

# 磁気記録

磁気記録の基礎と将来展望

(株)日立製作所 中央研究所

五十嵐 万壽和

## 1. 磁気記録とは

### 1-1. 磁気記録の原理

### 1-2. 磁気記録を用いたストレージ装置

## 2. 磁気記録とコンピュータ

### 2-1. 磁気メモリ

### 2-2. ハードディスクドライブ(HDD)

## 3. 高記録密度化に向けて

### 3-1. トリレンマ

### 3-2. 次世代磁気記録技術

## 4. 磁気記録の将来(まとめに代えて)

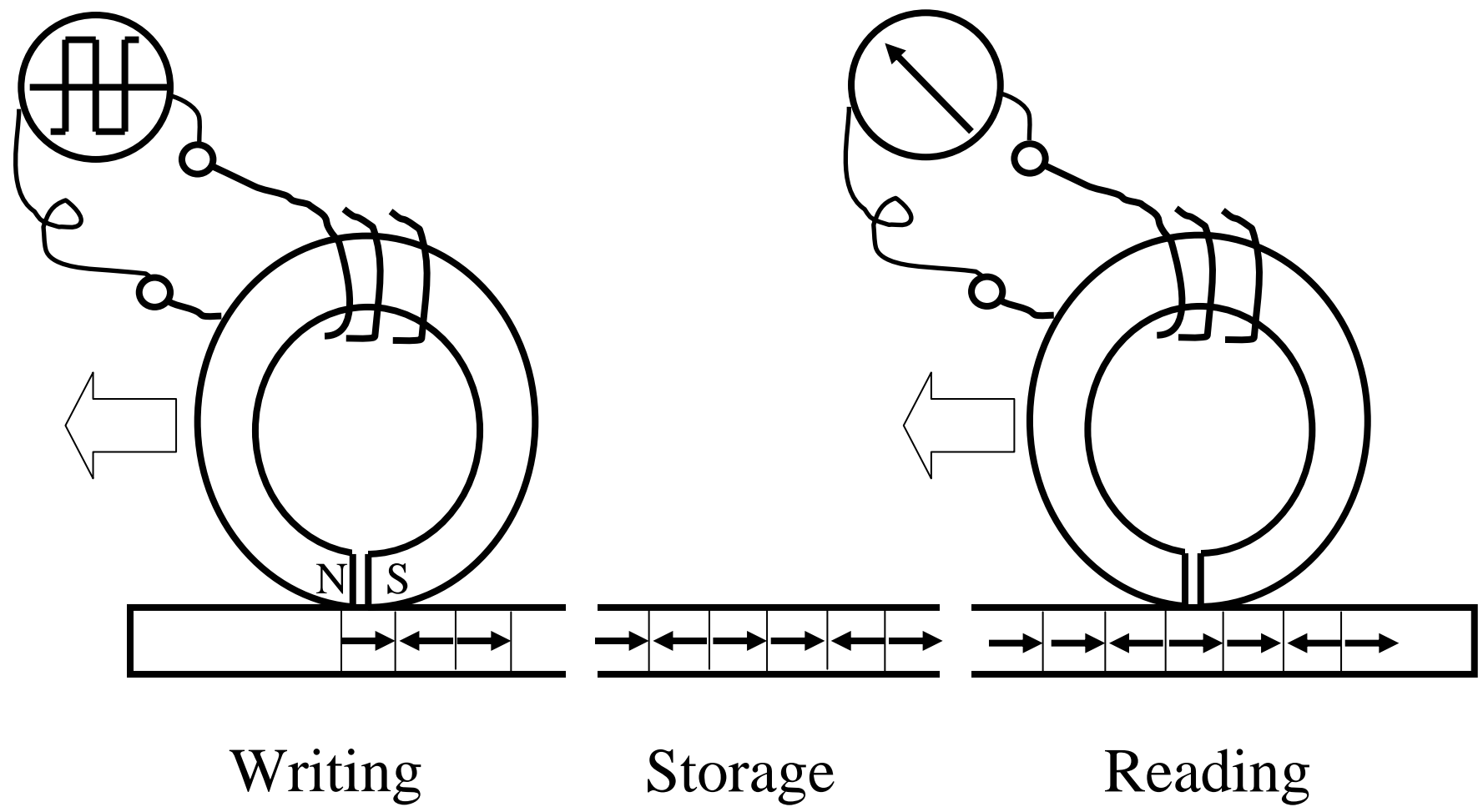


Fig. 1. Fundamental process of magnetic record (1-1)

Item	Application example
HDD(Hard disk drive)	PC, Server, HDD-recorder, Information appliances, Game Portable equipment, iVDR, Car navigation system
Magnetic tape	CMT (Cassette Magnetic Tape), VHS (Video Home System), DAT (Digital Audio Tape), DVC(Digital Video Cassette)
Floppy disk	PC
MO(Magneto-Optical disk)	PC, MD(Mini disk), HS(Hyper Storage)

Table 1. Storage devices that used magnetic record (1-2)

## 1. 磁気記録とは

### 1-1. 磁気記録の原理

### 1-2. 磁気記録を用いたストレージ装置

## 2. 磁気記録とコンピュータ

### 2-1. 磁気メモリ

### 2-2. ハードディスクドライブ(HDD)

## 3. 高記録密度化に向けて

### 3-1. トリレンマ

### 3-2. 次世代磁気記録技術

## 4. 磁気記録の将来(まとめに代えて)

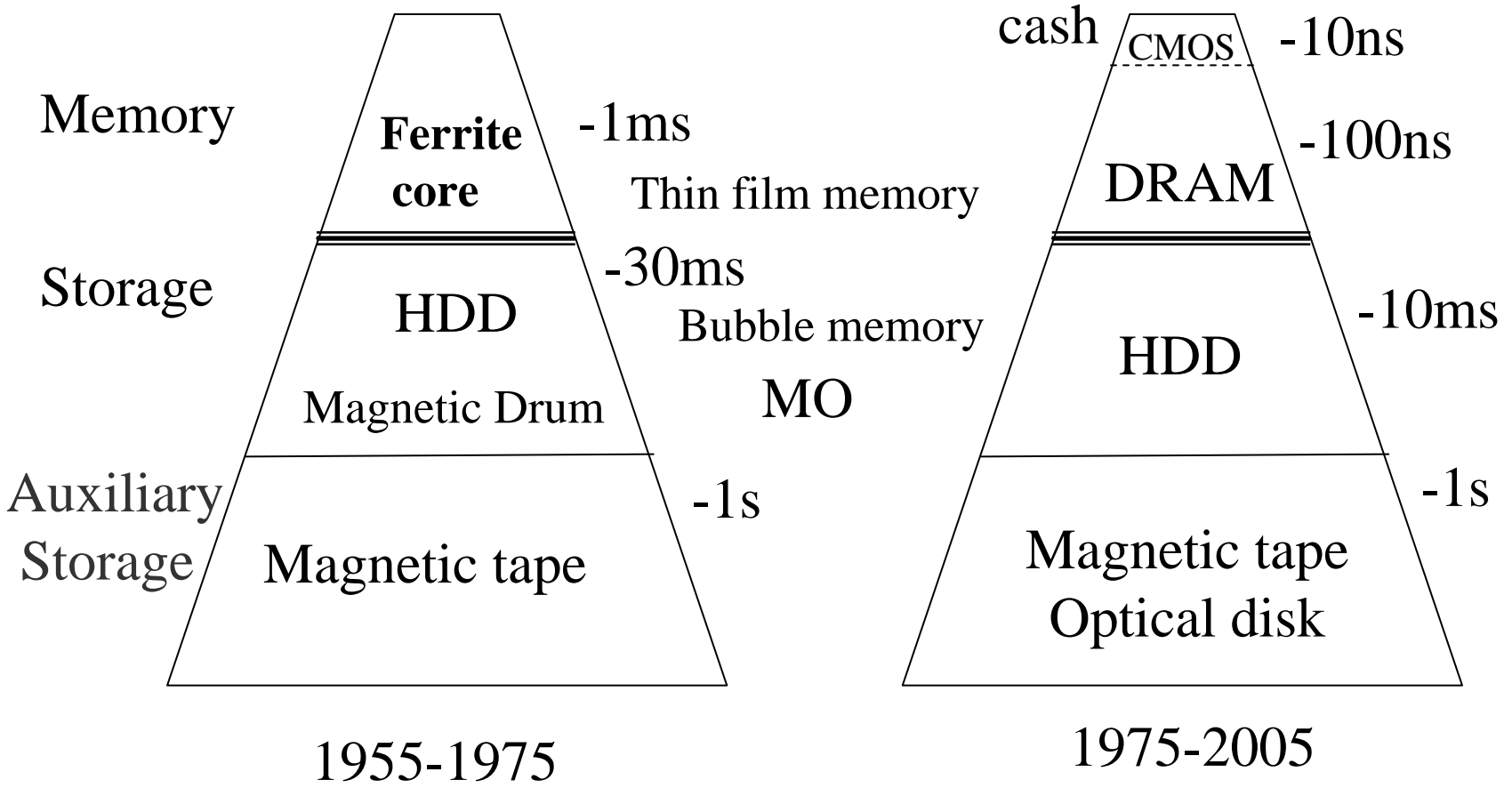


Fig. 2. Computer with magnetic record (2)

