SDC
STORAGE DEVELOPER CONFERENCE
SNIA ■ SANTA CLARA, 2014

Advanced Barium Ferrite Tape Technologies

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FUJIFILM Corporation

Contents

- Comparison of storage devices for archive.
- Overview of the evolution of tape technology.
- Metal Particulate (MP) technology.
- Barium ferrite (BF) technologies.
- Latest demonstration of 85.9 Gbit/in^2 (equivalent to 154TB per cartridge) and future.
- Summary.

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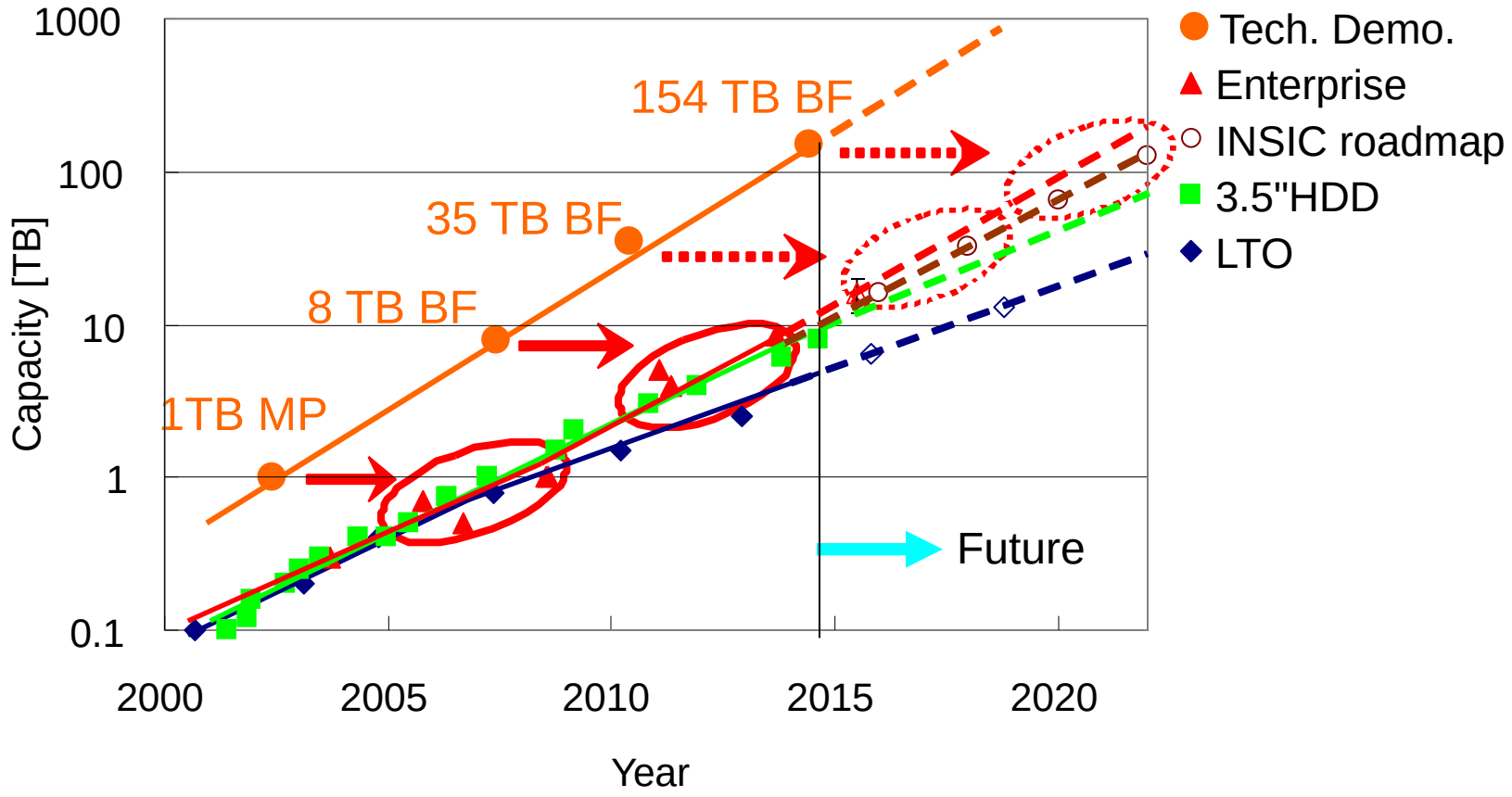
Capacity Trends – Linear Tape & HDD



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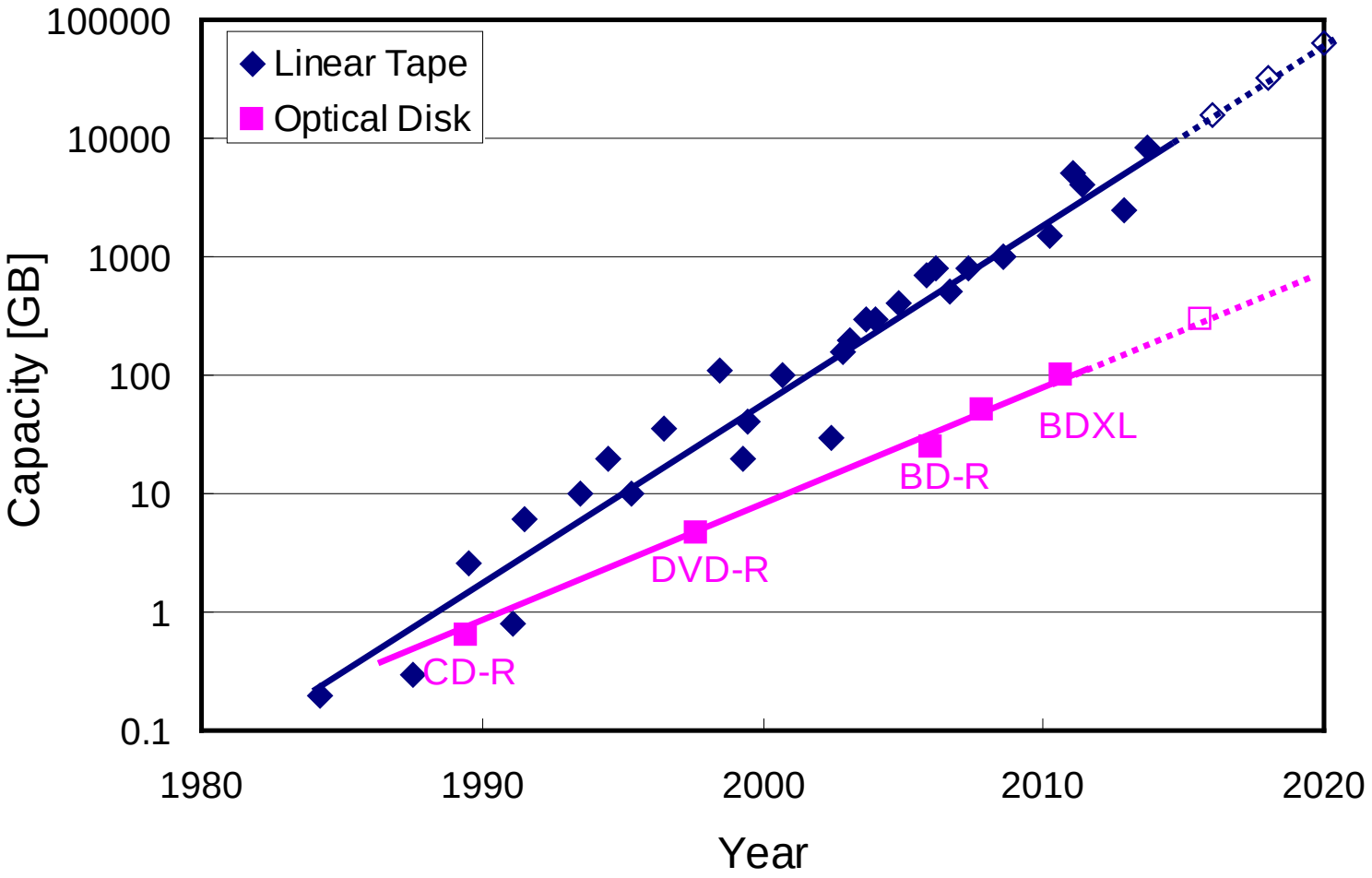
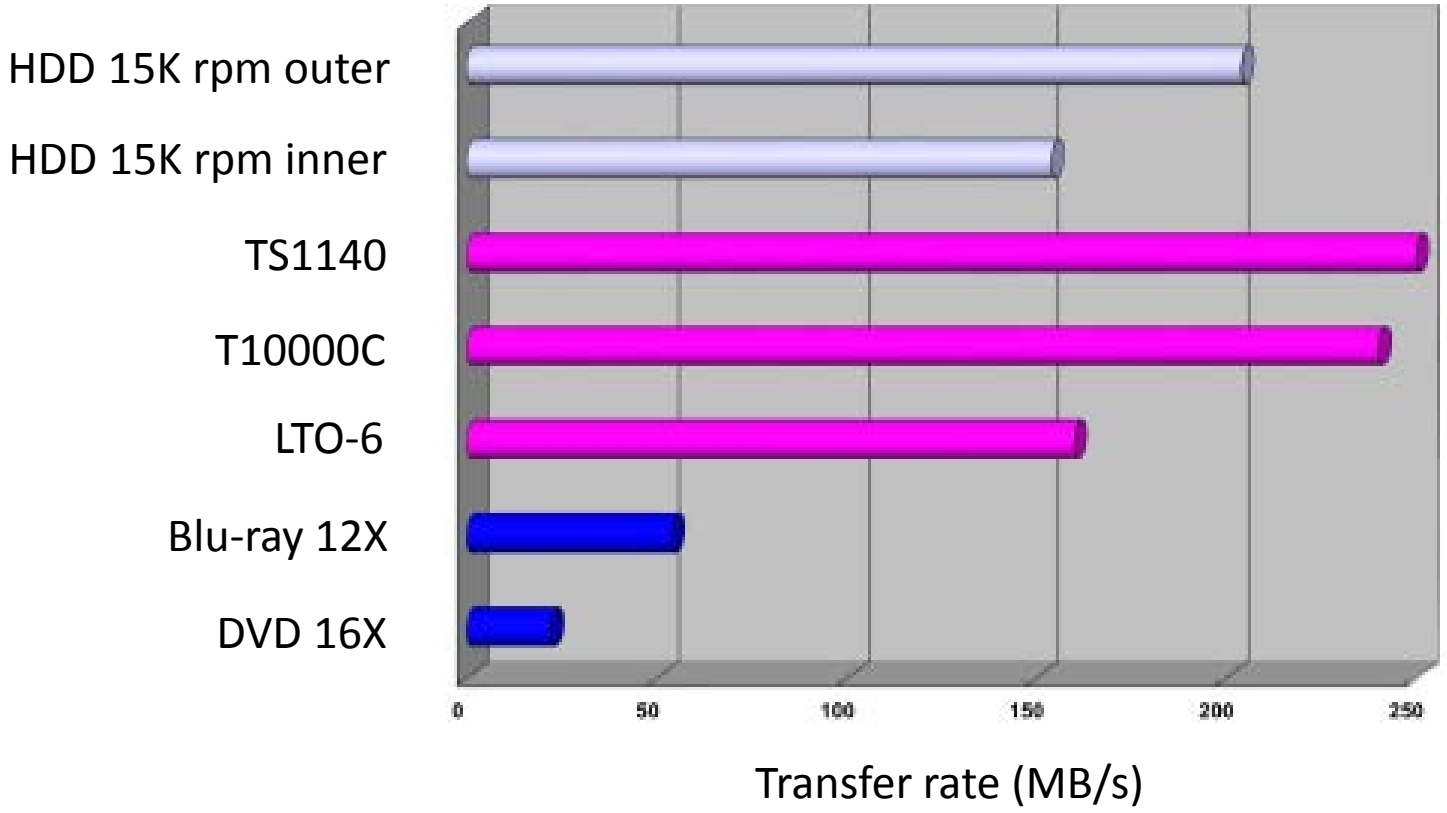
http://www.oracle.co.jp/events/jpm120809/materials/20120809-10_StorageSumit_A-2.pdf
http://www.lto.org/technology/index.html
http://www.insic.org/news/2012Roadmap/12index.html

Capacity Trends – Linear Tape & Optical Disk



Plots for future are from http://www.insic.org/news/2012Roadmap/12index.html
http://www.sony.net/SonyInfo/News/Press/201403/14-0310E/

Transfer rate comparison



http://home.jeita.or.jp/upload_file/20130924142035_HeGRhaN95v.pdf

Error rate comparison

System	Hard error rate
SATA consumer HDD	1E-14
SATA enterprise HDD	1E-15
Enterprise SAS/FC HDD	1E-16
LTO Tape system	1E-17
Enterprise Linear Tape	1E-19 ~ 1E-20

- All data written on the tapes are always verified by the reader just after writing.

http://remedio.tv/diversos/pctita_arquivos/PanasonicSlimBluRayBurner.htm
"Tape: Comparison of LTO and Enterprise", Instrumental, Inc. http://www.instrumental.com, April 19, 2013
http://www.seagate.com/files/www-content/support-content/documentation/product%20manuals/en-us/enterprise/Savvio/10K.5/100628563f.pdf
http://www.spectra.com/pdfs/lto_ultrium.pdf
https://www.spectralogic.com/index.cfm?fuseaction=home.displayFile&DocID=2513

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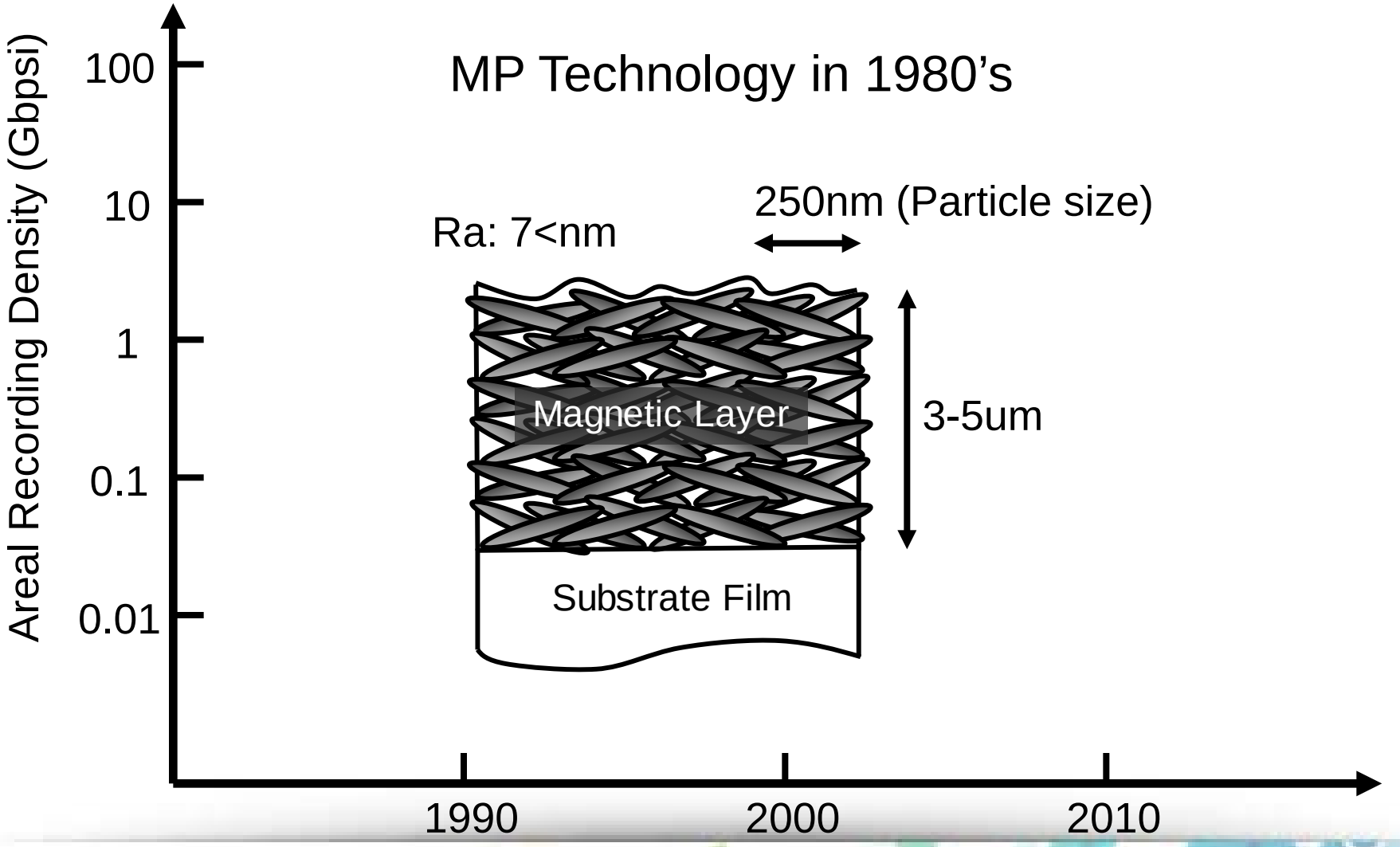
Overview of evolution of tape technology



