Tailoring anisotropy in (001) oriented $(Fe_{1-x}Cu_x)_{55}Pt_{45}$ films

Dustin Gilbert

D. A. Gilbert, et al., Appl. Phys. Lett. **102**, 132406 (2013)

Sign In View Cart Feedback Help

AIP Applied Physics Letters

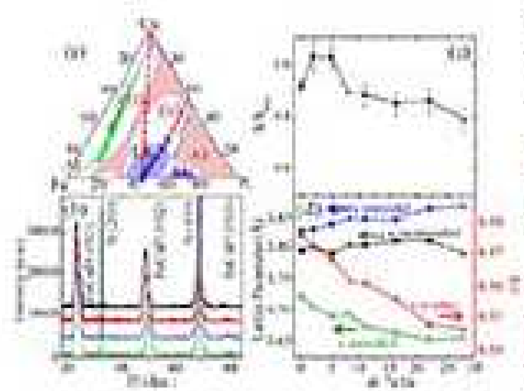
Volume/Page

Volume: Page/Article: GO

Home | Browse | About | Authors | Librarians | Features | Purchase Content | Advertisers | Scitation | AIP Journals

Research Highlights

Top Stories



Tuning magnetic anisotropy in (001) oriented L1$_0$ $(Fe_{1-x}Cu_x)_{55}Pt_{45}$ films

Dustin A. Gilbert, Liang-Wei Wang, Timothy J. Klemmer, Jan-Ulrich Thiele, Chih-Huang Lai, and Kai Liu

The authors have achieved (001) oriented L10 $(Fe_{1-x}Cu_x)_{55}Pt_{45}$ thin films, with magnetic anisotropy up to 3.6 × 10^7 erg/cm^3, using atomic-scale multilayer sputtering and post annealing at 400 °C for 10 s. By fixing the Pt concentration, structure and magnetic properties are systematically tuned by the Cu addition.

Appl. Phys. Lett. 102, 132406 (2013) | HTML | PDF

http://apl.aip.org/research_highlights_archive

Kai Liu

Liang-Wei Wang

Chih-Huang Lai

UC DAVIS

國立清華大學
National Tsing Hua University

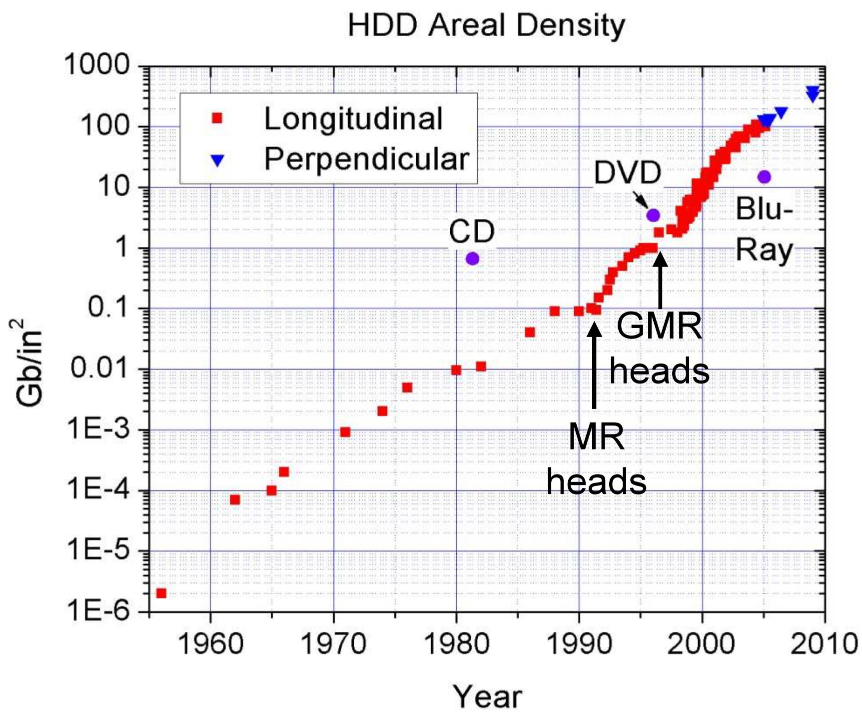
Timothy Klemmer

Jan-Ulrich Thiele

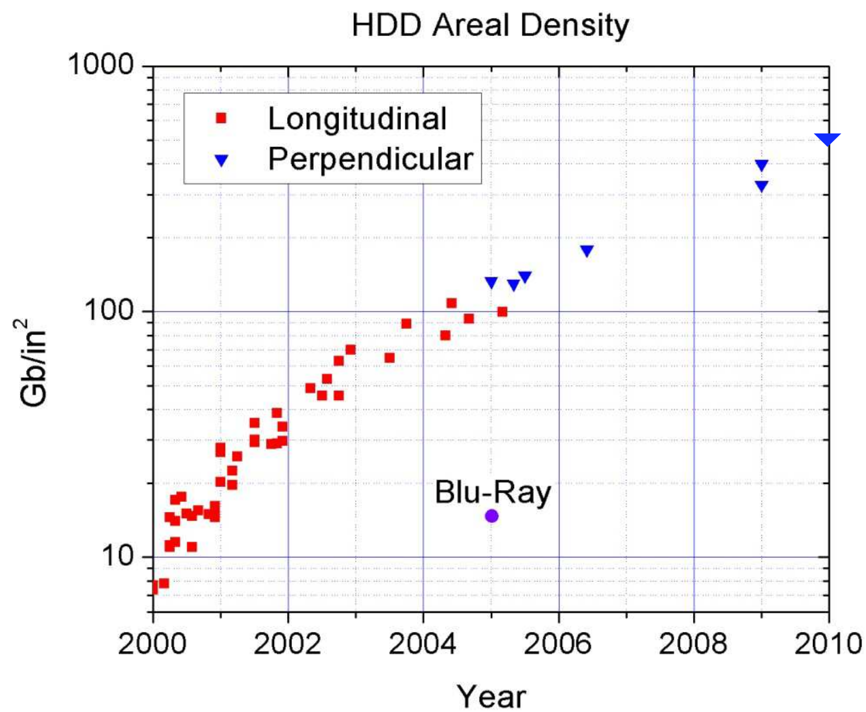
Seagate

Introduction

Historical areal density growth of HDDs



9 Orders of Magnitude



IBM RAMAC (1956)

2Mbyte

70 kbit/in^2

$100k/year

(~$50k/MB per year)

Seagate Barracuda 2TB HDD

500 Gbit/in^2

$129.99 & Free Shipping @Newegg.com

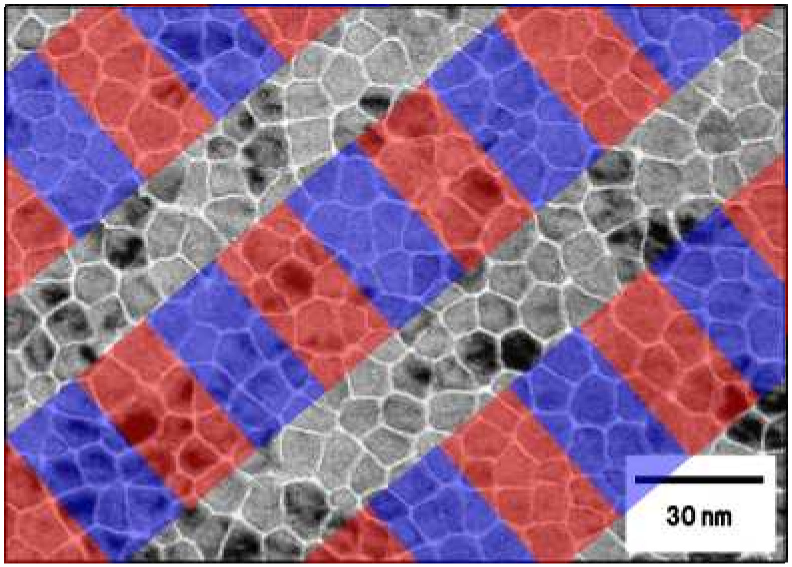
6.5¢/GB!

(~$0.00013/MB per year)

8 Orders of Magnitude

Seagate

Motivation



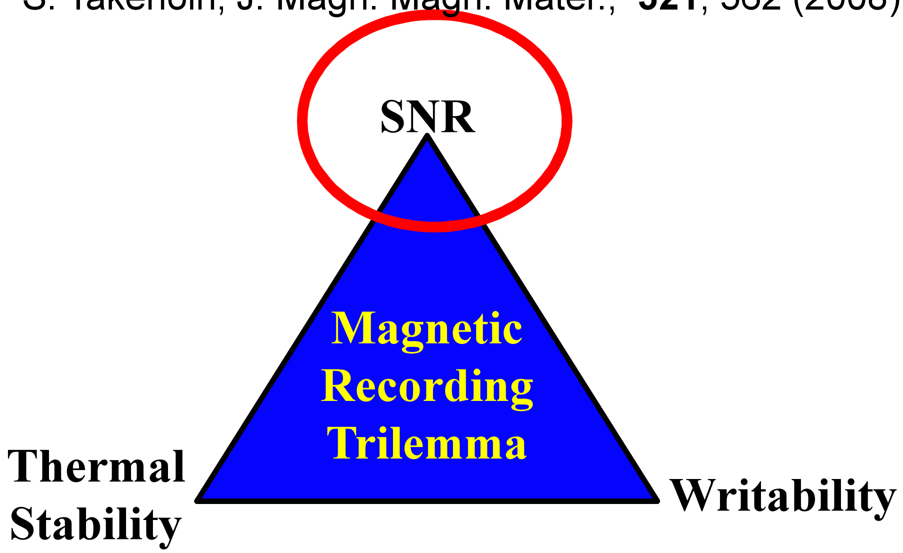
S. Takenoiri, J. Magn. Magn. Mater., **321**, 562 (2008).

Magnetic recording technologies write to a collection of grains

Higher density → fewer grains

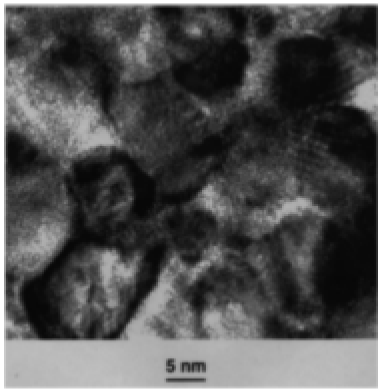
Poor edge definition ('jitter') →Poor SNR

Restore SNR by decreasing grain size



J. F. Hu, J. S. Chen and G. Ju, edited by S. N. Piramanayagam and T. C. Chong *Developments in Data Storage*
D. Weller and T. McDaniel, *Advanced Magnetic Nanostructures*

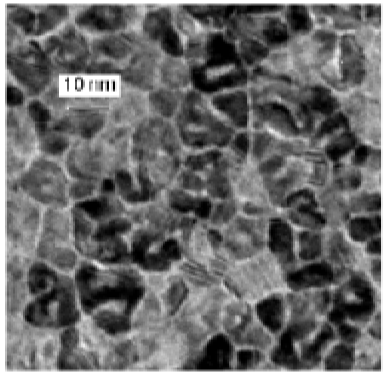
Grain Size Scaling in Recording Media



10 Gbit/in^2
product media

12 nm grains
$\sigma_{area} \cong 0.9$

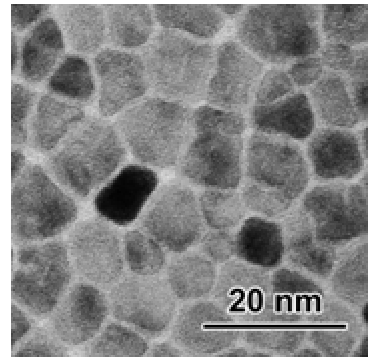
J. Li, *et al.*,
J. Appl. Phys. **85**, 4286 (1999)



35 Gb/in^2
prototype media

8.5 nm grains
$\sigma_{area} \cong 0.6$

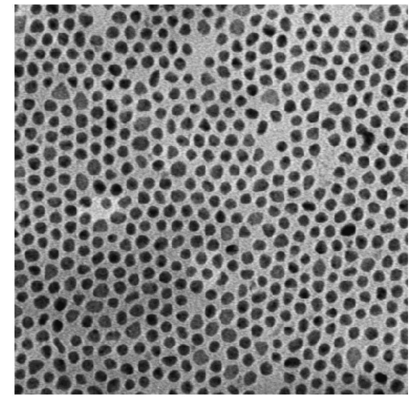
M. Doerner *et al.*,
IEEE Trans. Magn. **37**, 1052 (2001).



650 Gb/in^2
product media

8.5 nm grains
$\sigma_{area} \cong 0.15$

(2012)



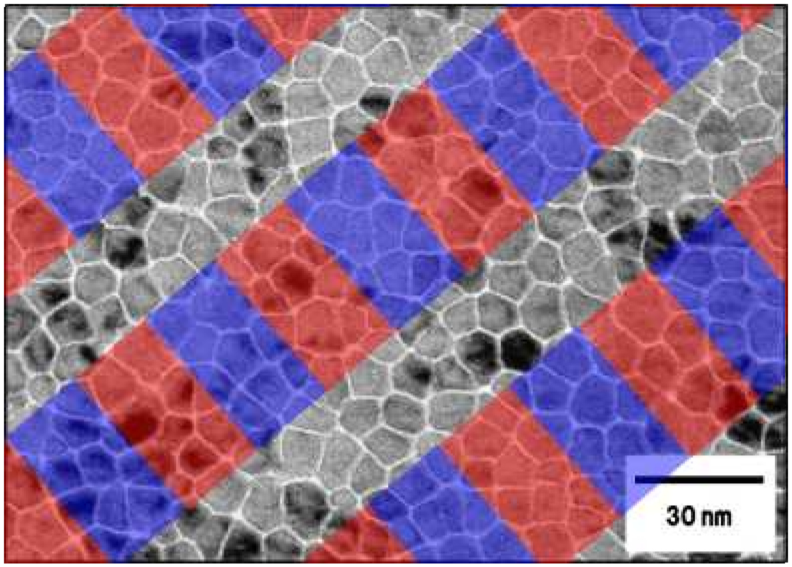
Nanoparticle arrays

4 nm particles
$\sigma_{area} \cong 0.05$

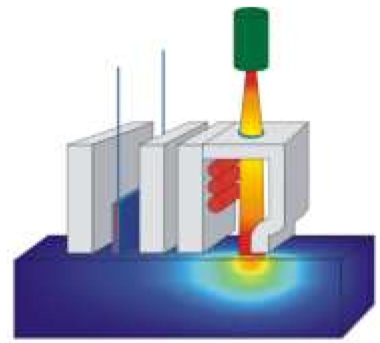
S. Sun *et al.*,
Science **287**, 1989 (2000).

