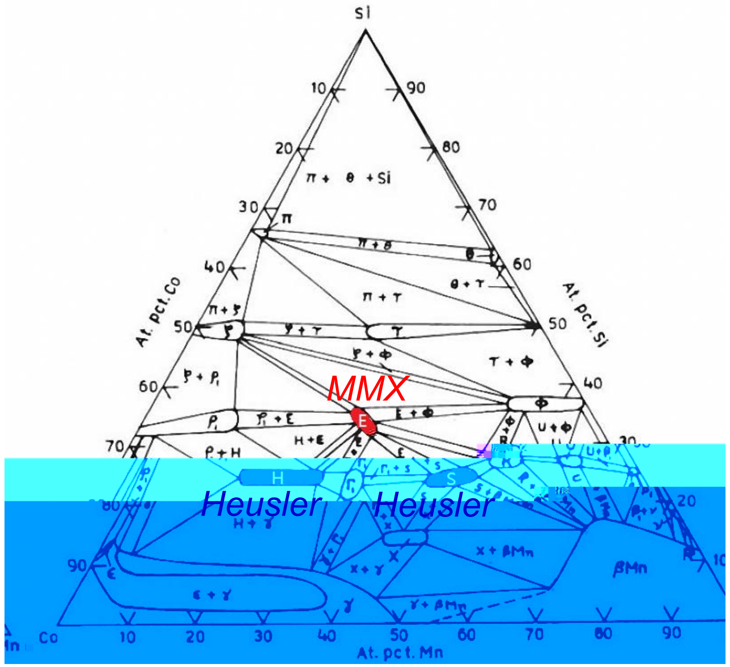
Δ

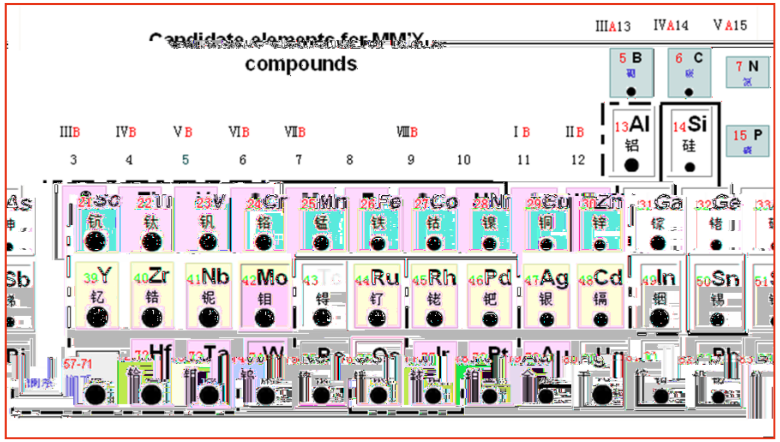
MM’X

-

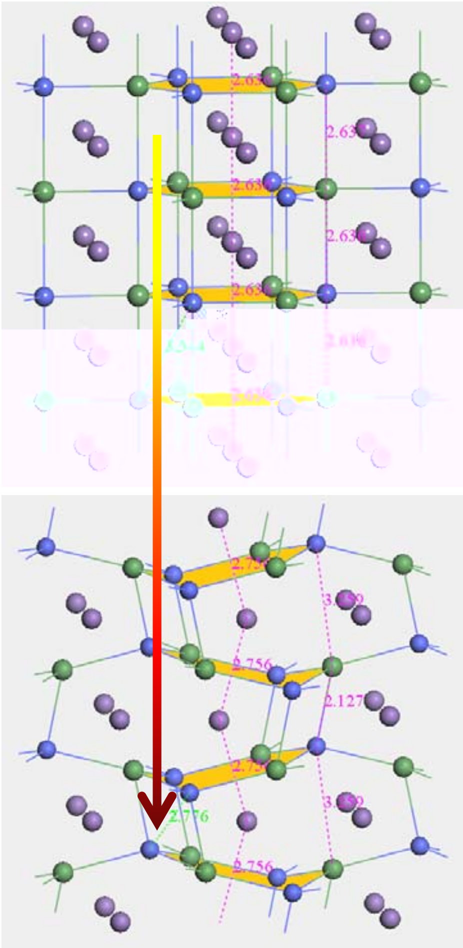
- Heusler

MM’X





MnCoGe,
MnNiGe,
MnCoSi,
MnNiSi,
MnCoSn,
FeNiGe,
FeCoGe,
MnFeGe,
CrCoGe,
ZrMnGe,



MM X

MM’X

MnCoGe/Sn/Si

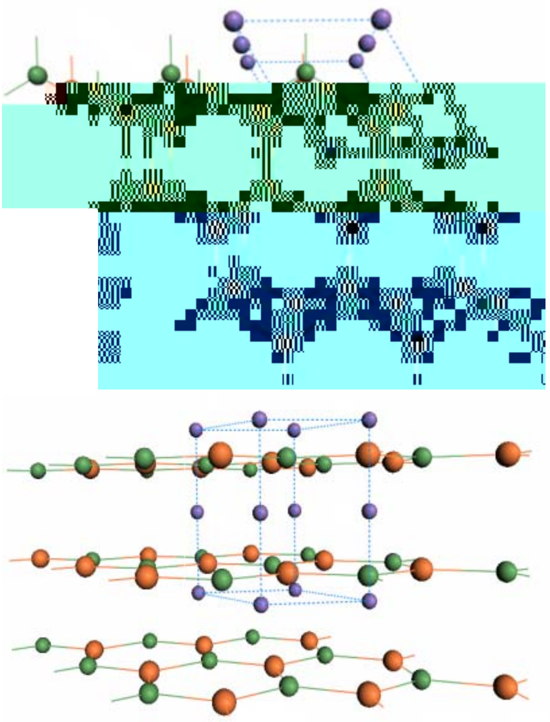
MnNiGe/Sn/.

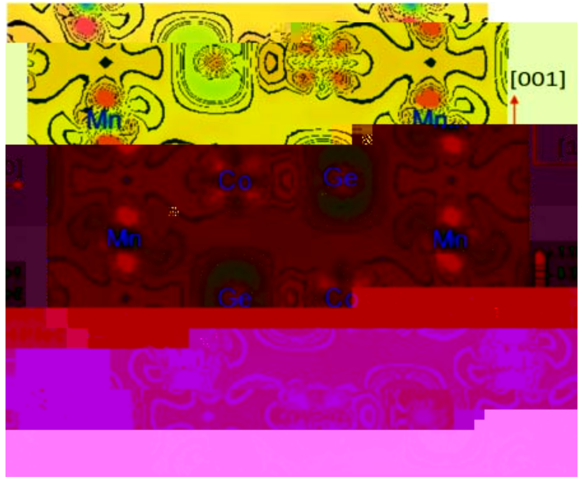
MnFeGe/..

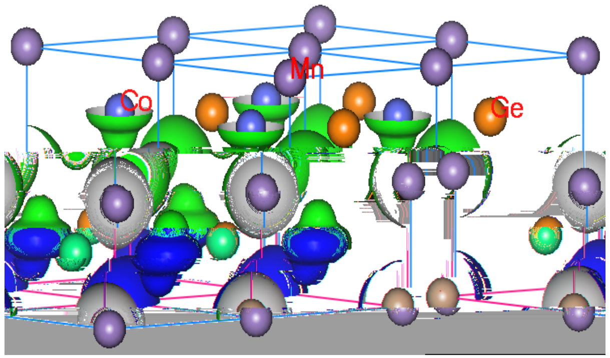
FeNiGe/..

FeCoGe/..

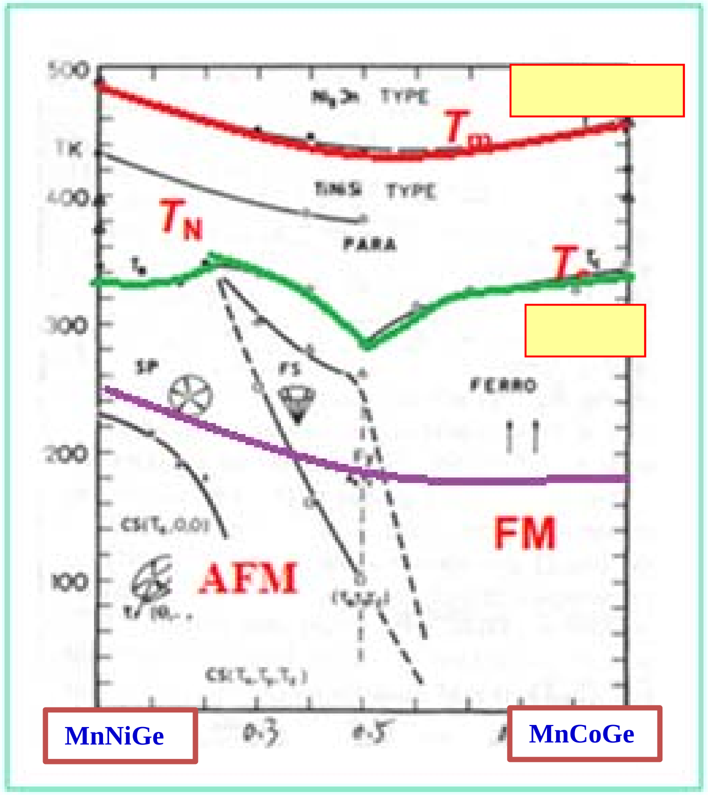
CrCoGe/..







MnNiGe & MnCoGe



Nizioł, S., et al. JMMM, 1982.

