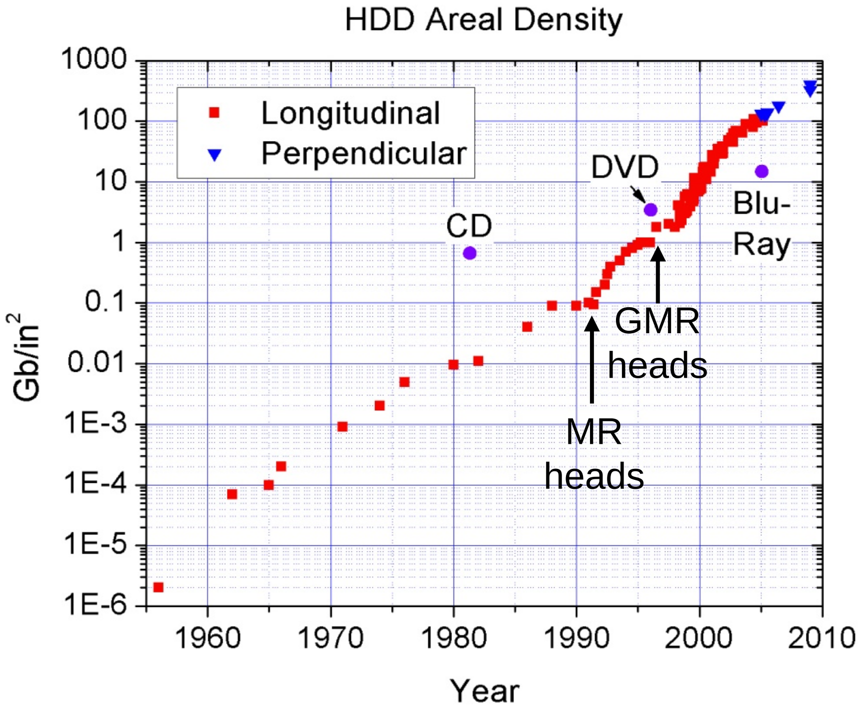
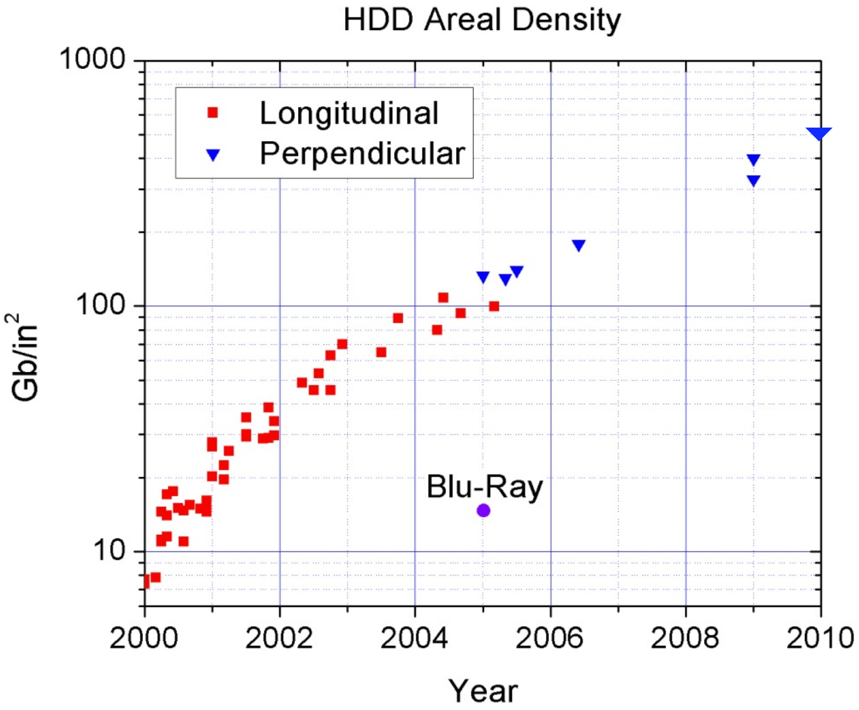
HAMR Media: A Metallurgist's Perspective

Timothy Klemmer
for the Seagate HAMR team

Historical areal density growth of HDDs





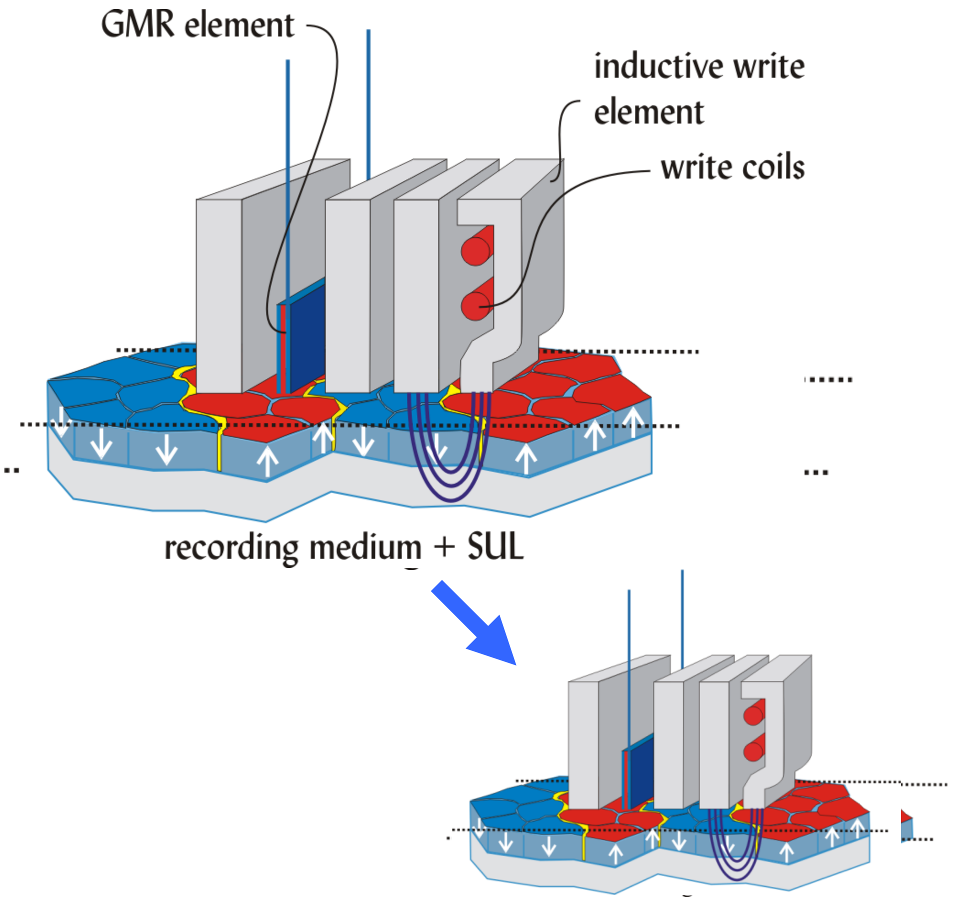
- From the media side, much of the advancement came from understanding the metallurgy of CoCrPt thin films: Alloying, grain size control, crystallographic texture

Seagate Barracuda 2TB HDD

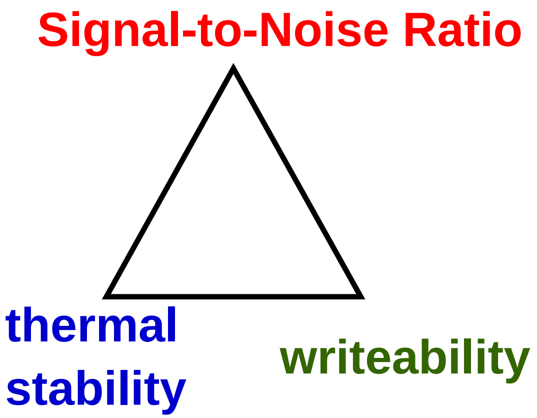
$129.99 & Free Shipping
@Newegg.com

6.5¢/GB!