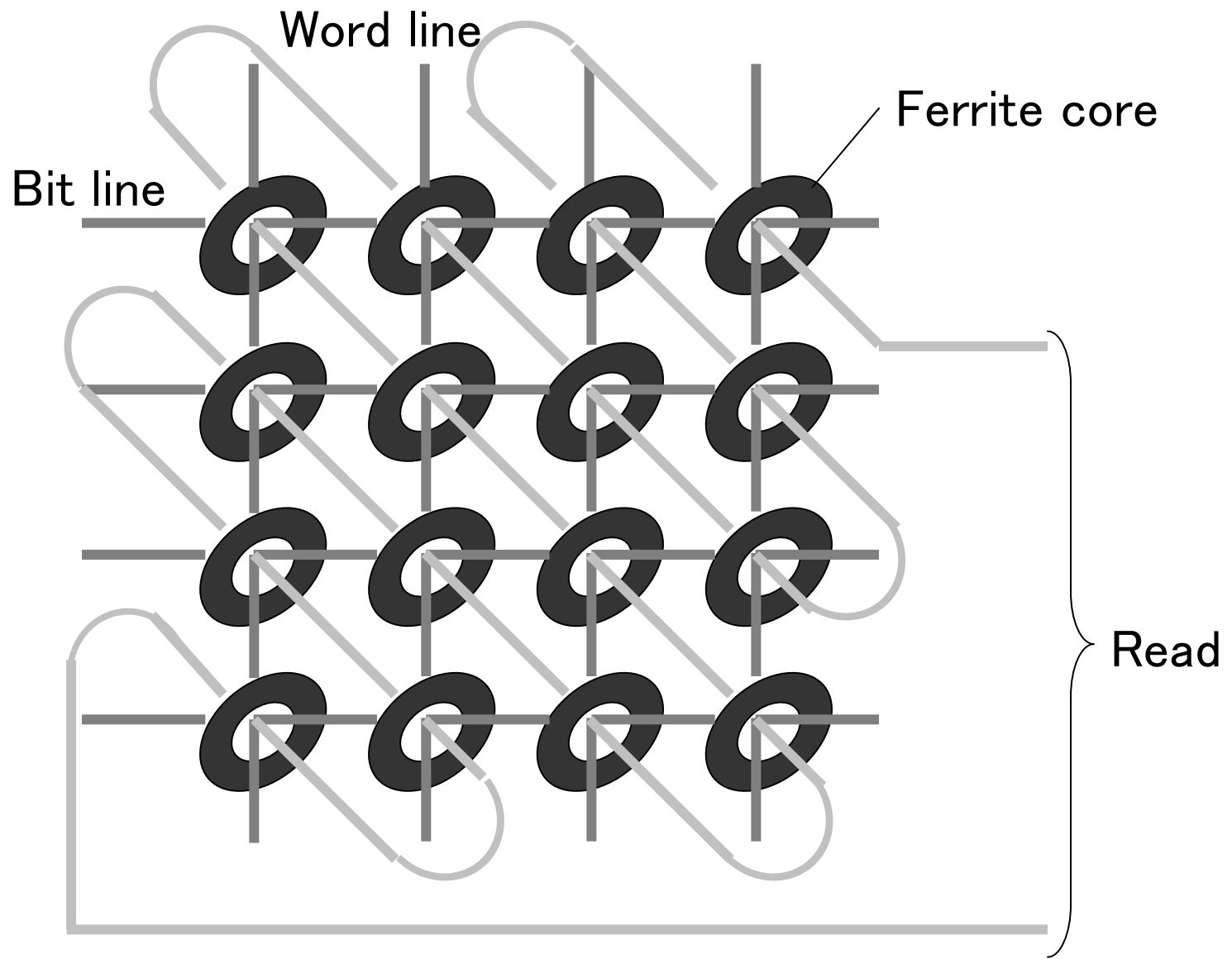


Fig. 3. Magnetic core memory (2-1-1)

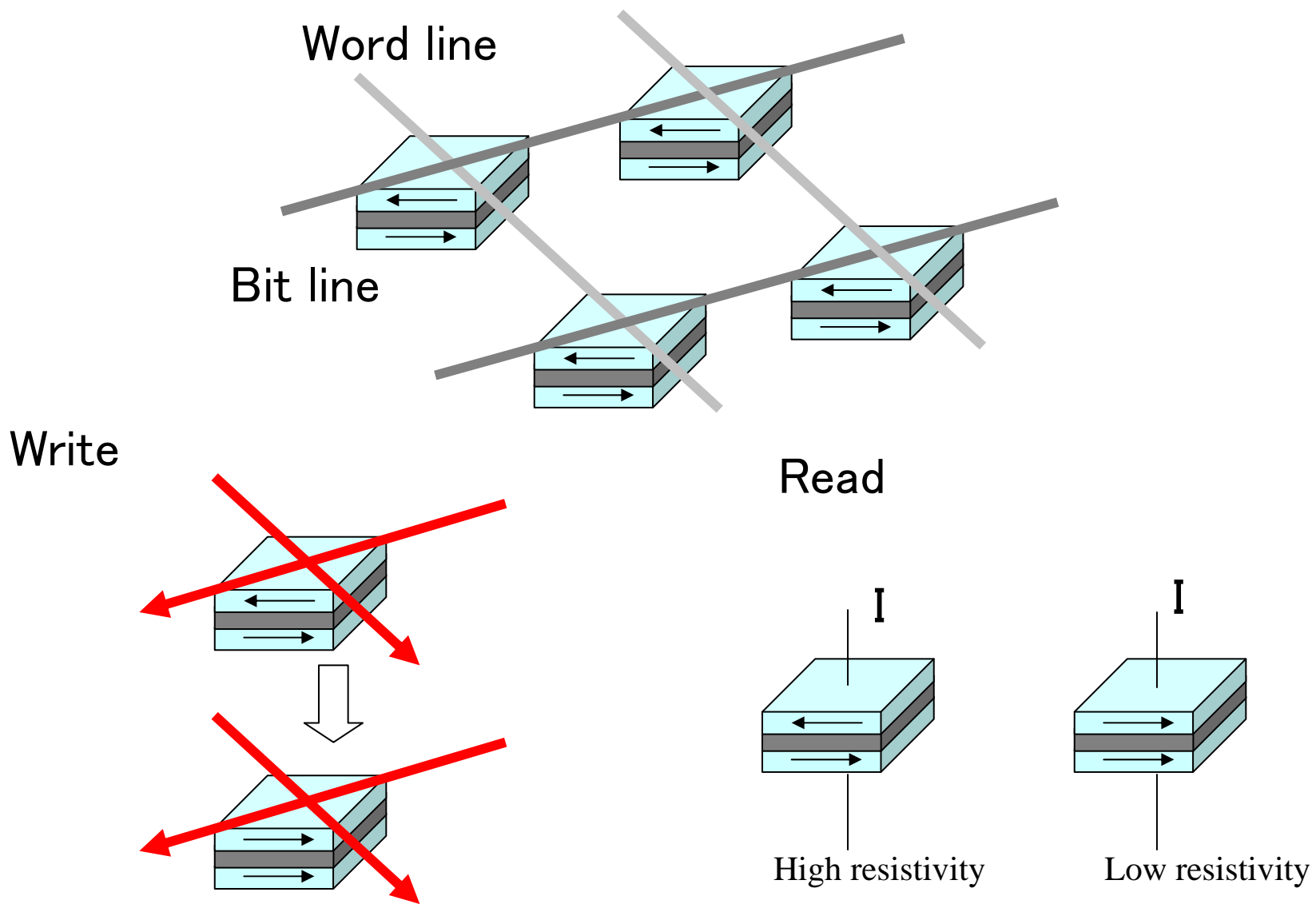


Fig. 4. MRAM (Magnetic random access memory, 2-1-4)



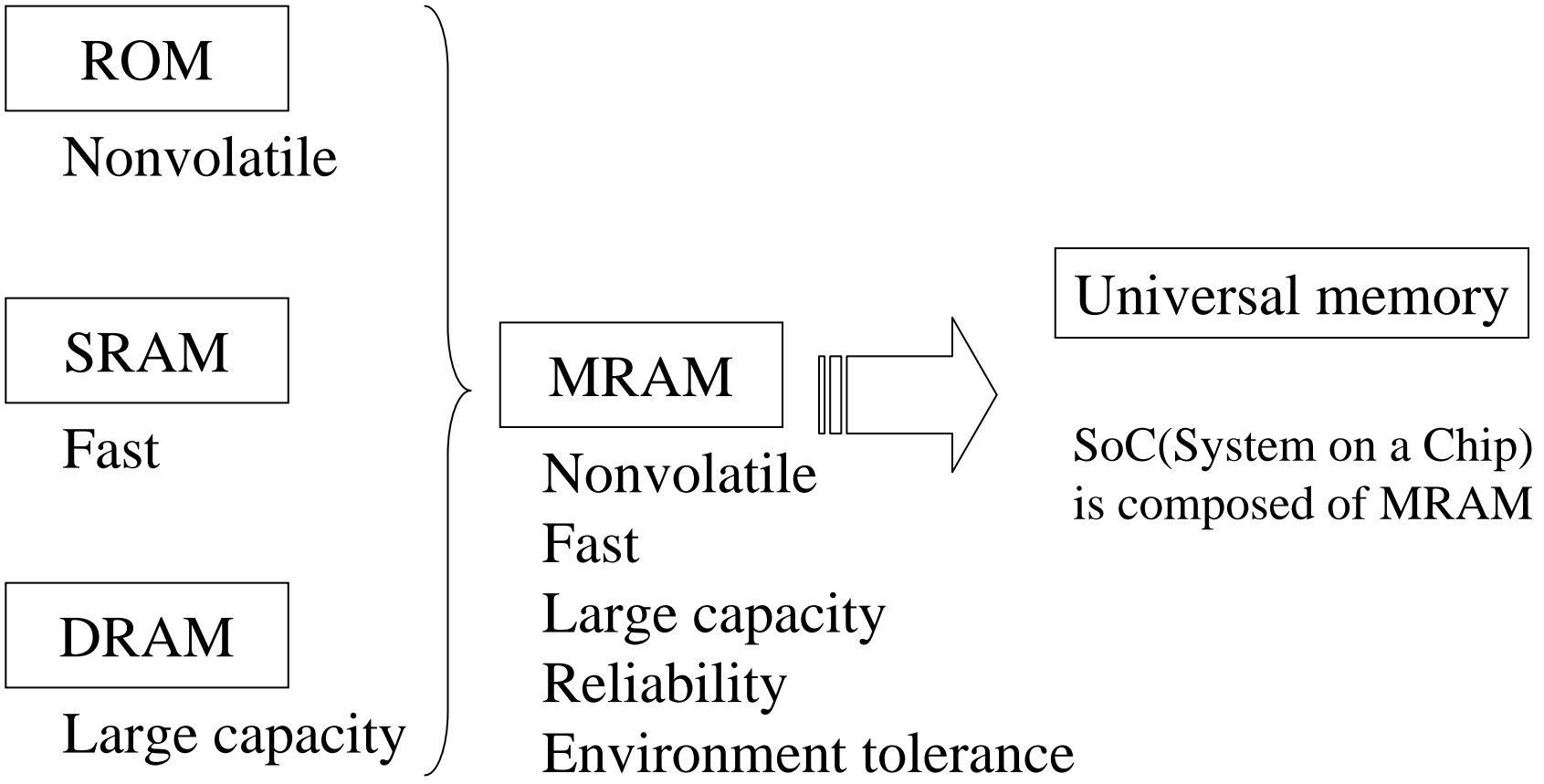


Fig. 5. Feature and strategy of MRAM (2-1-4)

