マグネティック・ナノイメージングと次世代磁気応用に関する研究会　2003.2.27

EB描画ダマシン法によるSi埋め込み磁性体サブミクロン構造の作製とMFM観察と非線形磁気光学効果

21世紀COE「ナノ未来材料」推進研究室

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Fabrication of permalloy nanostructure by Damascene technique

①Preparation of substrate: Spin-coating of **ZEP resist** with high etching resistance

②**EB-exposition**: Write patterns by EB

③**Development**: Formation of mask-pattern by development

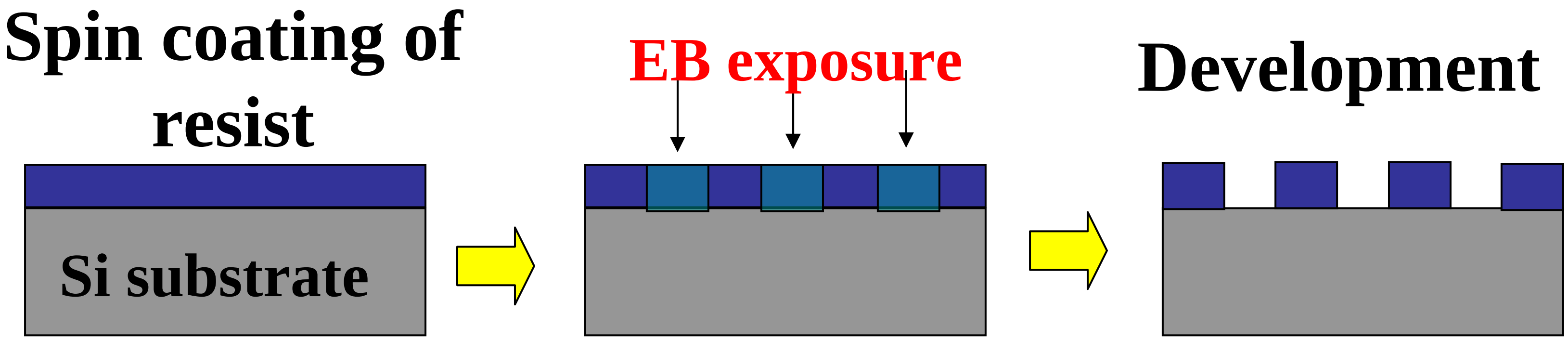
④**Etching** : By dry-etching process mask-pattern is transferred to the substrate

⑤**Deposition** of magnetic film: Deposition of magnetic films by sputter or evaporation

⑥**Polishing**: Obtain flat buried structure using **chemical-mechanical polishing**

Process is simplified by abbreviation of lift-off and repeated spin-coating

EB-patterning process



［1］**Dot size**

100nm×300nm rectangular dot with 300nm-spacing

100nm square dot with 300nm-spacing

［2］**Patterned area**: **3mm×3mm**

［3］**EB-resist thickness**: **300 nm**

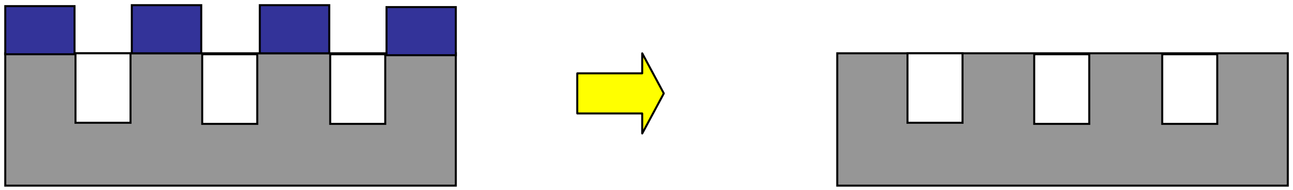
･･･by spin-coating with 5000 rpm rotation

［4］**Baking 160℃ 20min**

Clean Room Laboratory

- Electron beam lithography

Dry etching process



Etching　　　　　　　　　　　　Resist removal

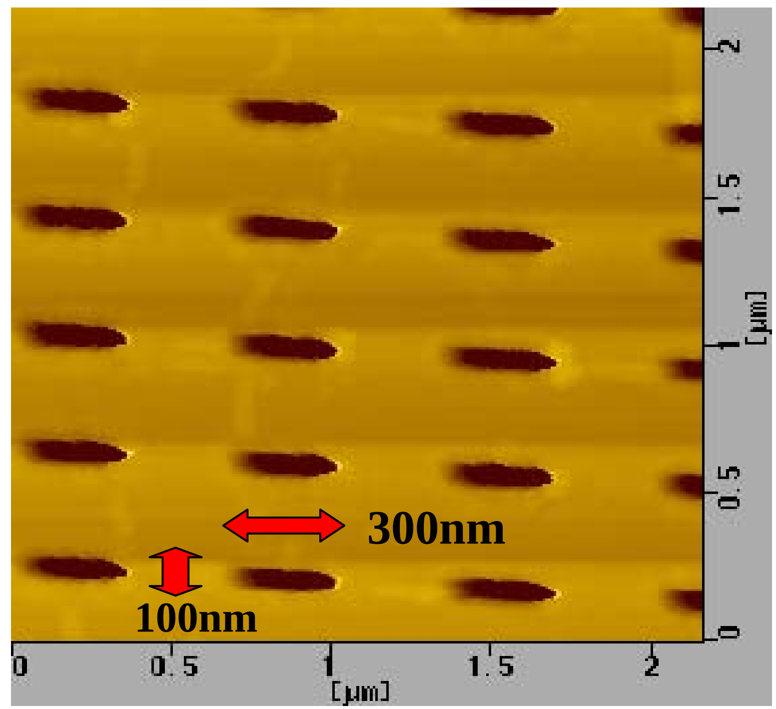
〔1〕Etching gas: CF_4

〔2〕Vacuum 3.0×10^{-3} Pa

〔3〕Gas pressure 9.2Pa

〔4〕RF power: 400W

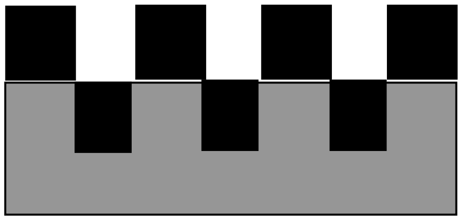
〔5〕Etching rate: 0.1 μm/min



Silicon surface after etching

Dry-etching

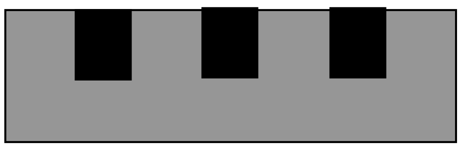
Embedding of permalloy



Embedding of permalloy film by electron beam deposition

〔1〕material: permalloy（$Ni_{80}Fe_{20}$）
〔2〕Vacuum 3.0×10^{-6}Torr
〔3〕Accelerating voltage 4kV
〔4〕Deposition rate 1.0Å/sec