◆T_C T_N

◆ , ,

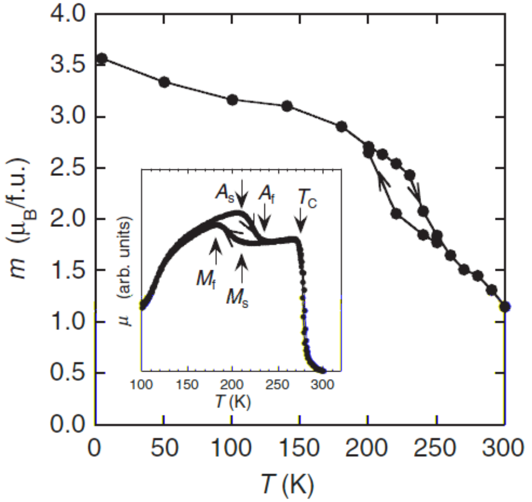
◆Mn

◆

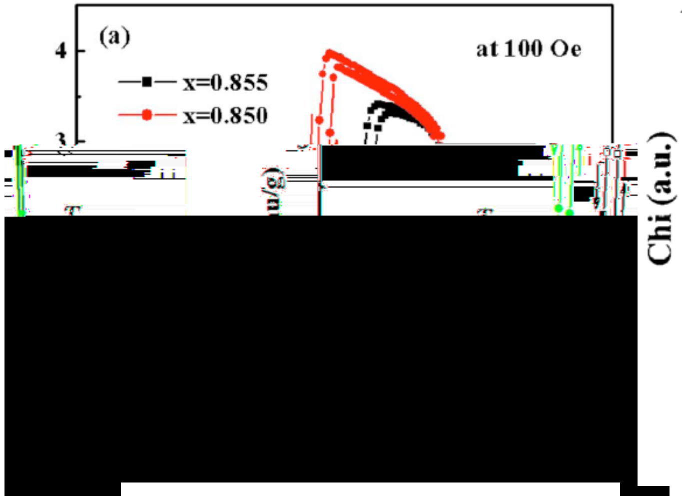
◆ T_C T_C

T_m>T_N &T_C

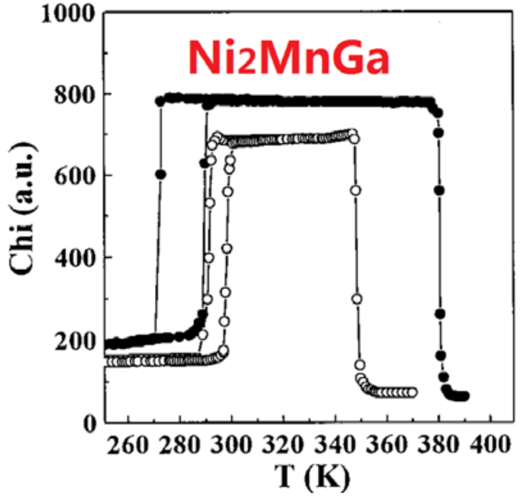
MM'X



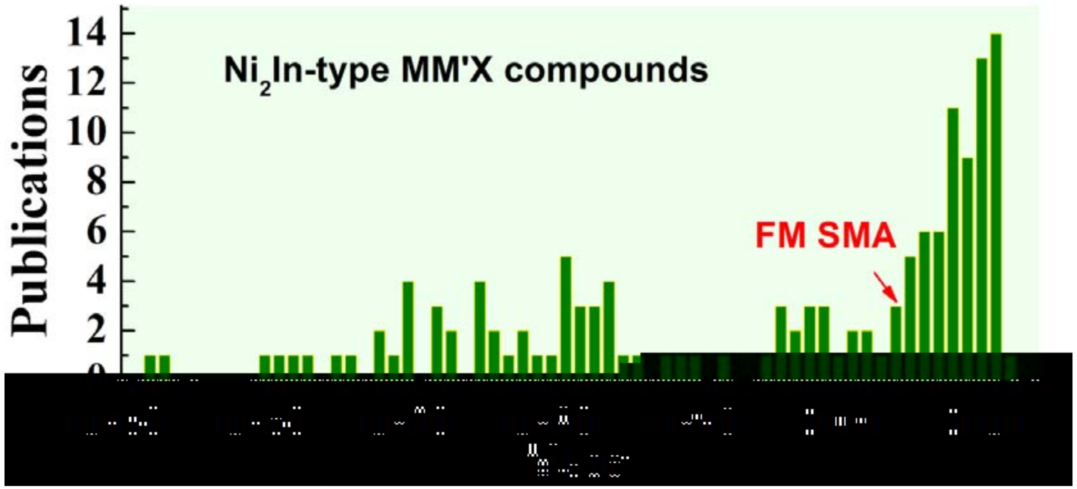
Koyama K, et al. JJAP, 2004



Zhang CL, et al. APL, 2008

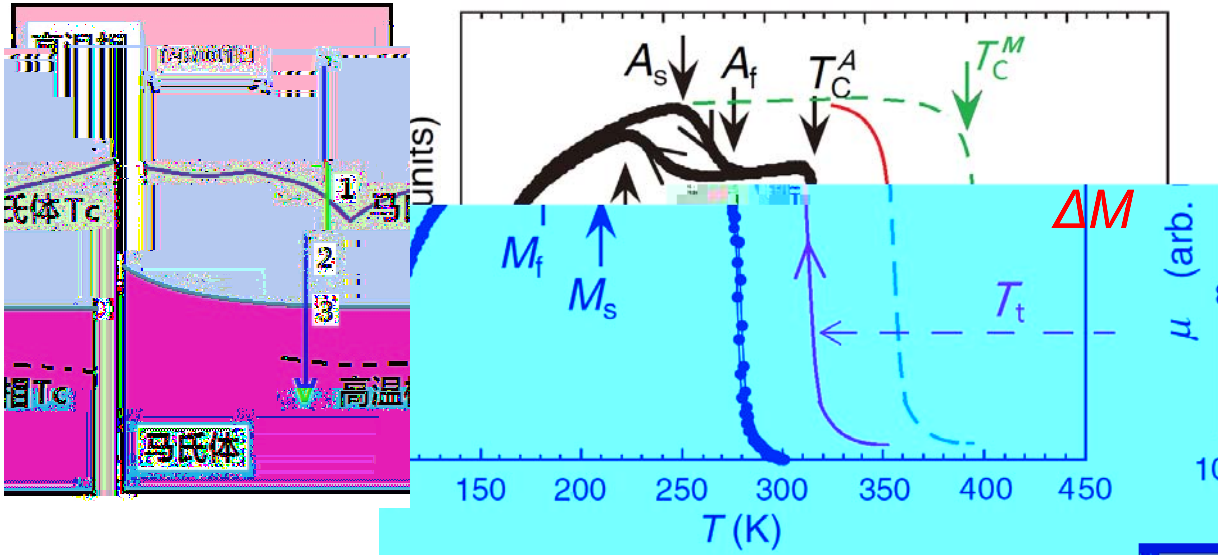


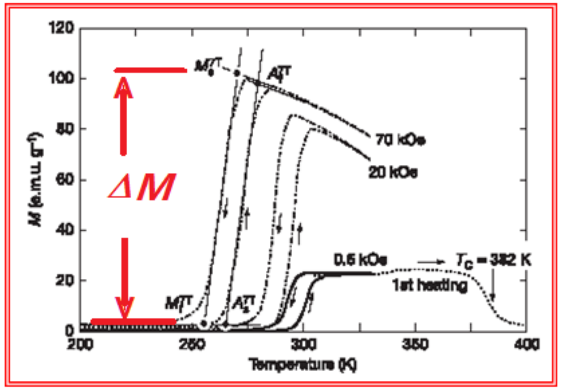
Wu GH, et al. APL, 2002



MnCoGe

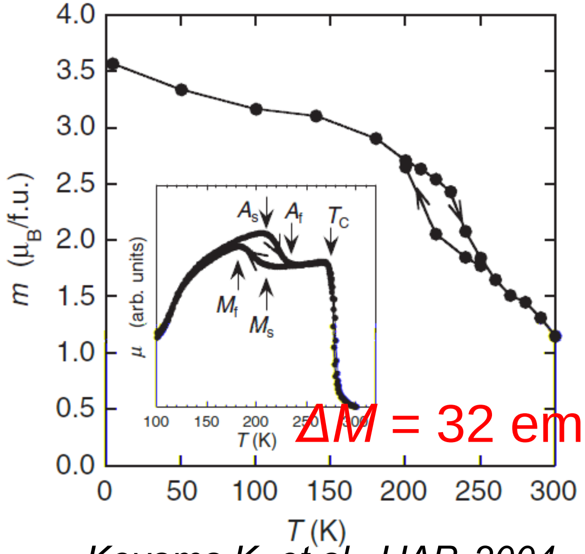
…





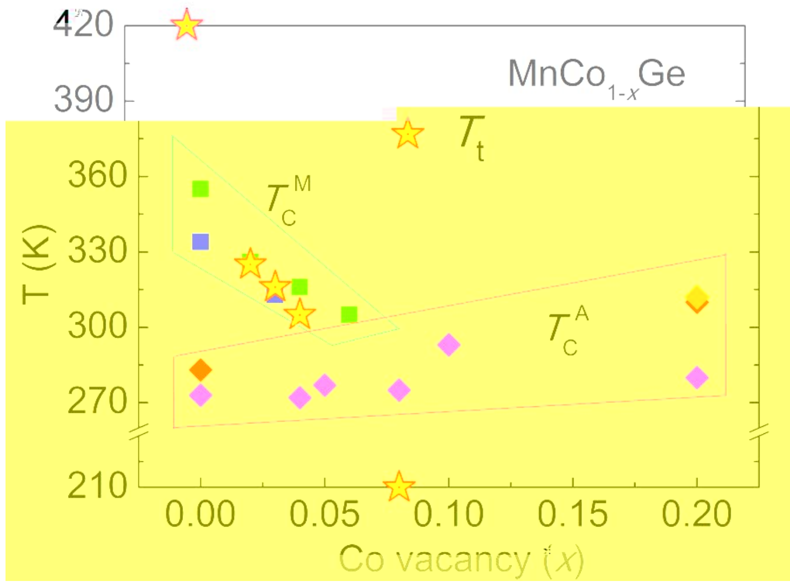
- Tc, Tc
-
- \-
- ΔM
-

( )



ΔM = 32 emu/g

Koyama K, et al. JJAP, 2004



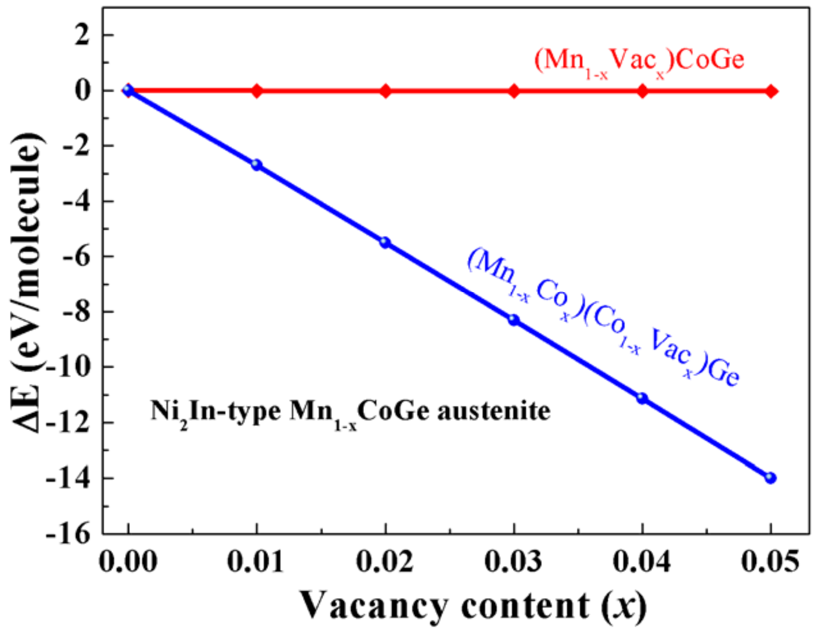
Fang, Y. K., et al.

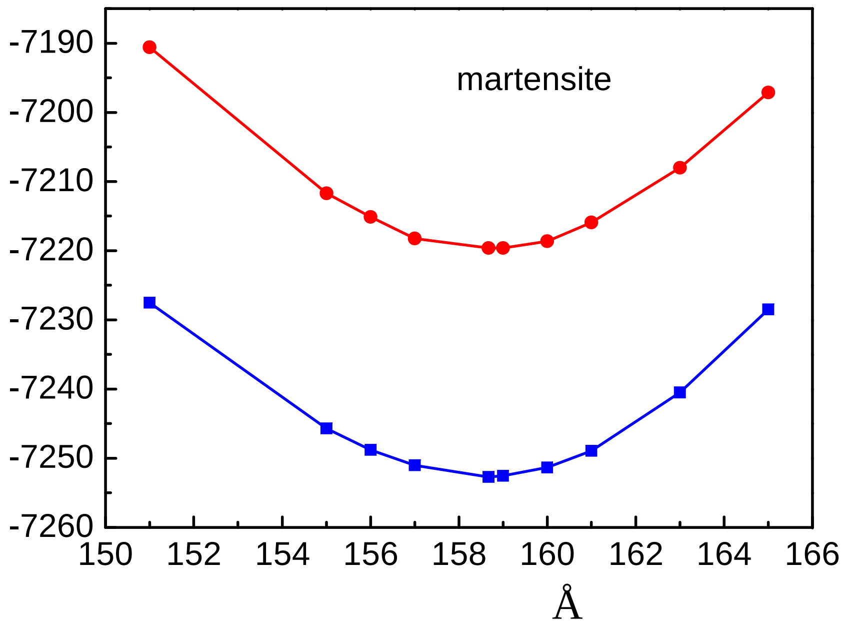
Koyama K, et al.

Markin, P. E., et al.

