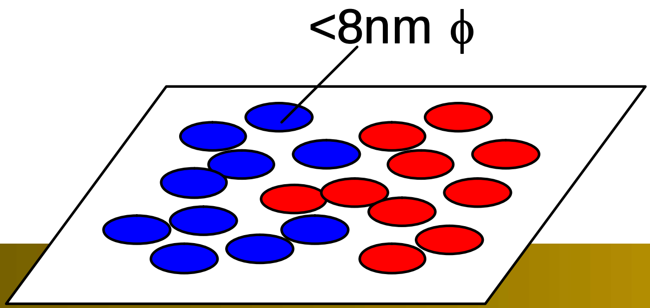
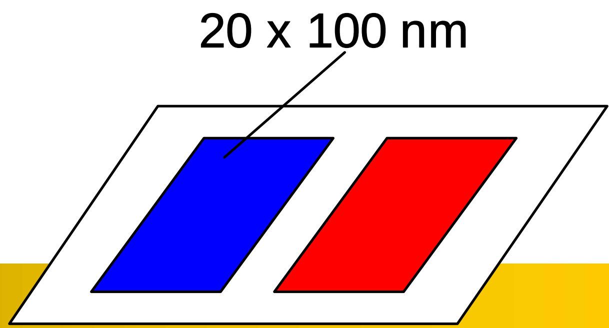
TOSHIBA
Leading Innovation >>>

X線反射率法を用いたパターン媒体の加工ダメージ評価

(株) 東芝　研究開発センター
喜々津　哲

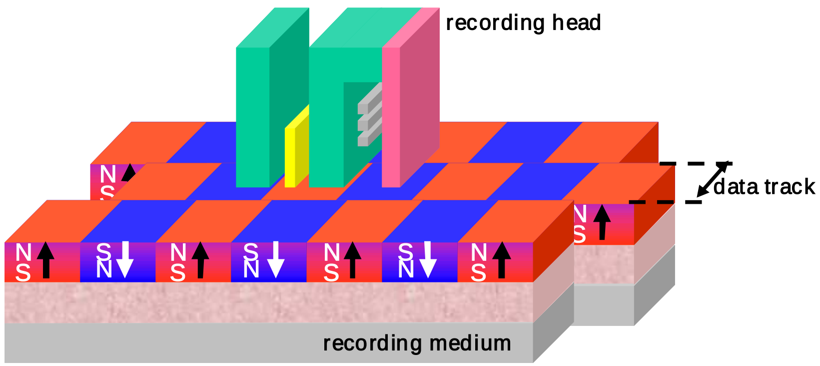
パターンド媒体のコンセプト

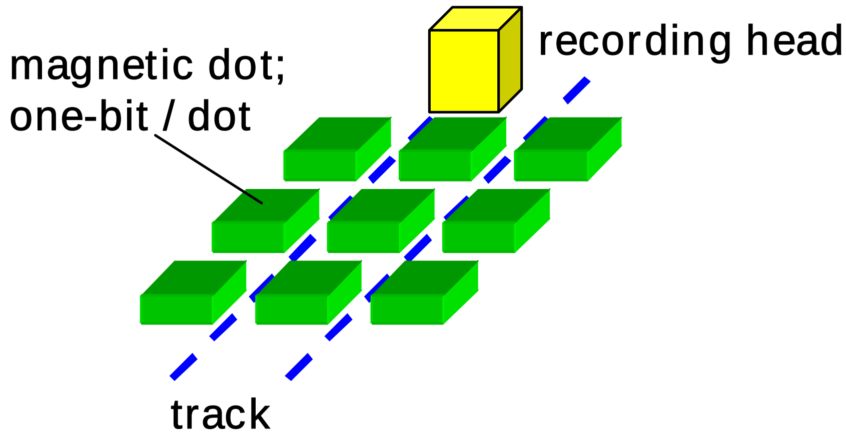




現行媒体:
微小磁性粒子による
の熱揺らぎ問題

パターンド媒体:
連続膜をビットサイズに加工
V大→熱揺らぎ回避



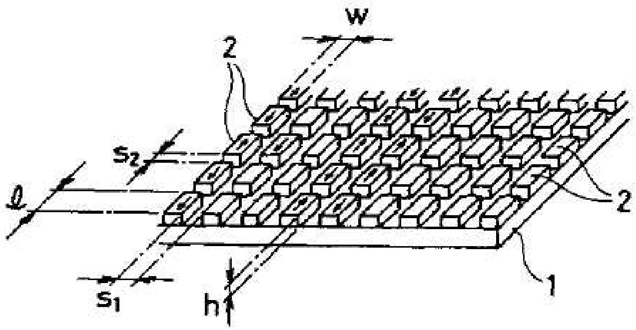


パターンド媒体の課題

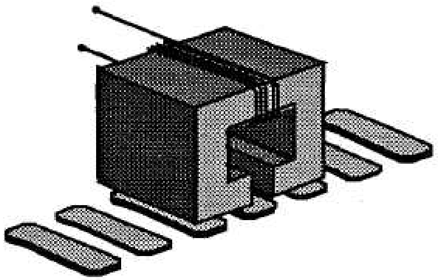
Challenging Issues
- **製造(加工)方法**
- **浮上性能/表面平滑化**

feature size~10nm

Engineering Issues
- **媒体の磁気特性デザイン**
- **サーボ、ヘッド位置制御法**
- **信号制御、チャネル (ビットに同期した記録)**
- **ヘッドデザイン**



Nakatani: Japanese Pat. (1989)

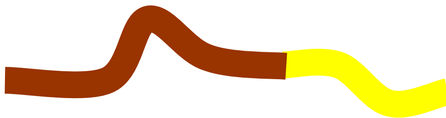


R. White: IEEE Trans. Magn., 33 p.990 (1997)

ポリマーの自己組織化を利用した微細パターン

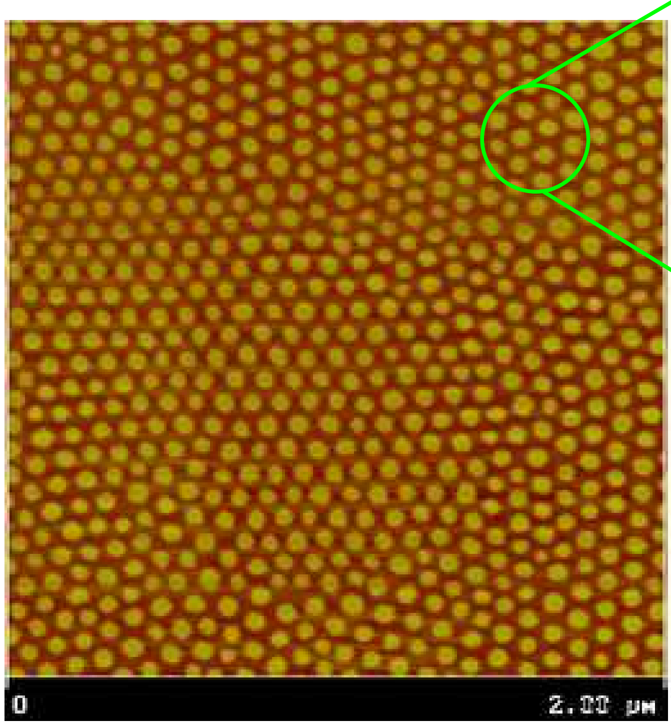
PS-PMMA ジブロックコポリマー(di-block co-polymer)

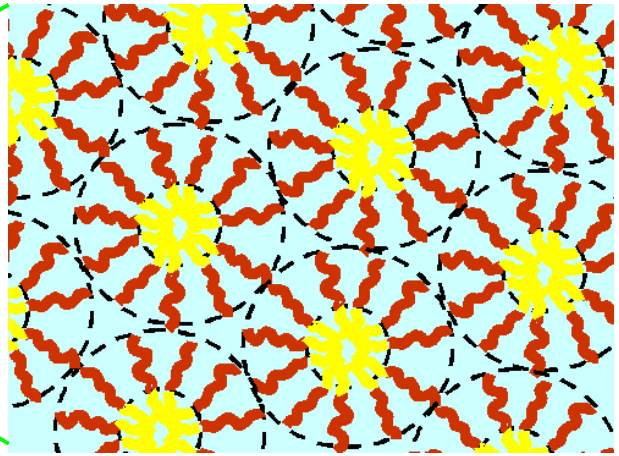
ポリスチレン (PS)
(**分子量**: 172000)

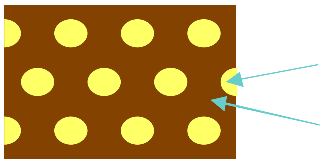


ポリメチルメタクリレート(PMMA)
(**分子量**: 41500)

