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Value from Innovation

Particulate Magnetic Tape for Data Storage and Future Technologies

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Outline

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1. Background

- Exponential growth of data and storage
- Advantages of tape storage

2. Innovation of Tape technologies

- Key technologies to increase capacity
- Future tape technologies

3. Summary

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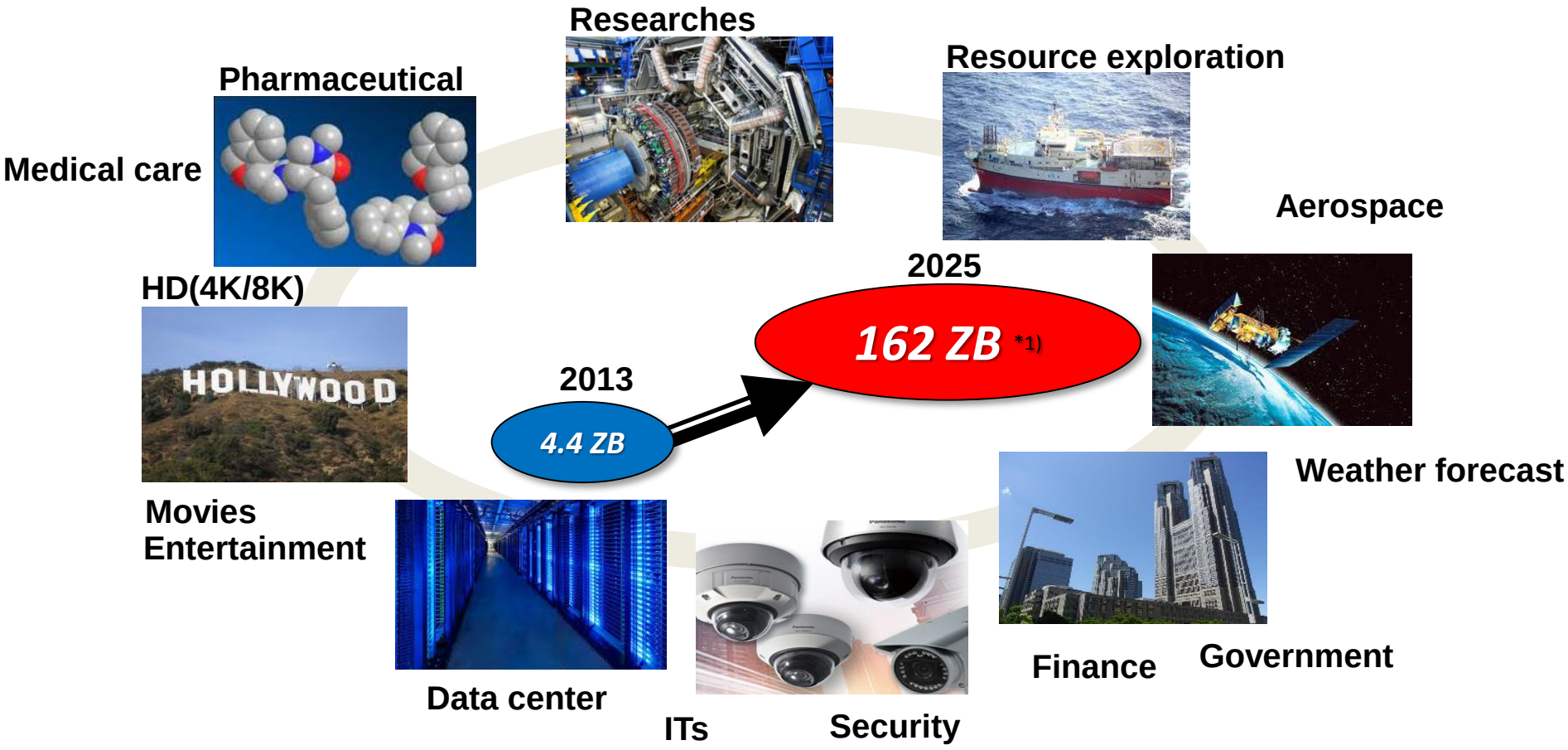
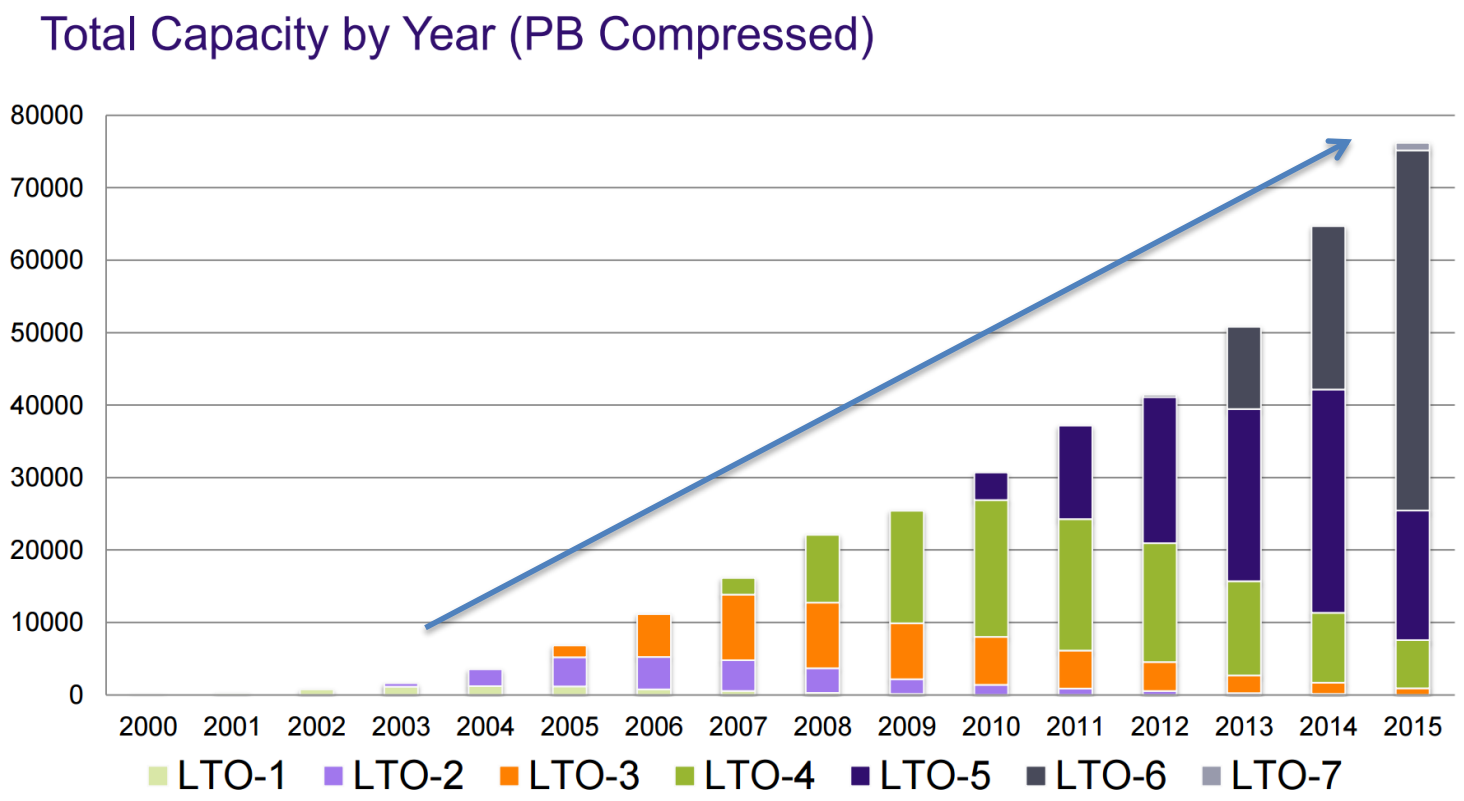
Exponential Growth of Data and Storage



*1) The IoT Cloud: Infrastructure Options for Accelerating the Shift to Digital Business Services, IDC, 2016.

Because of the exponential data growth, the demand for storage is also increasing.

Demand for Tape Storage



Source: http://www.lto.org/wp-content/uploads/2016/03/LTO_Media-Shipment-Report_3.22.16.pdf

- Tape has increased its demand in the market with the background of the exponential data growth

Advantages of Tape Storage

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1. Cost effectiveness

- Low Total Cost of Ownership (TCO)

2. Energy efficiency

- Low power consumption

3. High reliability

- Low hard (unrecoverable) error rate
- Long media life (30+years)

4. High capacity

- 15TB per single cartridge
- Continuous growth of cartridge capacity

Tape storage is suitable for data archiving !!