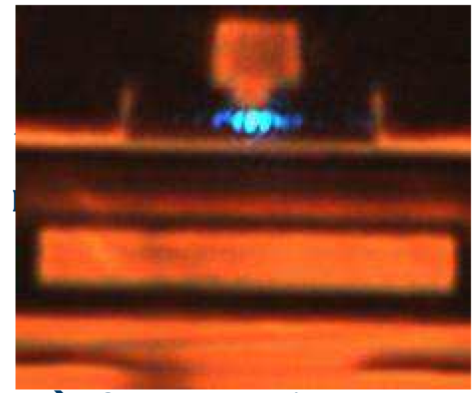
Smaller grains addresses SNR, but reduced thermal stability

Motivation



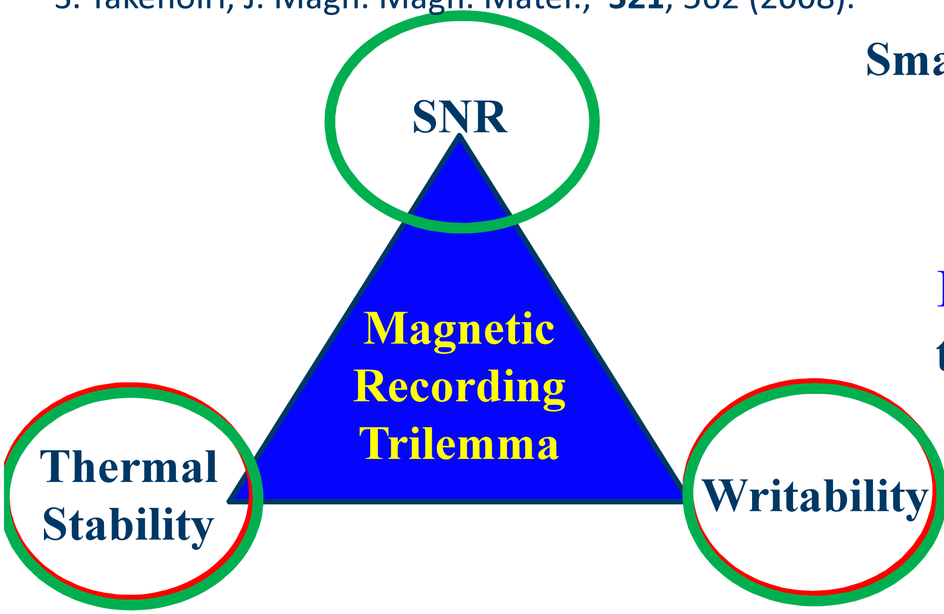
S. Takenoiri, J. Magn. Magn. Mater., **321**, 562 (2008).





Higher density → fewer grains

Poor edge definition ('jitter') →Poor SNR



Smaller grains addresses SNR, but reduced thermal stability $\sim e^{-\frac{K_U V}{K_B T}}$

High anisotropy (K_U) material addresses thermal stability, but reduces writability

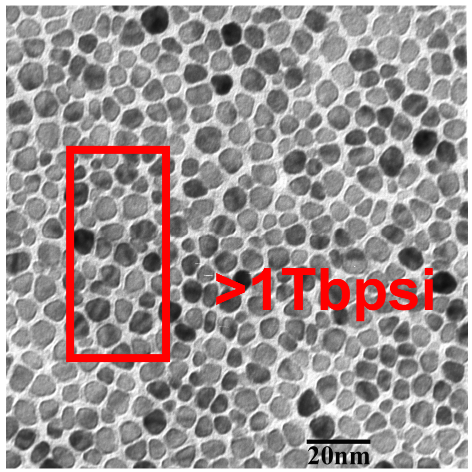
Energy Assisted Recording (e.g. HAMR, MAMR) can address writability

J. F. Hu, J. S. Chen and G. Ju, edited by S. N. Piramanayagam and T. C. Chong *Developments in Data Storage*
D. Weller and T. McDaniel, *Advanced Magnetic Nanostructures*

Heat-Assisted Magnetic Recording (HAMR)

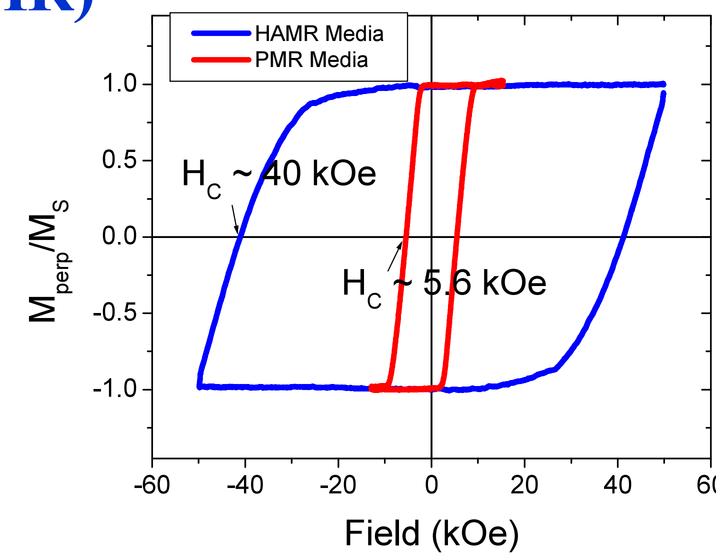
Increase Areal Density

increase density by smaller grains

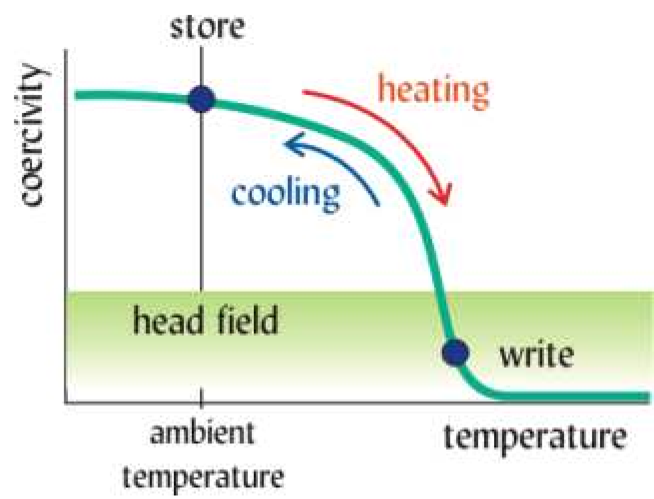


make smaller grain stable by increasing anisotropy

HAMR vs PMR Media Loops

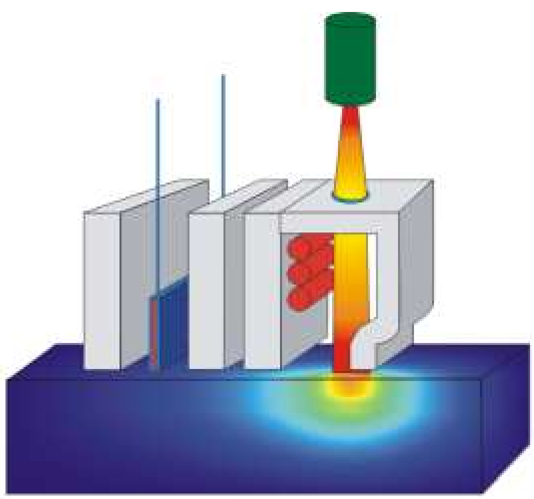


heat media to write



need localized heat source (<50nm)

integrated head with near field transducer



Seagate HAMR 1TB Announcement

60TB HDDs possible with next-generation storage tech -Seagate.

1007 Gbpsi (1975 kbpi x 510 ktpi)

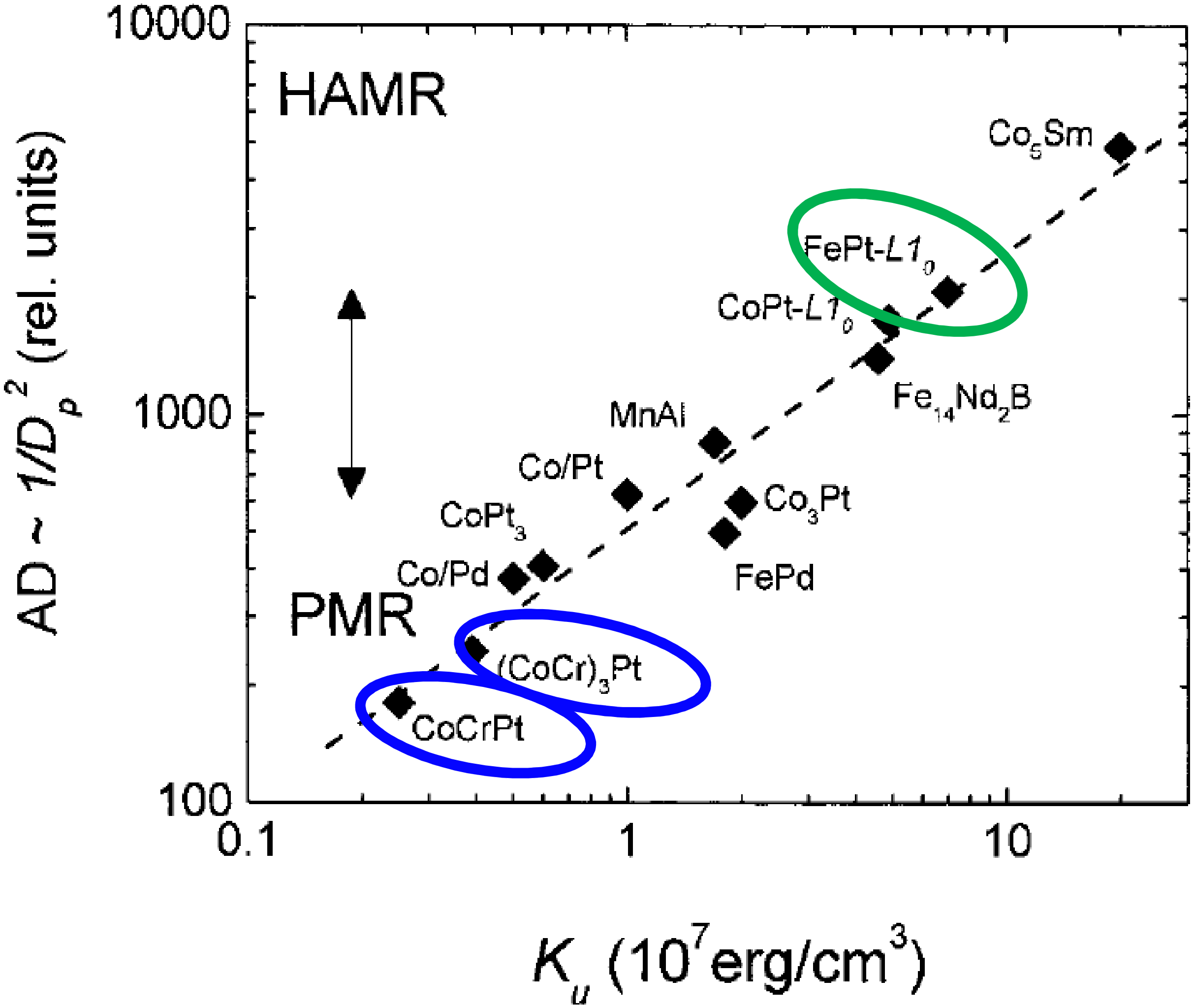
By: Zam | Mar 25, 2012 | In: News | Likes: 0 | Views:114

It's increasingly rare for mechanical drives to make headlines, but Seagate is beating the PR drum over an advancement that promises to drastically increase the capacity of hard drives. The company has achieved a storage density of 1 terabit per square inch, about 55% more than today's 620 gigabits per square inch. More abstractly, Seagate says that's more bits per square inch than our Milky Way galaxy has stars, which astronomers estimate between 200 and 400 billion.

At 620Gb per square inch, current 3.5-inch HDDs peak at 3TB in capacity, while 2.5-inch drives max out at 750GB. The new tech will roughly double that to 6TB and 2TB when it arrives "later this decade" and it will lead to astronomical capacities of up to 60TB over the following 10 years. Seagate hit the milestone by using heat-assisted magnetic recording (HAMR), which the company hails as a next-generation successor to 2006'sperpendicular magnetic recording (PMR).