AFM **位相像**





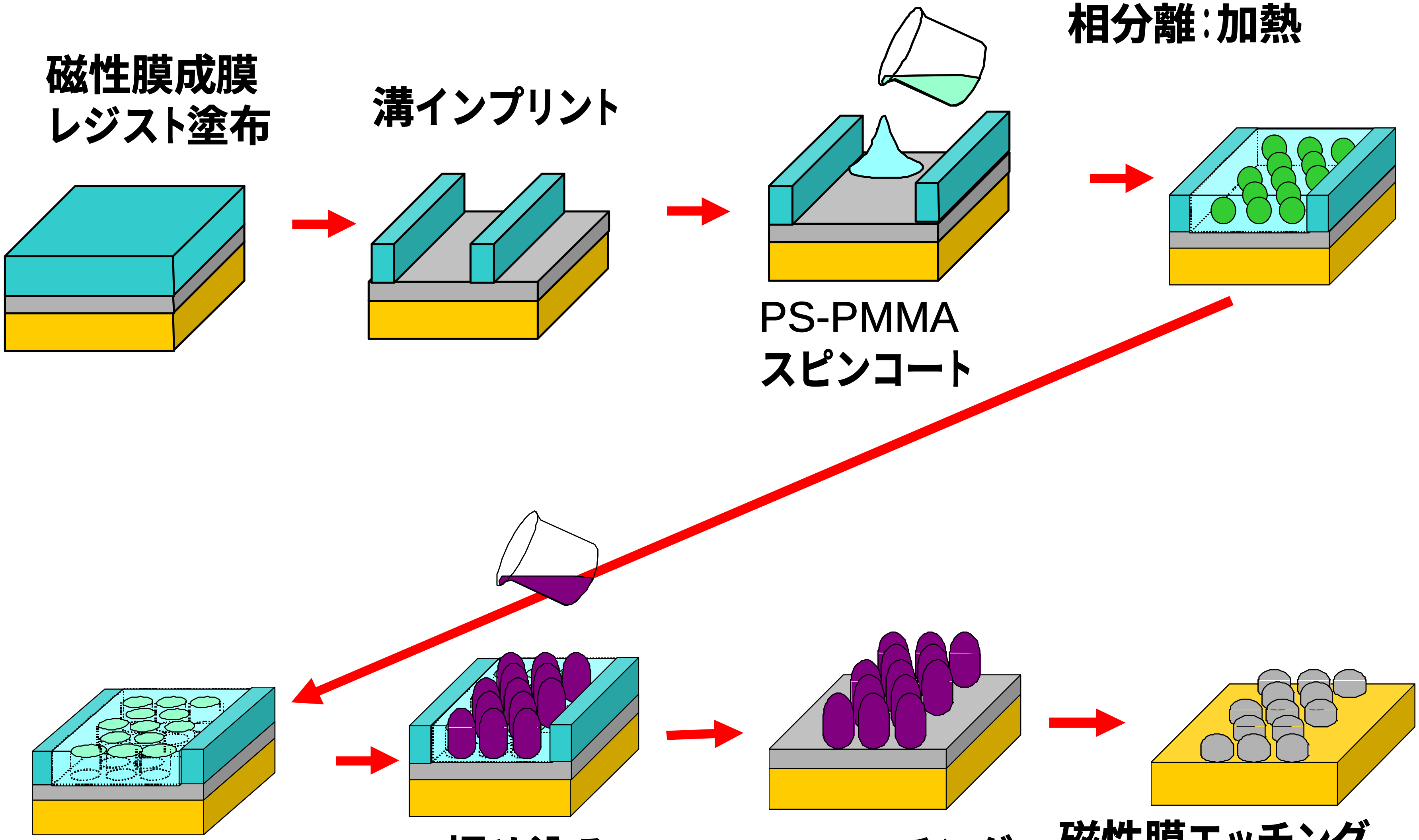


80 nm**間隔**, 40nm**直径**

自己組織化

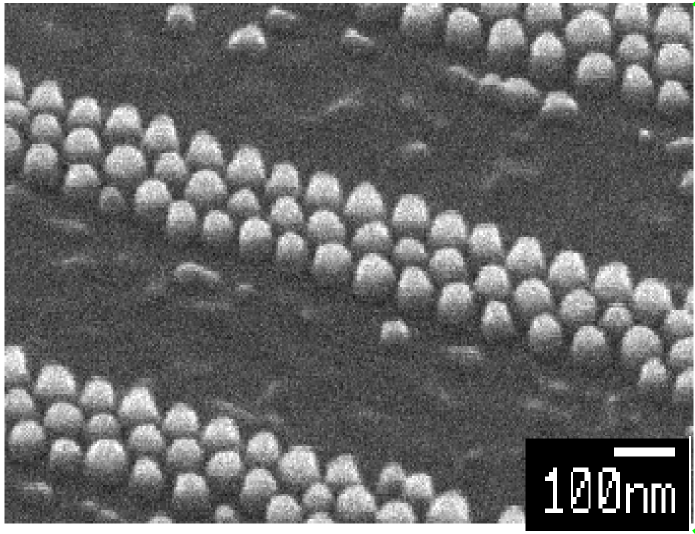
- **大面積のナノ構造を一度に形成**
- ~10nm**も可**

パターンド媒体形成プロセス



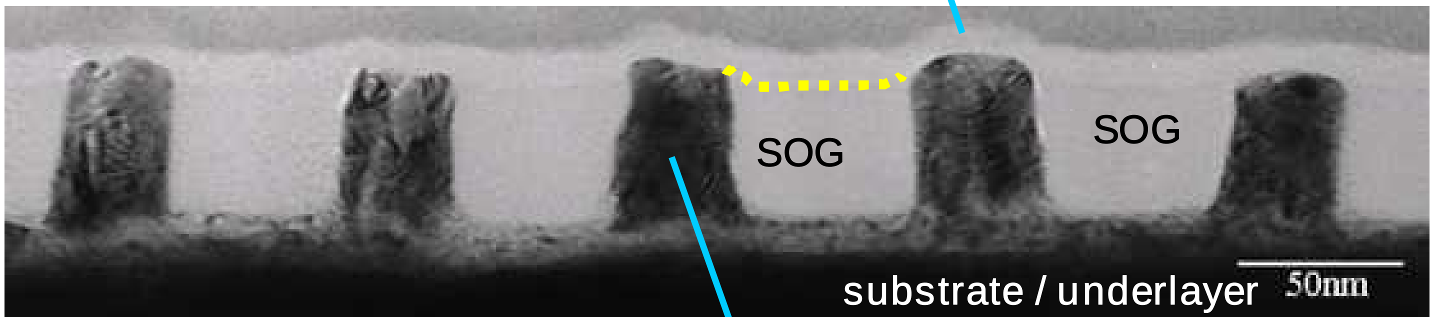
CoCrPtパターンド媒体

$Co_{74}Cr_{6}Pt_{20}$パターンド媒体(80 nmピッチ、40 nm直径)