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1. Background
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   - Advantages of tape storage

2. **Innovation of Tape technologies**
   - Key technologies to increase capacity
   - Future tape technologies

3. Summary

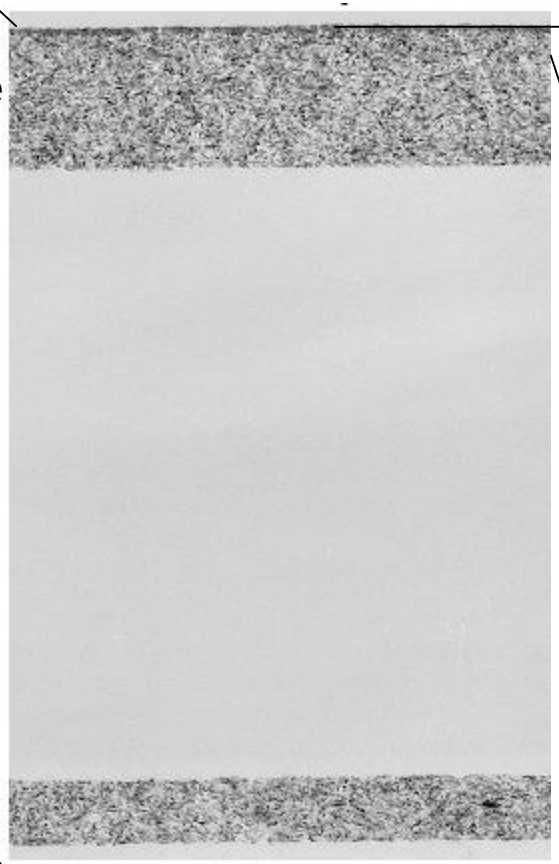
Structure of Particulate Magnetic Tape

Magnetic layer
Data recording

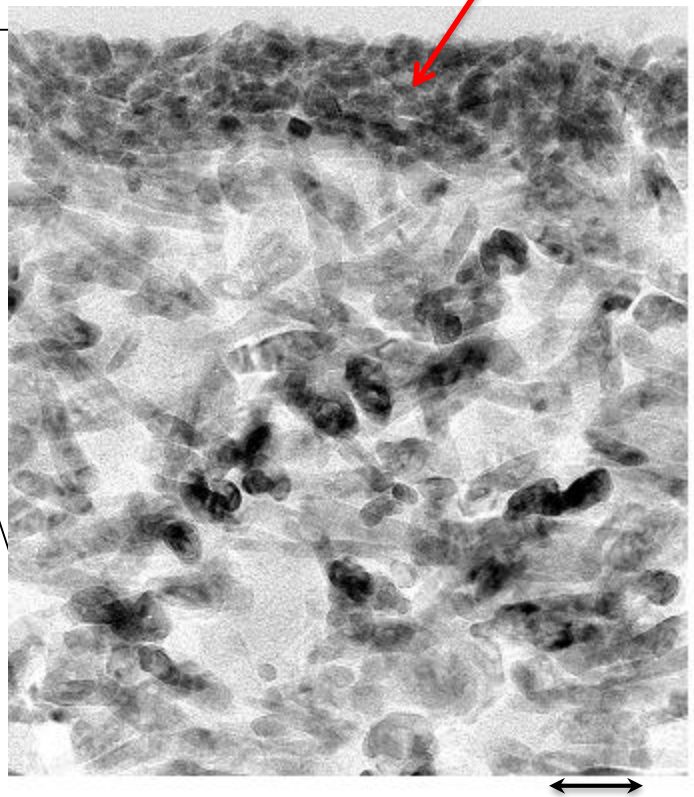
Under layer
Prevent static charge
Roughness control

Substrate

Backcoat
Prevent static charge

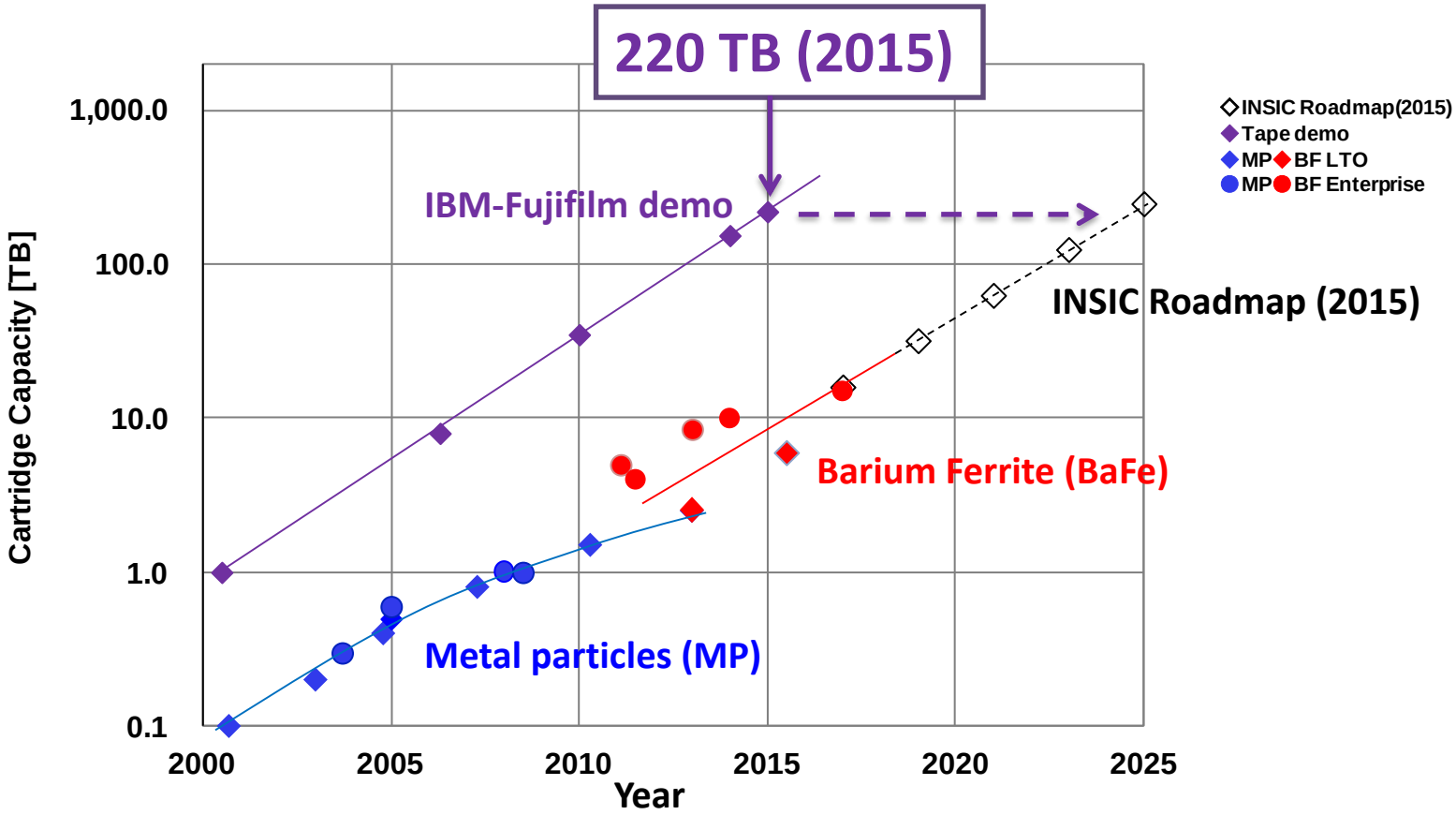


Magnetic particles



50 nm

Cartridge Capacity Trends



- IBM-Fujifilm have been developing tape technologies to continuously increase cartridge capacity.
- All the latest tape systems use Fujifilm's BaFe particle technology.
- The latest BaFe demo can support the next 10 years roadmap.

Key Technologies to Increase Capacity

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Extend tape length in a single cartridge