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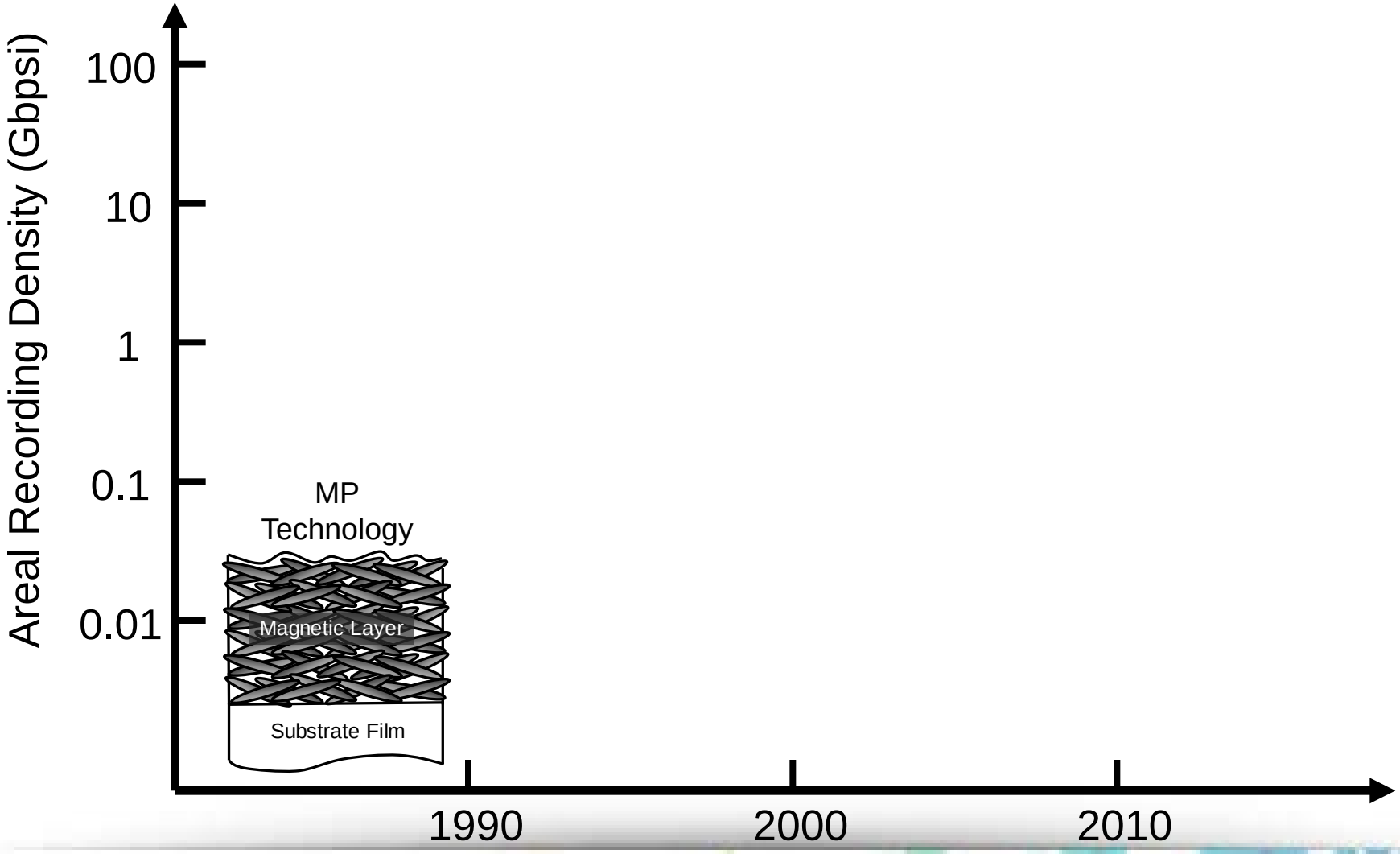

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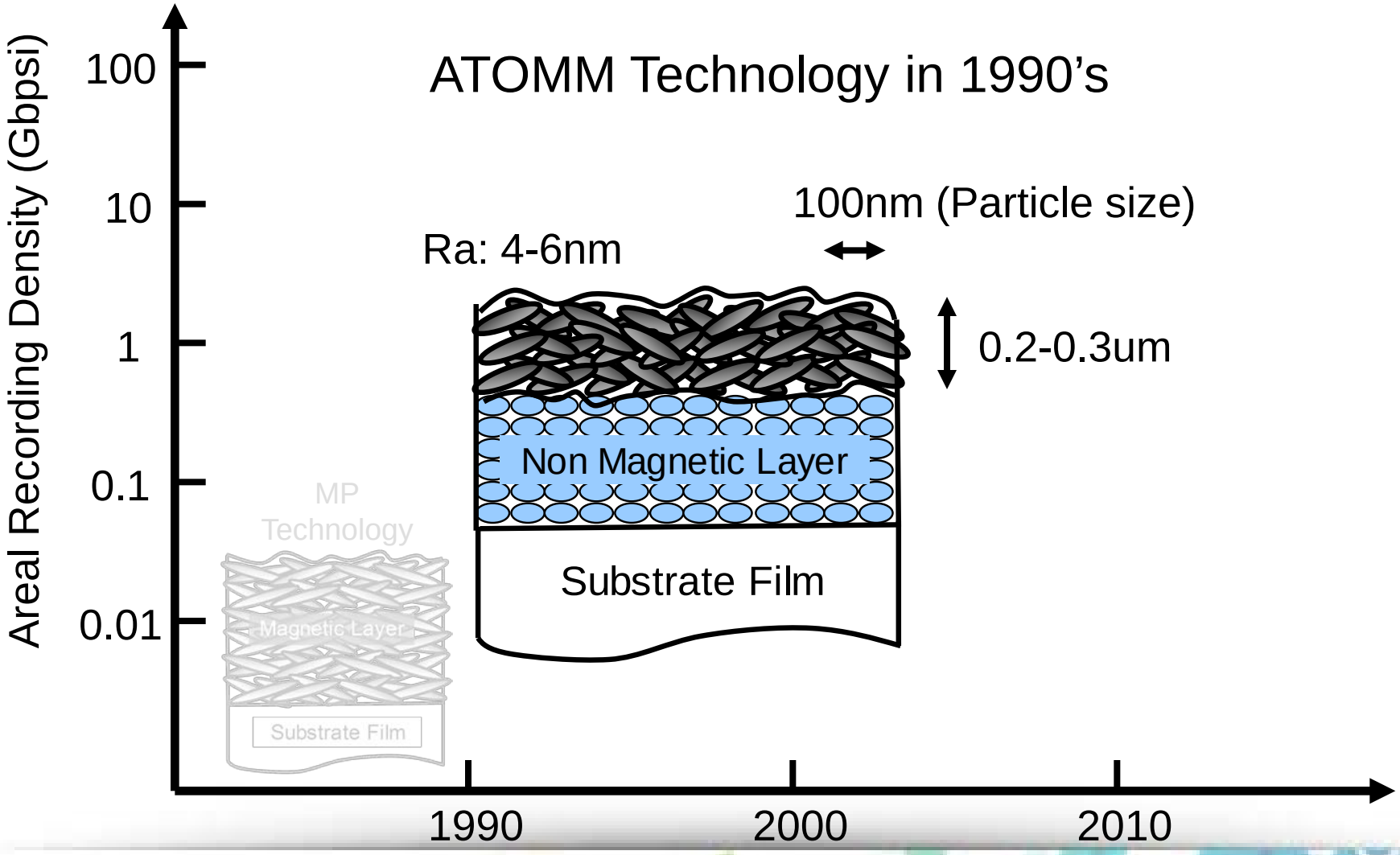
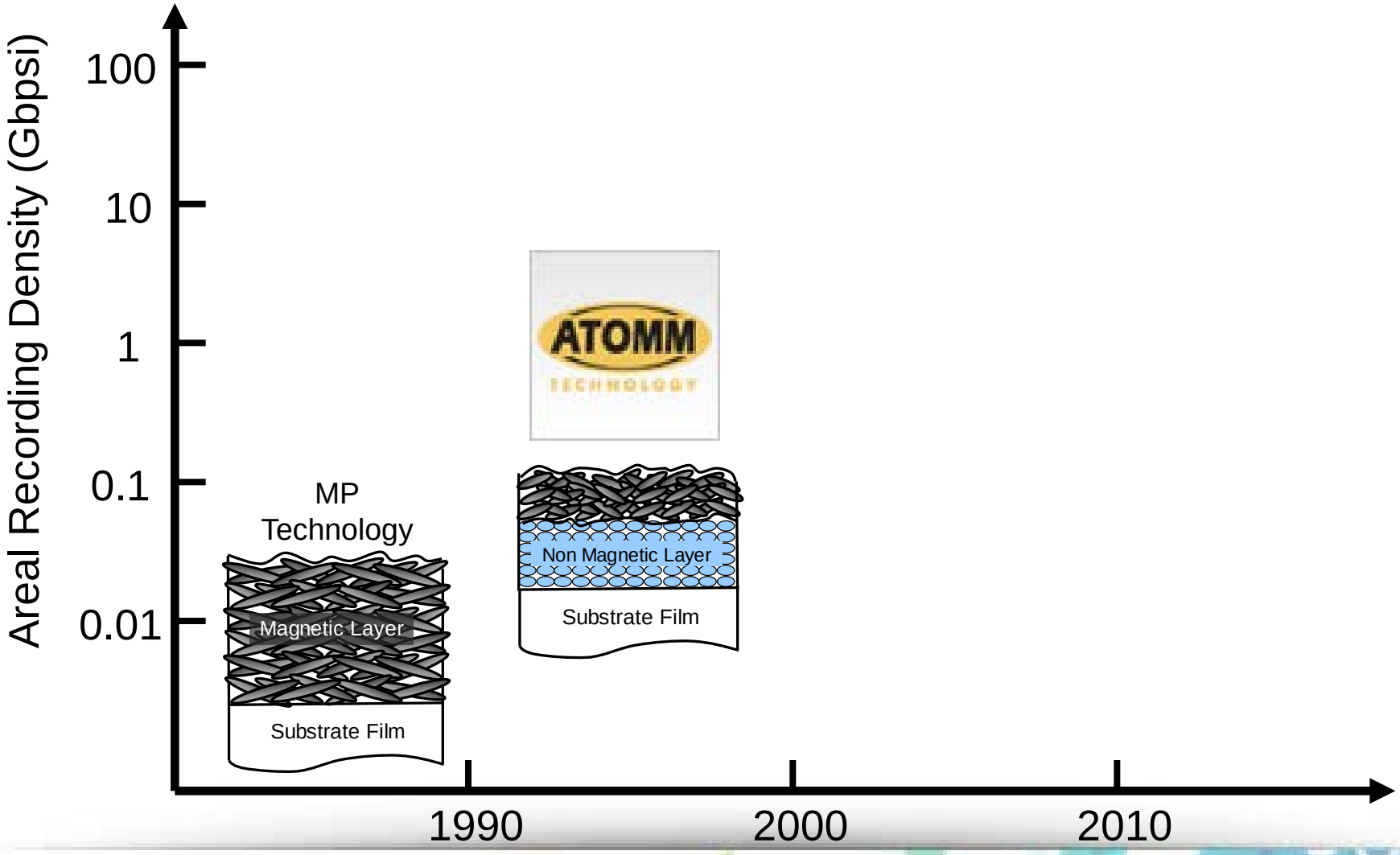


Overview of evolution of tape technology



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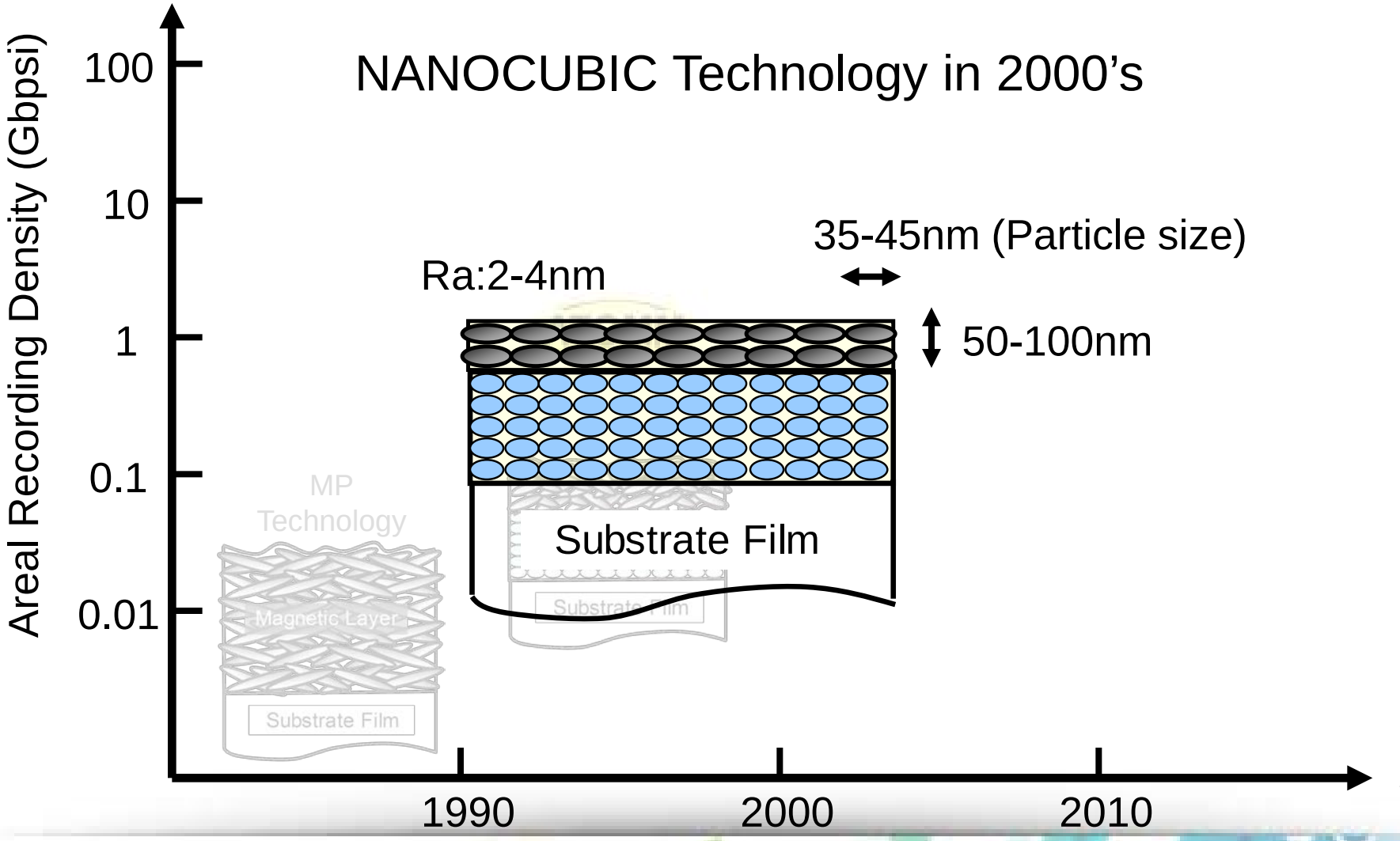