Chemical mechanical polishing



flatting

〔1〕Polishing chemicals: Si wafer

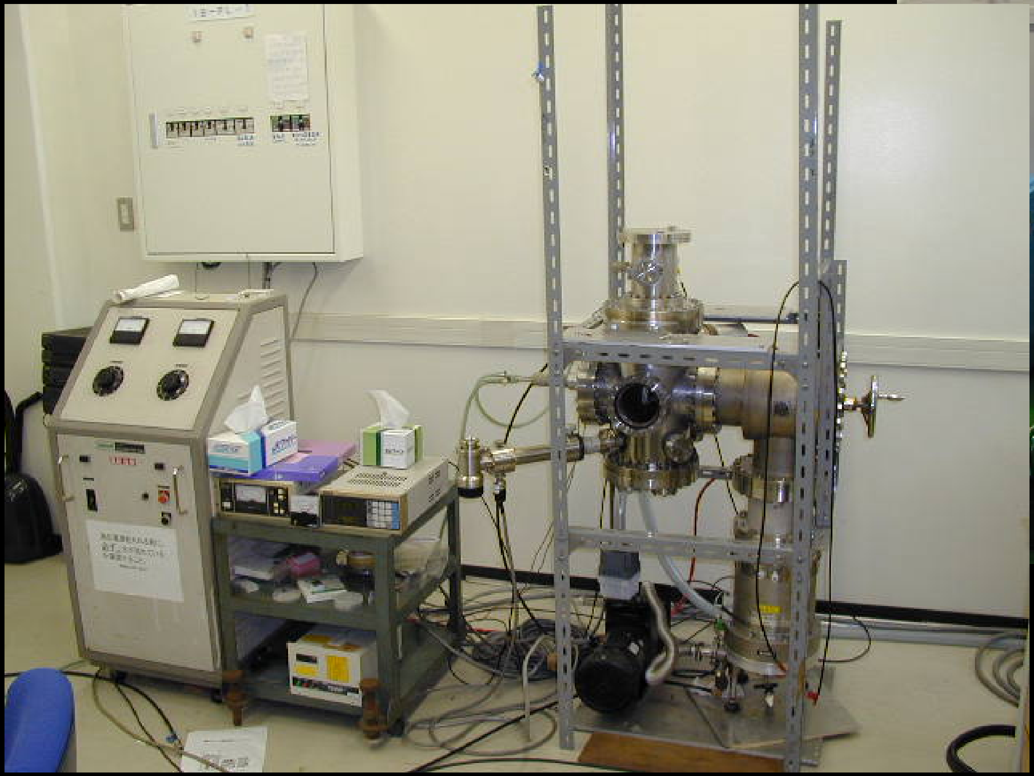
grain-size～20nm

〔2〕pH 11

〔3〕polishing rate: 60nm/min

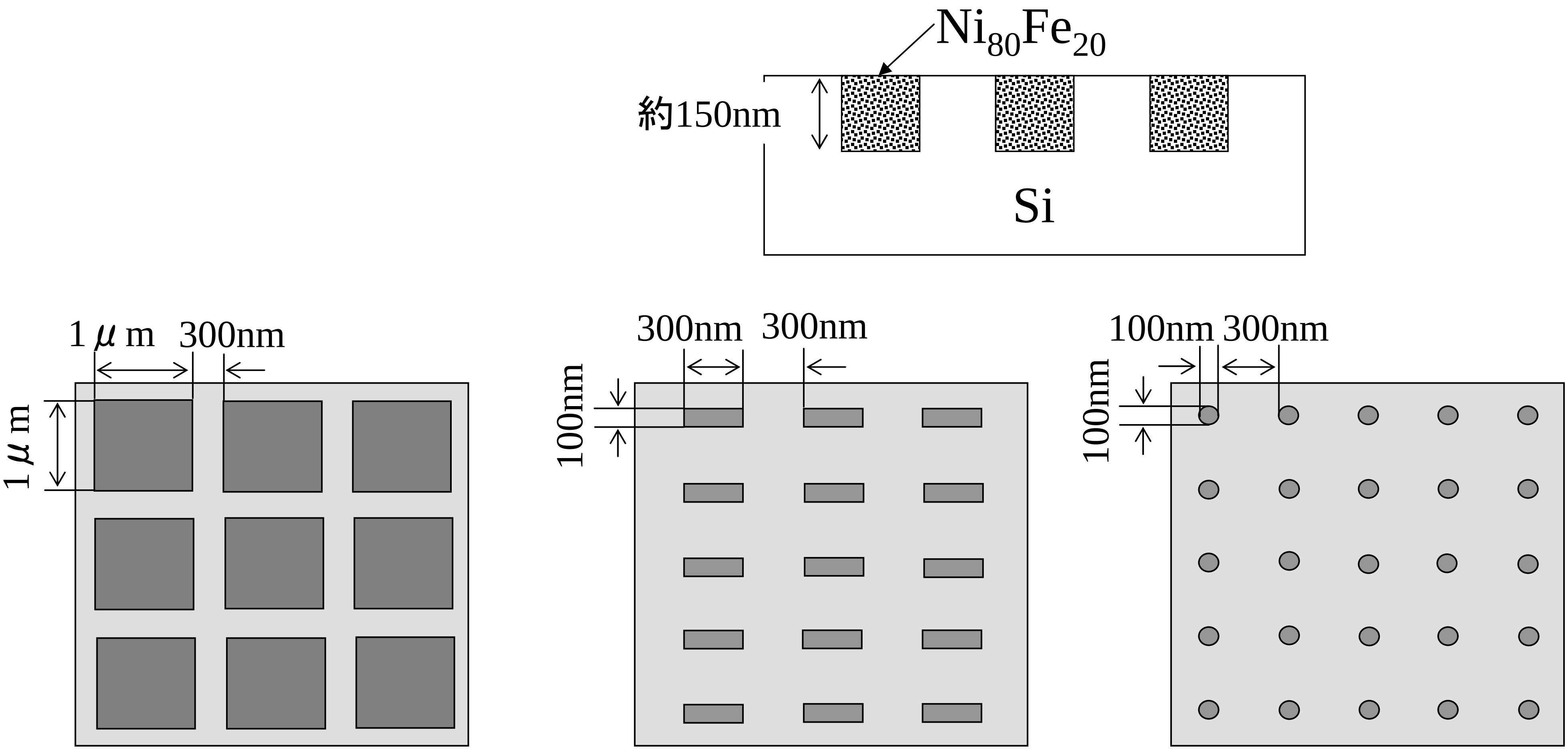
Laboratory

EB deposition



RF magnetron sputtering

Buried permalloy dot array



Square dots

Rectangular dots

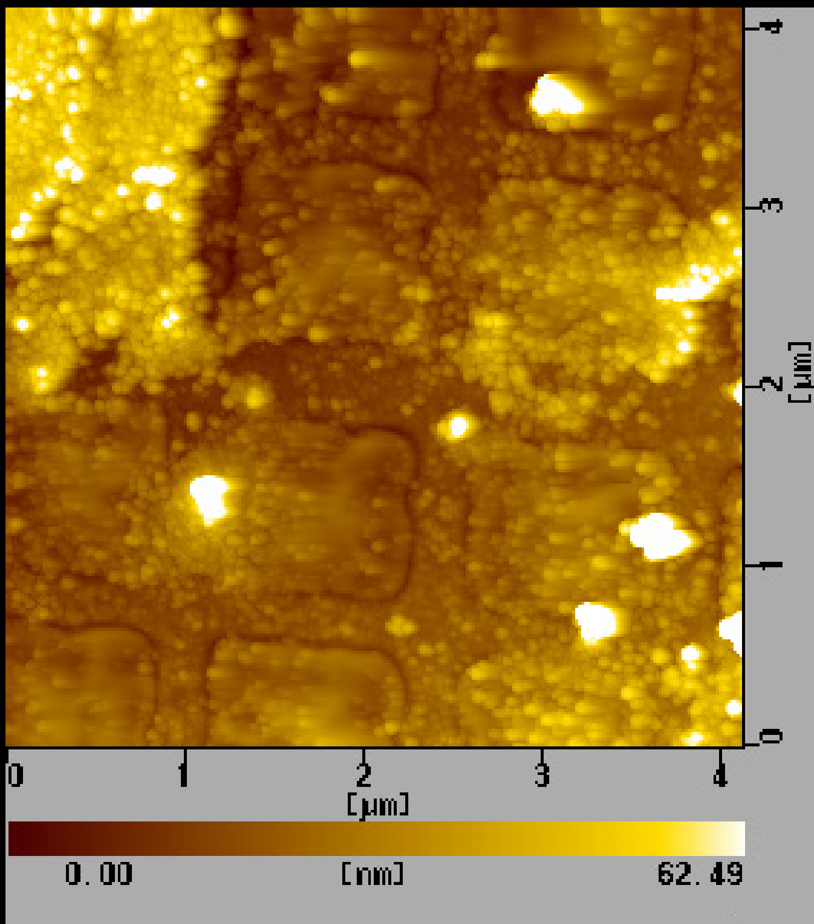
Circular dots

Observation

- AFM/MFM

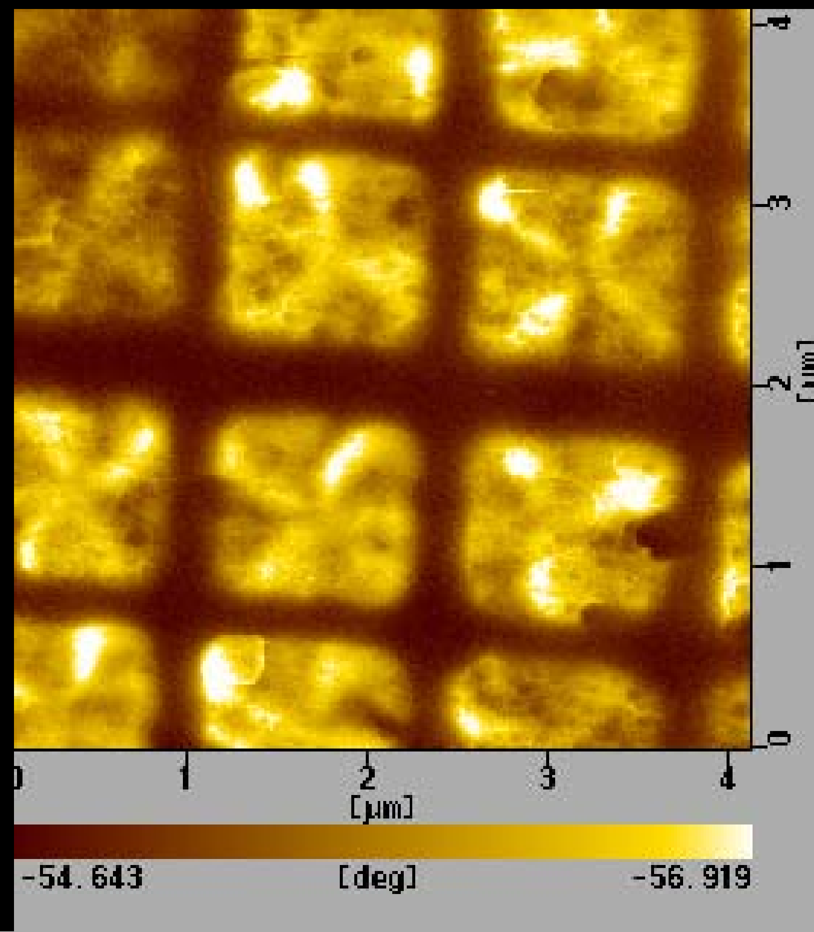
FE-SEM

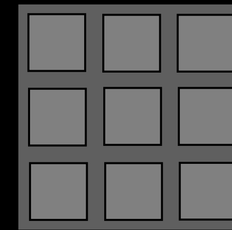