Scaling (and its limits) in magnetic recording



$SNR_p \propto 10 \cdot \log_{10}(N)$
$\cong 30$ dB for $N=1000$


Signal-to-Noise Ratio

thermal stability

writeability

$$\text{stability} \sim \frac{K_u V^*}{k_B T}$$

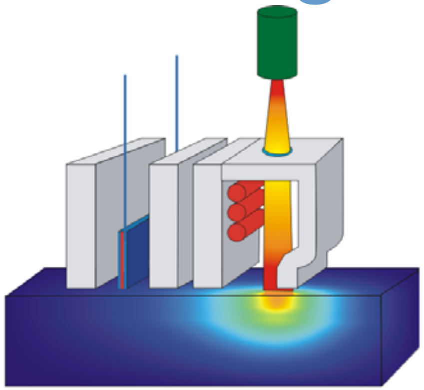
$$B_{S,\,max} = 2.4\ T$$

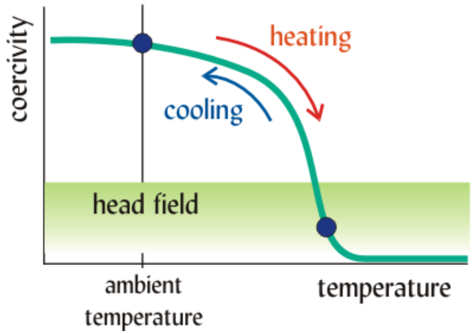
The achievable areal density using ‘conventional’ scaling is limited by trade-off between SNR, thermal stability and writeability

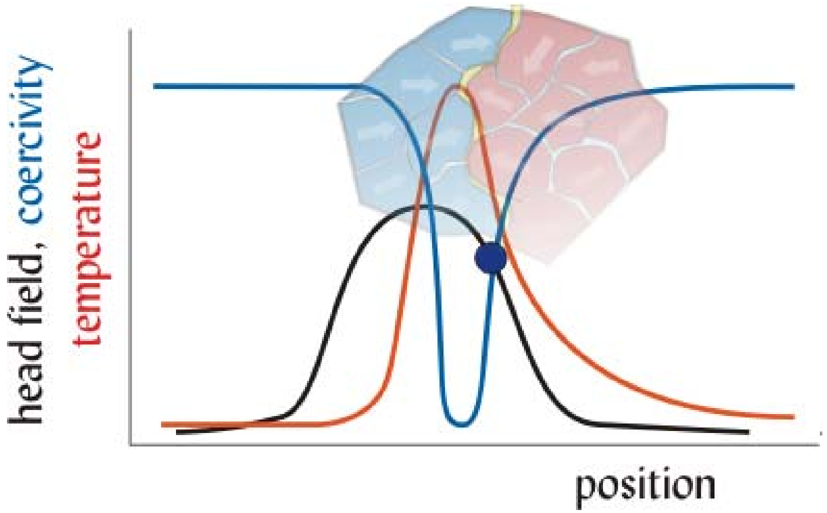
Longitudinal to Perpendicular Recording scheme change from Media perspective

- Longitudinal magnetic easy axis to Perpendicular easy axis
- Incorporate magnetic return path for head

HAMR - the recording process: magnetic vs. thermal gradient







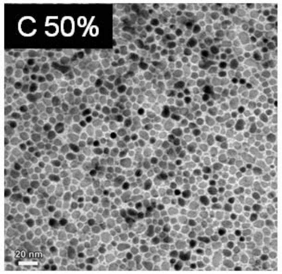
$$dH_{eff}/dx = dH_W/dx + dH_K/dT \cdot dT/dx$$

- write process determined by head field gradient and “effective thermal field” gradient
- convolution of thermal and magnetic head and media properties
- if these are of comparable size, best performance expected with alignment of trailing edges of thermal & magnetic field profiles ⇒ **challenge for head design**

$L1_0$-ordered FePtAg-C granular thin films for theramlly-assisted magnetic recording media

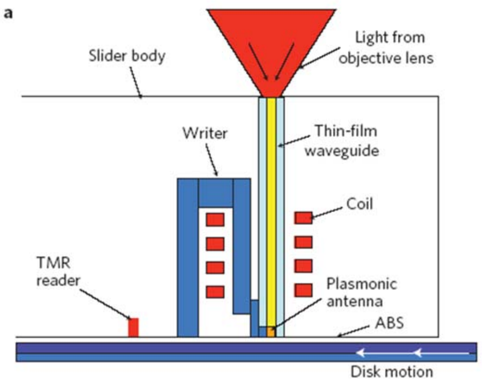
[1]Y.K. Takahashi, [1]L. Zhang, A. Perumal and [1]K. Hono
[2]B. Stipe
[1]*National Institute for Materials Science* (NIMS), *JAPAN*
[2] *Hitachi-GST, San Jose Research Center, USA*

Recording Demonstration by TAR Head
(collaboration with Dr. Stipe of HGST)

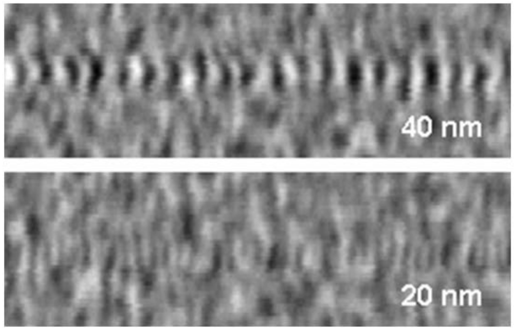


Schematic Diagram of TAR Head

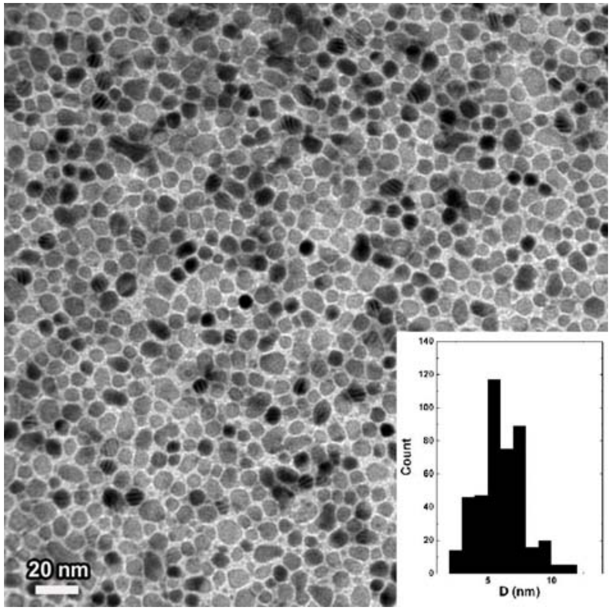
Including light delivery, waveguide, plasmonic antenna, magnetic writer, TMR reader, and disk motion direction

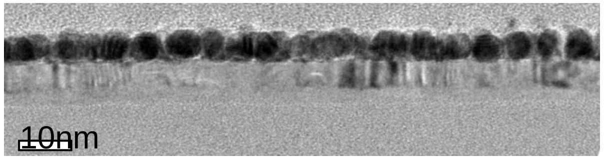


Ref.: B.C. Stipe et al, Nature Photonics (2010)
doi: 10.1038/NPHOTON.2010.90

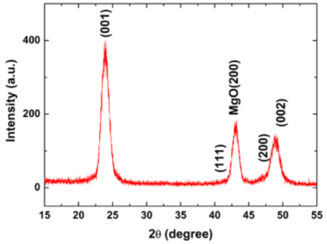


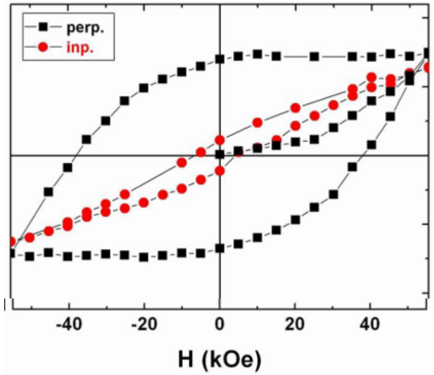
Track width 85nm
Min bit length 17nm reached,
i.e. areal density of 450Gbits/in^2