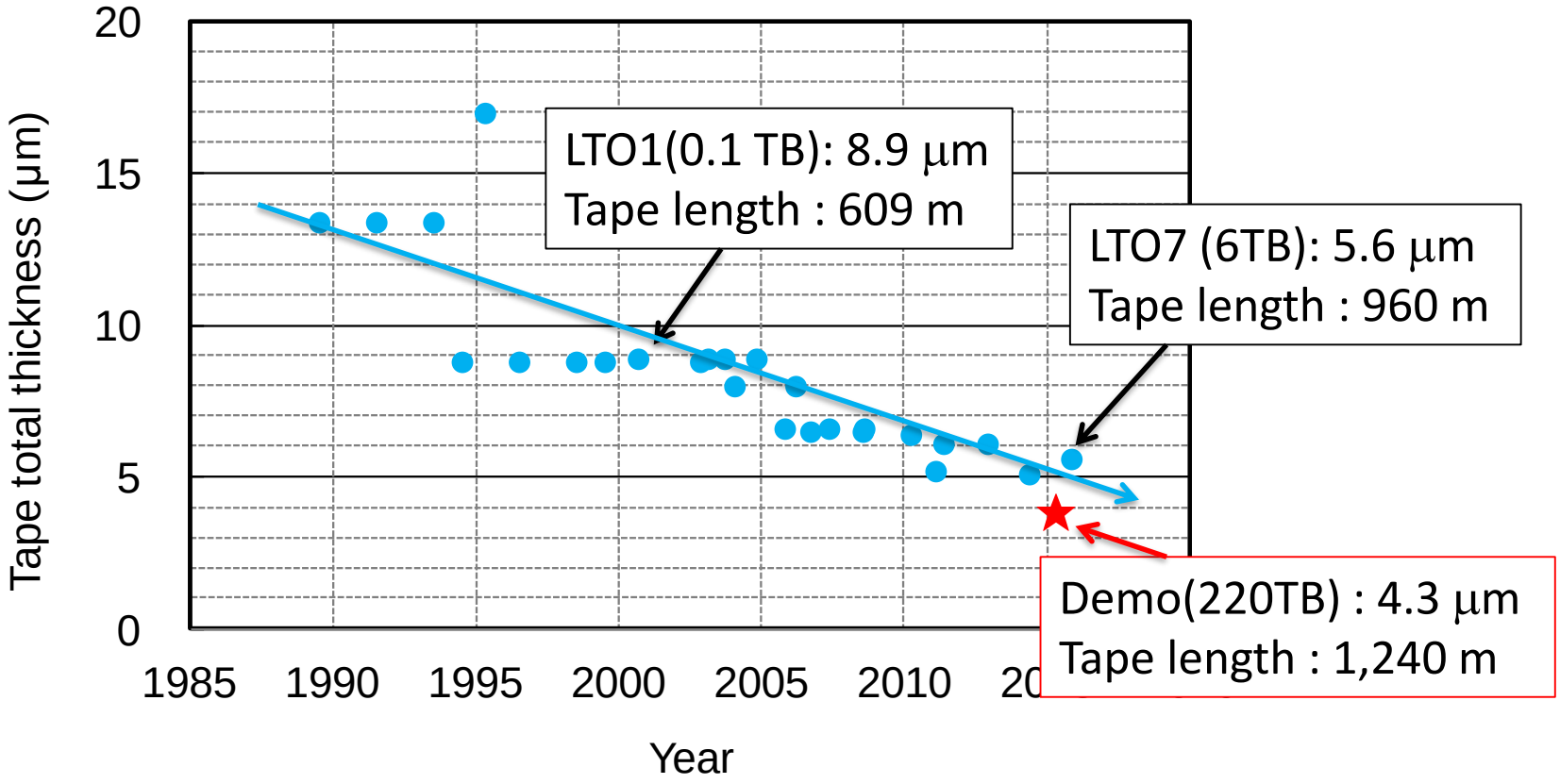
Reduce tape total thickness

Increase areal recording density

Enhance recording performance

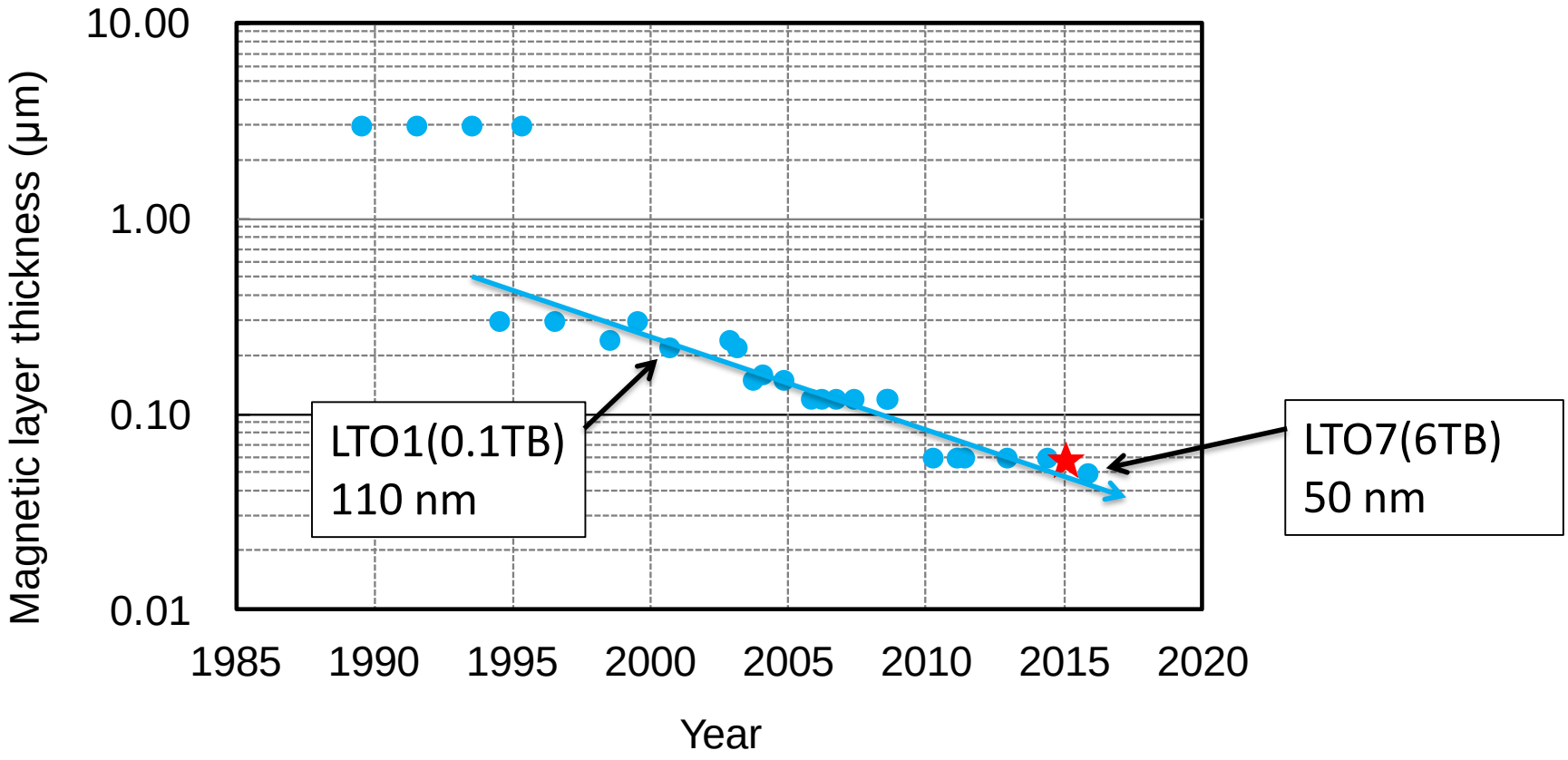
- Thin & Uniform coating
- Reduce tape surface roughness
- Reduce magnetic particle size

Tape Thickness Trends



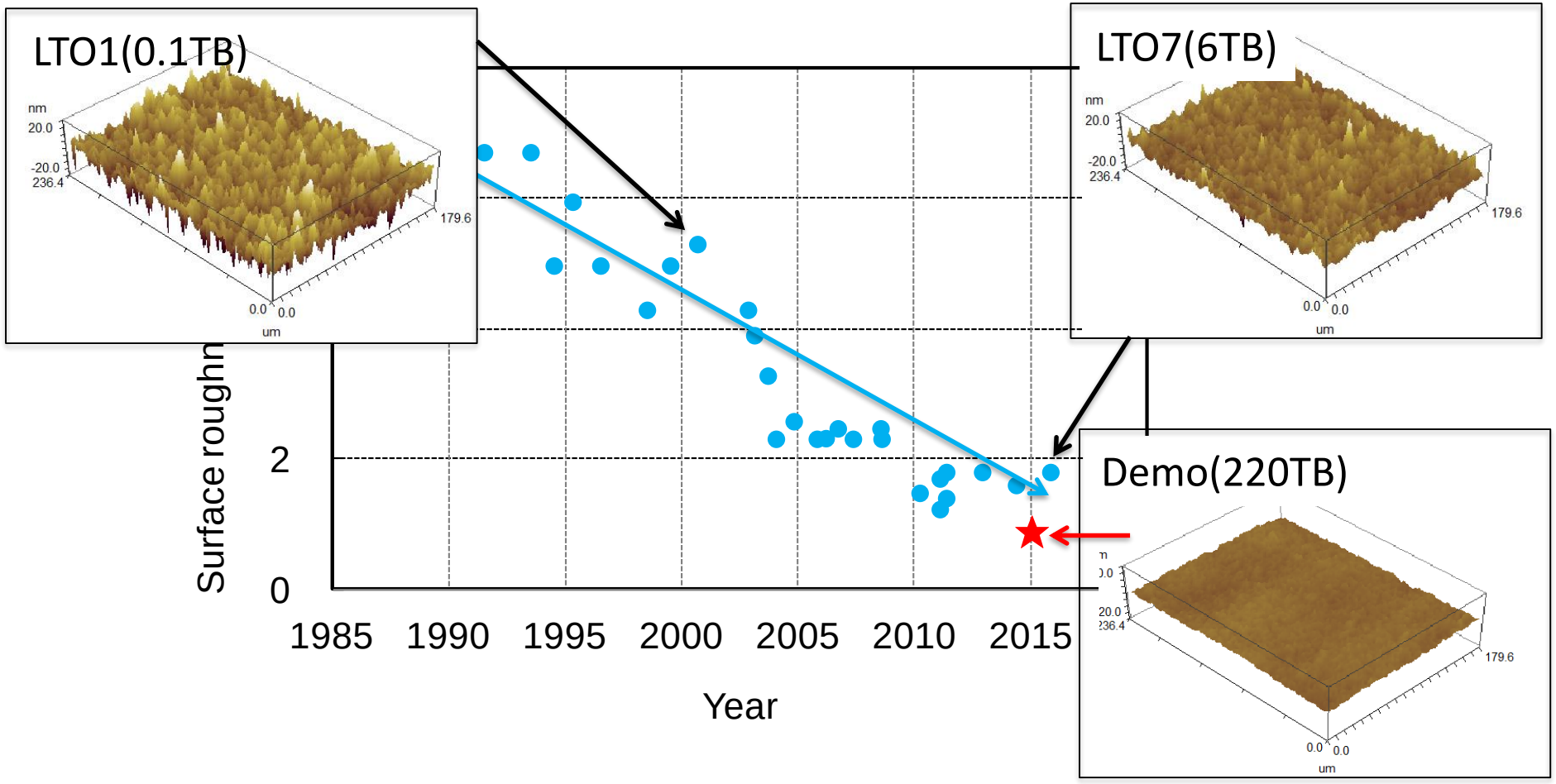
- Thickness of tape media decreases year by year.
- The demo(220TB) achieved a thickness of 4.3 μm, enabling tape length to exceed 1.2 km in a cartridge!