1μm square dot array



AFM

MFM

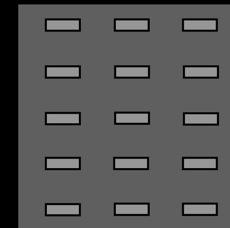




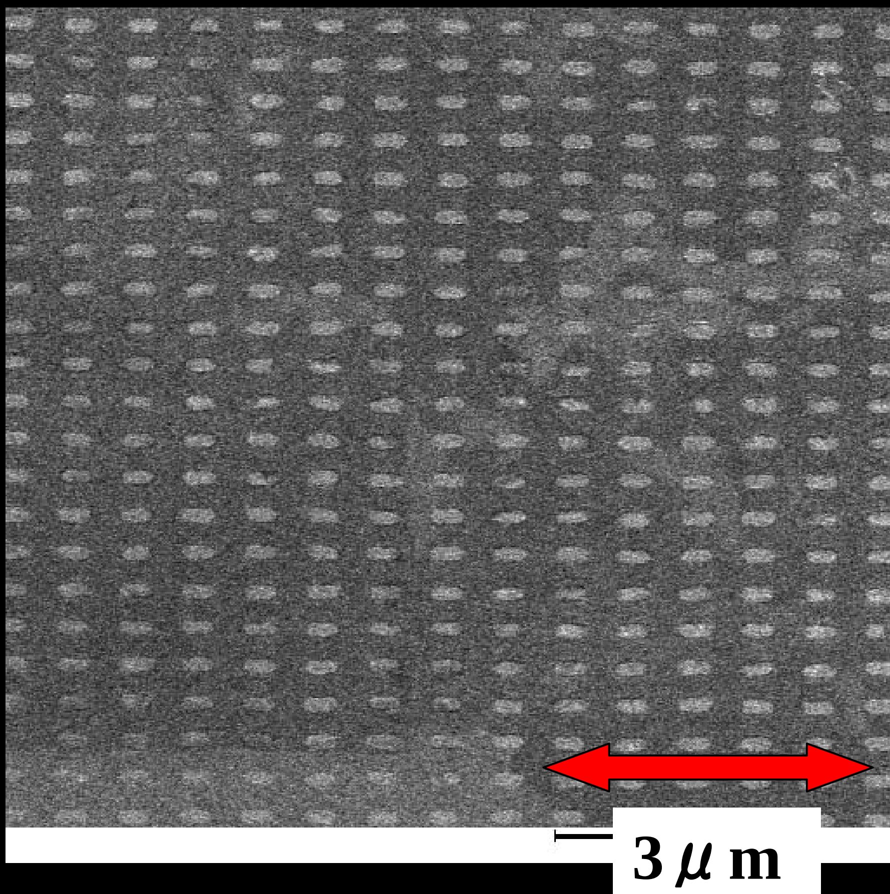
Square dots

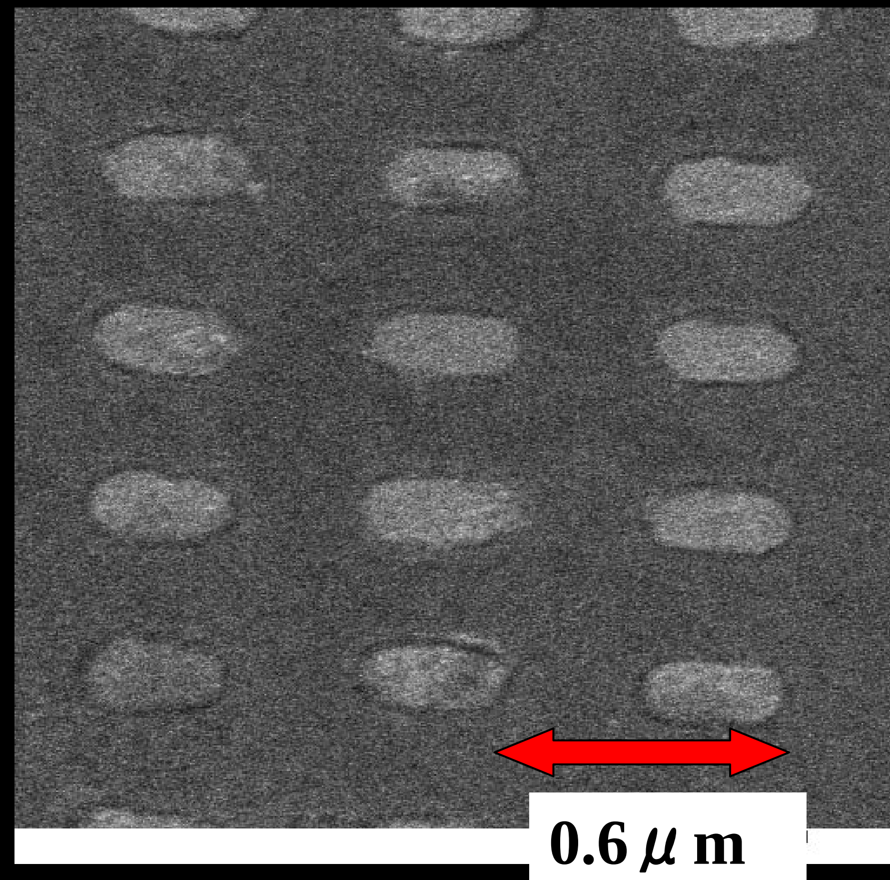
SEM observation

300nm × 100nmsquare dot, 300 nm space

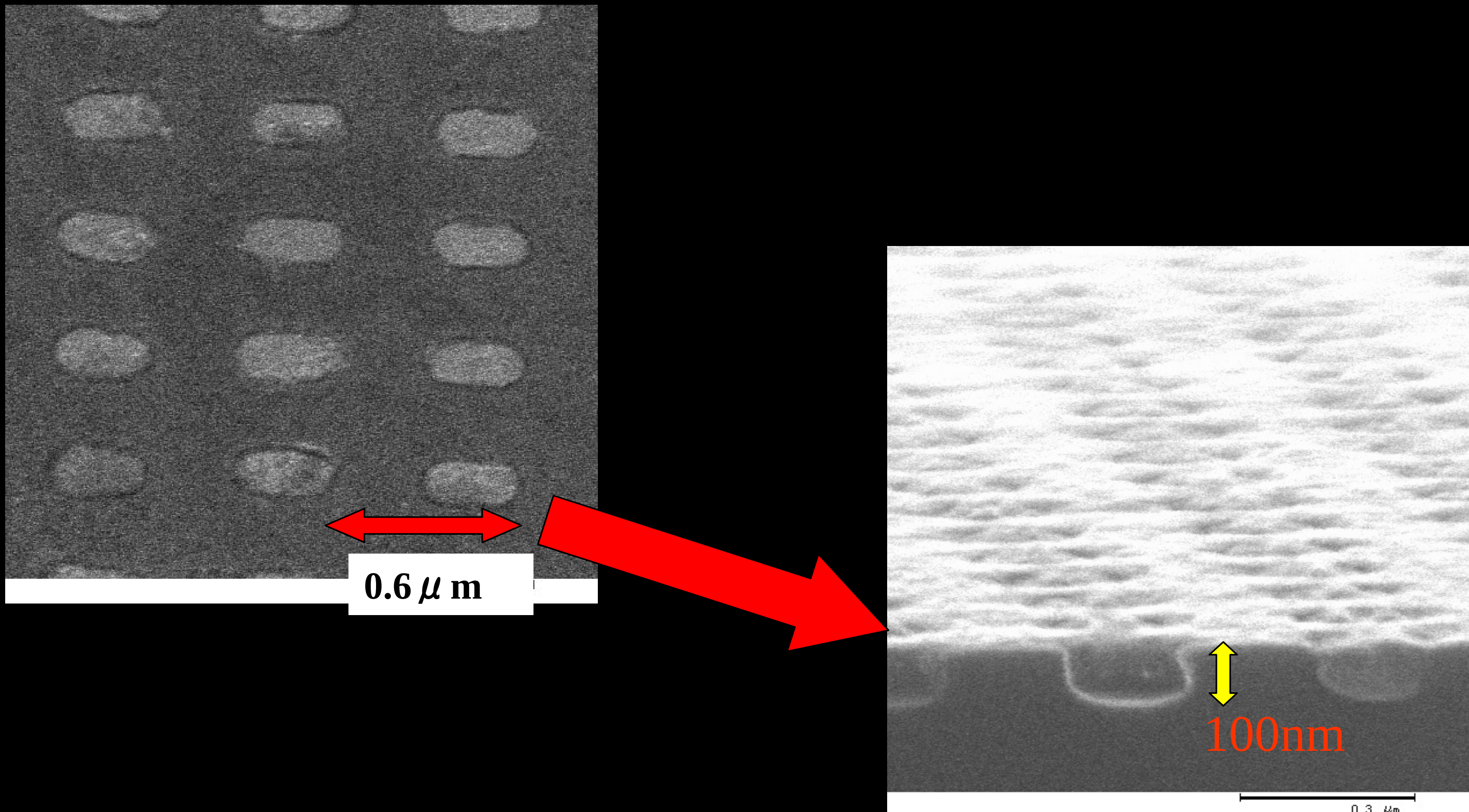


Rectangular dots



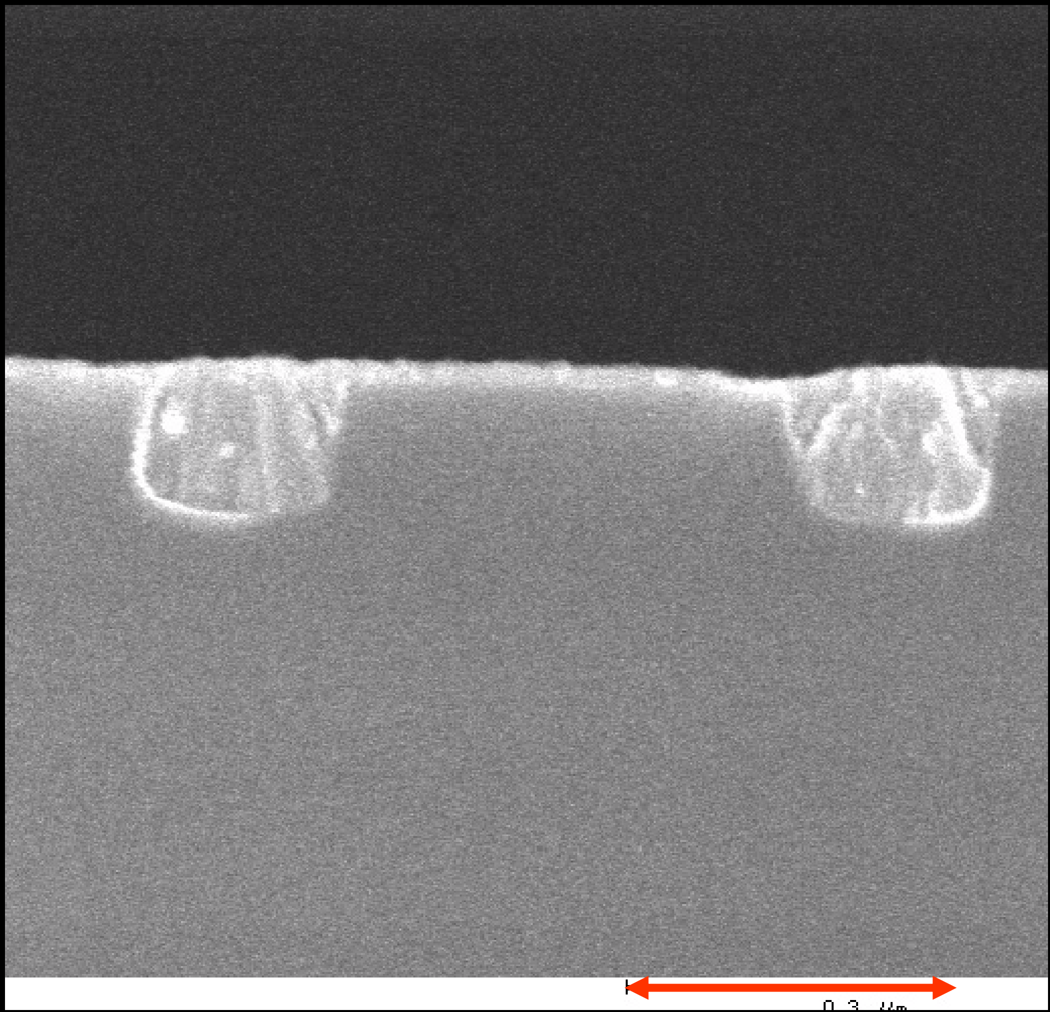


Cross sectional SEM observation



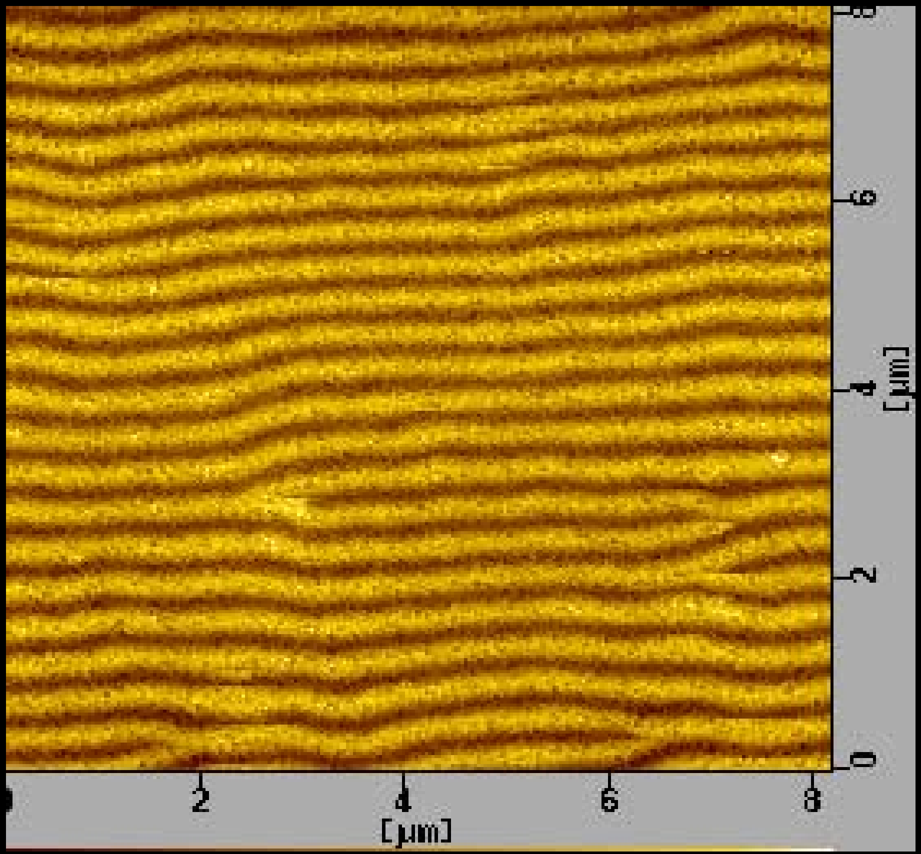
Dot depth?

Cross section SEM image of Line and space pattern (width =100nm)