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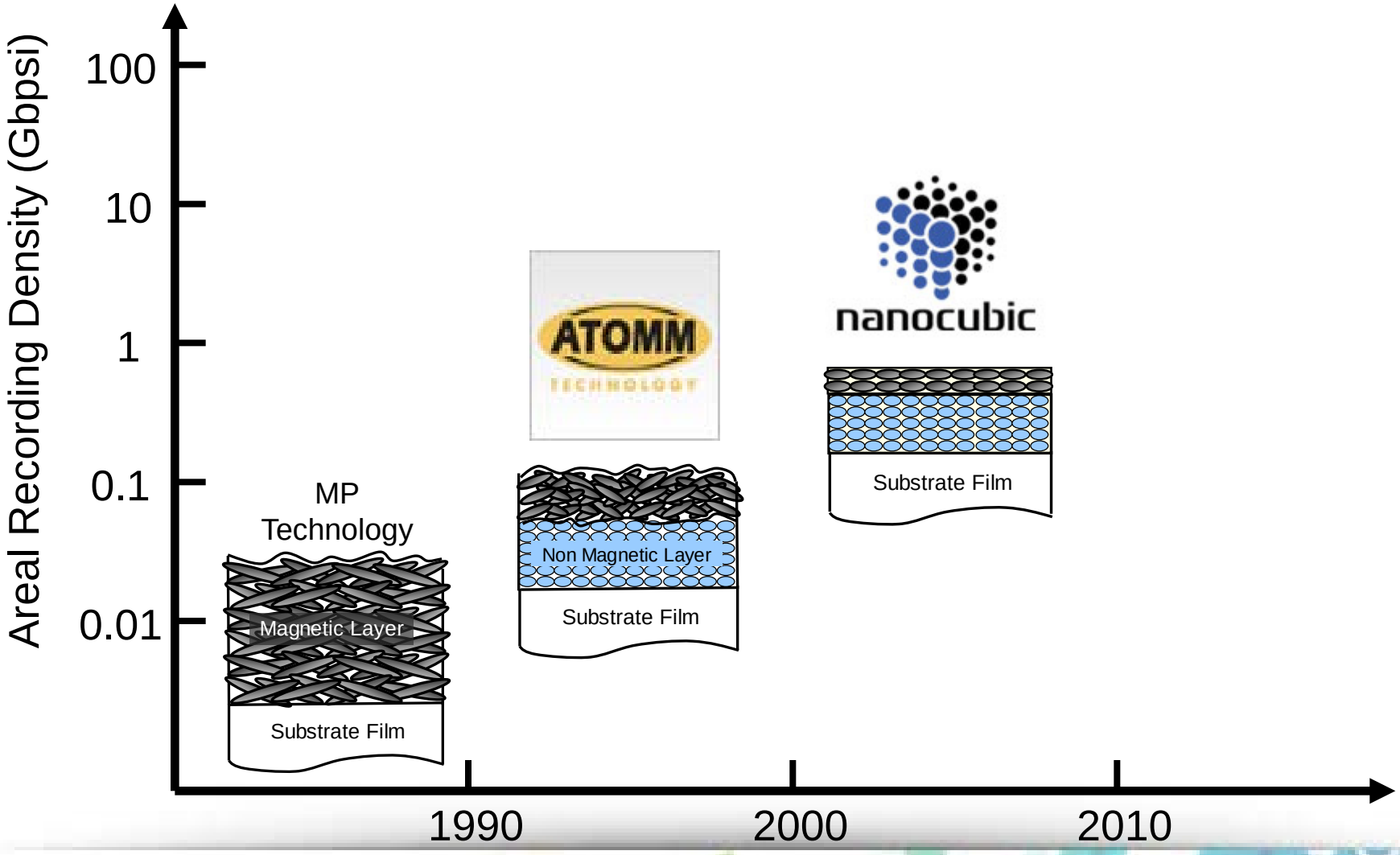

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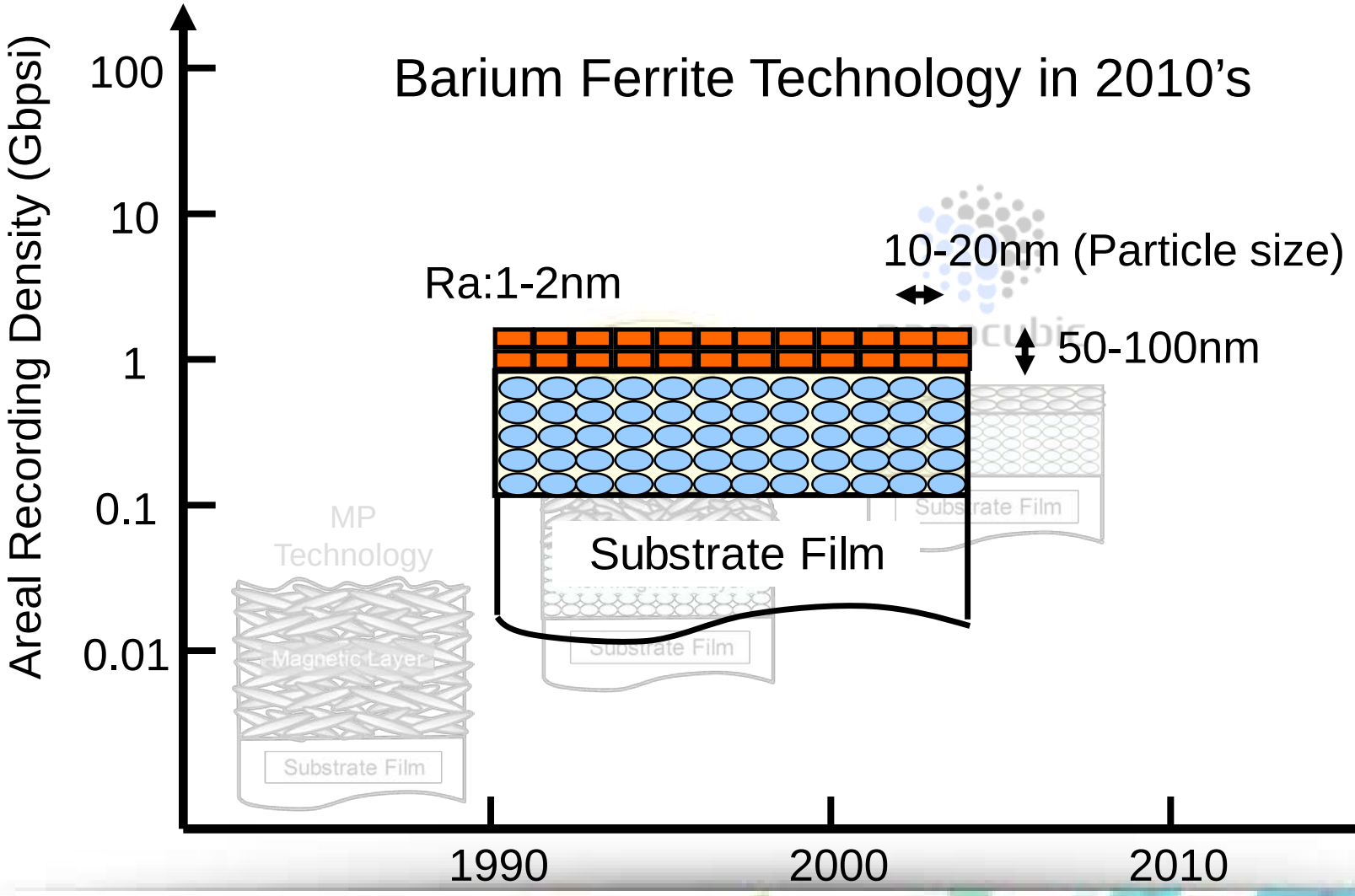

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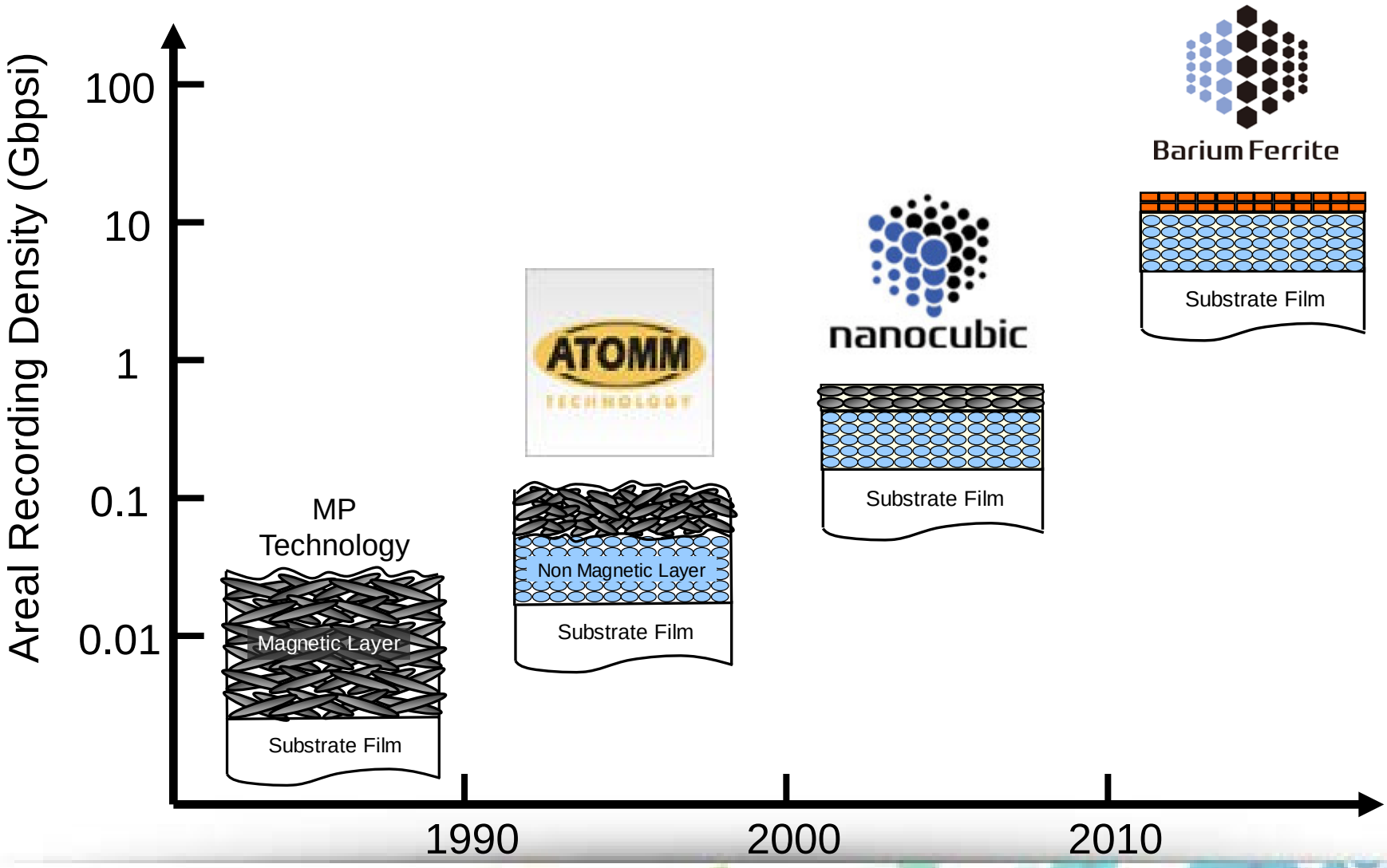

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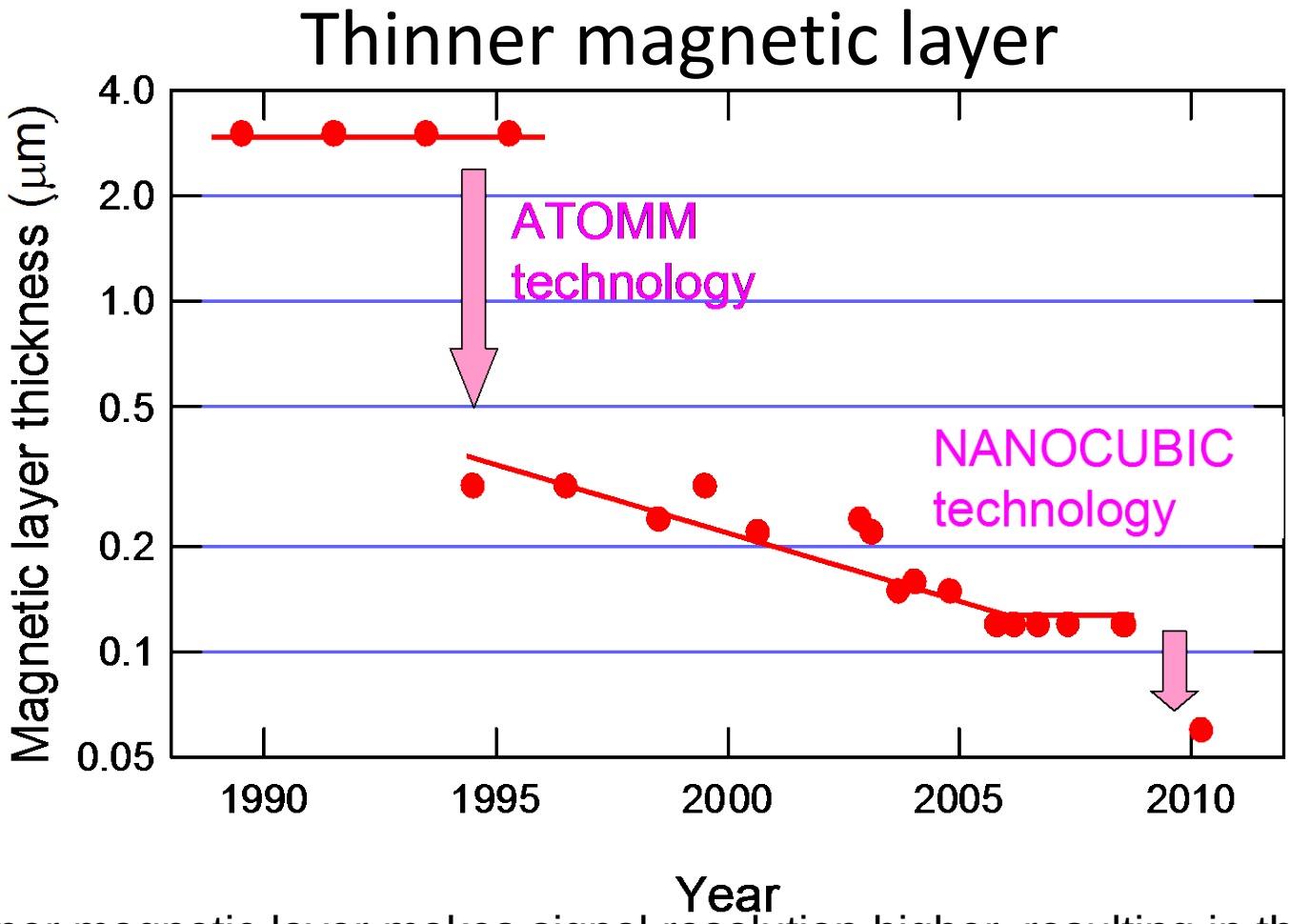
MP technology

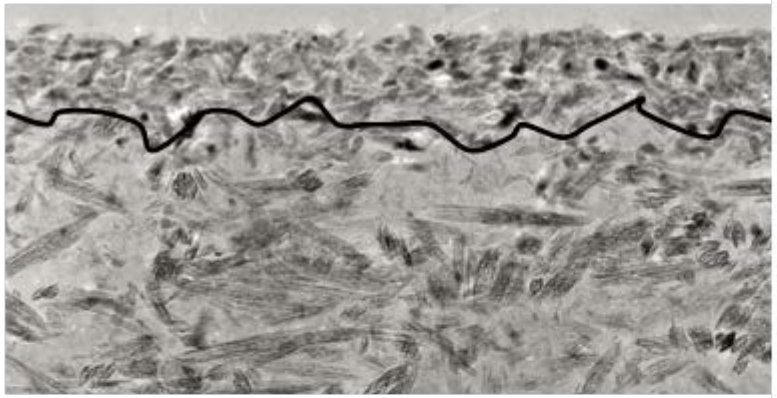


- Thinner magnetic layer makes signal resolution higher, resulting in the achievement of higher linear density.