-
- \- ΔM = 32 emu/g

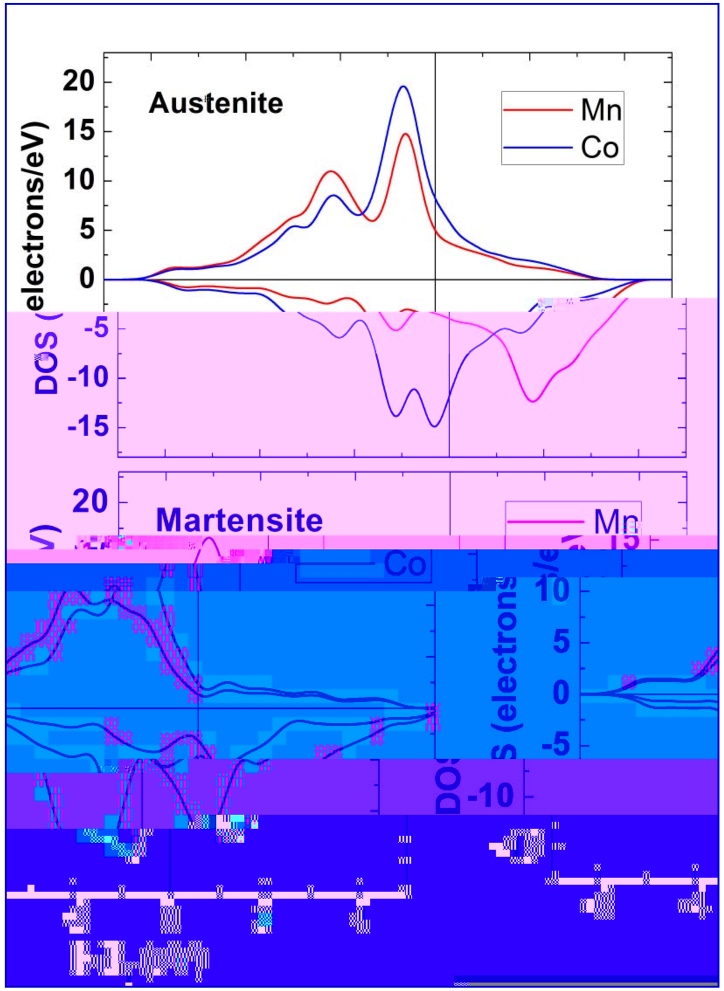
□ *V.S.* □





□

LAPW (*,VCA)*
GGA



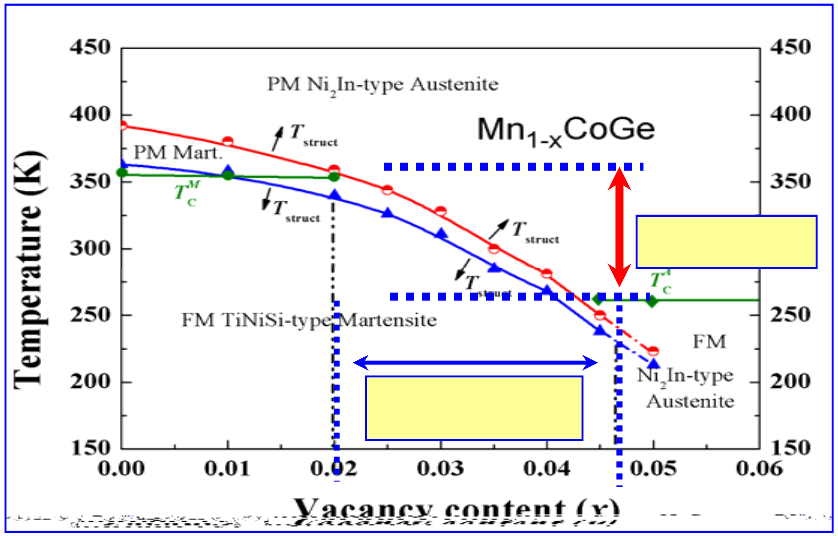
$$T_C \propto M_0^2/\chi_0$$

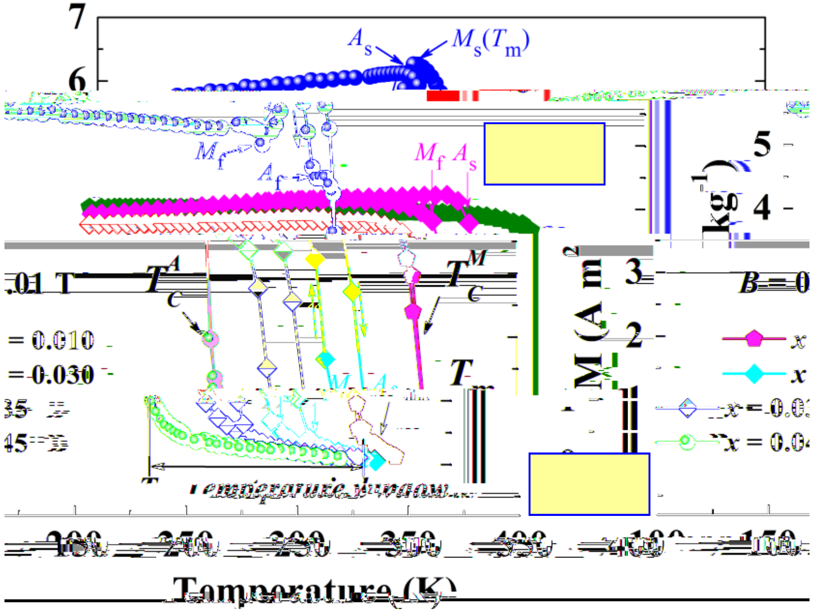
$$\chi_0^{-1} = \frac{1}{4\mu_B^2}\left[\frac{1}{N_\uparrow(\varepsilon_f)} + \frac{1}{N_\downarrow(\varepsilon_f)} - 2I\right]$$

Mohn , et al. J. Phys. F: Met. Phys. (1987)

MnCoGe	奥氏体		马氏体	
	Mn	Co	Mn	Co
自旋向上DOS	5.00	8.22	1.32	2.35
自旋向下DOS	3.87	11.82	2.10	4.75
原子磁矩（μ_B）	2.68	0.50	3.04	0.70

$Mn_{1-x}CoGe$ x=0-0.045

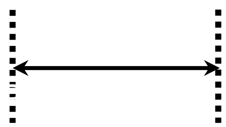




-
- ΔT ~ 90 K
-

.ñ ý Ä-(

H P X J



.ñP¡ ØPœ"? ƒ-(Ä . 7 Å

W.ñ'å

‹ -Lu :OÆ!Q ÕFƒ ¶ $Y Ö
0Ç .ñP¡-(W.ñ'å

MnCoGe

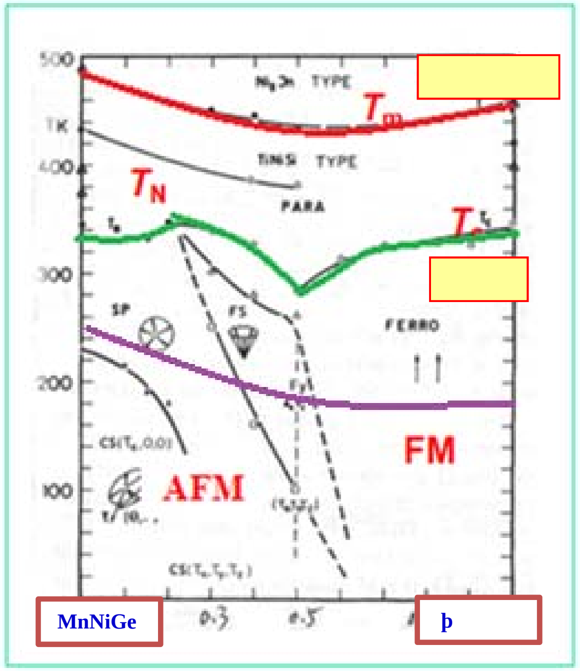
90 K

ΔM PM-FM

E. K. Liu, W.H.Wang and G.H.Wu et al. *Europhysics Letters* 91, 17003 (2010).

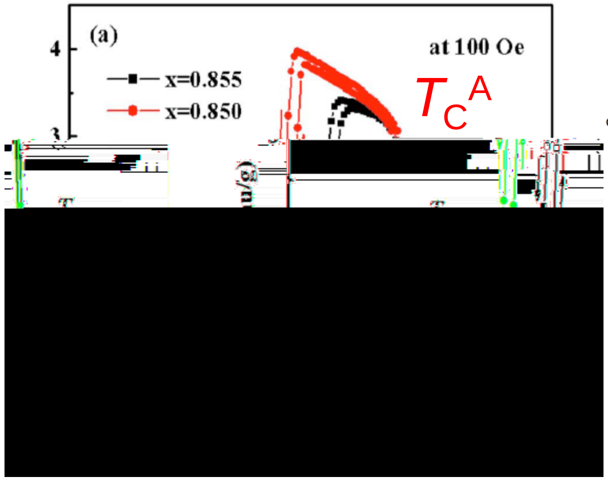
MnNiGe:Fe

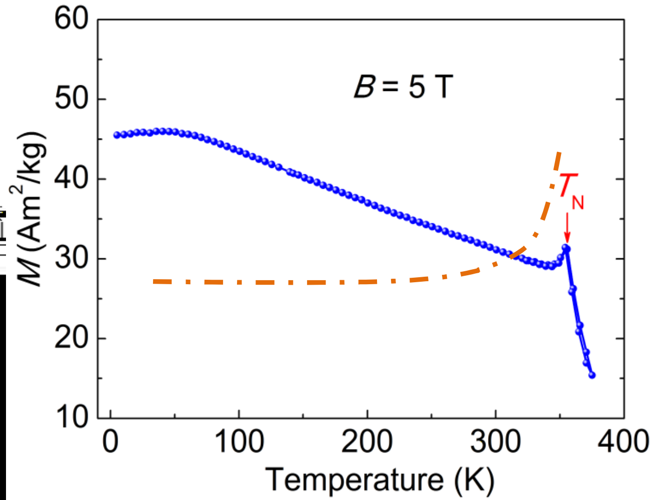
( )



Niziol, S., et al. JMMM, 1982.

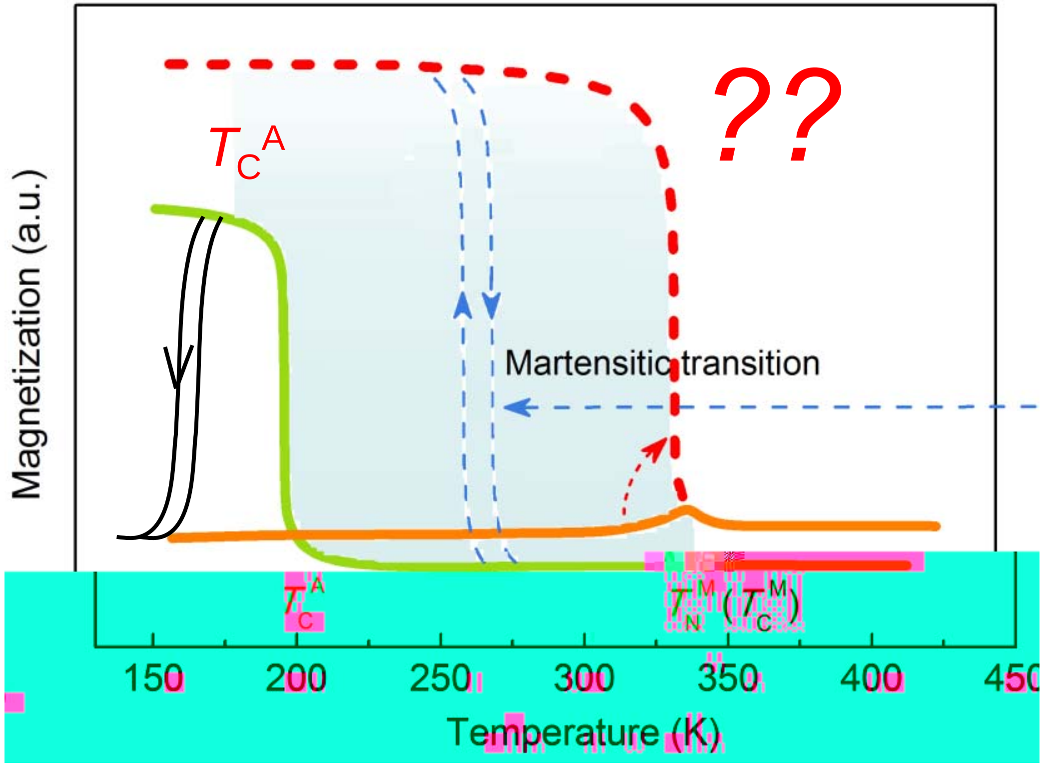
Zhang CL, et al. APL, 2008



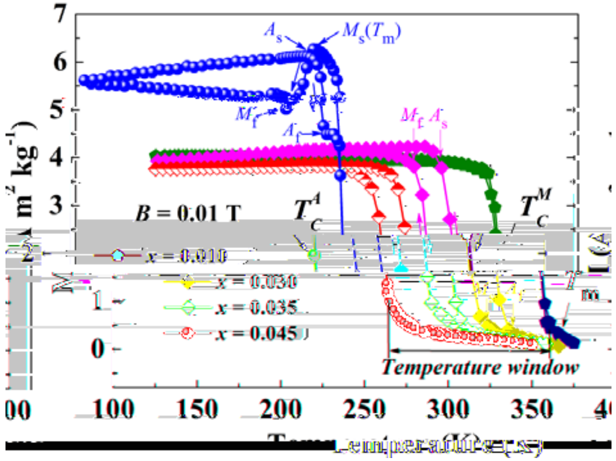


T_C^A=205 K
T_N^M= 350 K

MnNiGe ( )