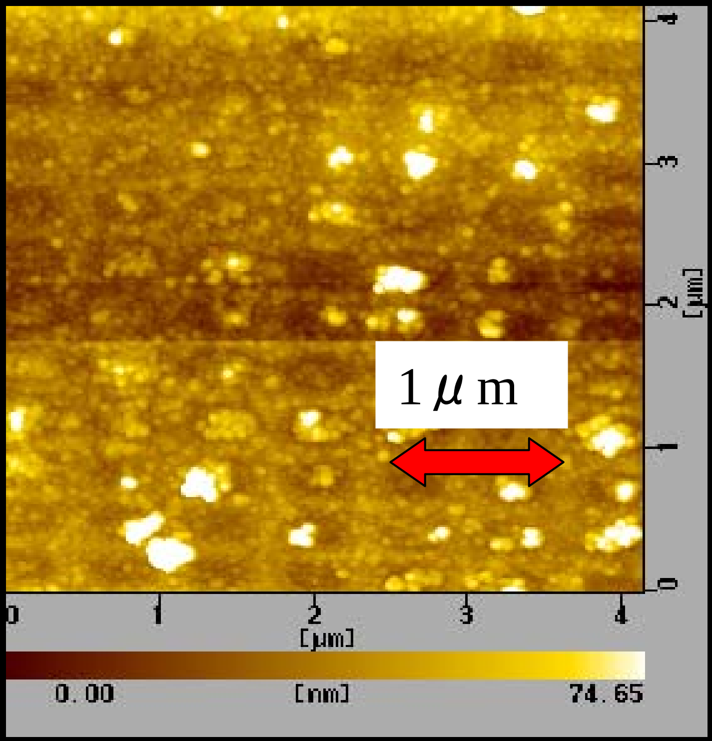


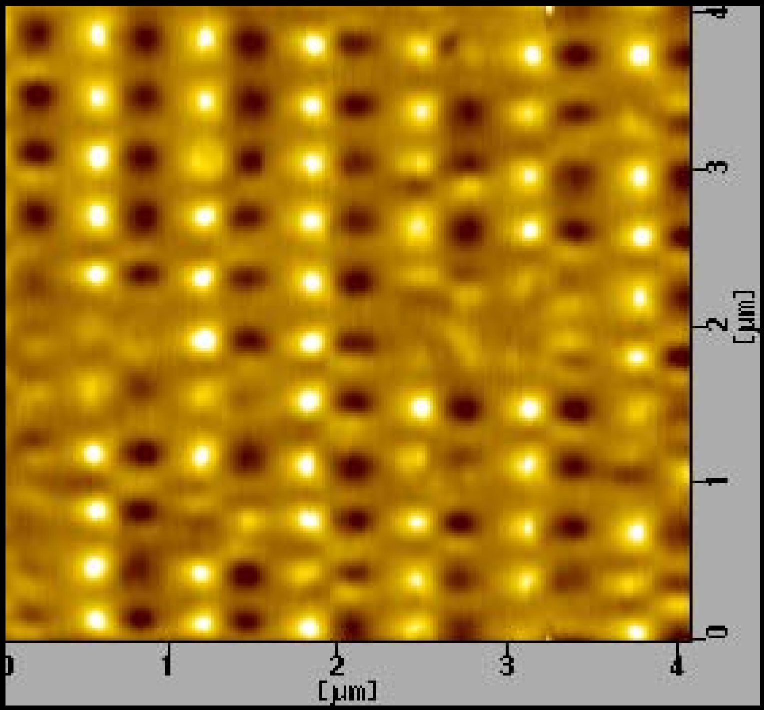
0. 3 μm

MFM observation of unpatterned permalloy film



AFM and MFM observation of 300 nm x 100 nm dot array

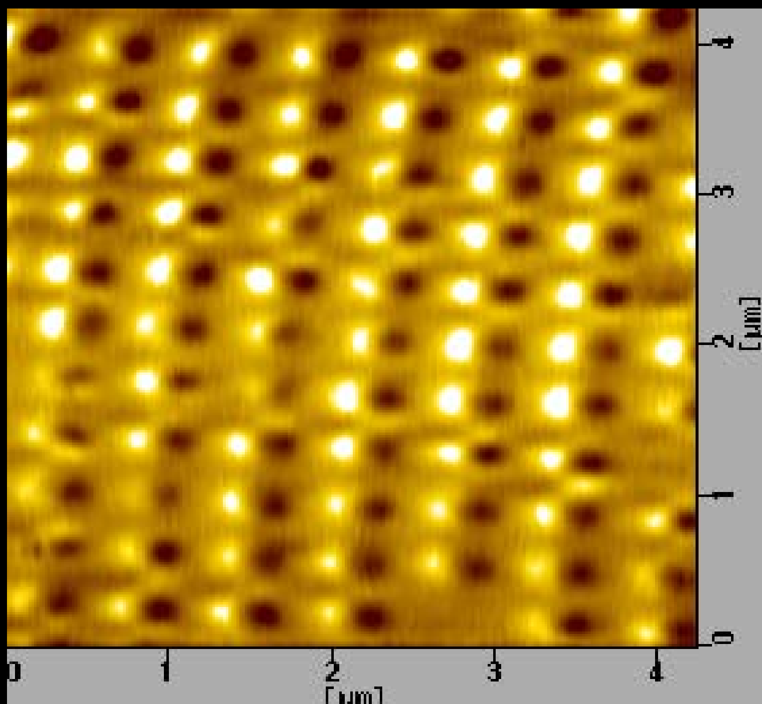




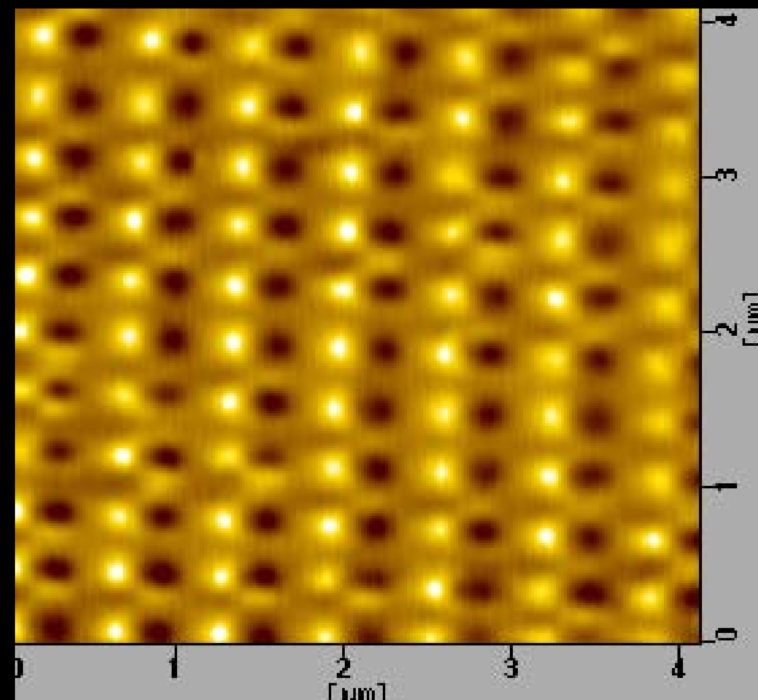
AFM Line scan ･･･Surface roughness~10nm

MFM image ･･･magnetization axis along the longer side direction

Comparison between two scans after magnetization in opposite direction

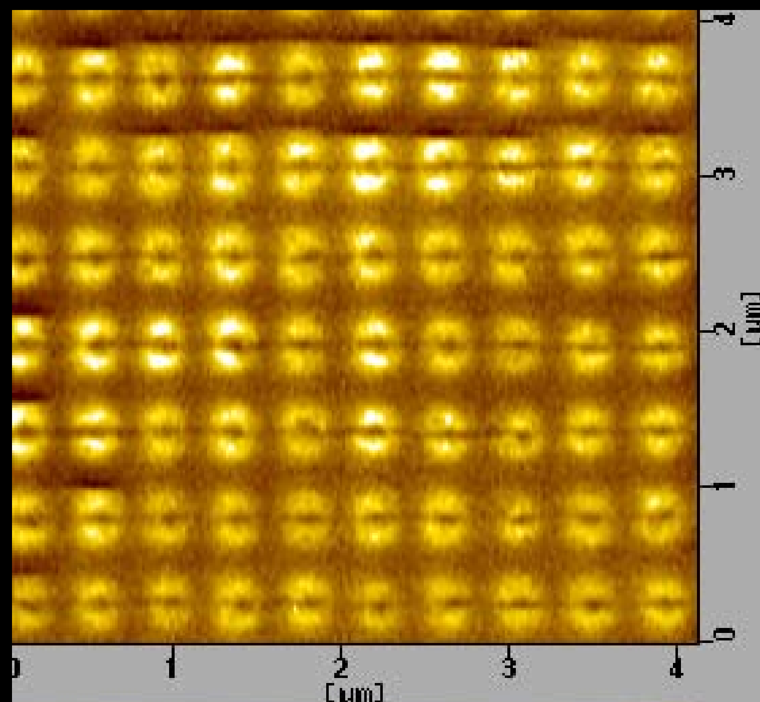


5kOe

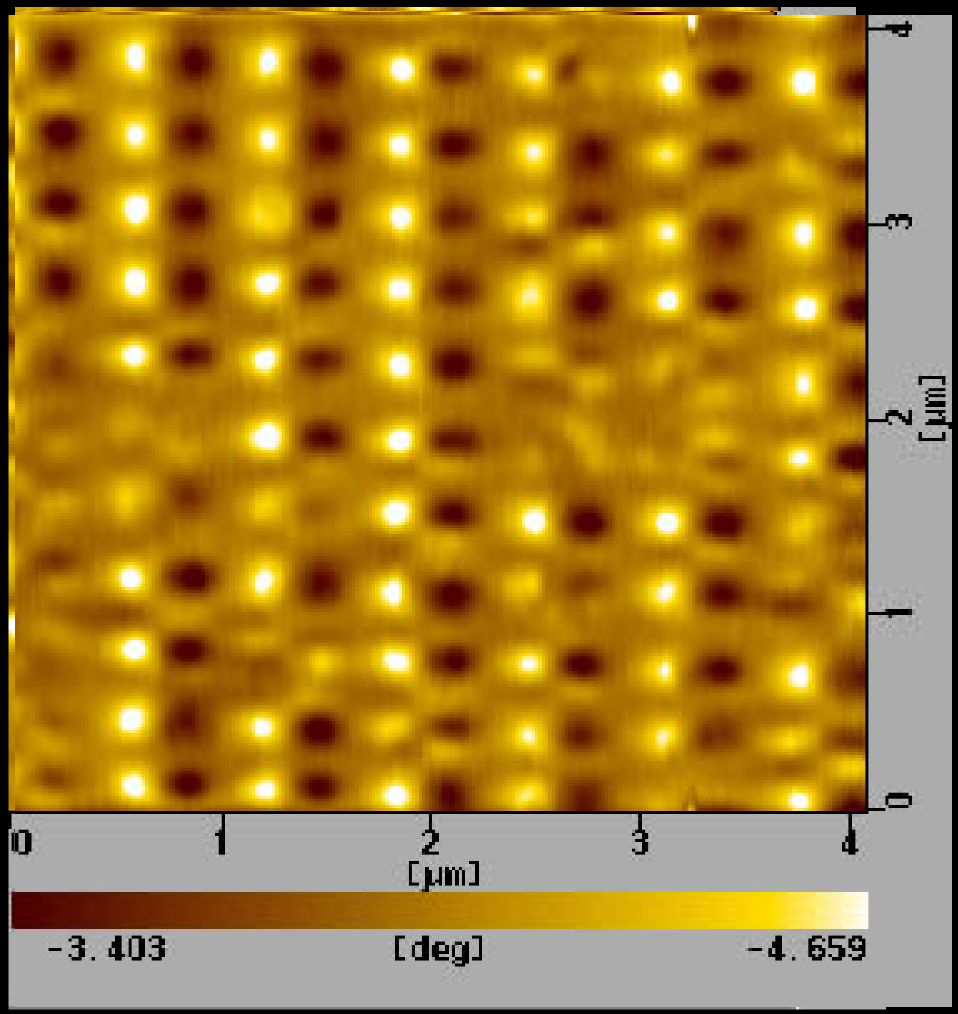


5kOe

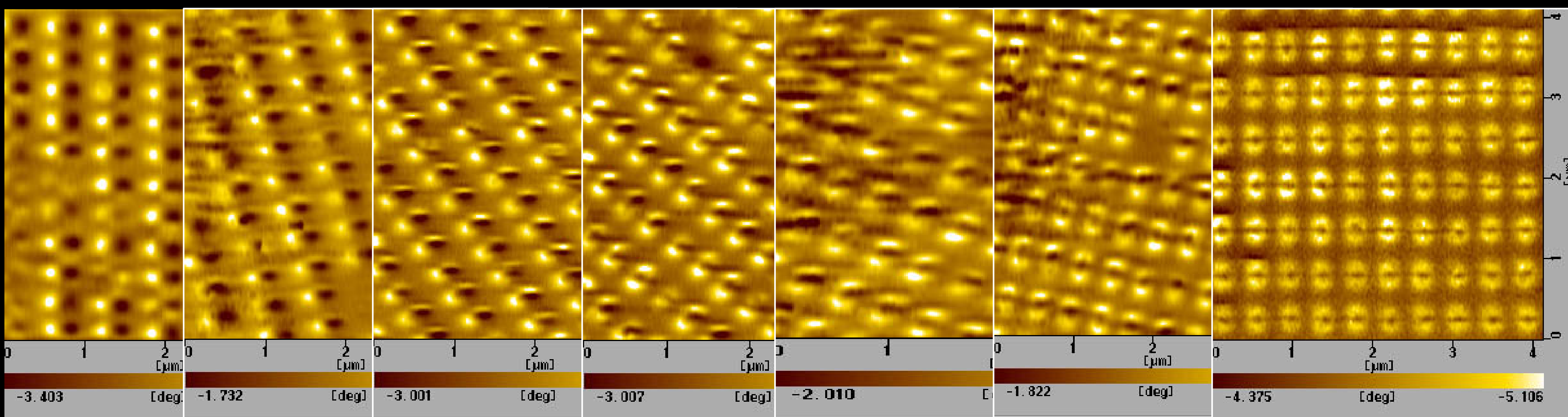
MFM-image for different scanning direction