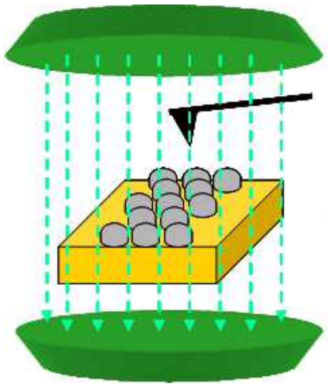
SEM像

全体像

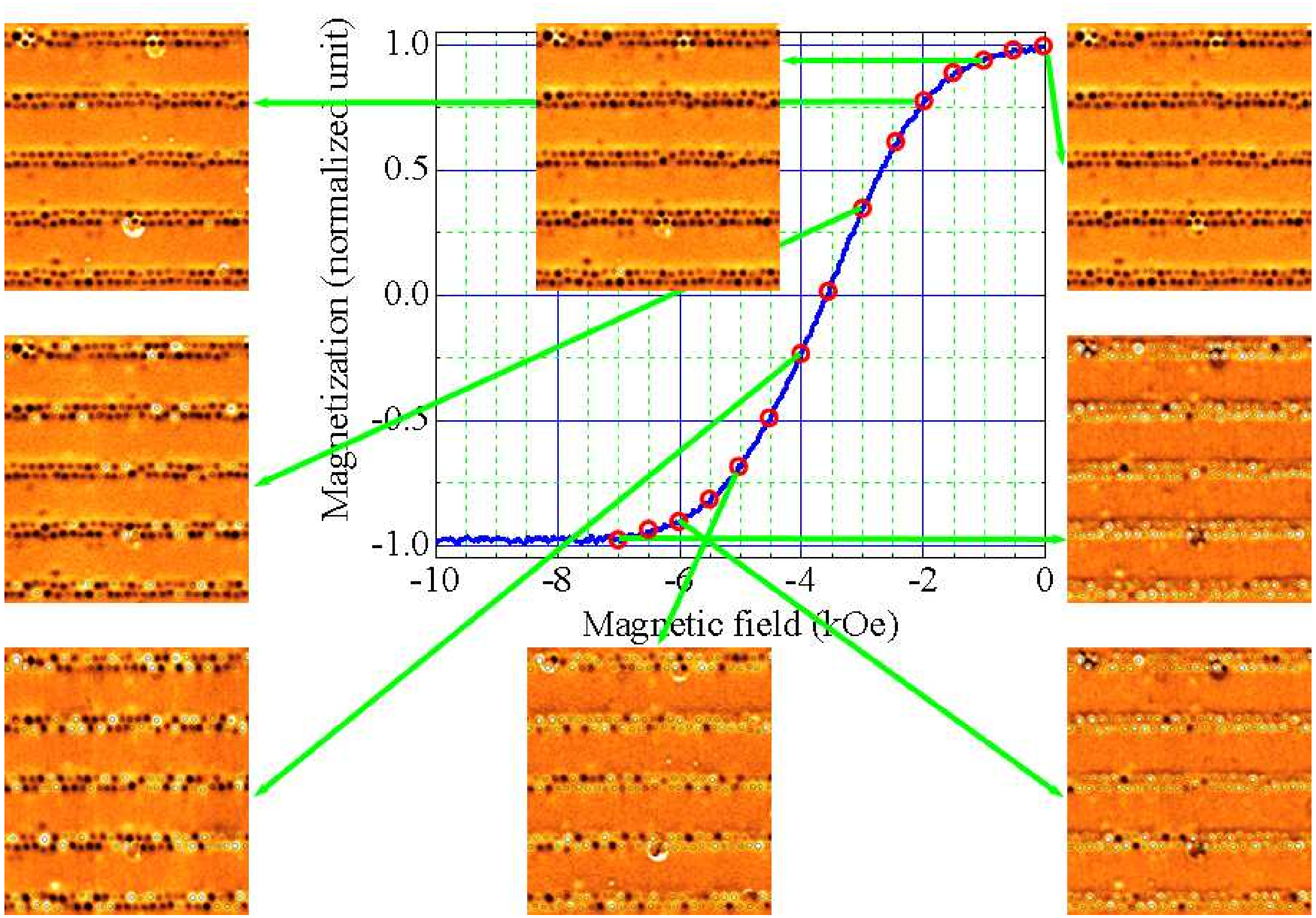


Y. Kamata: Intermag06 GE-09

MFMを使ったドット毎の磁気特性測定



磁界印加⇔MFM測定

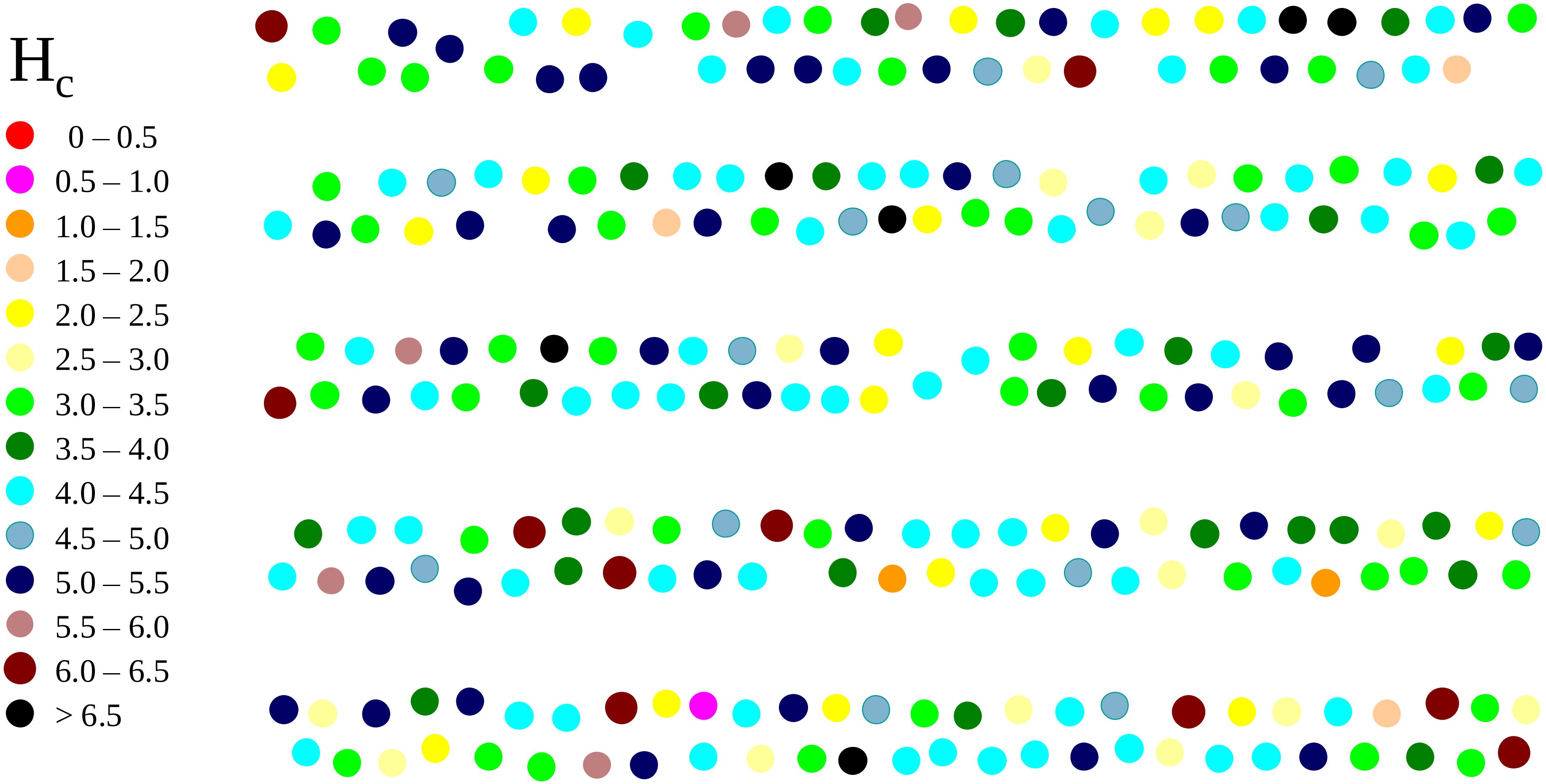


反転したドット個数を数える＝磁化量

J.Bai et al., J. Appl. Phys., Vol.96, No.2, 1133(2004).

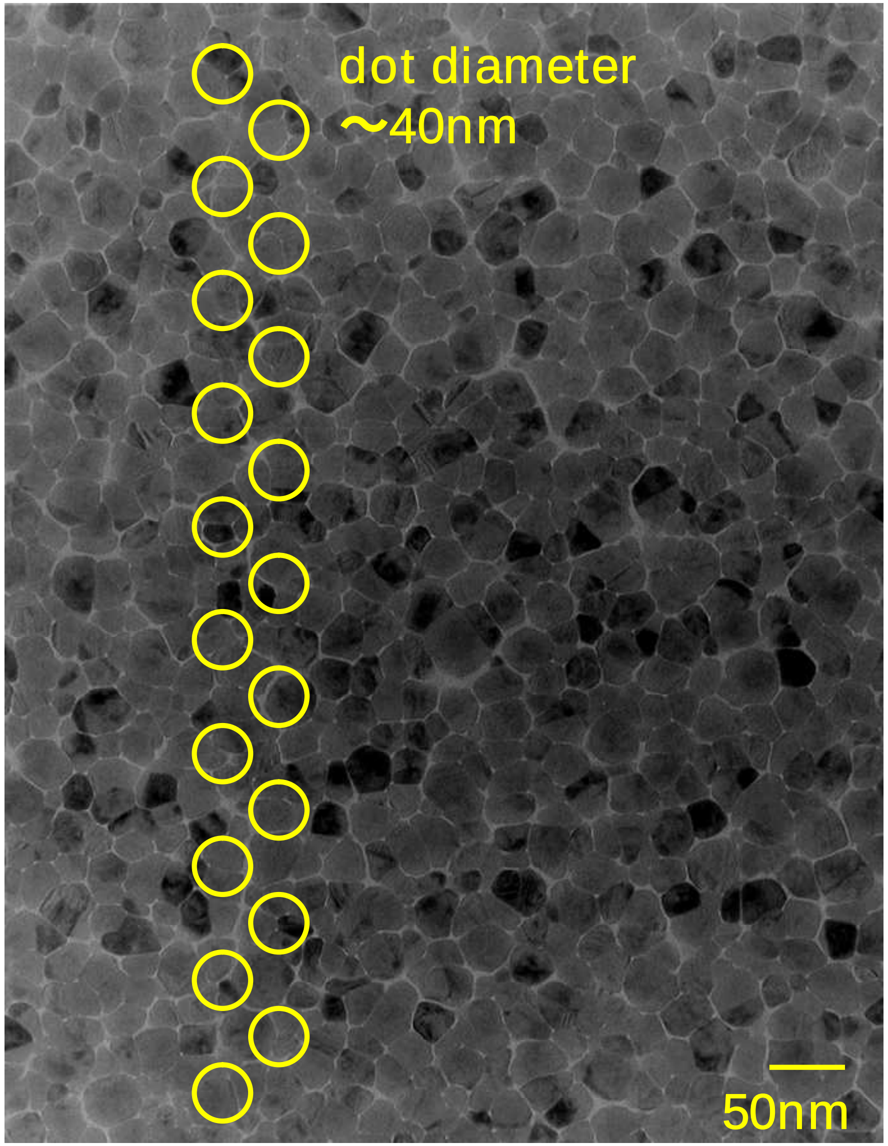
各ドットの保磁力分布

Hc distribution of aligned CoCrPt dots (40nmϕ)

