



Recent developments in magnetic recording media

Kumar Srinivasan
Western Digital

April 6, 2018

Acknowledgments:

*R. Acharya, P. Dorsey, G. Bertero, A. Ajan,
D. Tripathy, S. Jain, S. Pirzada, M. Desai*

U.S.D.C. CENTRAL DISTRICT OF CALIFORNIA	
CASE NO.	<u>8:22-cv-01599-JVS-DFM</u>
<u>MR Technologies, GMBH</u>	
VS. <u>Western Digital Technologies, Inc.</u>	
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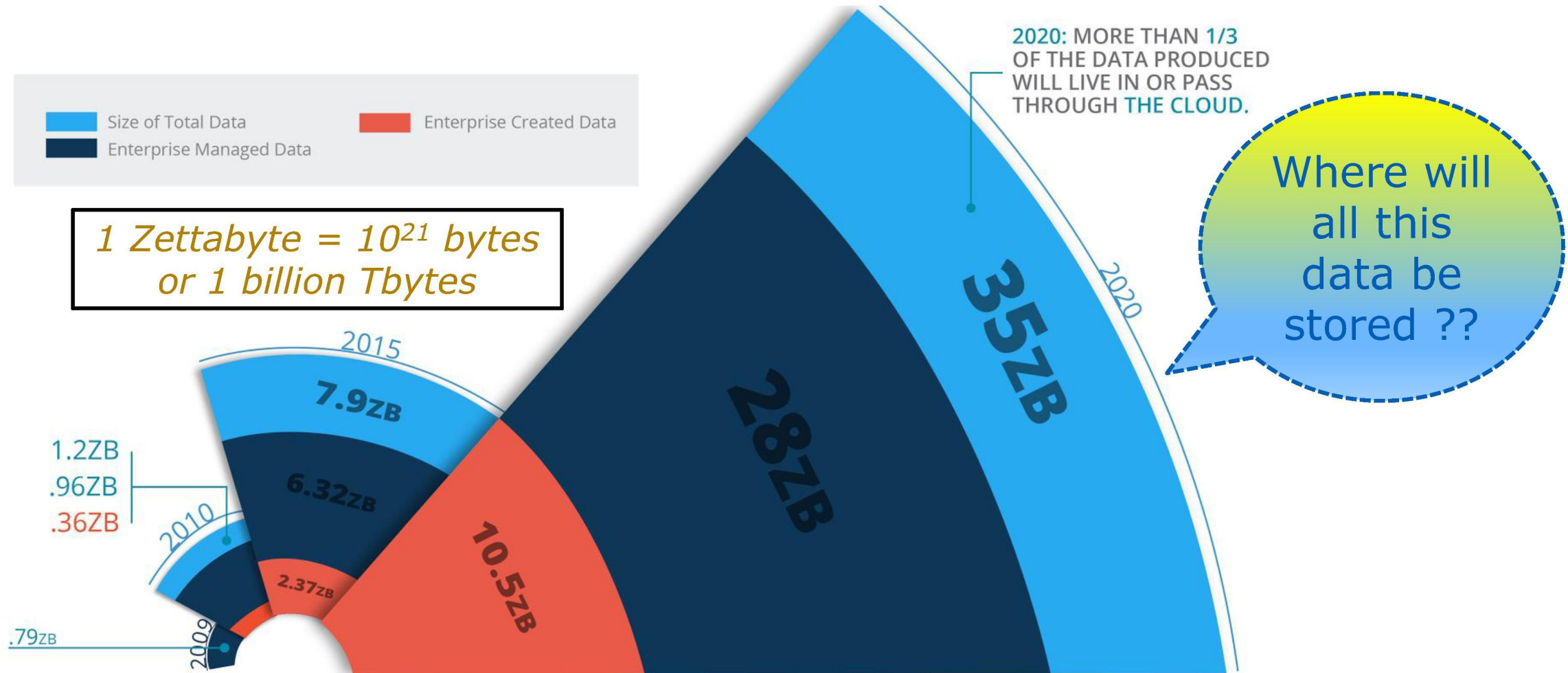
Outline

Recent developments in magnetic recording media

- Introduction
 - HDD's in the era of "Big Data"
- Current Technology - Perpendicular Magnetic Recording (PMR) media
 - Media "trilemma" and the exchange-spring principle
 - Towards graded anisotropy media
 - Grain size scaling & its limitations
 - Interfacial engineering to improve switchability
- Future Technology – Heat Assisted Magnetic Recording (HAMR)
 - The ideal HAMR medium:- FePt-X-Y
 - Single-layered vs. multi-layered segregant approach
 - Grain size progression
 - Challenges & prospects of FePt HAMR media
- Summary

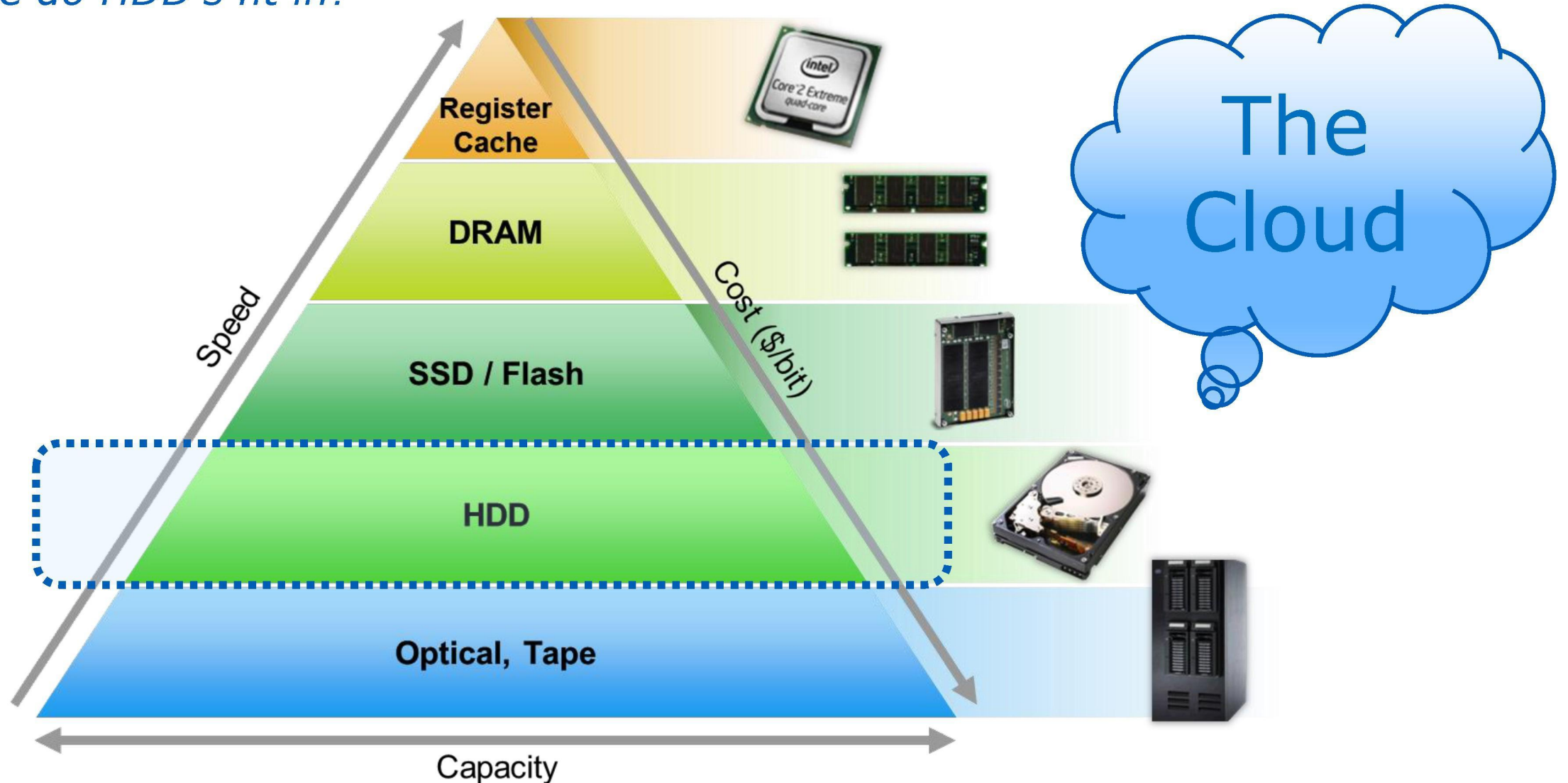
INTRODUCTION

The era of "BIG DATA"



Storage hierarchy

Where do HDD's fit in?



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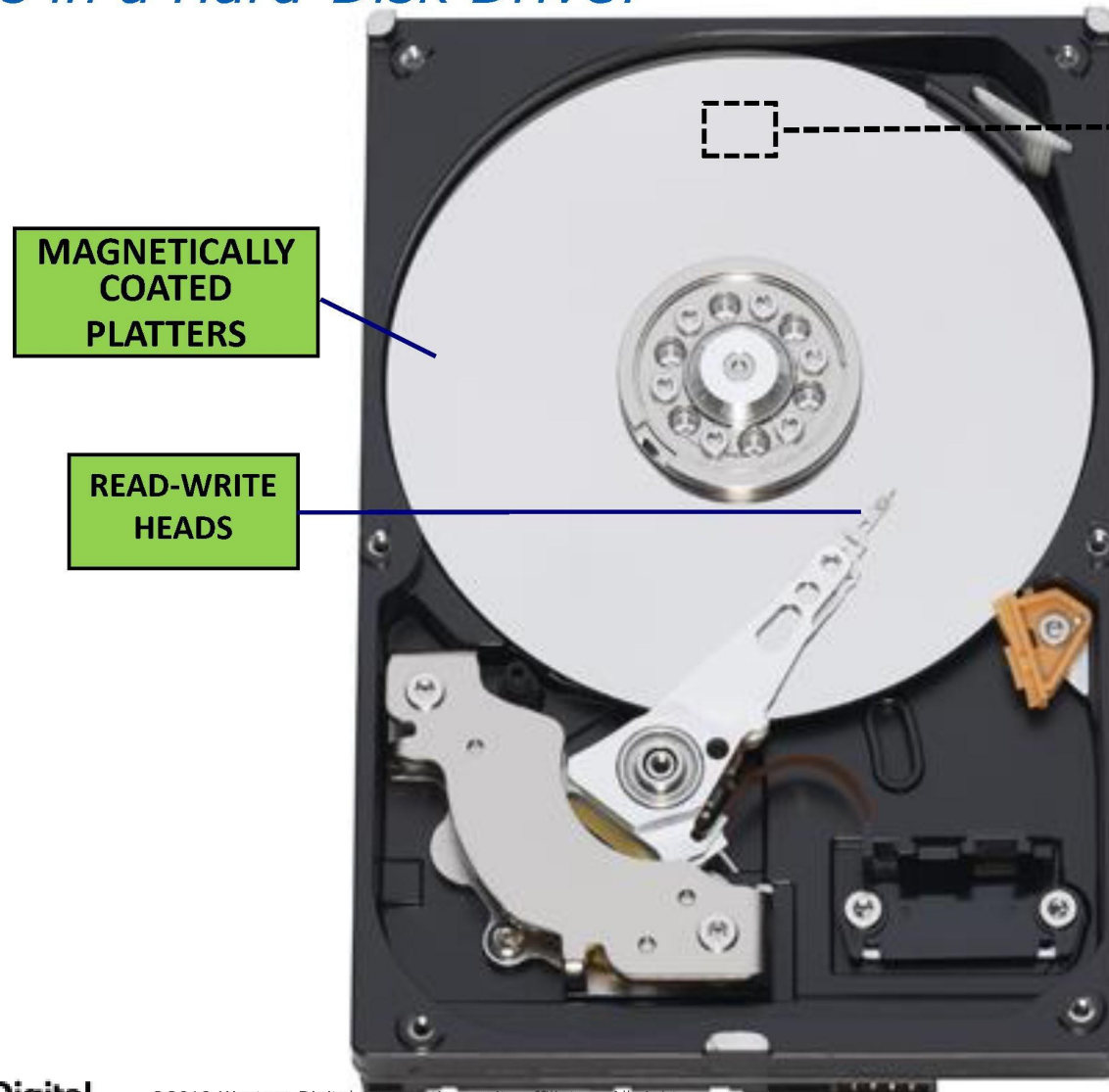
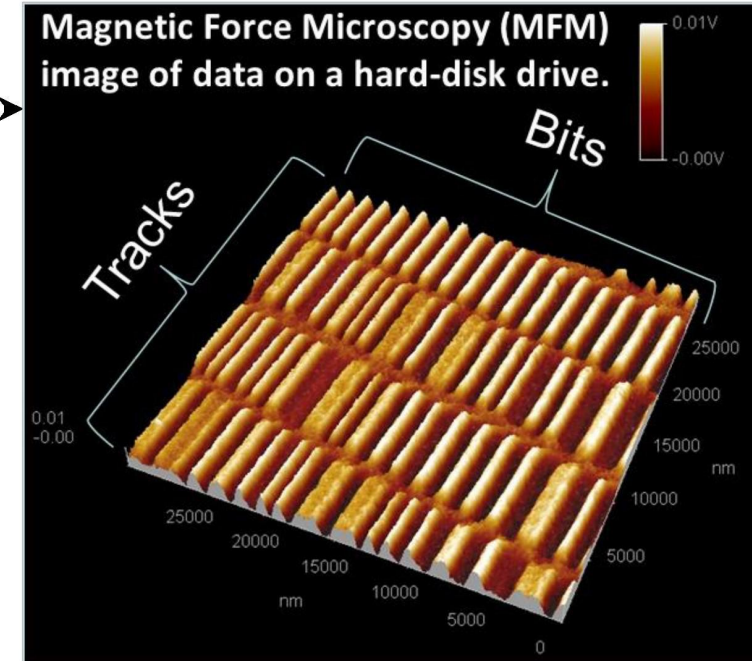
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4

Principles of Magnetic Recording

What's in a Hard-Disk Drive?



Source: <http://www.cambridgenano.co.uk>

- Inductive write-head to polarize the medium (N or S).
- Tunnelling Magneto-resistance (TMR) based read sensors read-back the written bits.