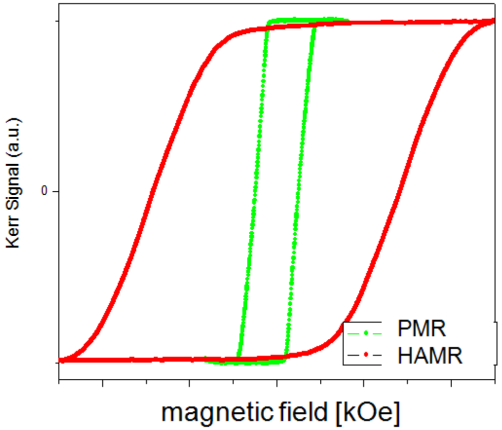
H_k ≈ *65 kOe*
$H_{C.perp}$ = 37kOe
$H_{C.inp}$ = 5kOe
K_u = 4.2×10^{7}erg/cc
M_s =740 emu/cc
E_b = 7.6eV (1.22x10^{-18}J)
K_uV/k_BT = *300*
H_{C0} =43.6kOe
Sigma H_k
T_c
$\Delta H_c/H_c$ =*0.27*

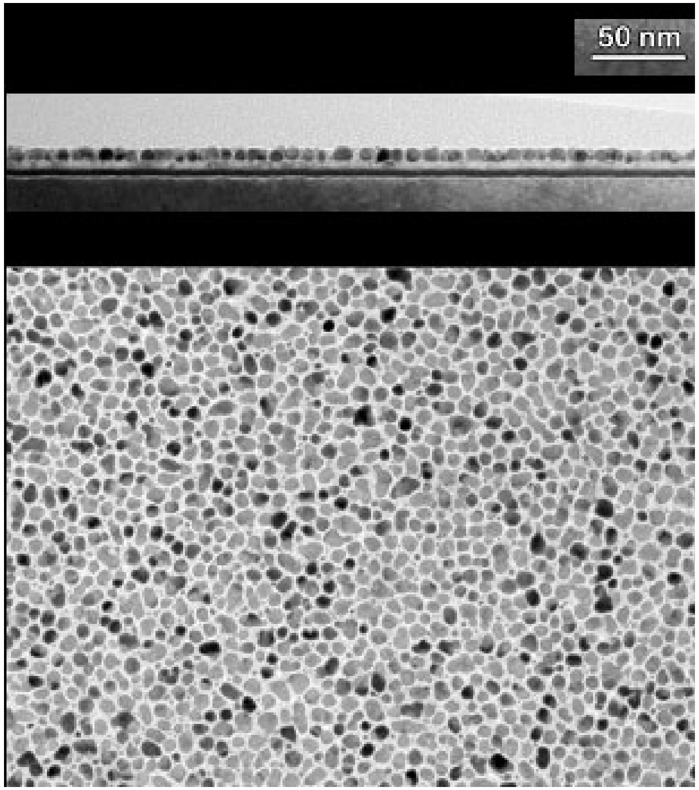


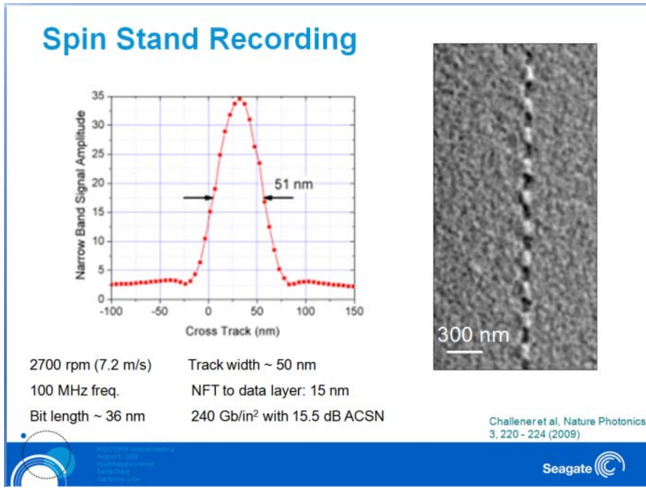


HAMR Recording at Seagate

Recording Layer
$L1_0$ FePt
Curie Point 650 K
Coercivity >20 KOe





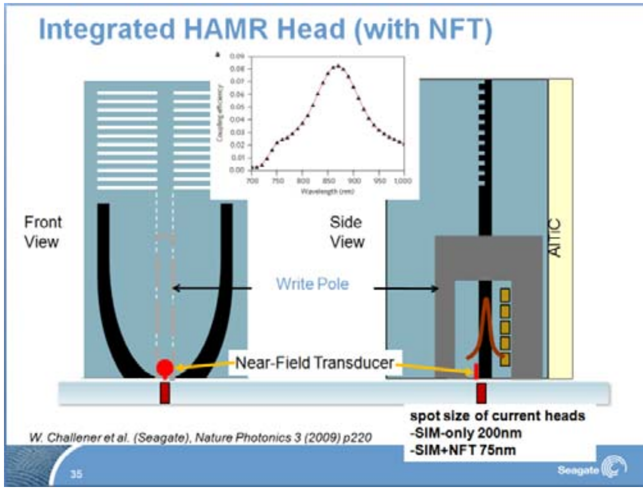

Spin Stand Recording

2700 rpm (7.2 m/s)
100 MHz freq.
Bit length ~ 36 nm

Track width ~ 50 nm
NFT to data layer: 15 nm
240 Gb/in^2 with 15.5 dB ACSN

Challener et al, Nature Photonics 3, 220 - 224 (2009)

Seagate


Integrated HAMR Head (with NFT)

spot size of current heads
-SIM-only 200nm
-SIM+NFT 75nm

W. Challener et al. (Seagate), Nature Photonics 3 (2009) p220

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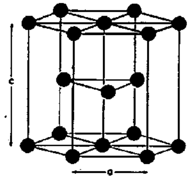
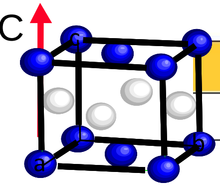
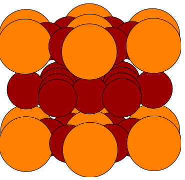
Seagate

M. Re (Seagate), INSIC Annual Meeting 2009, Santa Clara, Ca

Media Materials Options (Bulk Properties)





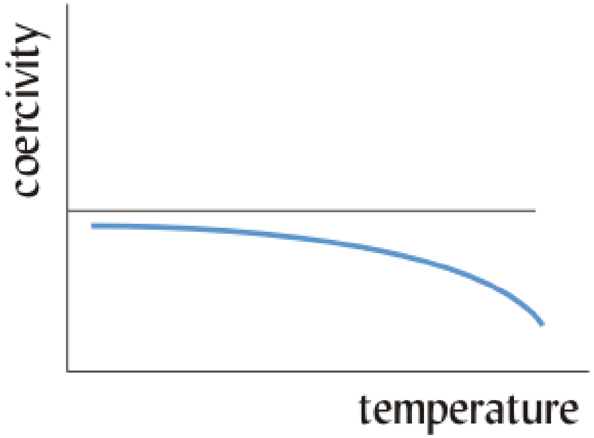


alloy system	material	K_1 (10^7erg/cm^3)	M_S (emu/cm^3)	H_K (kOe)	T_C(K)	$D_p^{(a)}$ (nm)	$D_p^{(b)}$ (nm)	$D_p^{(c)}$ (nm)	$D_p^{(d)}$ (nm)
	$CoCr_{20}Pt_{15}$	0.25	330	15.2		15.5	12.4	15.3	7.8
Co-alloys	Co_3Pt	2	1100	36.4	1200	6.4	6.9	8.5	4.3
	$(CoCr)_3Pt$	0.39	410	19		12.4	10.6	13.2	6.7
	$CoPt_3$	0.5	300	33.3	600	9.0	8.6	10.7	5.4
CoX/Pt(Pd)	Co2/Pt9	1	360	55.6	500	6.1	6.7	8.3	4.2
multilayers	Co2/Pd9	0.6	360	33.3	500	8.4	8.2	10.2	5.2
	FePd	1.8	1100	32.7	760	7.3	7.5	9.3	4.7
$L1_0$	FePt	7	1140	122.8	750	2.4	3.6	4.4	2.3
phases	CoPt	4.9	800	122.5	840	2.8	3.9	4.9	2.5
	MnAl	1.7	560	60.7	650	4.9	5.7	7.1	3.6
rare-earth	$Fe_{14}Nd_2B$	4.6	1270	72.4	585	3.4	4.5	5.5	2.8
transition m.	$SmCo_5$	20	910	439.6	1000	1.3	2.4	2.9	1.5

D_p: smallest possible thermally stable magnetic grain core size!