??
T_C^A
Magnetization (a.u.)
Martensitic transition
T_N^M (T_C^M)
150
200
250
300
350
400
450
Temperature (K)

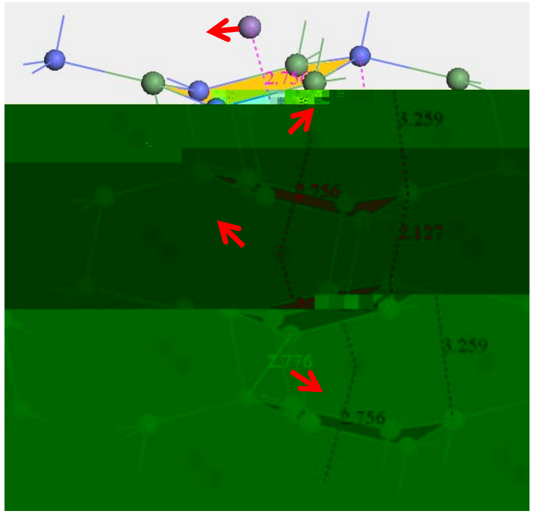


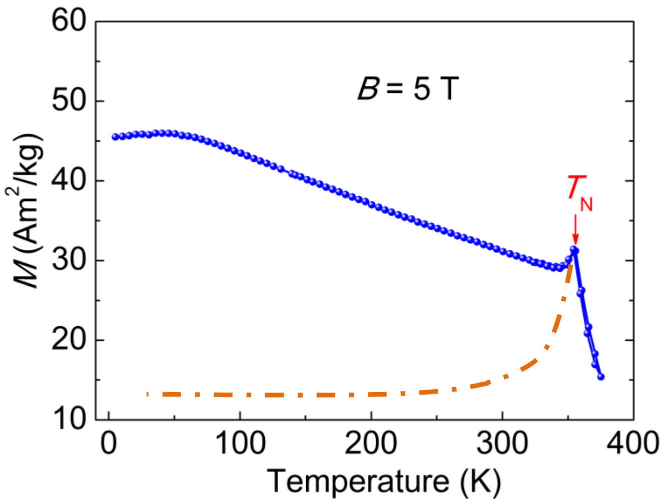
A_s
$M_s(T_m)$
M_f
A_f
M_f A_s
B = 0.01 T
T_C^A
T_C^M
x = 0.010
x = 0.030
x = 0.035
x = 0.045
Temperature window
7
6
5
4
3
1
0
100
150
200
250
300
350

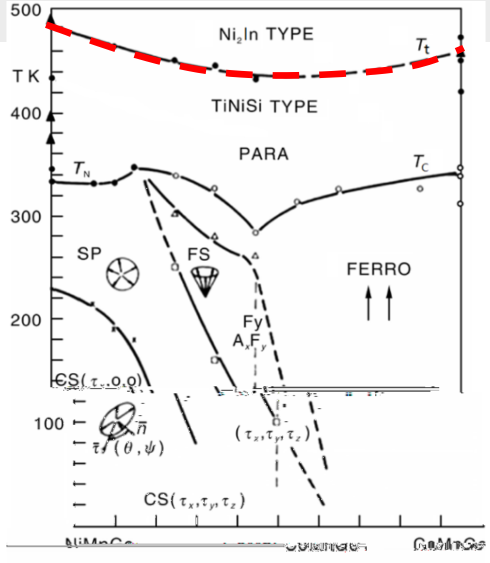
1.

2.

MnNiGe:Fe







Niziol, S., et al. *JMMM*, 1982.

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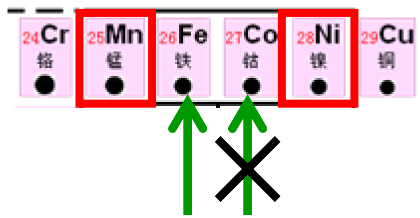
MnNiGe:



FM

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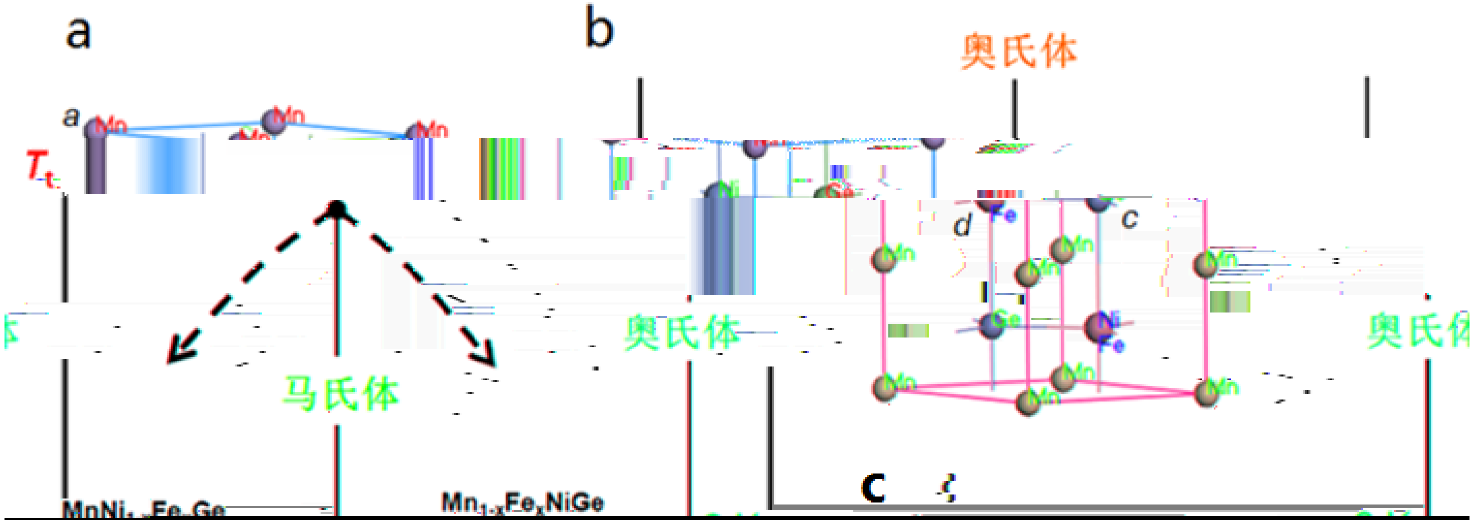
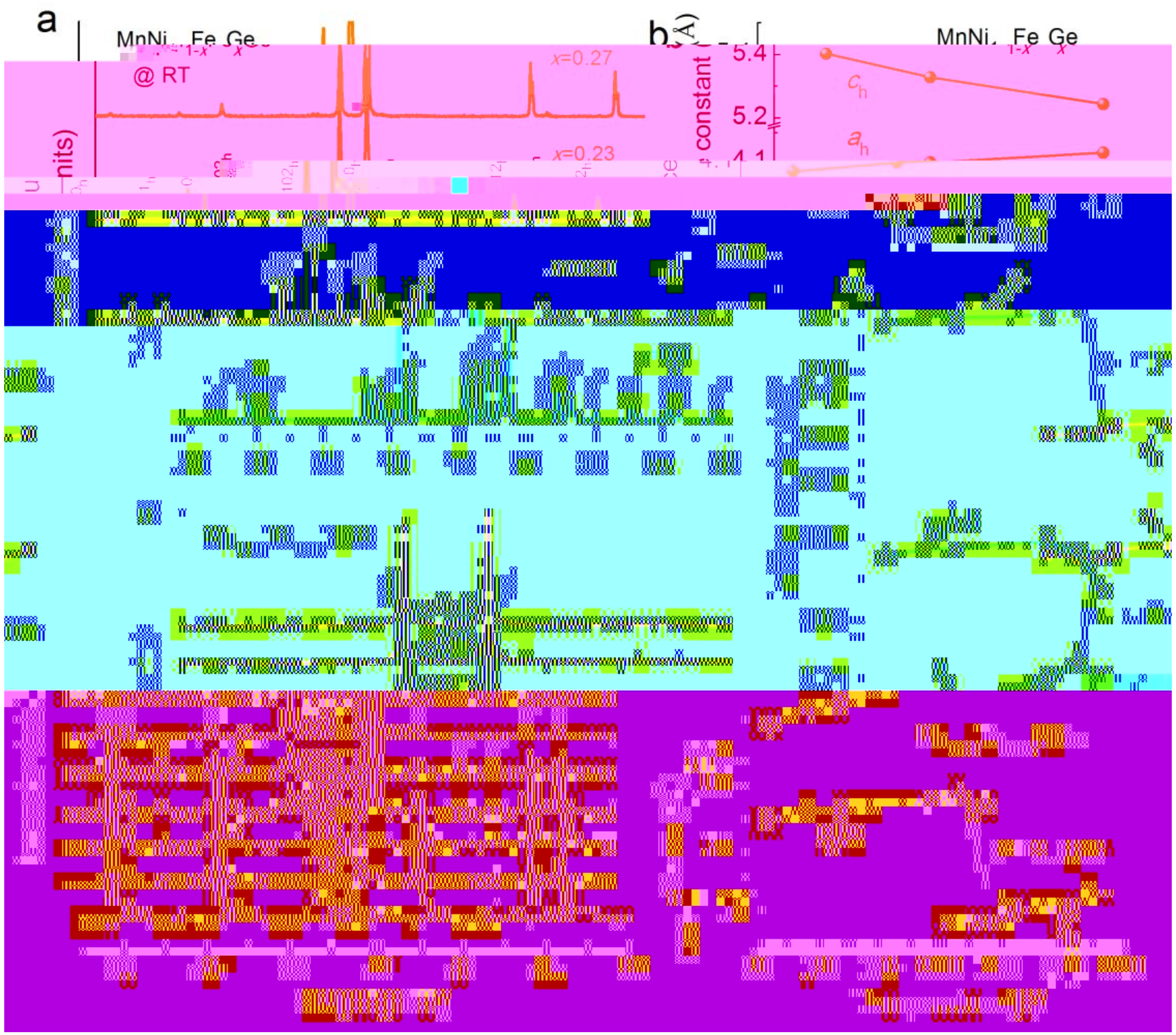


X

MnNiGe:Fe



Preparation:

Heat treatment:

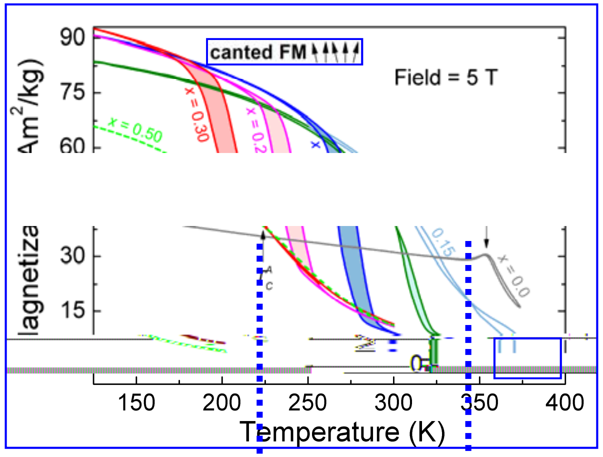
Structural analysis:

Thermal analysis:

Magnetic measurements:

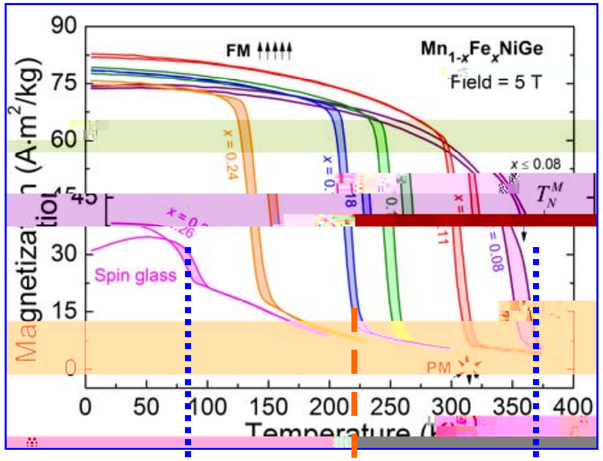
$a_{ortho}=c_{hex}$,
$b_{ortho}=a_{hex}$,
$c_{ortho}=\sqrt{3}a_{hex}$,
$V_{ortho}=2V_{hex}$