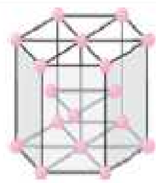
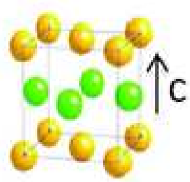
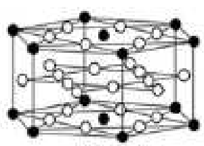
IEEE Trans. Magn. **49**, 686 (2013); **49**, 779 (2013);

WD Demonstrated HAMR Nov. 13 2013 at Ningbo Forum on Advanced Materials



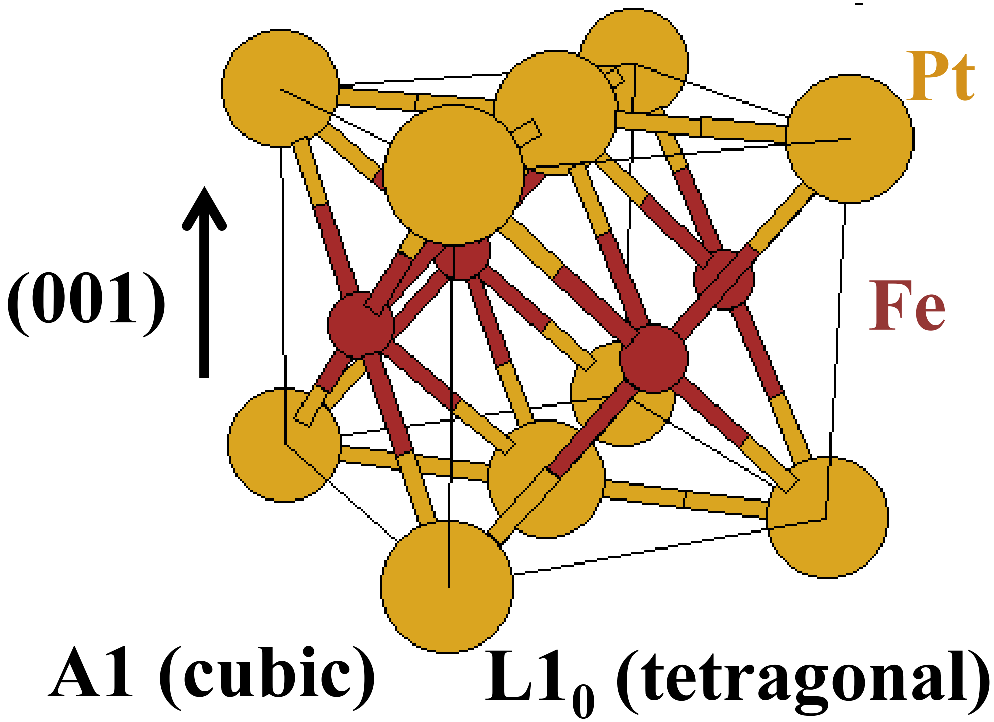
D. Weller and T. McDaniel, Ch11, *Advanced Magnetic Nanostructures*. (Sellmyer, Skomski, Eds, Springer, New York, NY, 2006)

High K Media Material Options

	alloy system	material	K_u (10^7 erg/cm^3)	M_S (emu/cm^3)	$T = 350$ K: H_K (kOe)	T_C (K)	δ=10 nm: D_p (a) (nm)	D_p (b) (nm)	D_p (c) (nm)	δ/<D> =2: D_p (d) (nm)
	Co-alloys	$CoCr_8Pt_{22}$	0.7	500	28.0	1000[a]	7.3	7.5	8.7	6.4
		Co_3Pt	2	1100	36.4	1200	4.3	5.3	6.1	4.5
		$CoPt_3$	0.5	300	33.3	600	8.6	8.3	9.7	7.2
	CoX/Pt(Pd) multilayers	Co_3/Pt_{10}	1.2	450	53.3	~700[b]	5.5	6.2	7.2	5.4
		Co_3/Pd_{10}	0.6	360	33.3	~700[b]	7.8	7.8	9.1	6.8
	ordered $L1_0/L1_1$ phases	FePd	1.8	1100	32.7	760	4.5	5.4	6.3	4.7
		FePt	7	1140	122.8	750	2.3	3.5	4.0	3.0
		CoPt	4.9	800	122.5	840	2.7	3.9	4.5	3.4
		MnAl	1.7	560	60.7	650	4.7	5.5	6.4	4.8
 $SmCo_5$	rare-earth transition metals	$Fe_{14}Nd_2B$	4.6	1270	72.4	585	2.8	4.0	4.6	3.4
		$SmCo_5$	20	910	439.6	1000	1.4	2.4	2.8	2.1

D_p: average thermally stable grain diameter

D.Weller, O. Mosendz, G. Parker, S. Pisana, T. S. Santos, Phys. Status Solidi A 210, 1245 (2013).



K_U: 5x10^7 erg/cm^3

M_S : 1150 emu/cm^3

T_C : 750 K

Chemically Stable, No Rare Earth Elements

High dH_K/dT

Very high temperature (up to 600° C) necessary for *L1$_0$* Transformation

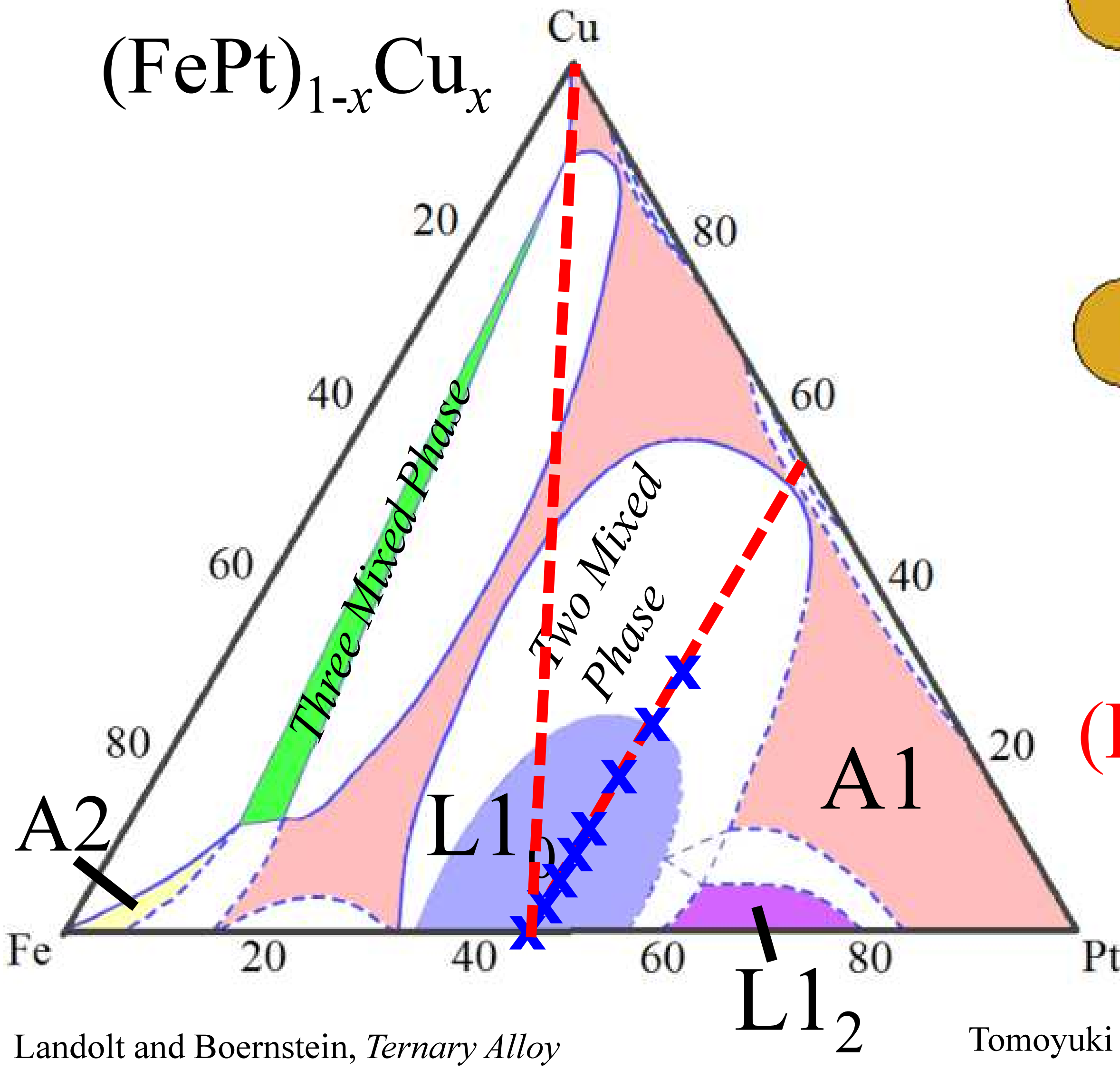
Desirable (001) Orientation

G. Meyer and J.-U. Thiele, Phys. Rev. B **73**, 214438 (2006).
J. U. Thiele, K. R. Coffey, M. F. Toney, J. A. Hedstrom and A. J. Kellock, J. Appl. Phys. **91**, 6595 (2002)

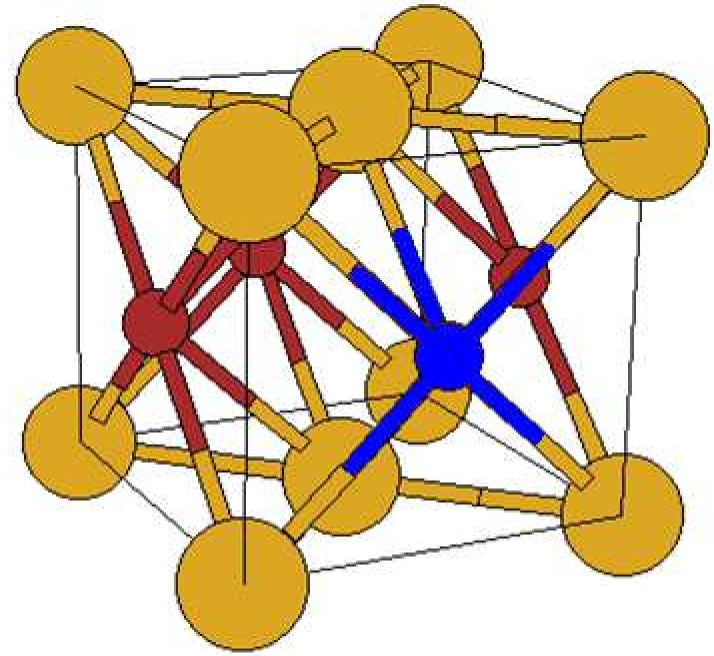
Forming ternary alloys to improve ordering

FePtCu

$(FePt)_{1-x}Cu_x$



$(Fe_{1-x}Cu_x)_{55}Pt_{45}$



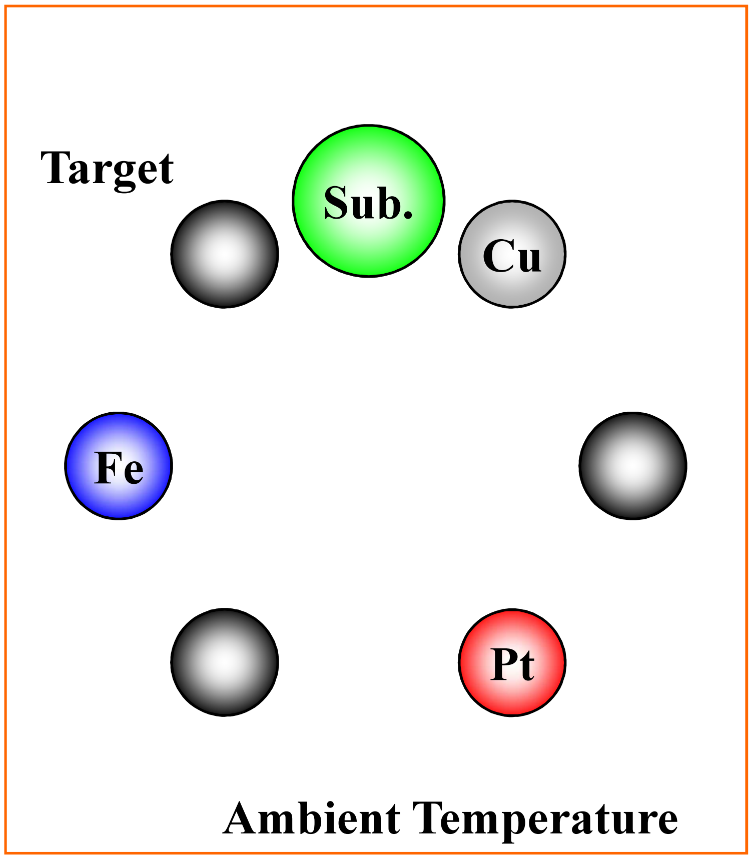
http://cst-www.nrl.navy.mil/lattice/index.html

Landolt and Boernstein, *Ternary Alloy Systems*. (Springer-Verlag Berlin, 2008)

Tomoyuki Maeda *et al.*, Appl. Phys. Lett. **80**, 2147 (2002)
B. Wang and K. Barmak, J. Appl. Phys. **109**, 123916 (2011)

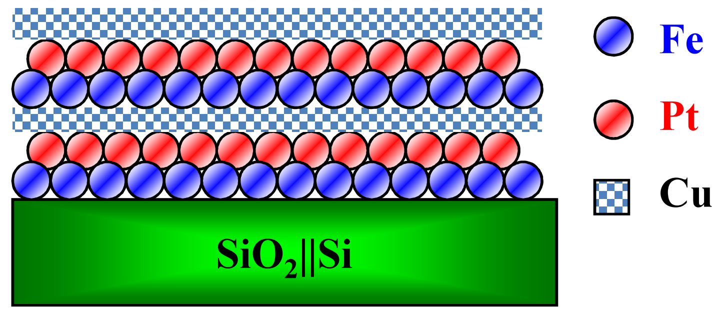
Synthesis

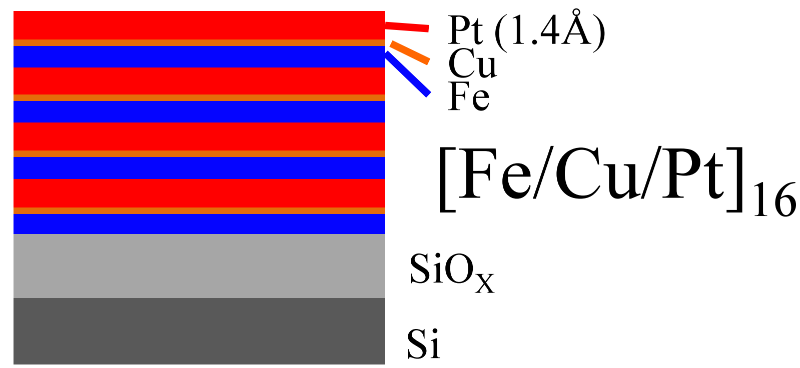
Atomic-scale Multilayer Sputtering



6 guns sputtering system

Atomic-scale $[Fe/Pt/Cu]_{16}$ MLs





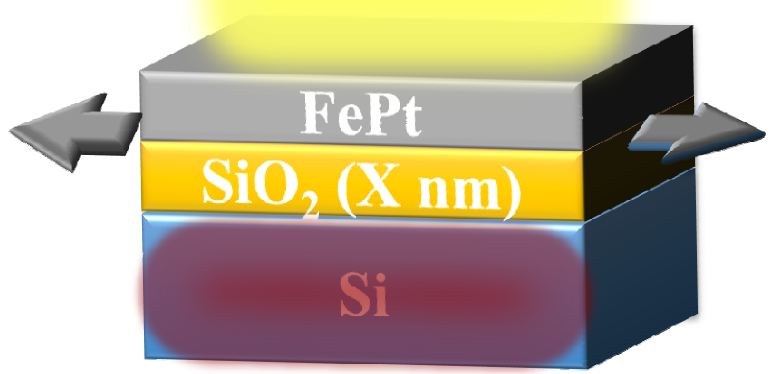
RTA (400° C), 10 Sec in vacuum

Y.-C. Wu, et al., Appl. Phys. Lett. **91**, 072502 (2007)