$L1_0$ FePt *vs* HCP CoCrPt for HAMR media

1



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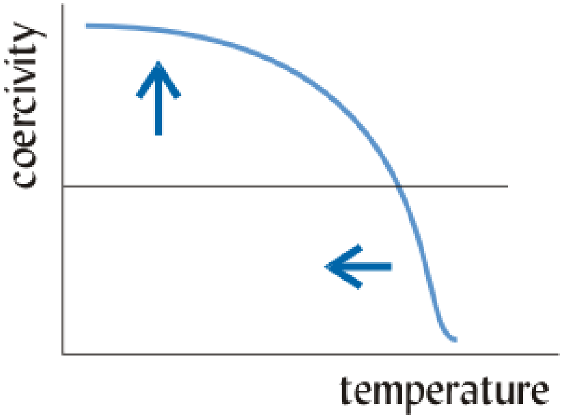


$$dH_{eff}/dx = dH_W/dx + dH_K/dT \cdot dT/dx$$

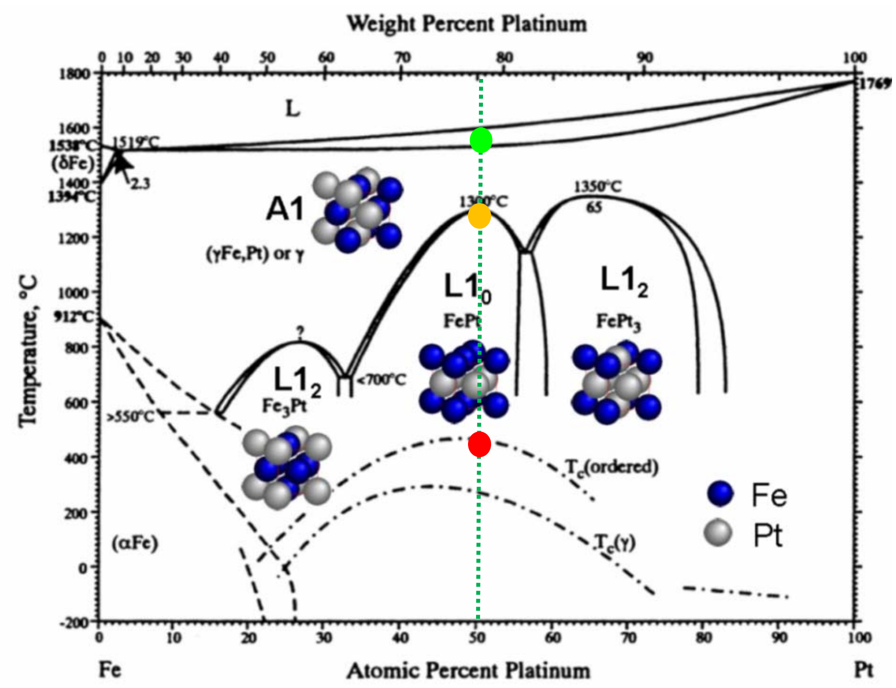
	material system	K_U [erg/cc]	$H_{K,\,max}$	dH_K/dT [Oe/K]	T_C [^oC]	$dH_K/dT \cdot dT/dx$ [Oe/nm] *
1	HCP CoPtCr	$0.2\text{-}1 \cdot 10^7$	30	10-30	800-1120	50-150
2	$L1_0$ FePt –based alloys	$1 - 7 \cdot 10^7$	100	100-200	200-500	500-1000

*assuming dT/dx = 5K/nm

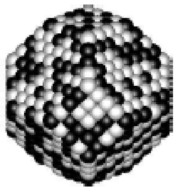
compare to magnetic head field gradient of ~ 100-200 Oe/nm in modern write heads

“exotic” materials or layer structures might provide even larger effective gradients, e.g., RE-TM ferrimagnets, temperature-dependent exchange coupling structures

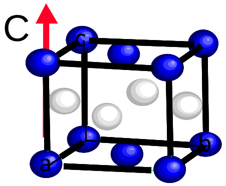
What is this L1$_0$?



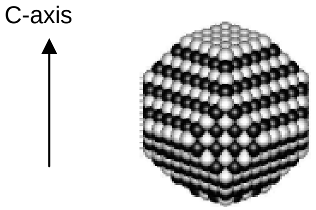
High Temp Phase=Disordered fcc



Disordered fcc Nanoparticle Example



Low Temp Phase=L1$_0$



L1$_0$ ordered Nanoparticle Example

examples of L1$_0$ alloys

	🟢	🟠	🔴
	T_{Melt} (K)	T_{crit}(K)	T_{curie} (K)
FePt	1823	1573	760
CoPt	1768	1098	840
FePd	1582	1063	750
NiPt	1728	893	NA
CuAu	1173	658	NA
TiAl	1729	1729	NA

- Origin of high K_u is chemical order.

- Rapid solidification resulting from room temperature sputtering, freezes in this high temperature disordered phase.
- These sputtered films require annealing to form high anisotropy phase

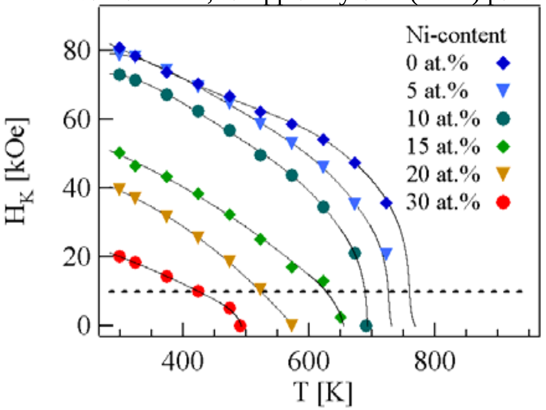
- $T_{critical}$~ Basically, strength of A-B (Fe-Pt) interaction and indicates the Driving Force for Ordering
- T_{curie} = HAMR write temperature

Alloying of FePt L1$_0$ thin films for HAMR ?

FeXPt +Y X= Stays in Core

- "Give and Take"- Example: T_C can be adjusted, e.g. by doping with Ni, but reduced T_C comes with reduced H_K AND L1$_0$ formation slows down.
- New material system! Systematic studies of intrinsic effects of 3rd element on T_{curie} ,K_u , L1$_0$ ordering and M_s

J.-U. Thiele, J. Appl. Phys. **91** (2002) p.6595



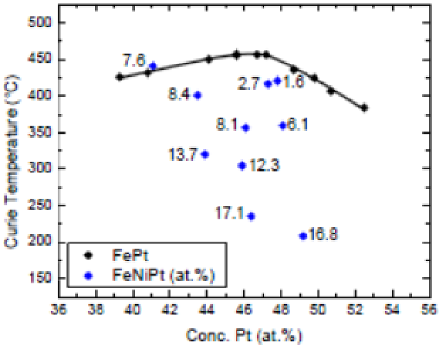
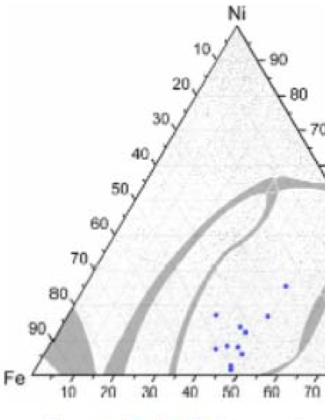


Figure 3: The effect of Ni additions on the L1$_0$ Curie temperature.