## 1. 磁気記録とは

### 1-1. 磁気記録の原理

### 1-2. 磁気記録を用いたストレージ装置

## 2. 磁気記録とコンピュータ

### 2-1. 磁気メモリ

### 2-2. ハードディスクドライブ(HDD)

## 3. 高記録密度化に向けて

### 3-1. トリレンマ

### 3-2. 次世代磁気記録技術

## 4. 磁気記録の将来(まとめに代えて)

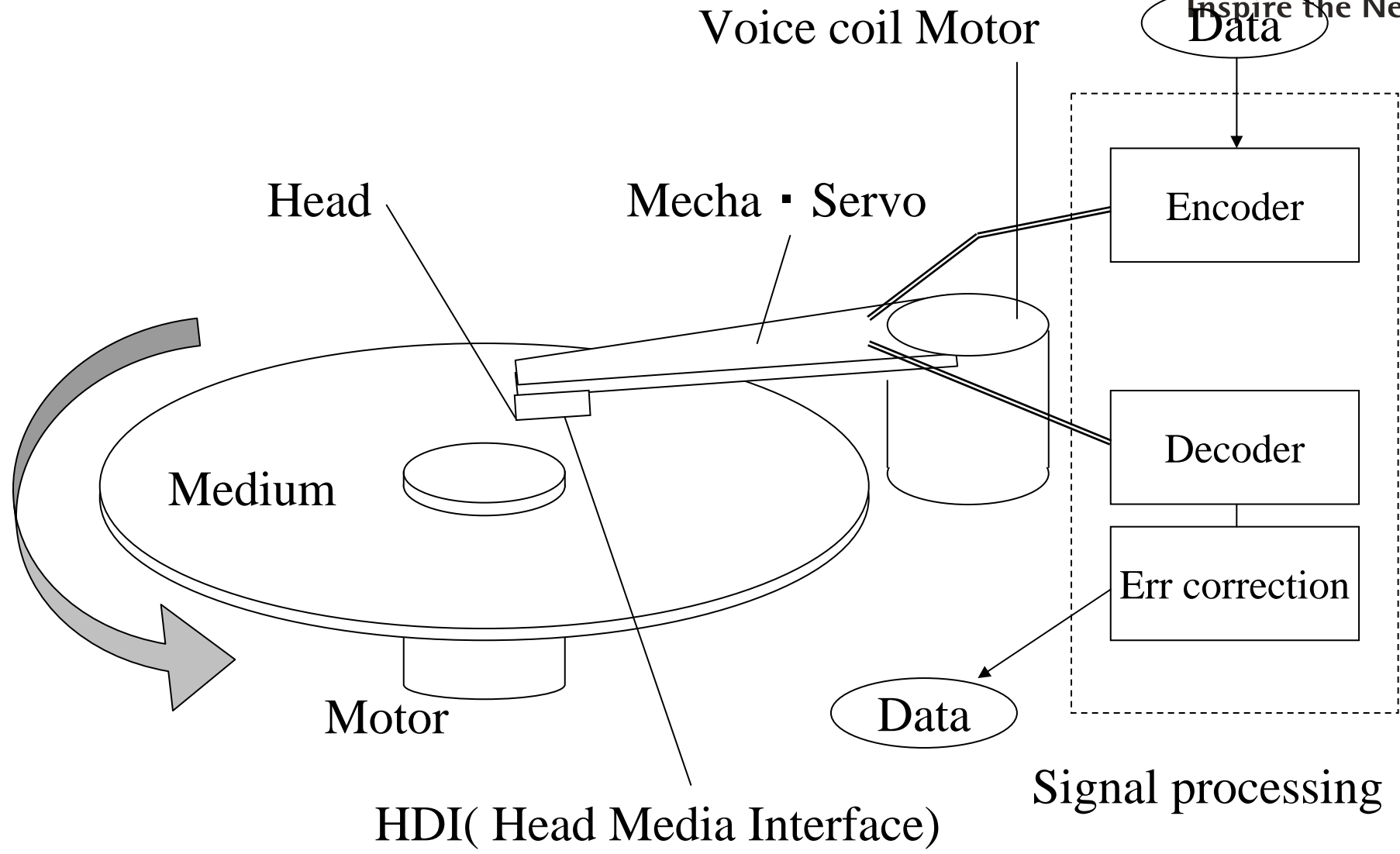


Fig. 6. HDD( Hard disk drive, 2-2-1)

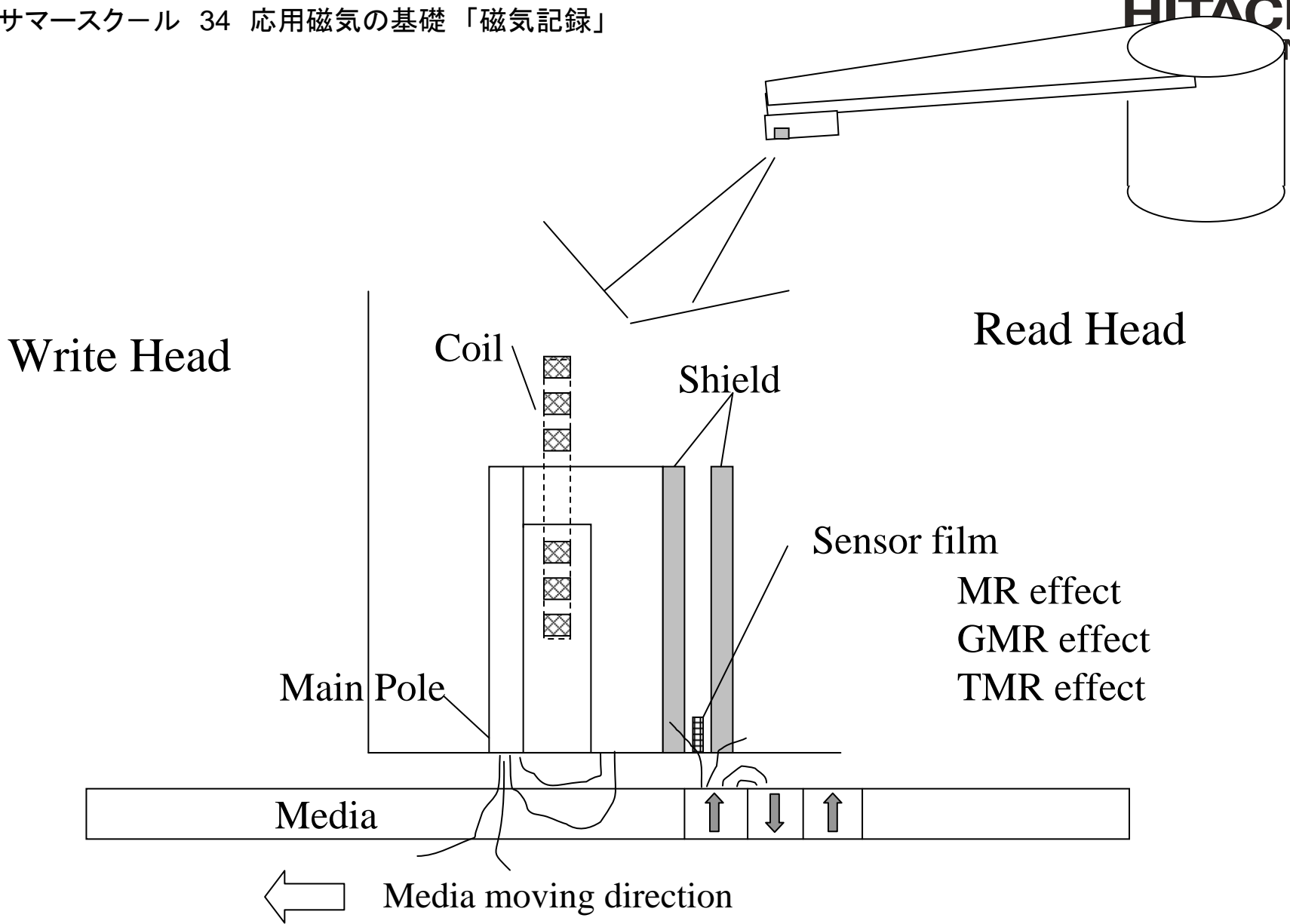


Fig. 7. Write and Read head in HDD (2-2-1)

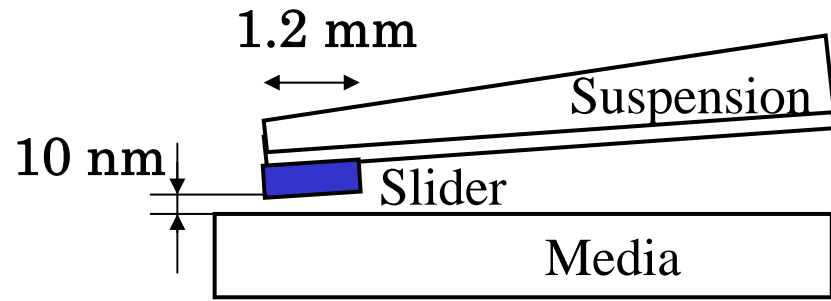
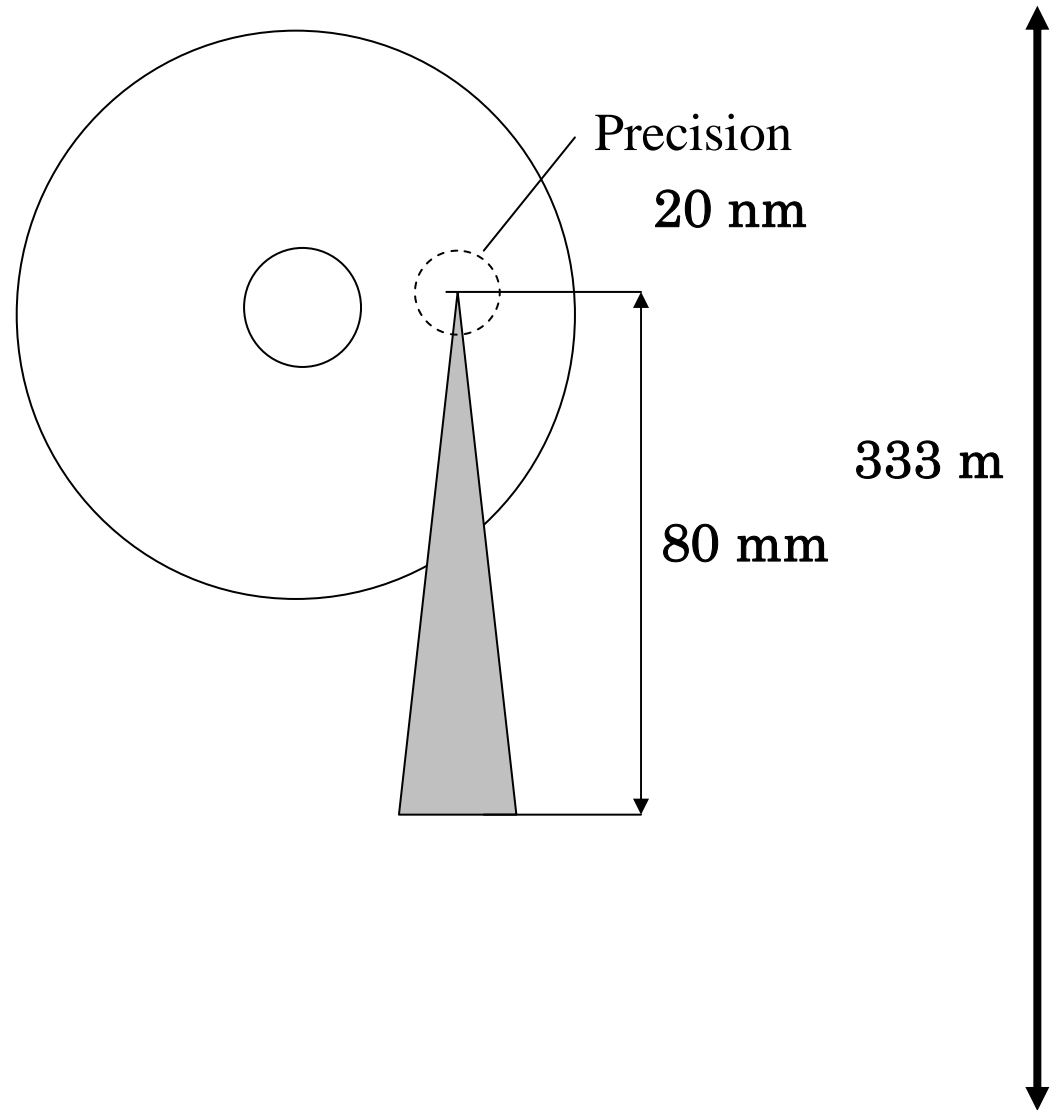