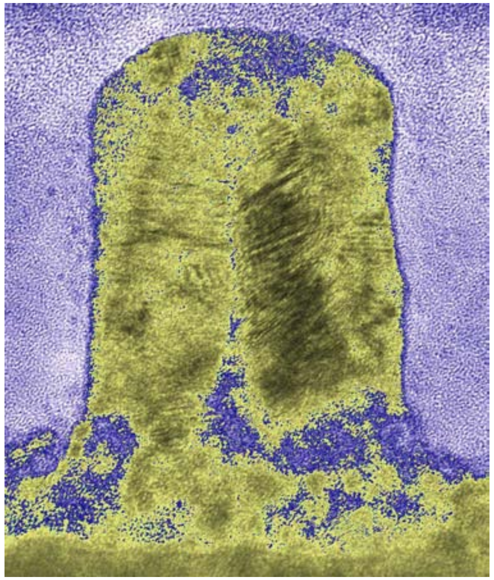


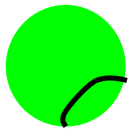
Y. Kamata: Intermag 06 GE-09

ドットの均一性：数本の粒界、異方性軸分布



磁性膜の平均粒径: 22.9 nm
パターンサイズ: 40 nm
→ドット中に粒界が1-2個

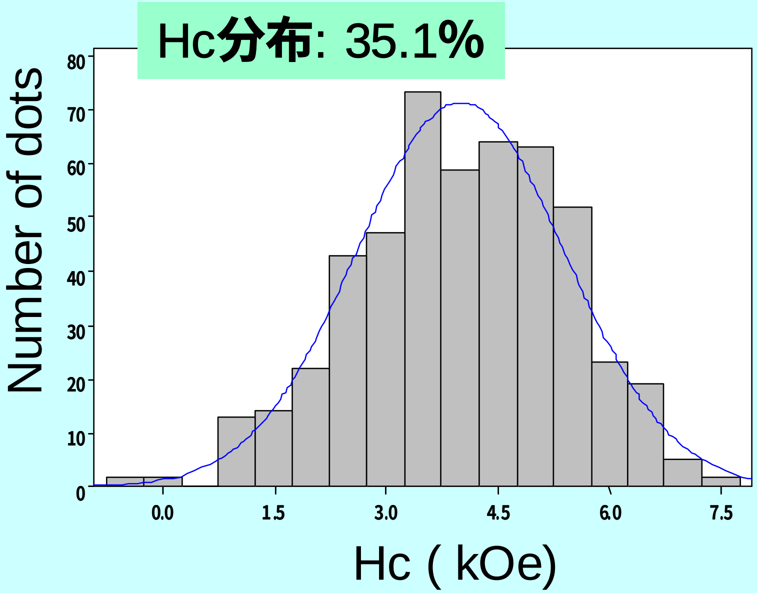


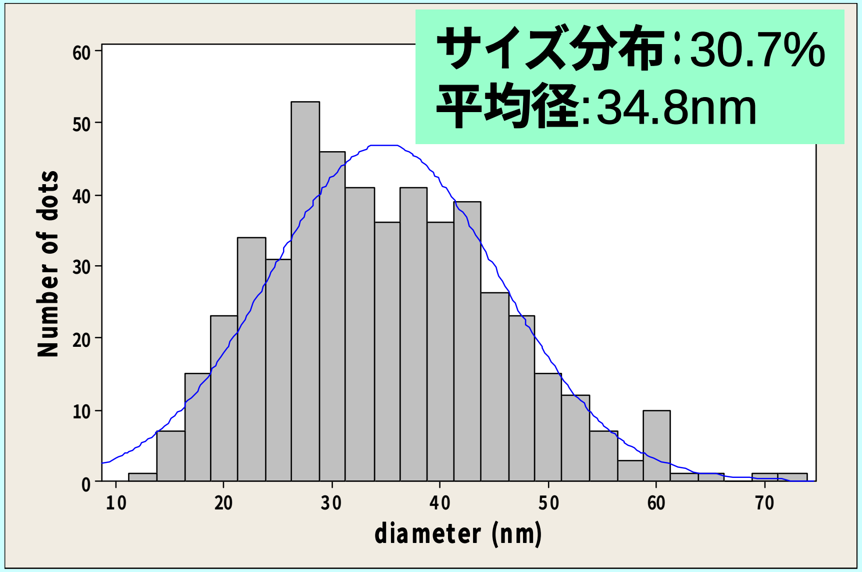


端っこにあると熱揺らぎ

垂直配向軸のばらつき、

磁気特性分布の原因





Y. Kamata: JJAP Vol.40,No.3A,999(2007)

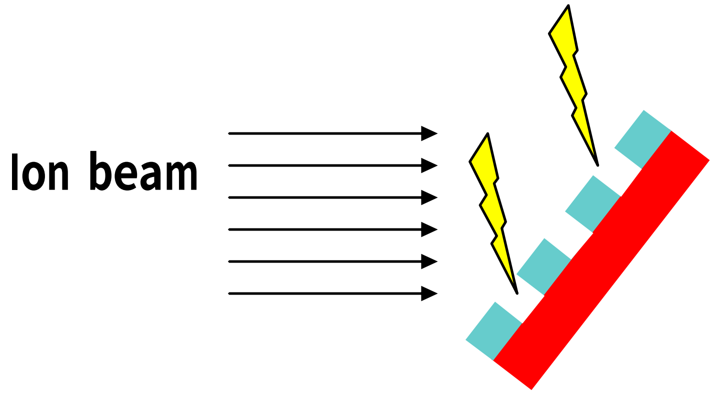
possible origin of the distribution

- dot size distribution
- microscopic composition dispersion
- grain boundary
- damage by the etching process

  ... TEM, simulation: little damage by ion milling

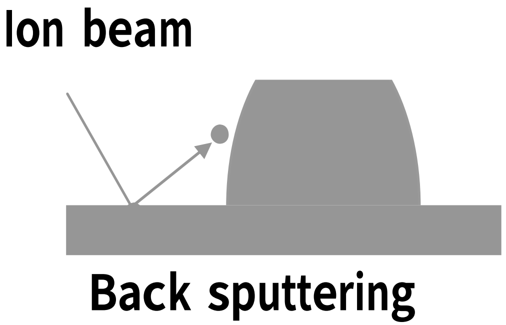
Ar イオンミリングプロセス

利点：どのような磁性膜でもエッチングできる
欠点：エッチングダメージ

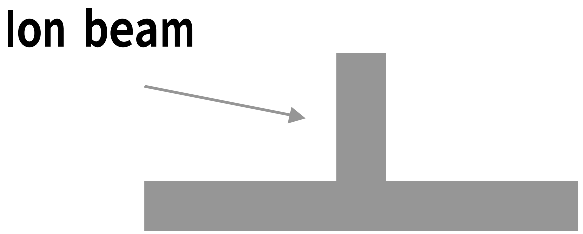


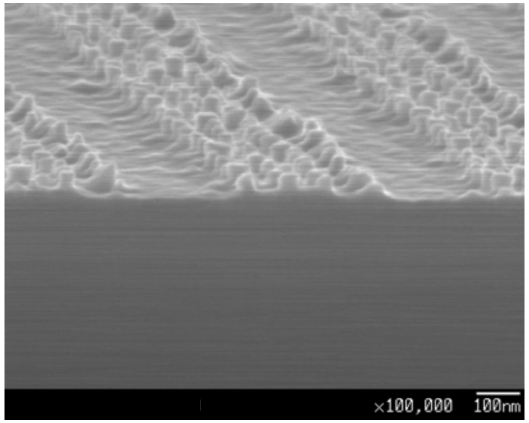
ダメージ
- 垂直磁気異方性の劣化
- 結晶性劣化
- ドット形状の破壊

redeposition：**再付着**



sidewall etching：**サイドエッチ**





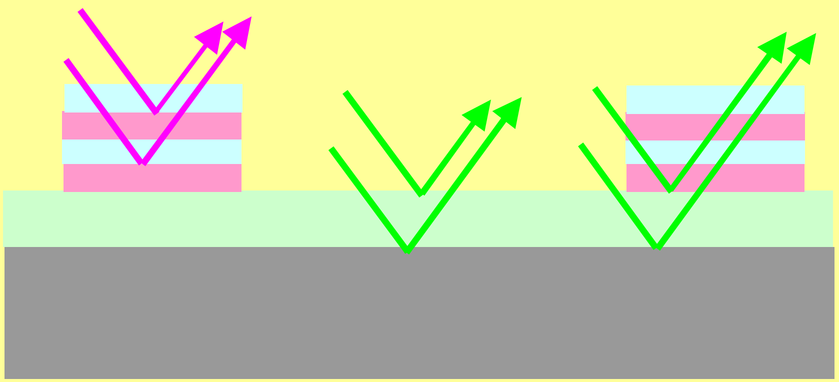
introduction (II)

motivation:

etching damage analysis of the patterned media
made by ion milling process with self assembled mask

- magnetic layer: Co/Pt multilayer
  magnetic properties by multilayer structure
  ➔ sensitive to the physical damage

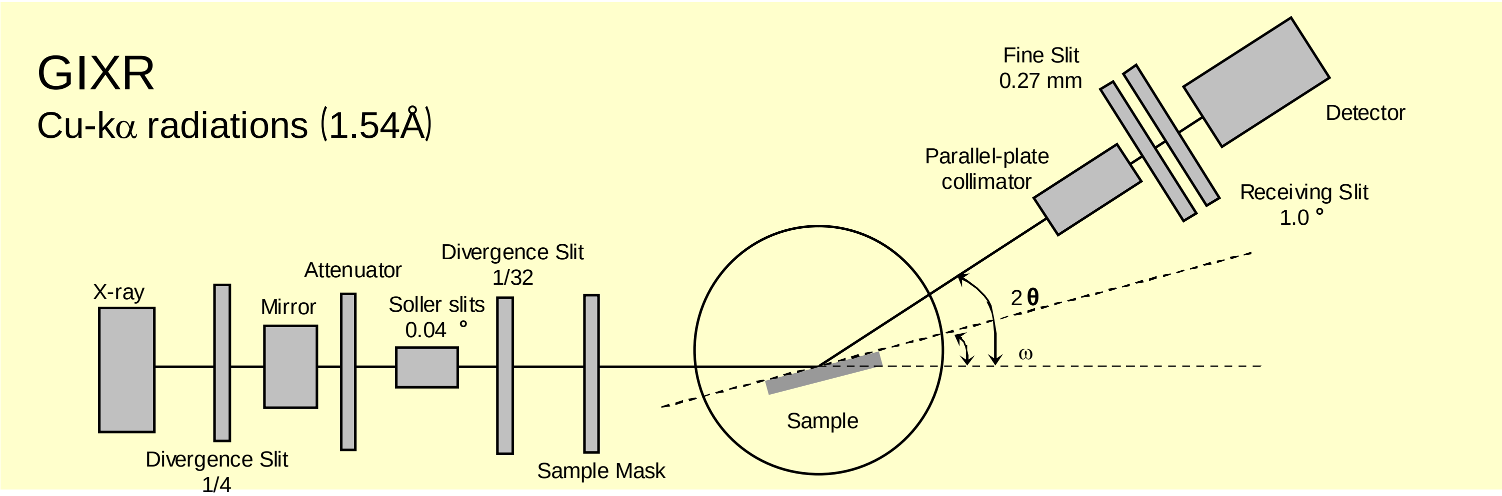
- method: Grazing Incidence X-ray Reflectivity (GIXR)
  layer structure, roughness