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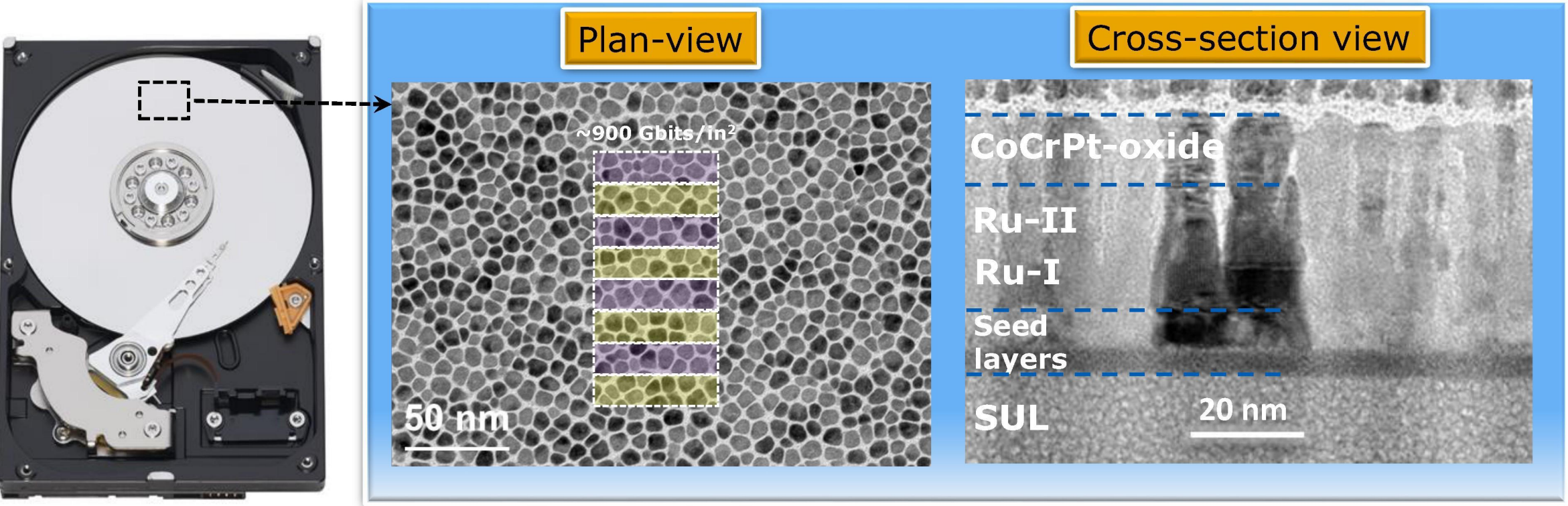
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The Magnetic Recording Medium

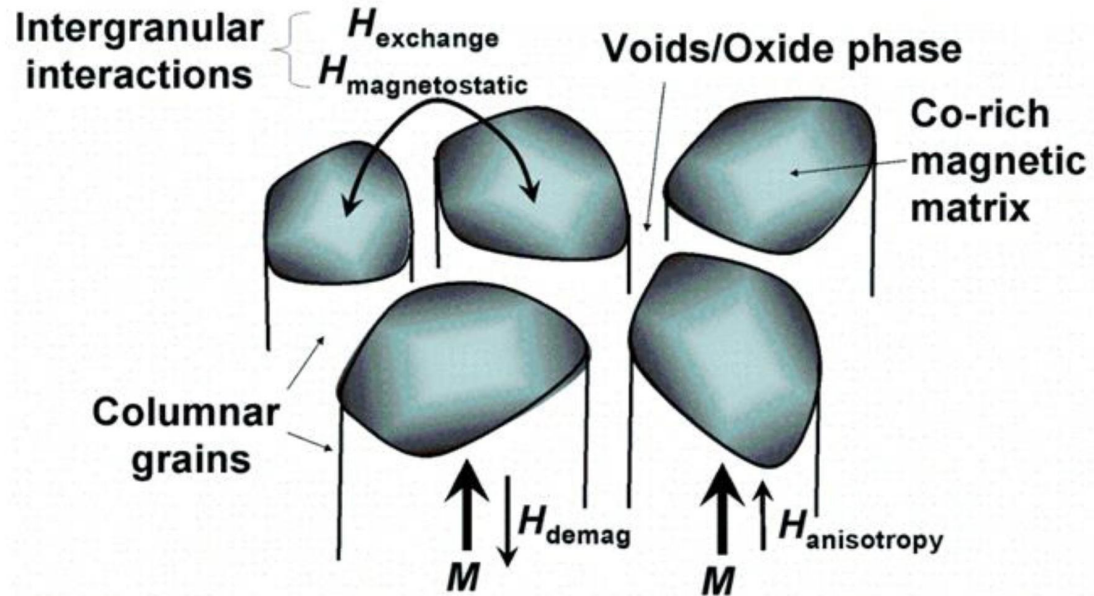
Modern Perpendicular Recording Media (PMR)



Core grain size (avg) ~ 7.0 nm ($\sigma \sim 18\%$)

The CoCrPt-X PMR media

Design perspectives



S. N. Piramanayagam and K. Srinivasan,
J. Magn. Magn. Mater., 321, pp.485-494 (2009)

• Hexagonal Co-Cr-Pt-Oxide

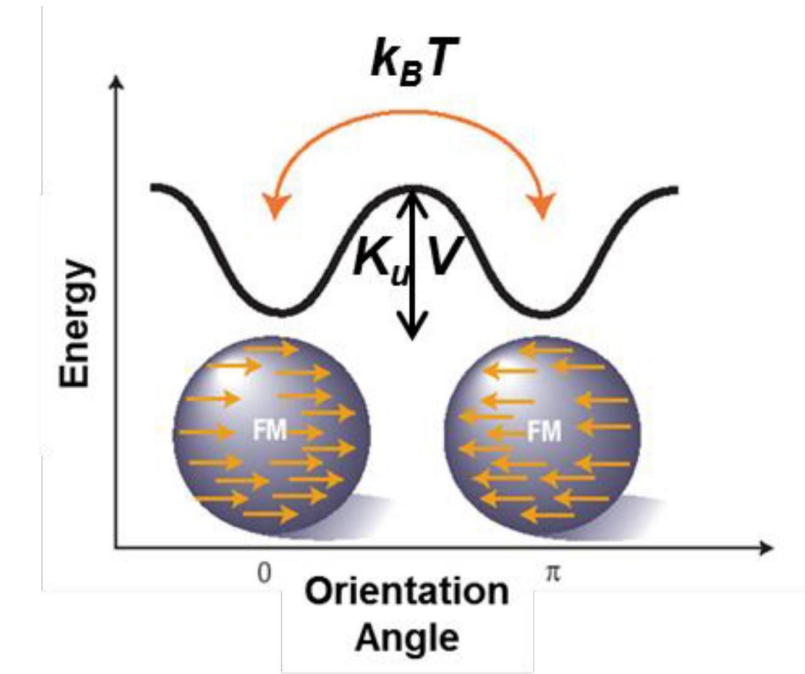
- Cr and Oxide such as SiO_2 , TiO_2 etc. for
 - i. phase separation
 - ii. magnetically isolate grains
 - iii. corrosion resistance
- Pt for increasing anisotropy (K_u)

• Sputter deposition process

- Low mobility conditions for inducing physical segregation of grains

The Media “Trilemma”

How to overcome it?



$SNR \propto \log (N)$

$N = \text{no. of grains/bit}$

**MEDIA
Signal-Noise
Ratio**

**DESIGN
SPACE**

**SUPERPARAMAGNETIC
LIMIT**

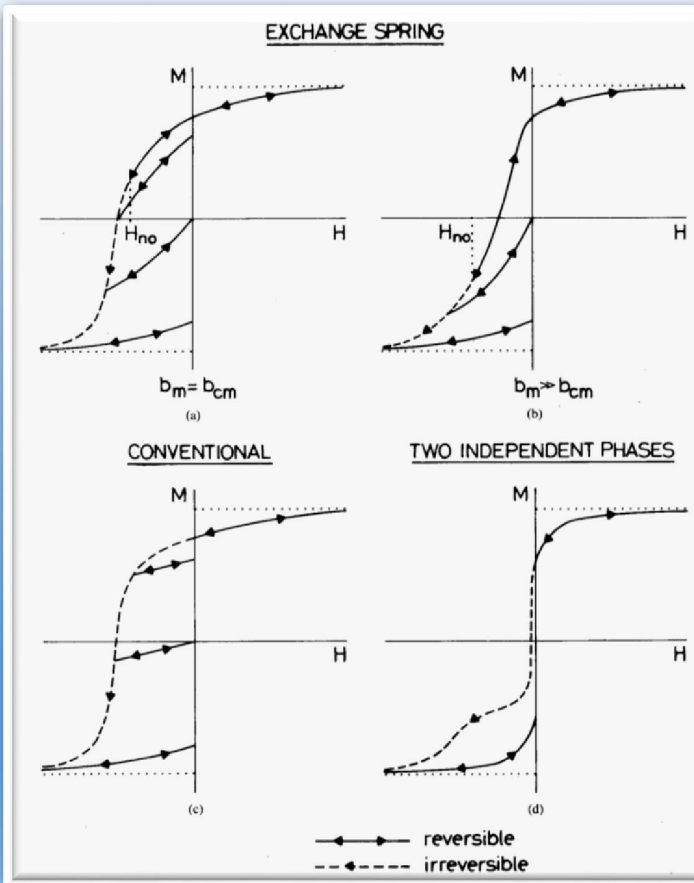
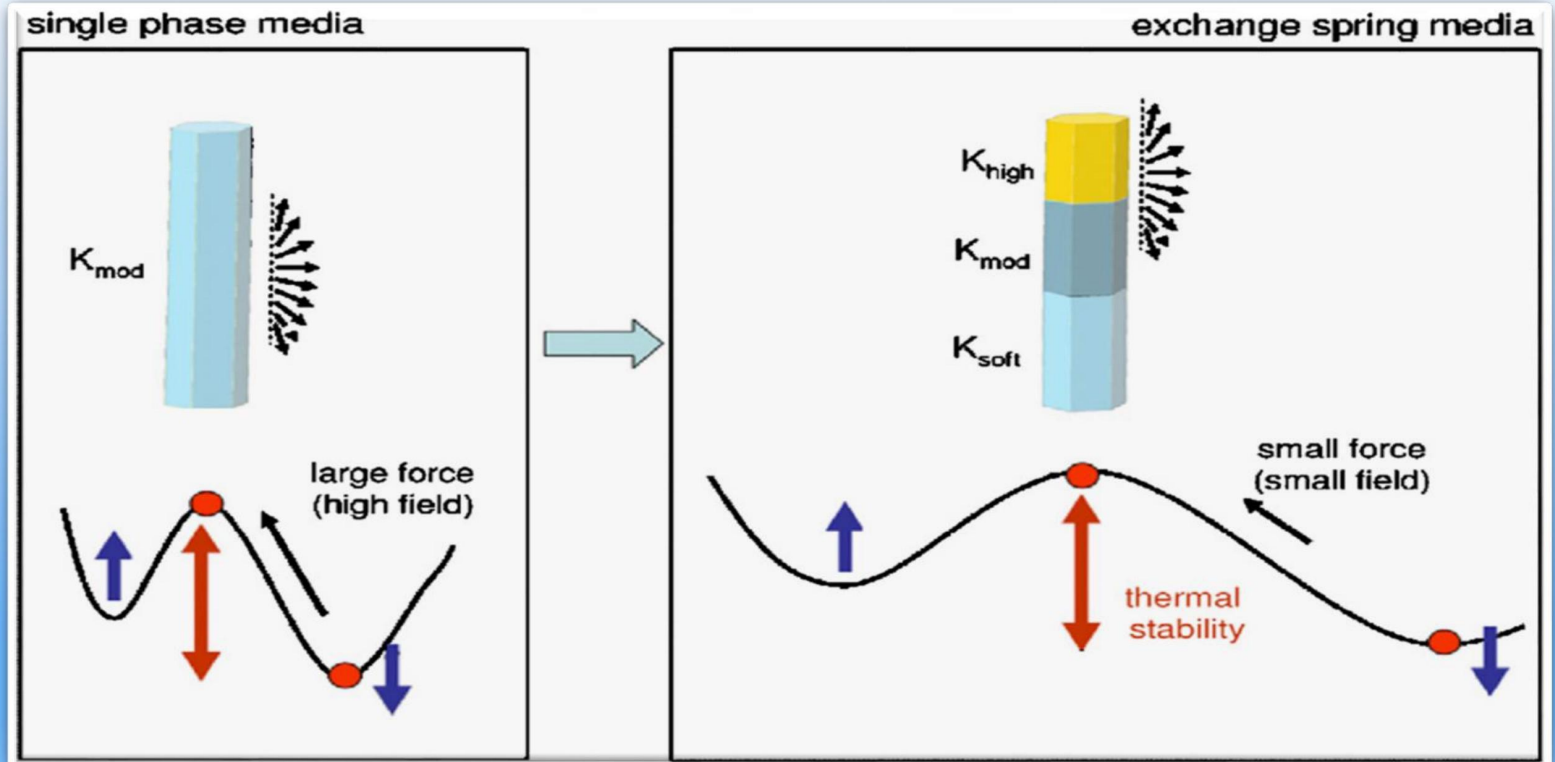
$\frac{K_u V}{k_B T} \sim 60$

**THERMAL
STABILITY**

**WRITABILITY/
SWITCHABILITY**

**Exchange-spring
“ECC” media**

Enter the "exchange-spring"

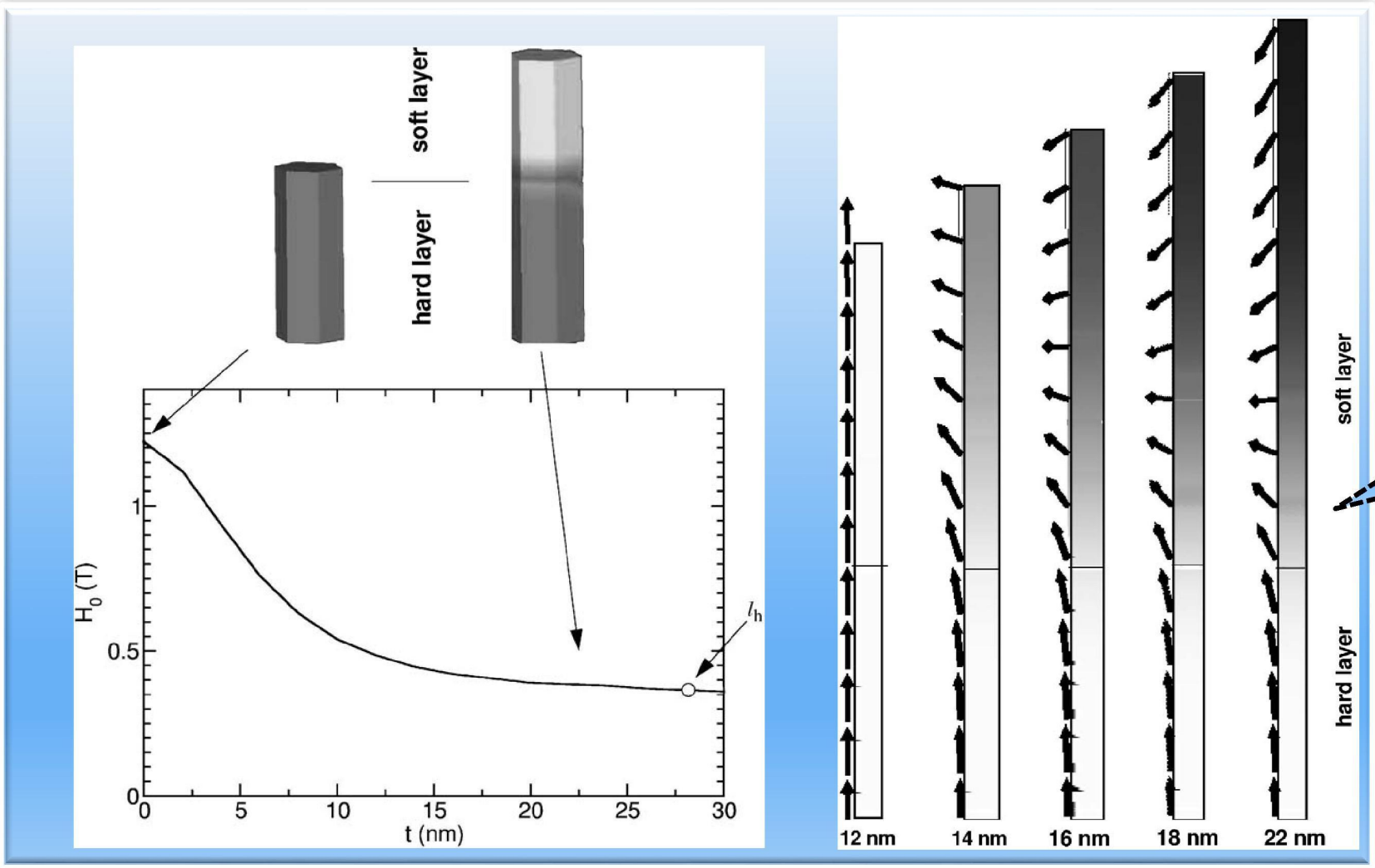


Suess et. al., J. Magn. Magn. Mater., 321, pp.545-554 (2009)

"The Exchange-Spring Magnet: A New Material Principle for Permanent Magnets", IEEE Trans. Magn., 27, pp.3588 (1991)

Keep the same energy barrier (thermal stability) but change the required force (field)!