Generation of Tensile Stress by RTA

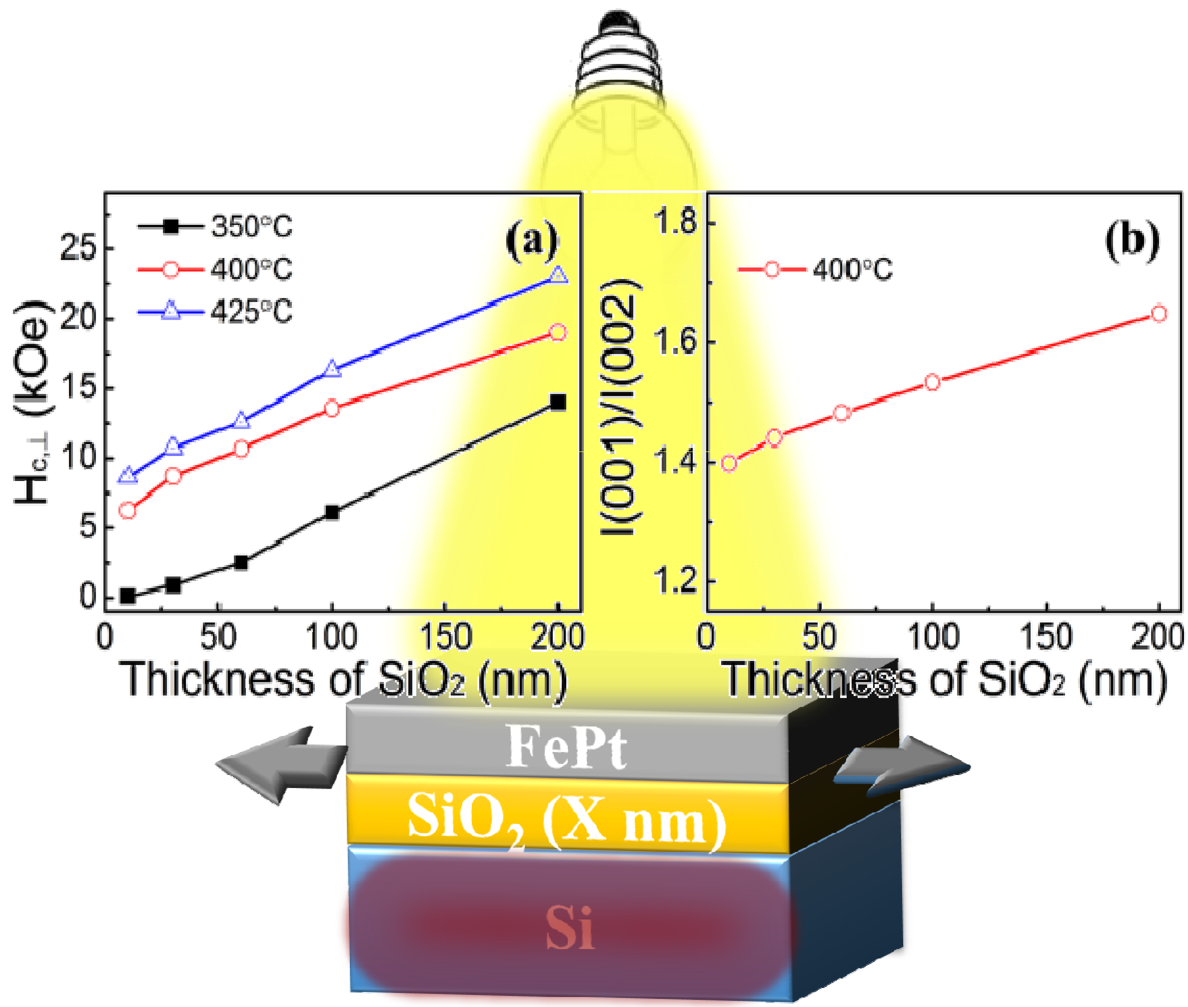
IR Light shines on sample

- **Si is heated (in few ps)**
- **Heat transfer to FePt (~ few ns)**



L. W. Wang, et al., APL 101, 252403 (2012)

Generation of Tensile Stress by RTA

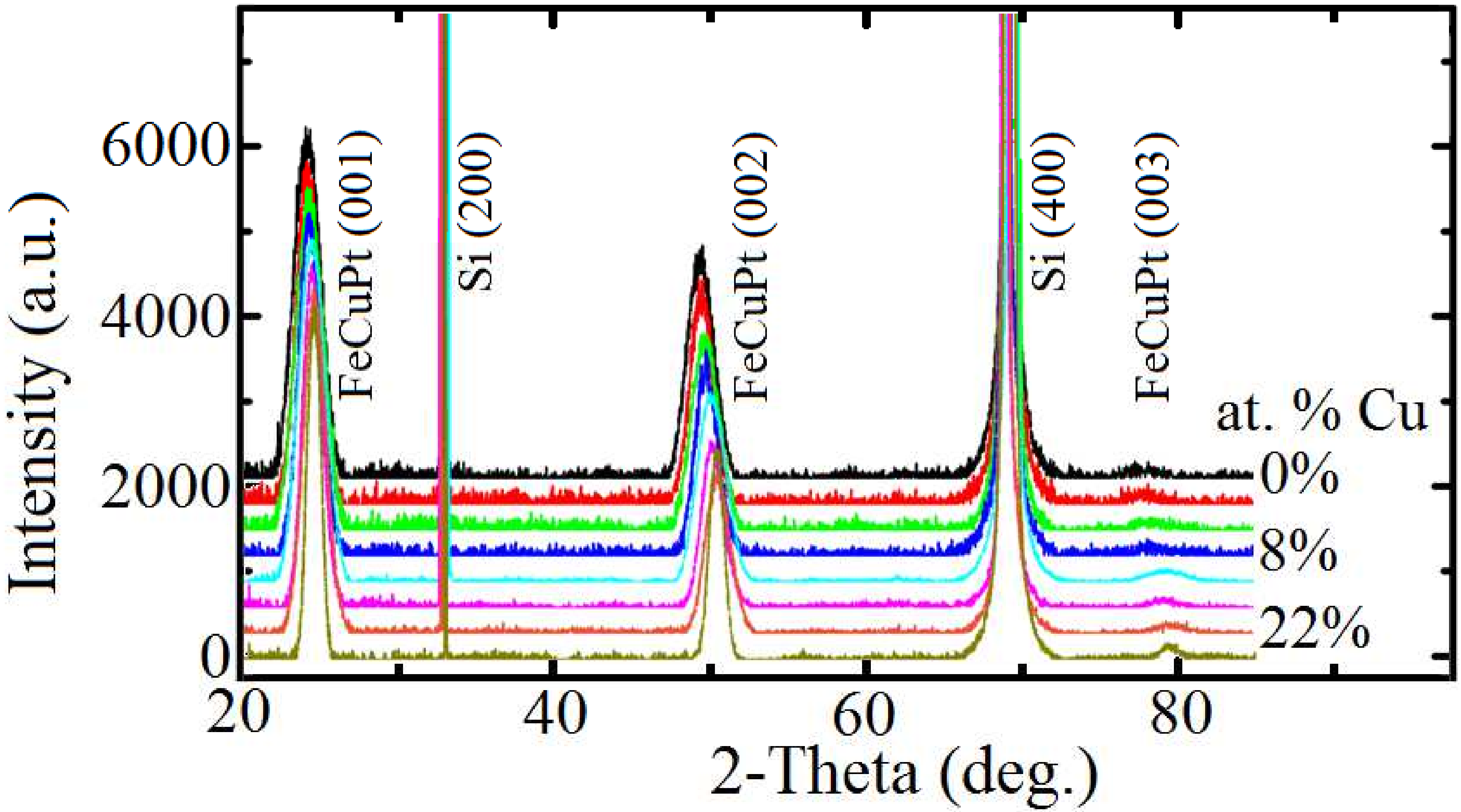


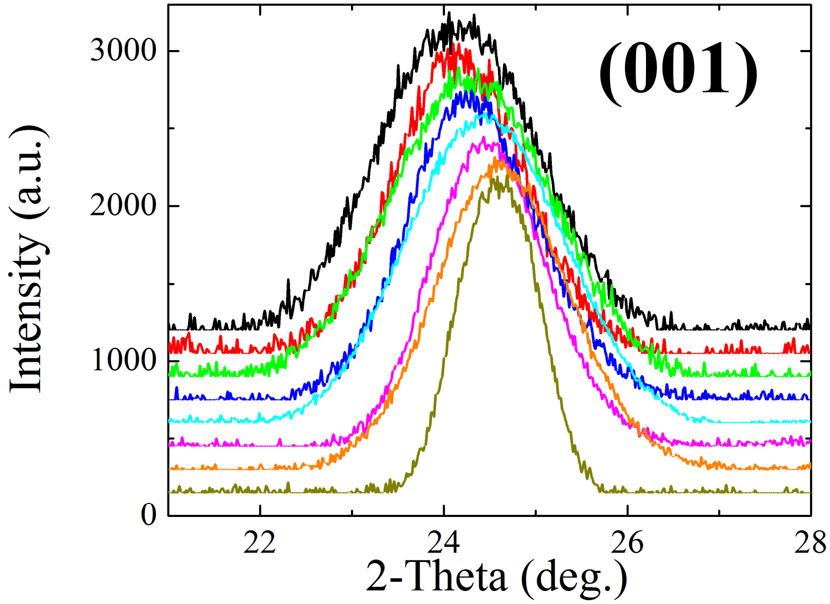
L. W. Wang, et al., APL 101, 252403 (2012)