Magnetic Layer Thickness Trends



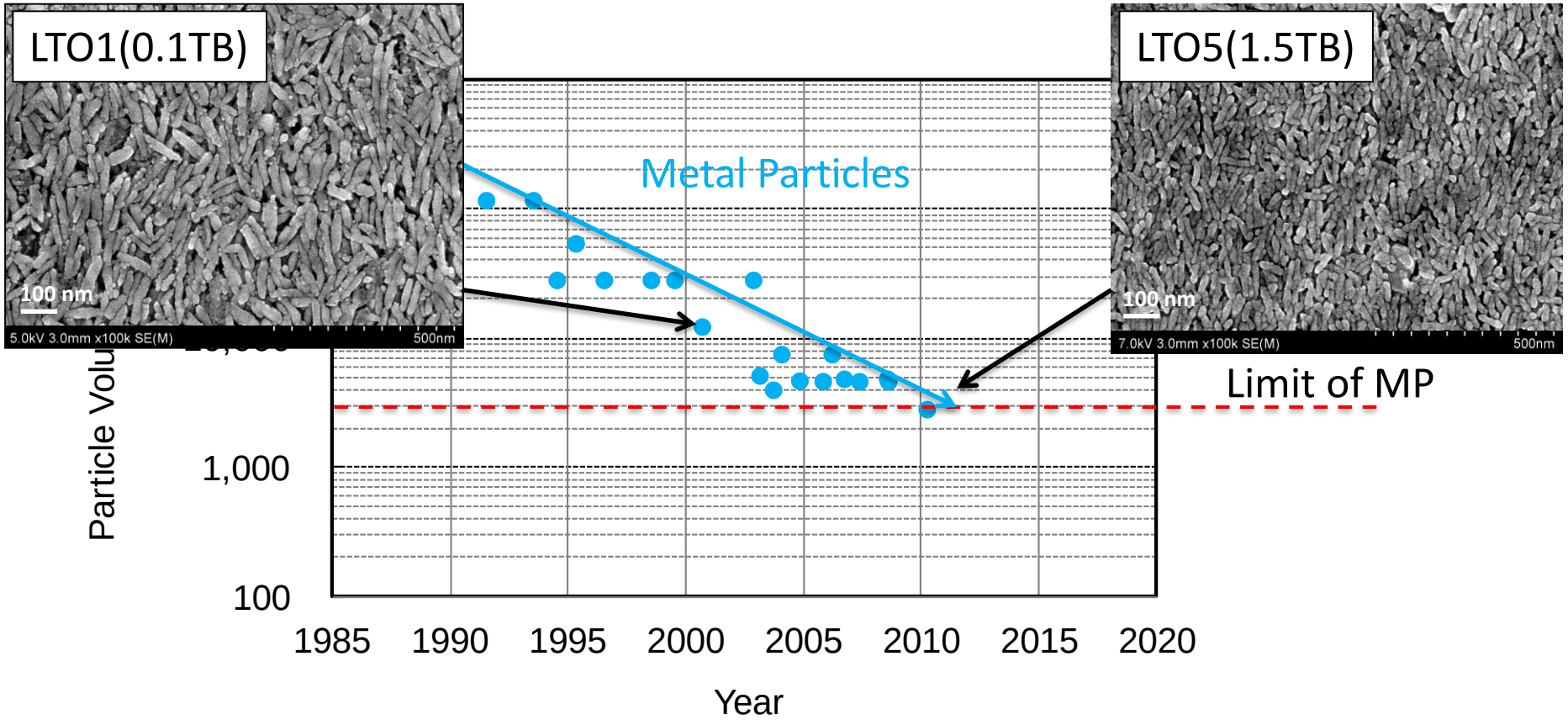
- Thickness of magnetic layer decreases year by year.
- Fujifilm has been developing advanced coating technologies to reduce magnetic layer thickness.

Surface Roughness Trends



- Surface roughness of tape media decreases year by year.
- The demo media achieved a much smoother surface as compared to the production media.

Magnetic Particle Volume Trends



- The size of magnetic particle decreases year by year.
- Metal particles (MP) faced limit to reduce their size below 2,800 nm^3.

Magnetic Particle Volume Trends (Cont'd)

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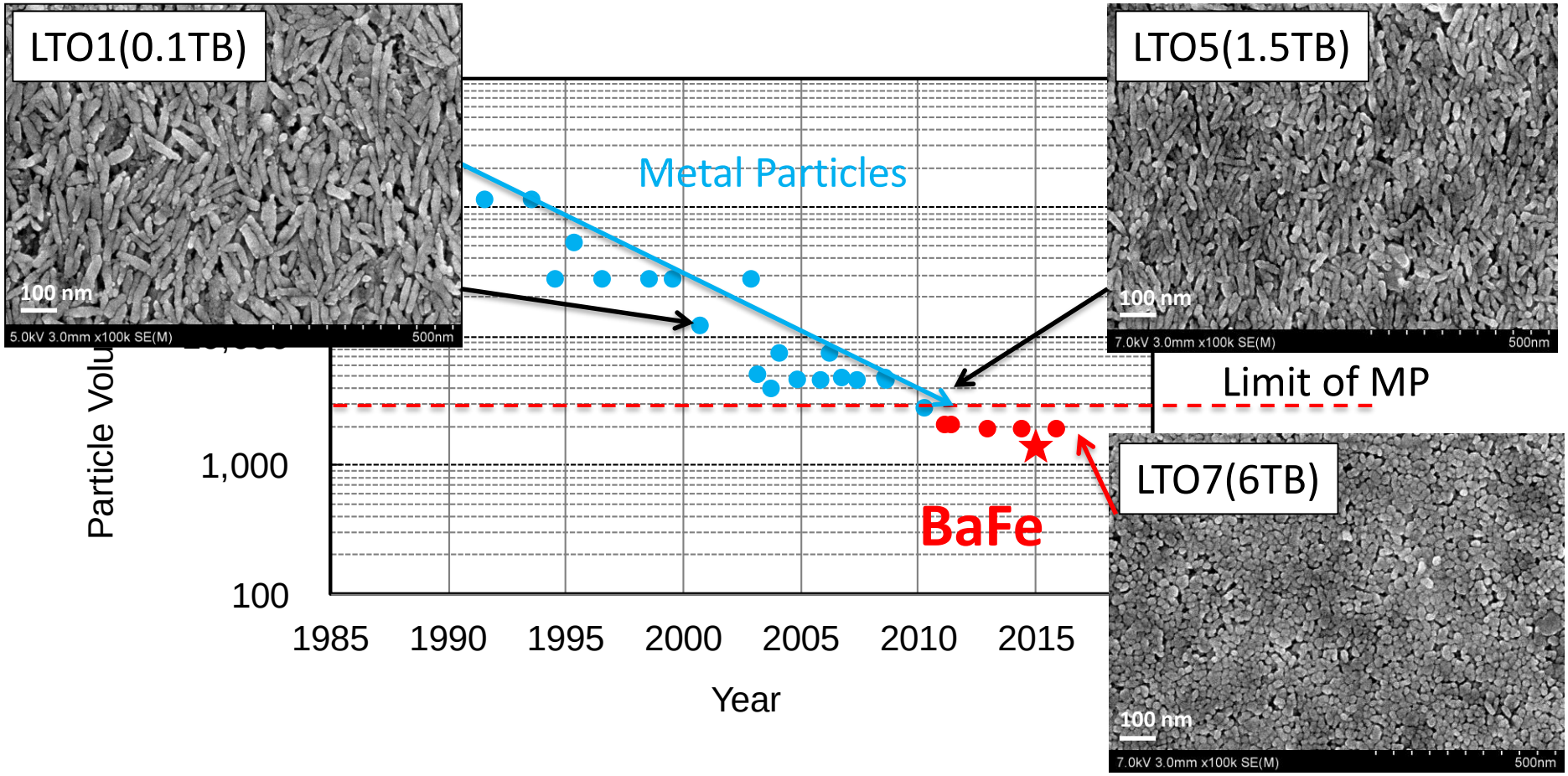

- The size of magnetic particle decreases year by year.
- Metal particles (MP) faced limit to reduce their size below 2,800 nm^3.

→ **BaFe has become the de facto standard for tape storage**

Size constraint on Metal Particles

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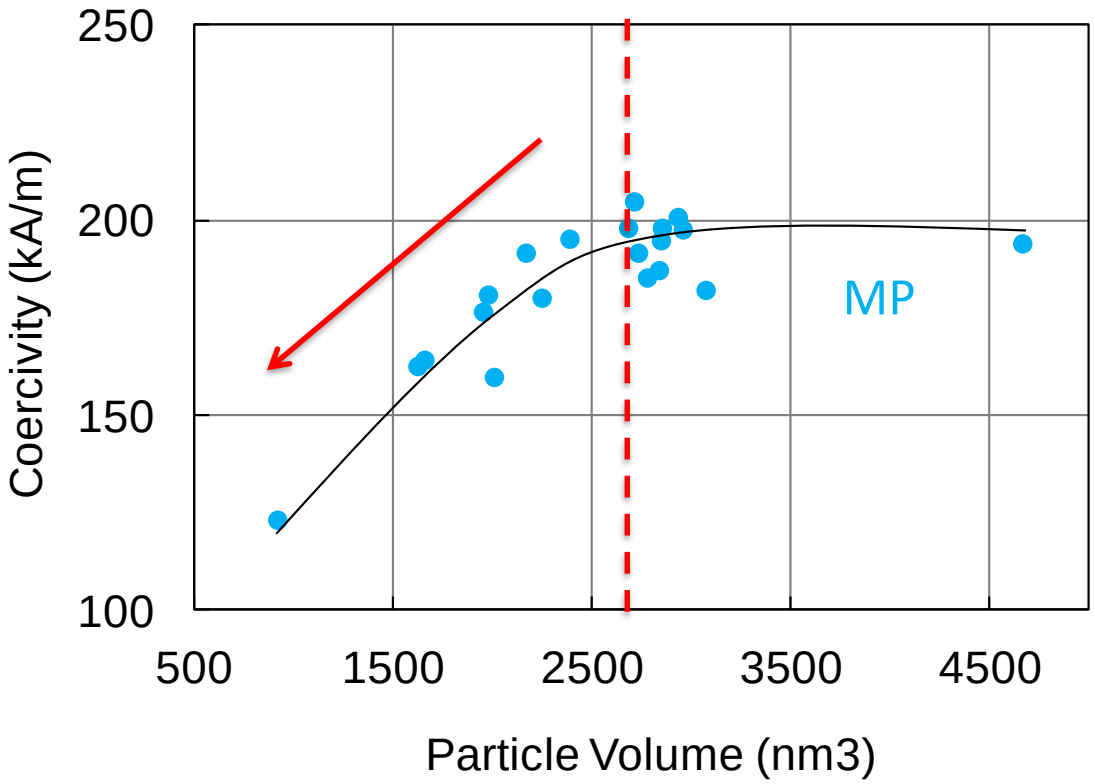
Coersivity vs. particle volume