The "exchange-spring" principle



Incoherent
magnetization
reversal

*Suess, J. Magn. Magn. Mater., 308,
pp. 183-197 (2007)*

Direct evidence for “incoherent reversal”

X-Ray Magnetic Circular Dichroism

APPLIED PHYSICS LETTERS 98, 262507 (2011)

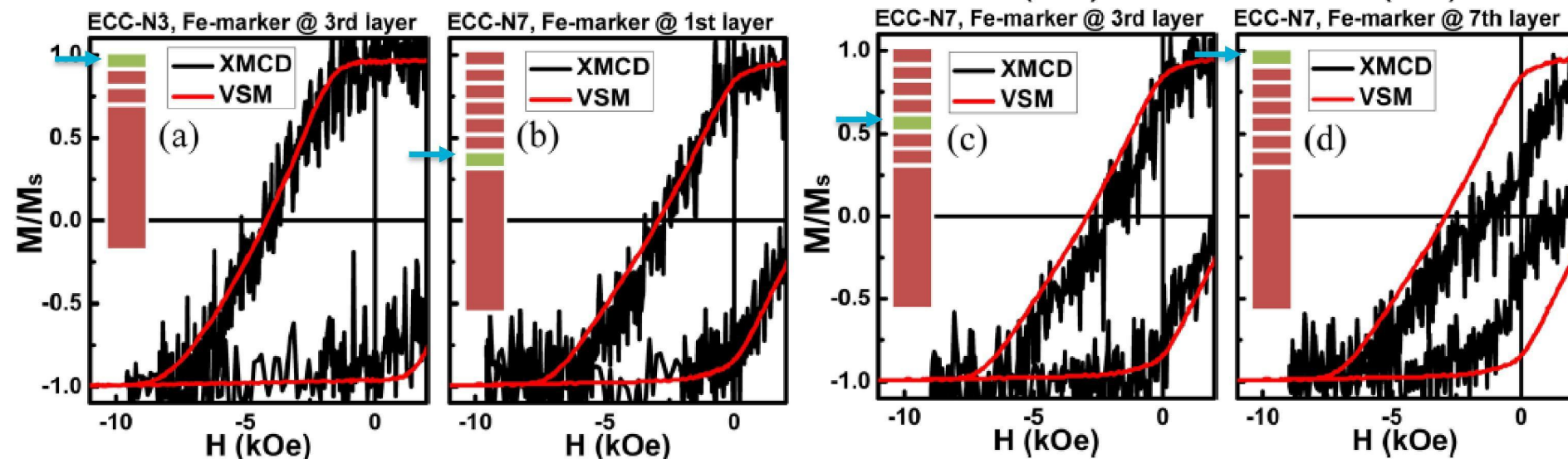
Direct probing magnetization reversal of exchange-coupled-composite media by x-ray magnetic circular dichroism

Hao-Cheng Hou,¹ Dieter Suess,² Jung-Wei Liao,¹ Meng-Shian Lin,¹ Hong-Ji Lin,³
Fan-Hsiu Chang,³ and Chih-Huang Lai^{1,a)}

¹Department of Materials Science and Engineering, National Tsing Hua University, 30013 Hsinchu, Taiwan

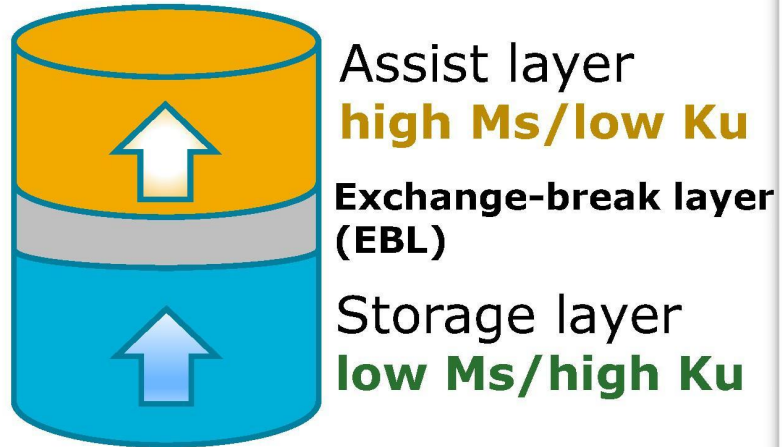
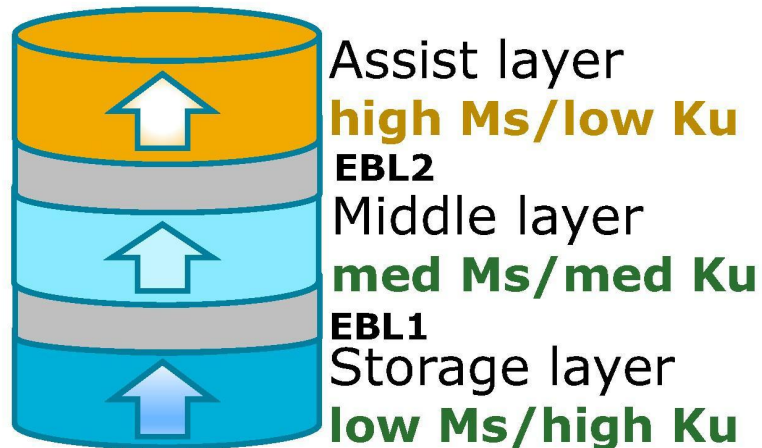
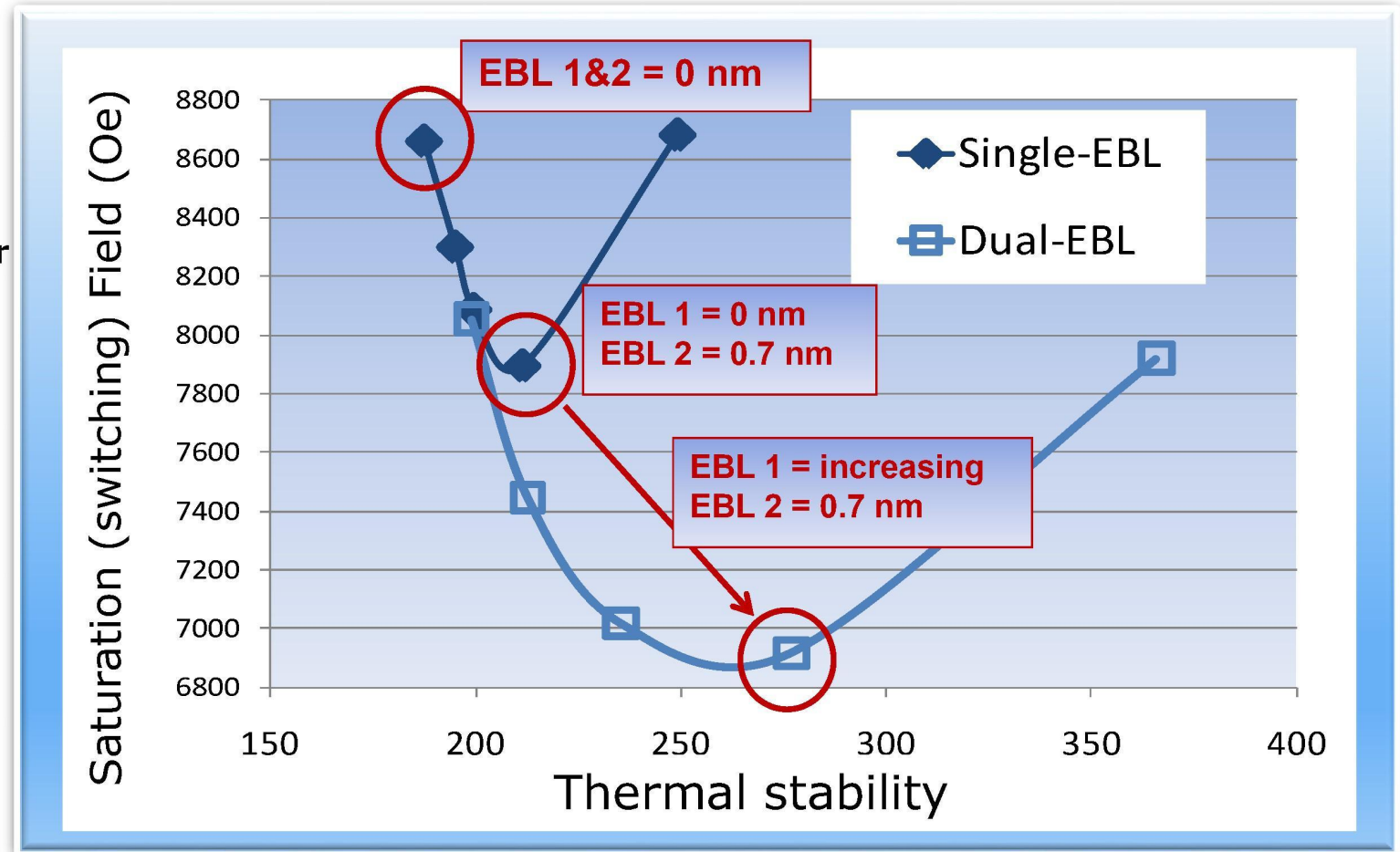
²Institute of Solid State Physics, Vienna University of Technology, 1040 Vienna, Austria

³National Synchrotron Radiation Research Center, 30076 Hsinchu, Taiwan



Interfacial engineering

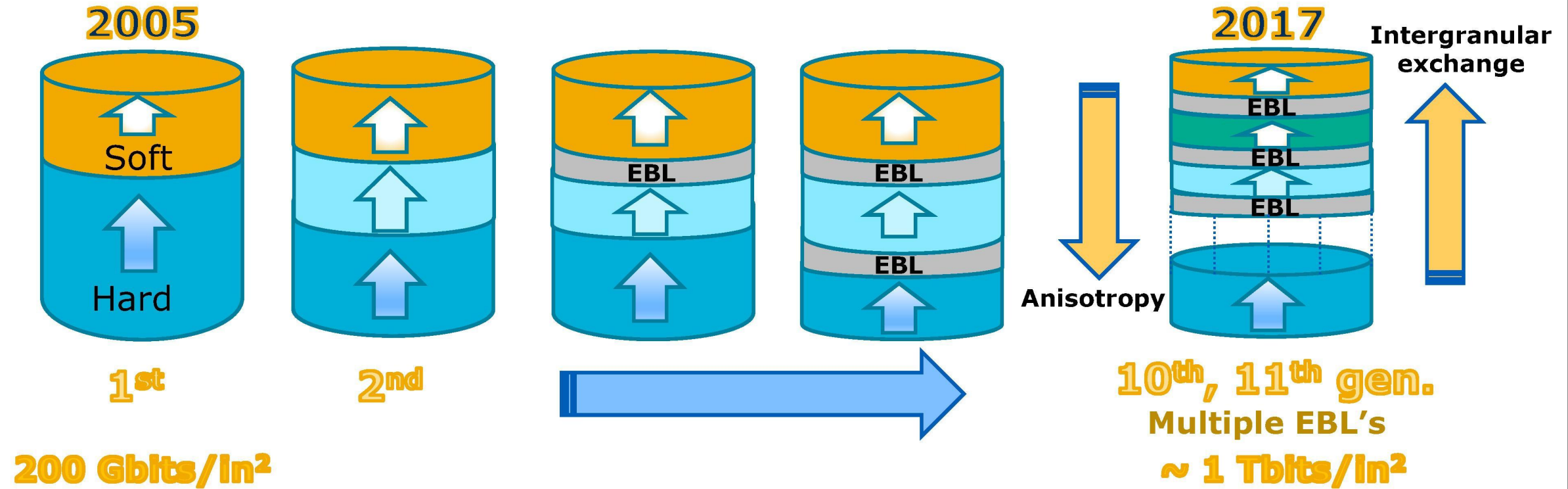
Exchange-break layers



G. Bertero et. al., "Advanced double exchange-break PMR media structures", TMRC 2010

Towards graded anisotropy media

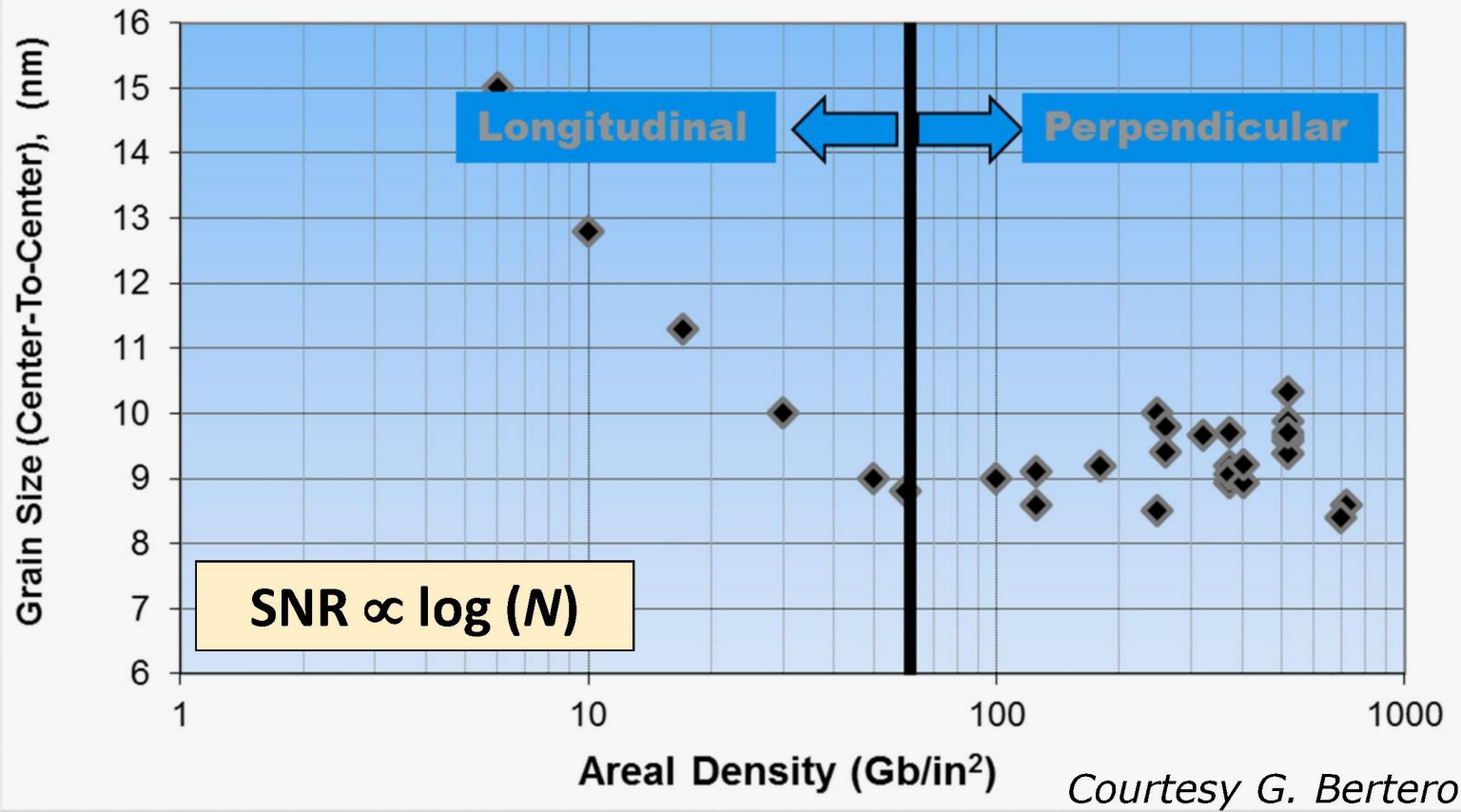
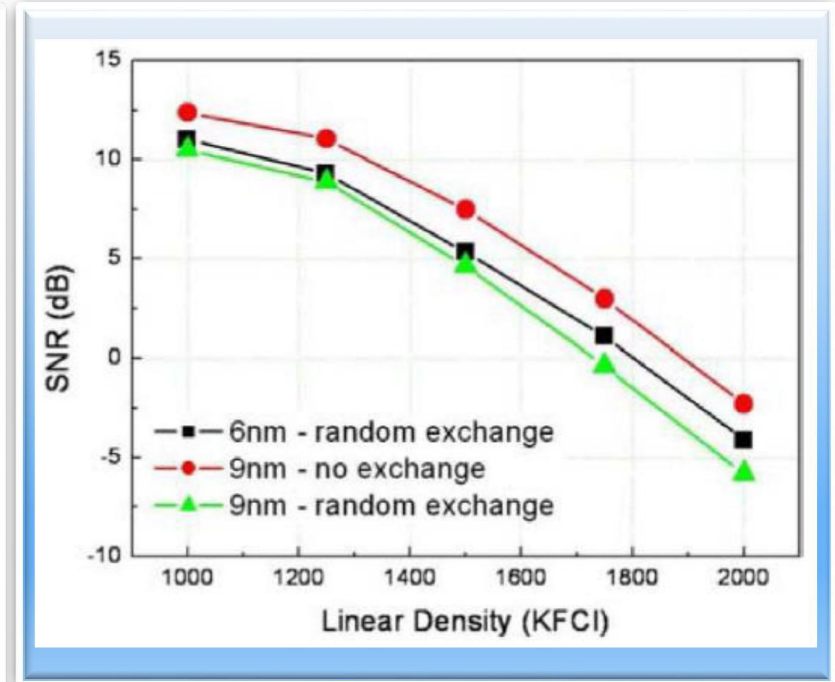
How many EBL's?