Differential Scanning Calorimetry
•T_{curie}
• "Kinetic Ordering Temperature"

D.C. Berry and K. Barmak, J. Appl. Phys. 102, 024912 (2007)



	T_{crit}(K)
FePt	1573
NiPt	893

Figure 1: The Fe-Ni-Pt ternary phase diagram

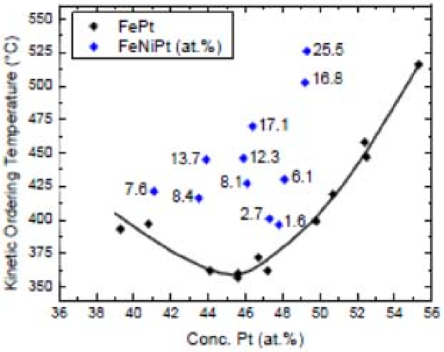


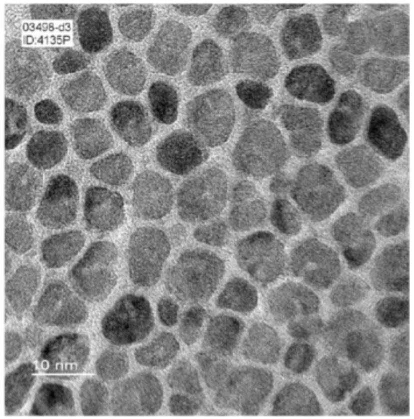
Figure 2: Effect of composition on the kinetic ordering temperature

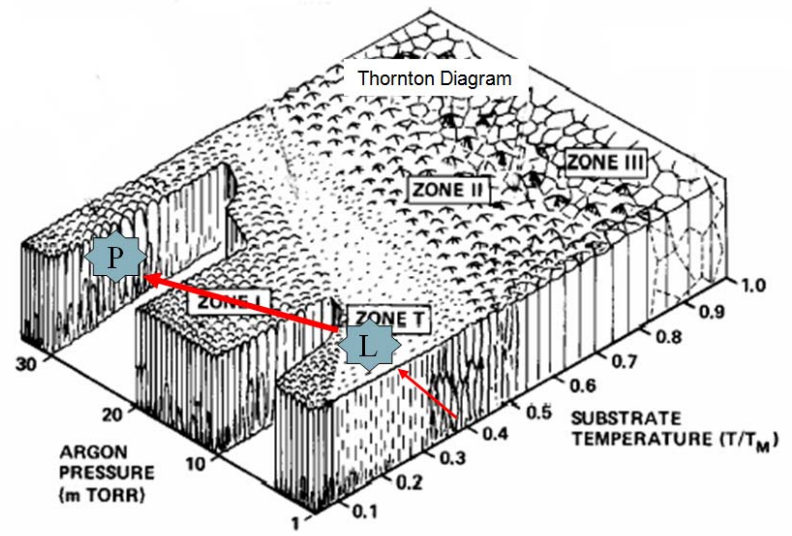
Magnetic and exchange coupling optimization in CoCrPt Media

P

Perpendicular Media

Oxide granularity

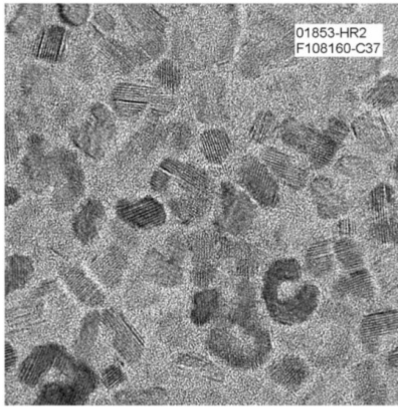




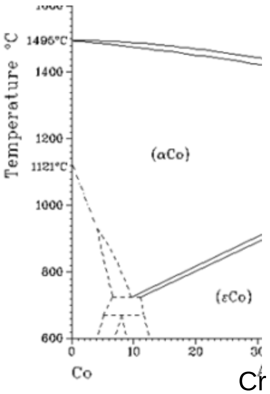
L

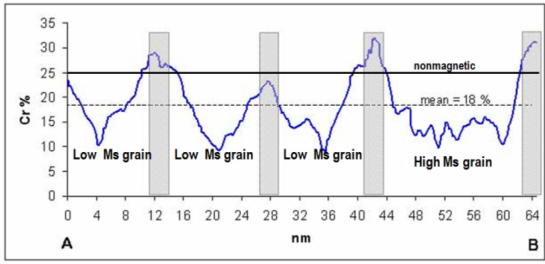
Longitudinal Media

Cr Segregation



- A transition in grain decoupling method happened at the Longitudinal to Perpendicular transition





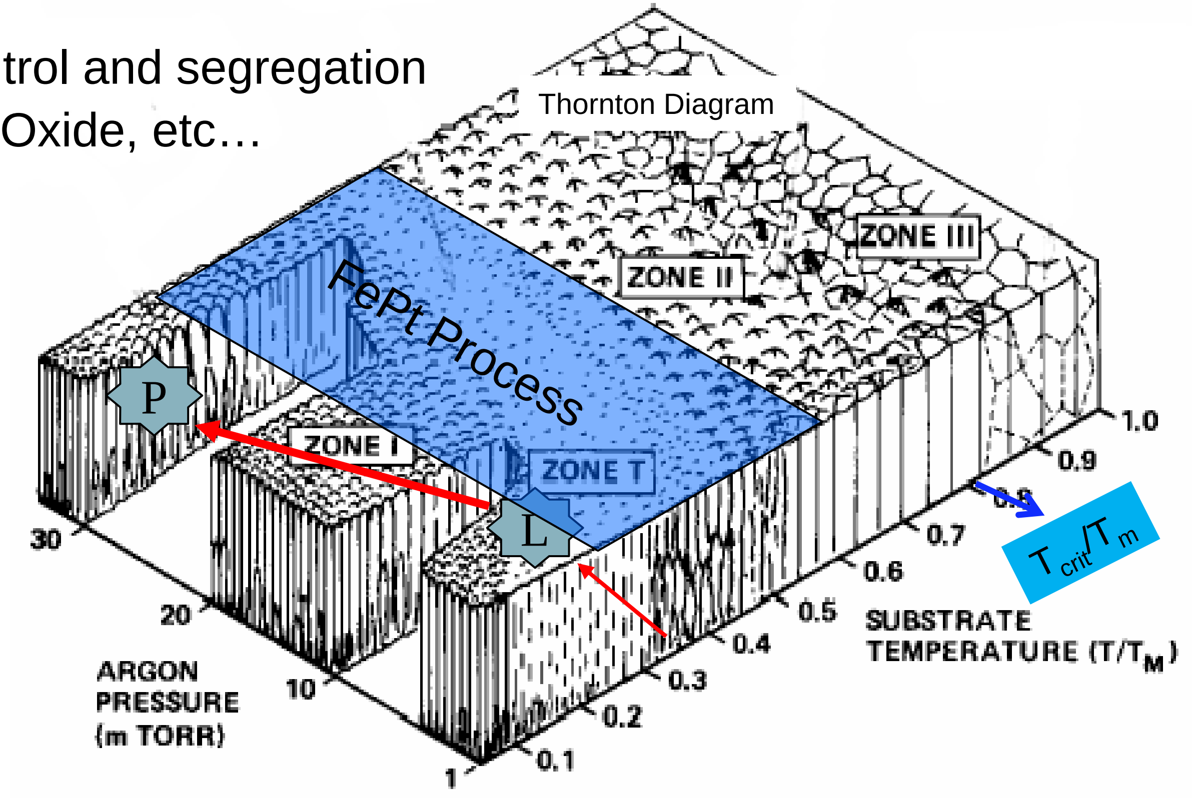
High Anisotropy and Decoupled Grains in FePt

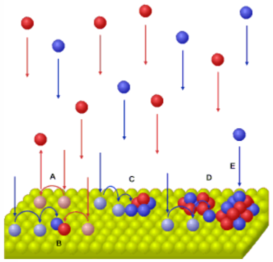
FeXPt +Y   Y=Goes to boundary FePt

FePt
Tm=1580 C
RT----T/Tm~0.16

300C	0.31
500 C	0.42
700C	0.53
900 C	0.63
1100C	0.74

- grain size control and segregation challenge: C, Oxide, etc…



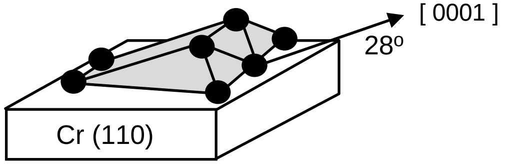


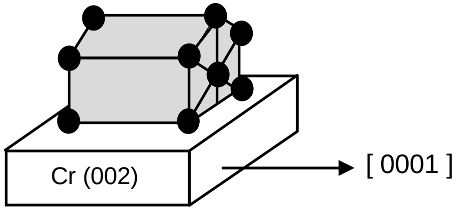
T_m indication of diffusion at T_{sub}
T_{crit} indication of chemical ordering driving force at T_{sub}