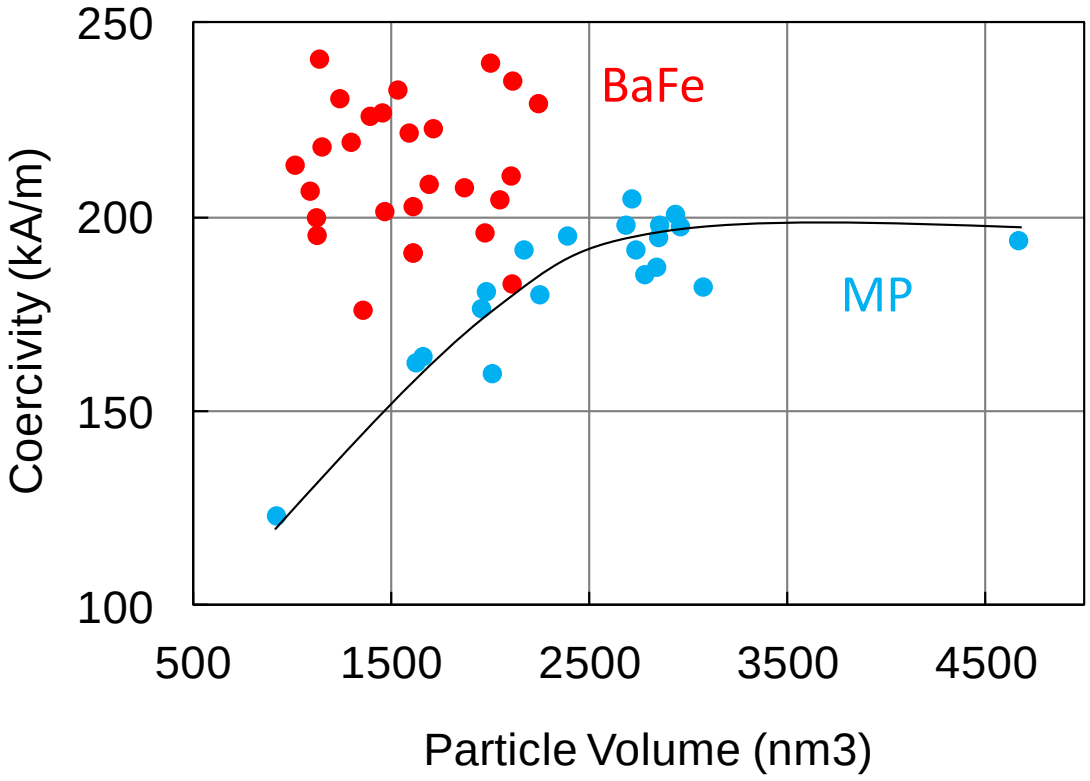


- Reducing the particle size to less than 2,800 nm^3 degraded the magnetic coercivity, which is critical to long-term storage of recorded data

→Capacity limit with metal particles

Advantages of BaFe particle

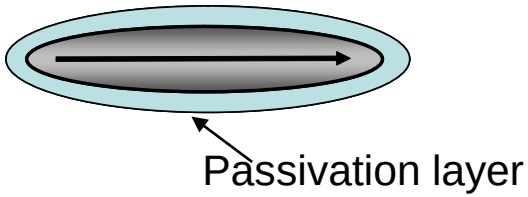
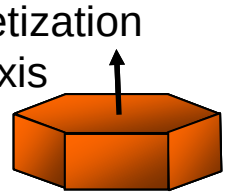
Coersivity vs. particle volume



- The coercivity of Bafe particles is independent on their size, and controllable by changing the particle composition

→The size of BaFe particles can be reduced for increased capacity!

Metal particles vs BaFe particles

	MP	BaFe
Particle Shape	 Acicular	 Hexagonal platelets
Material	FeCo alloy	$BaO(Fe_2O_3)_6$ Oxide
Origin of magnetic energy	Shape anisotropy	Magneto-crystalline anisotropy
Passivation layer	Required	Not Required

- The magnetic properties of BaFe particles are not influenced by their particle shape.
- A passivation layer is not required since BaFe particles are oxides.

→The size of BaFe particles can be reduced without degradation of their magnetic properties

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Perpendicular Orientation Technology

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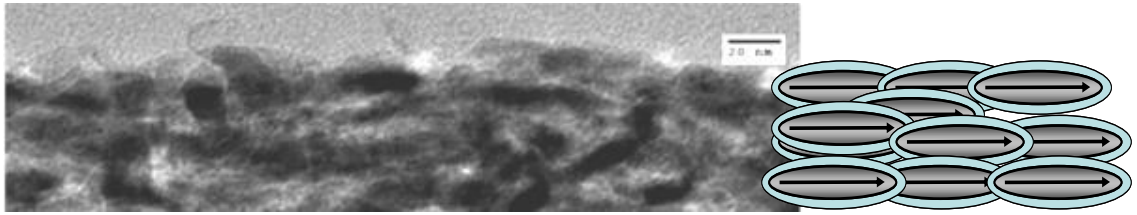
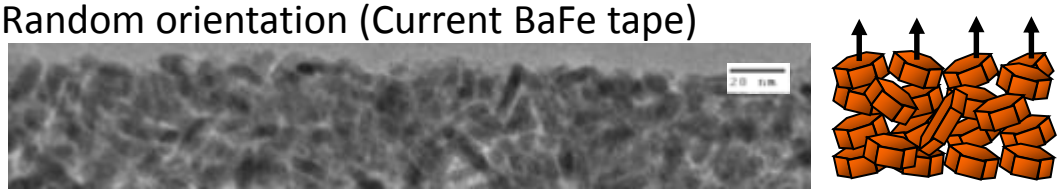
Particle orientation

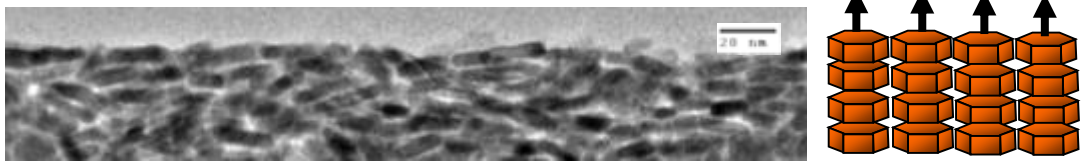
Longitudinal orientation (MP tape)



Random orientation (Current BaFe tape)

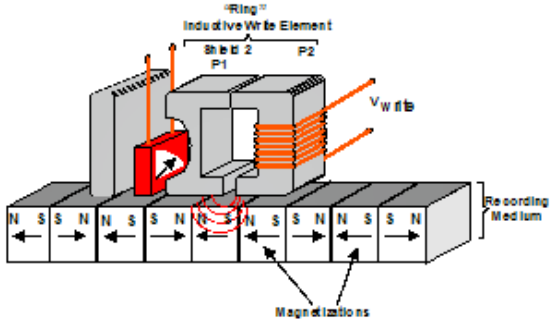


Highly perpendicular orientation (Demo 2015)

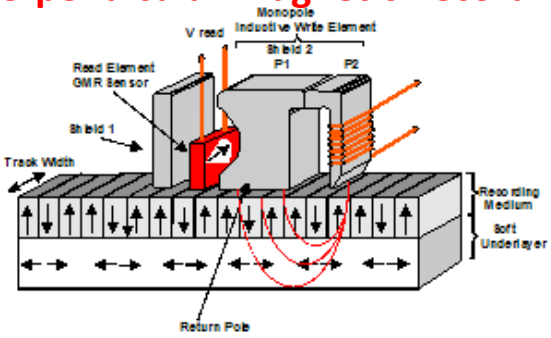


Recording system

Longitudinal Magnetic Recording



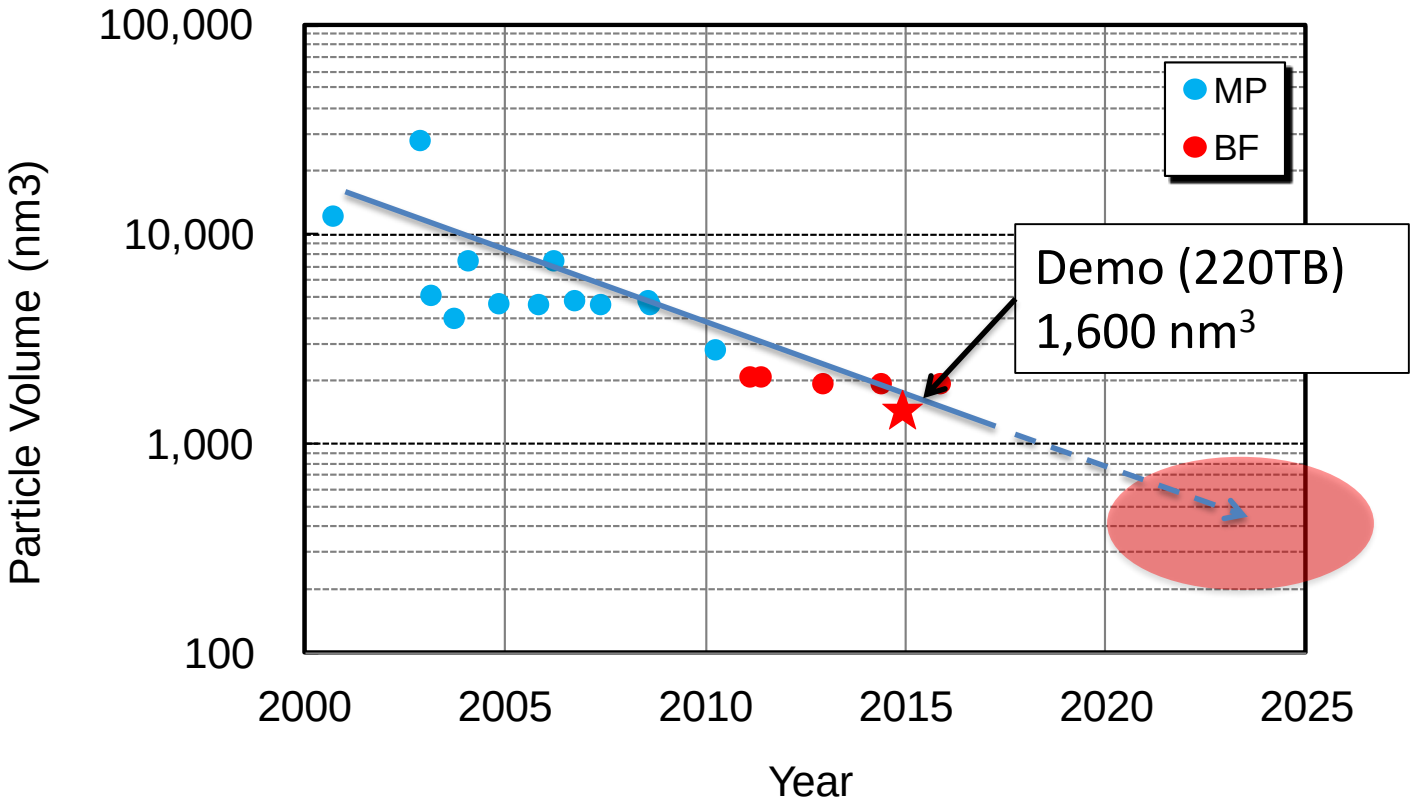
Perpendicular Magnetic Recording



- BaFe particles can be oriented in perpendicular direction.