Significant increase in complexity!

The Grain Size Challenge

Role of intergranular exchange



J. Zhu, *IEEE Trans. Magn.*, 46, pp.2391 (2010)

Intergranular exchange is a predominant factor!

Grain size scaling appears limiting in PMR media – Why?

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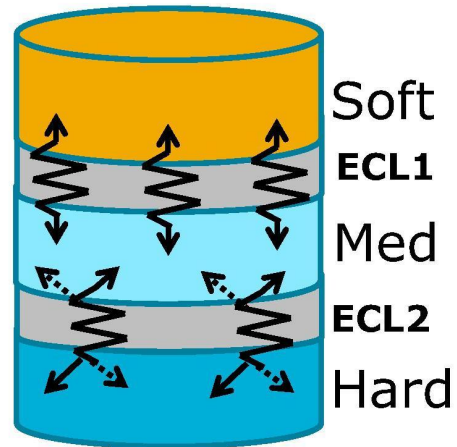
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More interfacial engineering

Can the switchability be further improved?



Type-I ECL:

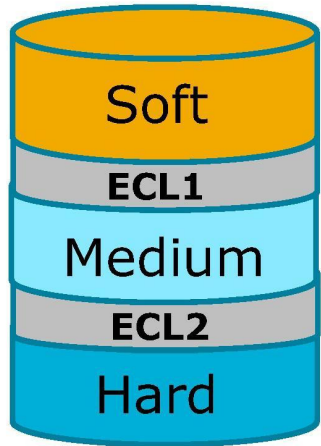
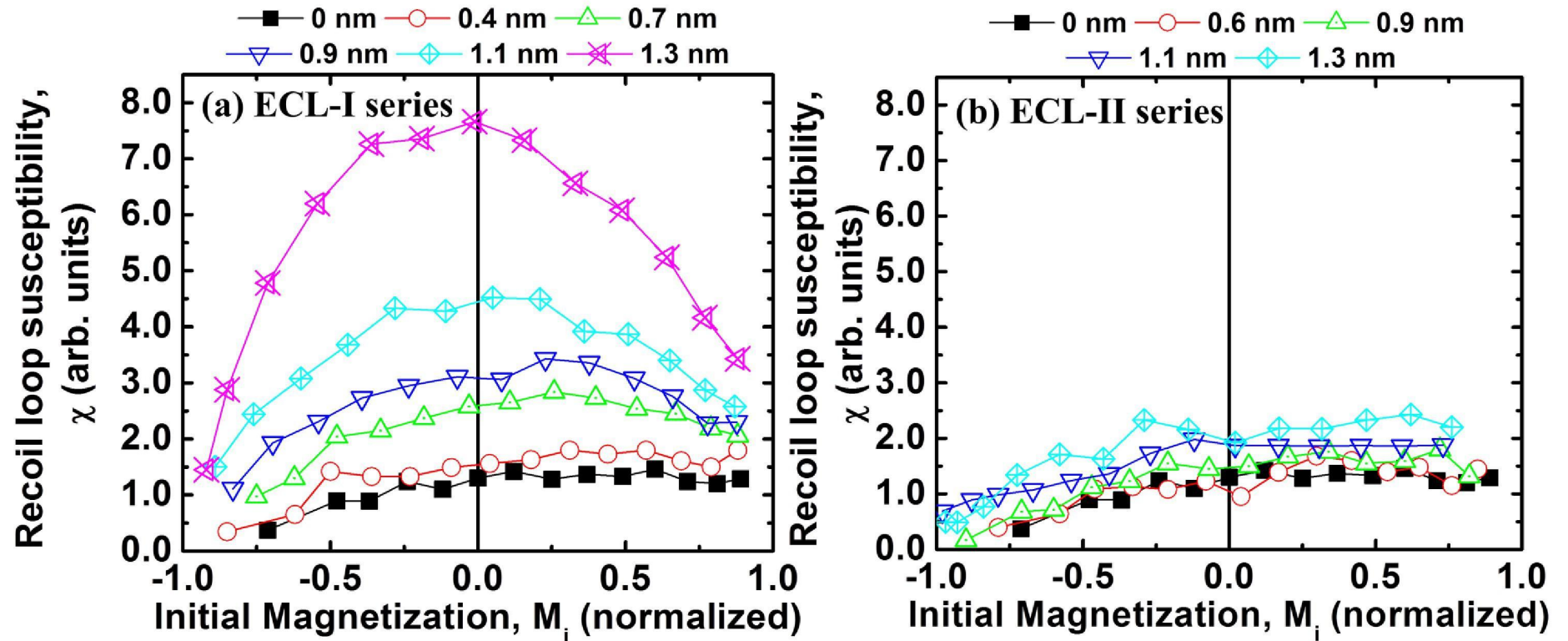
Enhanced exchange-spring

Type-II ECL:

Demagnetized/AP-coupled
interface

Evidence for two different modes of reversal

Reversibility: Recoil Loop Susceptibility

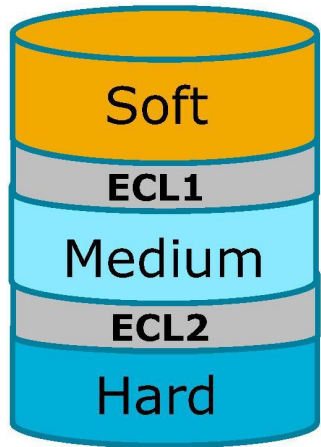
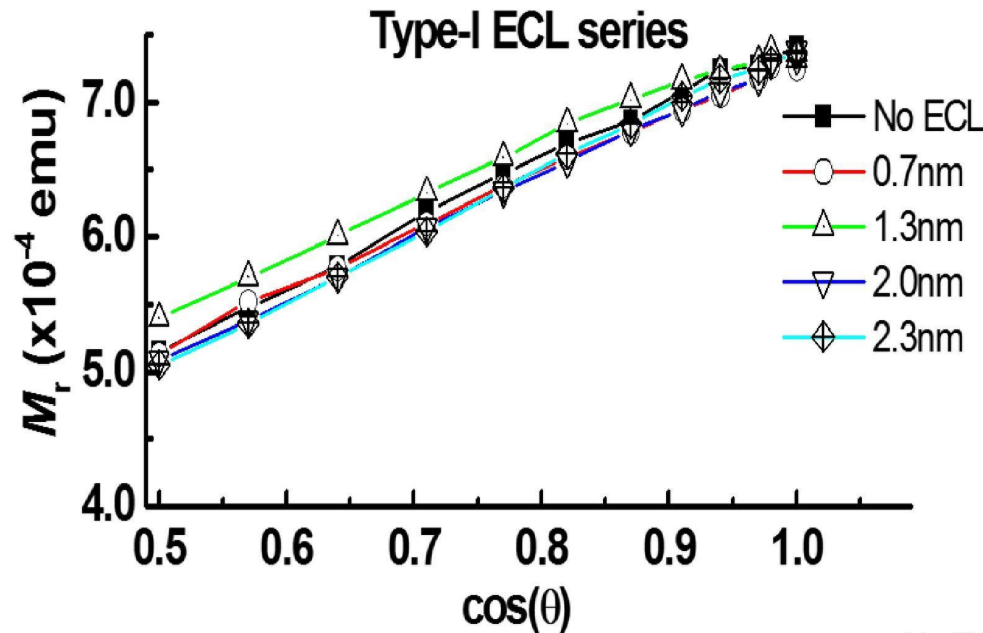
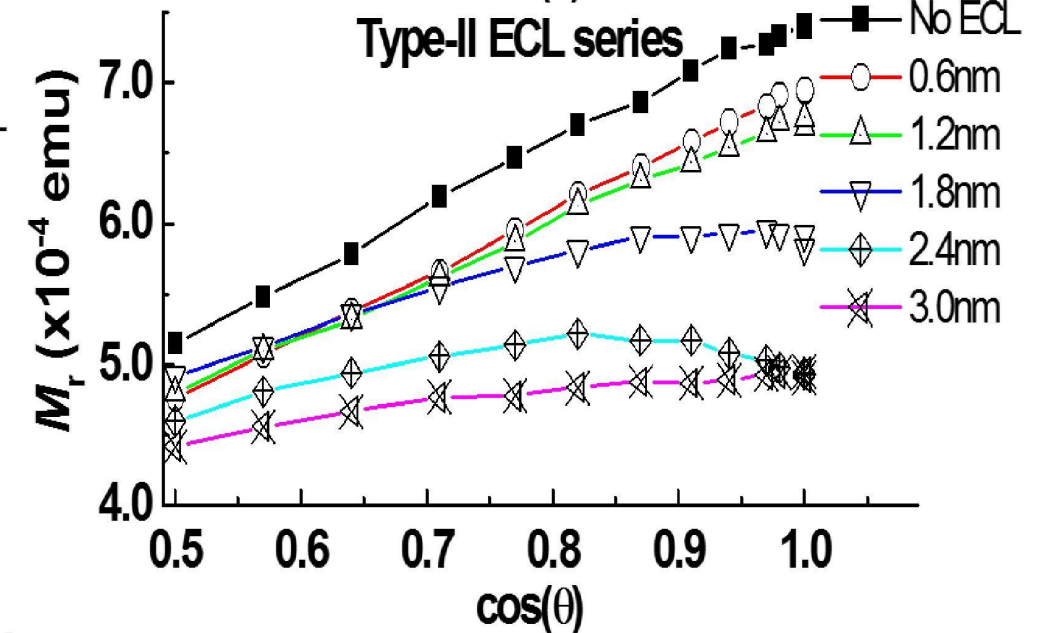


K. Srinivasan et. al.,
59th MMM Conf.,
Paper FQ-06 (2014)

No change in susceptibility for type-II ECL series!

More evidence for two reversal modes

Angular dependence of remanent magnetization



K. Srinivasan et. al.,
59th MMM Conf.,
Paper FQ-06 (2014)

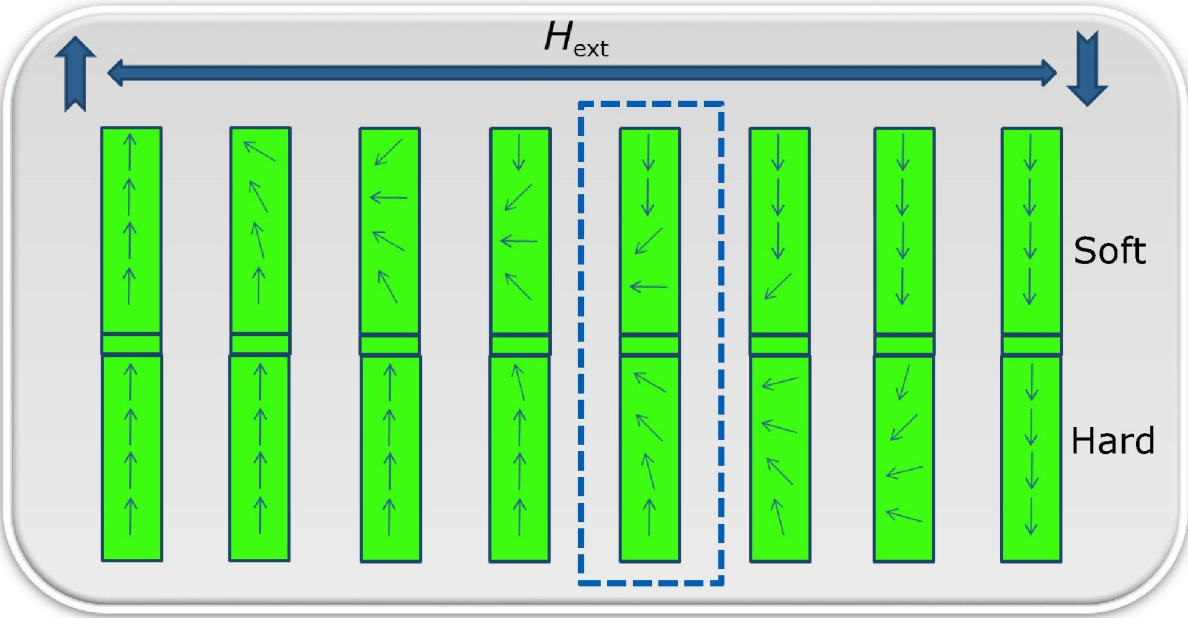
Linear $\cos(\theta)$
dependence for type-I

Complex dependence
for type-II

Two types of switching mechanisms

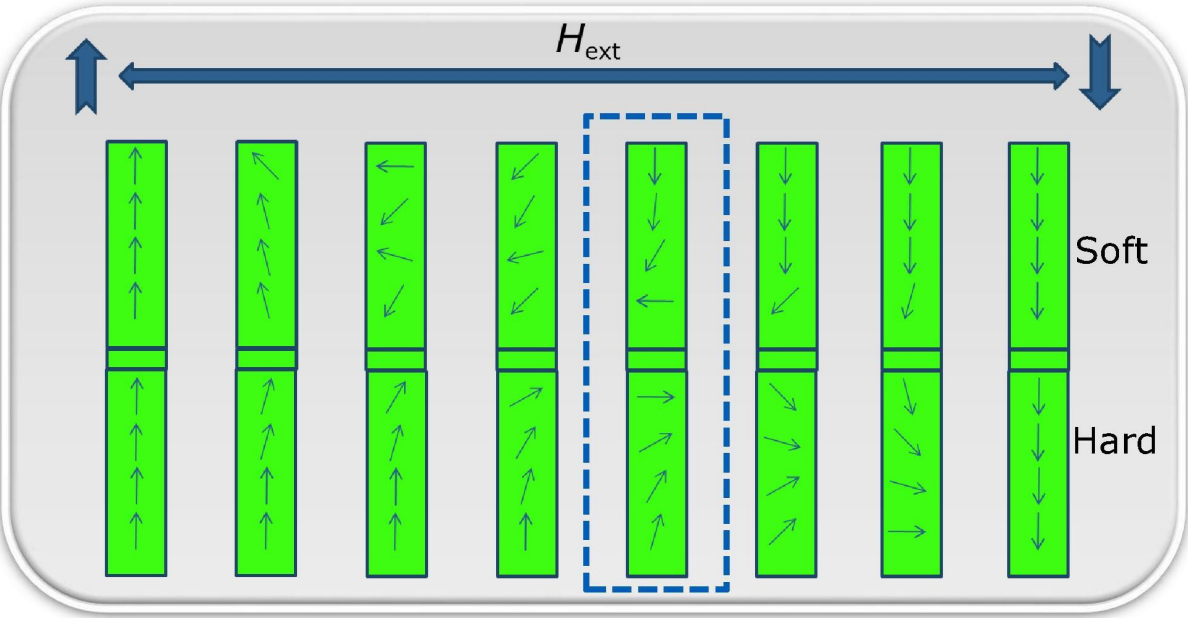
What interfacial "tuning" can do

Type-I ECL



Exchange-spring

Type-II ECL



Demagnetized /AP-coupled

K. Srinivasan et. al., 59th MMM Conf.,
Paper FQ-06 (2014)

So much for the
present...