- Rapid Solidification-Sputter Rate Dependence: full chemical order in thin films can only be obtained at very high deposition temperatures
  rate <1Å/sec $\Rightarrow T_{growth}$ ~ 400°C
  rate ~10Å/sec $\Rightarrow T_{growth}$ ~ 600°C

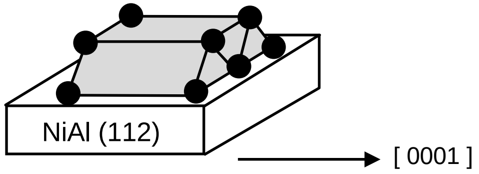
Seed Layer for Crystallographic orientation

Longitudinal

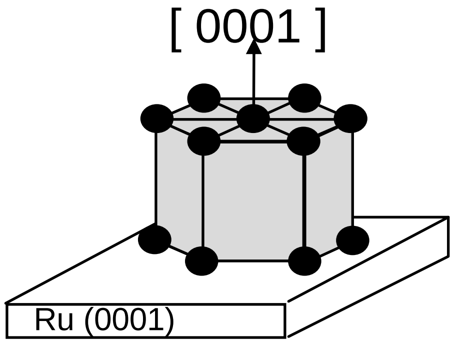




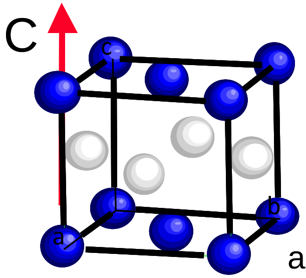
"Bi-crystal media"



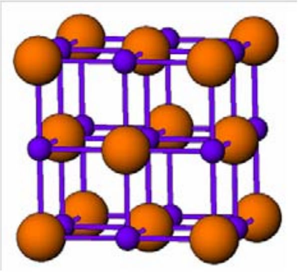
Perpendicular



Perpendicular HAMR ?



a_0~3.85 nm



MgO

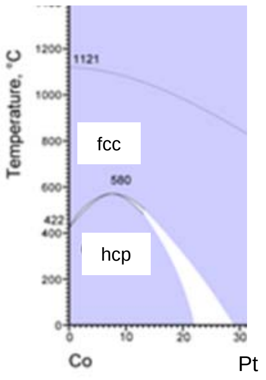
a_0~4.21 nm

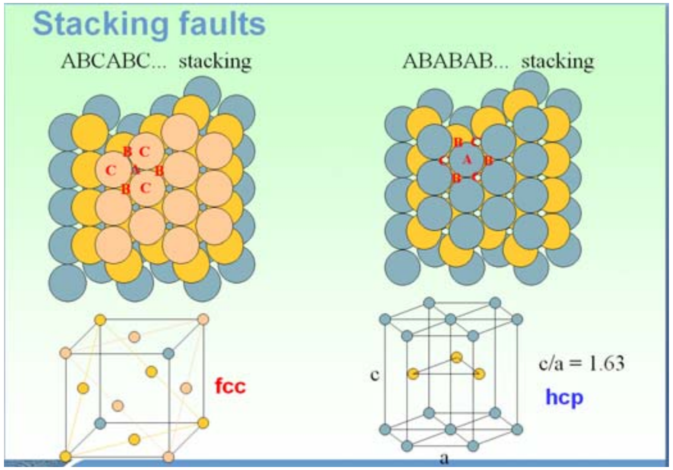
Epitaxial Misfit

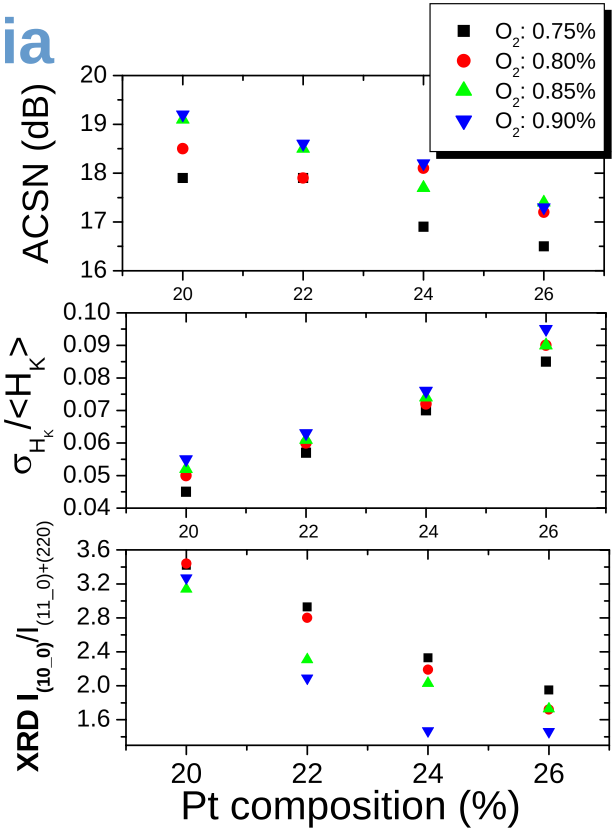
- FePt a_0 and MgO~9%
- FePt c_0 and MgO~12%

Crystalline defects in HCP CoCrPt Media

- Crystalline defects create distributions in H_k and degrade recording performance.

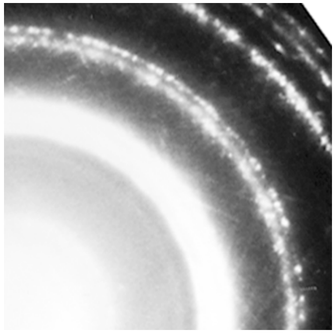




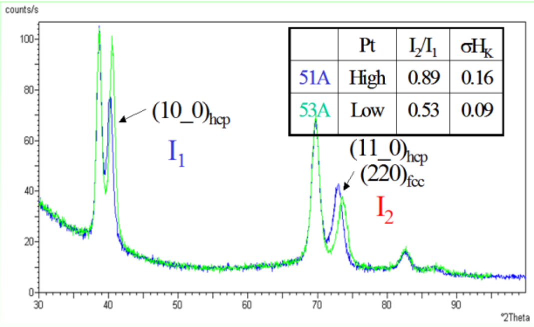


Longitudinal Media

"Stacking Faults in Co-alloy Longitudinal Media"
Bin Lu, Jie Zou, David N. Lambeth and David E. Laughlin, Intermag 2000, BP04

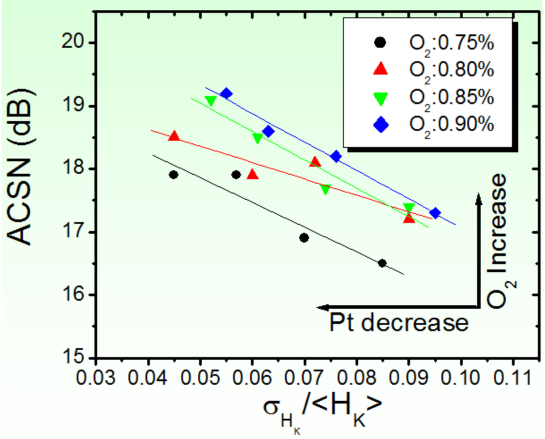


Perpendicular Media



	Pt	I_2/I_1	σH_K
51A	High	0.89	0.16
53A	Low	0.53	0.09

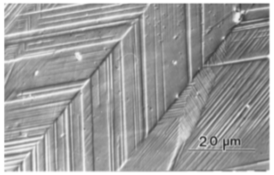
Ganping Ju MMM 2005 Paper CC-05



Seagate

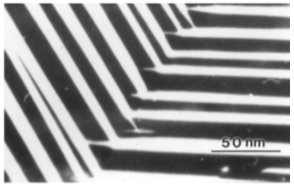
Crystalline Defects observed in $L1_0$ Alloys: Bulk Permanent Magnet examples