MP technology

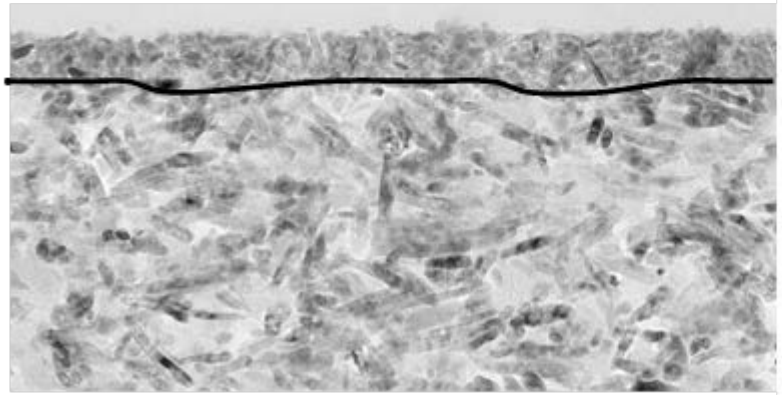
ATOMM Technology

Thickness (t)	110nm
Deviation（δ）	25nm
δ/t	23%



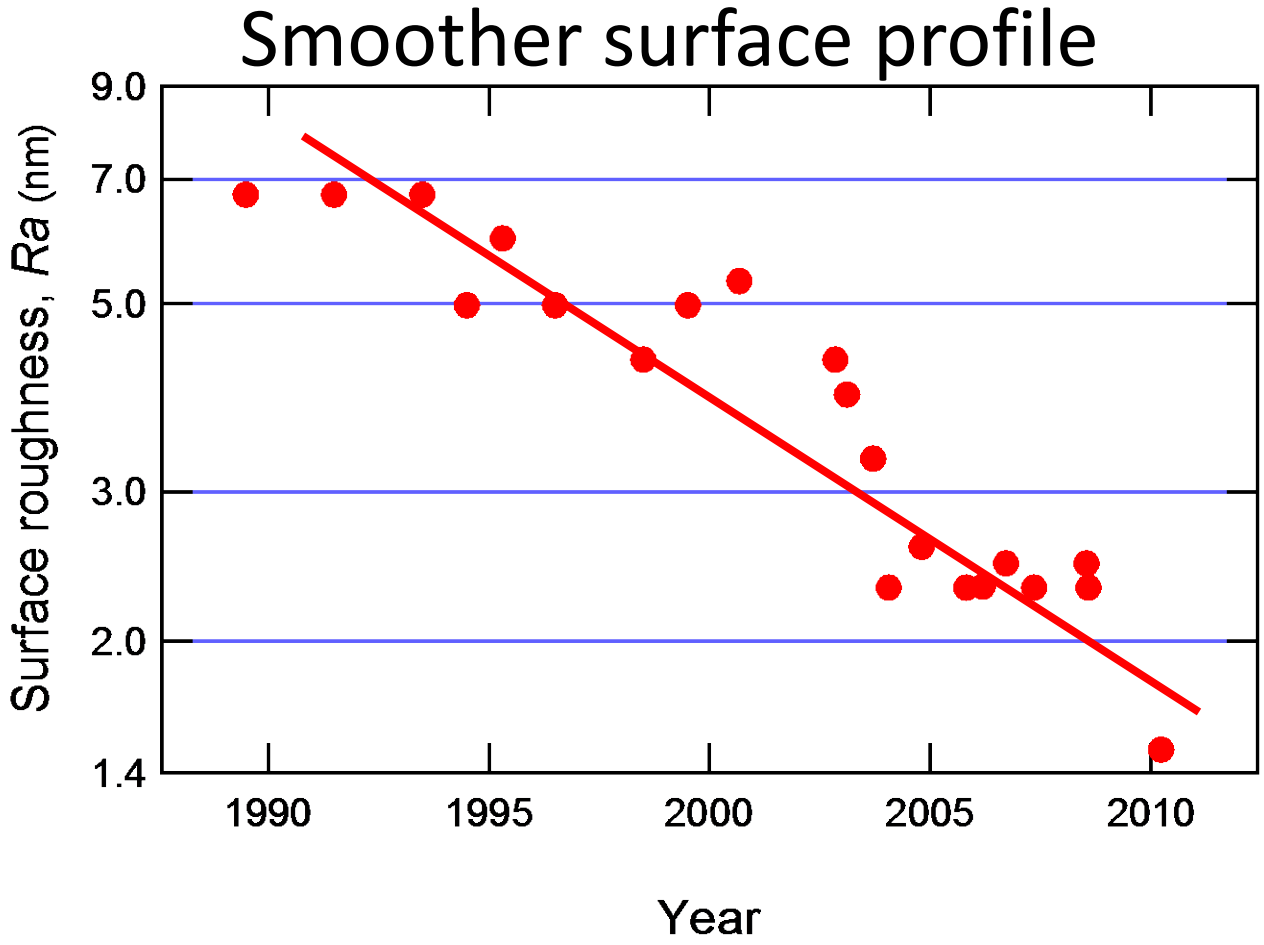
NANOCUBIC Technology

Thickness（t）	60nm
Deviation (δ)	6nm
δ/t	10%



- Thickness variation of magnetic layer is negligibly small by NANO-coating technology.

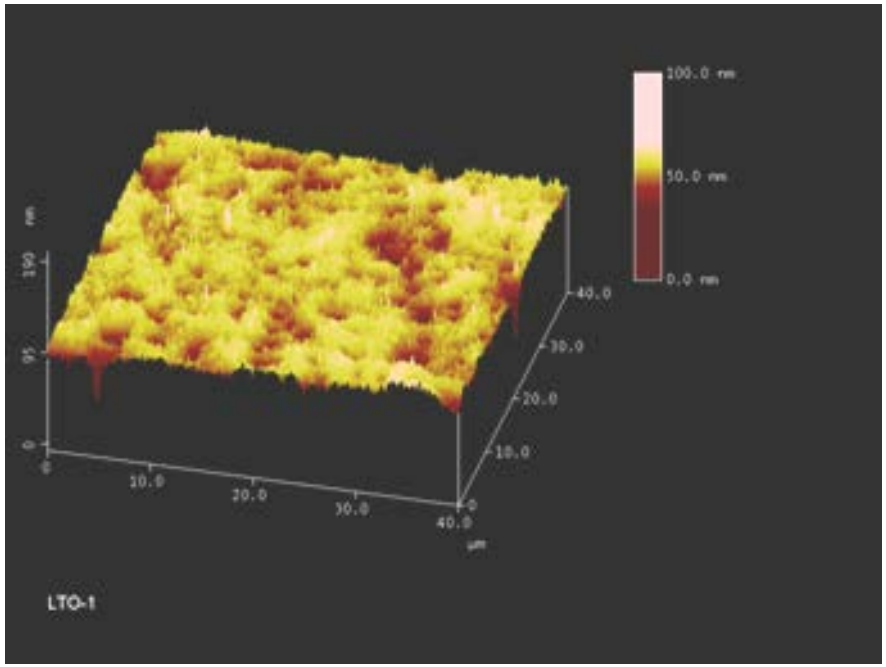
MP technology



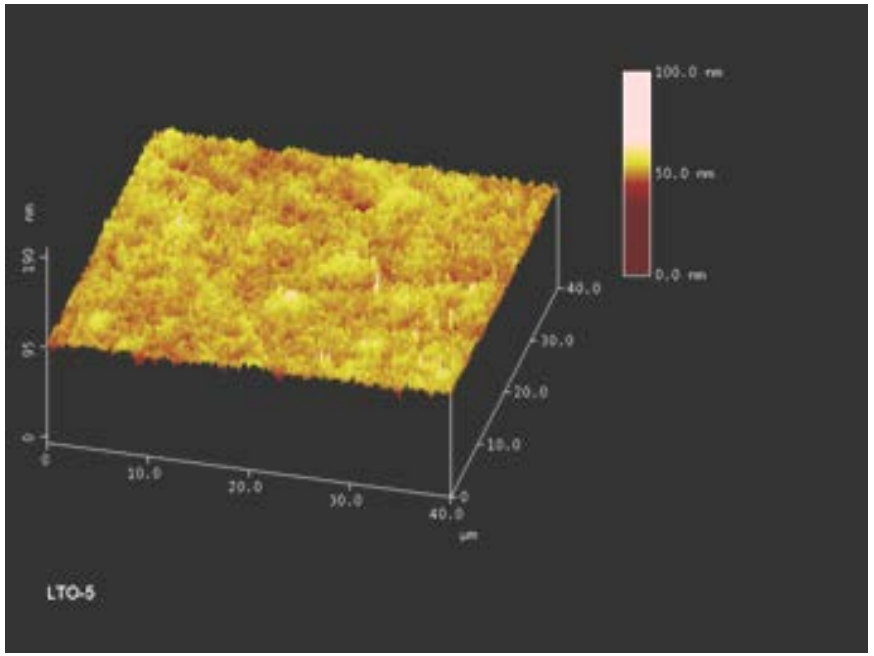
- Smoother surface reduce the spacing between head and media, resulting in the significant increase of the signal output at higher linear density region.

MP technology

ATOMM Technology (LTO-1)
Ra:5.2nm

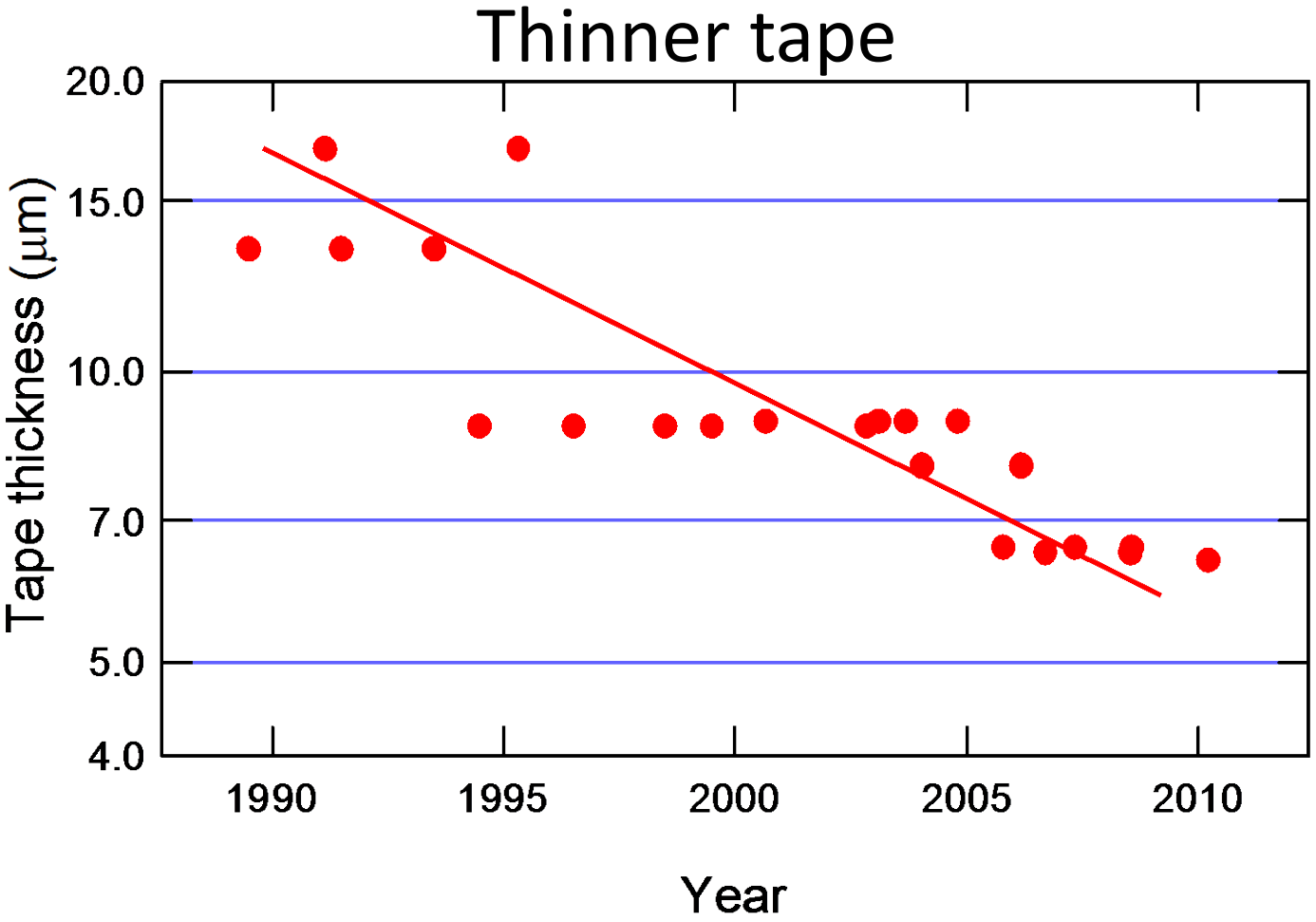


NANOCUBIC Technology (LTO-5)
Ra:2.6nm



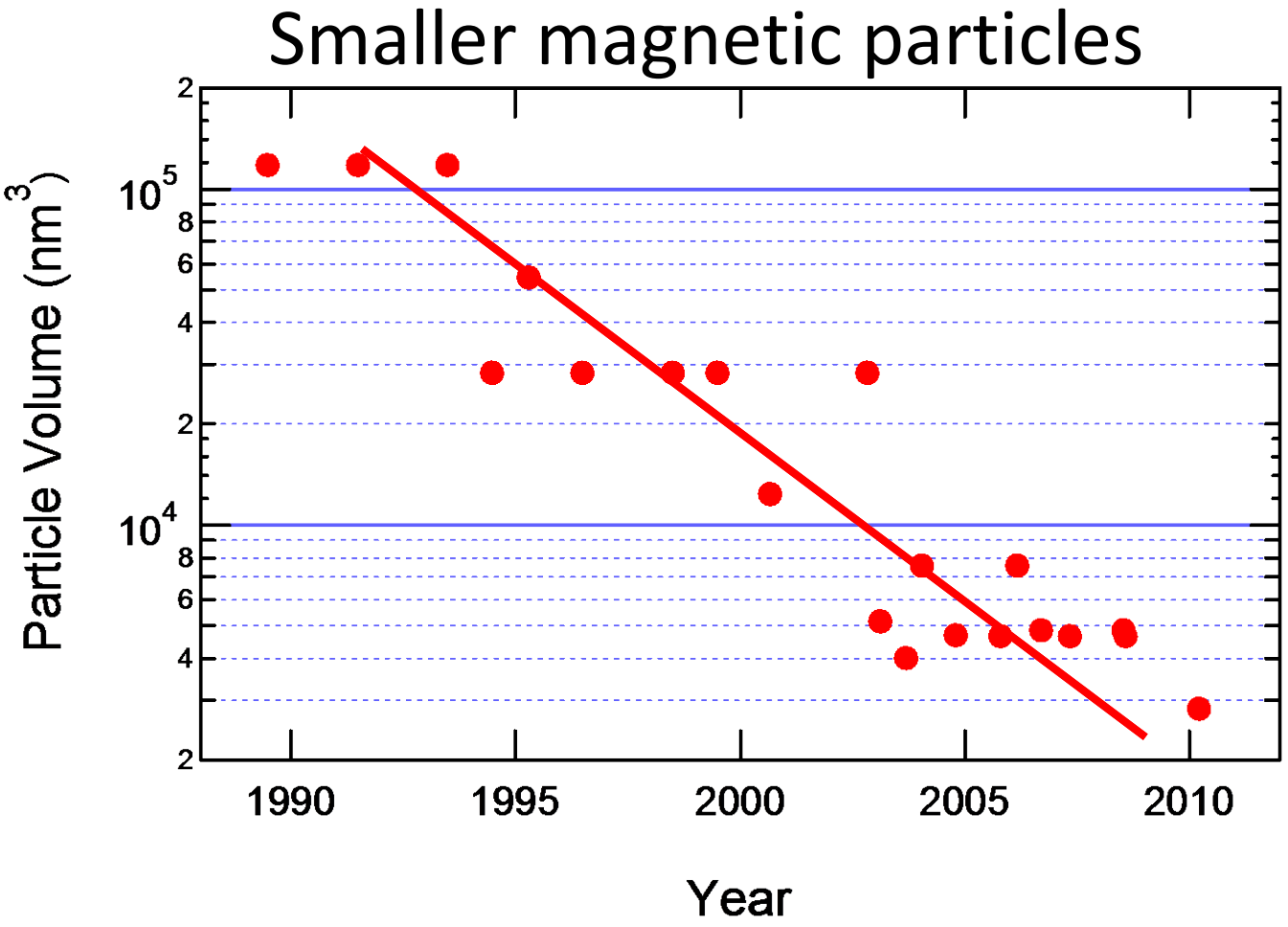
- Creates very smooth tapes by NANO-dispersion technology,