Scan-direction dependence

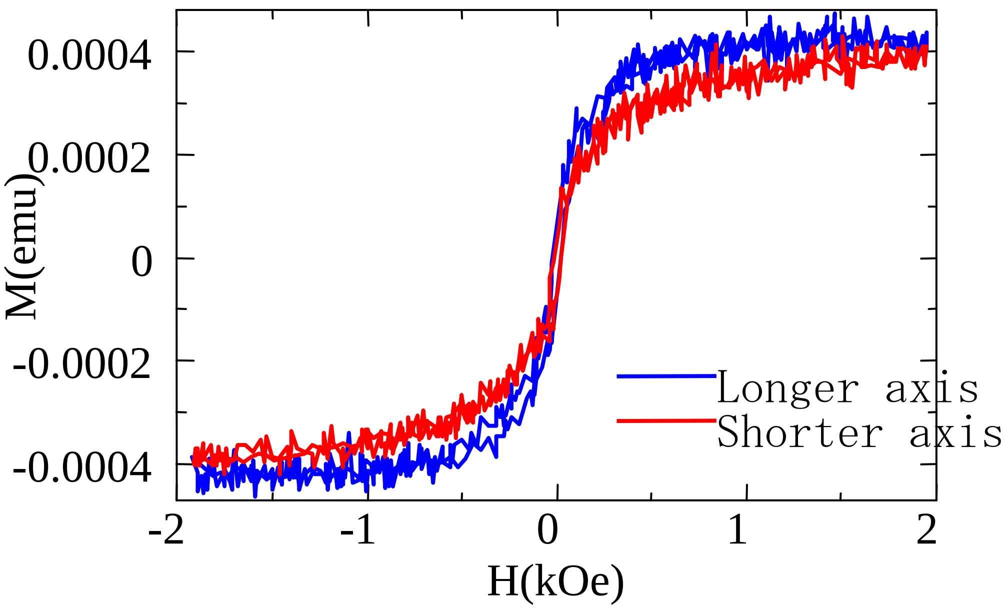


Pattern variation with scan direction

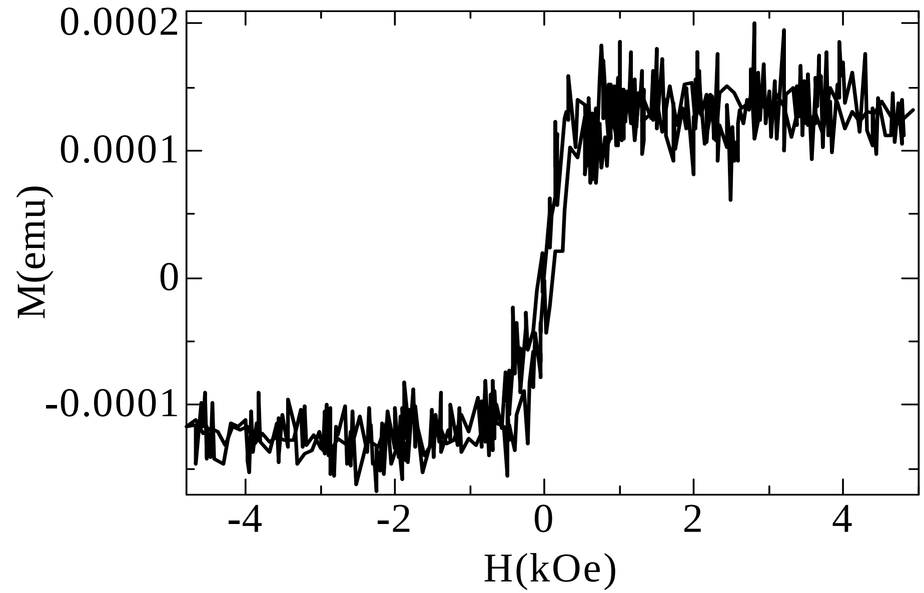


0° 15° 30° 45° 60° 75° 90°

VSM measurement

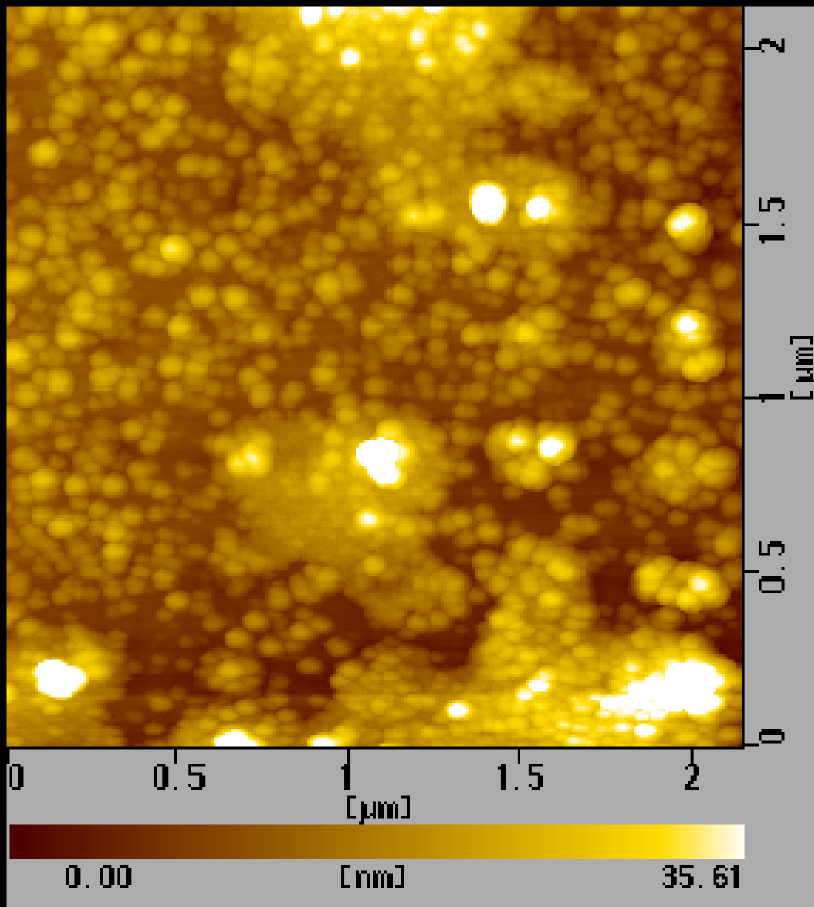


In-plane

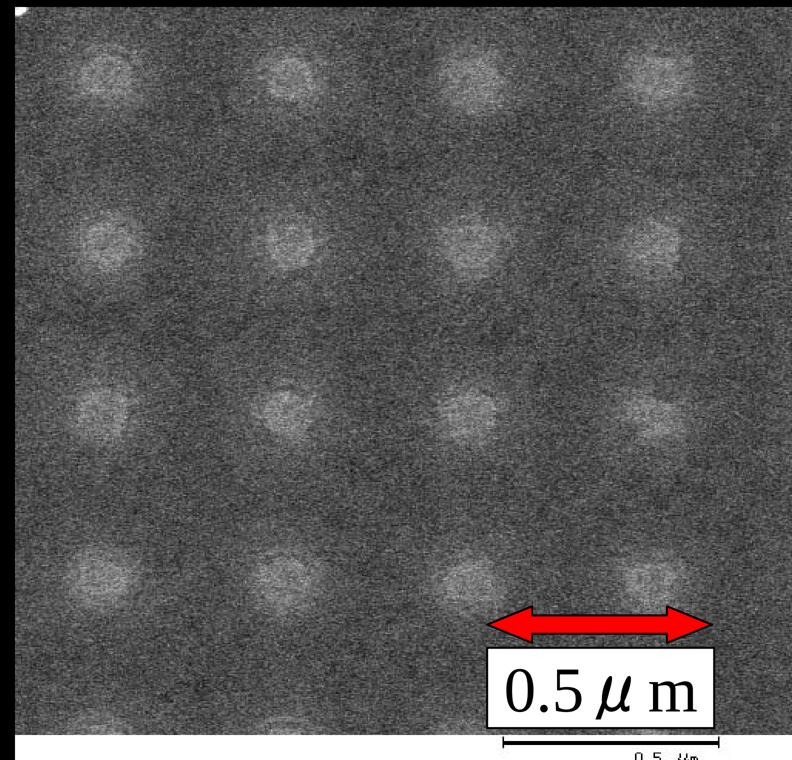


Perpendicular

100nm circular dots with 300 nm spacing



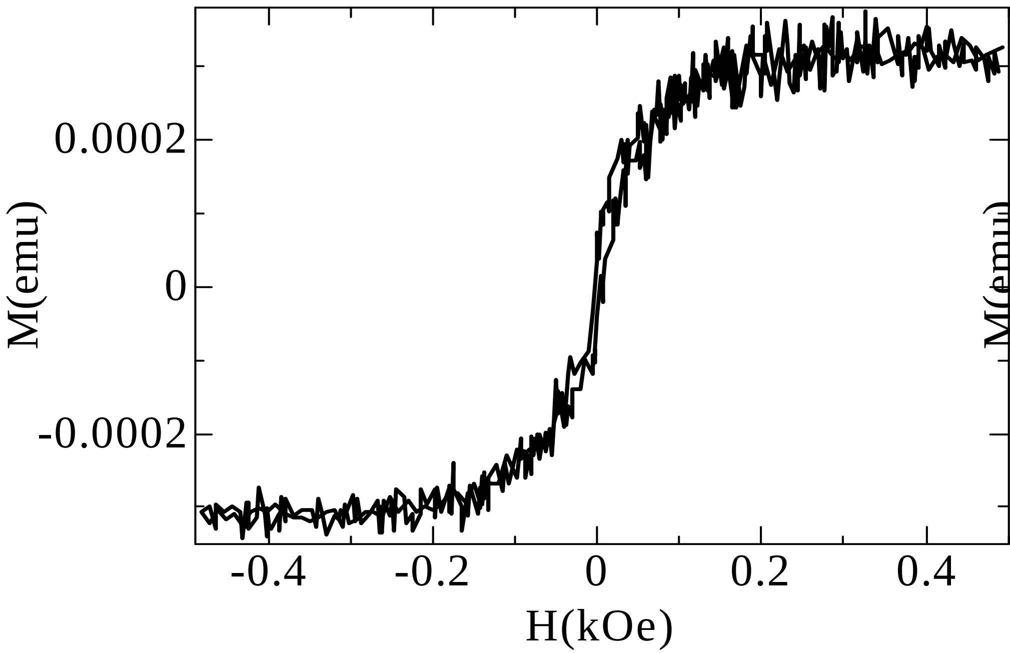
AFM

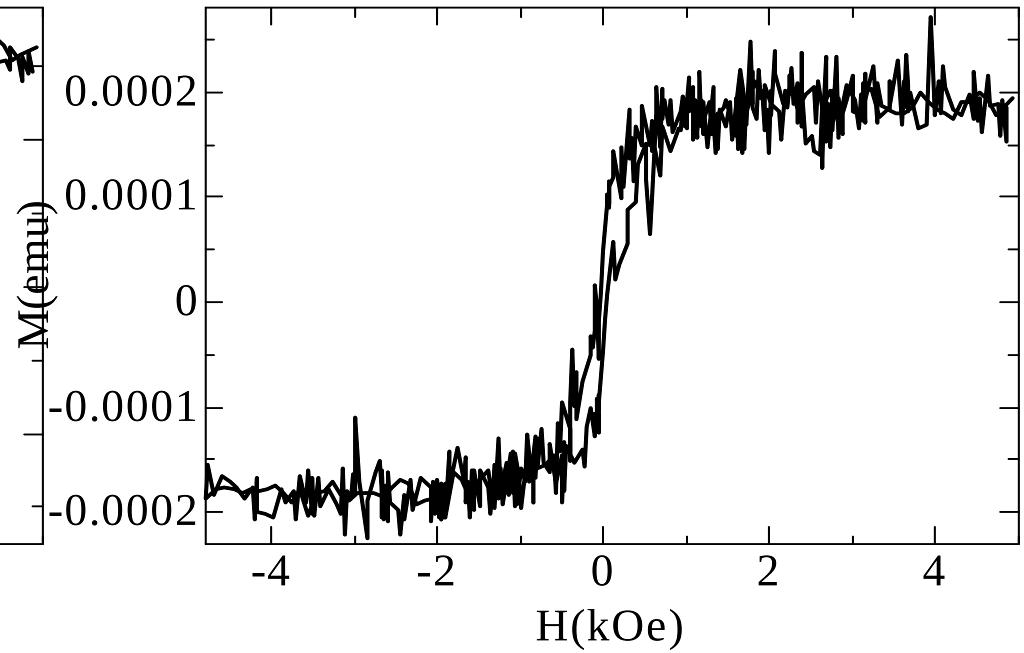


SEM

Surface roughness ~10nm