→PMR, which contributed to increase capacity of HDD can be applied in the tape storage system.

Magnetic Particle Volume Trends



• For the future tape, technologies to reduce particle size to less than 1,000 nm^3 will be required.

Ultra Fine Magnetic Particle Technology

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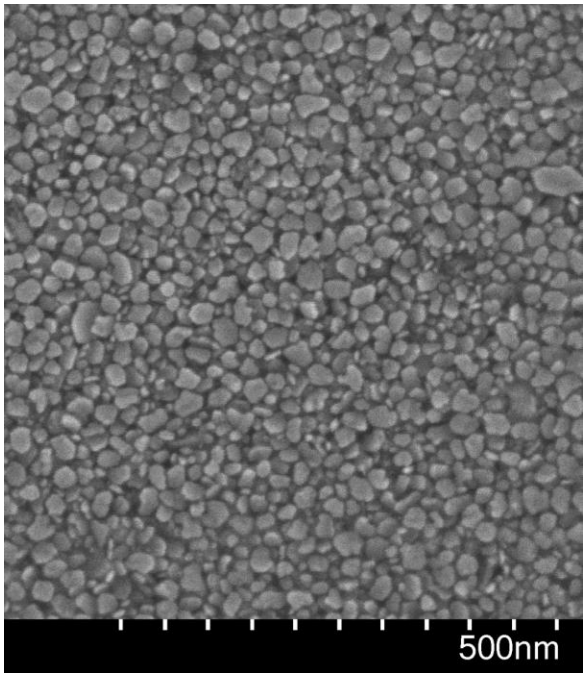
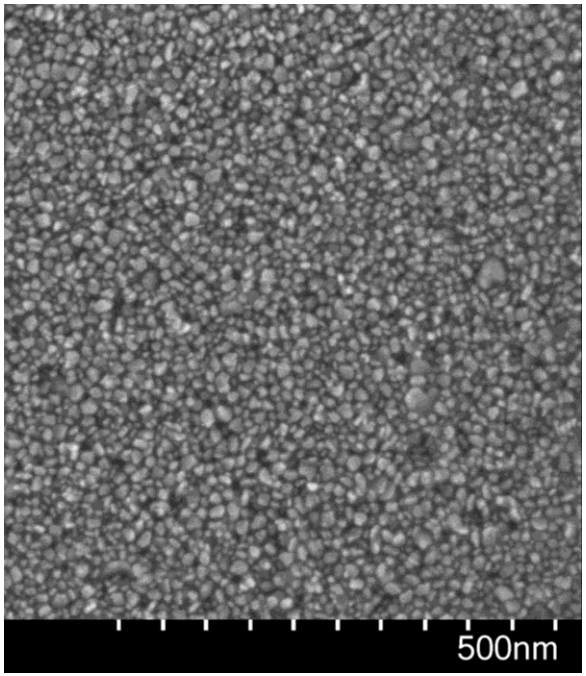
	Barium Ferrite	Strontium Ferrite NEW!!
Particle volume	1,600 nm^3	900 nm^3
Capacity (demo)	220 TB	(To be confirmed)





- Fujifilm has successfully developed "**Strontium ferrite particles**", with a particle volume of 900 nm^3.

Cartridge Capacity Trends

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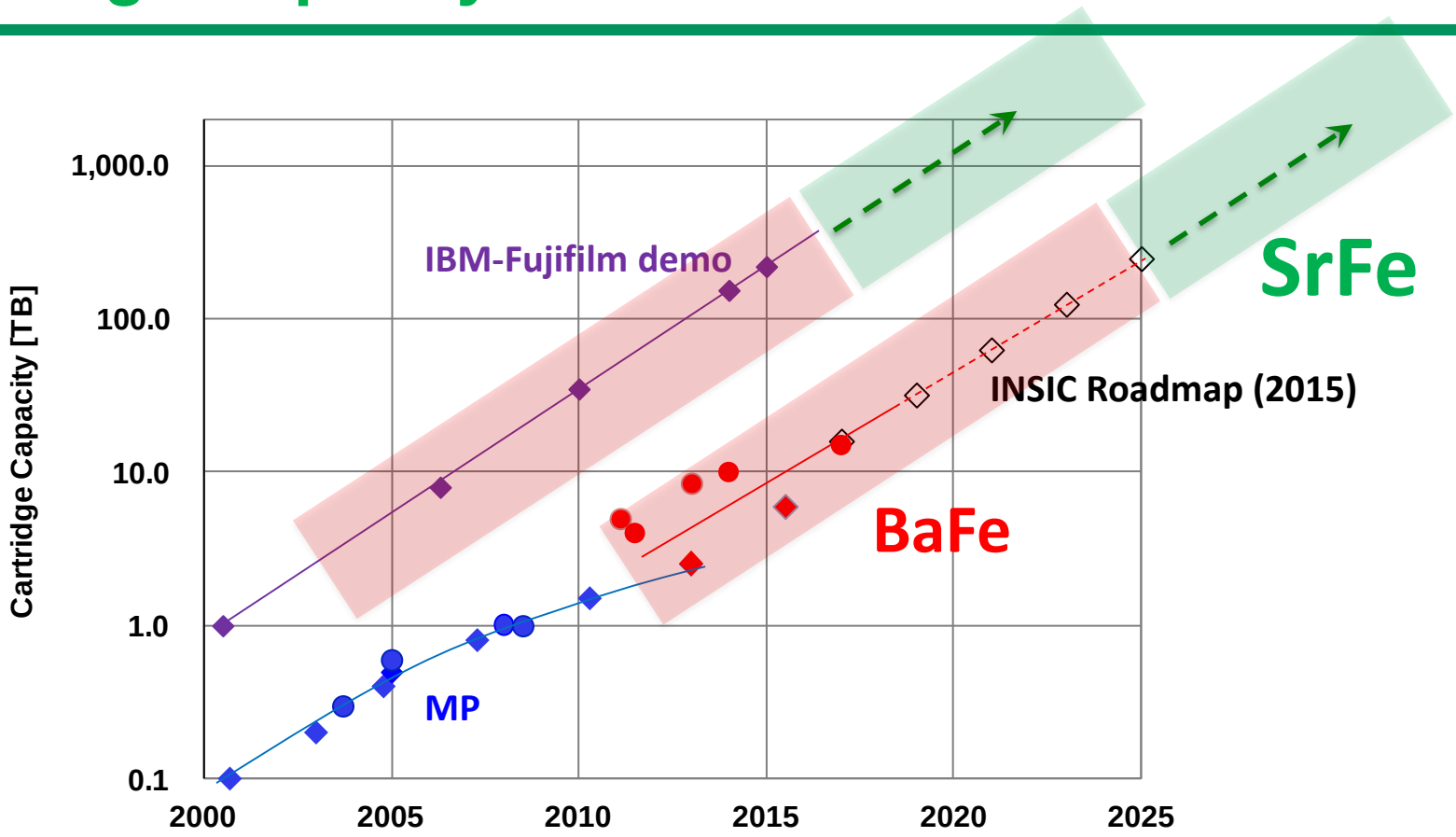

BaFe can support the next 10 year's tape roadmap.

SrFe will enable to further high capacity cartridge in the future !!

Summary

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- Tape storage is suitable for **data archiving** owing to its advantages.

- The cartridge capacity of particulate tapes has increased as a result of **innovations in tape technology**.

- Fujifilm's **BaFe particle technology** contributes to continuous growth of cartridge capacity of tape storage, and can support tape roadmap over the next 10 years.

- Fujifilm has successfully developed "**Strontium ferrite particles**", with a volume of 900 nm^3, which will enable to further high capacity cartridge in the future.

Future of tape storage is brighter than ever!!