Fig. 8. HDI (Head disk interface) in HDD (2-2-1)



0.08 mm



Fig. 9. Mecha ▪ Servo in HDD (2-2-1)

## Block diagram of PRML (Partial Response Maximum Likelihood)

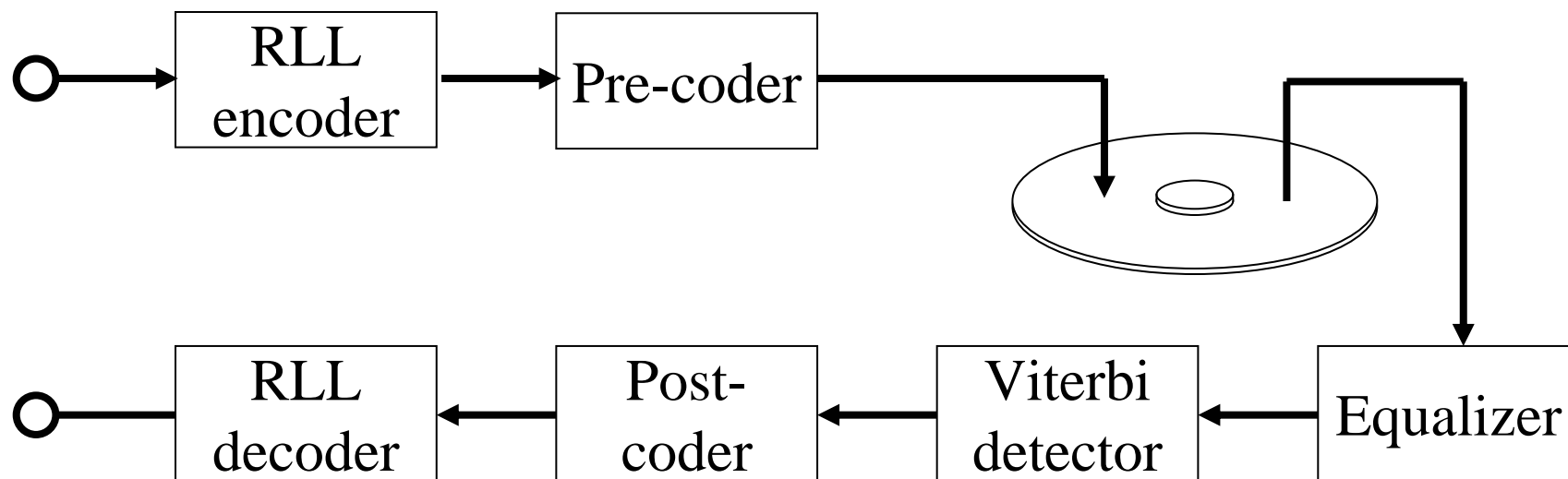
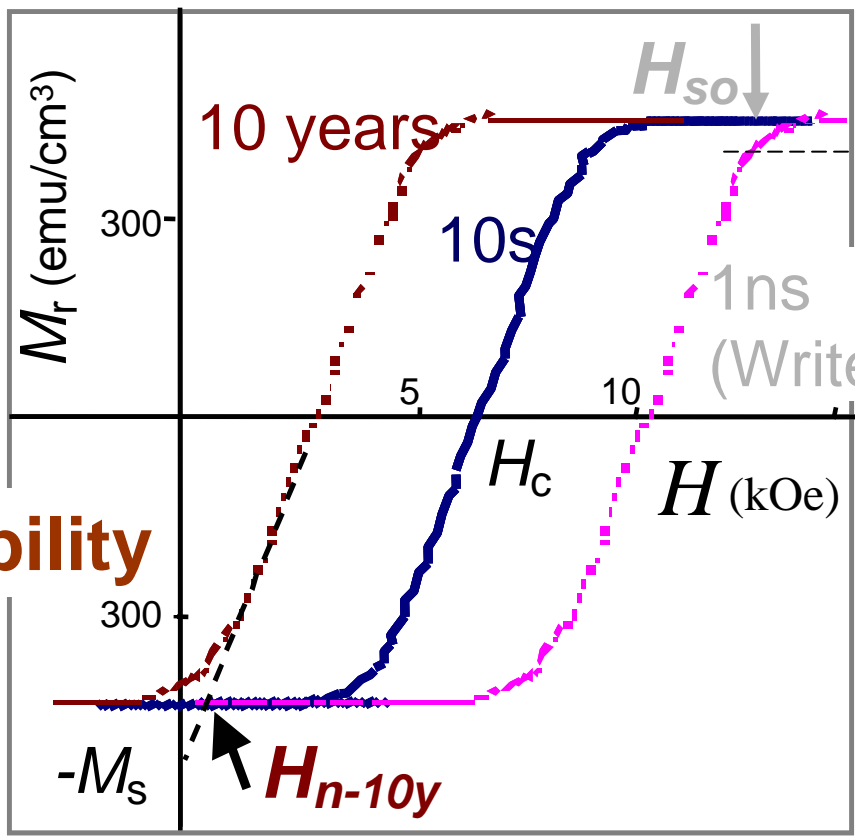
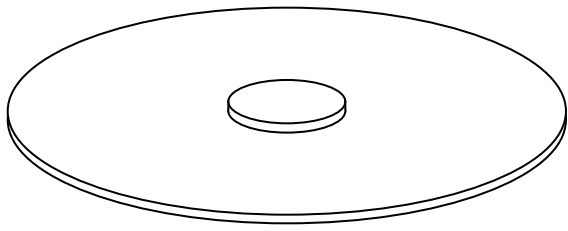


Fig. 10. Signal processing in HDD (2-2-1)

# HDDの基本構成-媒体



**Writability**

$$H_{so} < H_w$$

**Thermal stability**

$$H_{n-10y} > 0$$

$H_w$ : Maximum write field assumed to be 16kOe here

**Pulse time dependence of typical  $M_r$ - $H$  curves**

Fig. 11. Media in HDD (2-2-



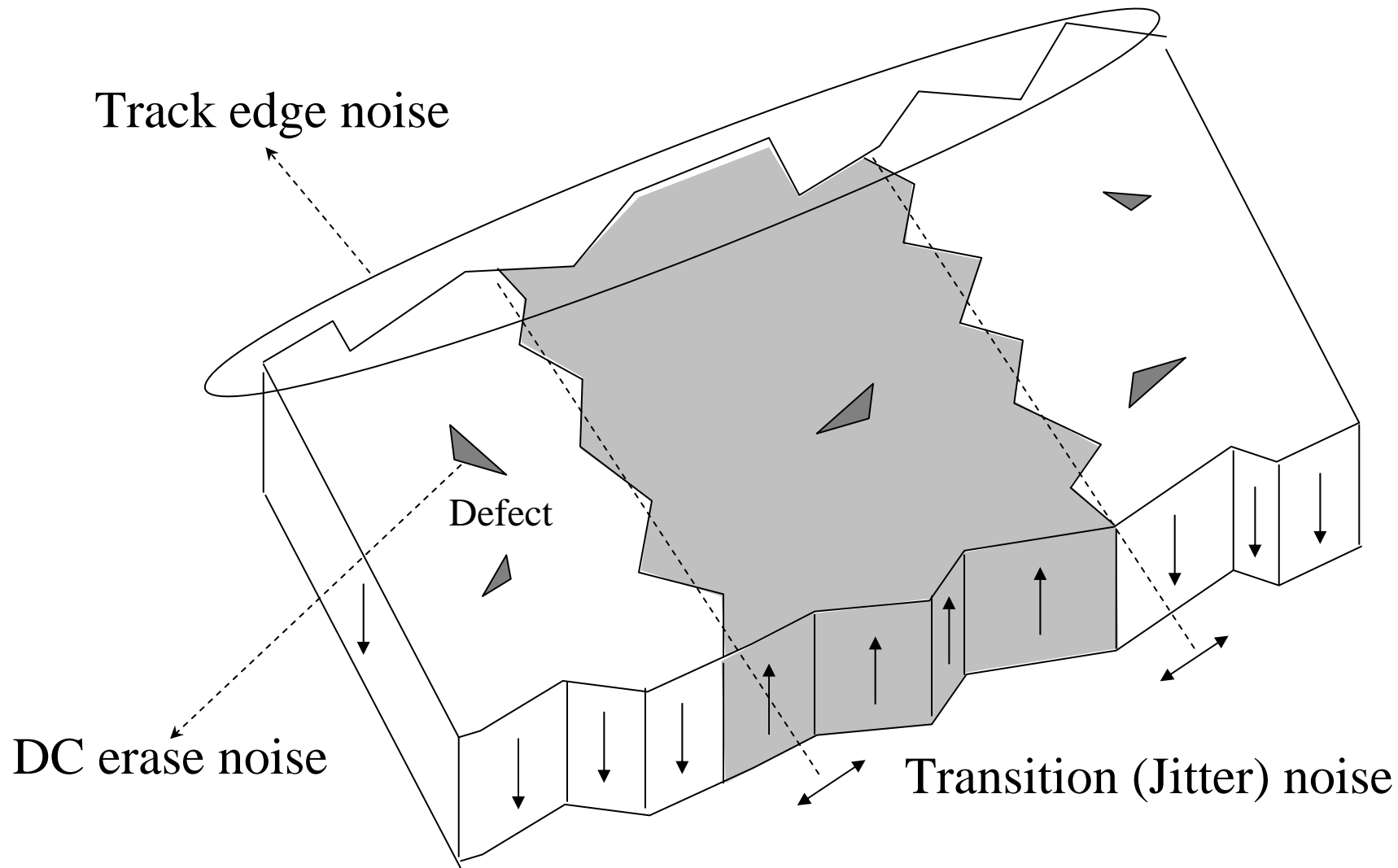


Fig. 12. Media noise in perpendicular recording media (2-2-2)

## 1. 磁気記録とは

### 1-1. 磁気記録の原理

### 1-2. 磁気記録を用いたストレージ装置

## 2. 磁気記録とコンピュータ

### 2-1. 磁気メモリ

### 2-2. ハードディスクドライブ(HDD)

## 3. 高記録密度化に向けて

### 3-1. トリレンマ

### 3-2. 次世代磁気記録技術

## 4. 磁気記録の将来(まとめに代えて)

Though it is necessary to lower bit volume  $S$  to raise the recording density, head field  $H_w$  cannot be enlarged any more because of the physical limit of head material.

$$\text{Head field: } H_w > H_k + \frac{4\pi M_s}{\alpha} = \frac{2K_u}{M_s} + \frac{4\pi M_s}{\alpha}$$

$M_s$ : Saturation magnetization

**Writability**

$H_k$ : Anisotropy field

$\alpha$ : Inclination of magnetization curve ( $H_c$ )