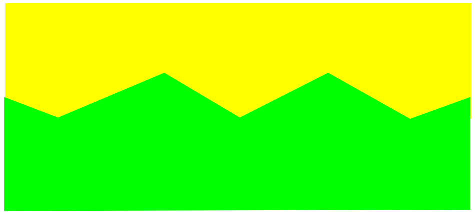
similar refraction is expected;
multilayer: reduced intensity
underlayer: increased intensity
dot edge: scattering

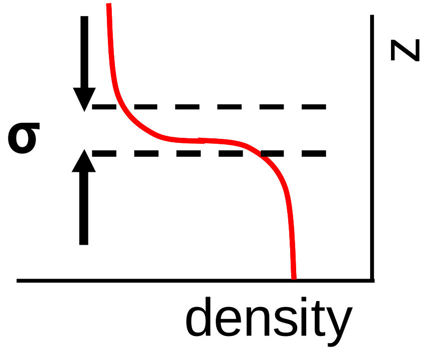
experiment - measurement

- saturation magnetization (M_s): VSM
- magnetic anisotropy energy (K_u): VSM, torque meter
- crystalline structure: XRD
- thickness and roughness: GIXR
- microstructure: TEM



Fitting model; roughness



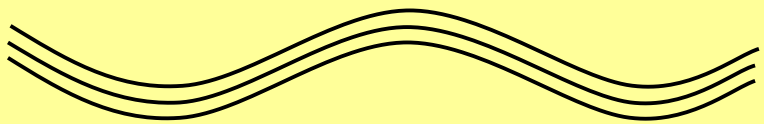


rough interface ➔ gradual density change: **ρ** (z)

ρ (z): error function

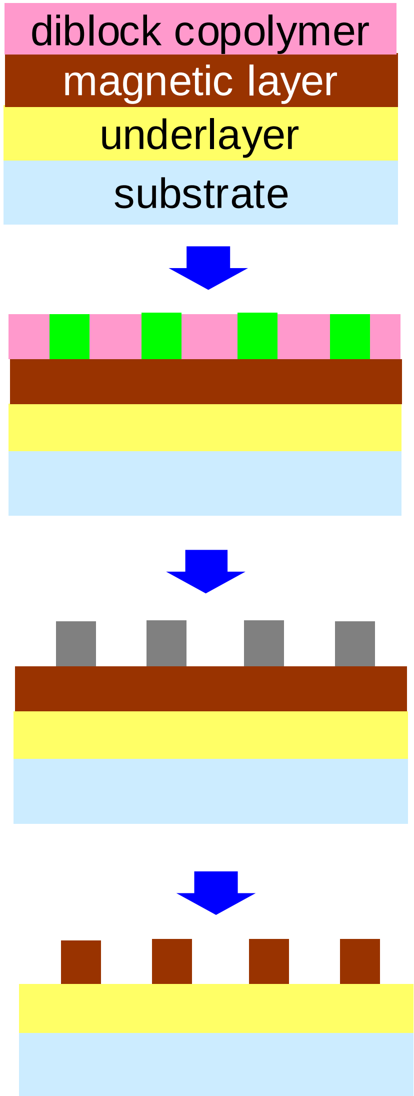
$$\rho(z) = \frac{1}{\sqrt{\pi}} \int_{-\infty}^{z} \exp(-\frac{t^2}{2\sigma^2}) \cdot dt$$