VSM measurement of circular dot array



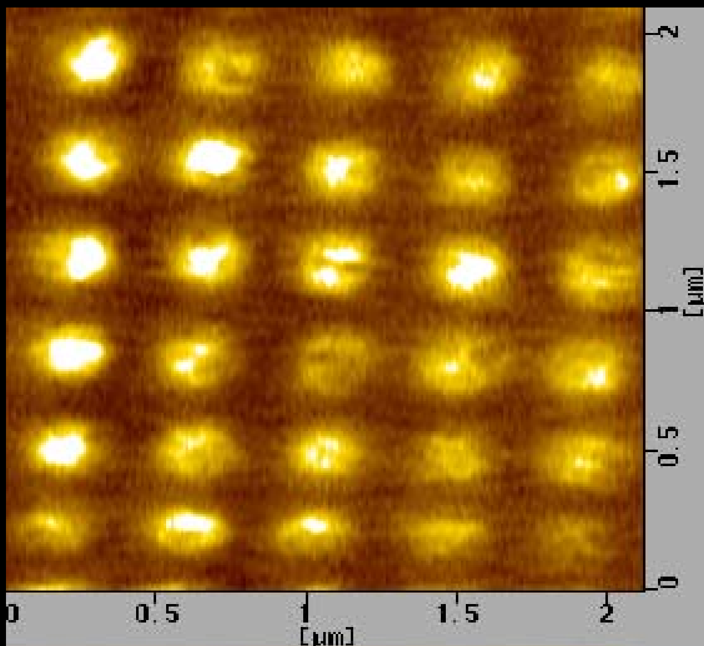


Parallel to the plane

Perpendicular to the plane

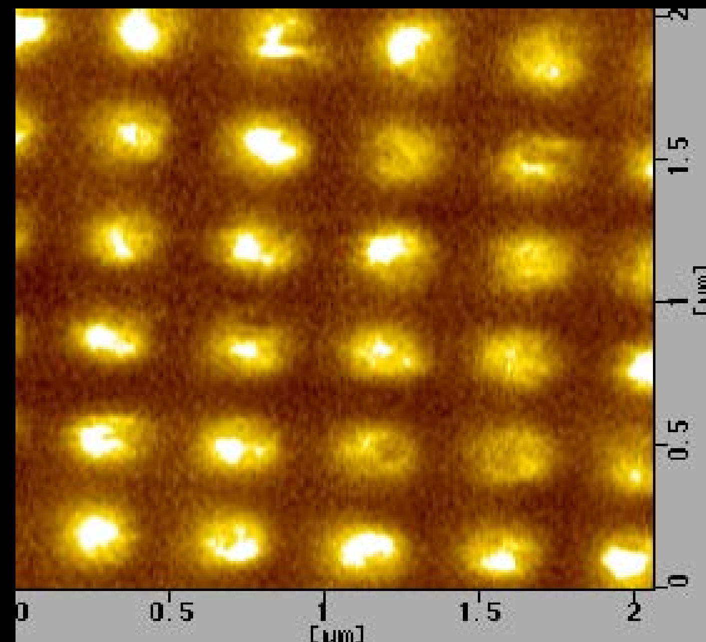
MFM measurement of circular dots

Demagnetized

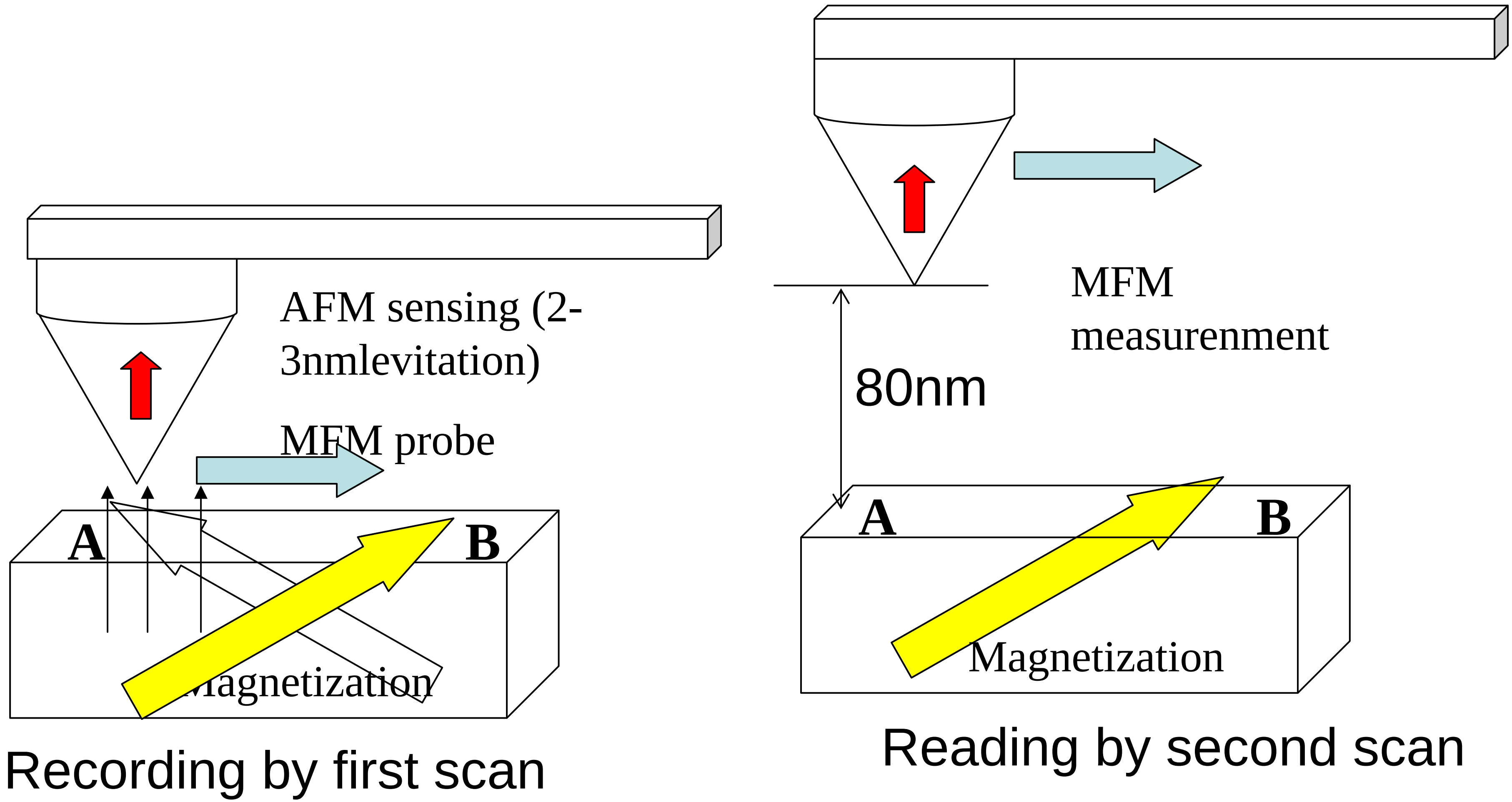


Magnetic field applied

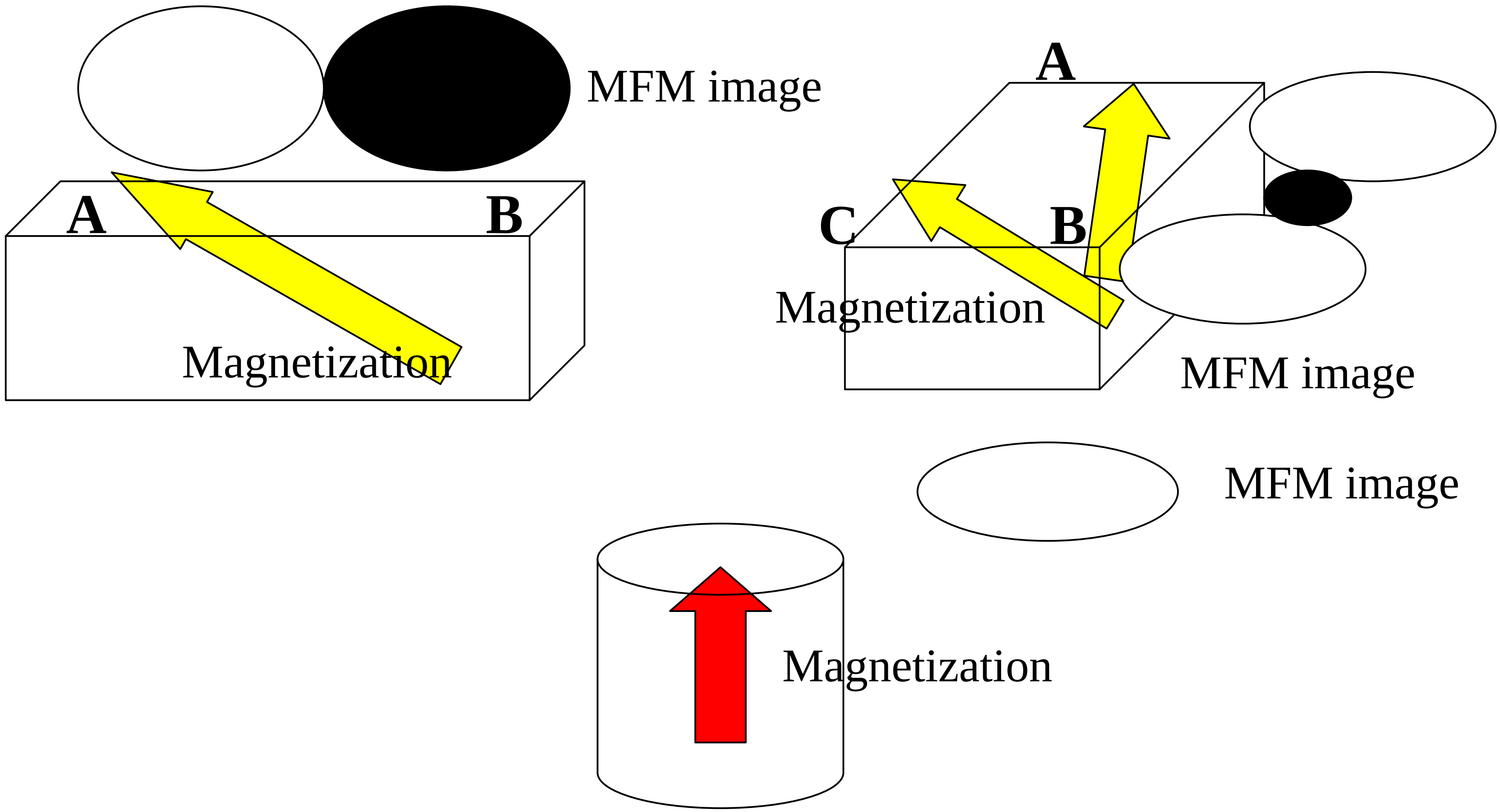
Perpendicular to the plane



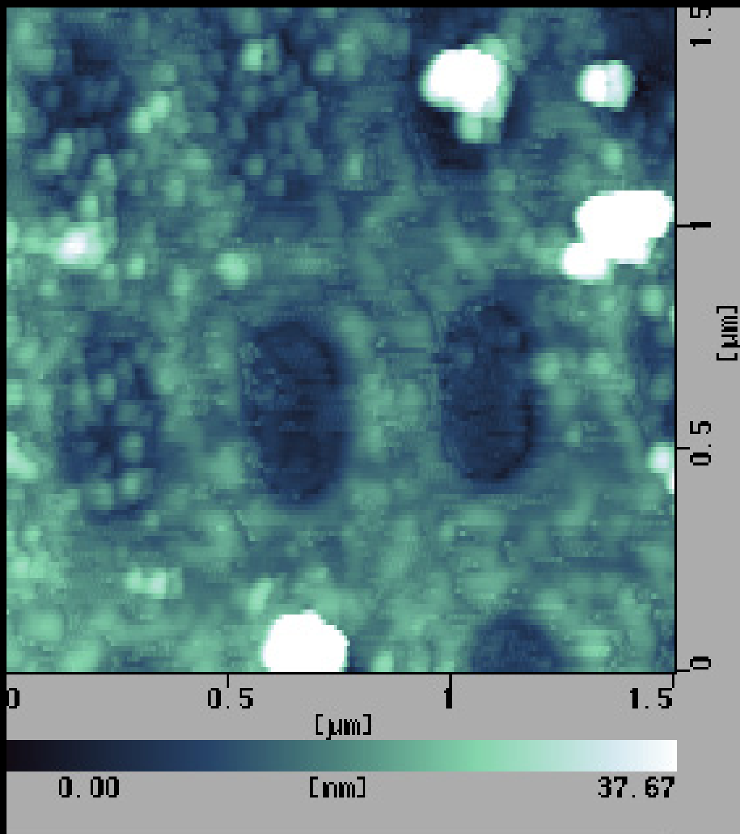
Influence of stray field from the MFM probe tip