$MnNi_{1-x}Fe_xGe$

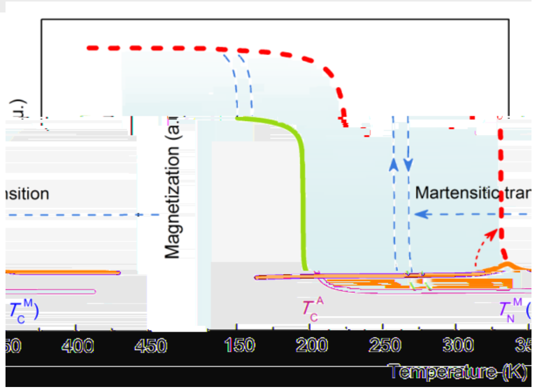


90K

$Mn_{1-x}Fe_xNiGe$



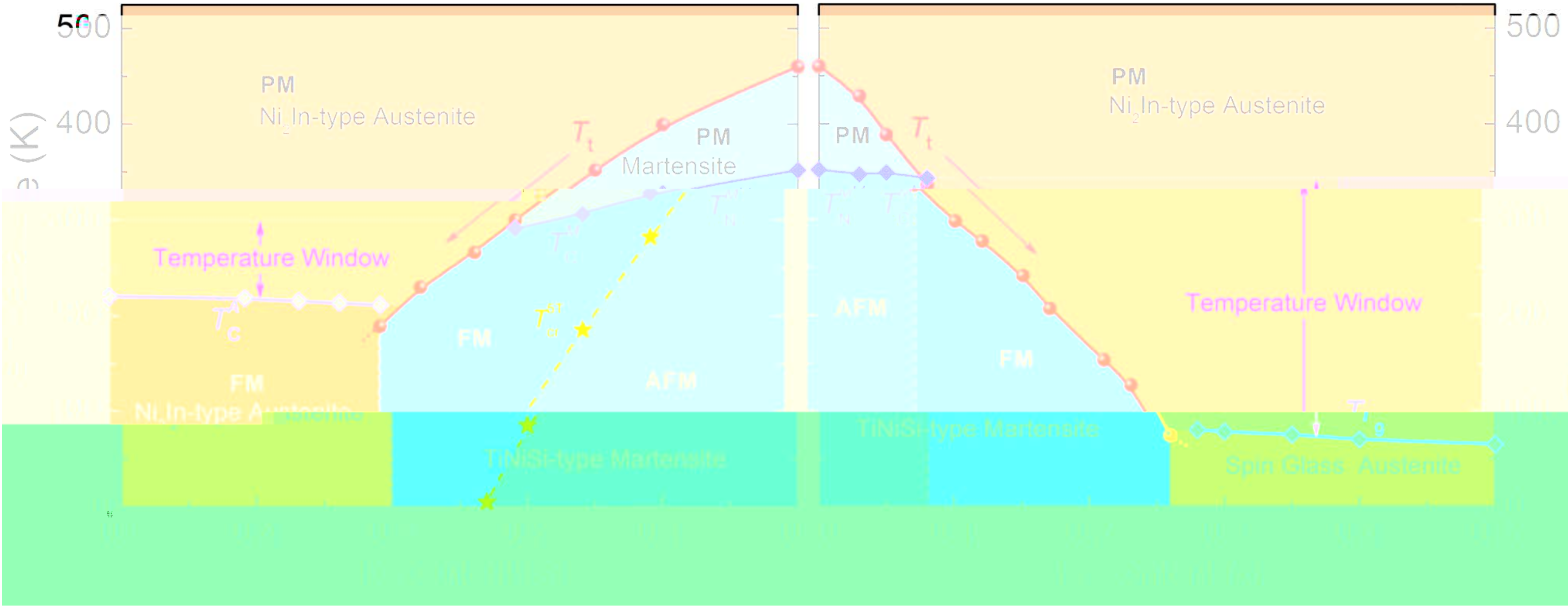
280K



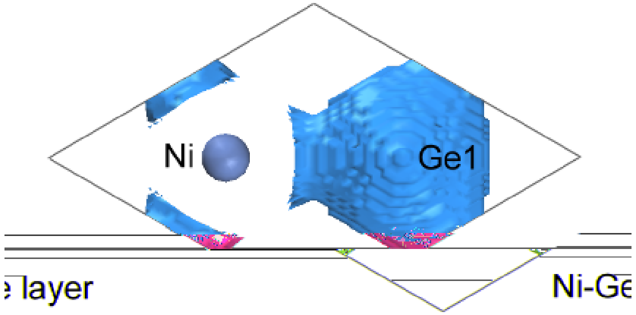
- **MnFeGe, FeNiGe** **T_t**
- **Fe** **Ni** **Mn** **AFM-FM**
- **FeNiGe** **Tc**

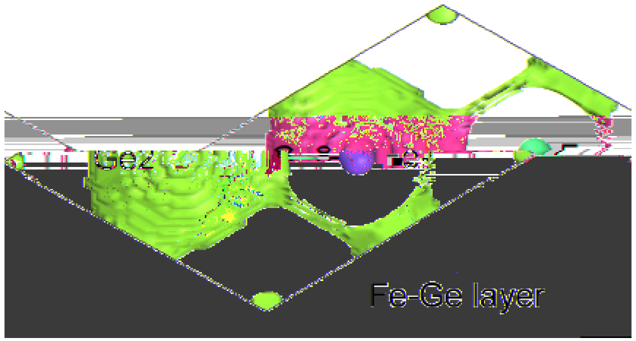
-

MnNiGe:Fe



500
400
PM
Ni2In-type Austenite
PM
Martensite
PM
Temperature Window
FM
AFM
AFM
FM
TiNiSi-type Martensite
TiNiSi-type Martensite
Temperature Window
Spin Glass Austenite
500
400





$MnNi_{0.5}Fe_{0.5}Ge$

◆ **MnNiGe (Fe** **MnFeGe Ni)**

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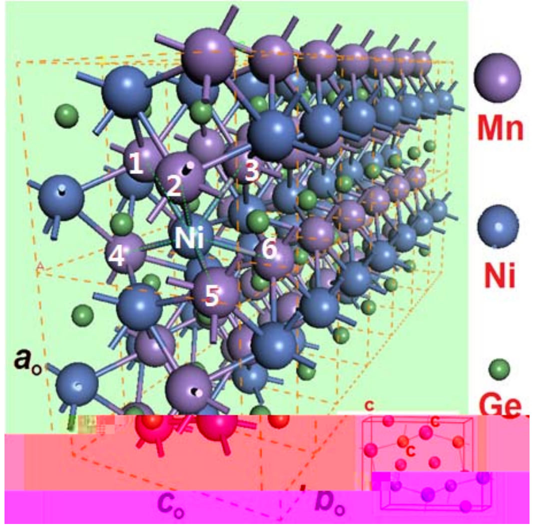
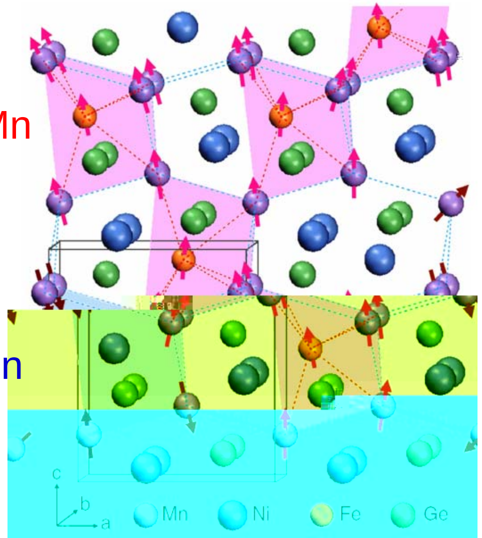
MnNiGe:Fe

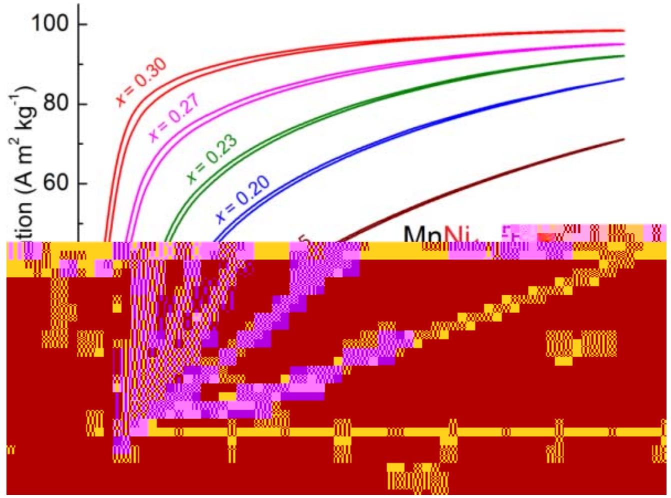
$(MnNi_{1-x}Fe_xGe)$



Fe@6Mn

Ni@6Mn

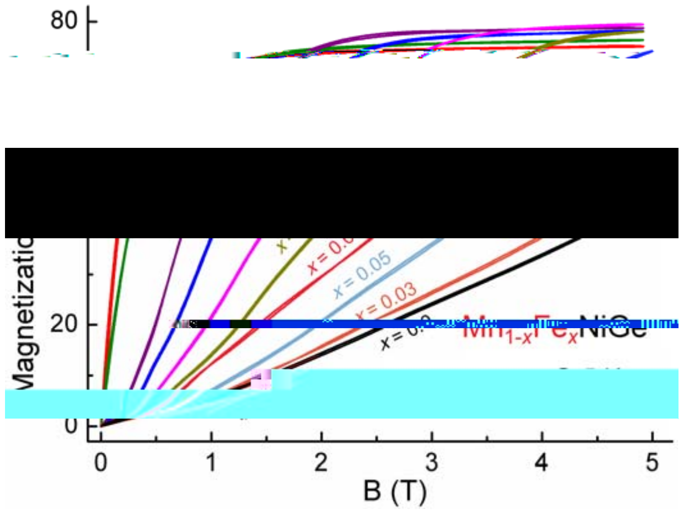




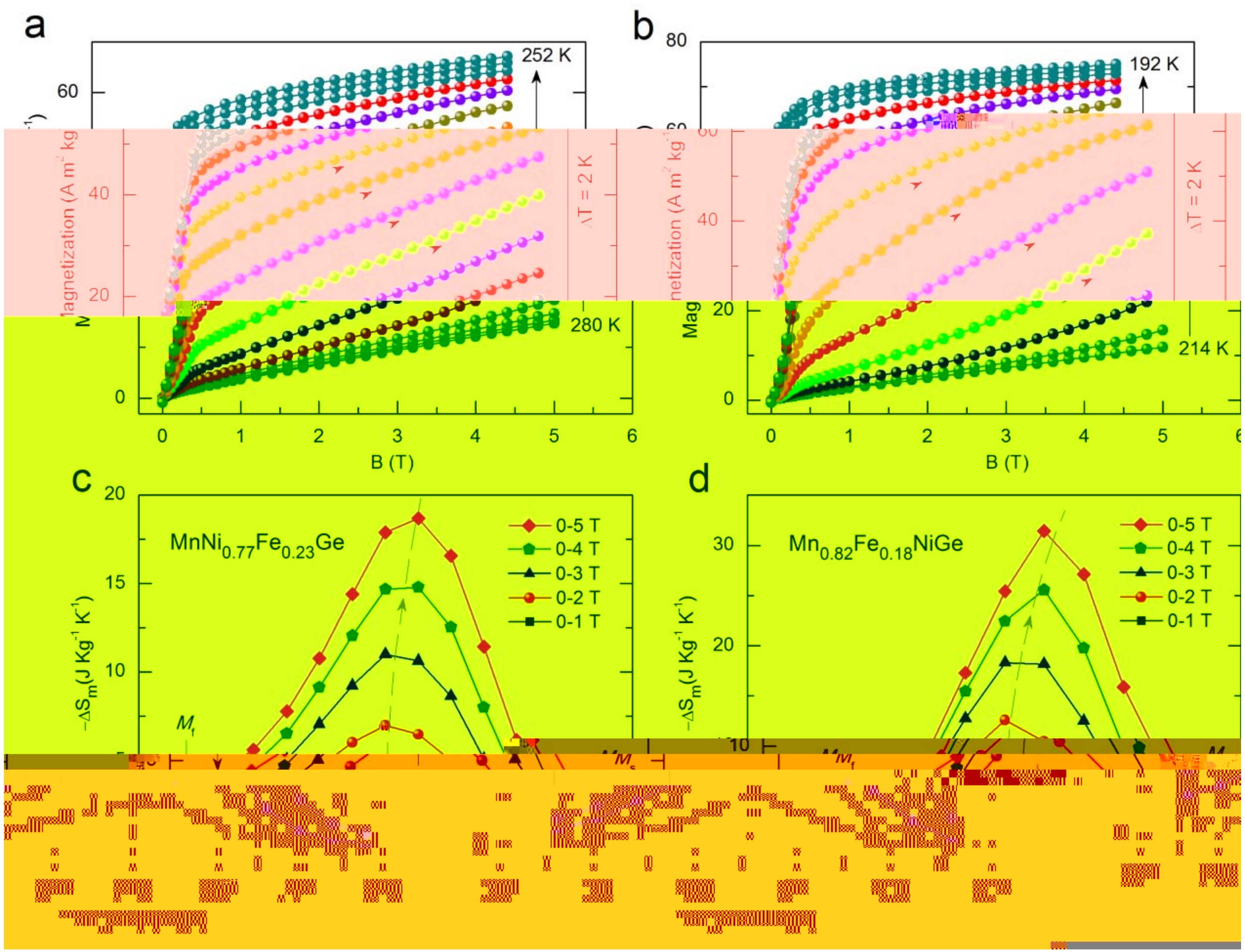
原子	间距 (Å)
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