σ : roughness



case of **σ** > thickness

experiment – fabrication process

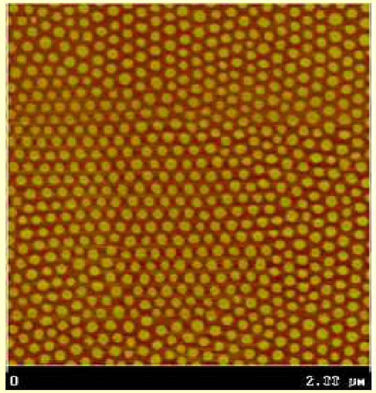


phase separation

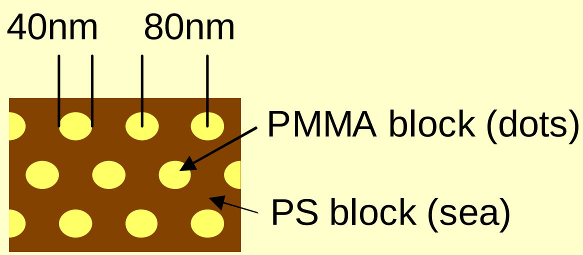
O_2 RIE
SOG substitution

Ar ion milling
CF_4 RIE

PS-PMMA diblock copolymer

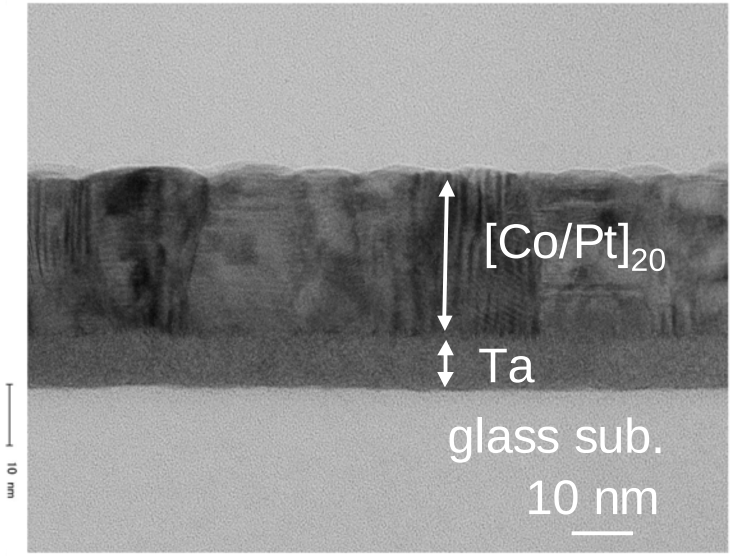


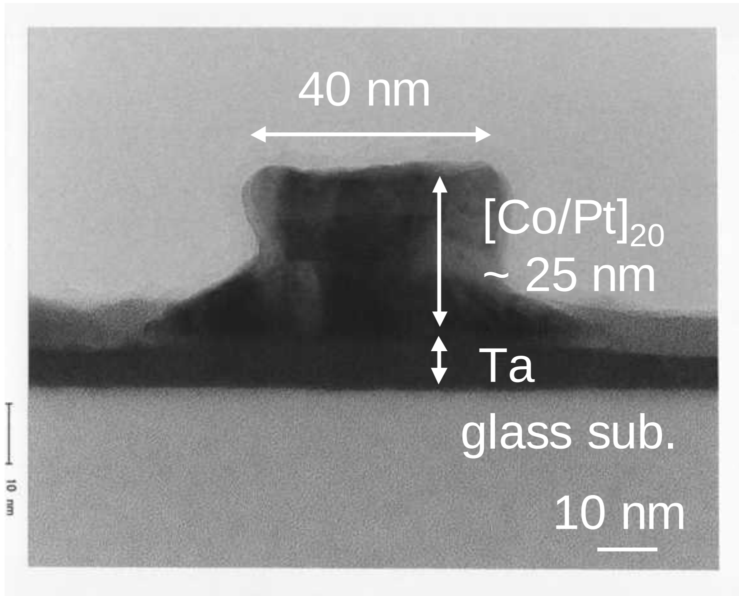
AFM

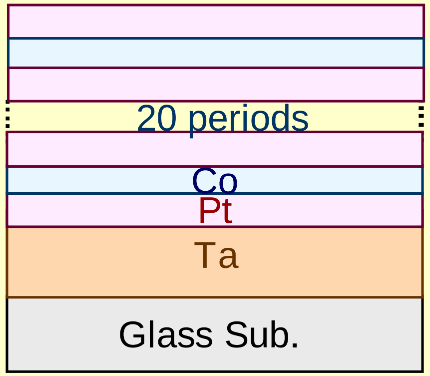


K. Naito et.al.: IEEE Trans.Magn. **38**, 1949 (2002)

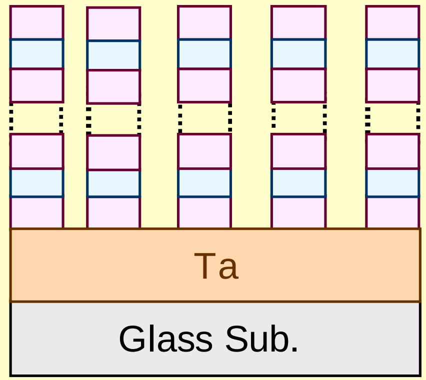
Co/Pt multilayer sample







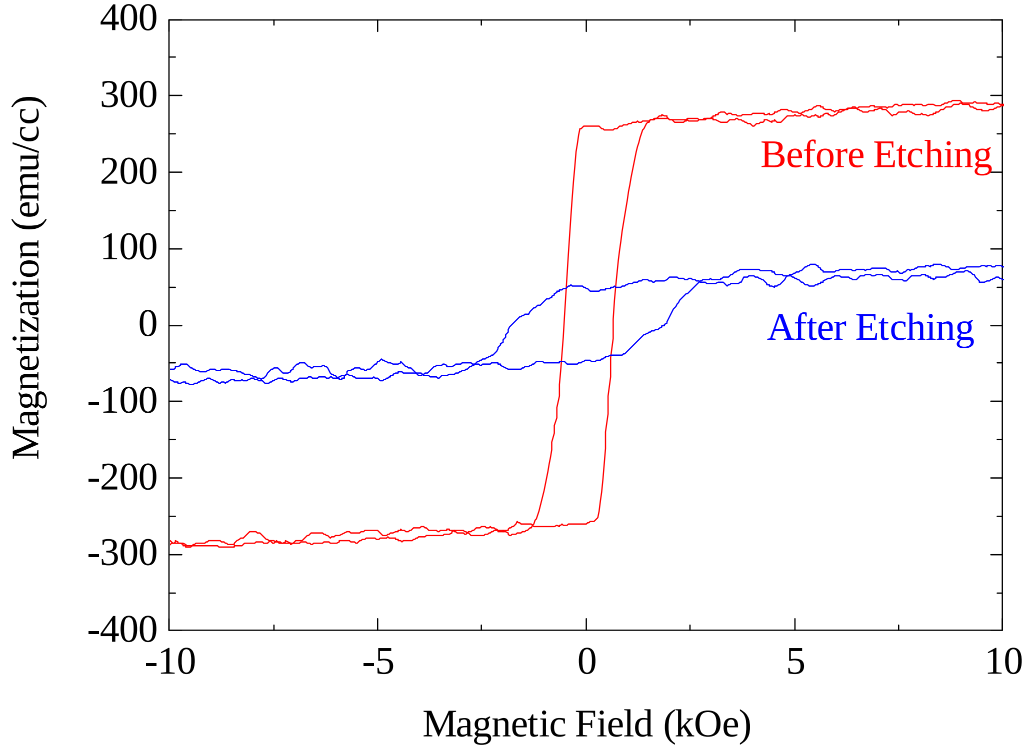
Before Etching

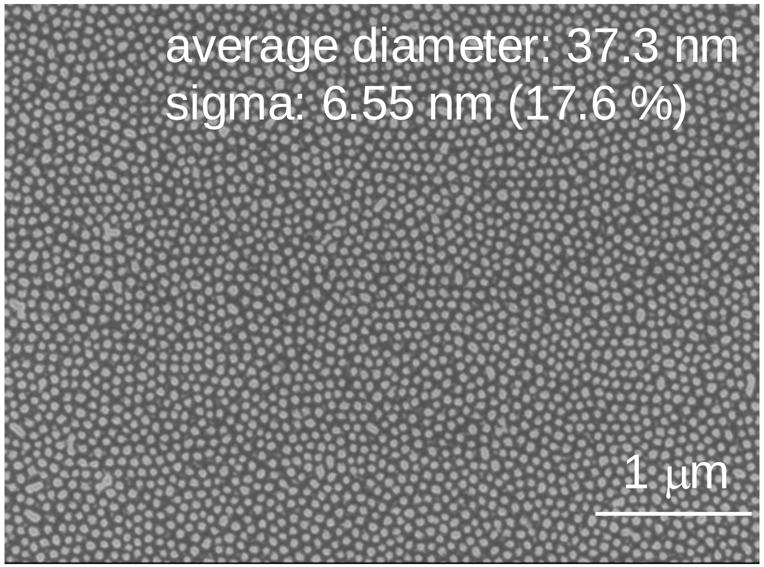


After Etching

- **Sputtering condition**
  - Co: 0.3nm, Pt: 0.9nm
  - DC sputtering
  - no substrate heating
  - Ar pressure: 0.5 Pa
- **Milling condition**
  - substrate cooling
  - accelerating voltage : 400 eV
  - Ar pressure : $2.5X10^{-4}$ Torr
  - etching angle : 30 deg.

magnetic properties



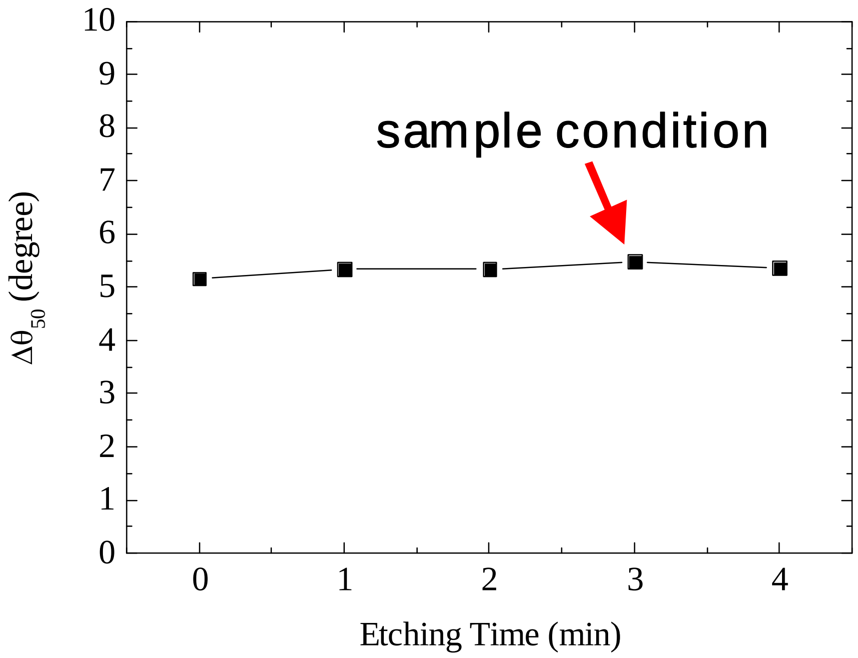


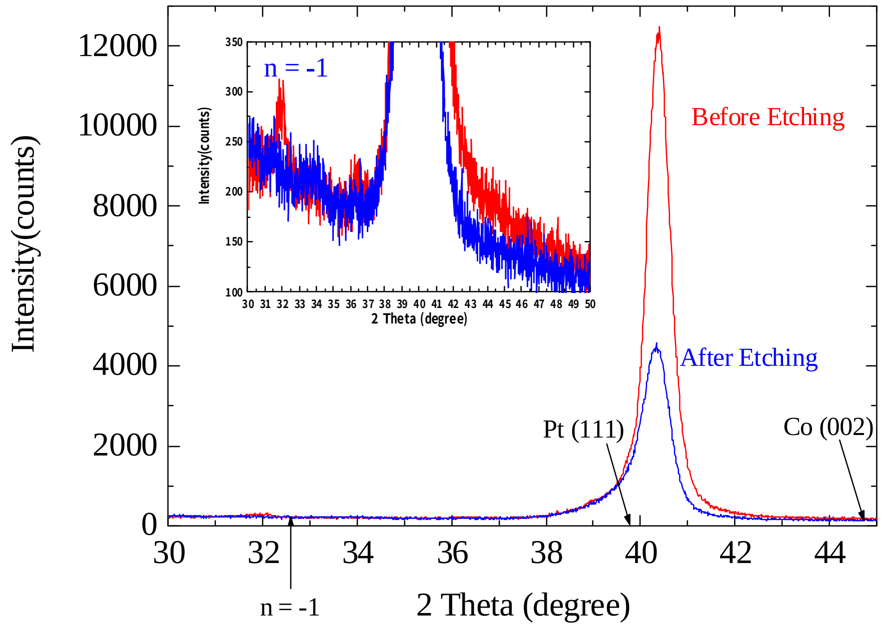
little damage to the magnetic properties

- reduction in M_s: proportional to the packing density
- K_u (by torque curve amplitude): no change

TOSHIBA
Leading Innovation >>>

crystal properties (XRD: θ-2θ)



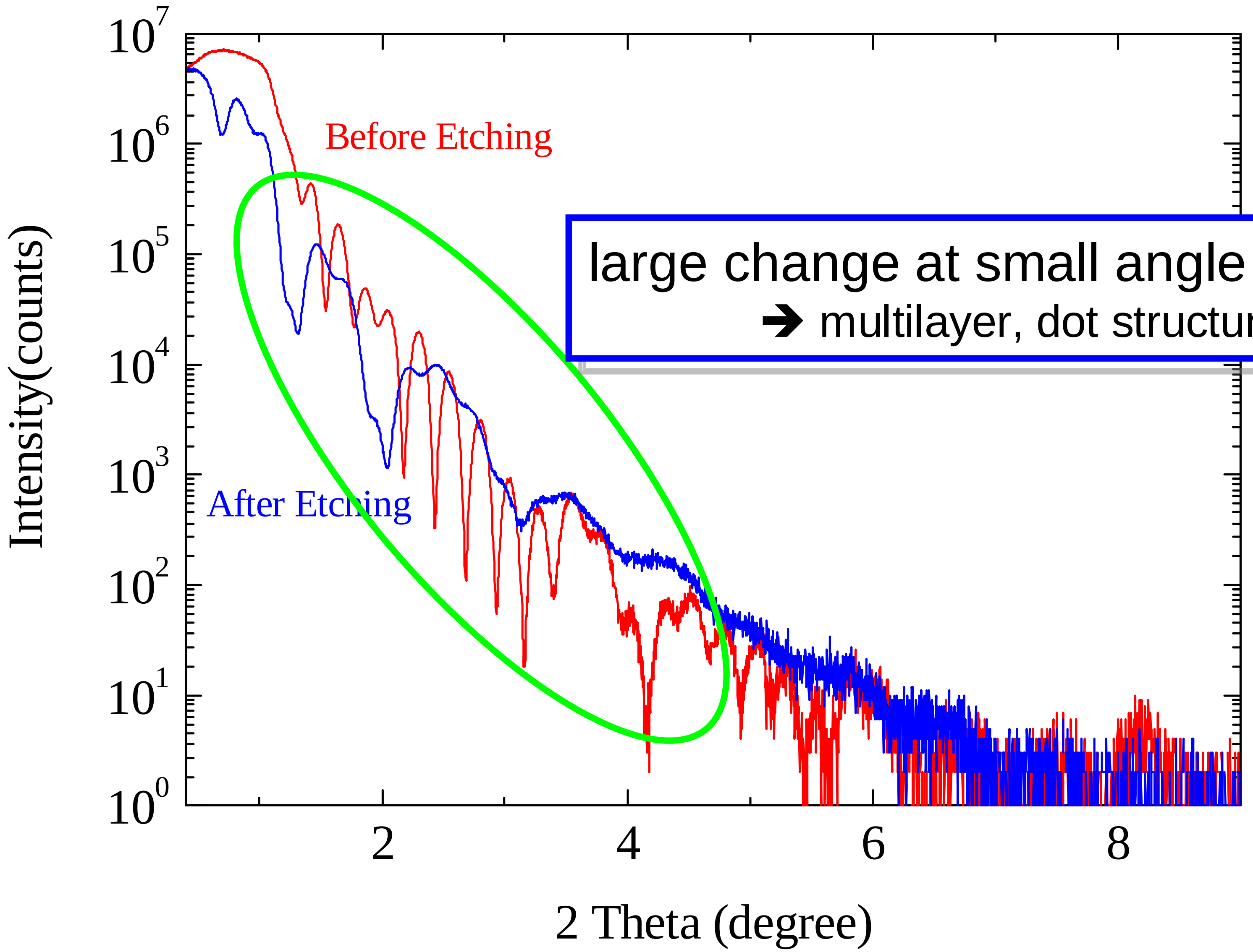


- $\Delta\theta_{50}$: little change throughout the etching process

- θ-2θ: - reduced intensity by volume reduction
  - before etching: satellite peak from multilayer structure
  - after etching: no satellite peak ➔ damage?