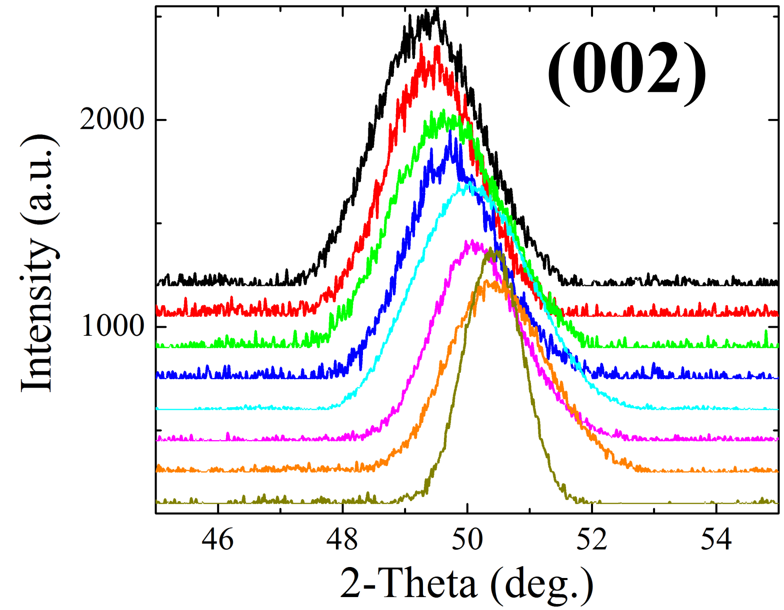
Structure Characterization

X-ray Diffraction

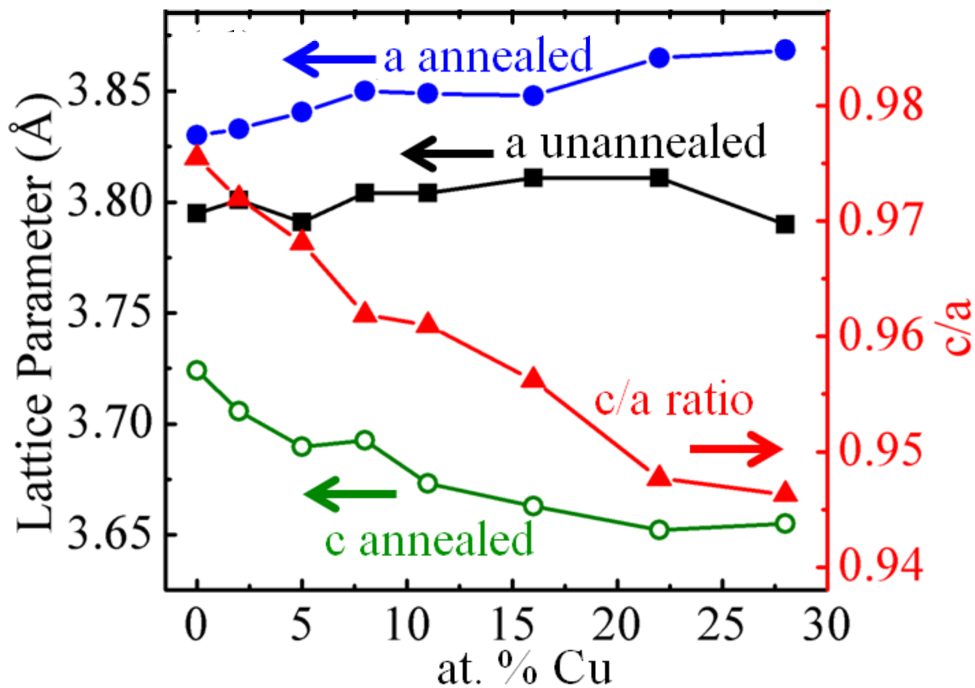
(001) Ordered tetragonal

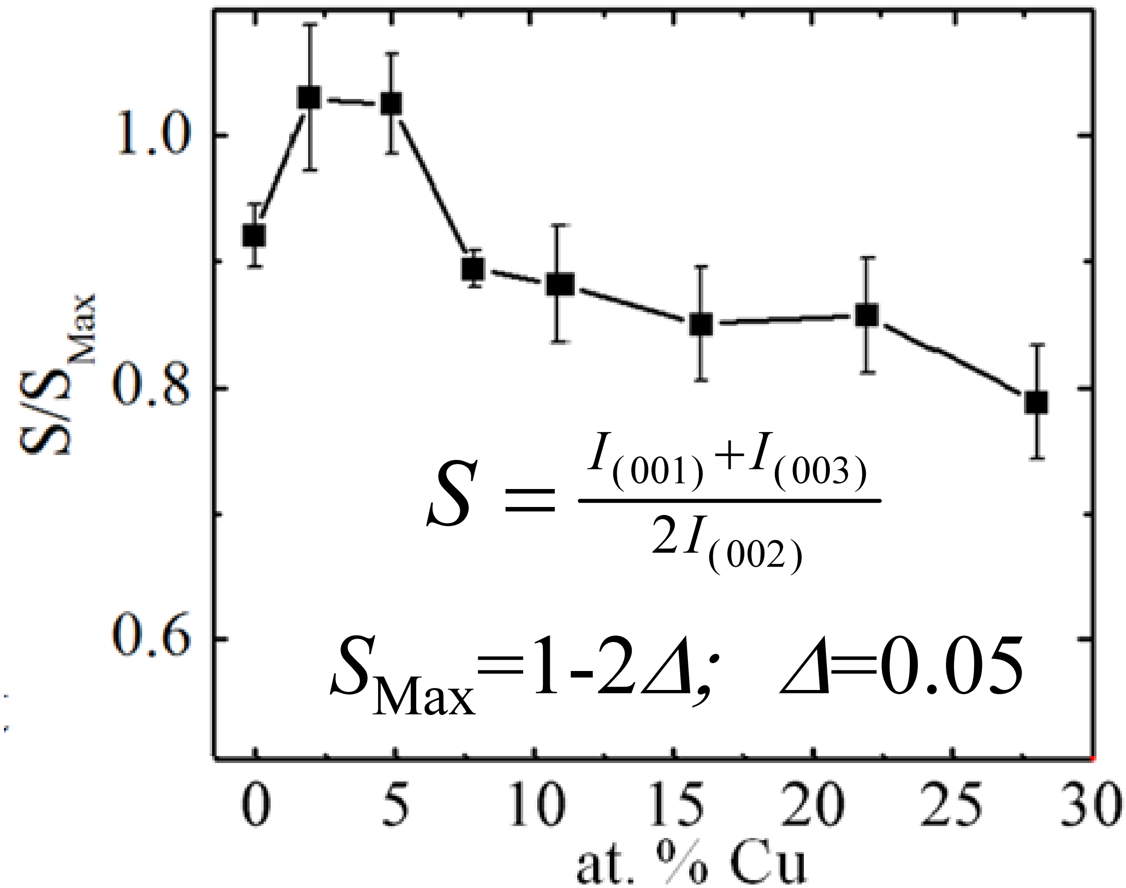



(001)
Intensity (a.u.)
2-Theta (deg.)
0
1000
2000
3000
22
24
26
28


(002)
Intensity (a.u.)
2-Theta (deg.)
1000
2000
46
48
50
52
54

Ψ=54.7 ° for (111)


a annealed
a unannealed
c/a ratio
c annealed
Lattice Parameter (Å)
c/a
at. % Cu
3.65
3.70
3.75
3.80
3.85
0.94
0.95
0.96
0.97
0.98
0
5
10
15
20
25
30



Highly Ordered $L1_0$

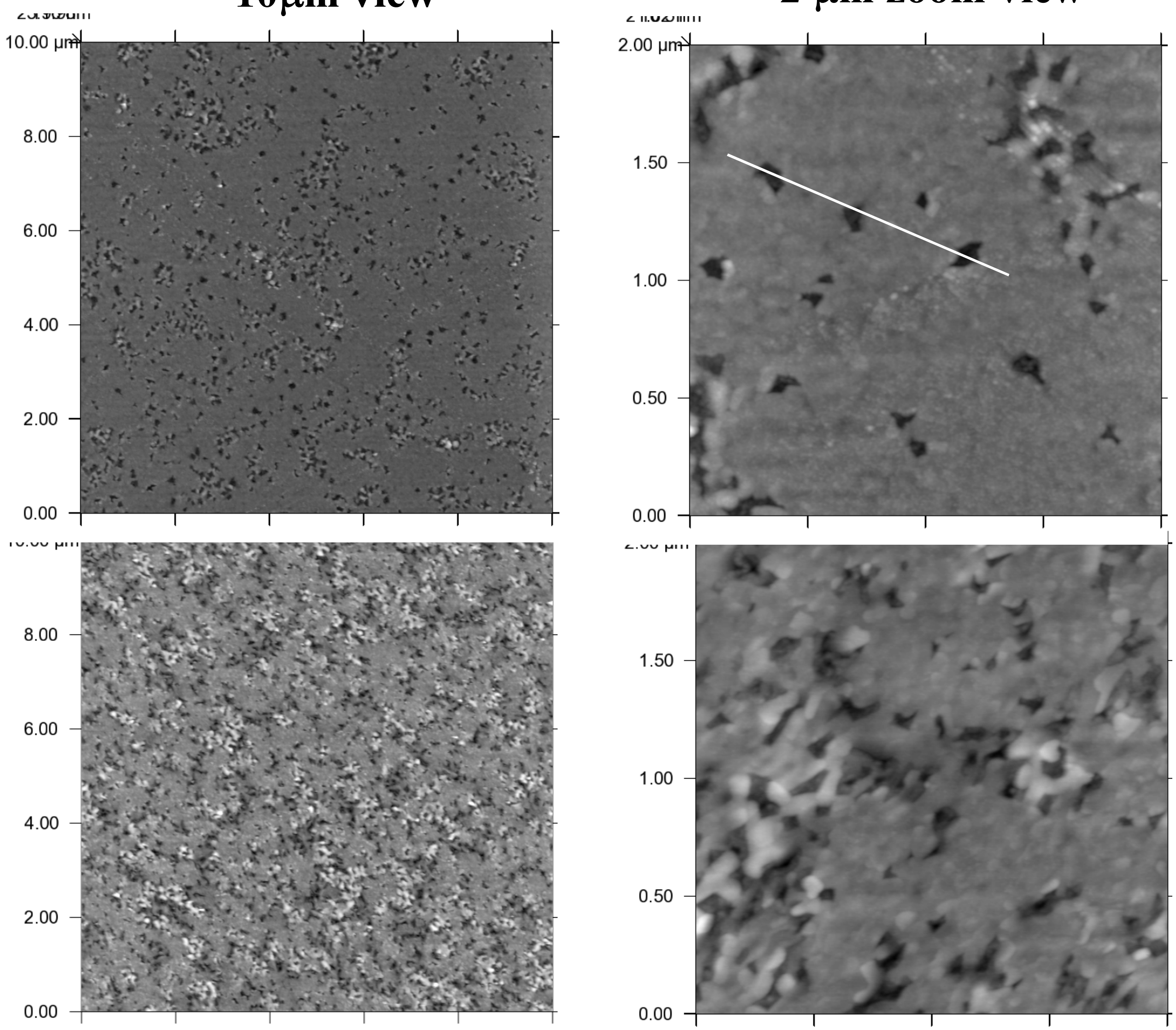
Alternative Characterization with Magnetics?

K. Barmak, J. Kim, L. H. Lewis, K. R. Coffey, M. F. Toney, A. J. Kellock and J. U. Thiele, J. Appl. Phys. **98**, 033904 (2005).

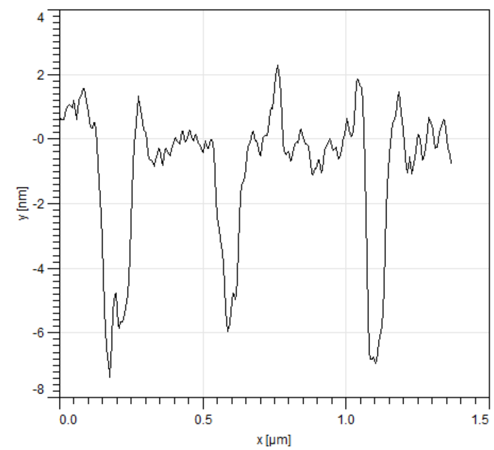
Topography and Magnetic Domains

AFM – Structural

10μm view **2 μm zoom view**



at. 0 % Cu

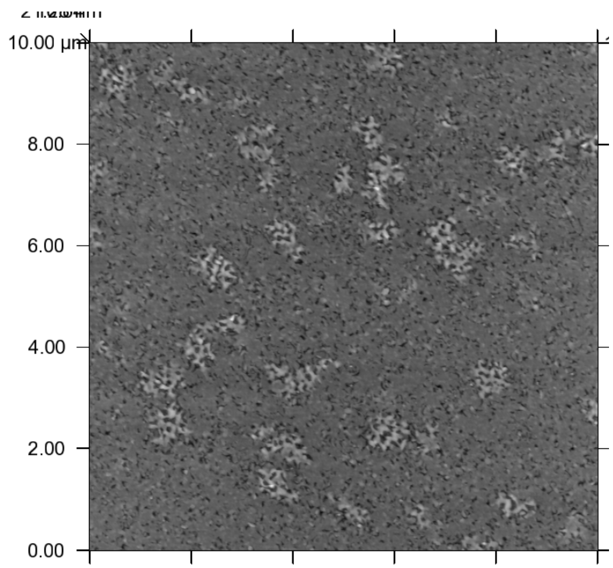


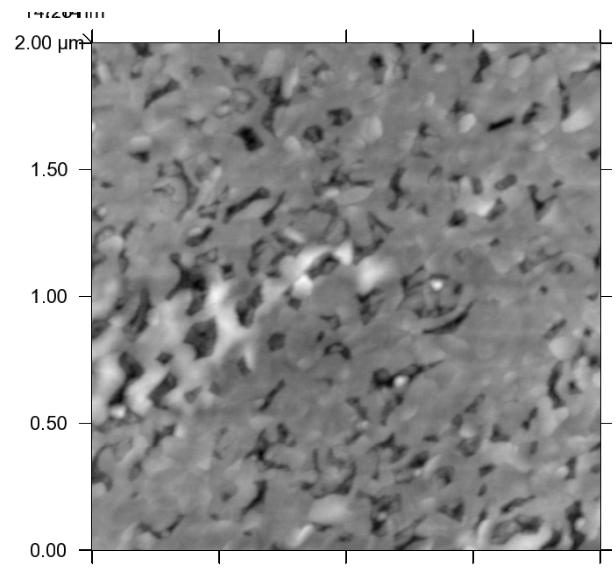
at. 8 % Cu

Y.-C. Wu, L.-W. Wang and C.-H. Lai, Appl. Phys. Lett. **93**, 242501 (2008).
Y.-C. Wu, L.-W. Wang, M. T. Rahman and C.-H. Lai, J. Appl. Phys. **103**, 07E126 (2008).

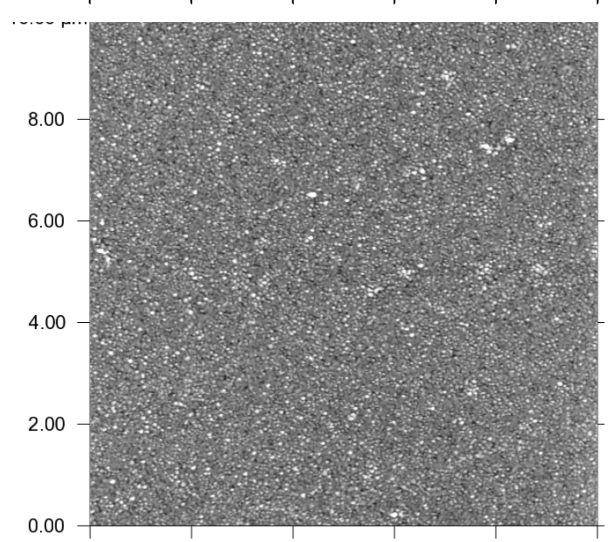
AFM – Structural (Cont'd)