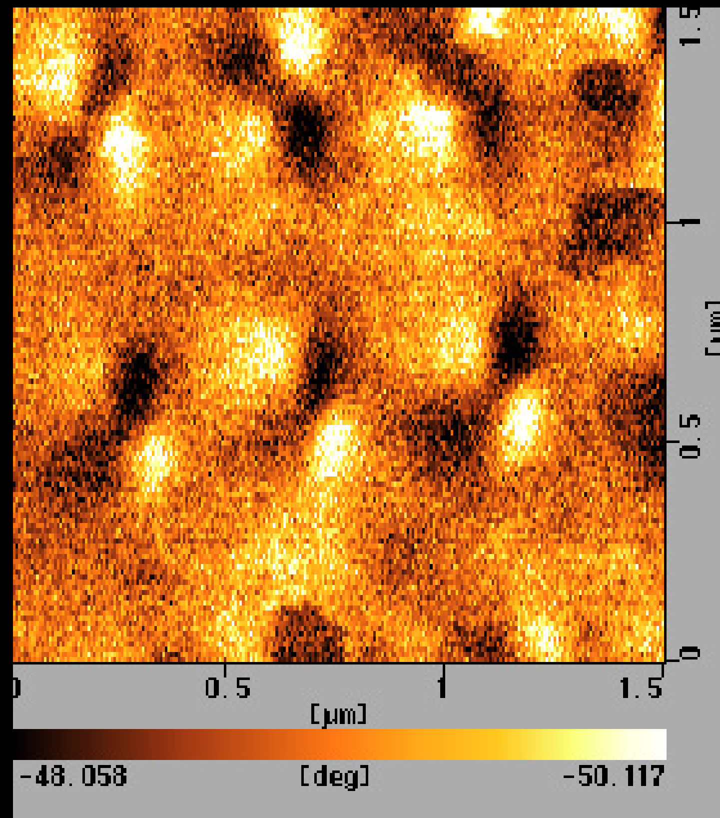
Models to explain MFM images



MFM image of 300nm x 100nm dot with a low-moment probe tip

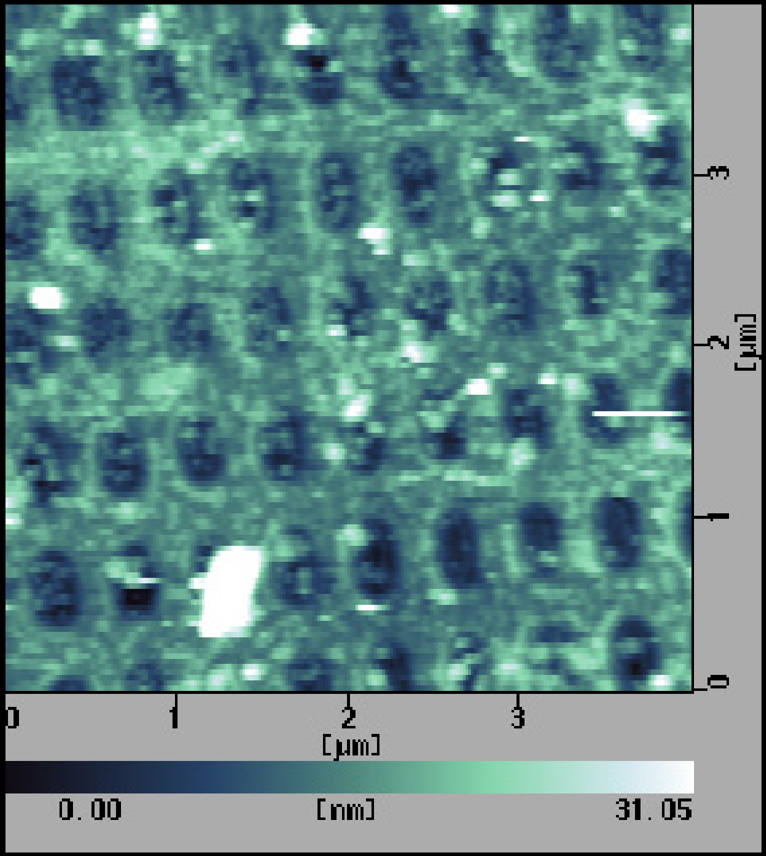


AFM

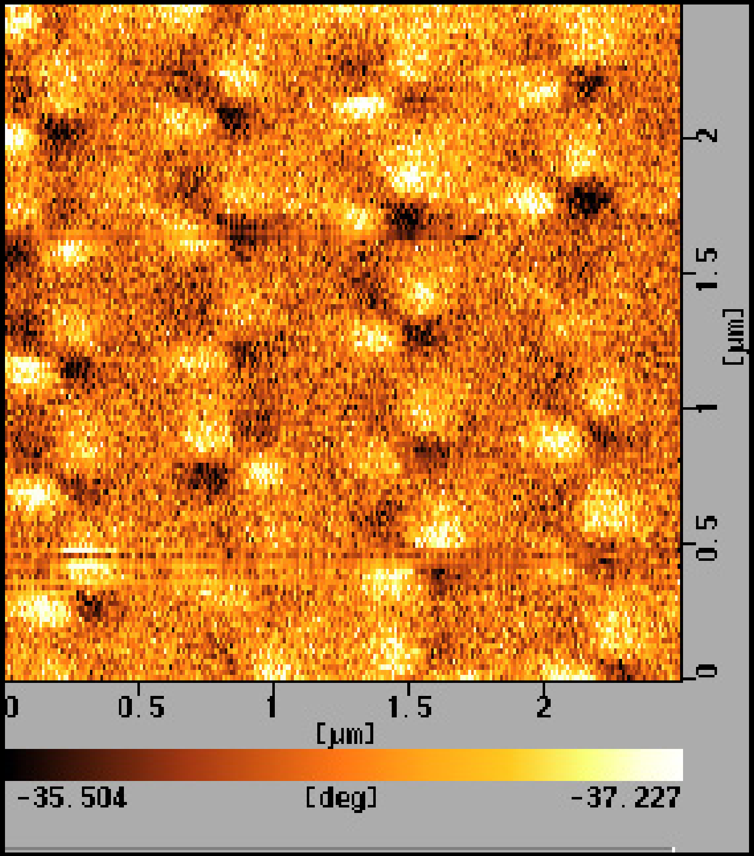


MFM

300nm x 100nm dot（wide scan） with a low-moment probe tip

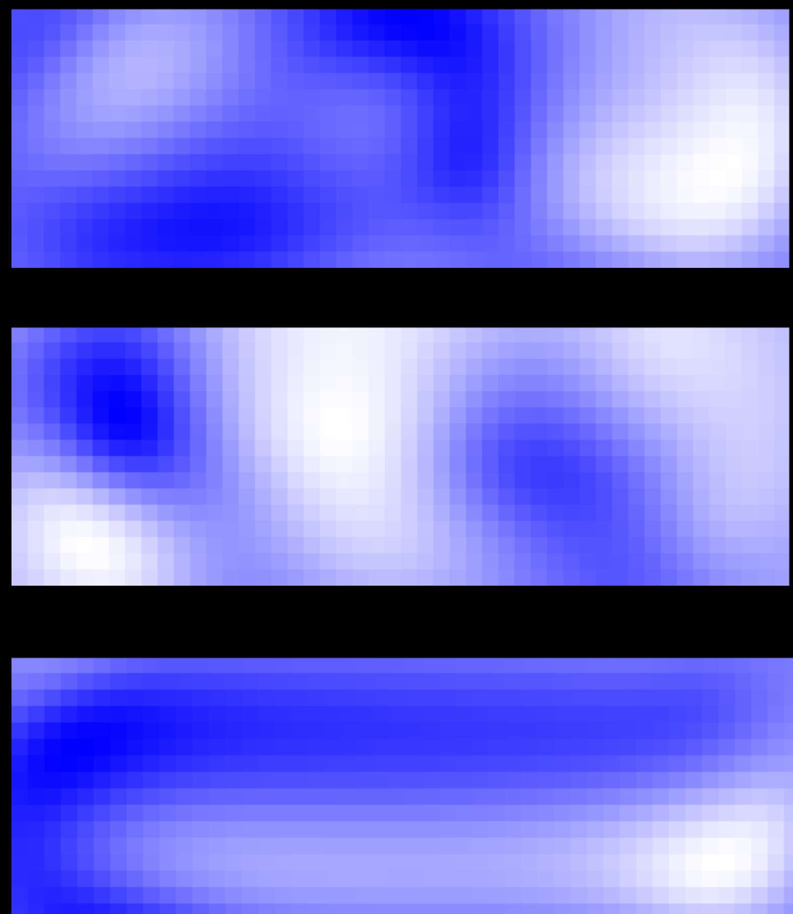


AFM