MP technology



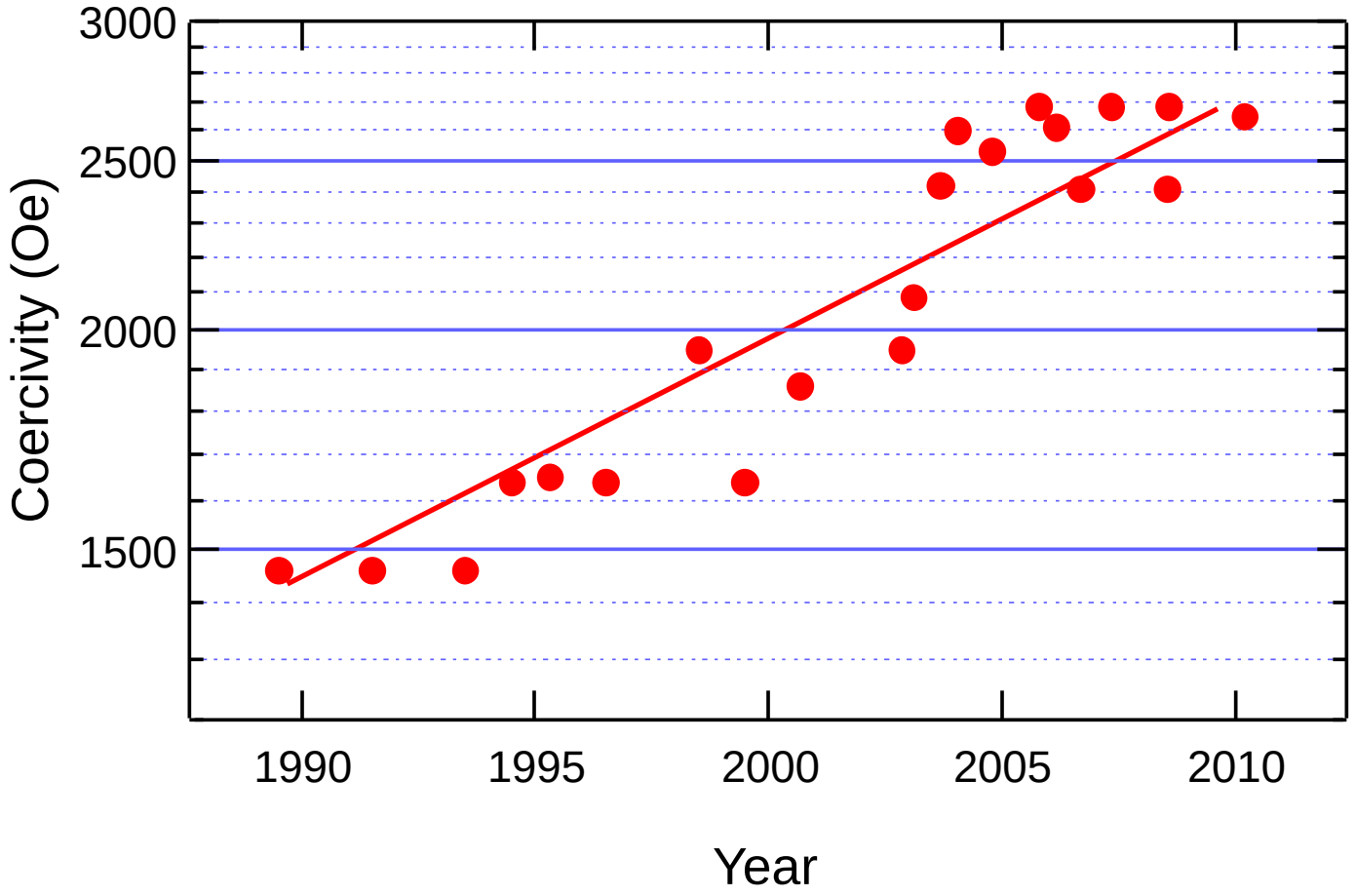
- Thinner tape makes longer tape windable in a same size of cartridge.

MP technology



- Smaller magnetic particles are essential to a higher recording density .

MP technology



- Increasing the magnetic coercivity while reducing the particle size down to 3,000 (nm^3).

MP technology

- Capacity increase in MP media have been achieved by making….
  - Thinner magnetic layer,
  - Smoother surface profile,
  - Thinner (i.e. longer) tape,
  - Smaller magnetic particles, and
  - Higher coercivity.

However, reducing particle volume less than 2,800 nm^3 without decreasing coercivity could not be achieved.

Barium ferrite (BF) technology must be developed.

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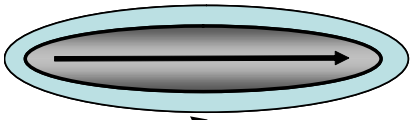
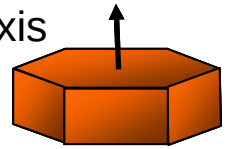
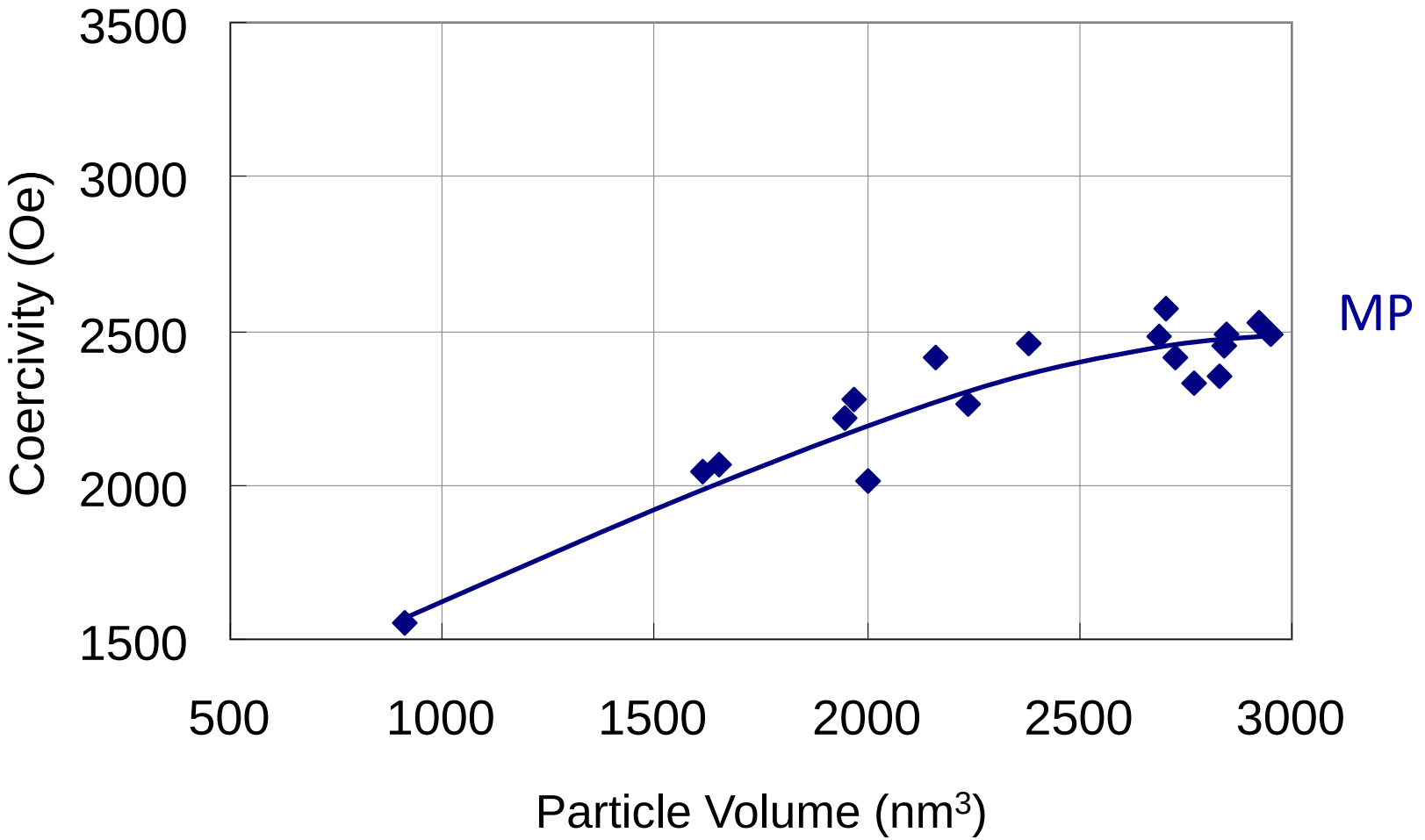
BF Technology - Particle

	MP	BF
Particle Shape	 Passivation layer Acicular	magnetization axis  Hexagonal platelet shaped
Origin of magnetic energy	Shape anisotropy	Magneto-crystalline anisotropy
Material	FeCo alloy	$BaO(Fe_2O_3)_6$ Oxide
Passivation layer	Required	Not Required

- The magnetic property of barium ferrite particle is NOT affected from its shape.
- The barium ferrite particle does NOT need the passivation layer because it is oxide.

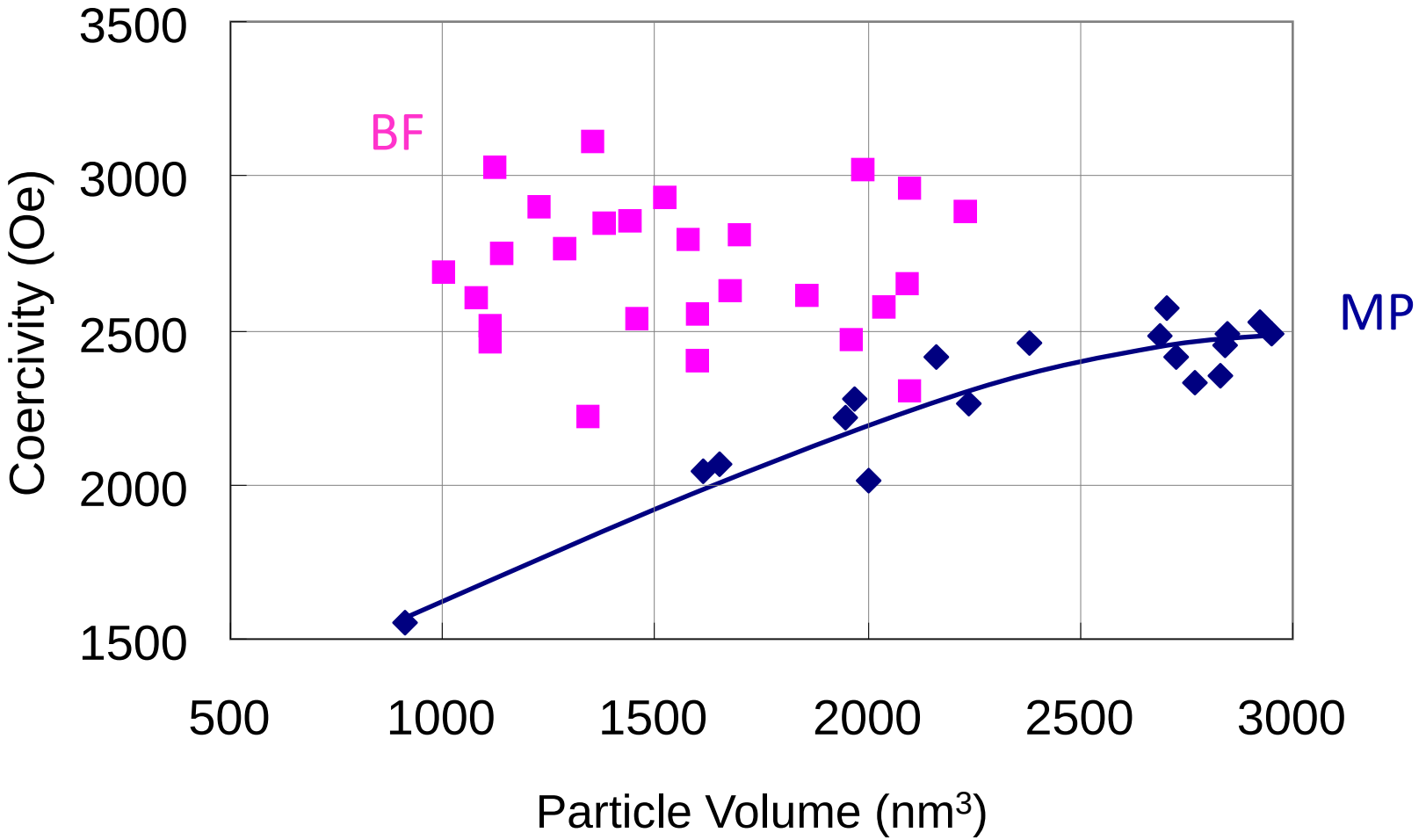
➔The size of barium ferrite particle can be reduced with maintaining high coercivity.

BF Technology - Particle



- Reducing the particle size less than 2,800 (nm^3) declined the magnetic coercivity, which is very important to keep the data, resulting in the saturation of capacity increase with metal particles

BF Technology - Particle

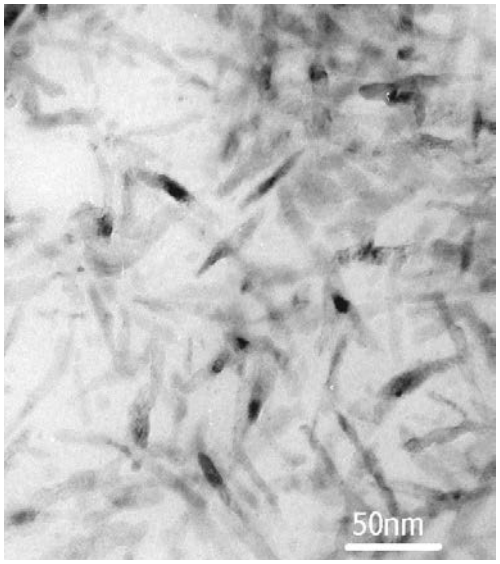


- Coercivity of barium ferrite particles is independent of their size. Smaller particles can be utilized for higher capacity.

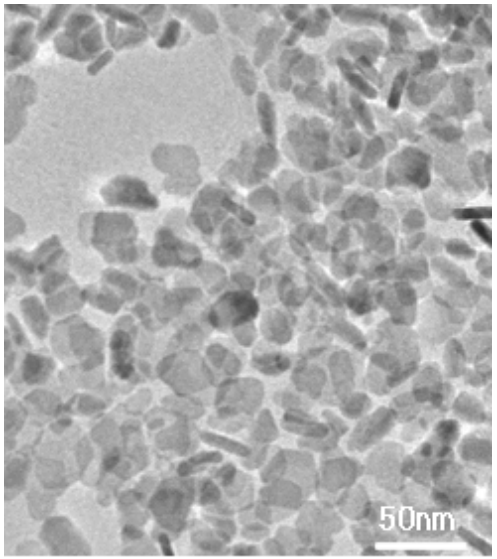
BF Technology - Particle

TEM image of fine Barium ferrite particles

Latest MP
Volume: 2850 nm^3
coercivity: 2380 [Oe]



BF
Volume: 1600 nm^3
coercivity: 2400 [Oe]

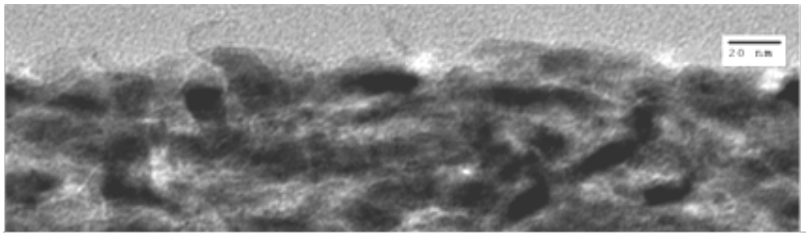


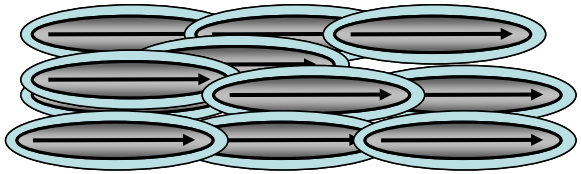
- Even though the volume of barium ferrite shown above is 45 % smaller than the latest MP, their coercivity can be maintained.