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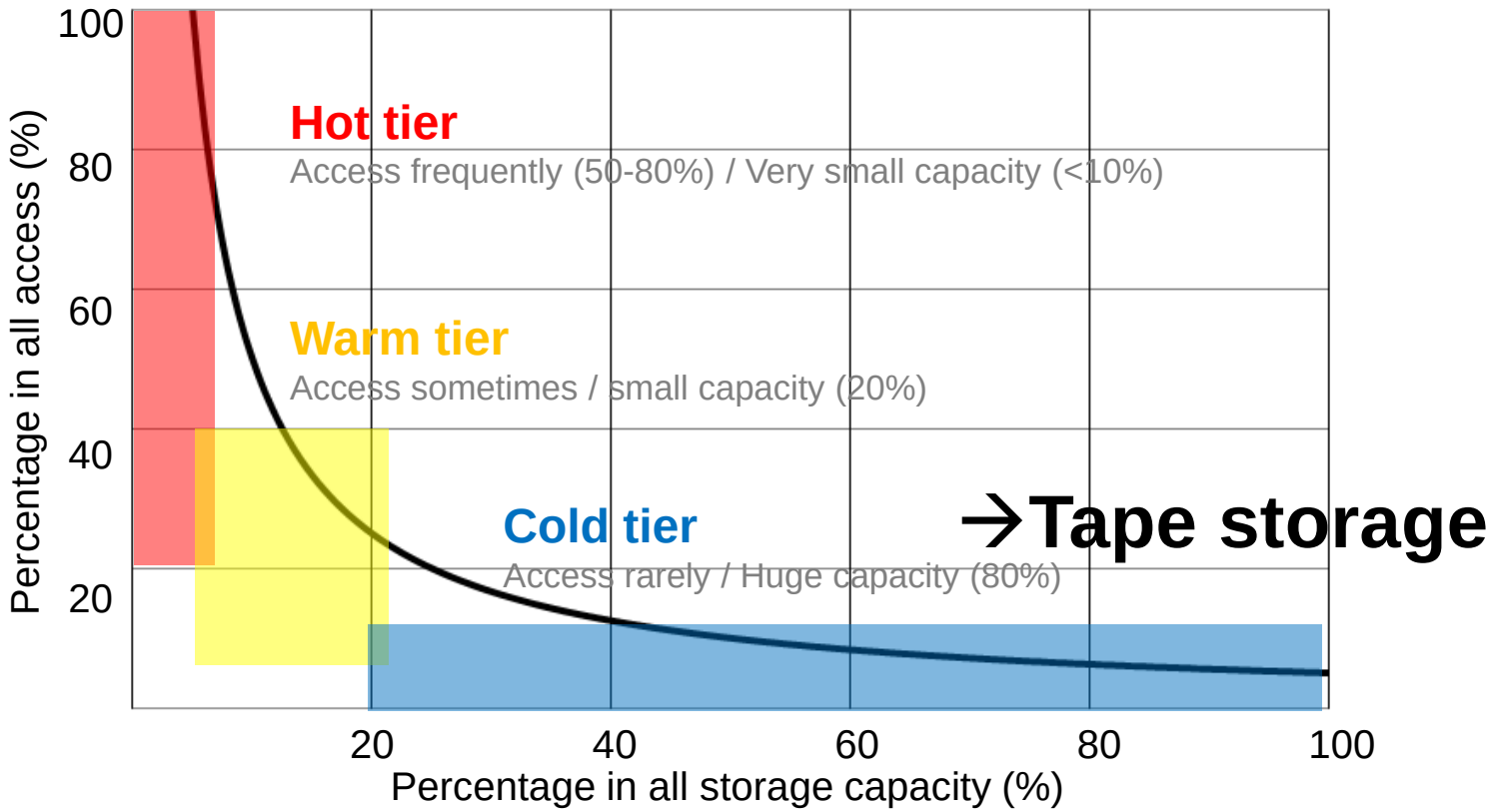
Value from Innovation

Appendix

New Role of Tape as Cold Data Storage



- Most data is very rarely accessed, however, data must be retained for preservation to ensure compliance with legal requirements or, for future reference to analyze business opportunities.**

  →Storage for COLD data has become a HOT topic

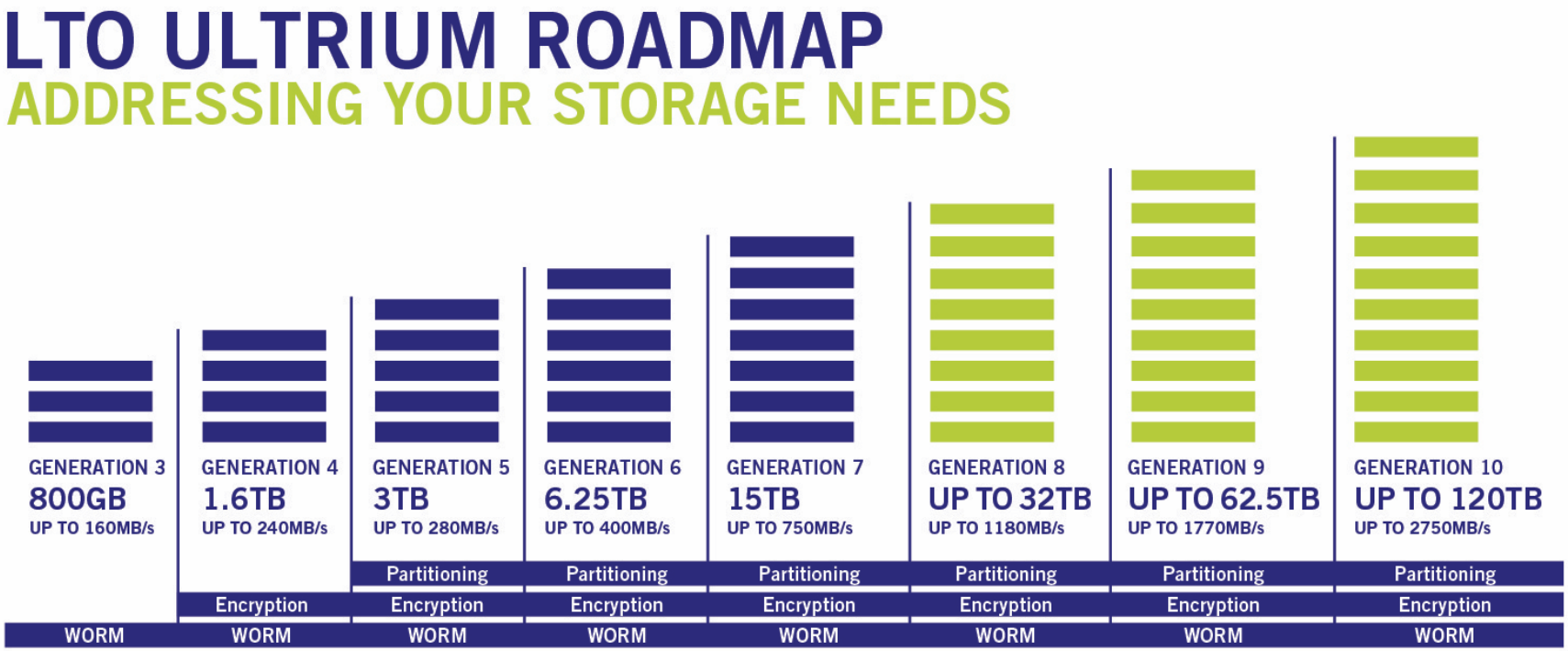
- But budget is limited.

  →Reliable yet inexpensive storage media is required.

*90% data in NAS is never accessed. (Source: University of California, Santa Cruz)

**Retention of 20 year or more is required by 70%. (Source: SNIA-100 year archive survey)

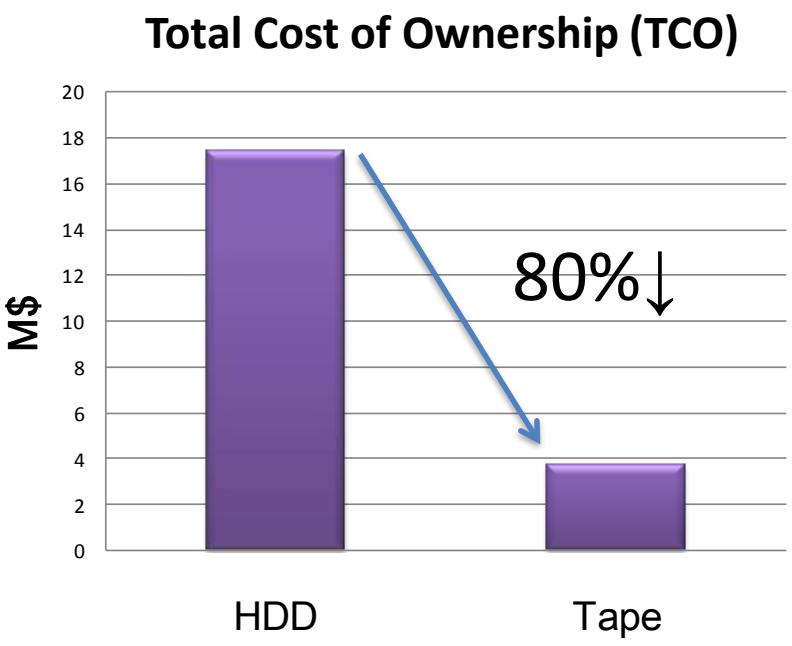
LTO Roadmap

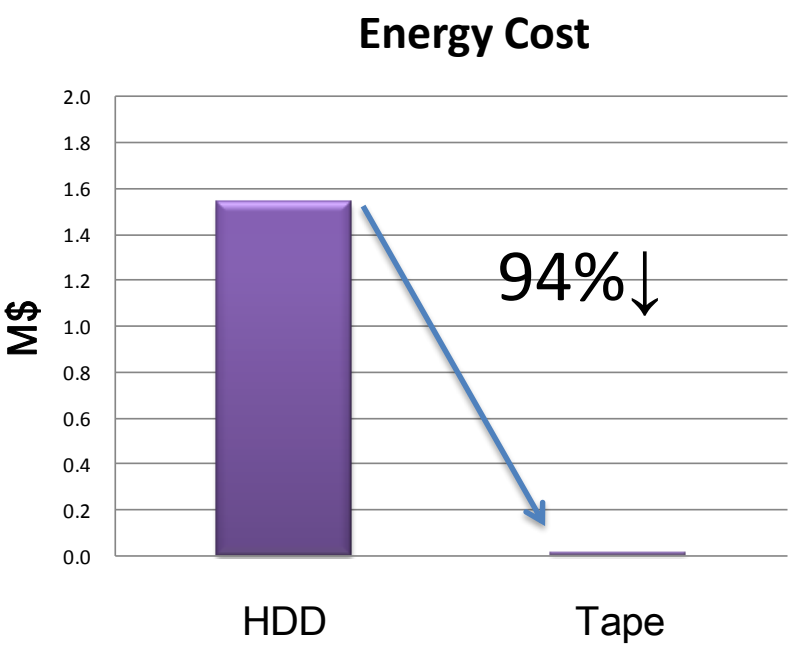


Note: Compressed capacities for generations 1-5 assume 2:1 compression. Compressed capacities for generations 6-10 assume 2.5:1 compression (achieved with larger compression history buffer).
Source: The LTO Program. The LTO Ultrium roadmap is subject to change without notice and represents goals and objectives only.