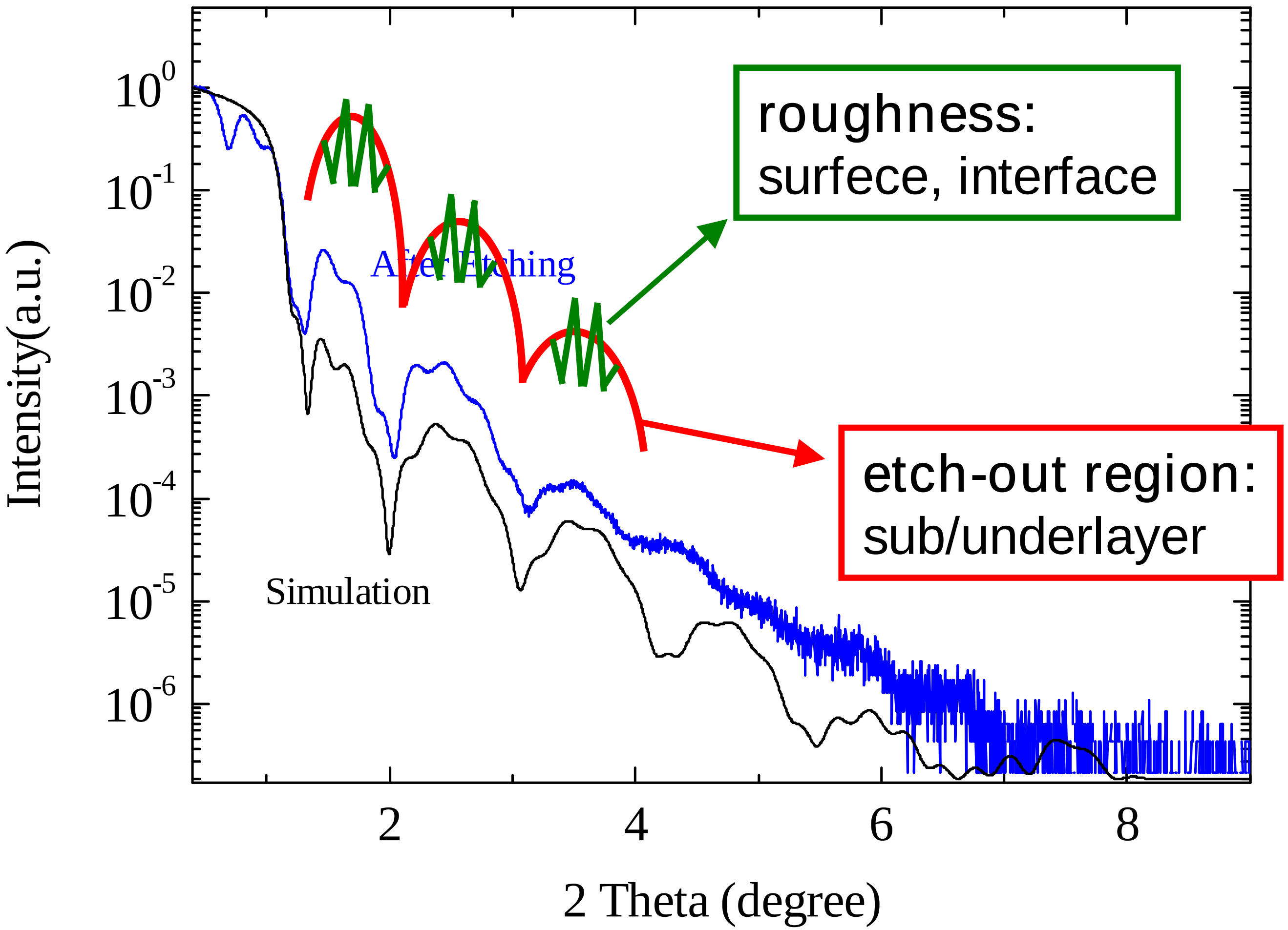
TOSHIBA
Leading Innovation >>>

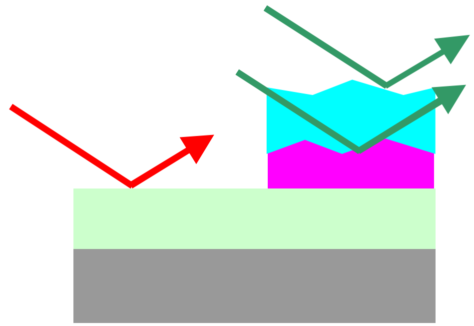
X-ray reflection profile



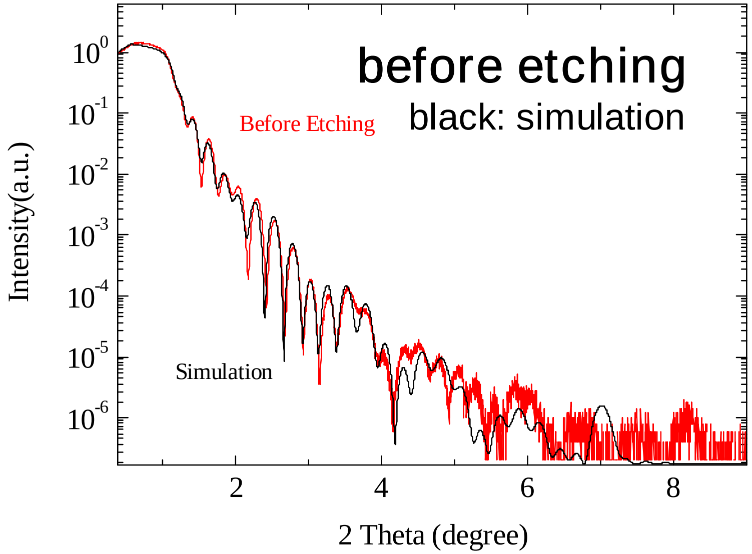
large change at small angle region;
➔ multilayer, dot structure

profile details (after etching)



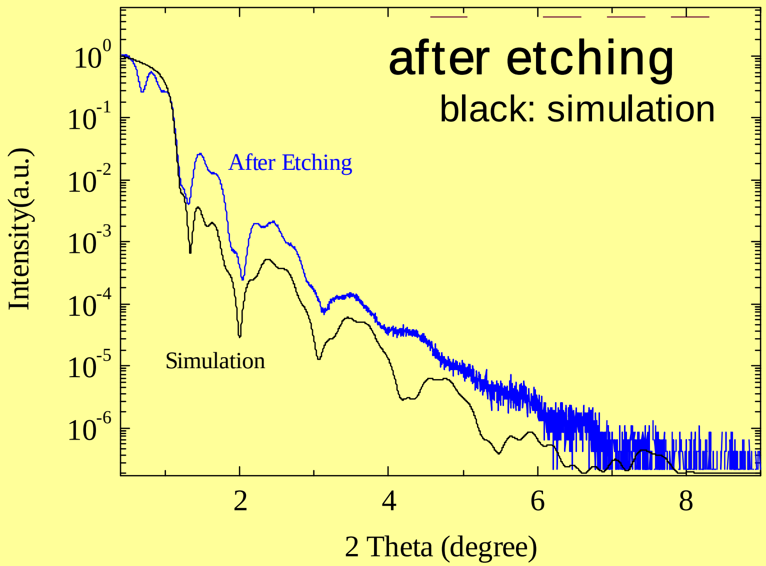


fitting results



	Nominal thickness (nm)	Fitting thickness (nm)	Roughness (nm)
Top Pt	0.9	0.90	0.90
[Co/Pt] $_{20}$	0.3/0.9	0.37/0.90	0.45/0.90
Ta	8.0	7.45	0.50
Glass Sub.	—	—	0.5

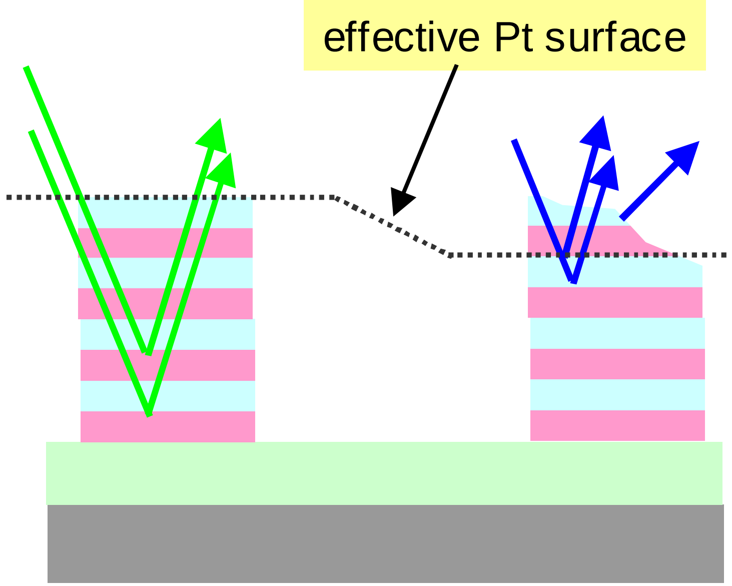
- good agreement with nominal thickness
- roughness ~1nm at [Co/Pt] and top