1) <u>C-Axis variants</u>
In perpendicular media these will be observed as σ_θ



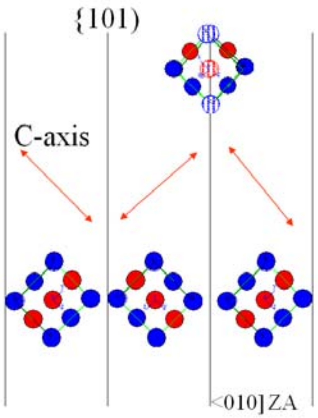
optical

After Okumara, 1999

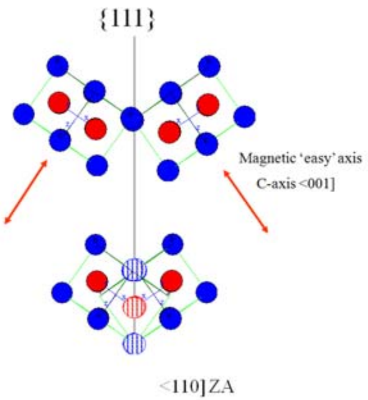


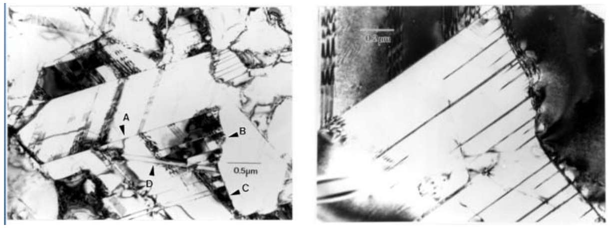
TEM

After Zhang, 1991



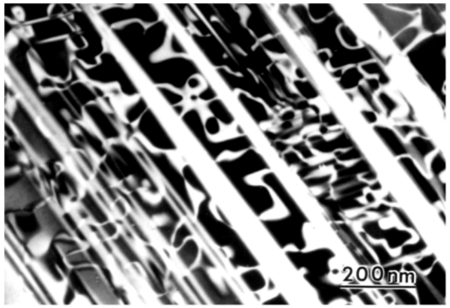
Twin

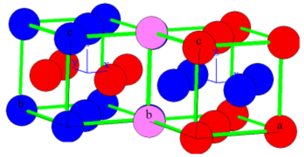




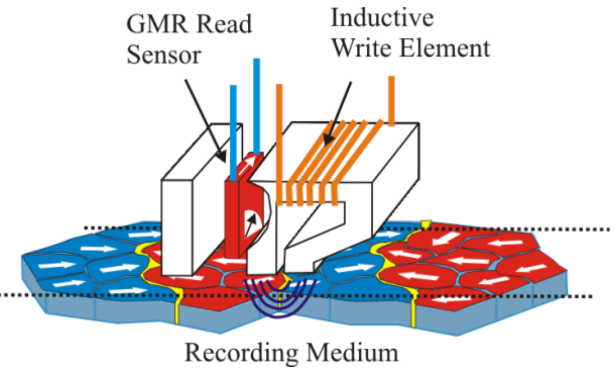
2) <u>{111} twins</u>
In perpendicular media these will be observed as σ_θ

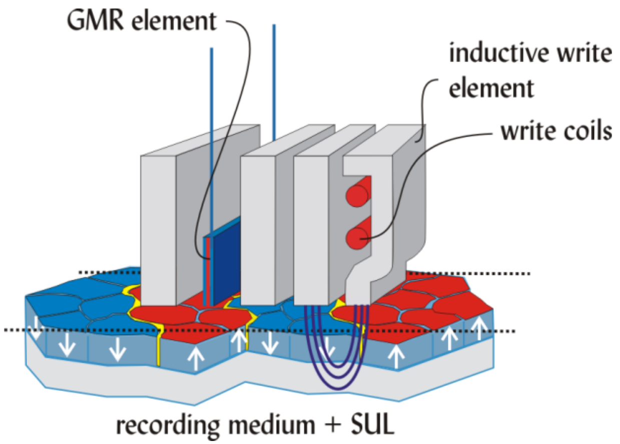
3) <u>Antiphase Boundaries/ Domains</u>
And
4) <u>Remnants of disorder</u>
In perpendicular media these will be observed as σ_{HK}

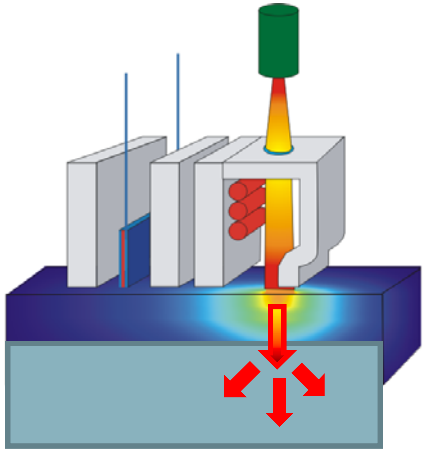




Soft Under Layer vs Heatsink







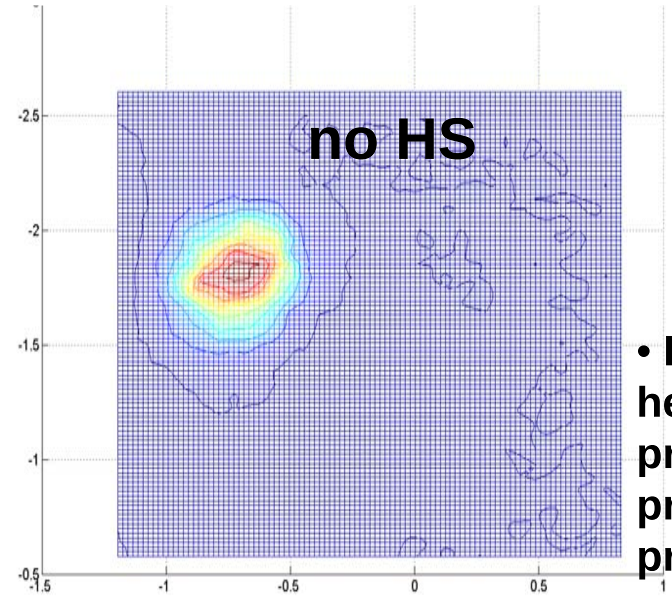
Recording Medium+ Heatsink

Soft Under Layer:
- Increases magnetic field gradient at the write transition.
- Relatively high permeability material.
- Closes the magnetic circuit from the head

Heatsink:
- Increases Temperature gradient at the write transition.
- Relatively high thermal conductivity material.
- Dissipates the heat from the head