BF Technology - Particle

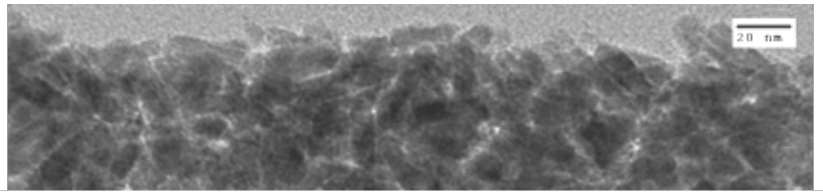
Particle Orientation

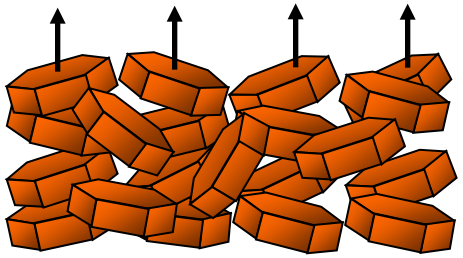
MP tape



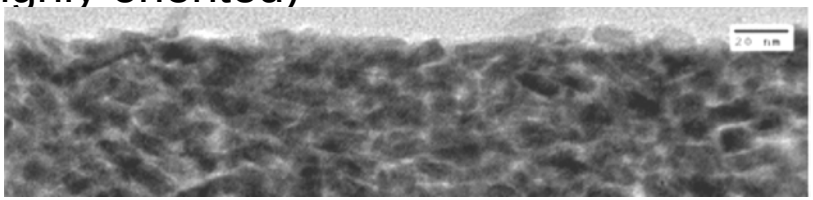


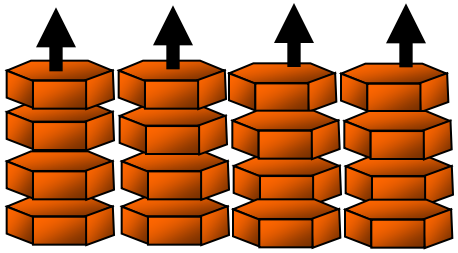
BF tape (non-oriented)





BF tape (highly oriented)



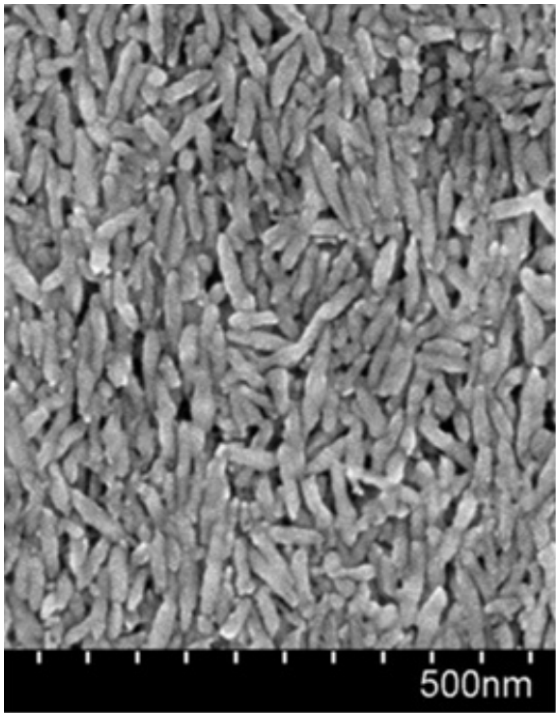


- Barium ferrite particles can be oriented perpendicularly while MP are oriented longitudinally.

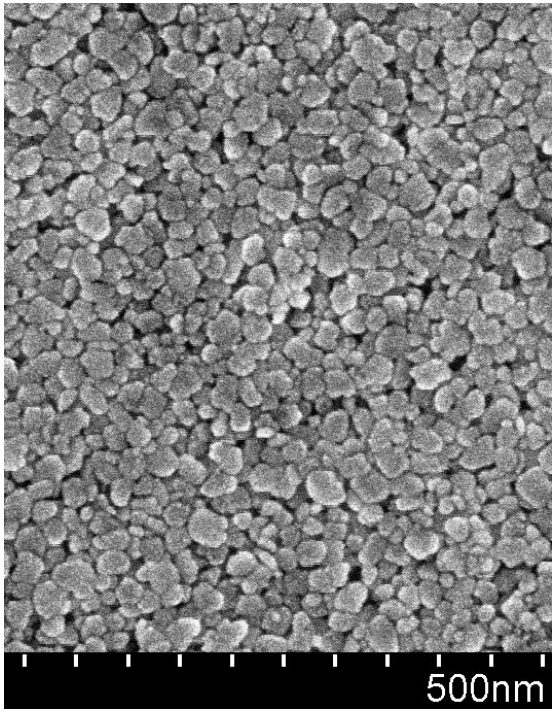
BF Technology - Particle

SEM Image of tape surface

Latest MP tape

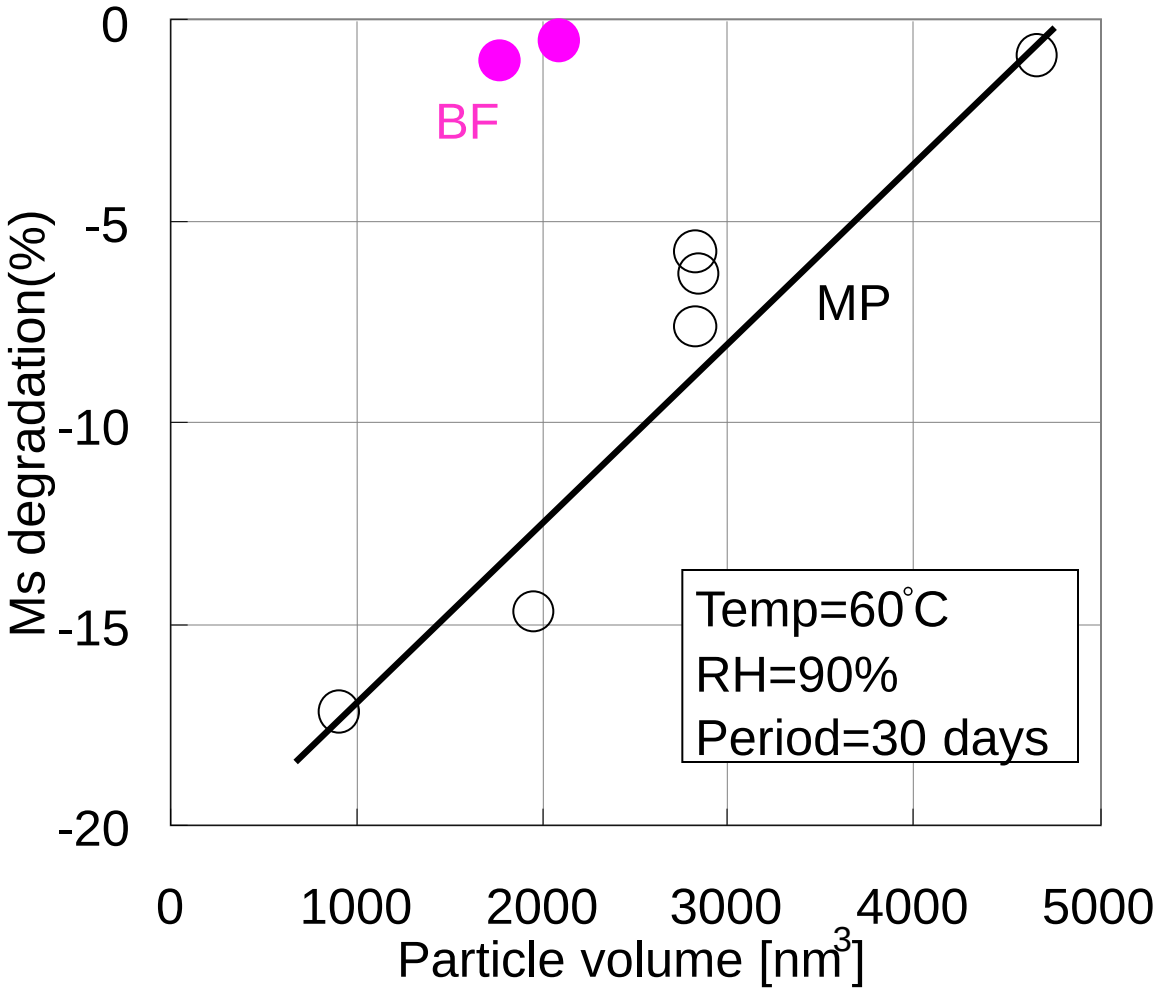


BF Tape



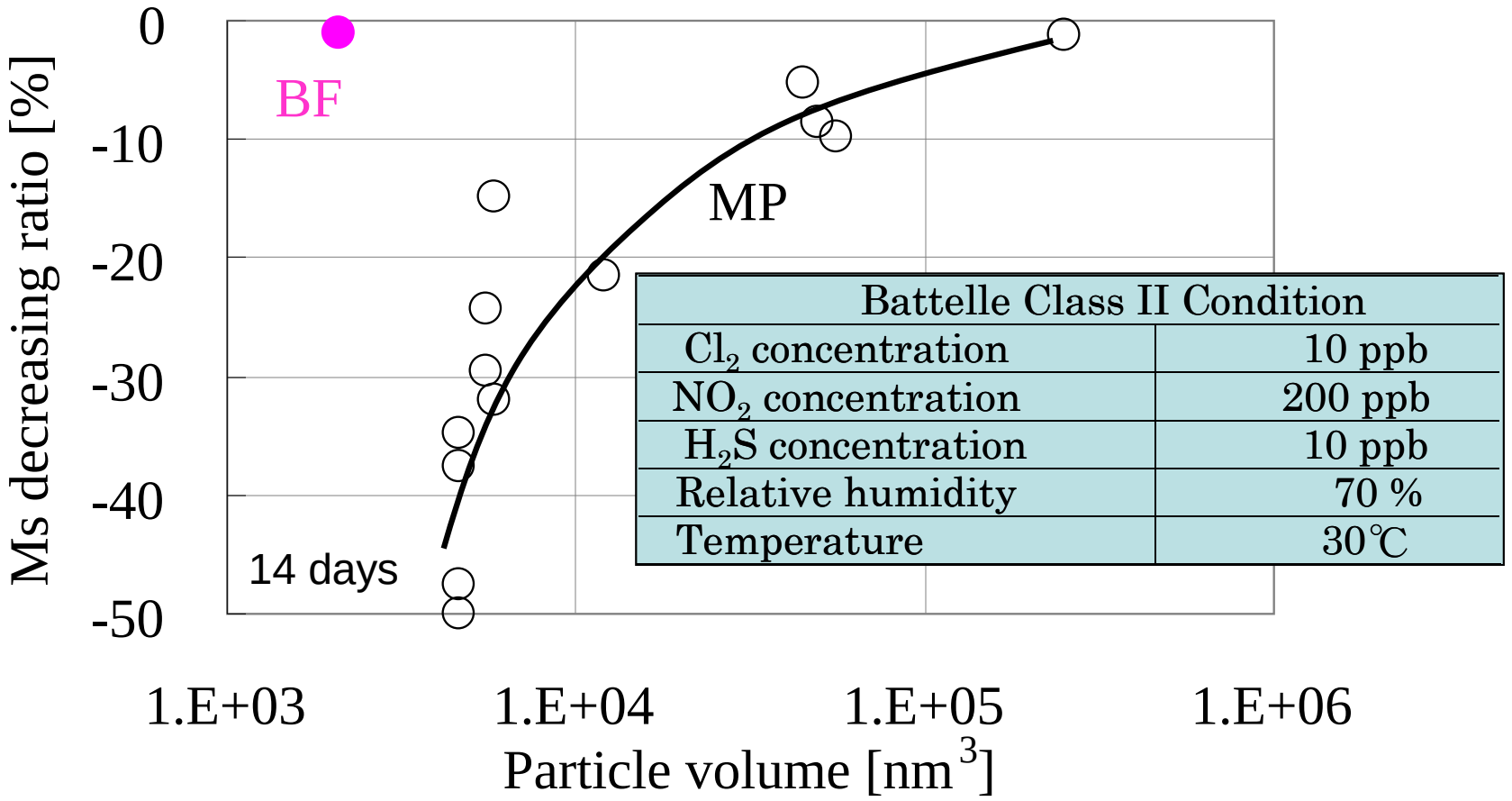
- Barium ferrite particles are well isolated and packed in the high density.

BF Technology - Stability



- Barium ferrite media are stable even in the very hot and humid conditions.

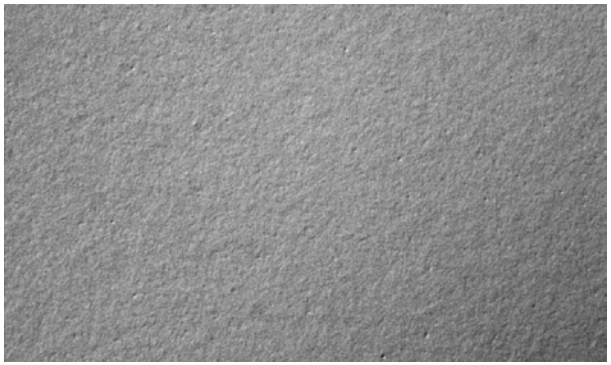
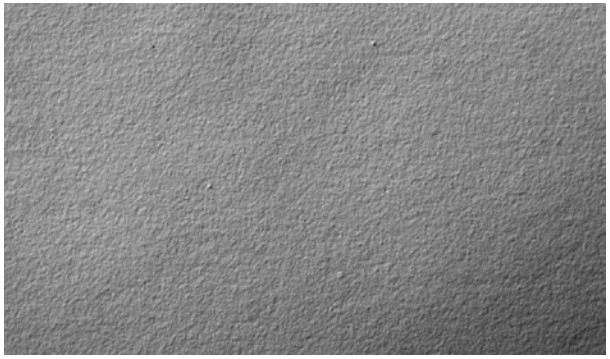
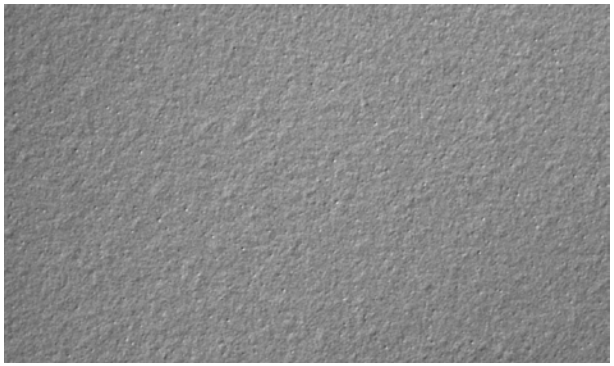
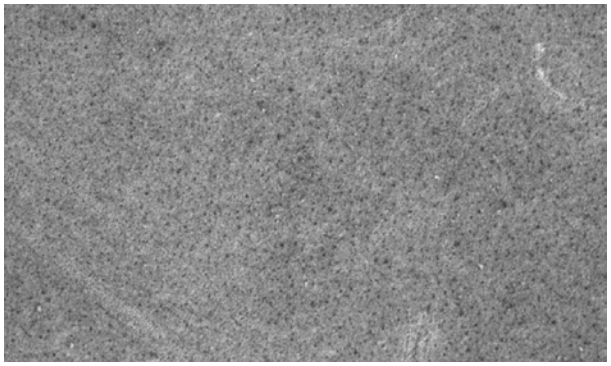
BF Technology - Stability



Battelle Class II Condition	
Cl_2 concentration	10 ppb
NO_2 concentration	200 ppb
H_2S concentration	10 ppb
Relative humidity	70 %
Temperature	30℃

- Barium ferrite media are stable even in the corrosive atmosphere (Battelle Class II, 14 days).