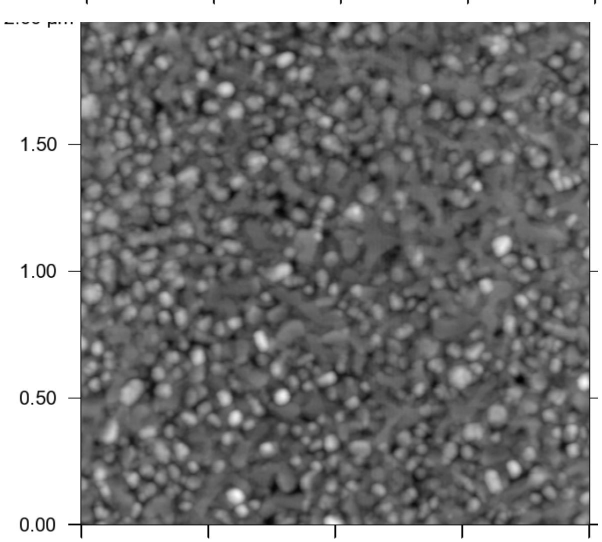
10µm view | **2 µm zoom view**



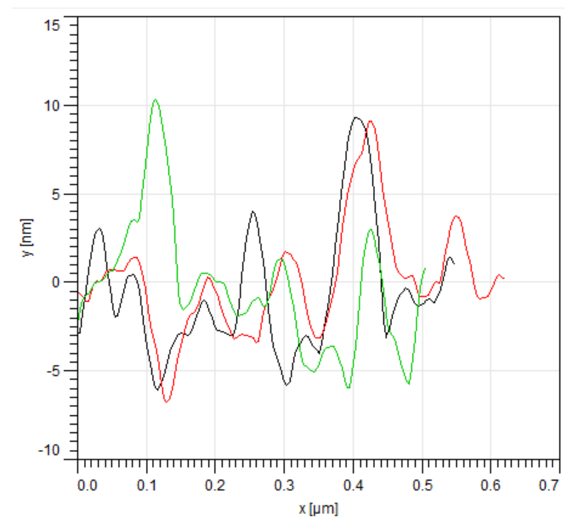


at. 16 % Cu



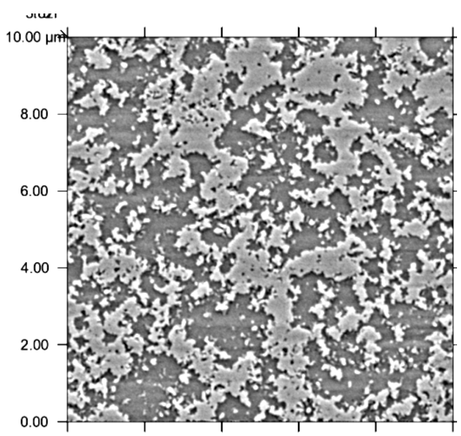


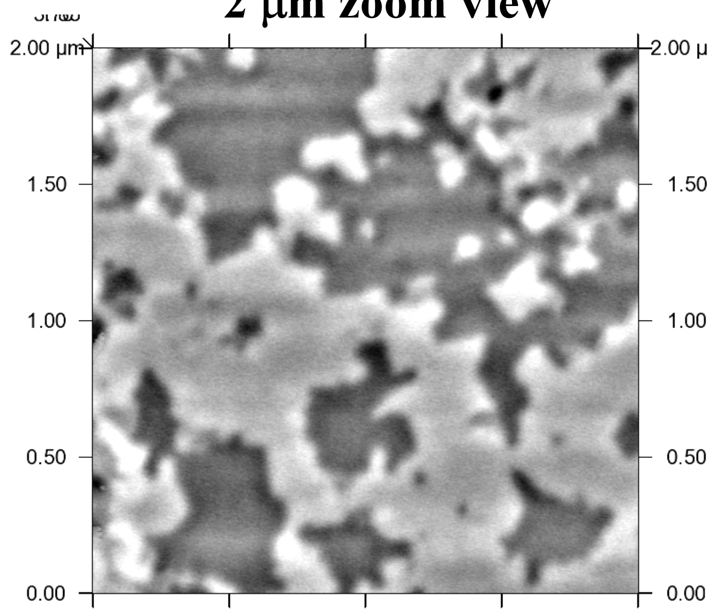
at. 27 % Cu

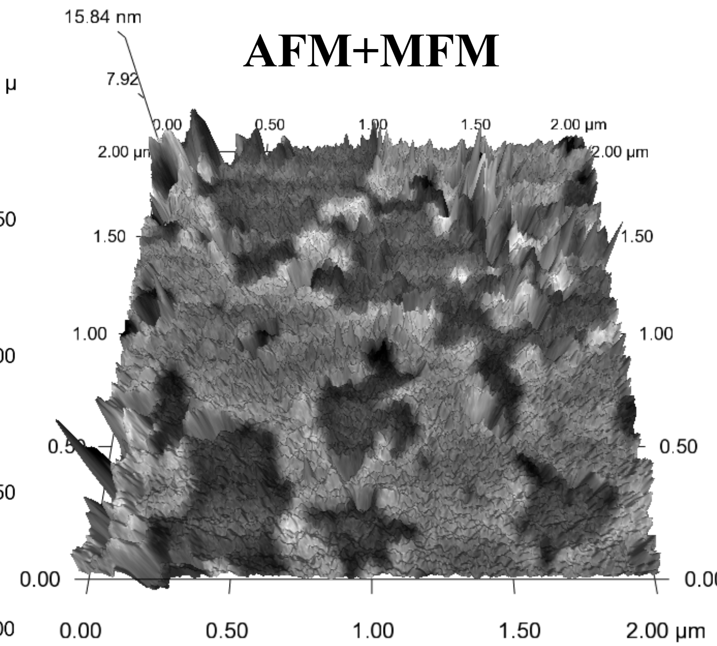


MFM-Magnetic

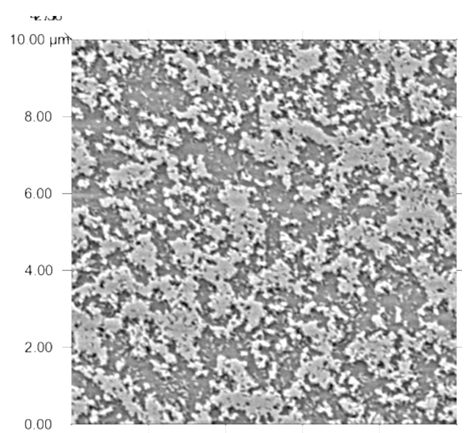
10µm view | **2 µm zoom view** | **AFM+MFM**

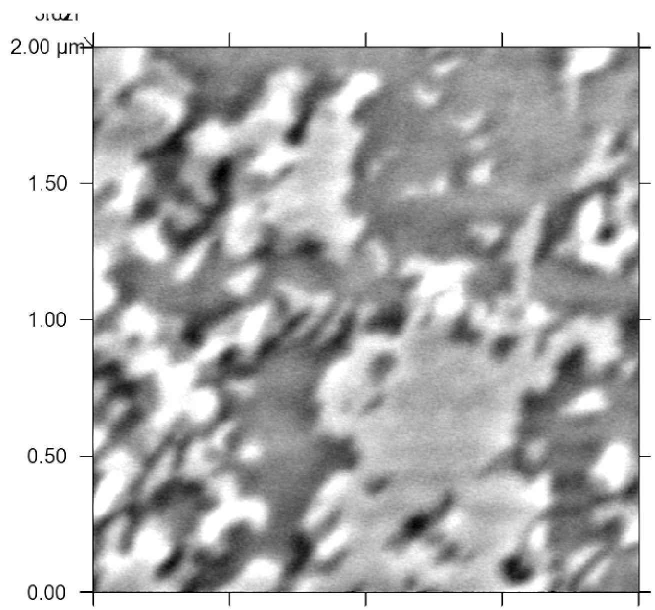


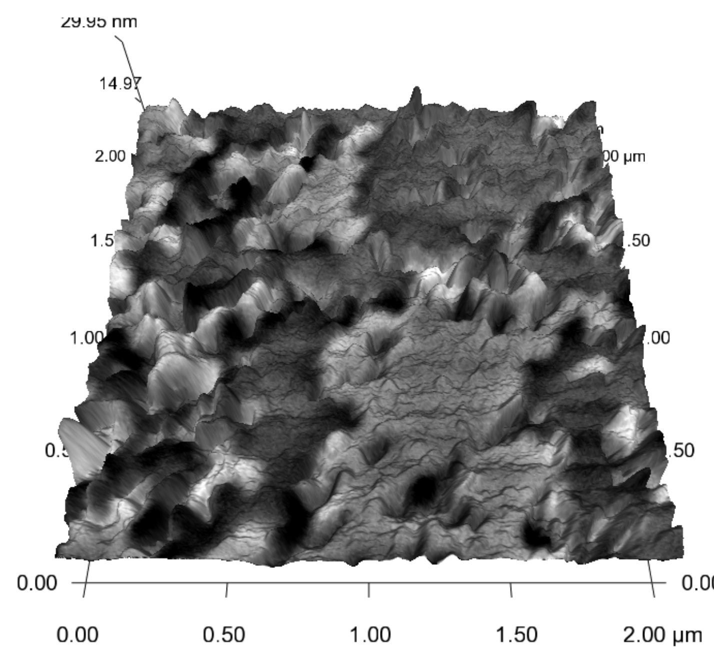




at. 0 % Cu



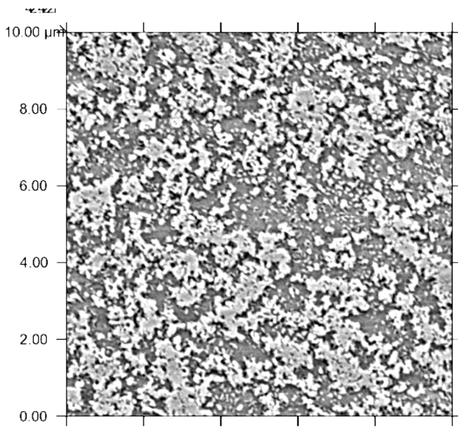




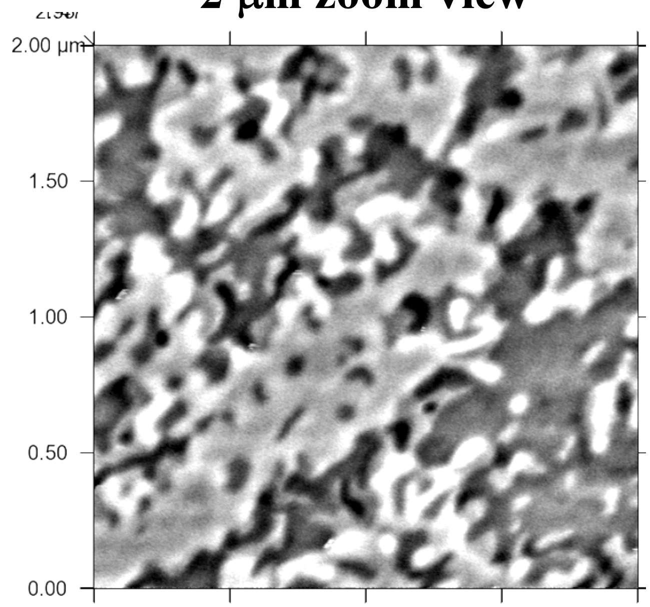
at. 8 % Cu

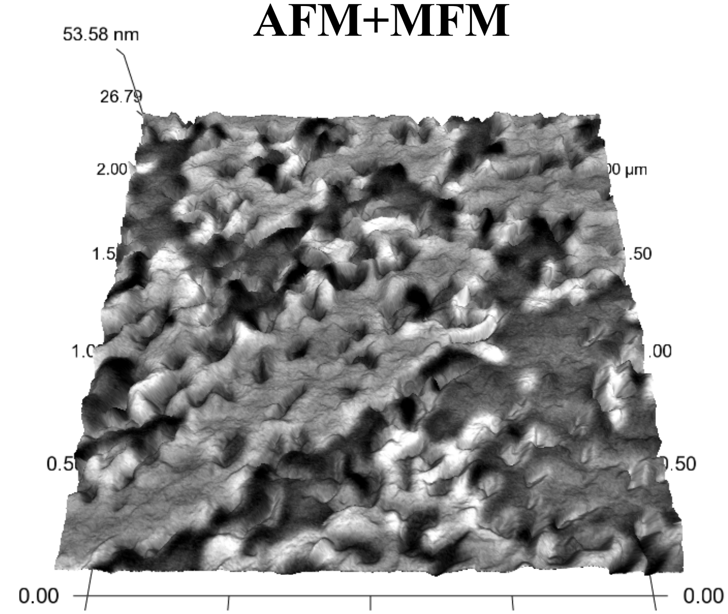
MFM-Magnetic (cont'd)

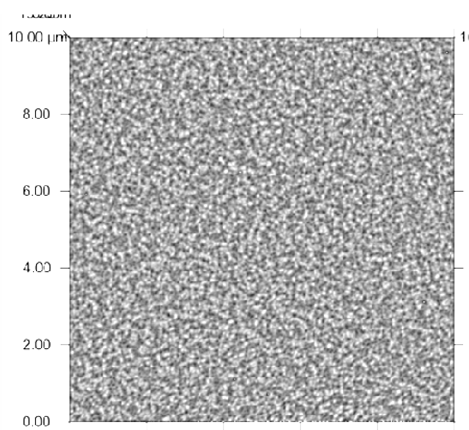
10μm view | **2 μm zoom view** | **AFM+MFM**