...what about the
future??



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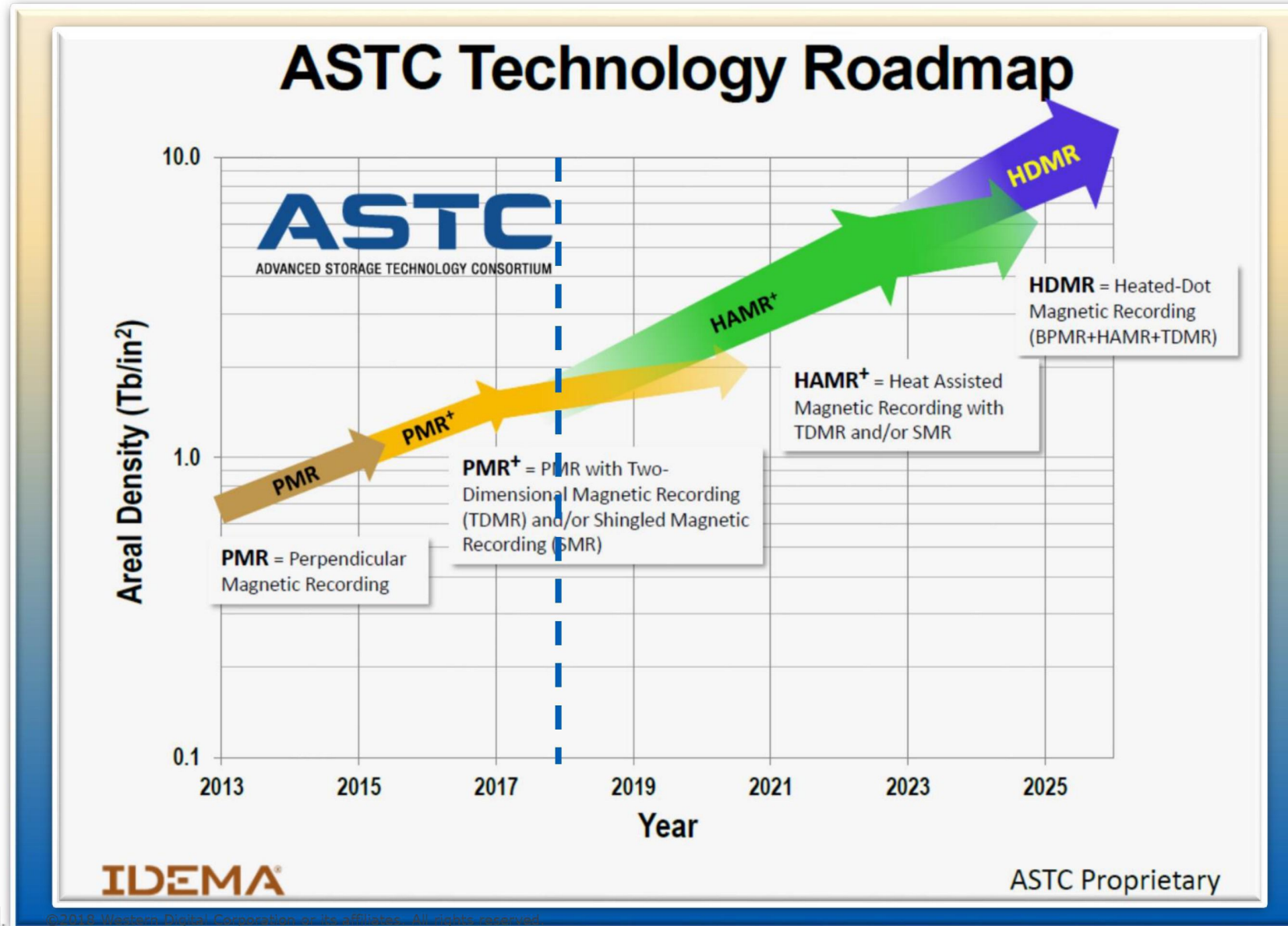
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19

Where is magnetic recording headed?



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MR Technologies GmbH
Ex. 2010, IPR2026-00015
Page 20 of 33

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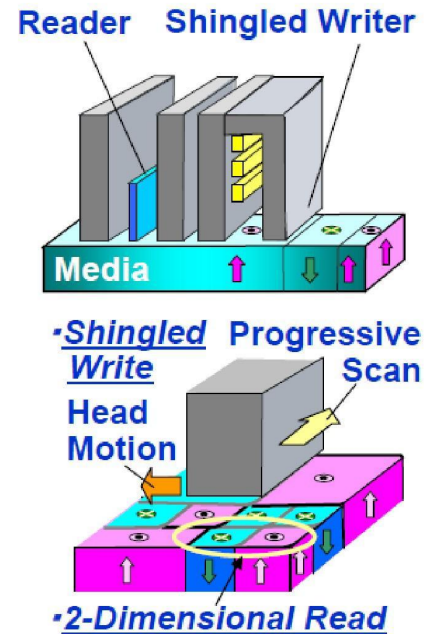
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Future technology options

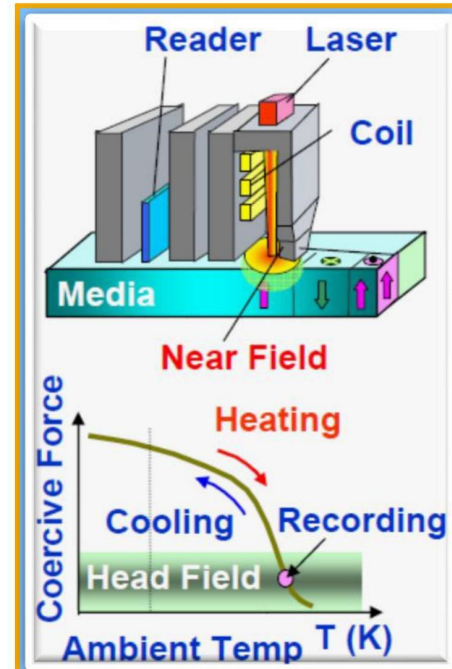
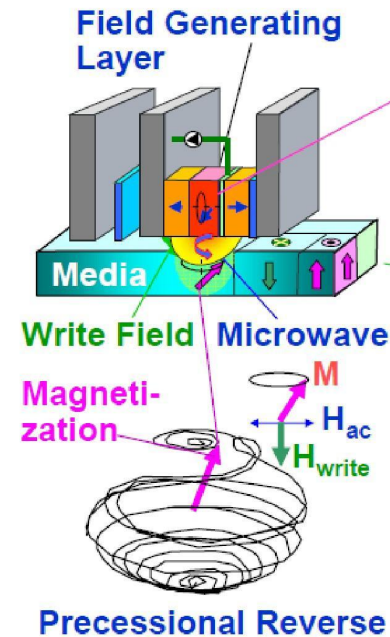
Current

Shingled / Two Dimensional Magnetic Recording



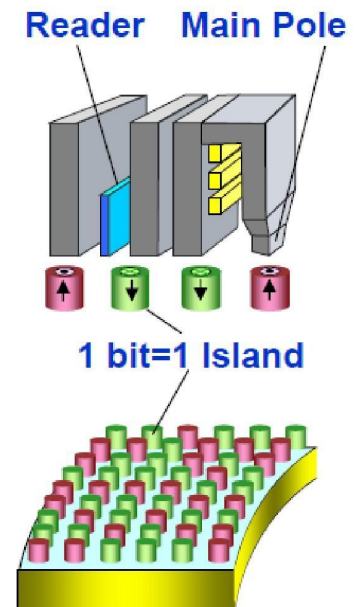
Near-term

Heat / Microwave Assisted Magnetic Recording



Far-out

Bit Patterned Media



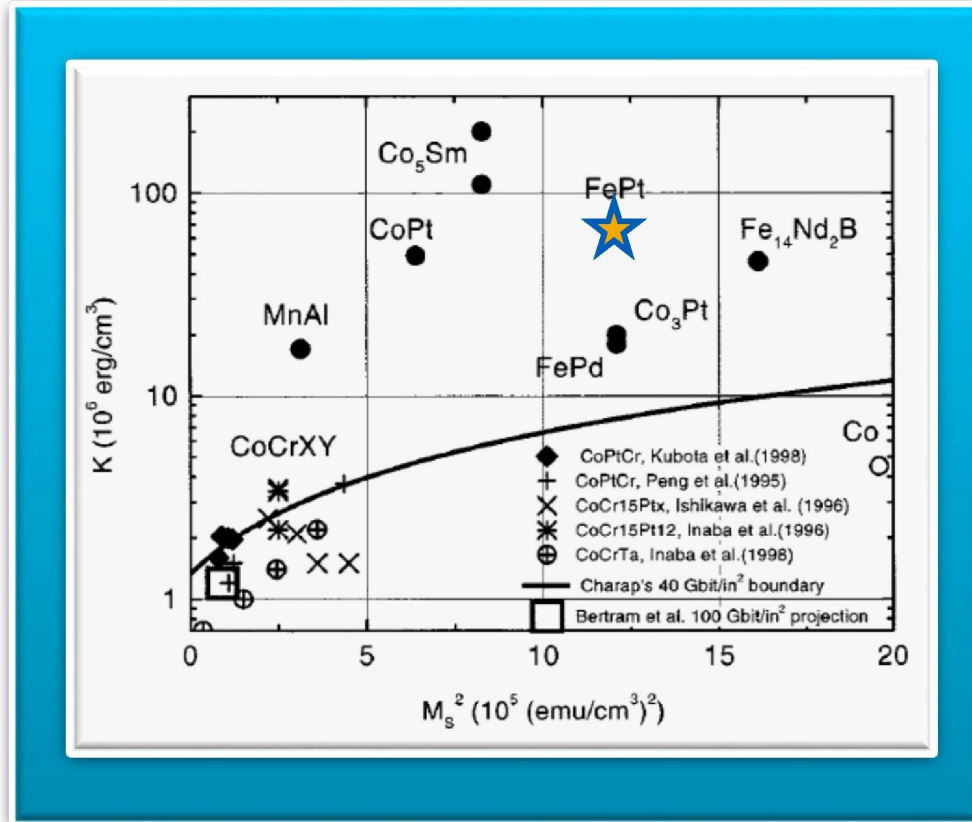
$$\frac{dH_{eff}}{dx} = \frac{dH_k}{dT} \cdot \frac{dT}{dx}$$

Source: Y. Shiroishi, FA-01, Intermag (2009)

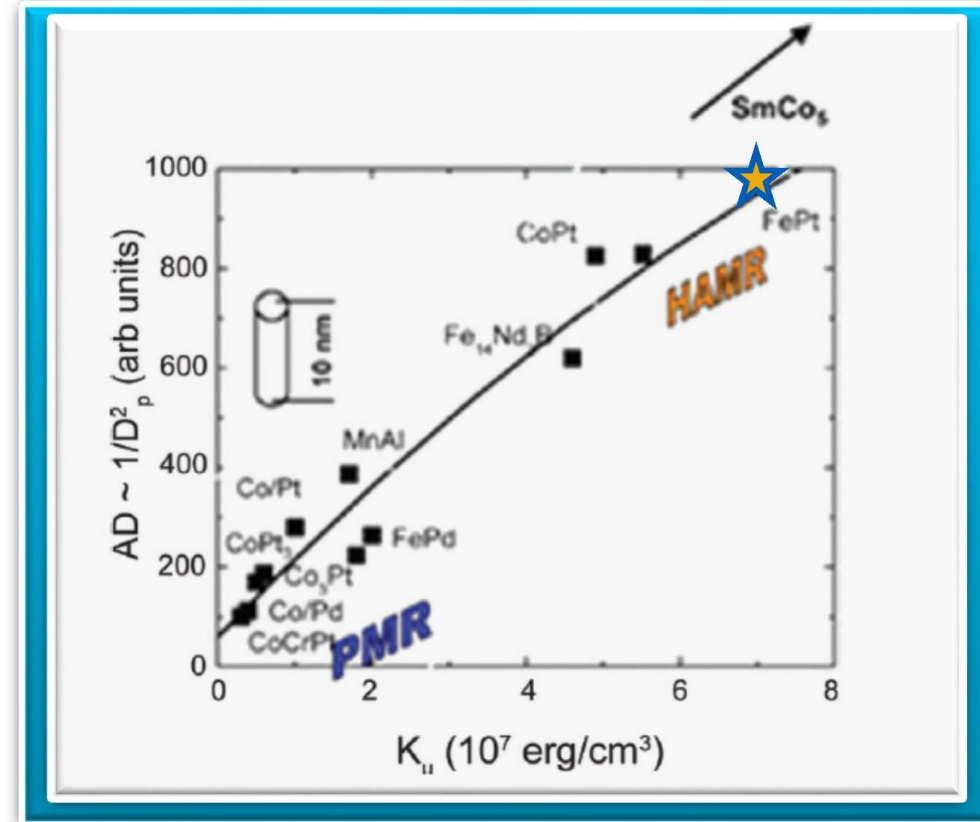
- **Very high K_u** magnetic materials enable media with smaller thermally stable grains.
- Higher temperature gradients allow for **high effective field gradients**.

Media material choices

What are the high Ku magnetic materials?