	理论计算	实验测量
Mn	2.8-2.9	
Ni	0.08-0.2	
Fe	1.44	
Ge	-0.02	
分子磁矩	3.33	3.11

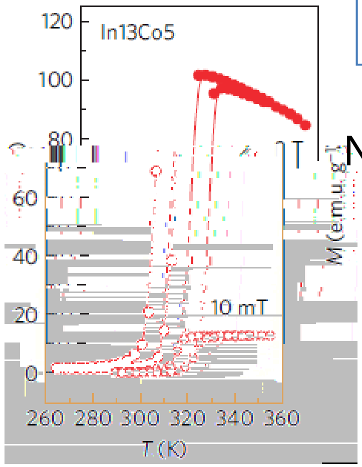
$MnNi_{0.25}Fe_{0.25}Ge$



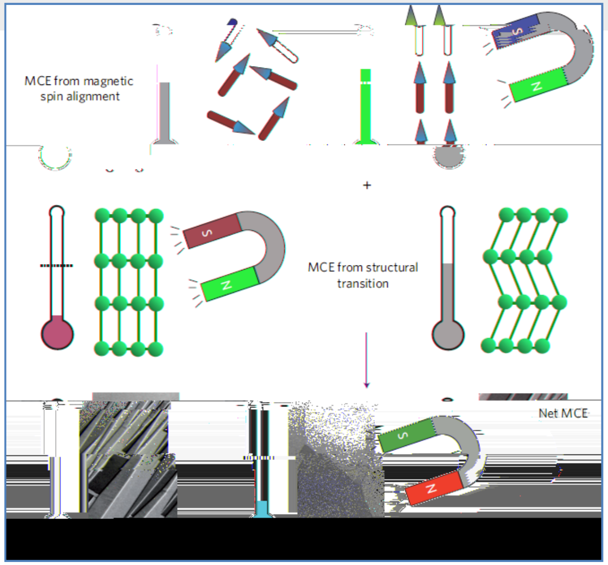
LOOP Process Method

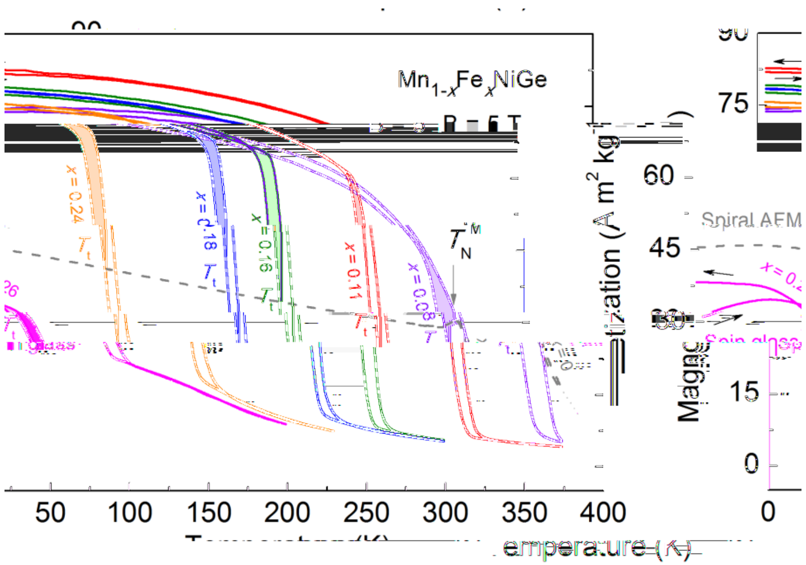


MnNiGe:Fe



Heusler alloy
$Ni_{45.2}Mn_{36.7}In_{13}Co_{5.1}$





E.K. Liu, W.H. Wang and G.H.Wu. et al.,
Nature Communications, , 873, 2012

MnNiGe:Fe

nature COMMUNICATIONS

OPEN

1. Stable magnetostructural coupling with tunable magnetoresponsive effects in hexagonal ferromagnets

作者: Liu, Enke; Wang, Wenhong; Feng, Lin; 等.

NATURE COMMUNICATIONS 卷: 3 文献号: 873 出版年: MAY 2012

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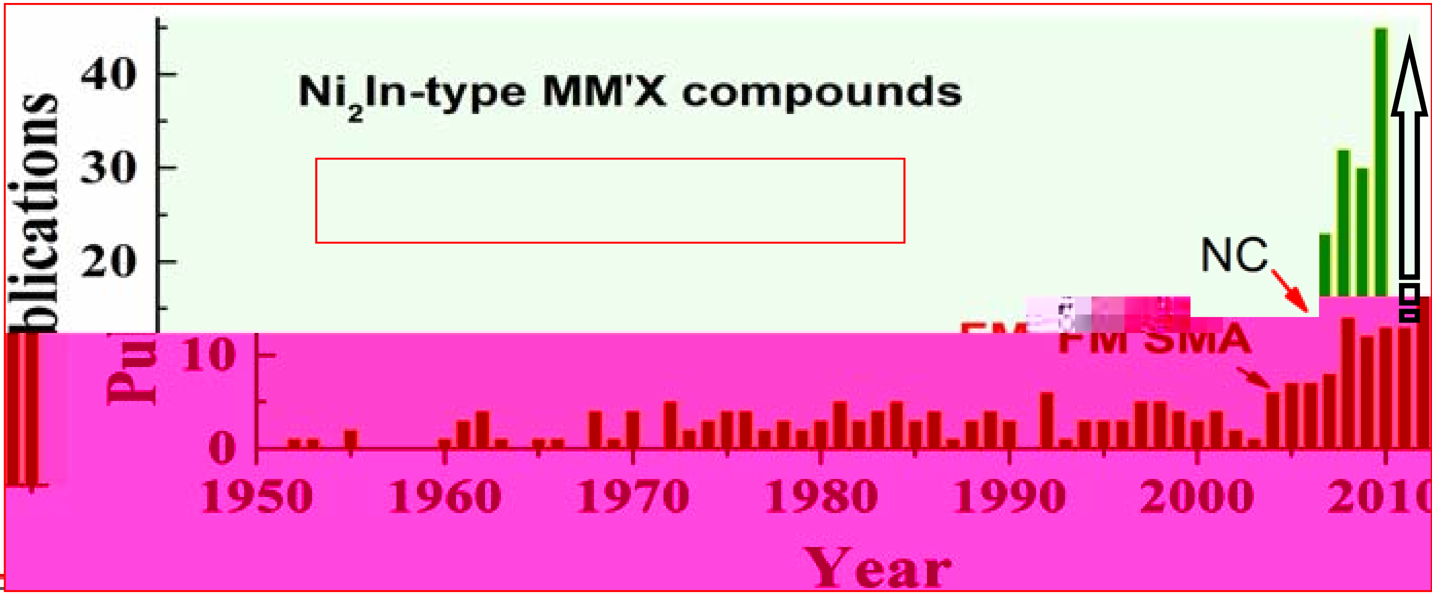
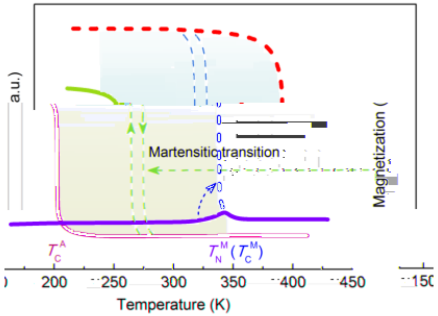
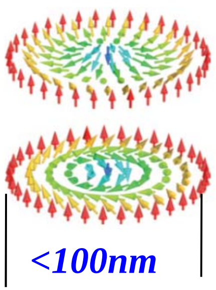


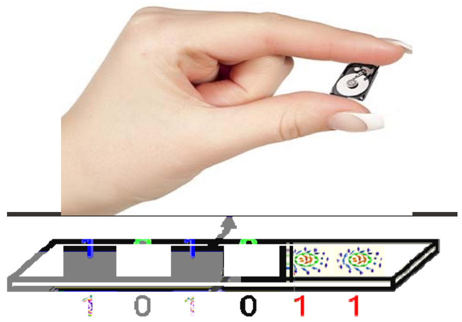
$MnNi_{1-x}Fe_xGe$ $Mn_{1-x}Fe_xNiGe$ **90 K 280 K** **PM-FM**

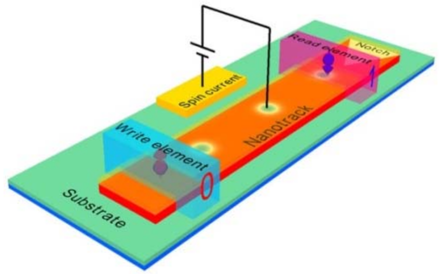


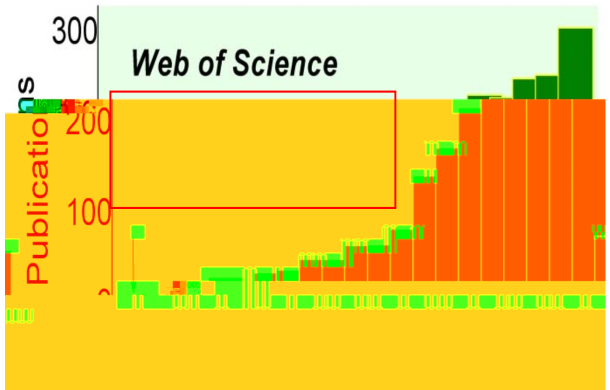
E. K. Liu, W.H.Wang and G.H.Wu et al. 3, 873, 2012

Tony Skyrme 1962









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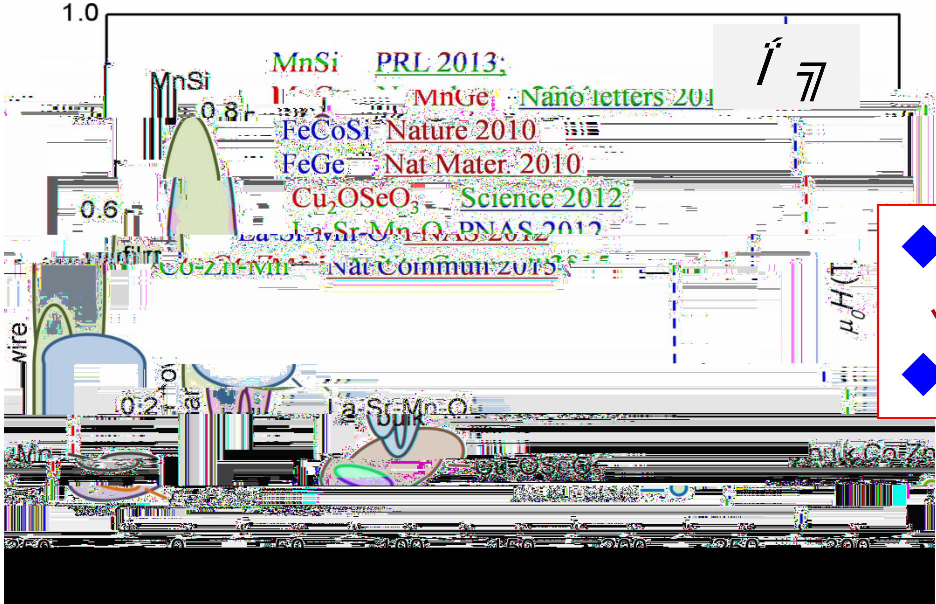
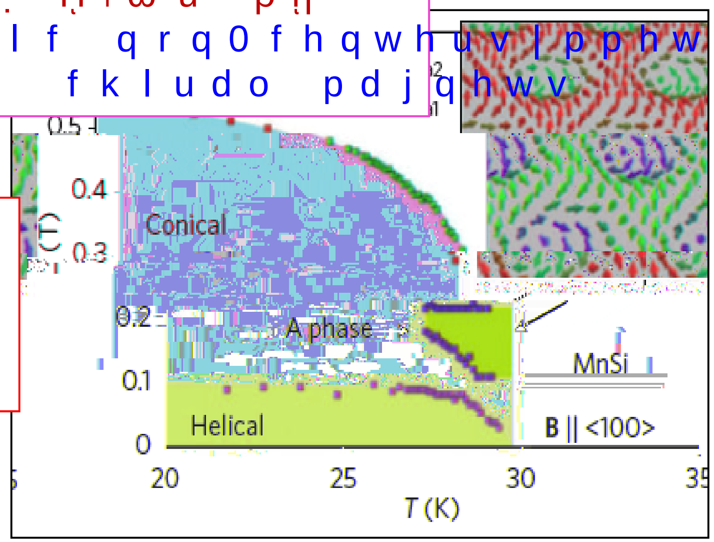