BF Technology - Stability

	Initial	After exposure
BF		
MP		

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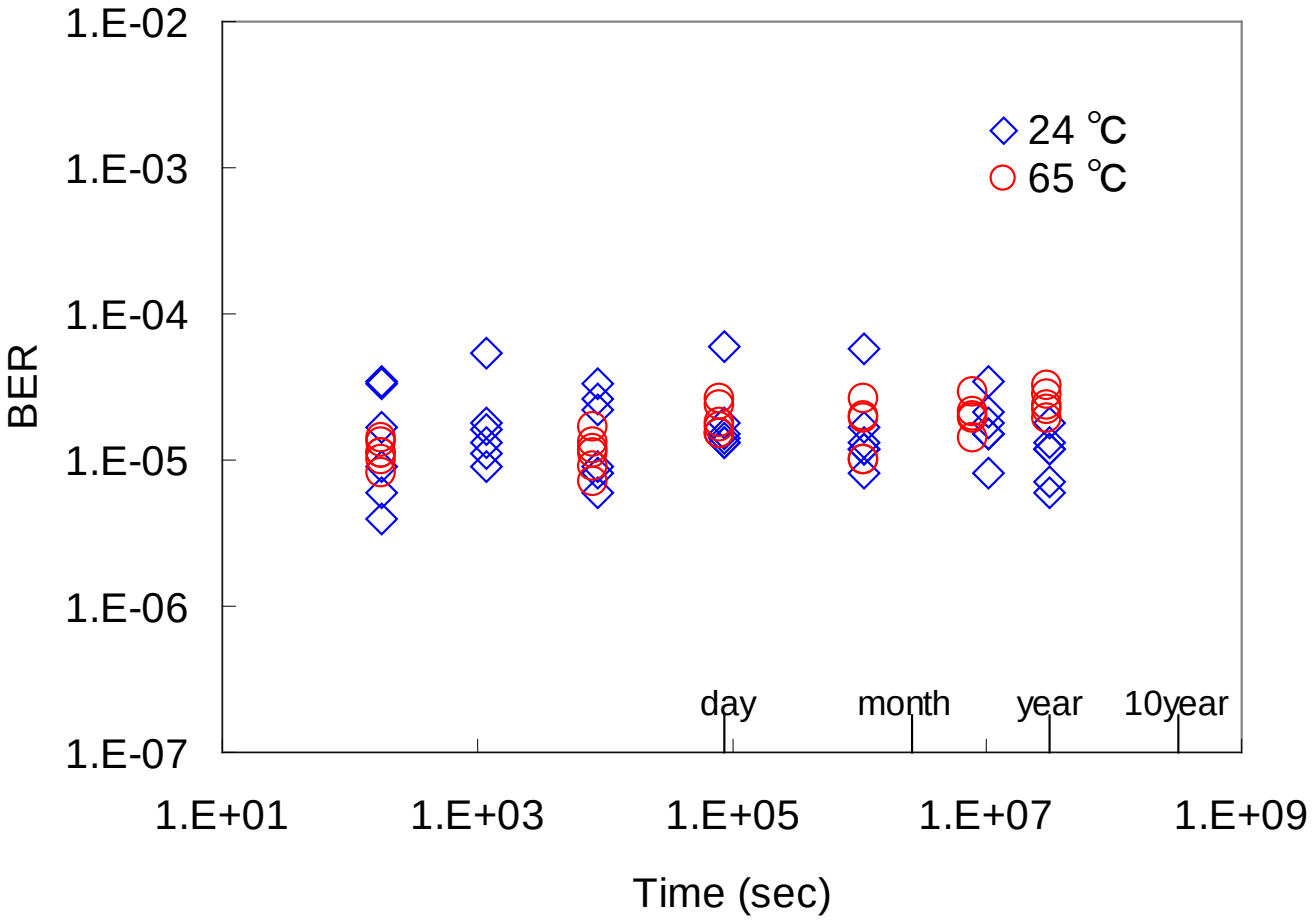
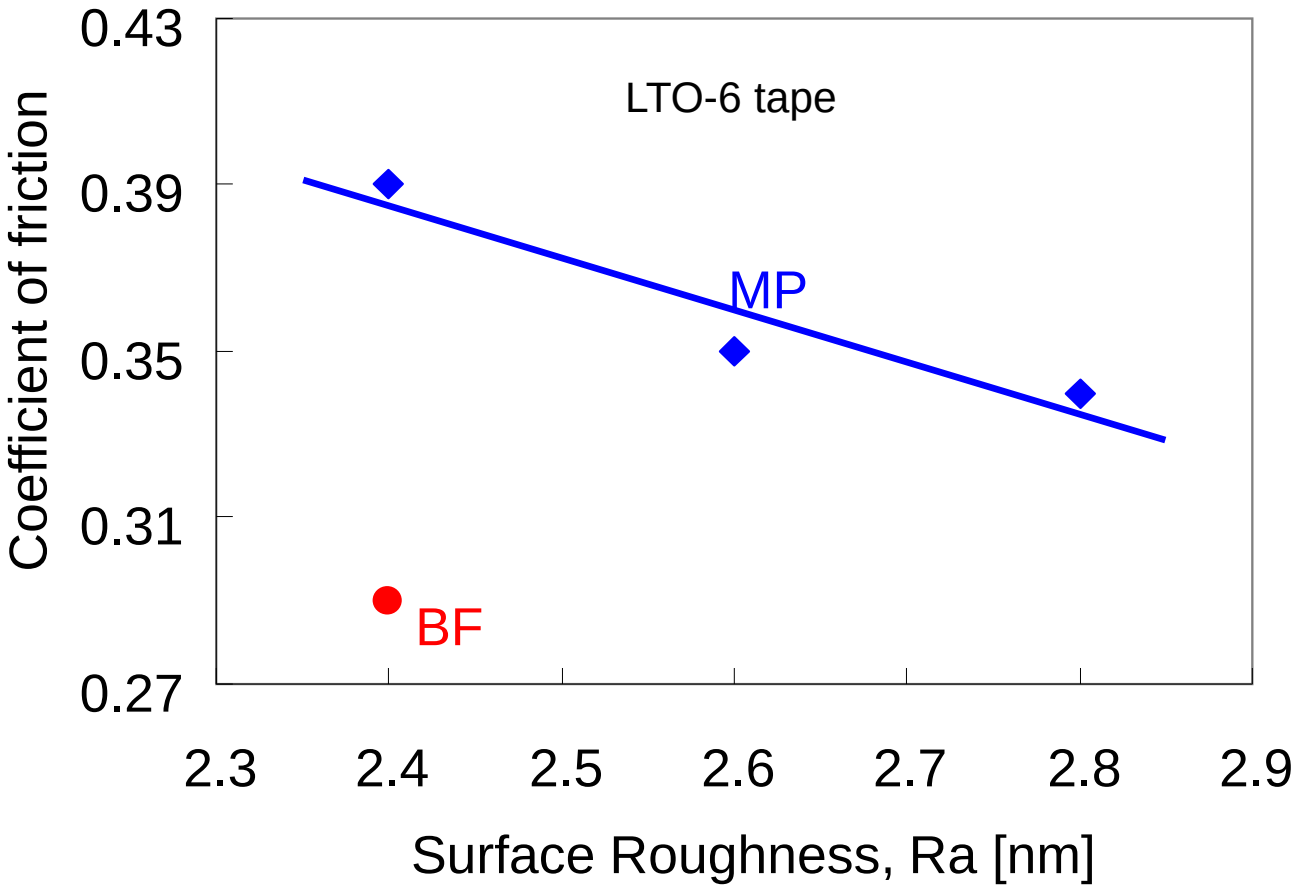


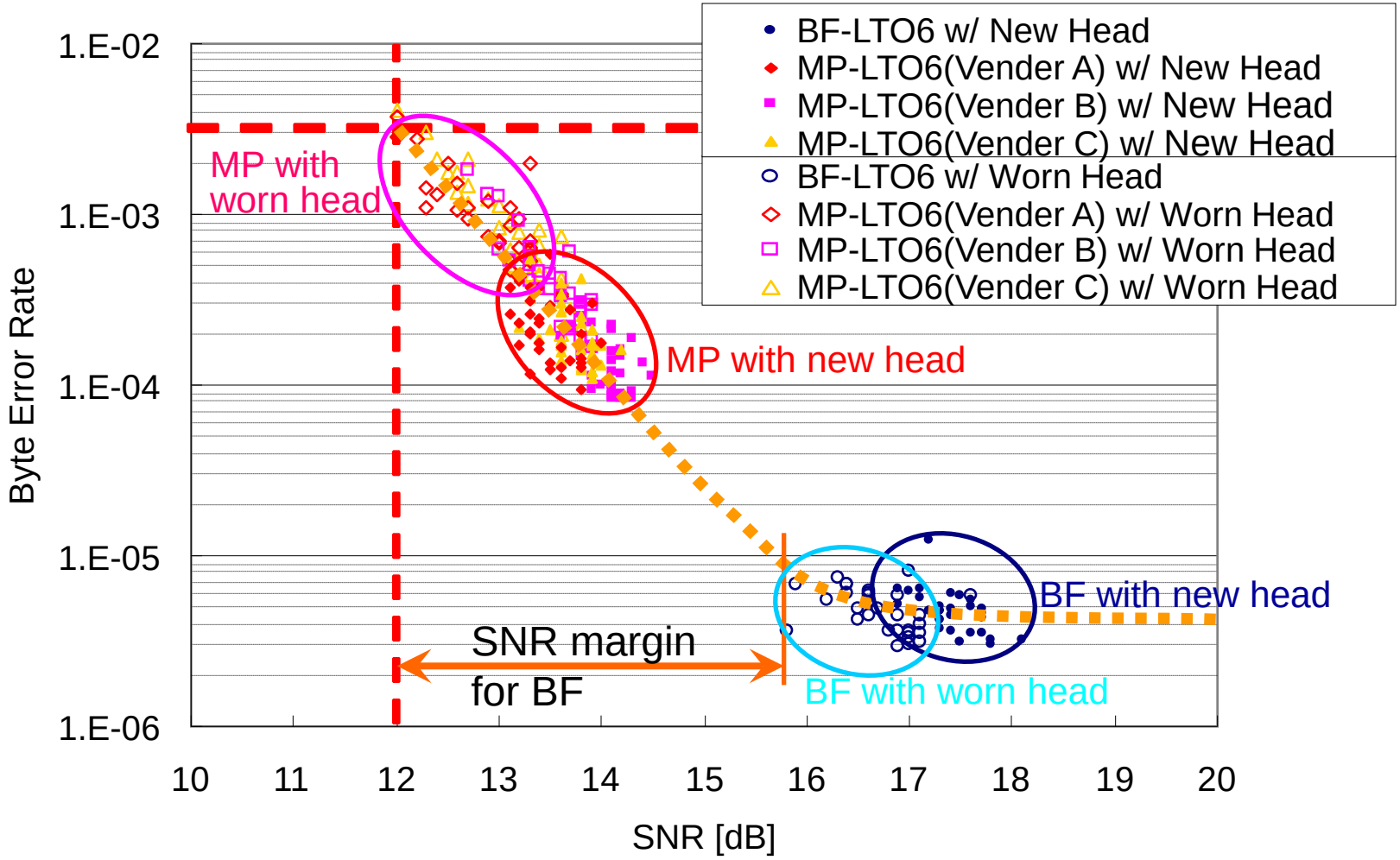
- Error Rate does not degraded even in very hot environment (65 C) for more than 1 year($3x10^7$ sec).

BF Technology - durability



- Comparison of COF of LTO-6 media. All four samples are sold as LTO-6 media, and we obtained them from the market.

BF Technology - Drive life



Head degradation will not affect to BER of BF media

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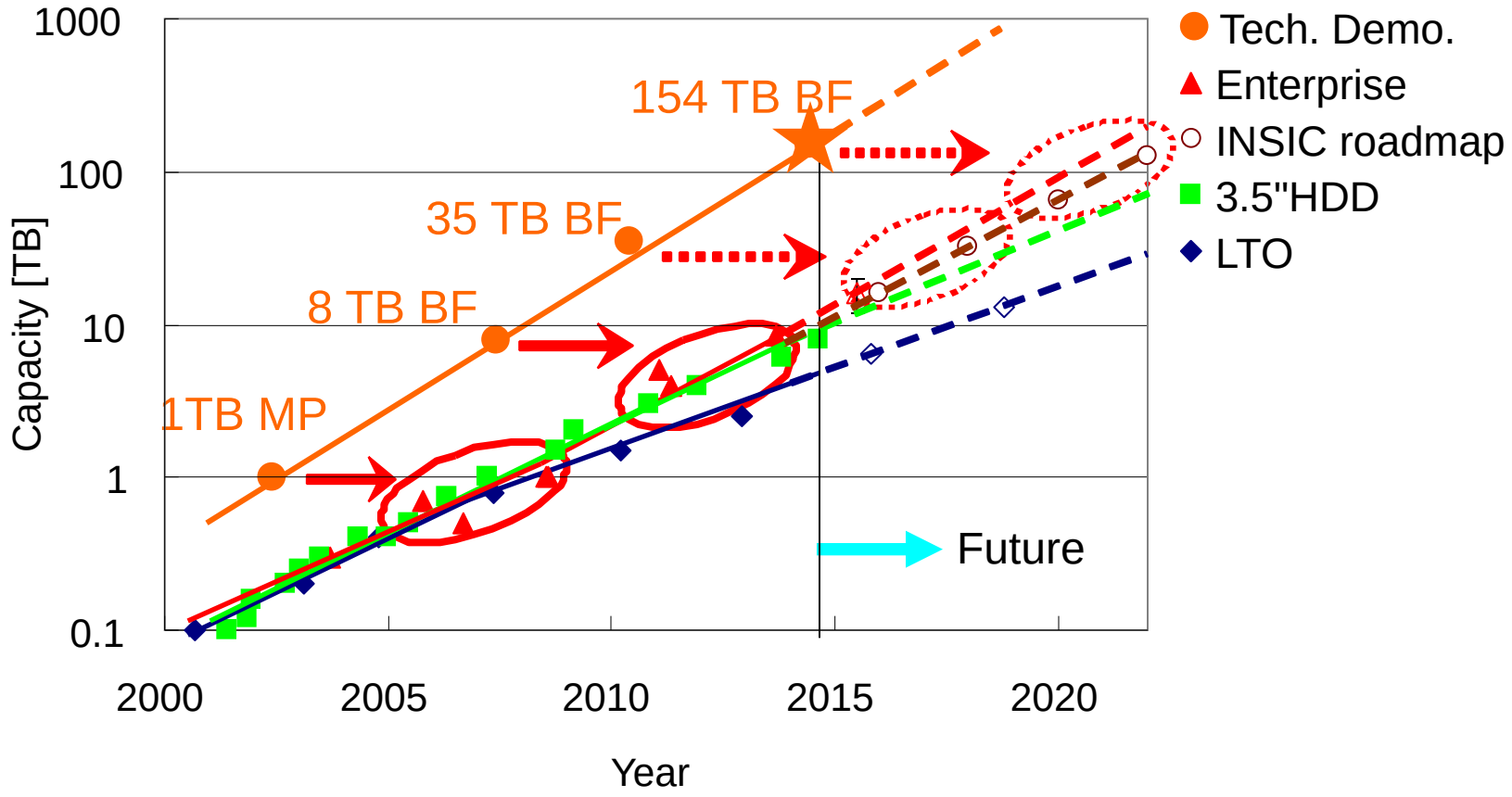

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http://www.oracle.co.jp/events/jpm120809/materials/20120809-10_StorageSumit_A-2.pdf
http://www.lto.org/technology/index.html
http://www.insic.org/news/2012Roadmap/12index.html