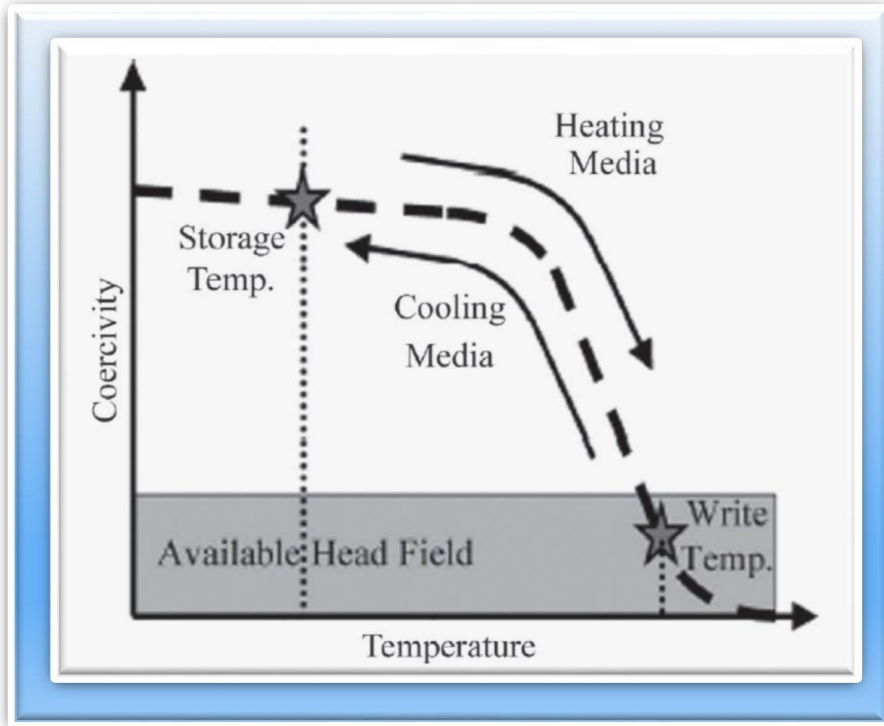
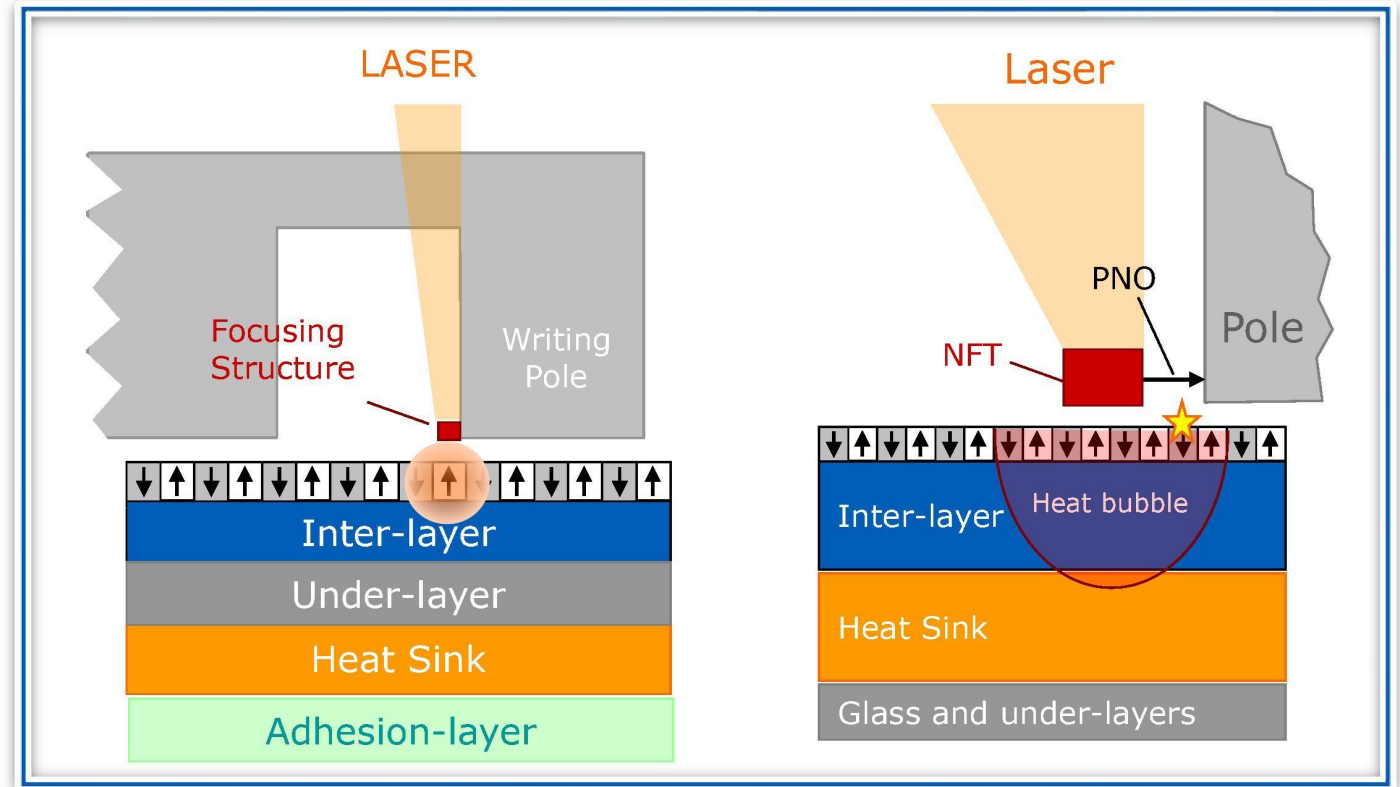
Weller et al., IEEE Trans Magn., 36, pp. 10 (2000)



E. Gage et. al., ch.4 "Energy Assisted Magnetic Recording", in "Ultrahigh Density Magnetic Recording", eds. Gaspare & Varvaro (2016)

Heat-assisted magnetic recording

Principles of HAMR recording



E. Gage et. al., ch.4 "Energy Assisted Magnetic Recording", in "Ultrahigh Density Magnetic Recording", eds. Gaspare & Varvaro (2016)

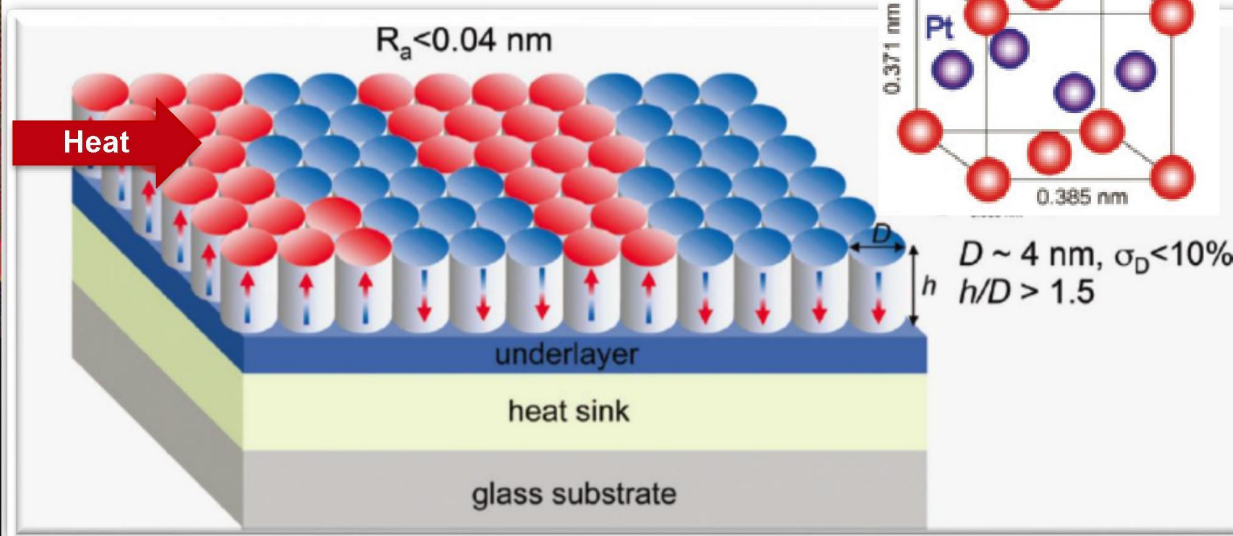
$$\frac{dH_{eff}}{dx} = \frac{dH_k}{dT} \cdot \frac{dT}{dx}$$

Thermal gradient is a key enabler

The Fe-Pt HAMR recording medium

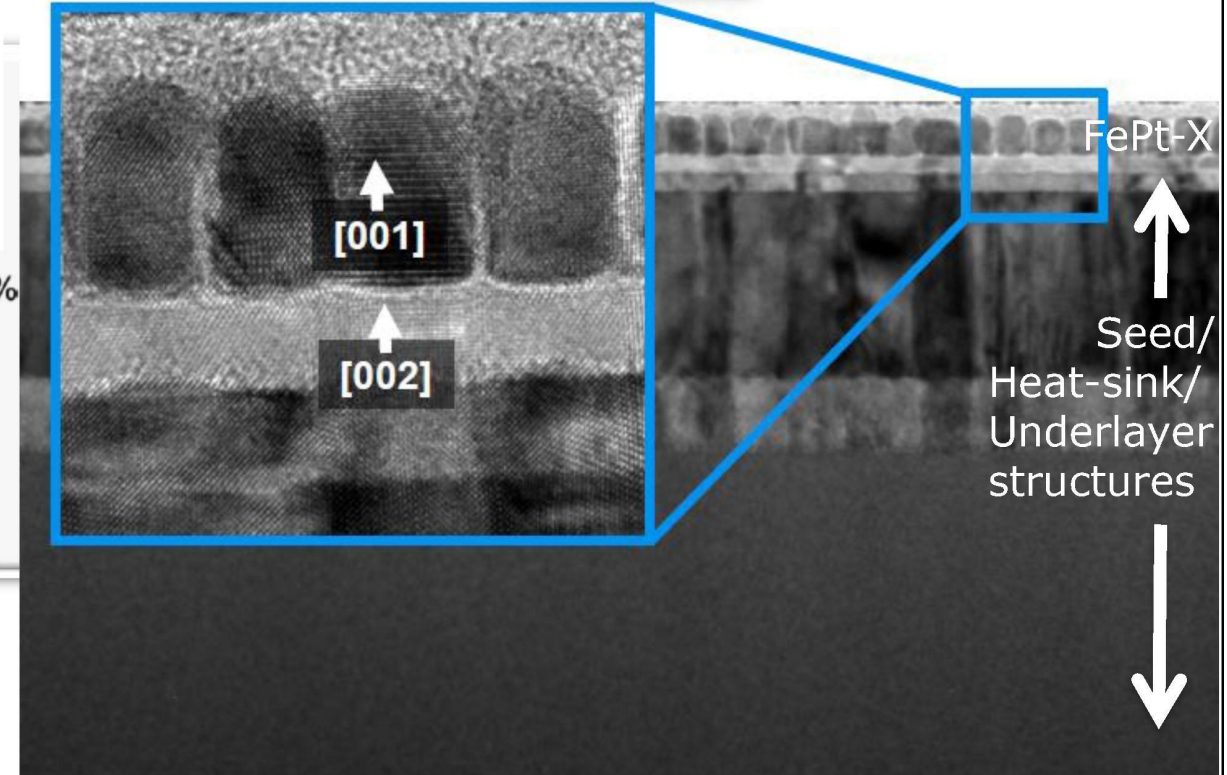
Media requirements

Ideal



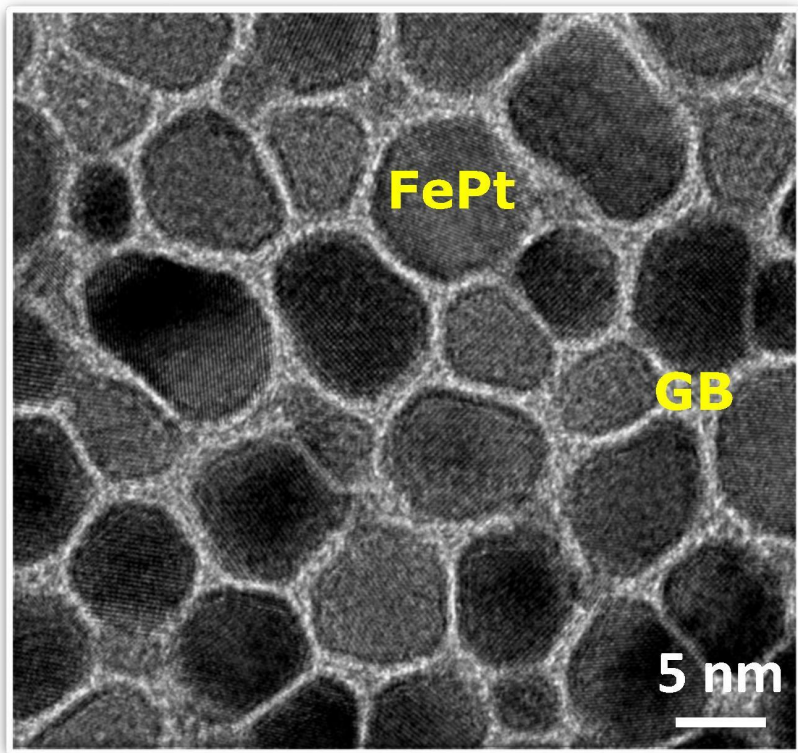
K. Hono et. al., ch.5 "L10 FePt granular films for HAMR media", in "Ultrahigh Density Magnetic Recording", eds. Gaspare & Varvaro (2016)