	Nominal thickness (nm)	Fitting thickness (nm)	Roughness (nm)
Top Pt	0.9	0.80	3.80
[Co/Pt] $_{20}$	0.3/0.9	0.38/0.80	0.45/0.90
Ta	8.0	7.40	0.55
Glass Sub.	—	—	0.5

- little change in ML structure (roughness)
- large roughness at the top Pt layer

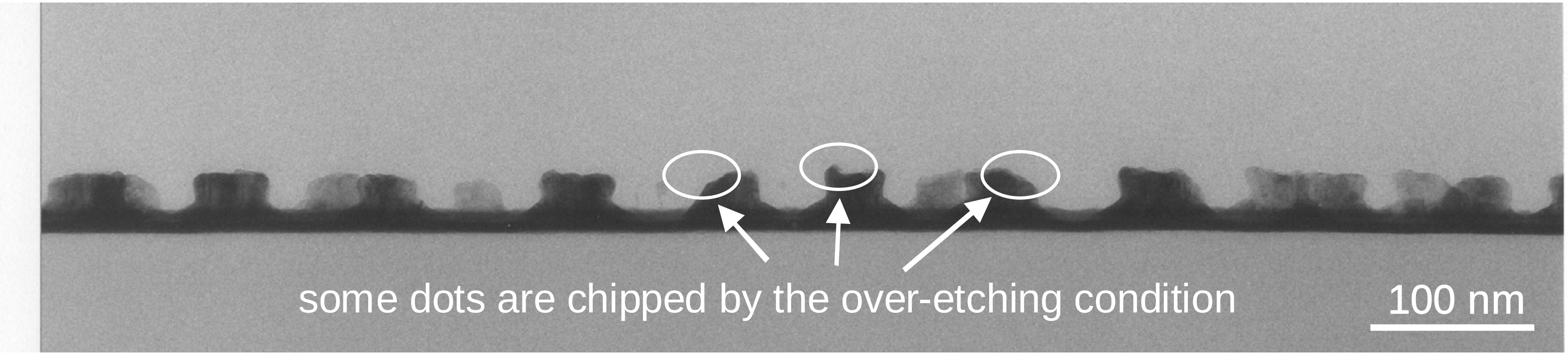
origin of the large surface roughness



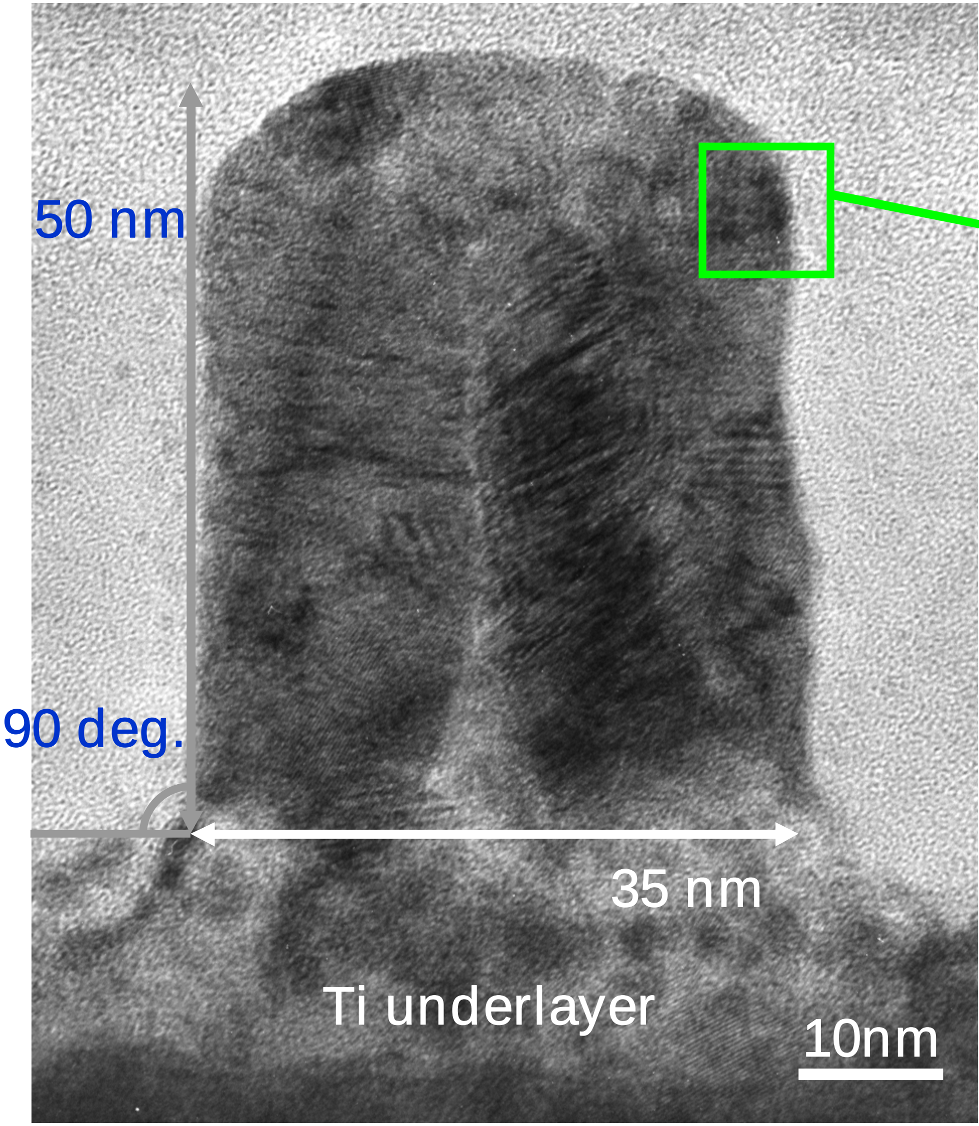
chipped dots
but
smooth ML structure

⇕

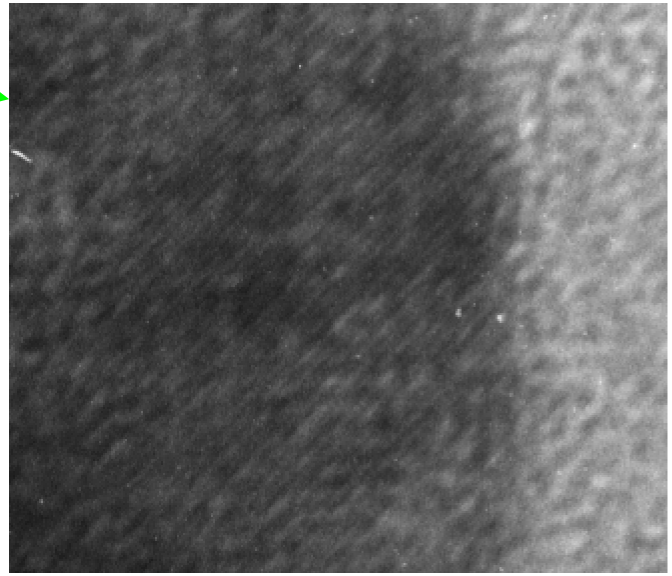
little change in magnetic properties



CoPt合金の例：サイドダメージは少ない



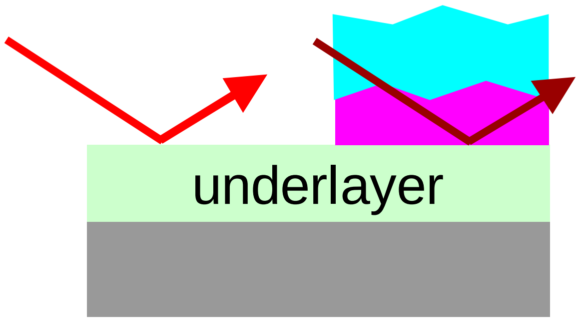
clear crystalline lattice:
no damage



Etching angle : 30 deg.
Etching time : 8 min.

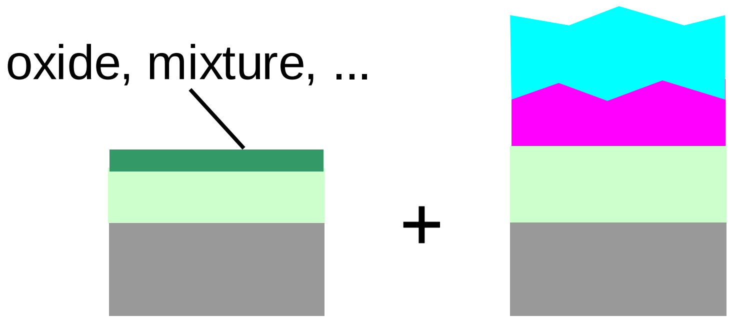
for further precise estimation

Issue: strong reflection from the etched-out region



difference in reflectivity of underlayer between etch-out region and dot region

➔ Analytical estimation is difficult.



Summation of two spectra (or subtraction) could work well.

conclusion

Grazing Incidence X-ray reflection method
for etching damage analysis of BPM

- Co/Pt multilayer patterned media:
  large surface roughness with smooth ML structure
  chipping by the over-etching condition
  smooth ML ⇔ little damage of magnetic properties
- ion milling process causes less damage
- issues for precise estimation
  ;strong reflection from reside underlayer