$$dH_{eff}/dx = dH_W/dx + dH_K/dT \cdot dT/dx$$

Effects of HS for model media

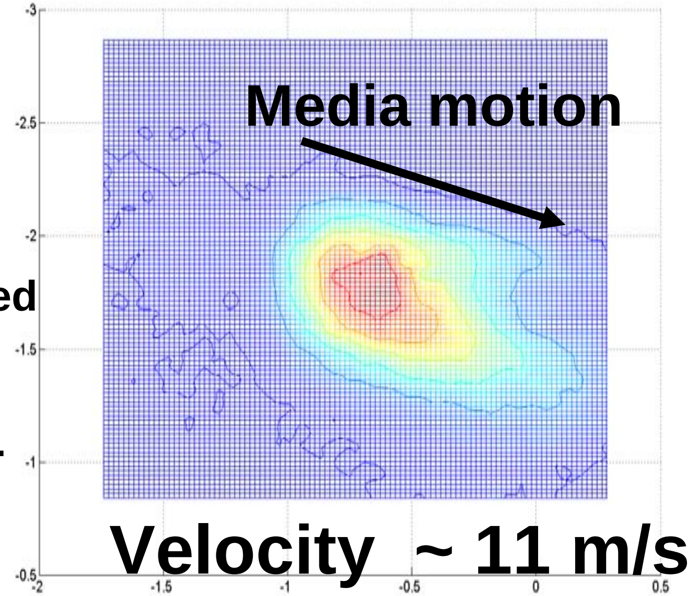


mag. media

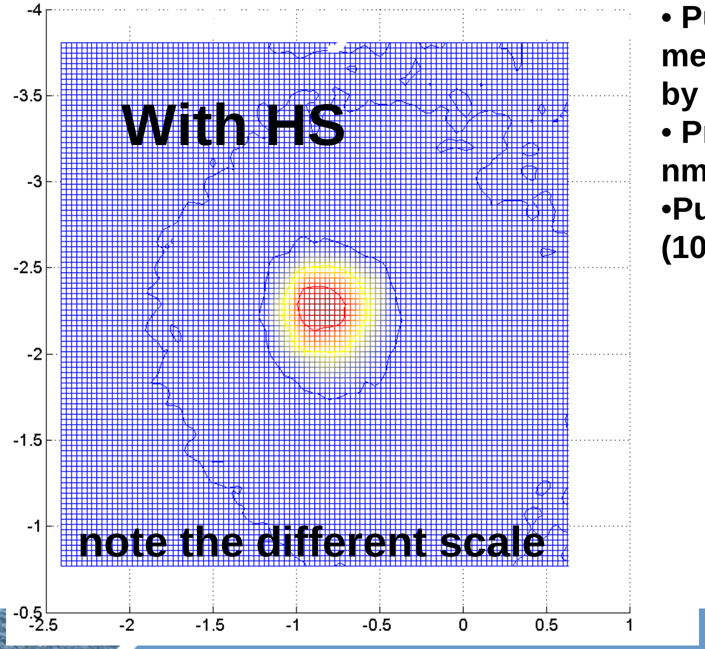
Interlayer

Glass

- **Proper thermally designed heat sink prevents preheating effects and produces very confined T-profiles**



Velocity ~ 11 m/s



note the different scale

- **Pump induced thermal profile measured as reflectivity changes by a XY scanning probe**
- **Probe/Pump spot size ~280/380 nm**
- **Pump frequency up to 100 MHz (10 ns)**

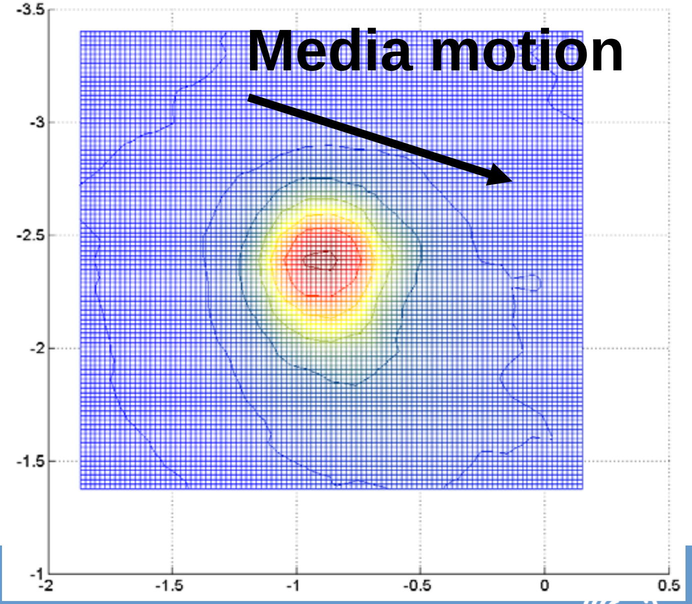
mag. media

Interlayer

HS (600 nm)

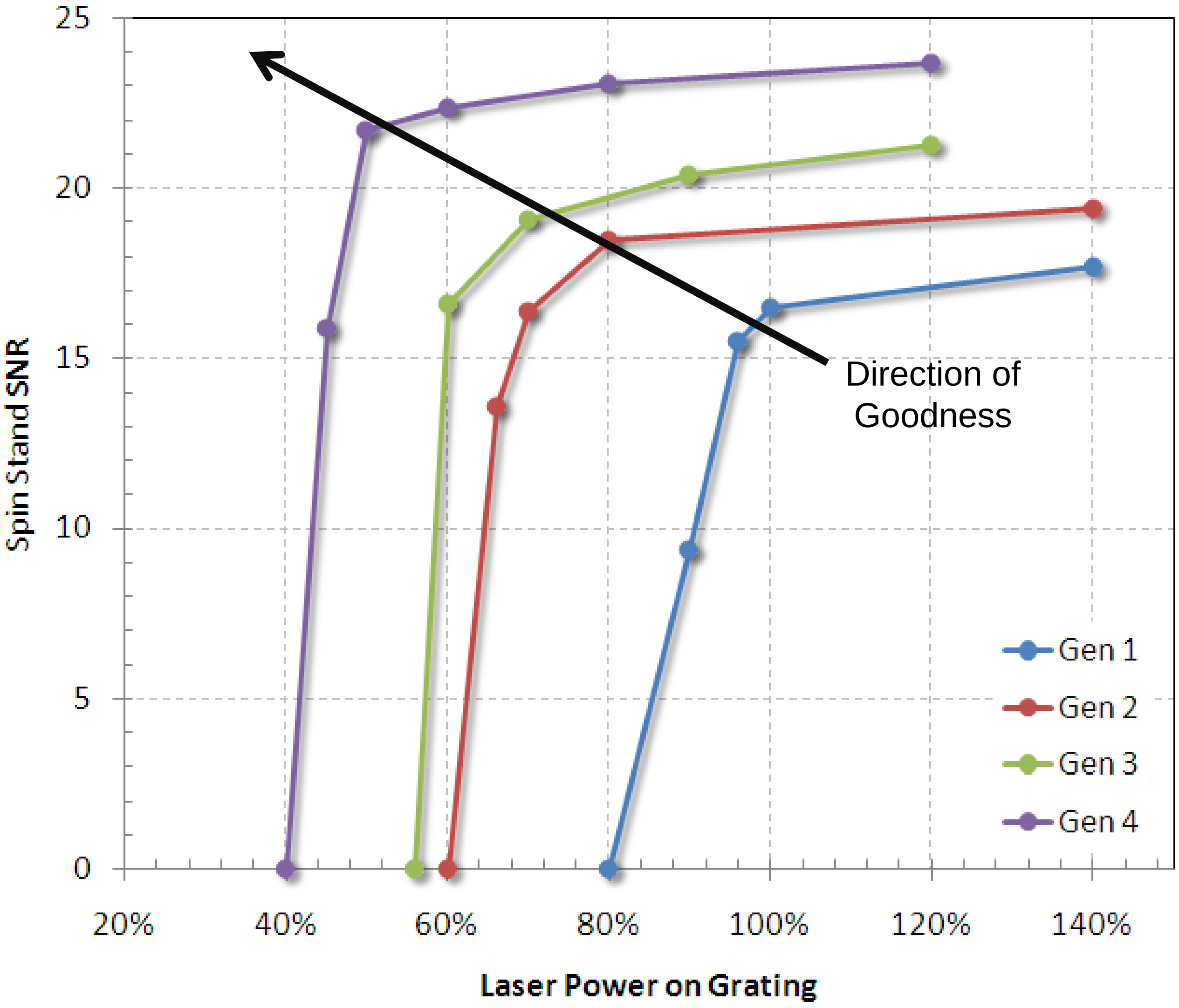
Glass

G. Ju IDEMA 2007



FePt Media Progress at Seagate

Thermal design should be optimized for good SNR and low laser power



Direction of Goodness

Mark Re
2009 INSIC Annual Meeting

Challenges for FePt Media

- A New Materials system for Magnetic Storage Layer
  - Process Heat required to form high anisotropy phase
  - Similar to Longitudinal/ Perpendicular CoCrPt (>30 years optimization)
    - FeXPt+Y optimization (K_u, M_s, Grain definition, distributions)
    - Grain defining methods and control
    - Seed Layers for magnetic anisotropy orientation
    - Control of intrinsic defects causing distributions
    - Extendibility
- Heat Assisted Magnetic Recording
  - T_{curie} Tuning (FeXPt)
  - Heatsink design for thermal gradient