**SNR (Signal to Noise Ratio)**

**Thermal stability**

$$SNR \propto M_s \sqrt{F} = M_s \sqrt{\frac{S}{V}}$$

$$\text{Thermal stability factor: } K_\beta = \frac{K_u V}{k_B T} > 60$$

$F$ : Number of grains in a bit

$S$ : Bit volume,  $V$ : Grain volume

$K_u$ : Anisotropy energy

$k_B T$ : Thermal energy

Fig. 13. Trilemma in high density magnetic recording (3-1)

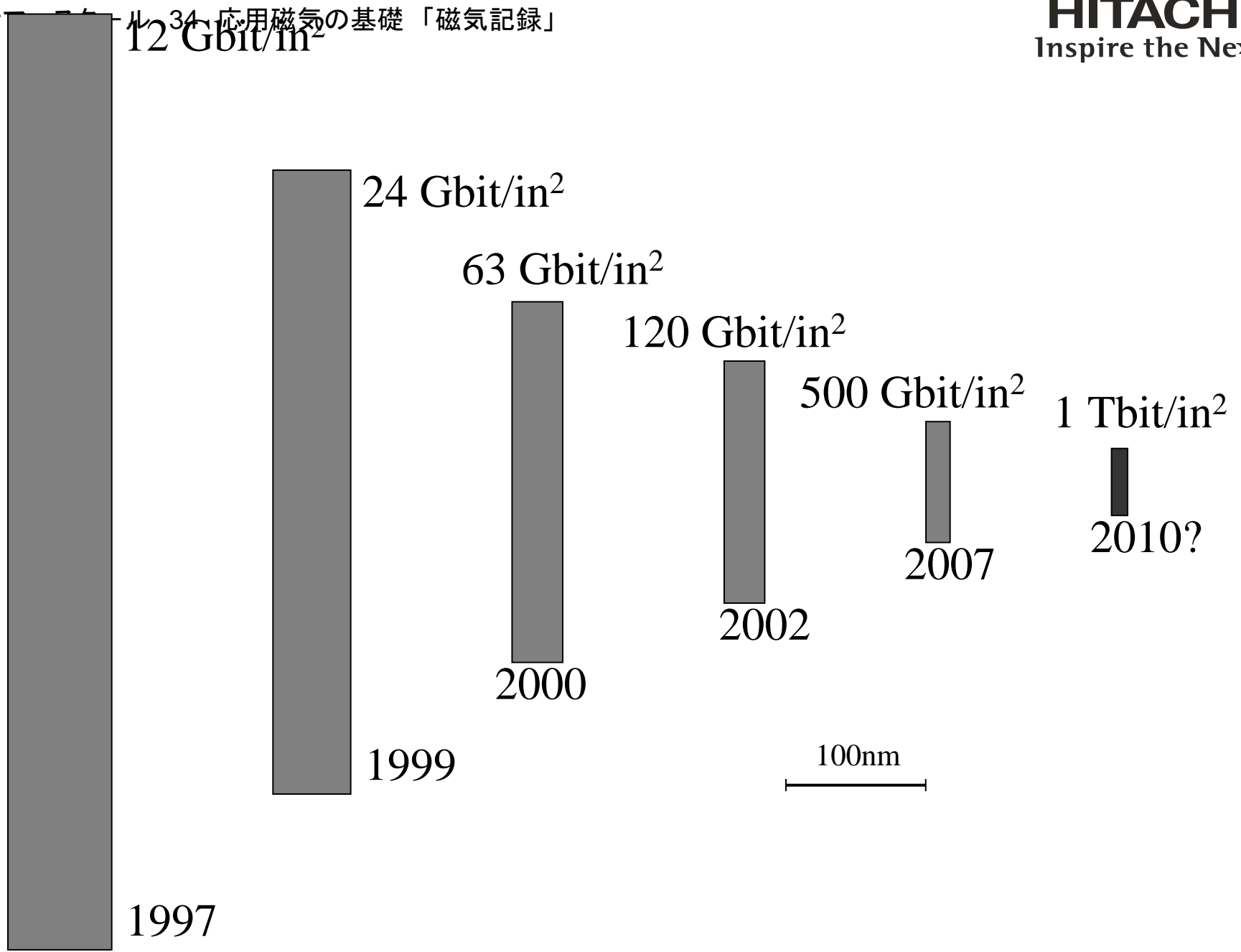
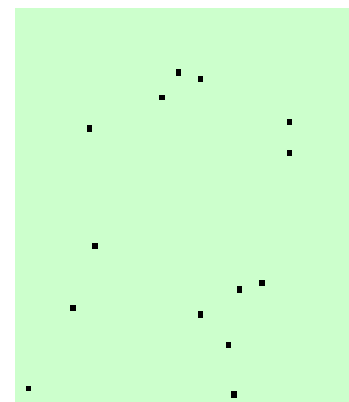
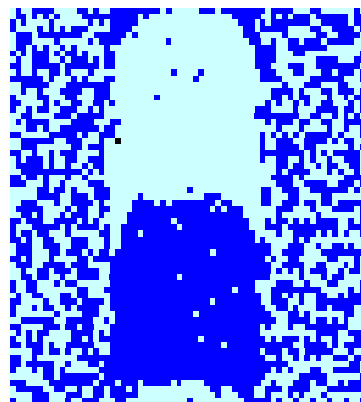
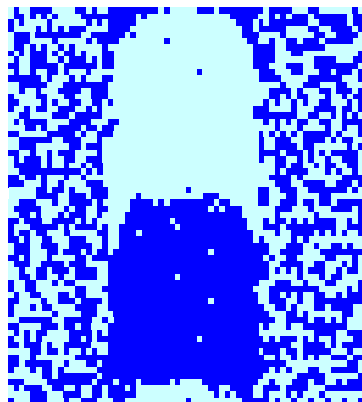


Fig. 14. Progress of bit cell size and high recording density (3-1-1)

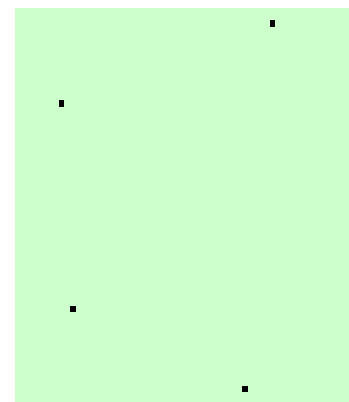
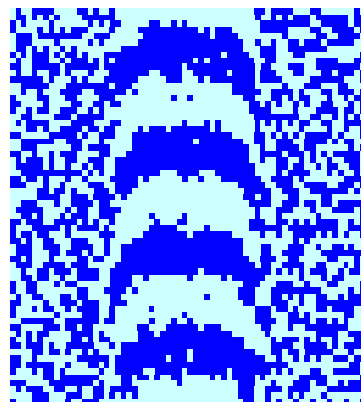
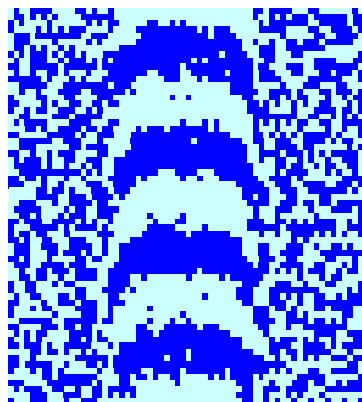
Magnetization distribution

Switched grains

110kFCI



412kFCI



As written

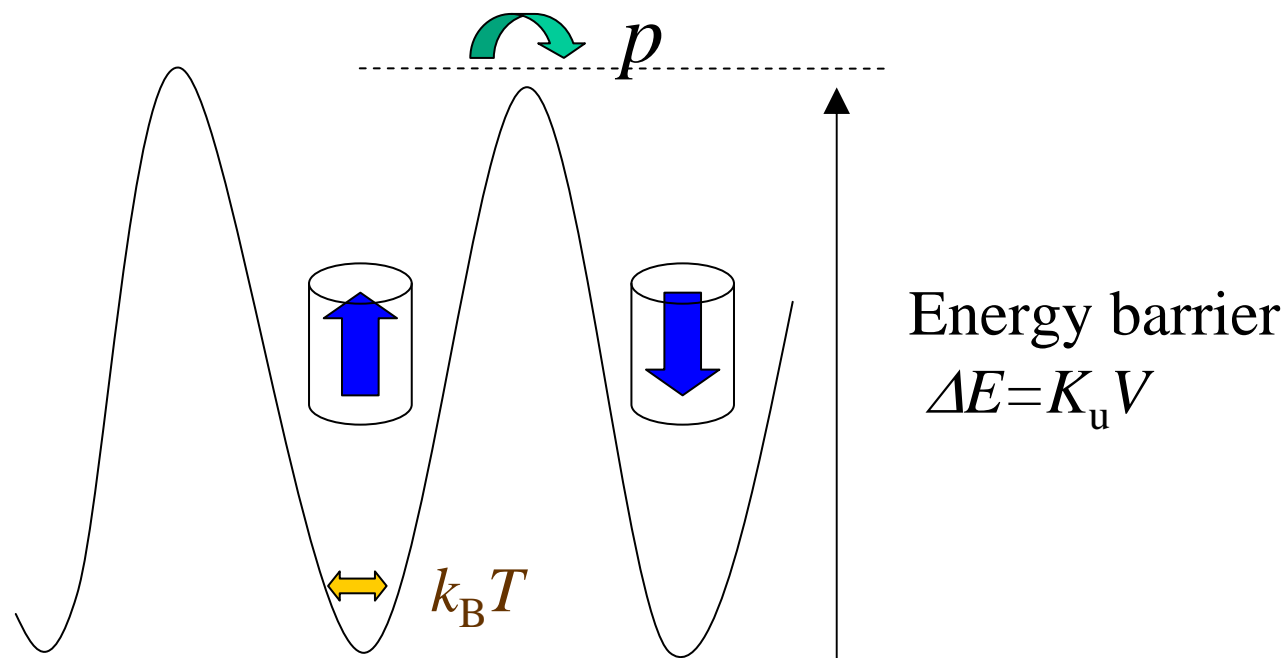
0.4s after write

$$K_{\beta} = \frac{K_u V}{k_B T} = 40$$

Fig. 15. Thermal degradation of written states (3-1-2)

$$\text{Switching probability: } p = f_o \exp\left(\frac{-\Delta E}{k_B T}\right)$$

$f_o$ : Attempt frequency  $10^{10}$ - $10^{11}$  Hz



To keep the information for 10 years,  $K_\beta = \frac{K_u V}{k_B T} > 60$

Fig. 16. Thermal stability (3-1-2)