Source; https://www.lto.org/technology/what-is-lto-technology/

Case Study of TCO (The Clipper Group)





Preconditions:

- Initial Capacity: 1PB
- Annual Growth Rate: 55%
- Storage Refresh Period: 3 years
- Total Storage Period: 9 years

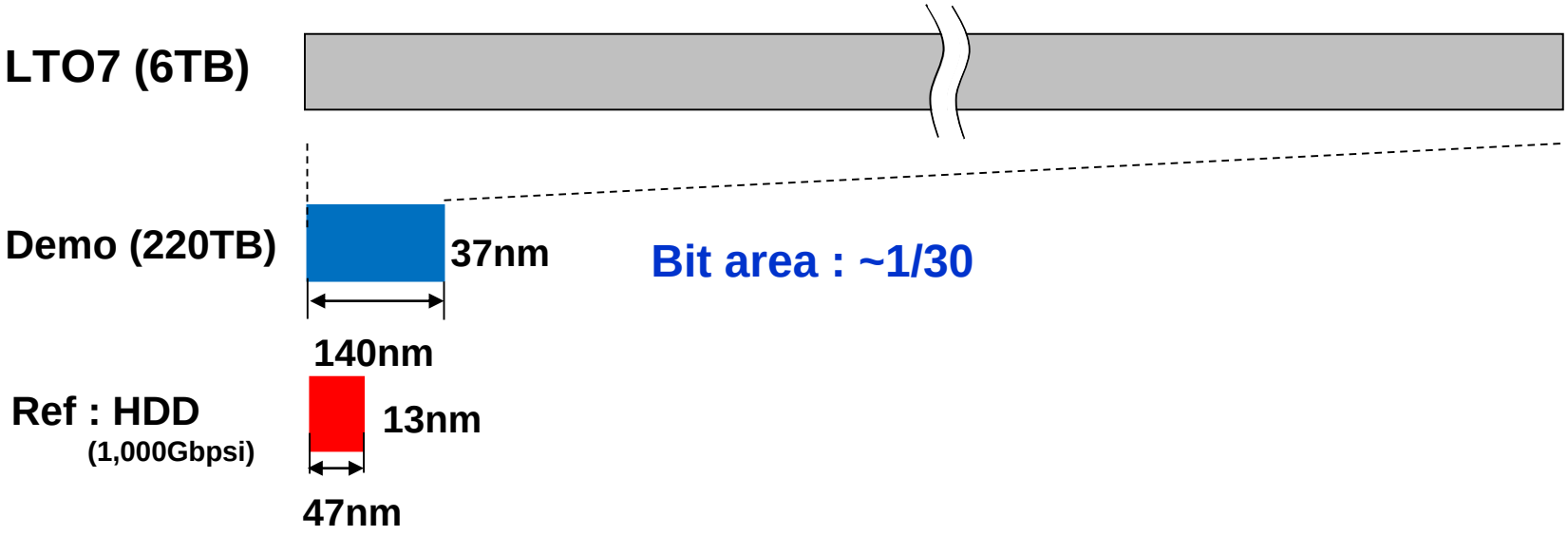
Source: The Clipper Group

- Tape storage provides large capacity with a low TCO and low energy consumption

Technical demonstrations

220TB demo in 2015 (IBM and Fujifilm)

- Media type: BaFe particulate tape
- Areal recording density of 123Gbpsi was achieved, enables a single tape cartridge to store up to 220TB, which is 37 times larger capacity than the latest LTO format.



330TB demo in 2017 (IBM and Sony)*

*https://www.sony.net/SonyInfo/News/Press/201708/17-070E/index.html

- Media type: Sputtered tape
- Areal recording density of 201Gbpsi was achieved, corresponding to 330TB

Tape Manufacturing Process

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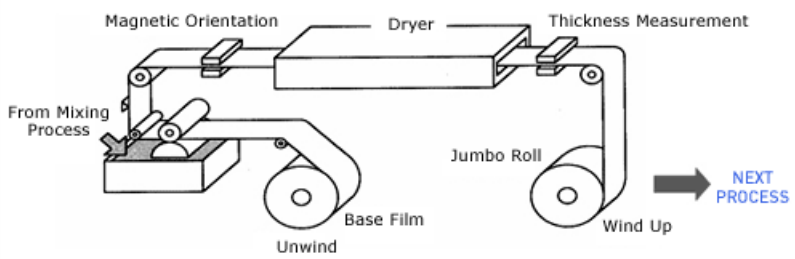
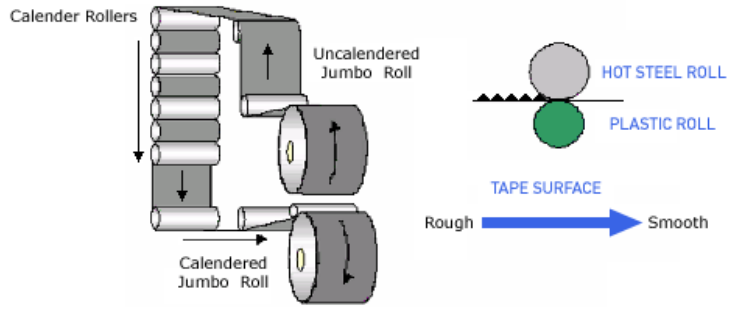
Dispersion Process

Figure; http://www.sony-asia.com/microsite/b2b/technical/manufacturing-technology/metal-partical-tape/

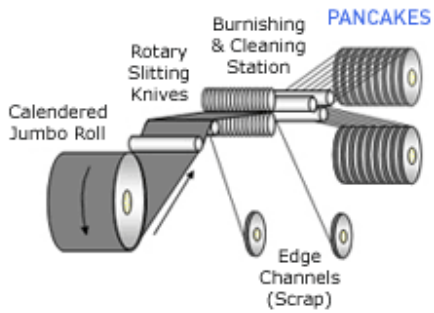
Coating Process



Calendaring Process



Slitting Process



Format & Packaging

- High productivity coating manufacturing system

  →**Mass production at a low media cost**

Advanced Coating Technology

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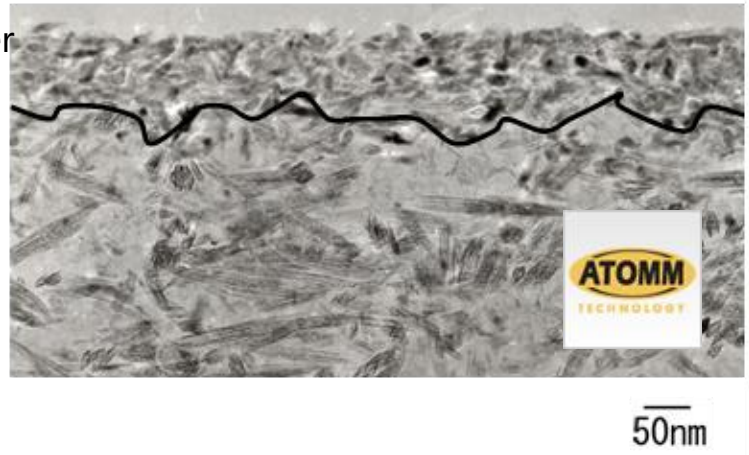
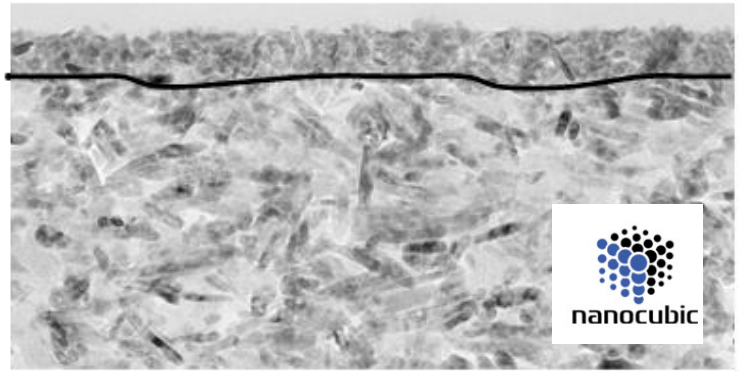
ATOMM Technology

Average thickness 110 nm
Thickness deviation 25 nm



NANOCUBIC Technology

Average thickness 60 nm
Thickness deviation 6 nm



- Thinner magnetic layer with less deviation was achieved by NANOCUBIC coating technology.

Storage Media Comparison for Cold Data

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Blue characters show advantages			Tape (Latest formats data)	Capacity Optimized-HDD	Optical disc
Current	Capacity	[TB/unit]	6 to 15	4 to 10	0.128(Blu-ray) 1.5TB/cart(12 discs)
	Sustained transfer rate	[MBps]	252 to 360	≈160 to 249 (Slower at inner positions**)	Up tp 138 (Read) Up tp 55 (Write) (Slower at inner positions**)
	Access time in libraries	[s]	≈30(shorter tape)-80 (incl. loading)	mili	≈60-90 (inlc. loading)
	Media lifetime	[year]	30	3 to 5	50
	Cost/GB	[$/GB]	≈0.01（LTO)	≈0.05	≈0.10 (Archival disc)
	CO2*	Relative value	1/10 to 1/30	1	Similar to tape
	Hard error rate		1E-19 to 1E-20	1E-15 to 1E-16	-
	Write after verify		Yes (No transfer rate loss)	Optional (Transfer rate may drop in write operation)	Optional (Transfer rate may drop in write operation)
	Latest media tech		BaFe	SMR/He-Shield	Multi layer
Future	Capacity	[TB/unit]	220(Demonstrated in 2015) 48(LTO10)	20 with HAMR / TDMR 100 by 2025?	≈0.46/disc
	Transfer rate	[MBps]	Multi Ch / Linear denisity 1,100（LTO10）	Up to 250? (Constrain of rpm)	≈250 (Read) ≈125 (Write)

*Source: JEITA tape storage committee (2013)
**Bits per rotation at an inner position are less than at an outer, so transfer rate is slower at an inner position. (up to -50%)
*** http://www.everspan.com/specs, http://hlds.co.kr/v2/HL200_eng.pdf