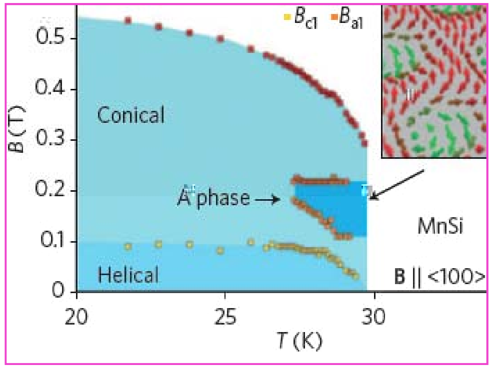
NANO LETTERS

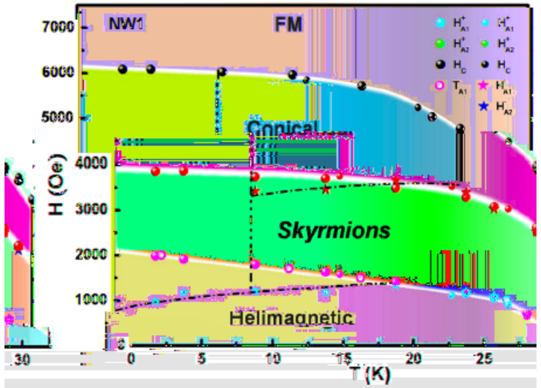
Letter

pubs.acs.org/NanoLett

Highly Stable Skyrmion State in Helimagnetic MnSi Nanowires

Haifeng Du,[†,‡] John P. DeGrave,[§] Fei Xue,[†,‡] Dong Liang,[§] Wei Ning,[†,‡] Jiyong Yang,[†,‡] Mingliang Tian,[*,†,‡] Yuheng Zhang,[†,‡] and Song Jin[*,§]





26~30K in bulk

10~ 35K in nanowires

MnNiGa

PHYSICAL REVIEW B 88, 054403 (2013)

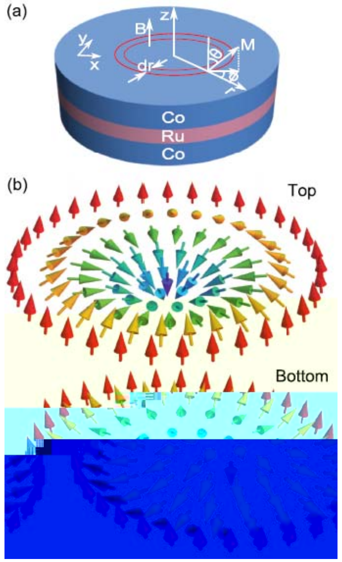
Skyrmion ground state and gyration of skyrmions in magnetic nanodisks without the Dzyaloshinsky-Moriya interaction

Y. Y. Dai,* H. Wang,* P. Tao, T. Yang, W. J. Ren, and Z. D. Zhang†
Shenyang National Laboratory for Materials Science, Institute of Metal Research and International Centre for Materials Physics, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, People's Republic of China

PHYSICAL REVIEW B 90, 174411 (2014)

Experimental realization of two-dimensional artificial skyrmion crystals at room temperature

B. You,[1] J. Du,[1] R. W. Li,[3] and H. F. Ding[1,*]



DMI

[redacted]

MnNiGa

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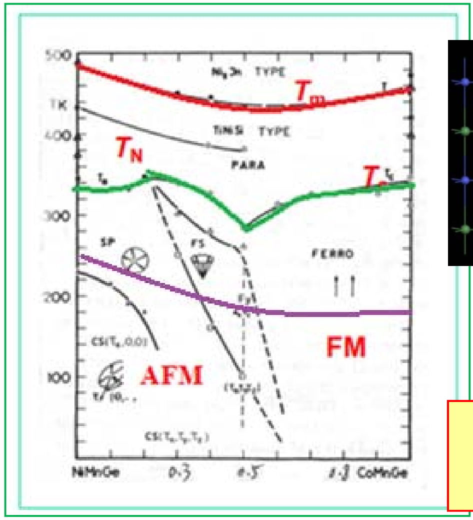

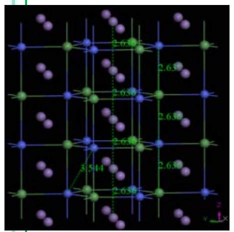

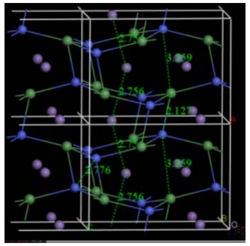

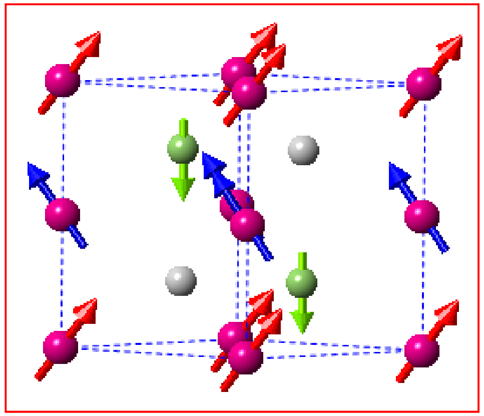

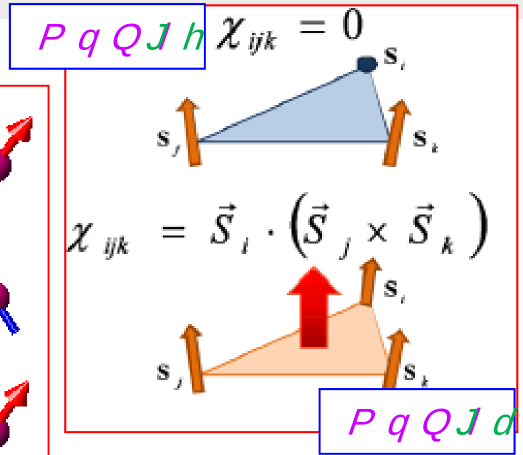

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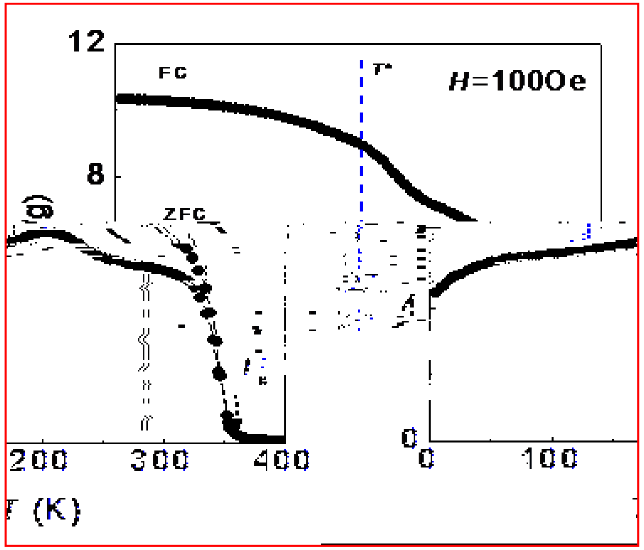