## 1. 磁気記録とは

### 1-1. 磁気記録の原理

### 1-2. 磁気記録を用いたストレージ装置

## 2. 磁気記録とコンピュータ

### 2-1. 磁気メモリ

### 2-2. ハードディスクドライブ(HDD)

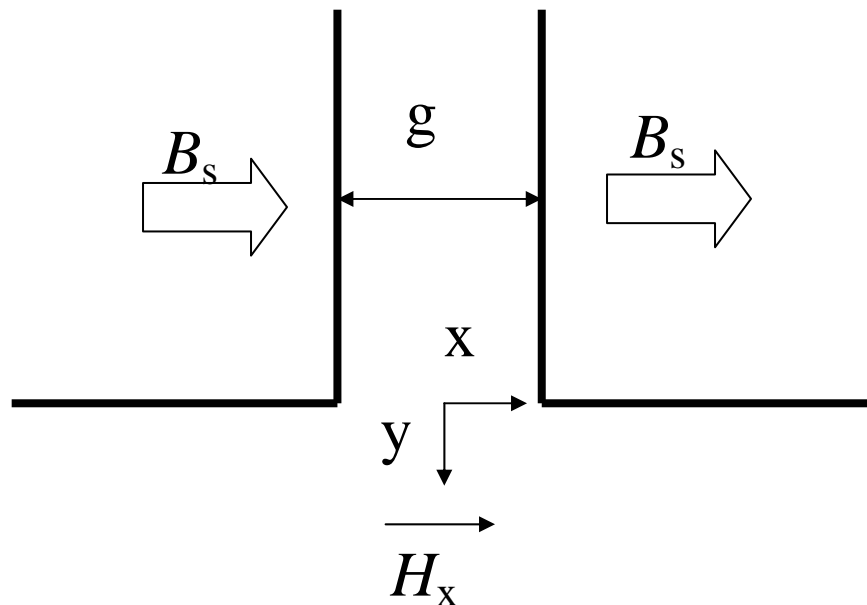
## 3. 高記録密度化に向けて

### 3-1. トリレンマ

### 3-2. 次世代磁気記録技術

## 4. 磁気記録の将来(まとめに代えて)

### Karlqvist head field



$$H_x = \frac{B_s}{\pi} \left( \tan^{-1} \left( \frac{x + g/2}{y} \right) - \tan^{-1} \left( \frac{x - g/2}{y} \right) \right)$$

### Slater-Pauling curve

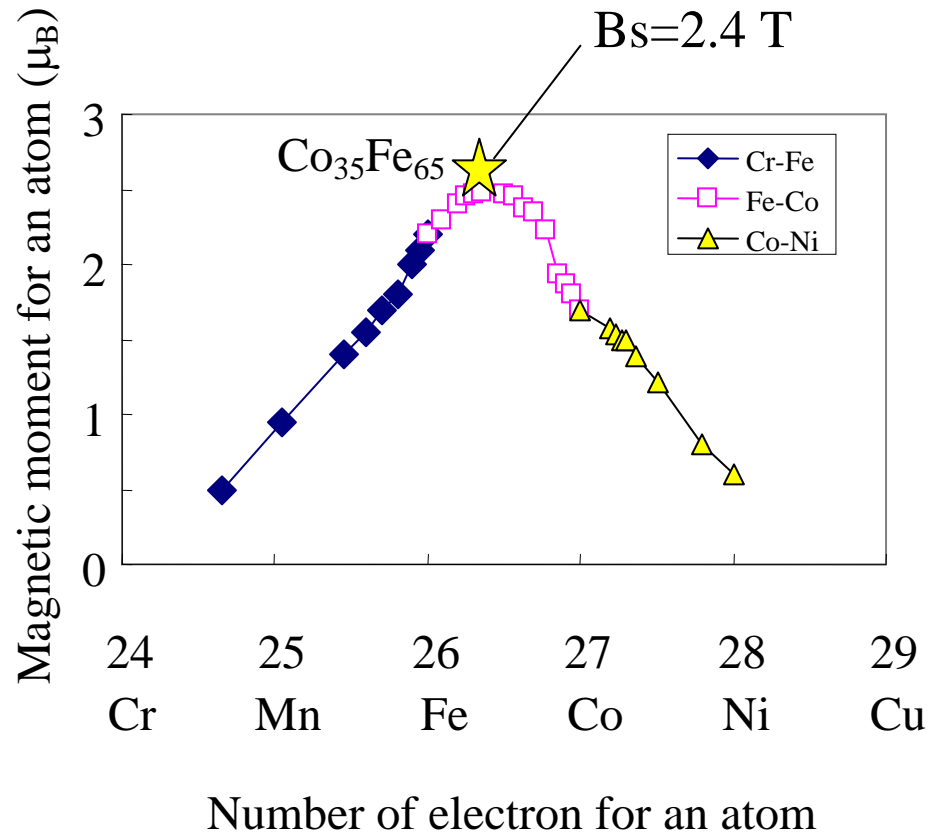


Fig. 17. Physical limit of head field (3-1-3)