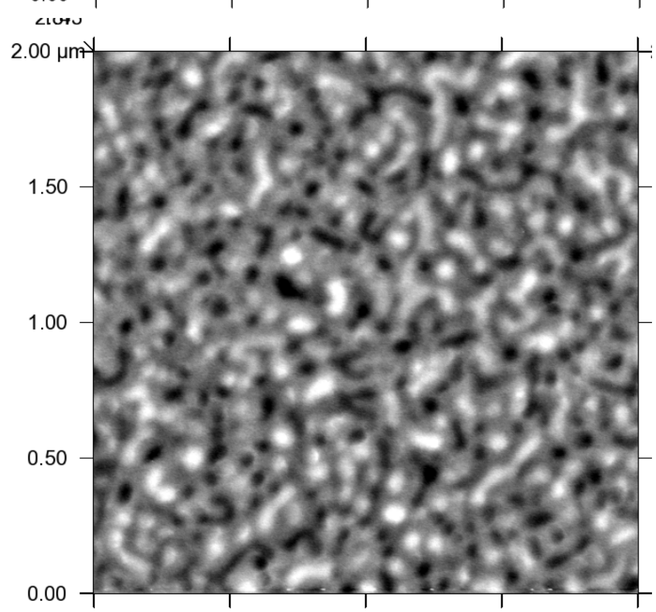
at. 16 % Cu

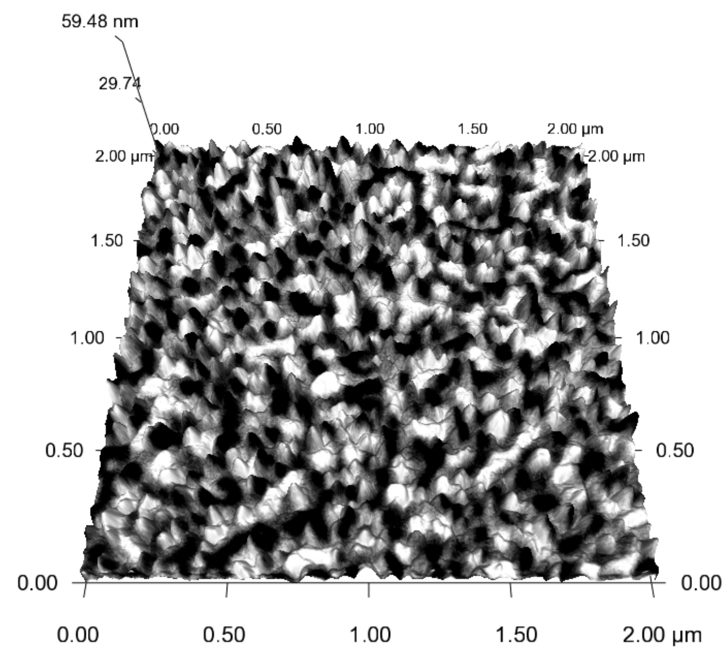






at. 27 % Cu





Magnetometry

Phase Transformation with Annealing

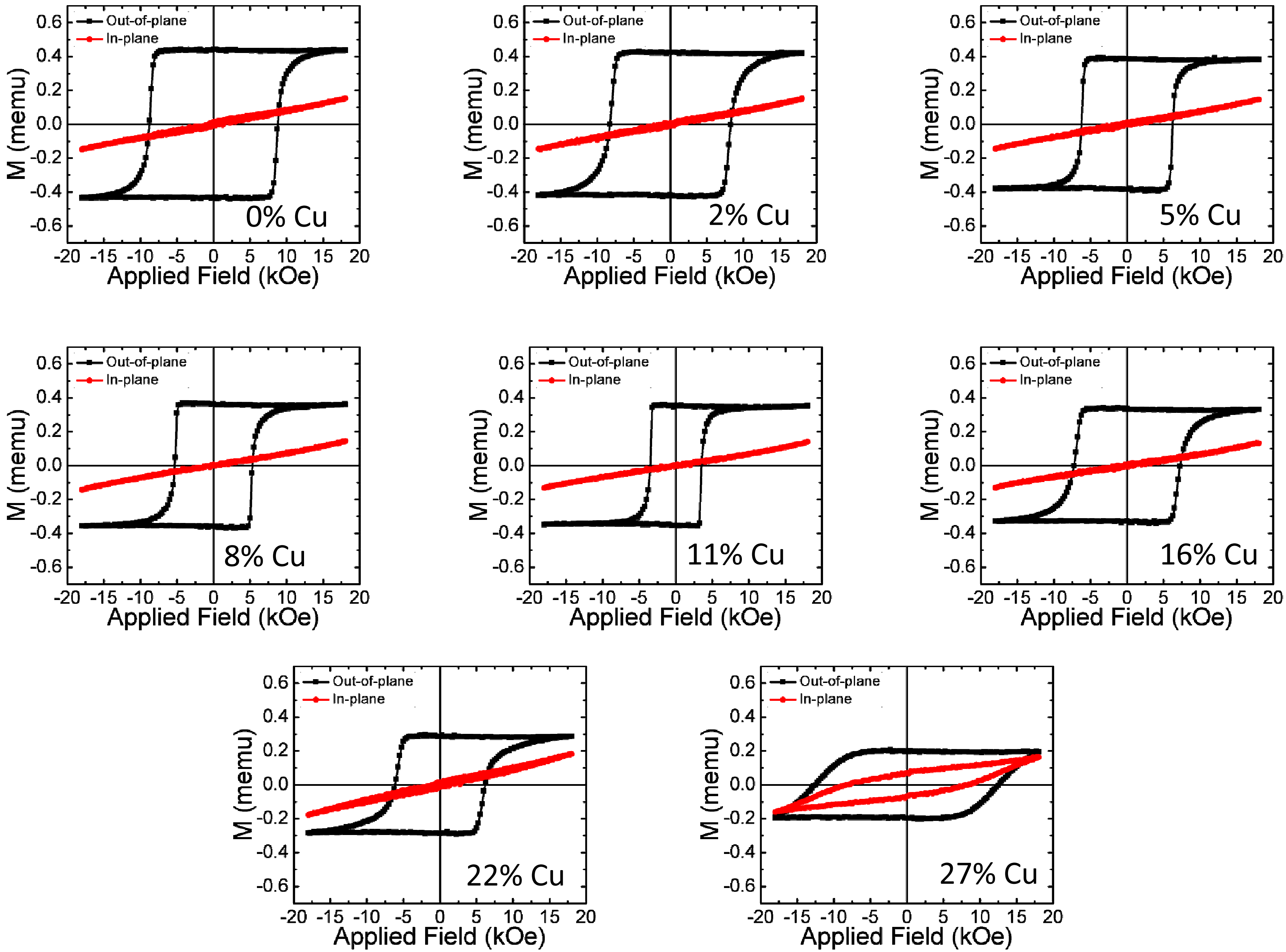
Nucleation & growth

R. A. Ristau, K. Barmak, L. Henderson-Lewis, K. R. Coffey, and J. K. Howard, J. Appl. Phys. 86, 4527 (1999)

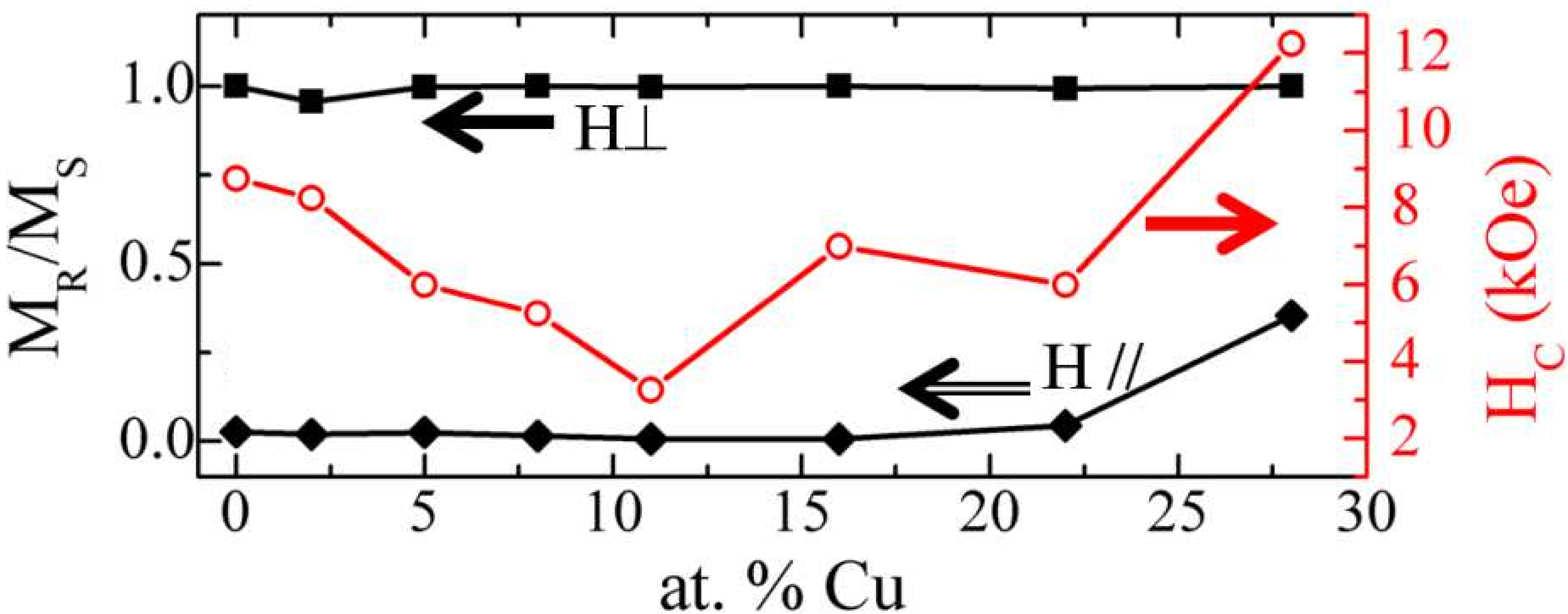
B. Wang, K. Barmak, and T. J. Klemmer, J. Appl. Phys. 109, 07B739 (2011)

B. Wang, K. Barmak, J. Appl. Phys. 109, 123916 (2011)

Magnetic Properties of Fully Annealed $(Fe_{1-x}Cu_x)_{55}Pt_{45}$

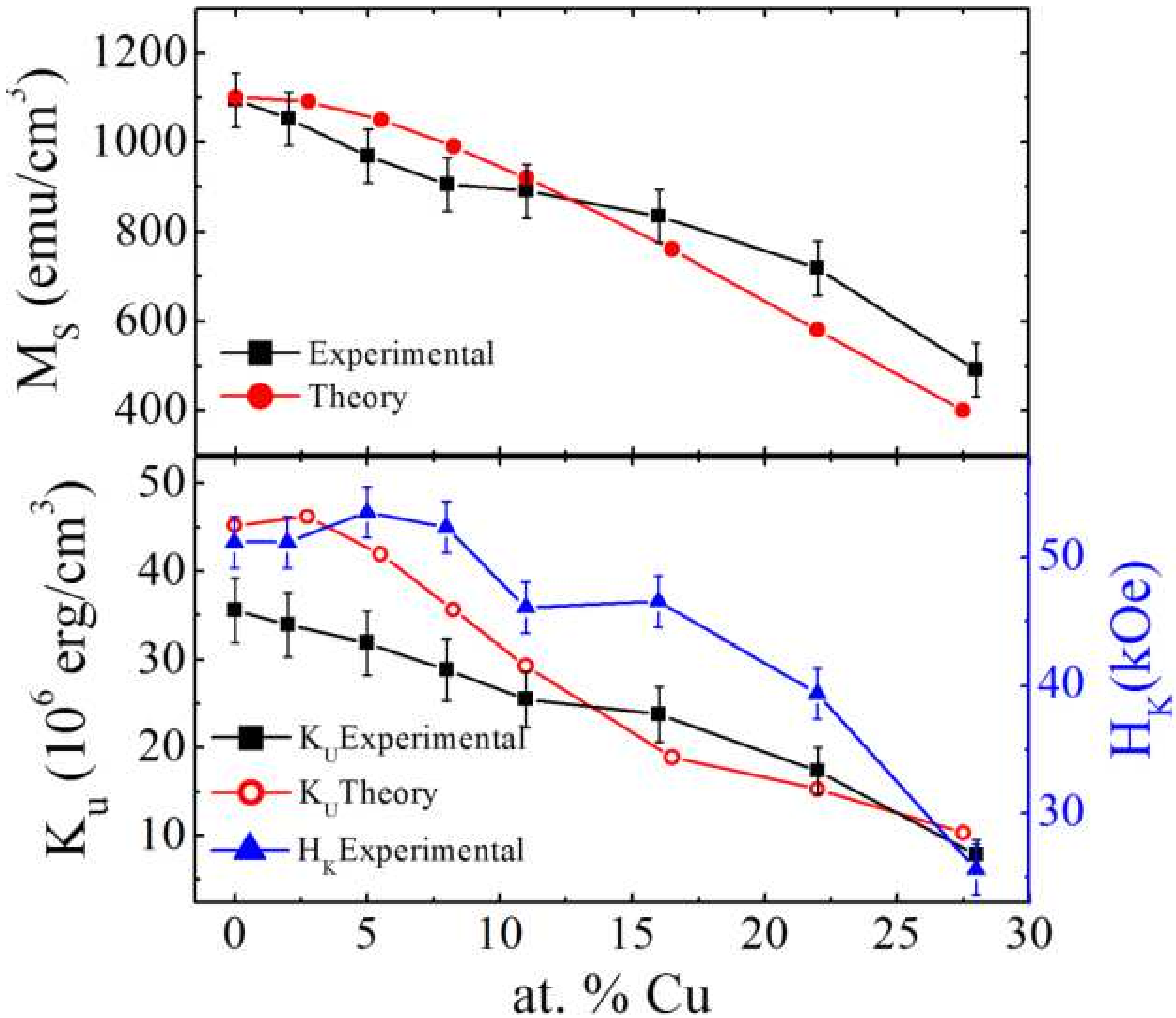

Out-of-plane
In-plane
M (memu)
Applied Field (kOe)
0% Cu
2% Cu
5% Cu
8% Cu
11% Cu
16% Cu
22% Cu
27% Cu