Actual

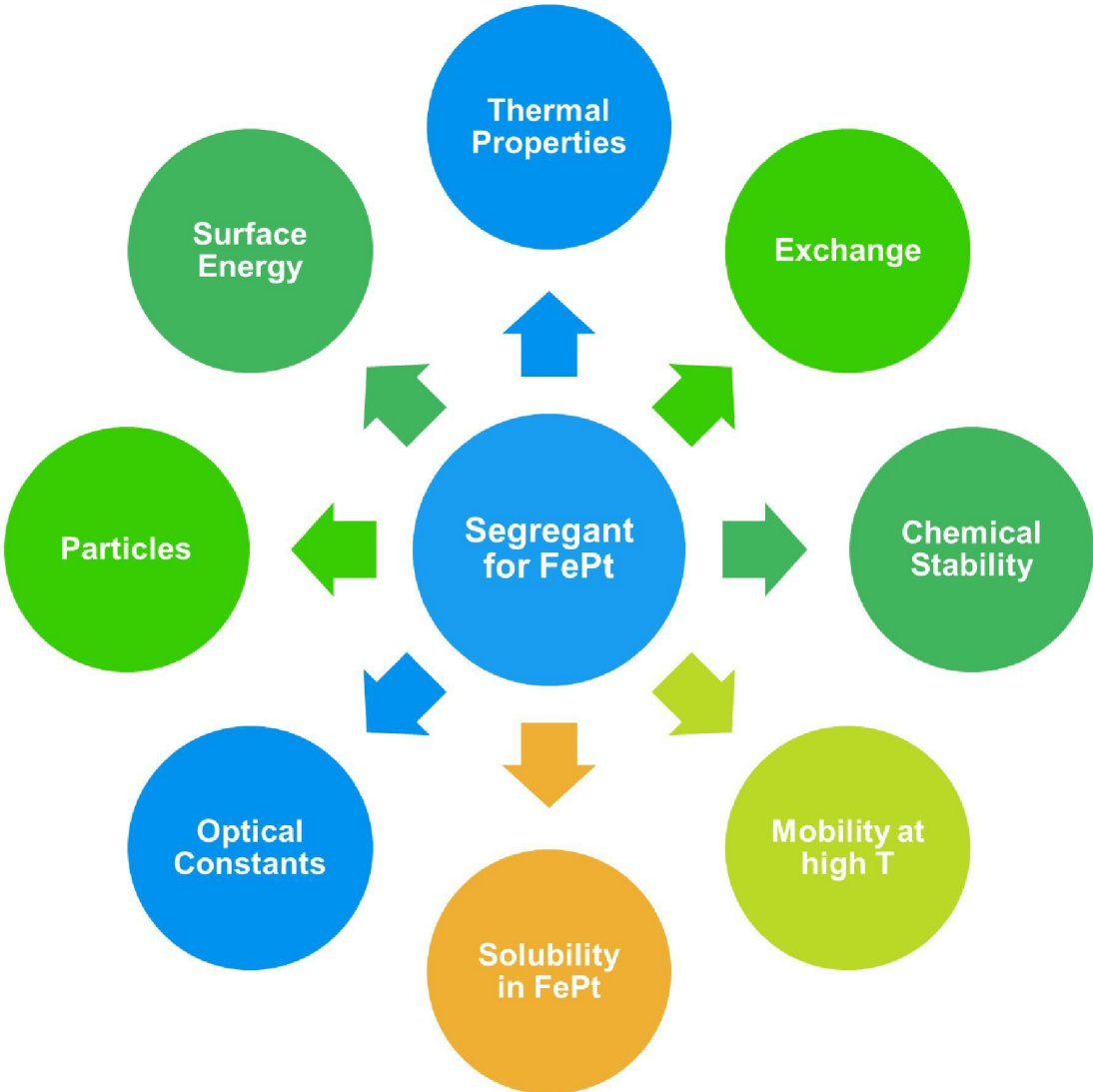


The FePt-X media system

Design perspectives



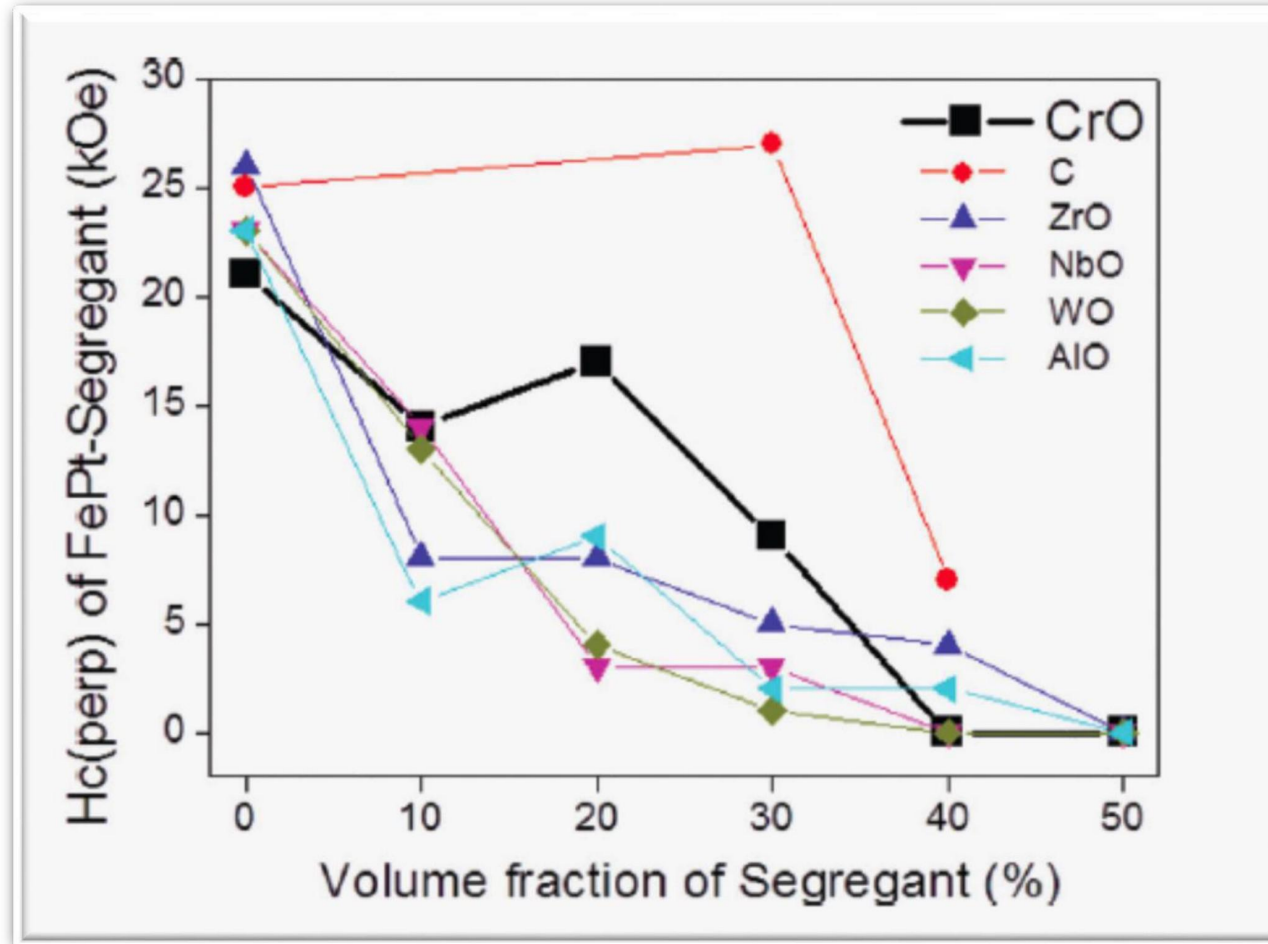
Grain boundary – C, SiO₂, B, other oxides, nitrides & carbides



The "ideal" segregant

Effect on magnetic properties

Carbon is a
unique segregant!

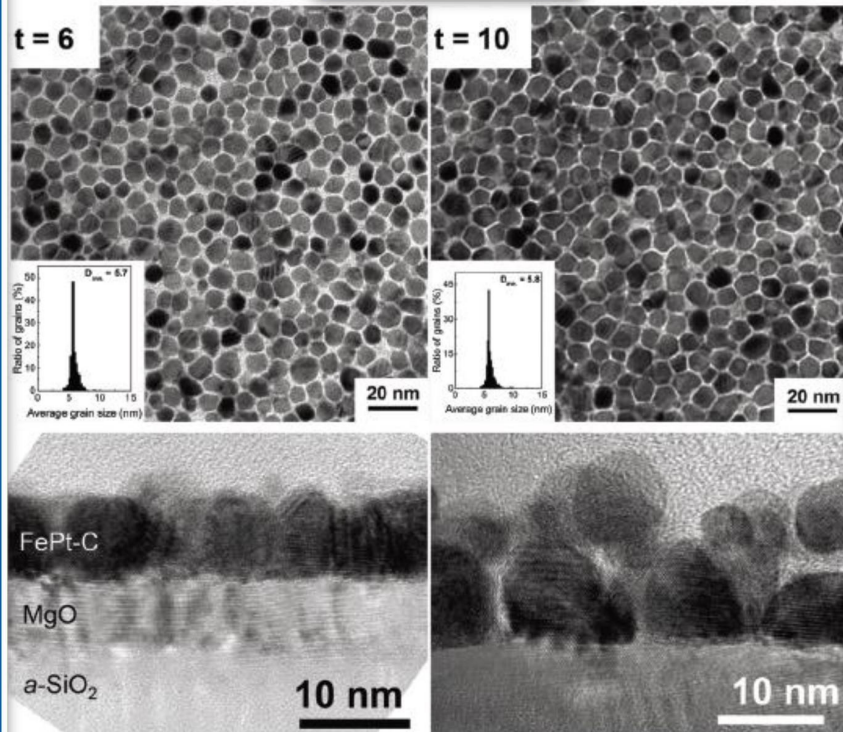


Shiroyama et. al., IEEE Trans. Magn., 49, p. 3616 (2013)

Single-layered FePt-X systems

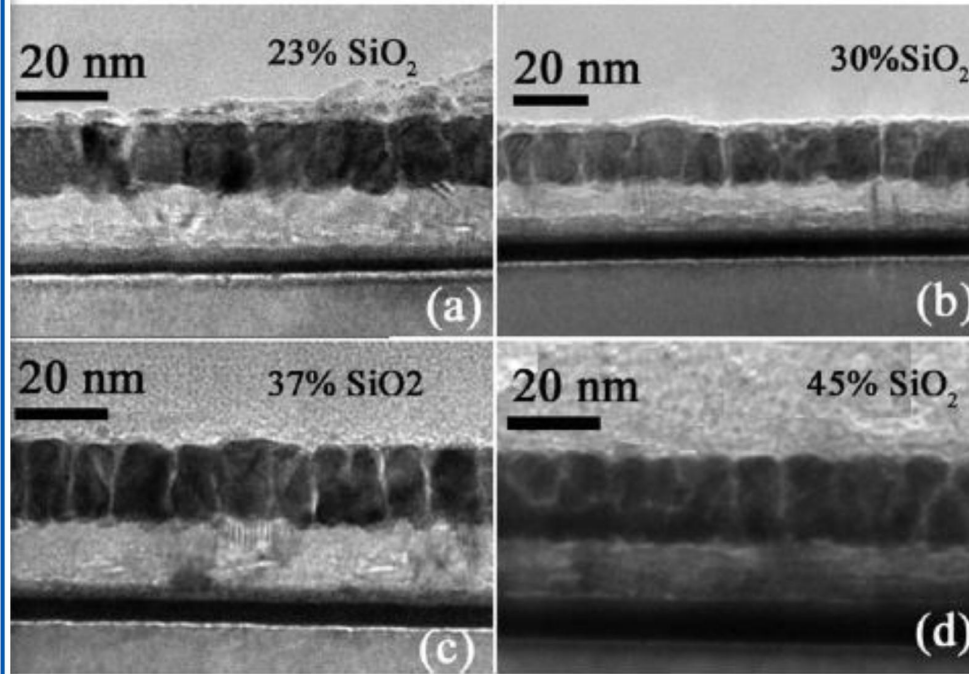
Types of segregants

FePt-C



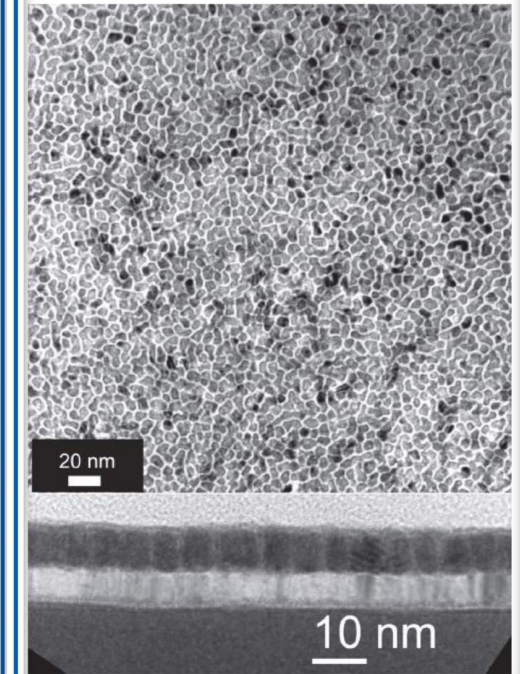
A. Perumal et. al., Appl. Phys. Expr., 1, p. 101301 (2008)

FePt-SiO₂



Yang et. al., J. Appl. Phys., 111, p. 07B720 (2012)

FePt-TiO₂



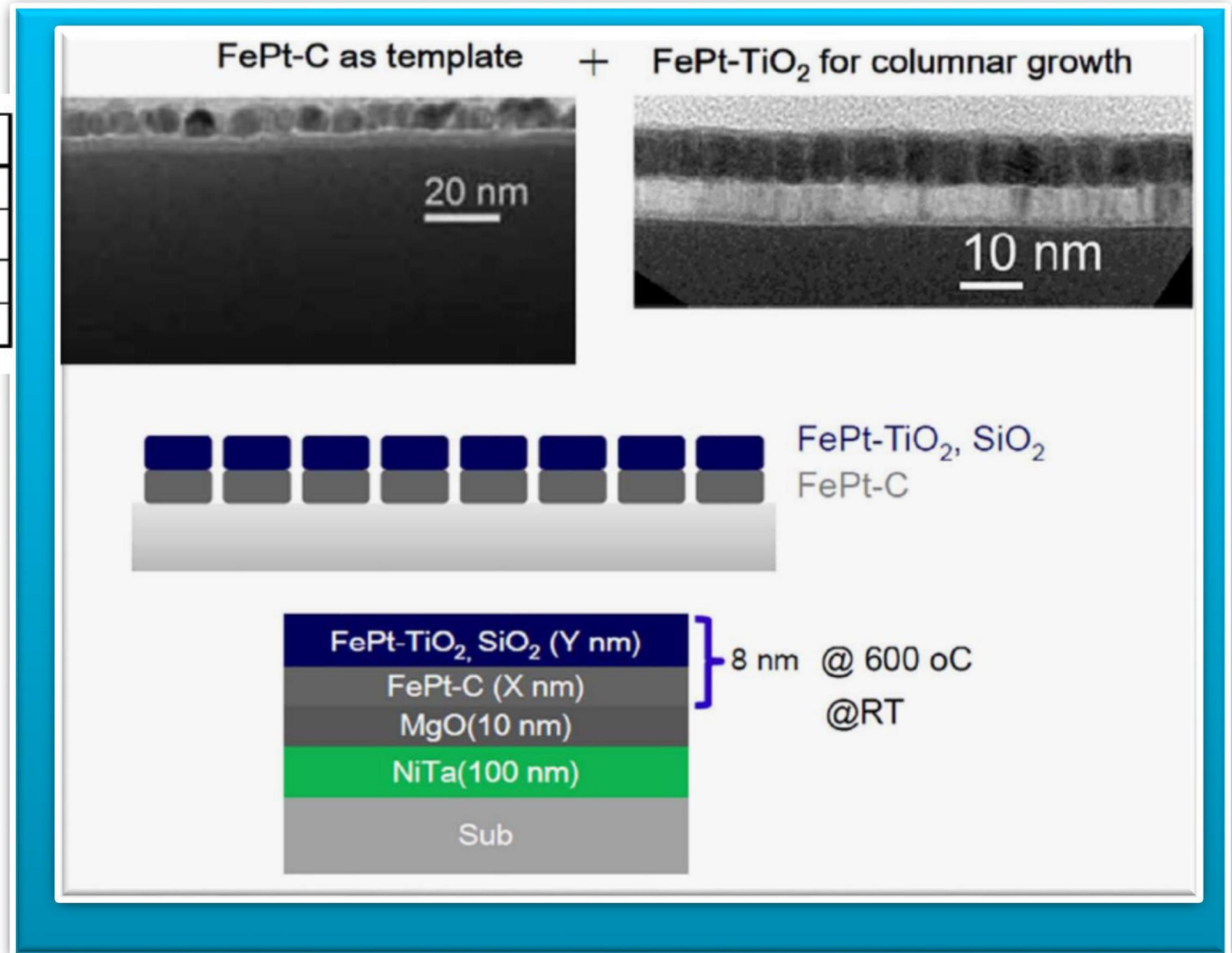
Varaprasad et. al., IEEE Trans. Magn., 49, p. 718 (2013)