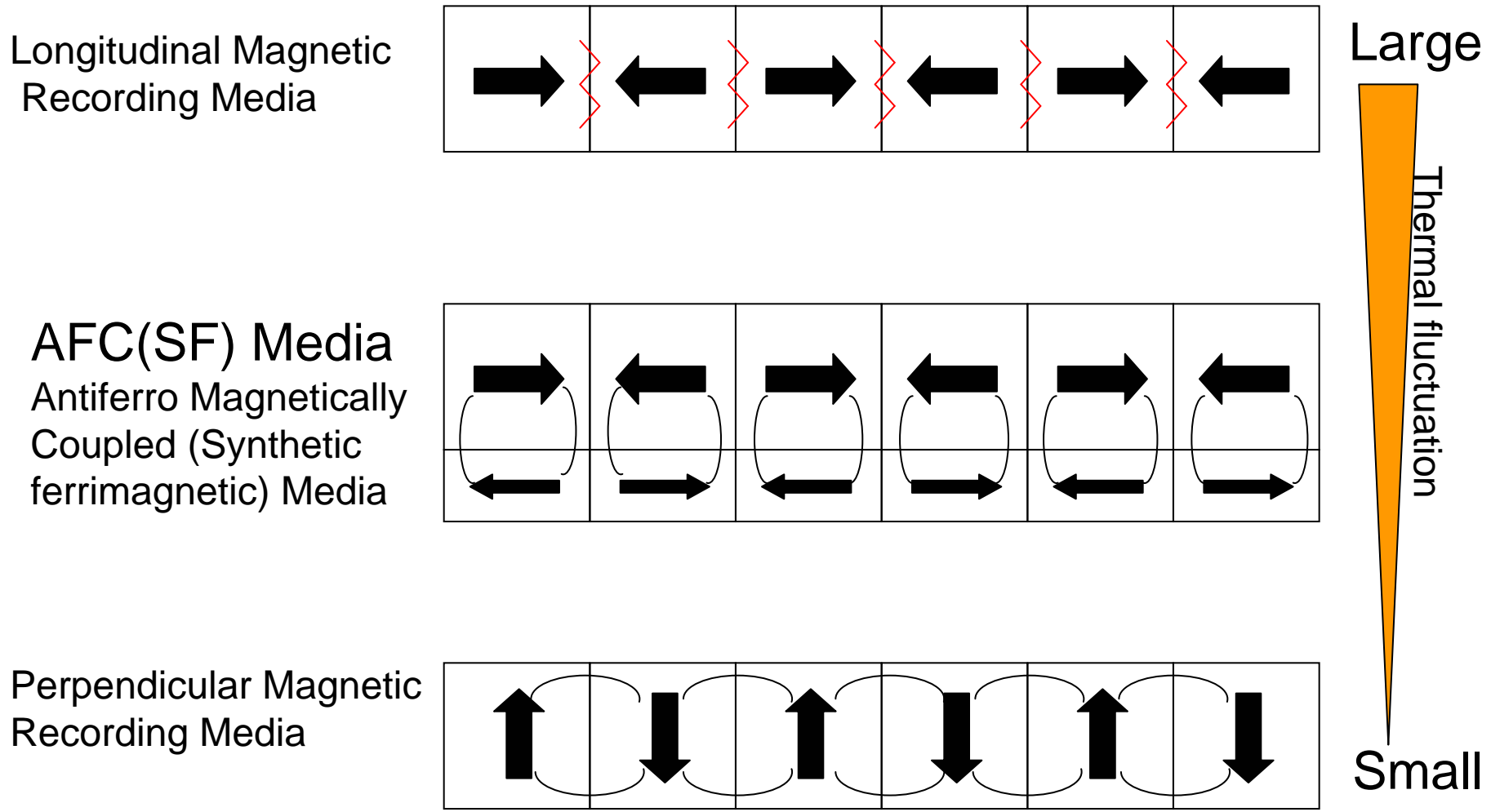


Fig. 18. Longitudinal & Perpendicular magnetic recording media

## Current screen & Spin scattering layer

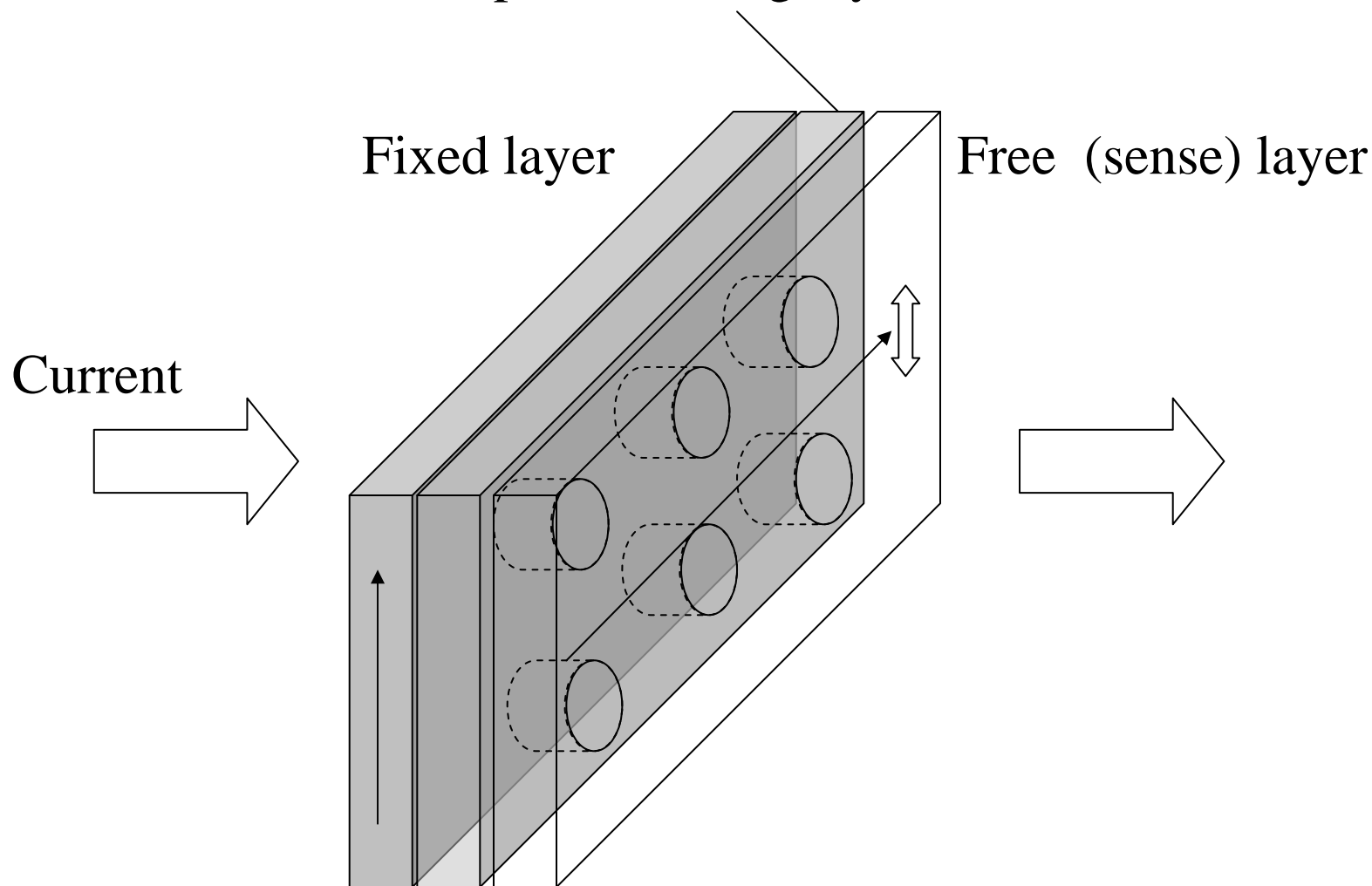
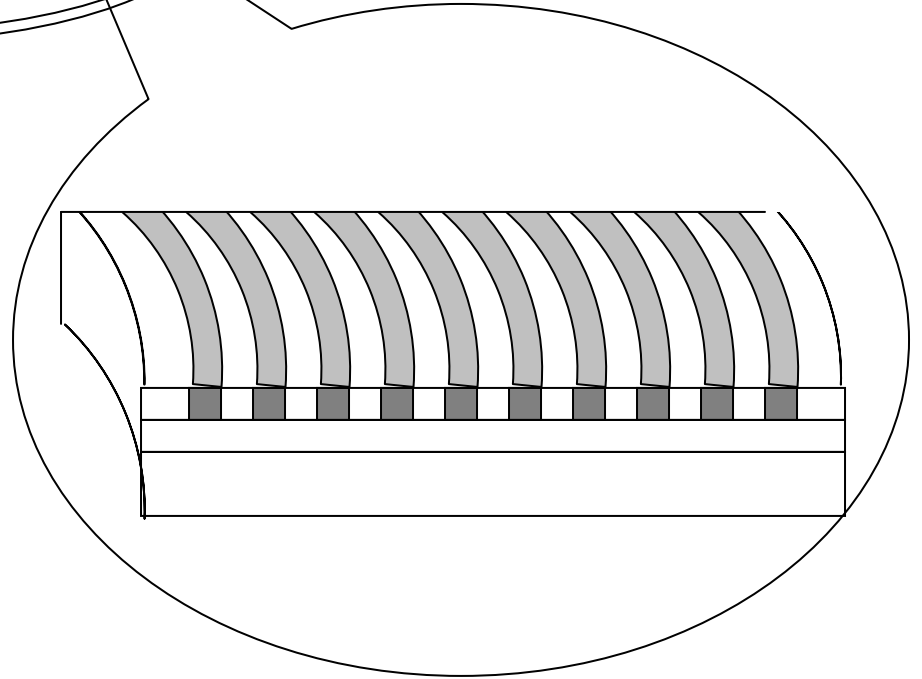
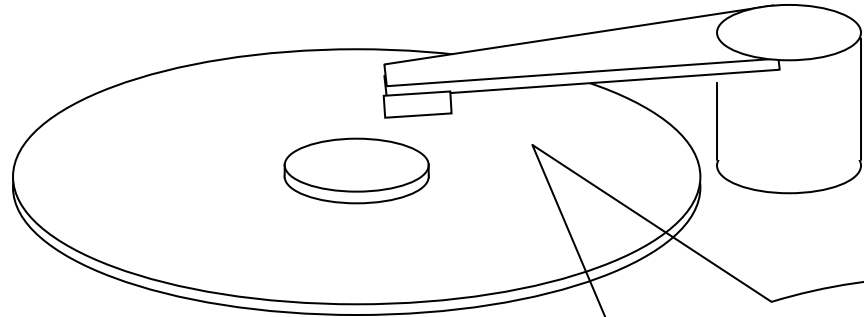


Fig. 19. CPP-GMR(Current Perpendicular to Plane – Giant Magneto-Resistive) head(3-2-2-



### Design concept

- 1) Depress track edge noise
- 2) lowering the demag field
- ⇒ Writability, Thermal stability

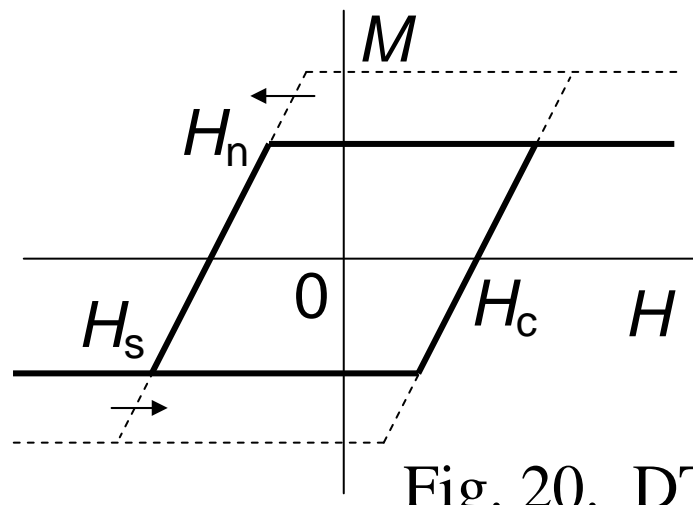
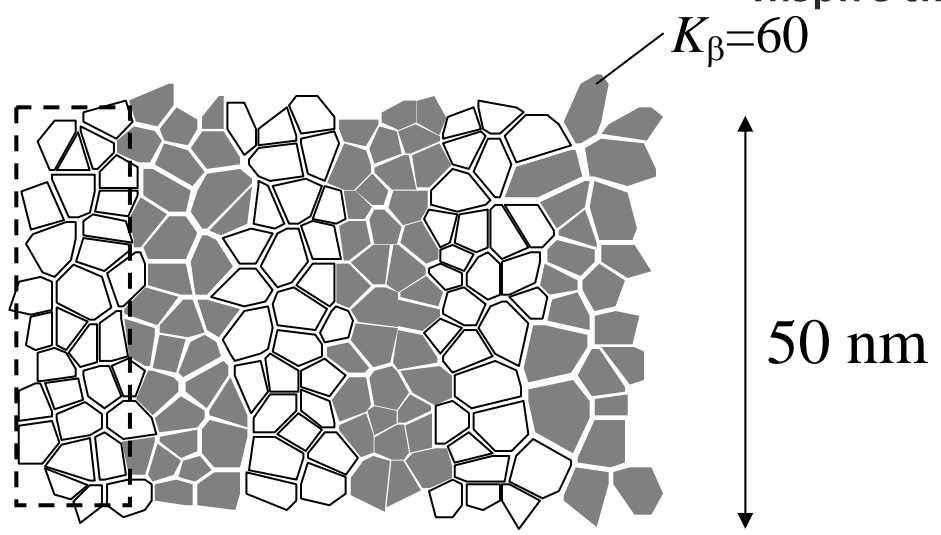


Fig. 20. DTM( Discrete Track Media,3-2-2 )

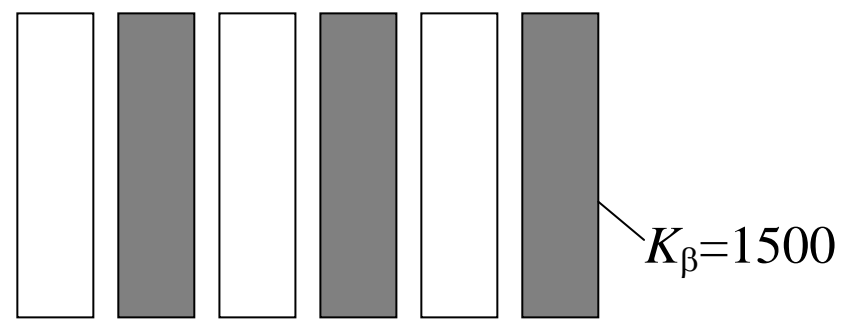
Recording on conventional media  
1 bit=26~28 grains

800Gbit/in<sup>2</sup>

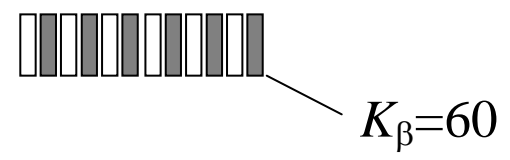


Recording on BPM  
1 bit=1 grain

800Gbit/in<sup>2</sup>



20 Tbit/in<sup>2</sup>



Design concept  
1) Thermally stabilize

$K_{\beta}=K_u V/k_B T$ : Thermal stability factor

Fig. 21. BPM(Bit Patterned Media, 3-2-2-1)

**ECC-Media**  
(Exchange Coupling Composite)

**Super ECC-Media**

**Hard/ Soft stacked-Media**

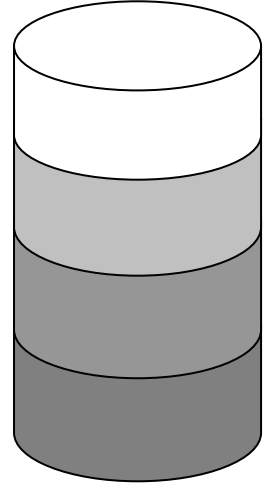
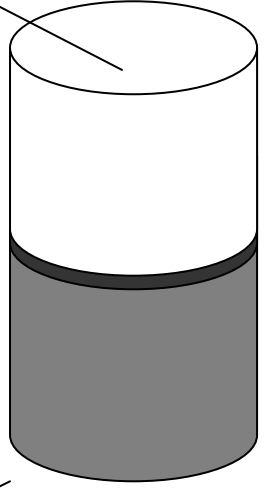
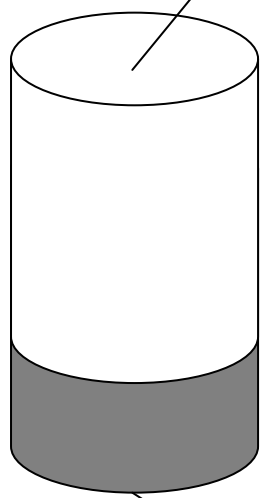
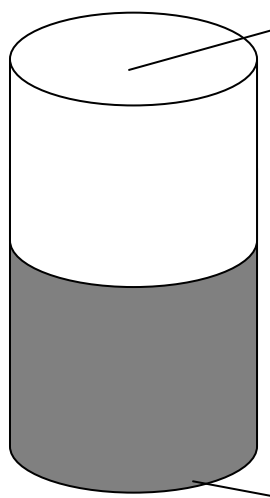
**Graded-Media**

Soft (lower  $K_u$ )

Hard(Higher  $K_u$ )

Softer

Harder



2005 R. Victora

2006 S. Greaves

2005 T. Shimatsu

2006 Vienna 大

Design concept

1) lowering the switching field

Fig. 22. Hard & Soft composite media ( 3-2-2-1)