Magnetic Properties



Strong Perpendicular Anisotropy

Effects of Cu-content

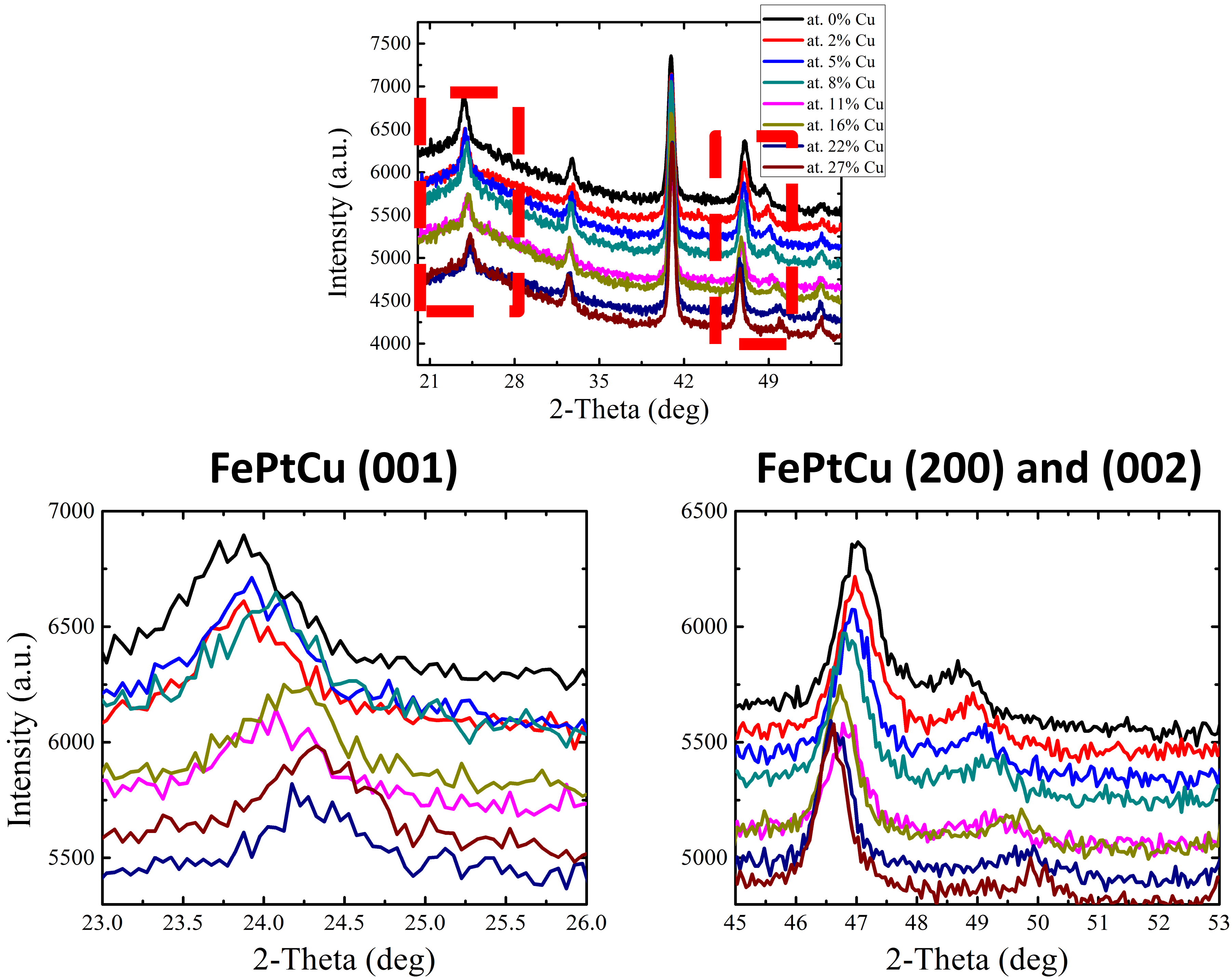


A. Sakuma, *J. Phys. Soc. Jpn.,* **63**, 3053 (1994).

T. Suzuki, H. Kanazawa, and A. Sakuma, IEEE Trans. Magn. **38**, 2794 (2002).

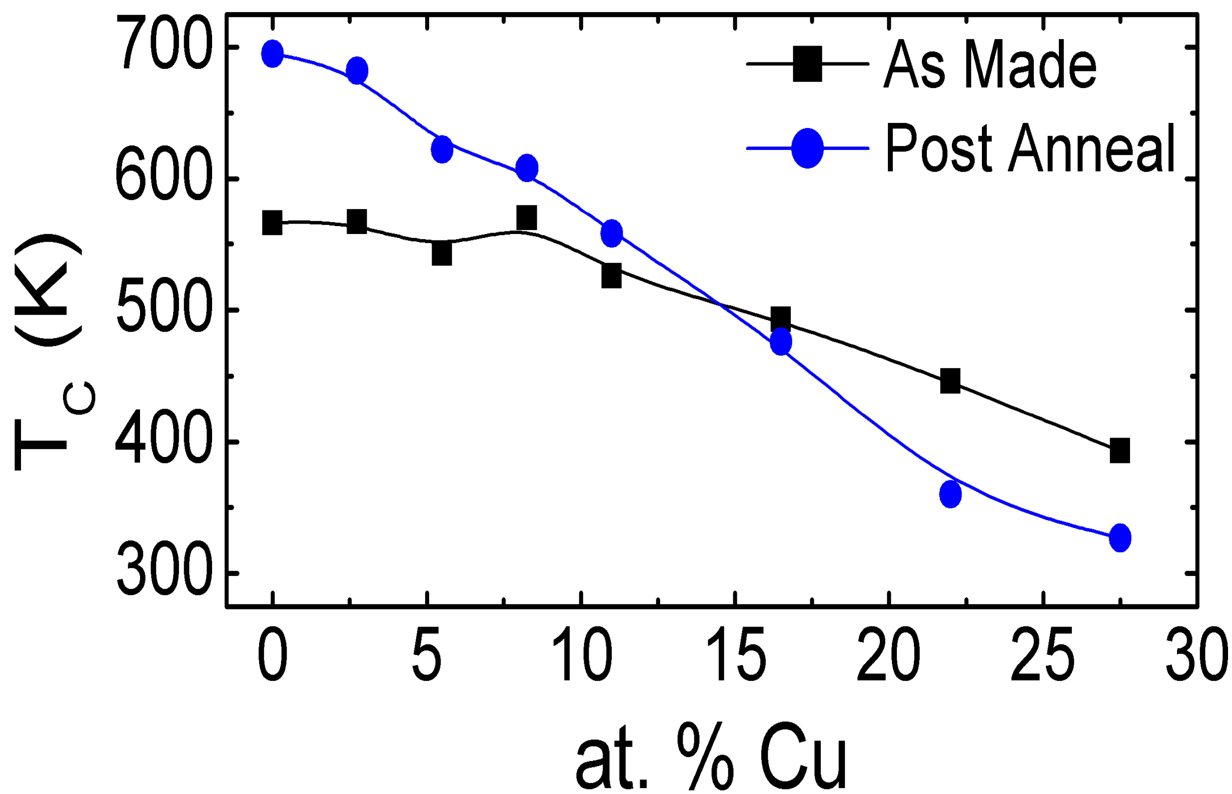
Co-Sputtered $(Fe_{1-x}Cu_x)_{55}Pt_{45}$

from Composite $Cu_{55}Pt_{45}$ and $Fe_{55}Pt_{45}$ targets
50nm thick on glass substrate
20nm MgO capping layer



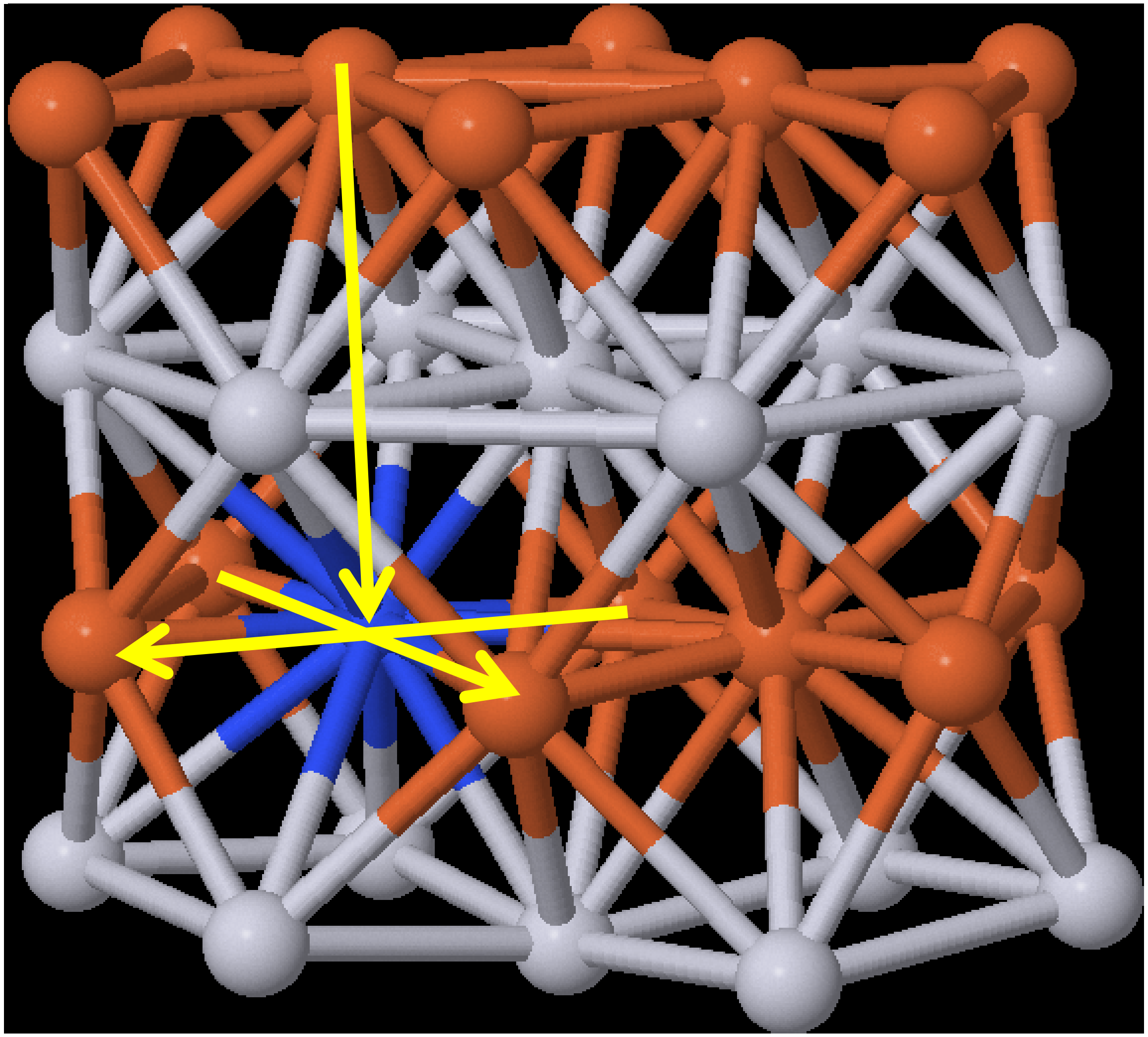
at. 0% Cu
at. 2% Cu
at. 5% Cu
at. 8% Cu
at. 11% Cu
at. 16% Cu
at. 22% Cu
at. 27% Cu
Intensity (a.u.)
2-Theta (deg)
FePtCu (001)
FePtCu (200) and (002)
Intensity (a.u.)
2-Theta (deg)
2-Theta (deg)

Effects of Cu-content



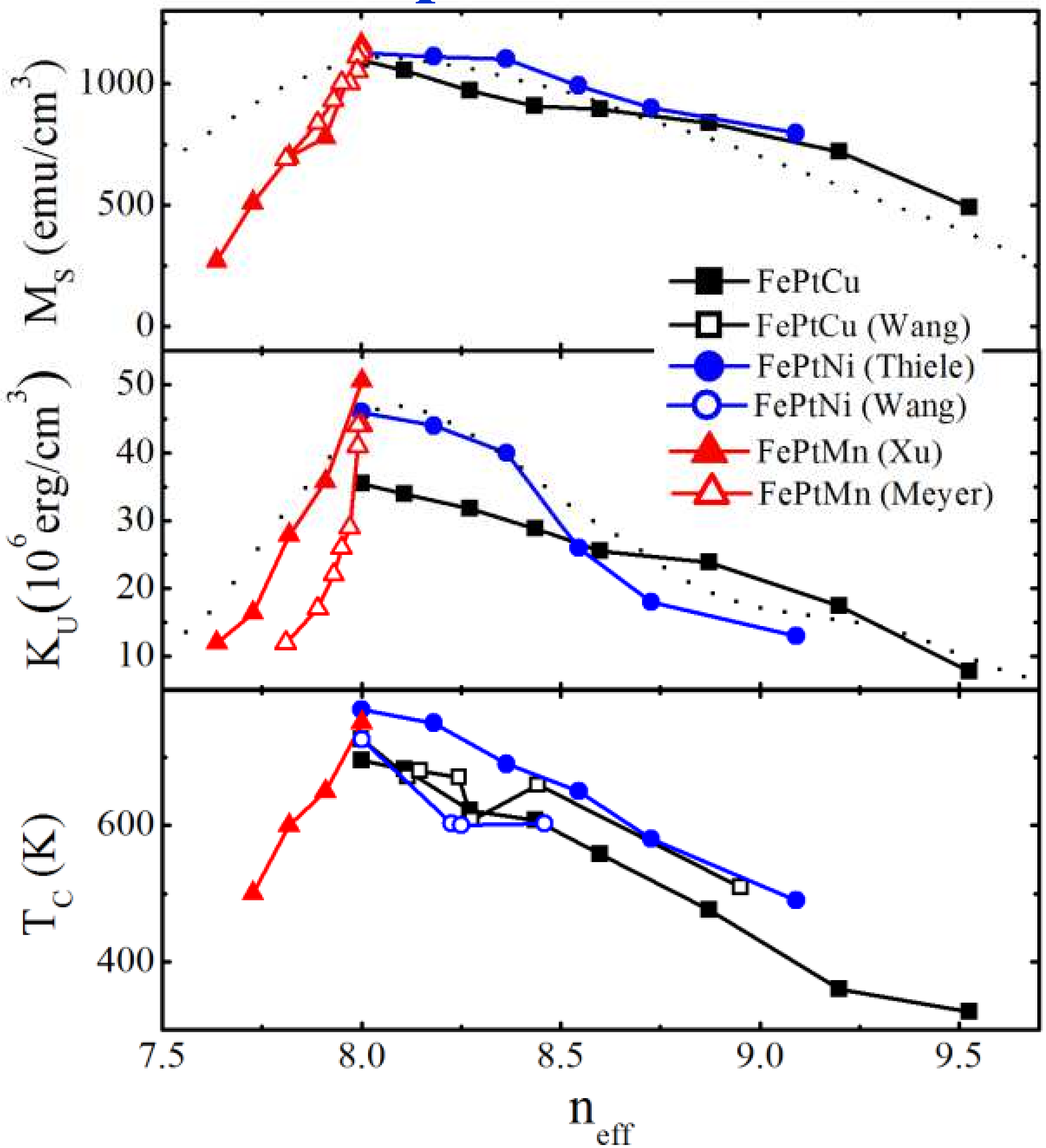
Lower T_C beneficial for HAMR media

T_C Trend



A. Sakuma, *J. Phys. Soc. Jpn.,* **63**, 3053 (1994)
O. N. Mryasov, Phase Transitions **78**, 197 (2005)

Comparison to other Ternary Alloys



T. Suzuki, H. Kanazawa, and A. Sakuma, IEEE Trans. Magn. **38**, 2794 (2002).

B. Wang , K. Barmak, J. Appl. Phys. **109**, 123916 (2011).
J. U. Thiele, K. R. Coffey, M. F. Toney, J. A. Hedstrom and A. J. Kellock, J. Appl. Phys. **91**, 6595 (2002)
D. B. Xu, J. S. Chen, T. J. Zhou and G. M. Chow, J. Appl. Phys. **109**, 07B747 (2011).
G. Meyer and J.-U. Thiele, Phys. Rev. B **73**, 214438 (2006).

n_{eff} effective electron number
Mn: $3d^5 4s^2$
Fe: $3d^6 4s^2$
Ni: $3d^8 4s^2$
Cu: $3d^{10} 4s^1$

Summary

- $(Fe_{1-X}Cu_X)_{55}Pt_{45}$ films grown by AMS technique showed near **full ordering** with **(001) orientation** after RTA at 400° C for 10 sec

- Magnetic properties (M_S, K_U, T_C) can be continuously tuned by inclusion of Cu

- Phase fractions quantitatively determined by magnetometry

- Resultant films fare well against alternatives, and show promise for future recording technologies

Acknowledgements

NSF (DMR-1008791), Seagate Internship Program & Hsinchu Science Park ROC, Grant No. 101A16