Multi-layered approach: FePt-X/FePt-Y systems

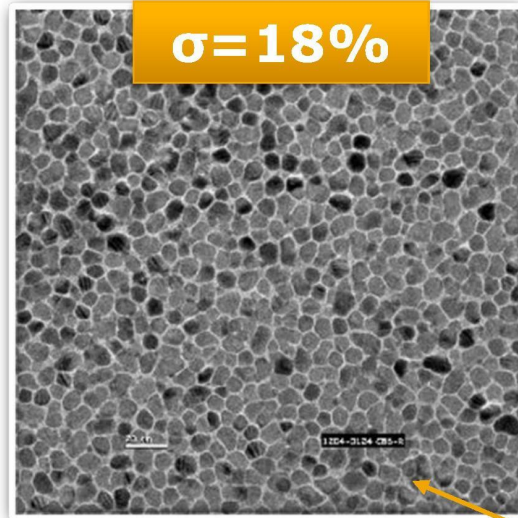
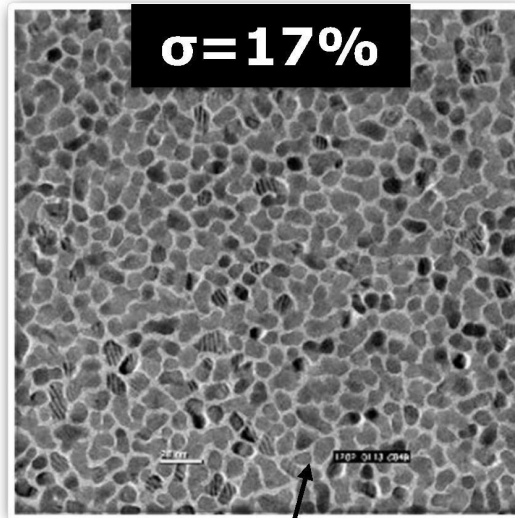
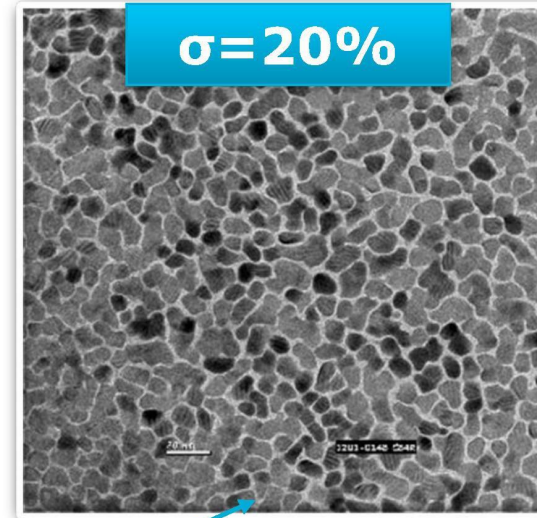
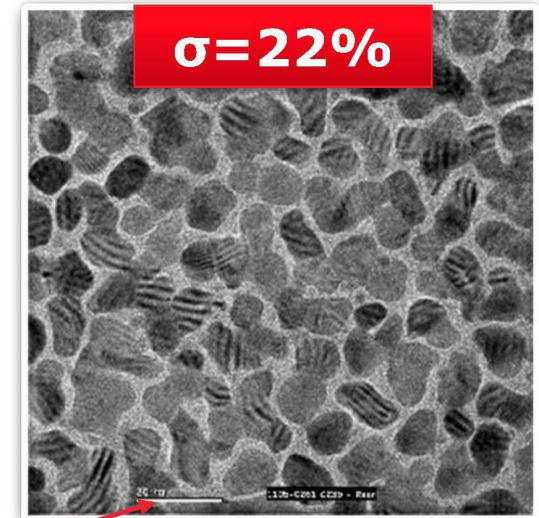
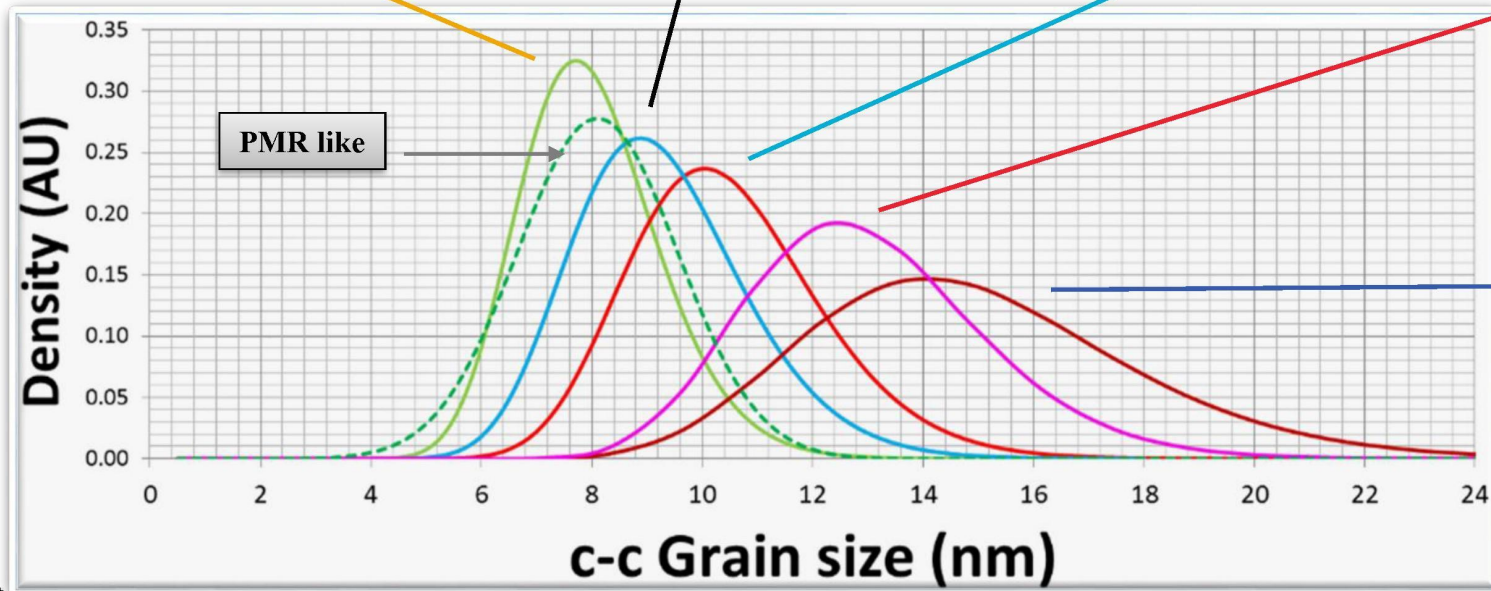
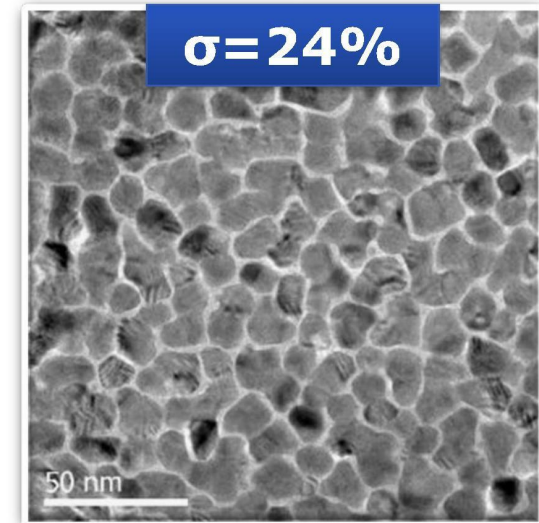
Combining segregant types

C segregant (40 vol%)	SiO ₂ or TiO ₂ segregants (50 vol%)
1. Good particle separation	1. Poor particle separation
2. High degree of L1 ₀ ordering	2. Poor degree of L1 ₀ ordering
3. Spherical type grains	3. Cylindrical type grains
4. Rough surface	4. Excellent surface smoothness

Weller et. al., "A HAMR Media Technology Roadmap to an Areal Density of 4 Tbits/in²", IEEE Trans. Magn., 50, p. 3100108 (2014)



HAMR media grain size progression



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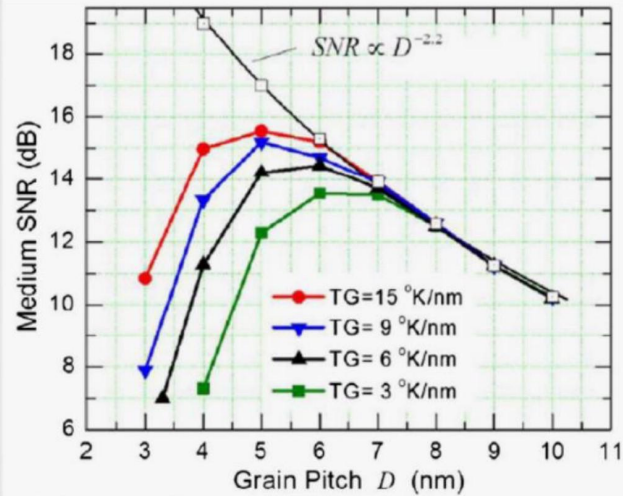
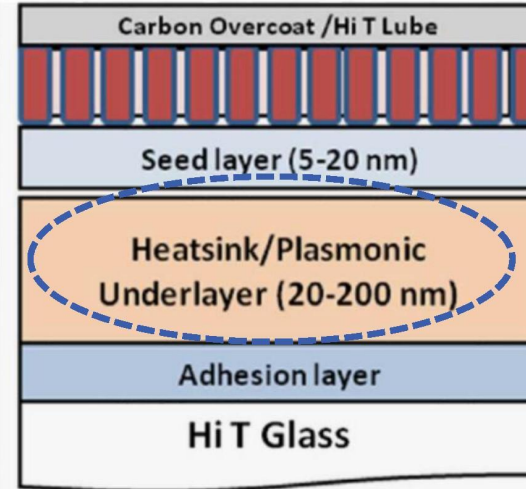
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29

Challenges of HAMR recording medium

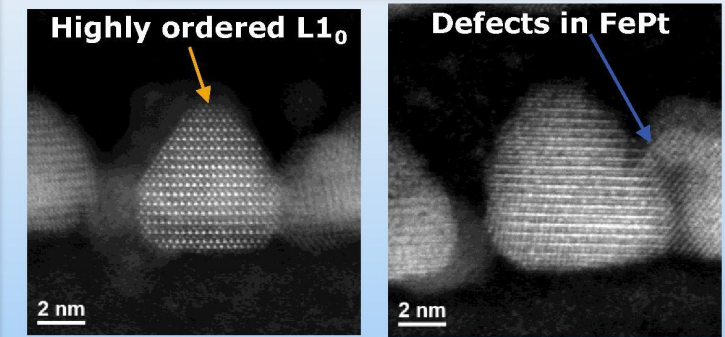
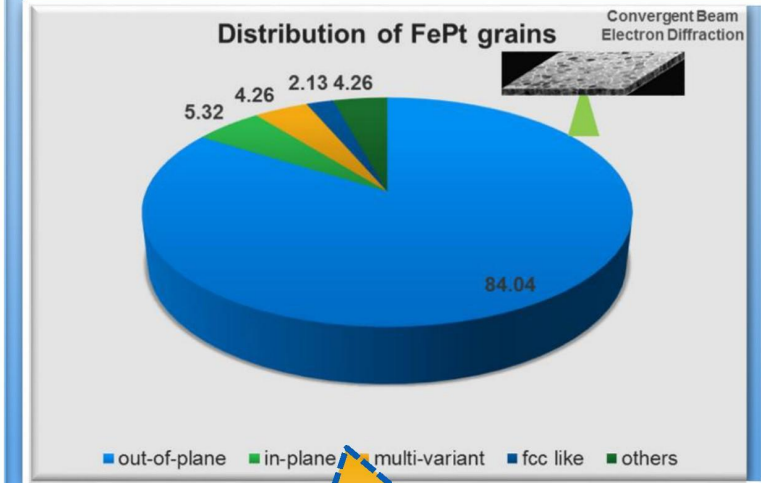
Thermal gradient (TG)



Significant challenge

Weller et al.,
IEEE Trans.
Magn., 50, p.
3100108 (2014)

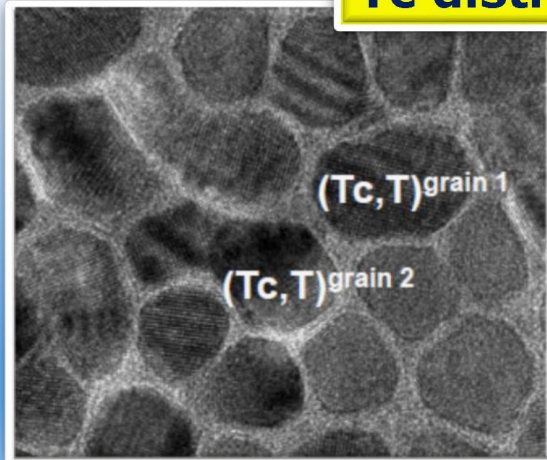
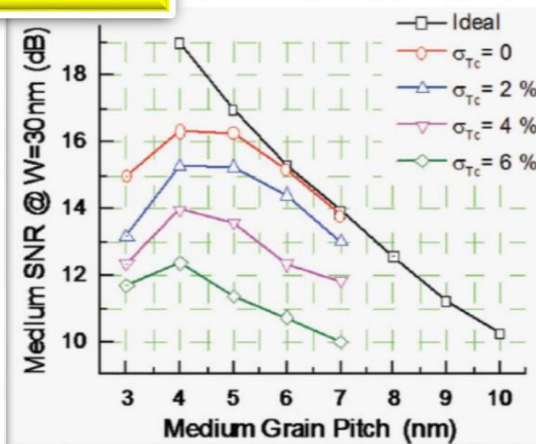
Defective grains



Reduction of in-plane variants is key

Courtesy Prof. J. Zhu, Carnegie Mellon Univ.

Tc distribution



T_c variation needs to be minimized

Zhu et al., J. Appl. Phys., 115, p. 17B744 (2014)

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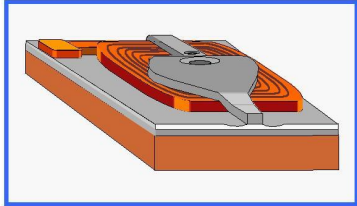
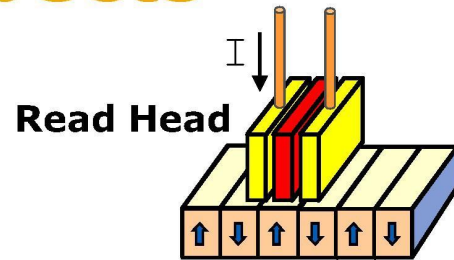
MR Technologies GmbH
Ex. 2010, IPR2026-00015
Page 30 of 33

WD0239517

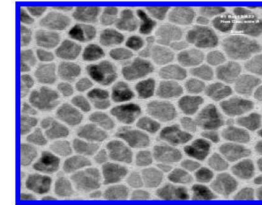
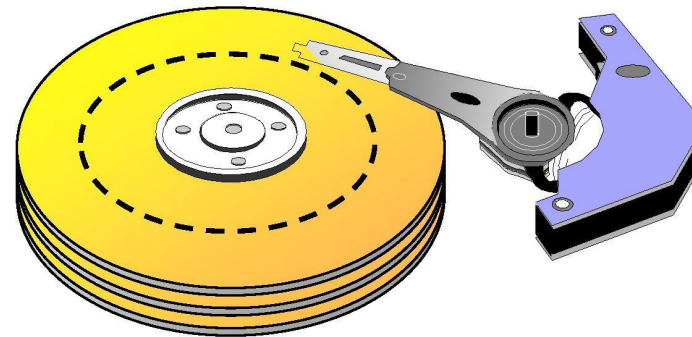
JX-2030.030

HAMR prospects

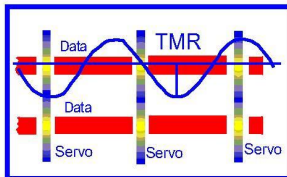
Write Head w/ Laser



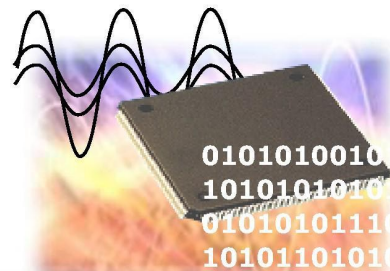
Media



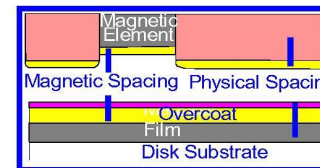
Servo Mechanics



Signal Processing



Head/Disk Spacing



Significant challenges all-around...

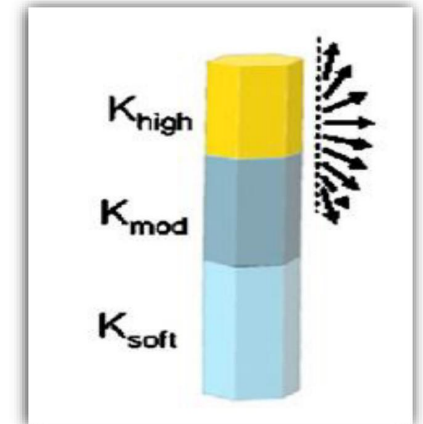
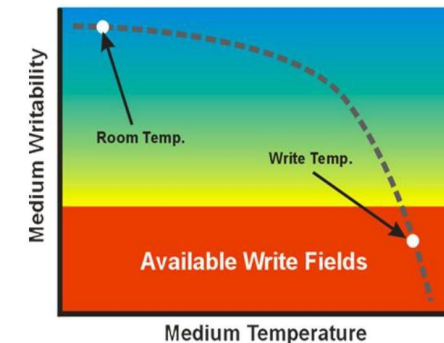
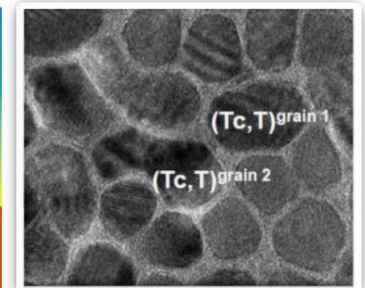
...but a lot of progress made

Expect commercial HAMR drives within the next few years!

Summary

Recent developments in magnetic recording media

- The Future of HDD technology is still bright
 - Cloud/archival storage will be key
- PMR is the prevailing magnetic storage technology
 - Grain size scaling does not benefit PMR (exchange-dominated)
 - The “exchange-spring” principle has guided most of the advances in PMR media since inception
- HAMR is the near-term outlook for HDD
 - Significant challenges overcome, but many still remain
 - Commercial HAMR drives expected in the next few years





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33

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Page 33 of 33

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