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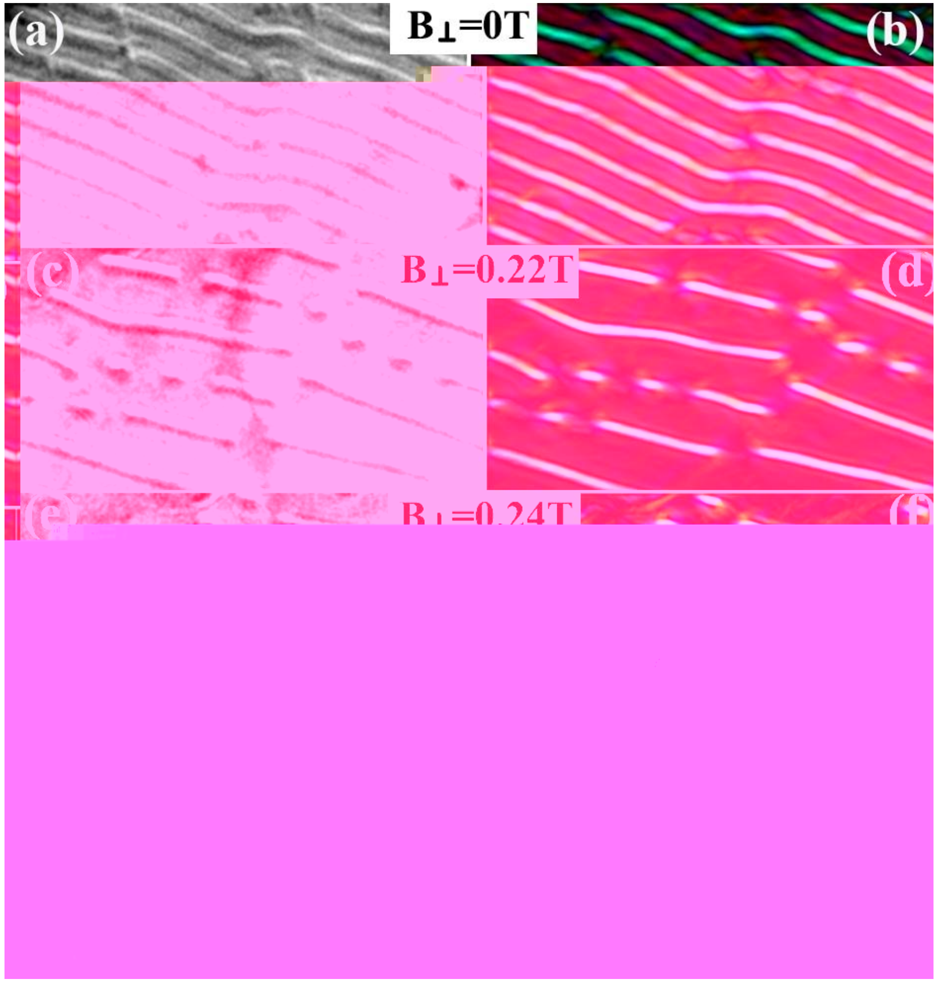
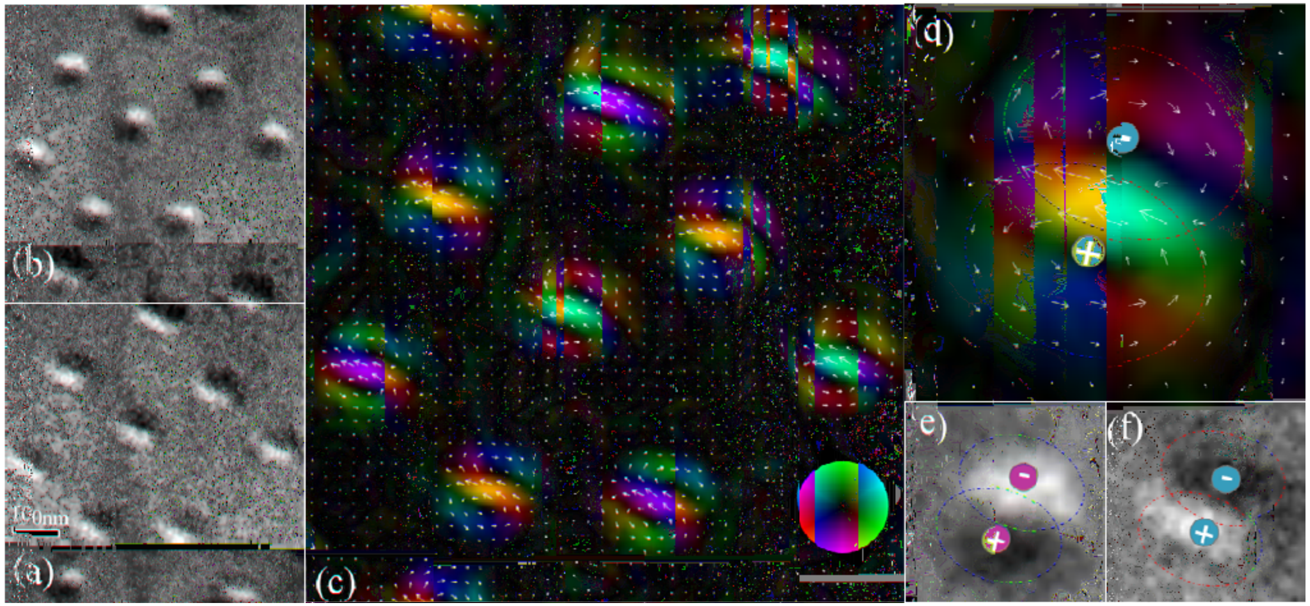
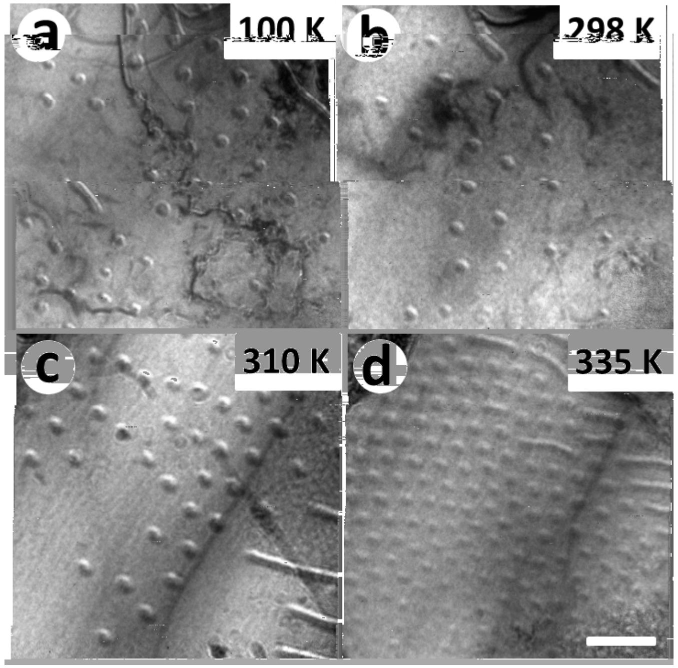
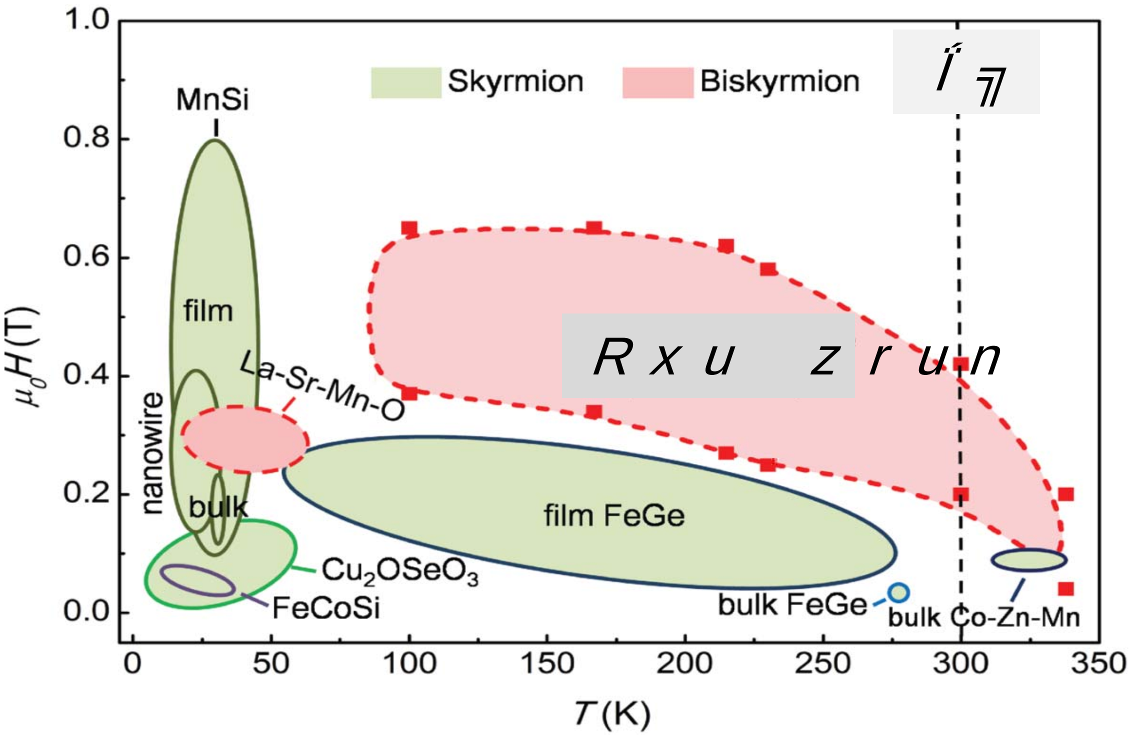

(a)
B⊥=0T
(b)
(c)
B⊥=0.22T
(d)



Biskyrmions ***DM*** ***skyrmions***





W.H.Wang , et al., Adv. Mater. 2016

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A Centrosymmetric Hexagonal Magnet with Superstable Biskyrmion Magnetic Nanodomains in a Wide Temperature Range of 100-340 K

Overview of attention for article published in Advanced Materials, May 2016

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Published in	Advanced Materials, May 2016
DOI	10.1002/adma.201600889

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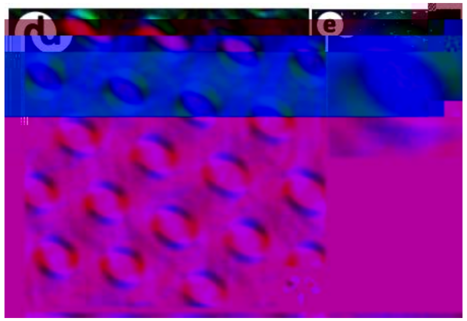
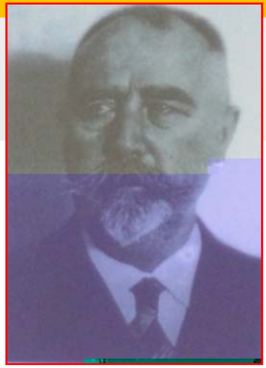


W.H.Wang and G.H.Wu et al. Advanced Materials 28, 6887 (2016)



F. Heusler

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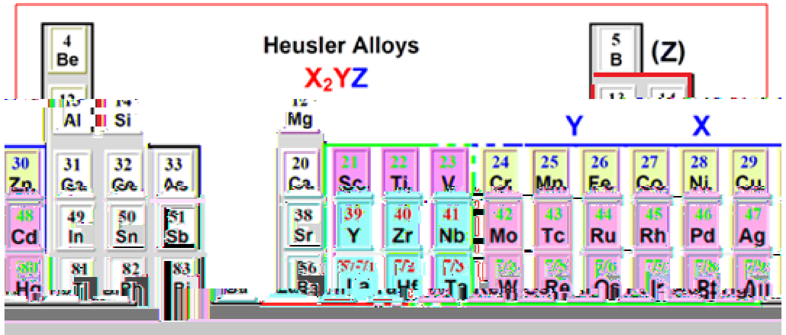

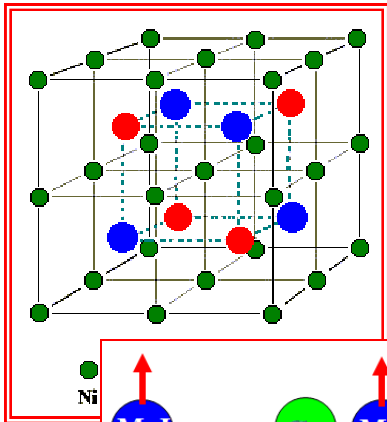

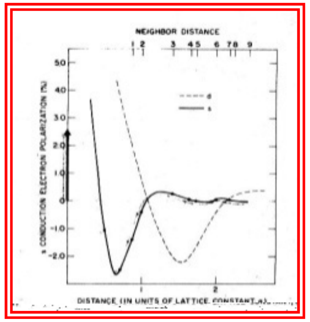

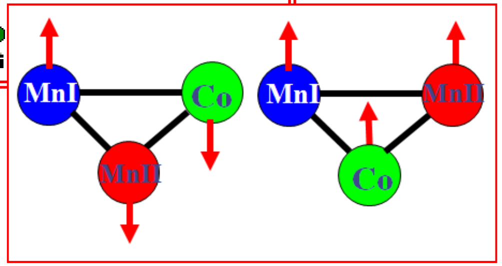

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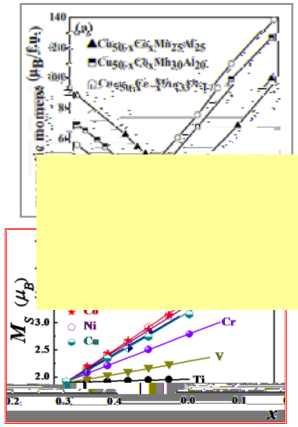

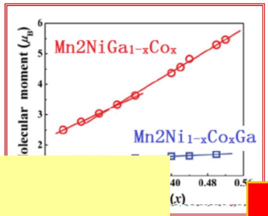

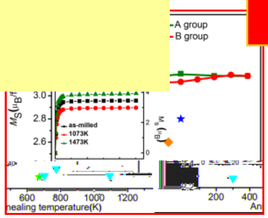

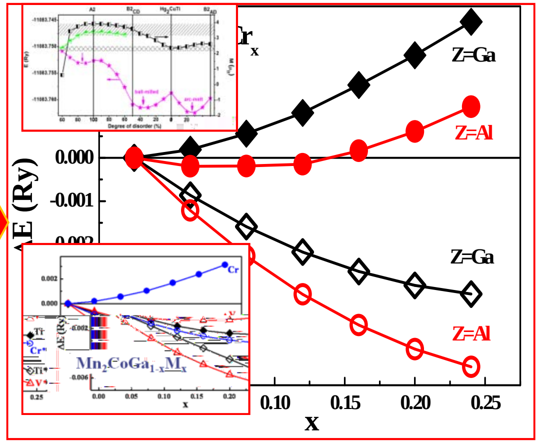

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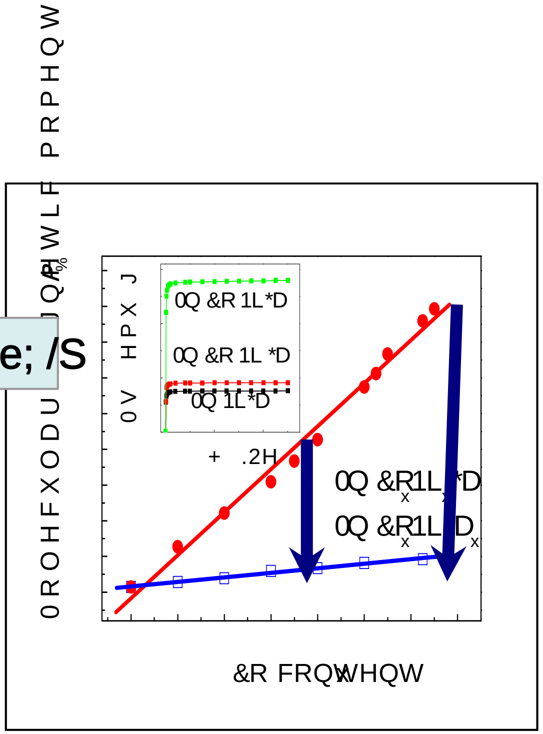

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