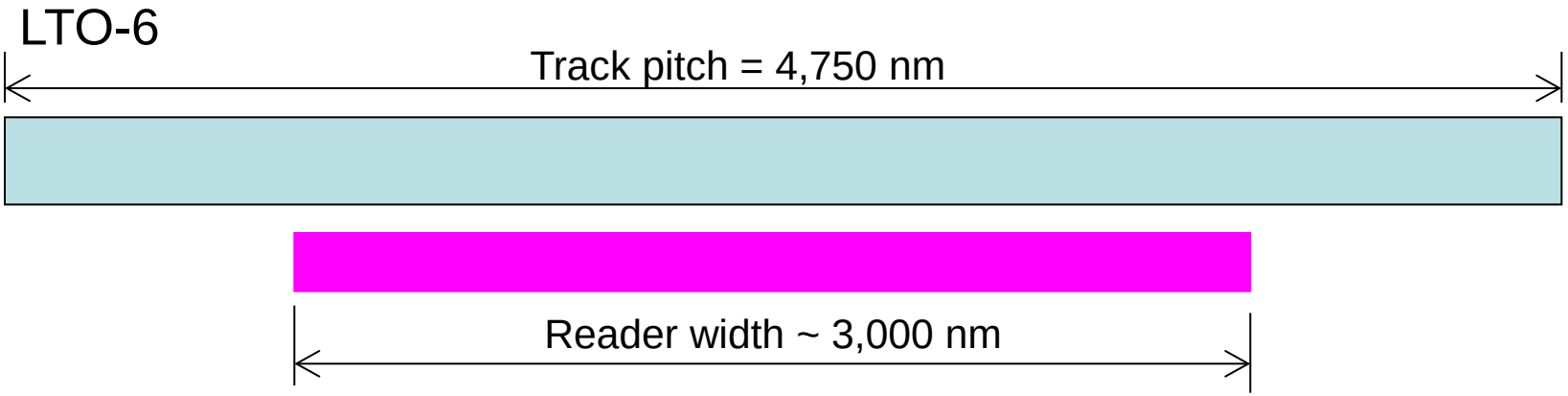
Key technologies used in the demonstration

Demonstrated by IBM and FUJIFILM

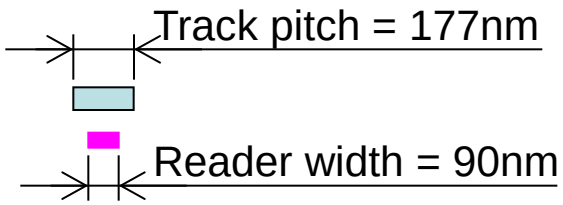
- Super narrow reader
  - 90nm reader width GMR head
- High precision actuator for track following
  - 87nm tracking margin
- High moment writer
  - Co_x-Fe_{100-x} high moment thin film
- Advanced Error correction code
  - Iterative Reed-Solomon
- Advanced perpendicular BF media
  - 1,600 nm^3 BF with perpendicular orientation

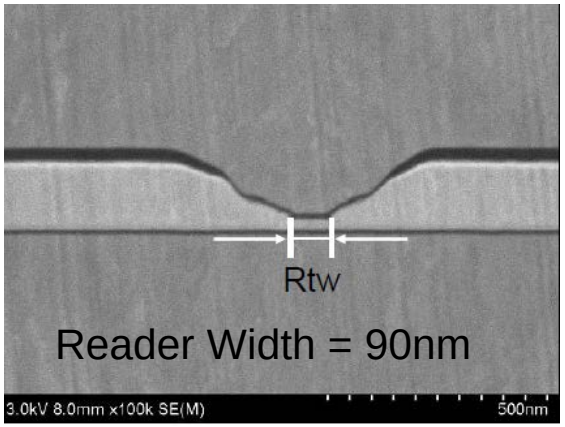
This work was done in collaboration with IBM Research - Zurich

Super narrow reader



85.9 Gbit/in^2 demonstration



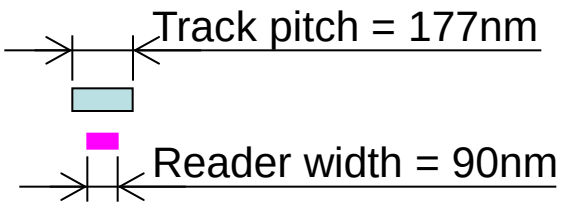


SEM image of GMR reader

Presented at TMRC2014 F2, pp.79-80, Aug. 2014
Details will be published in IEEE Transaction on Magnetics Vol. 51, No. 1 in January 2015.

High precision actuator for track following

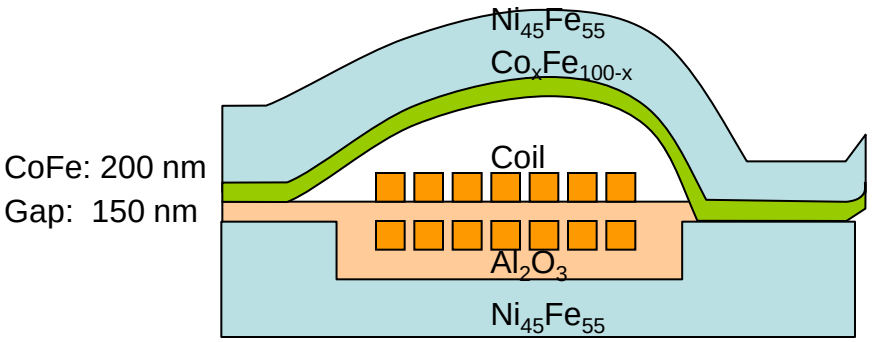
85.9 Gbit/in^2 demonstration

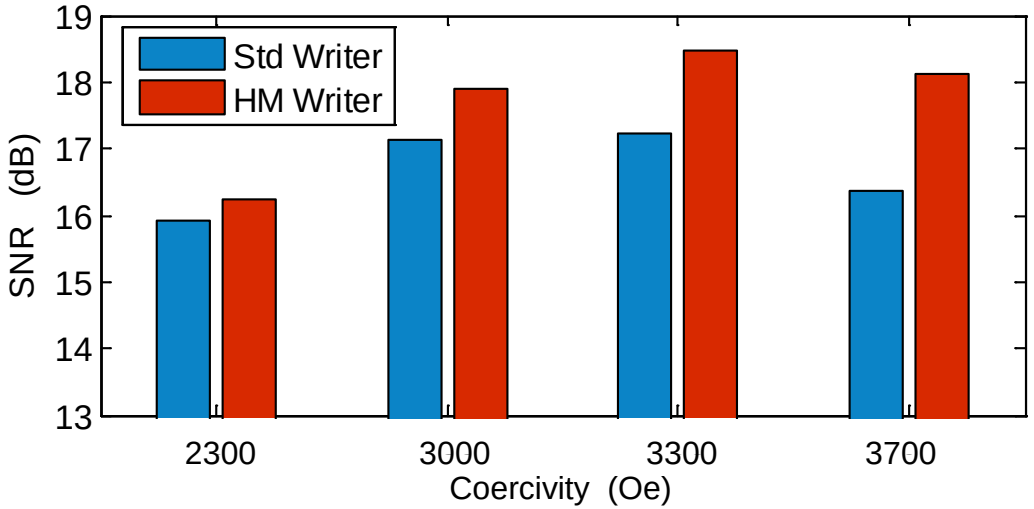


Track margin =177 nm – 90 nm
= 87 nm

Presented at TMRC2014 F2, pp.79-80, Aug. 2014
Details will be published in IEEE Transaction on Magnetics Vol. 51, No. 1 in January 2015.

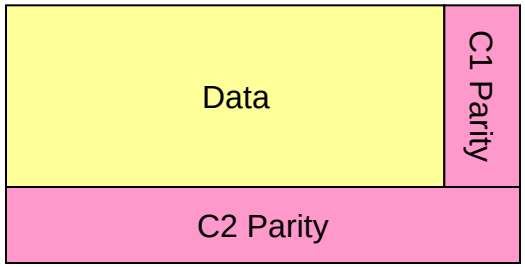
High moment writer

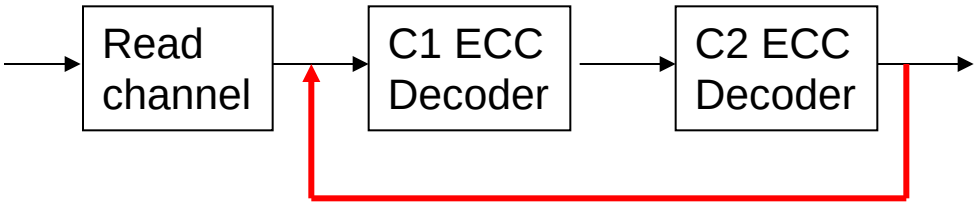


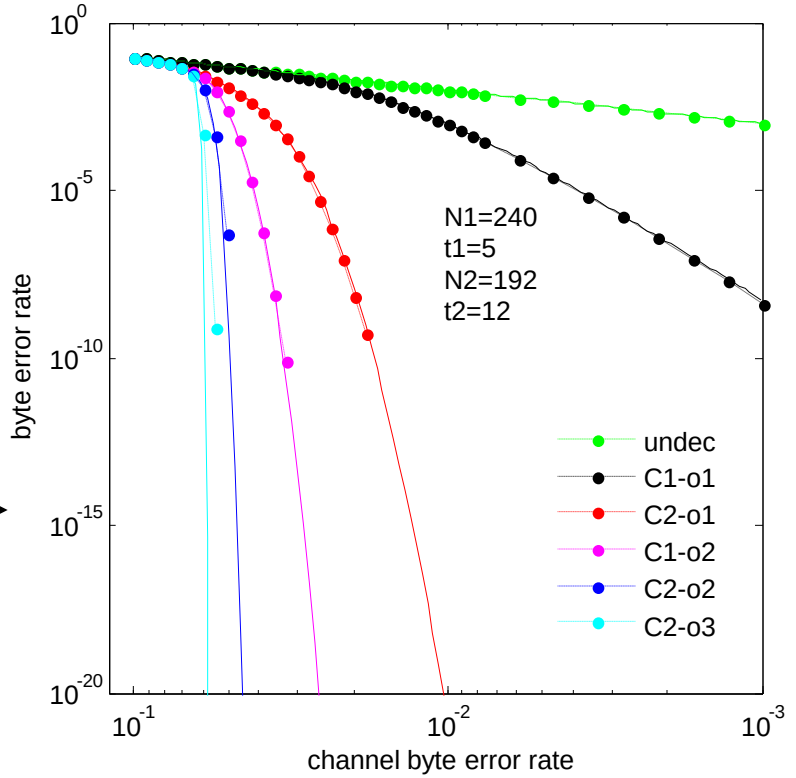


Presented at TMRC2014 F2, pp.79-80, Aug. 2014
Details will be published in IEEE Transaction on Magnetics Vol. 51, No. 1 in January 2015.

Advanced error correction code

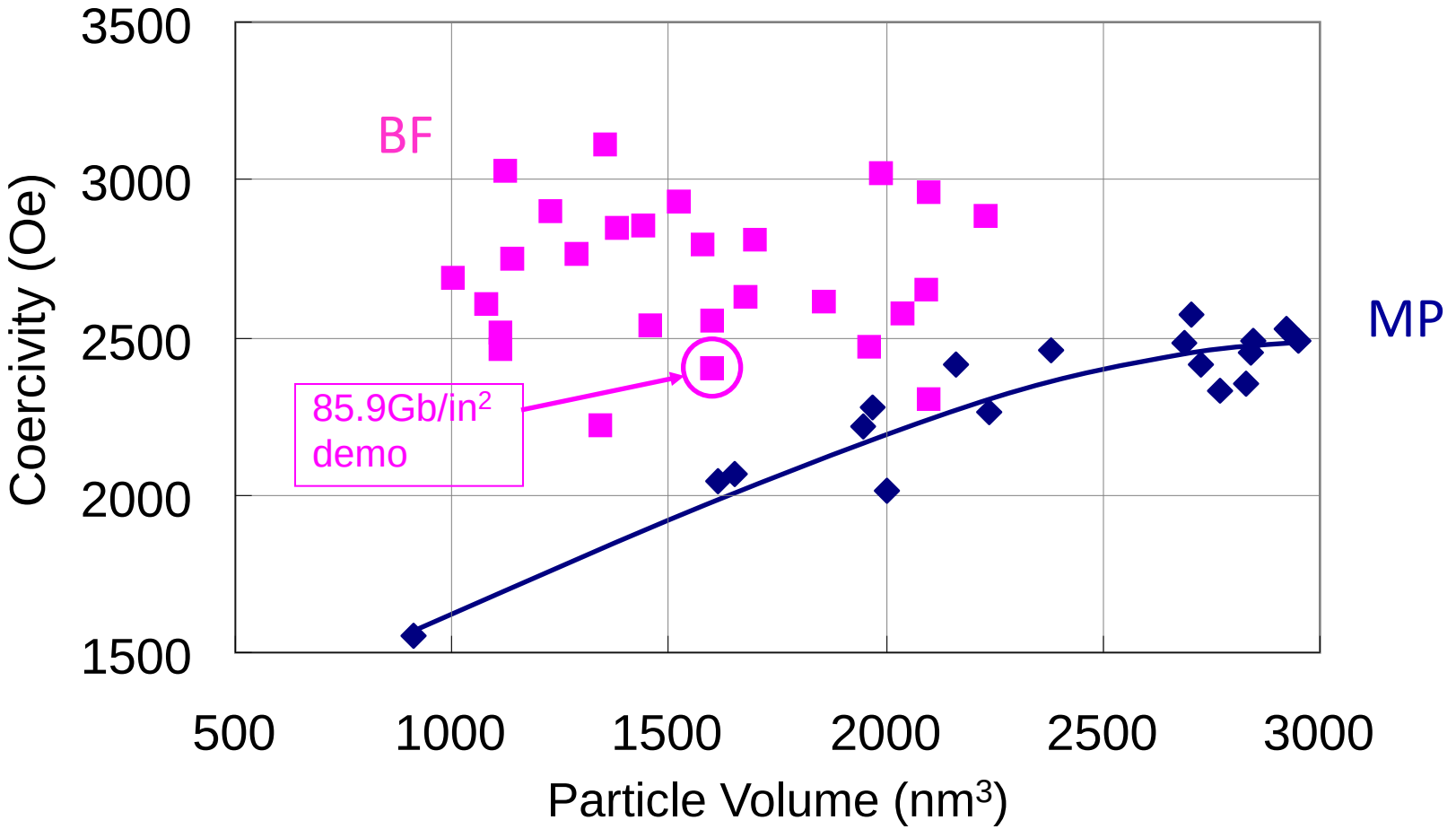






Presented at TMRC2014 F2, pp.79-80, Aug. 2014
Details will be published in IEEE Transaction on Magnetics Vol. 51, No. 1 in January 2015.

Advanced perpendicular oriented BF media



- Coercivity of barium ferrite particles is independent of their size. Smaller particles can be utilized for higher capacity.

Presented at TMRC2014 F2, pp.79-80, Aug. 2014
Details will be published in IEEE Transaction on Magnetics Vol. 51, No. 1 in January 2015.

Latest demonstration

System parameter		LTO-6	Latest demo
Linear density	kbit/in	385	600
Track density	kT/in	5.3	143
Areal density	Gbit/in^2	2.06	85.9
Tape length	%	100	148
Capacity	TB	2.5	154

Tape parameter		LTO-6	Latest demo
Magnetic particle size	nm^3	1,900	1,600
Surface roughness	nm	2.0	0.8

- Details of this demonstration will be published in IEEE Transaction on Magnetics Vol. 51, No. 1 in January 2015.

Future Tape System beyond 300 TB

– Technologies to be used in late 2020s or 2030s –

Technologies which will be used

- Smaller barium ferrite particles.
  - down to 1,000 nm^3 (1,600 nm^3 was used for 154 TB).
- More advanced reader technology.
  - TMR reader (GMR reader was used for 154 TB).
- More advanced channel technologies.

Technologies which may be applicable (for much beyond 300 TB)

- Energy assisted recording.
- Single pole write head with soft under layer.

Summary

- The Capacity of magnetic tape cartridge has been increased by reducing, Particle volume, Magnetic layer thickness, Surface roughness, and Total tape thickness.
- Increasing cartridge capacity using MP with keeping long term stability becomes difficult because MP no longer can reduce their particle size without reducing coercivity.
- BF particles are very promising and technologies corresponding to 154 TB per cartridge was demonstrated, which will be launched in several years.
- Tape has come back as the highest capacity storage since 2011 by applying BF technology and the current highest capacity of tape system is 8.5TB.
- Some of the technologies to be required for over 154 TB have already been developed and they will be used for over 300 TB tape cartridges.