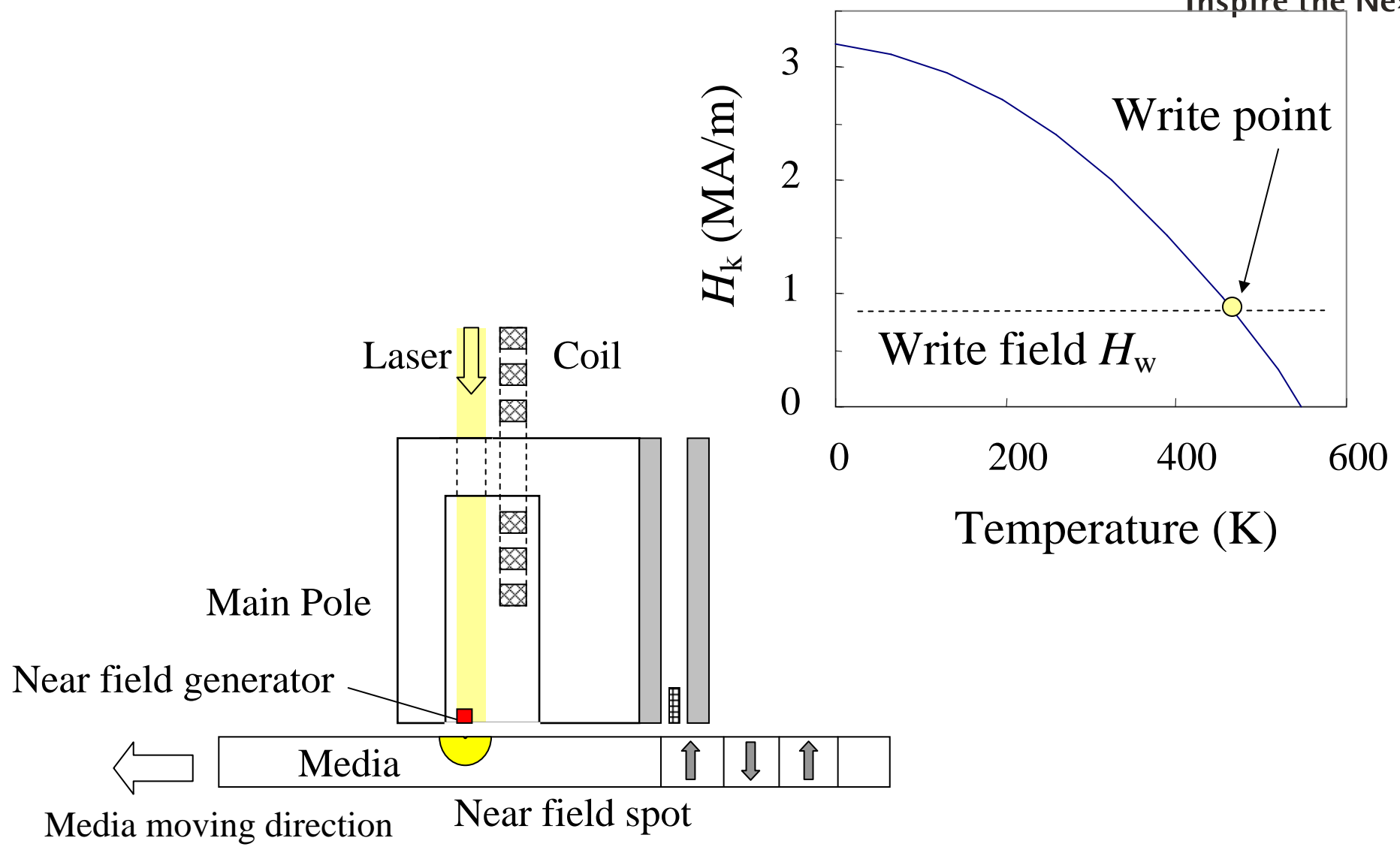
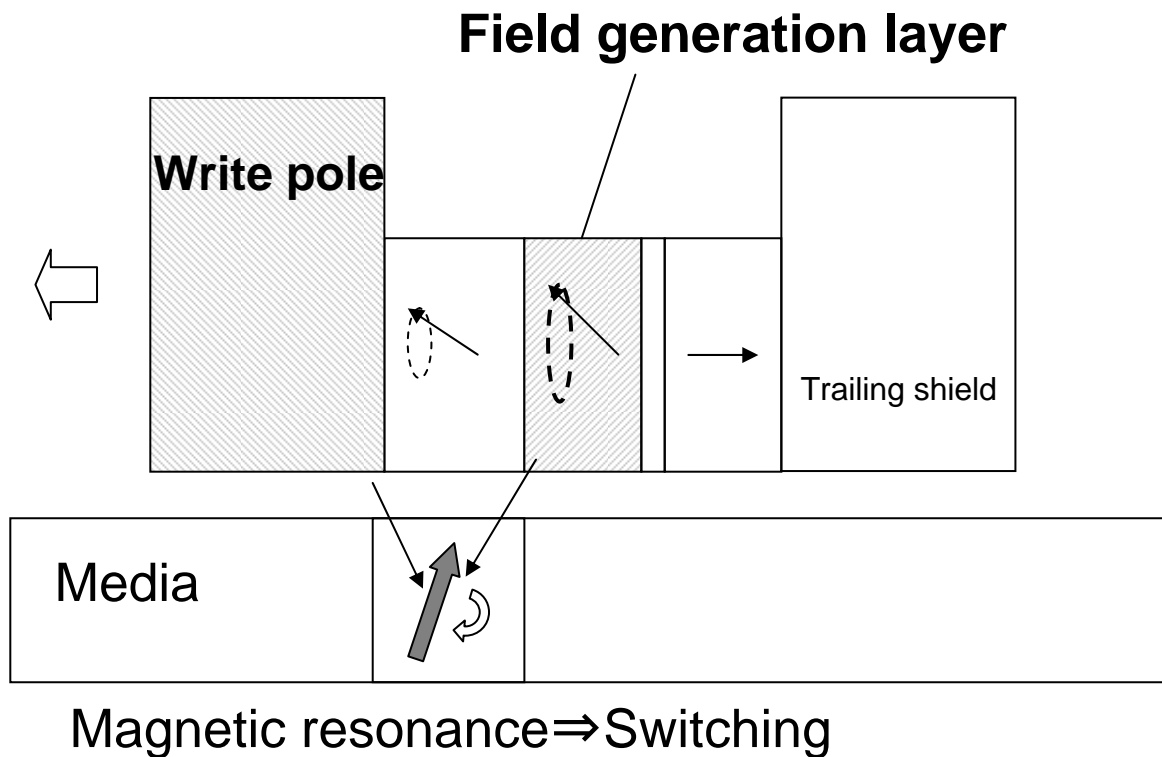


Fig. 23. TAR(Thermally Assisted Magnetic Recording, 3-2-2-2)



2007 J. Zhu

Design concept

1) lowering the switching field

Fig. 24. MAMR(Microwave Assisted Magnetic Recording, 3-2-2-2)

## 1. 磁気記録とは

### 1-1. 磁気記録の原理

### 1-2. 磁気記録を用いたストレージ装置

## 2. 磁気記録とコンピュータ

### 2-1. 磁気メモリ

### 2-2. ハードディスクドライブ(HDD)

## 3. 高記録密度化に向けて

### 3-1. トリレンマ

### 3-2. 次世代磁気記録技術

## 4. 磁気記録の将来(まとめに代えて)



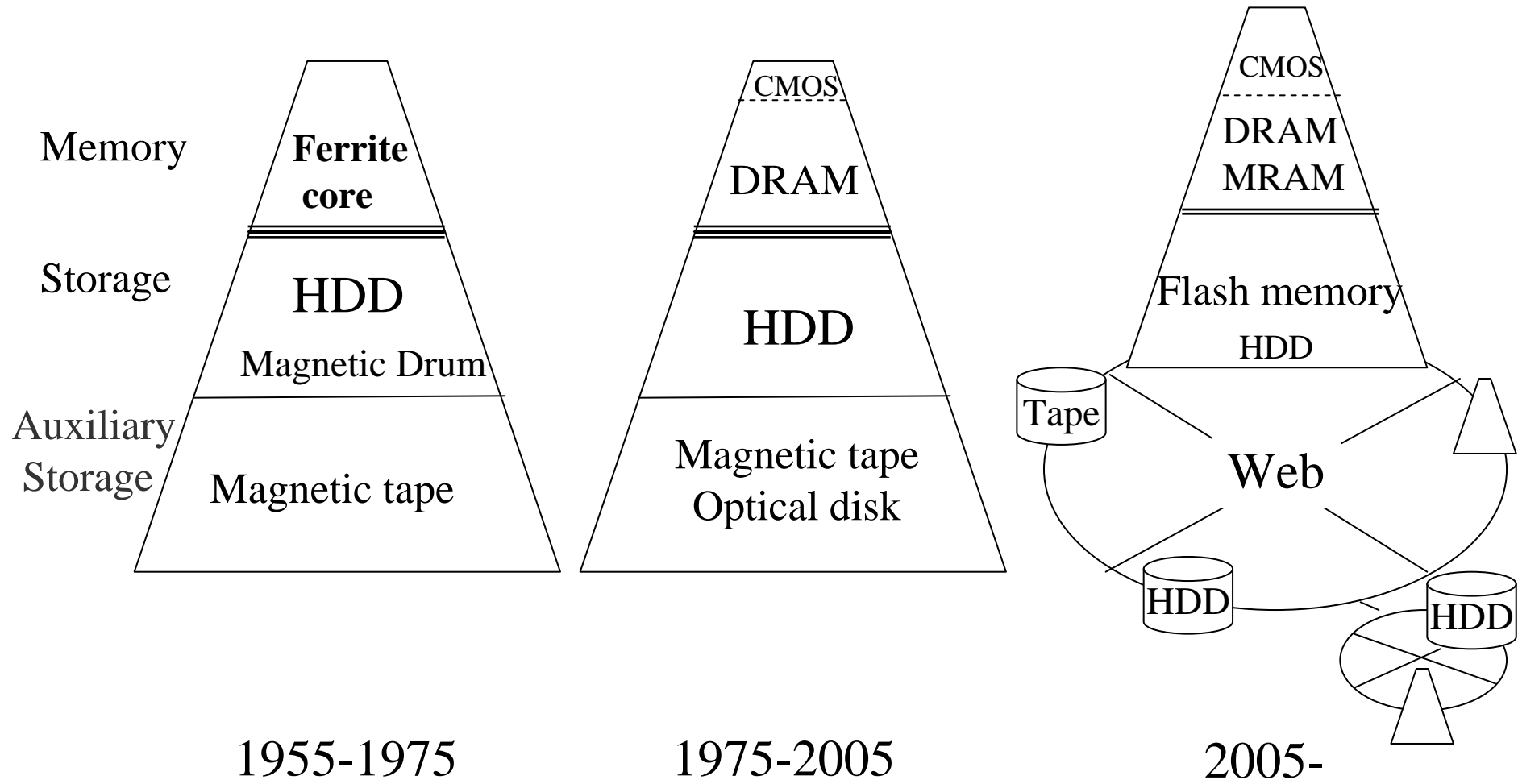


Fig. 25. Magnetic recording in the future (4)

*That's a wrap.*

[masukazu.igarashi.qu@hitachi.com](mailto:masukazu.igarashi.qu@hitachi.com)