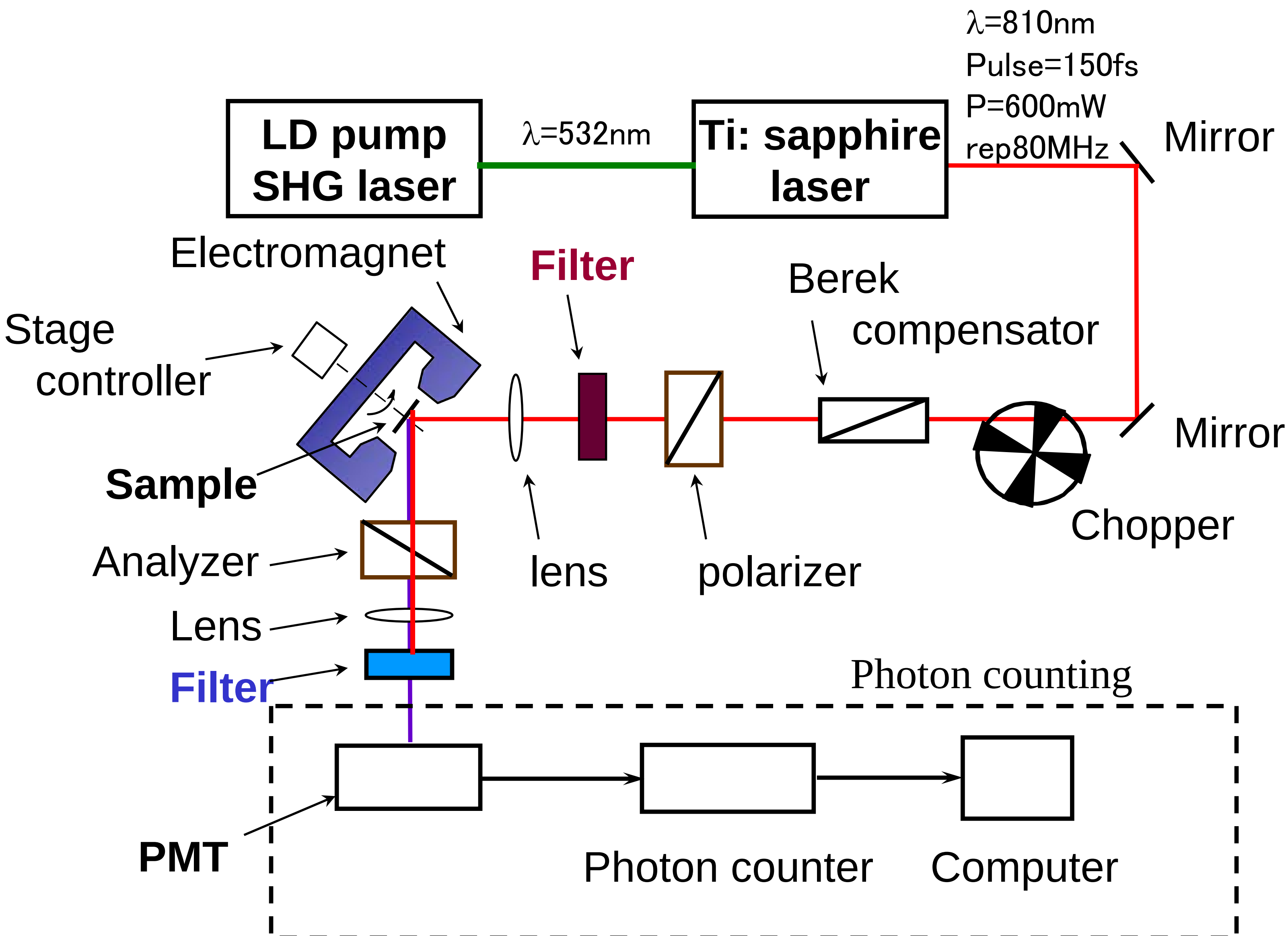
MFM

Simulation by Nakatani



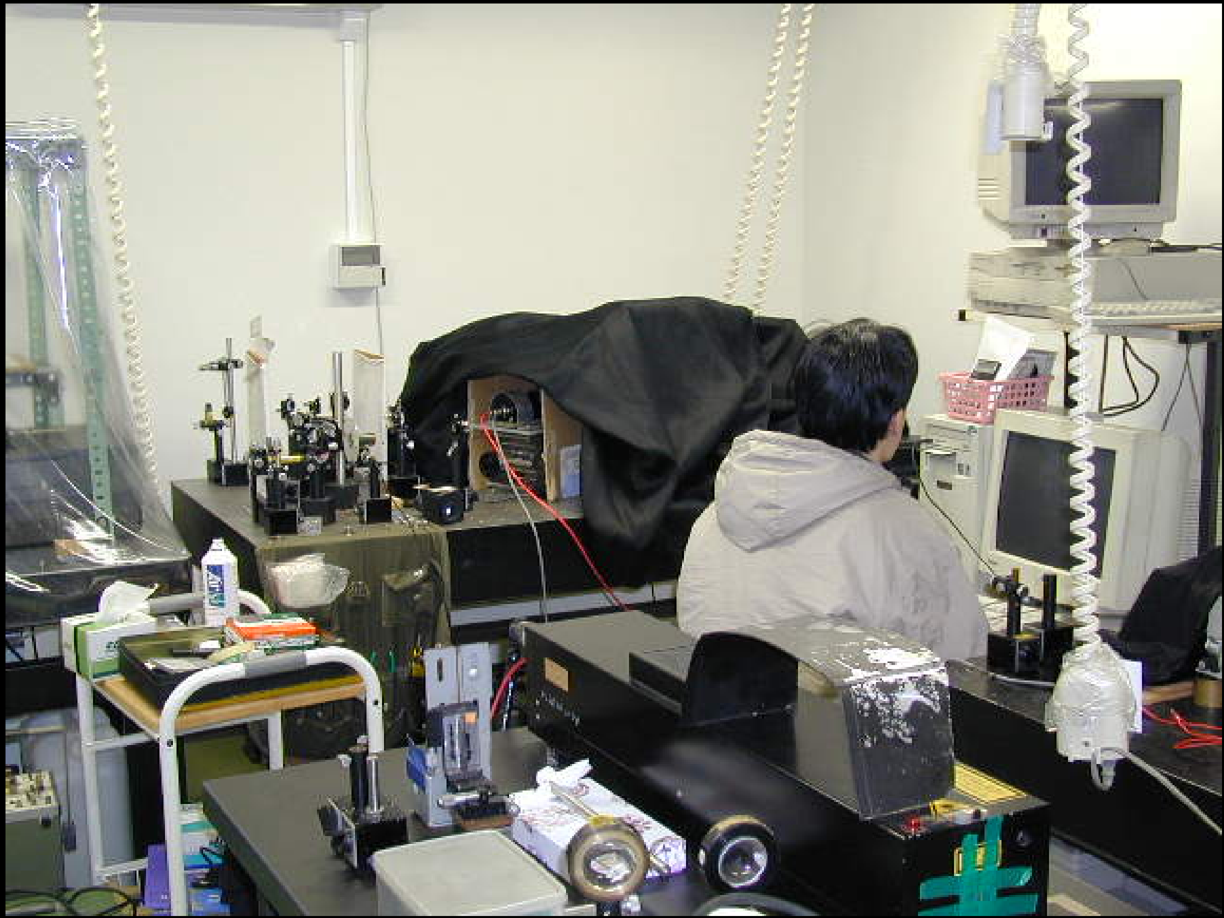
Observation of dot-array structures using magnetically induced second harmonic generation (MSHG)

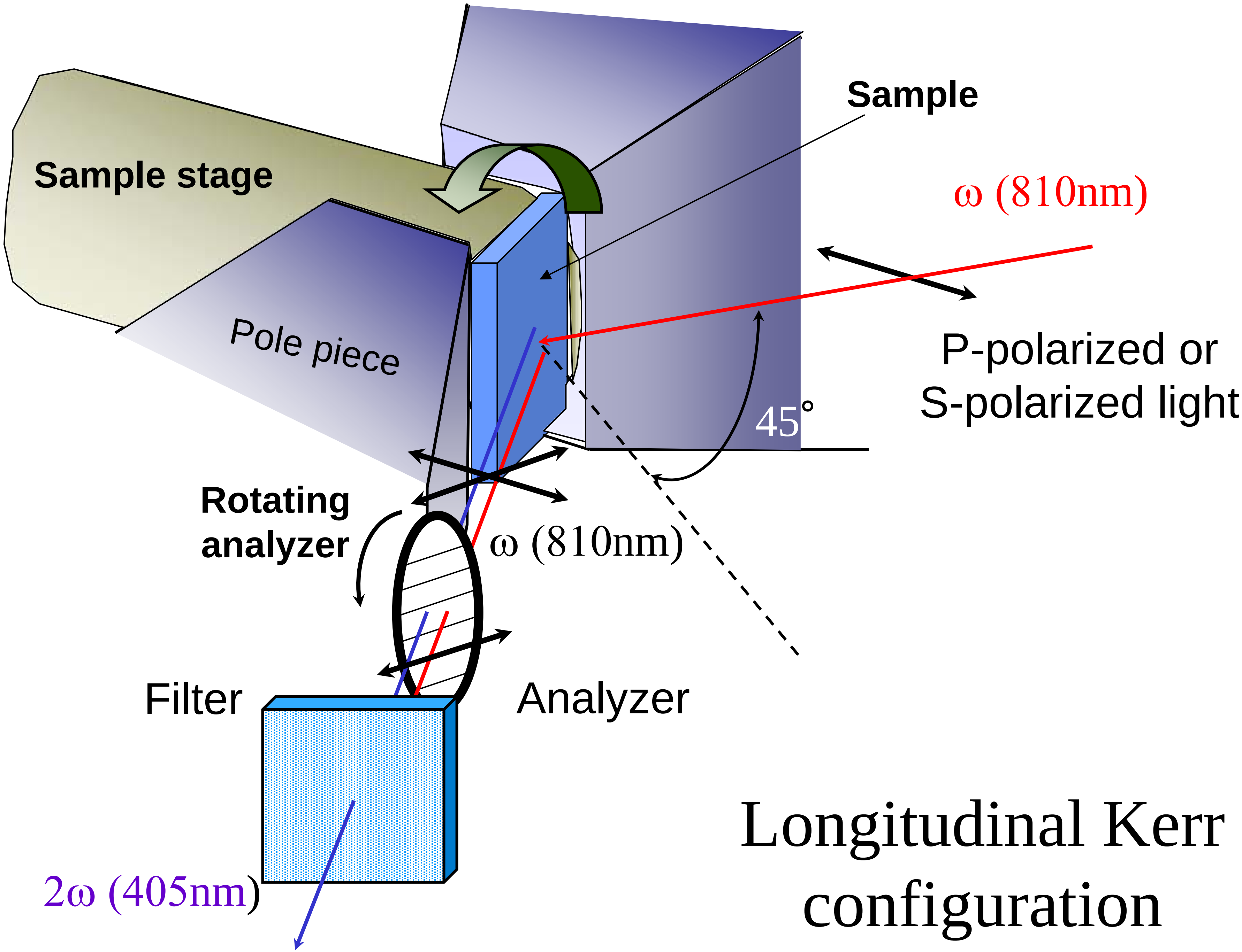
MSHG Measureing System



Laboratory

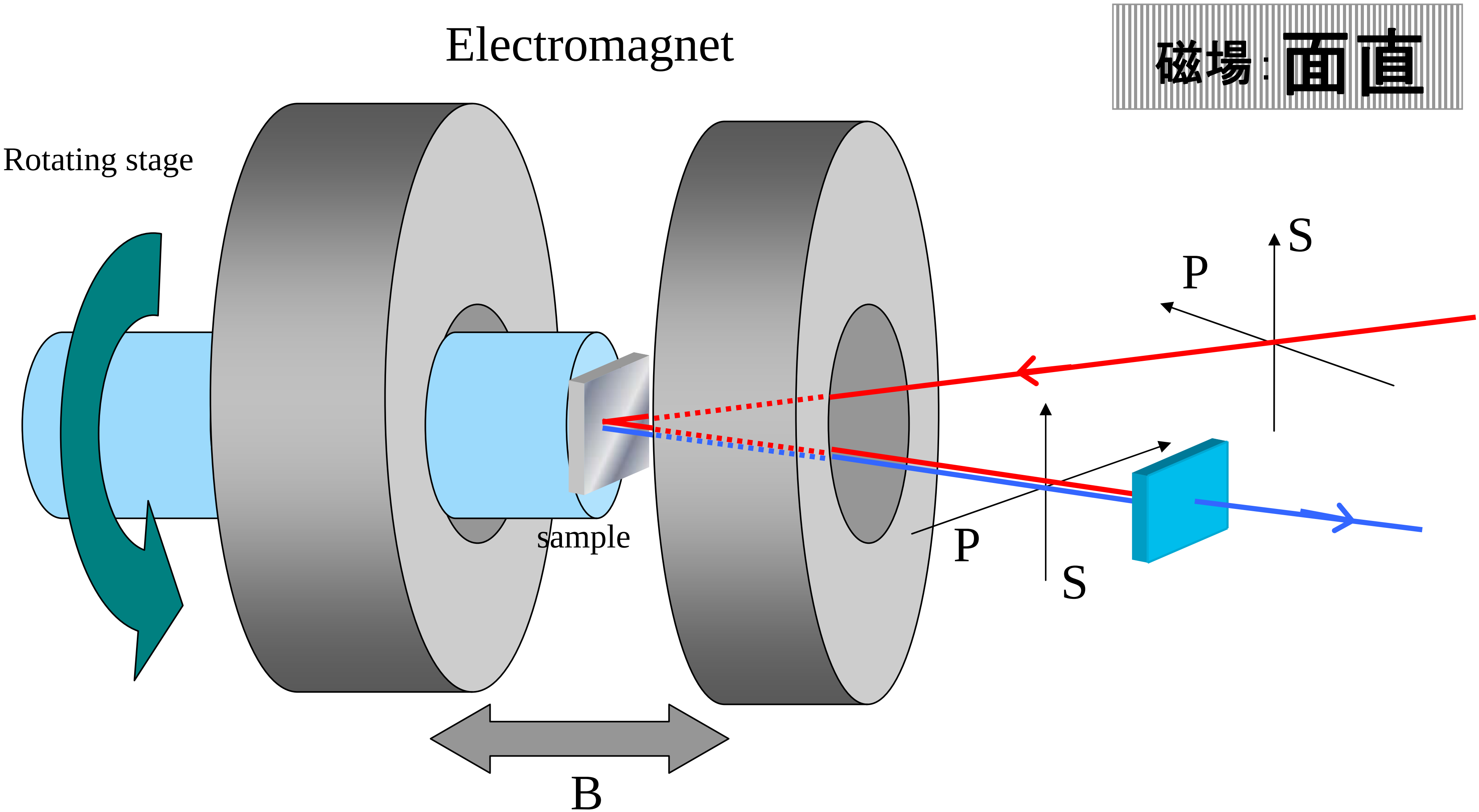
- Nonlinear MO measurement system



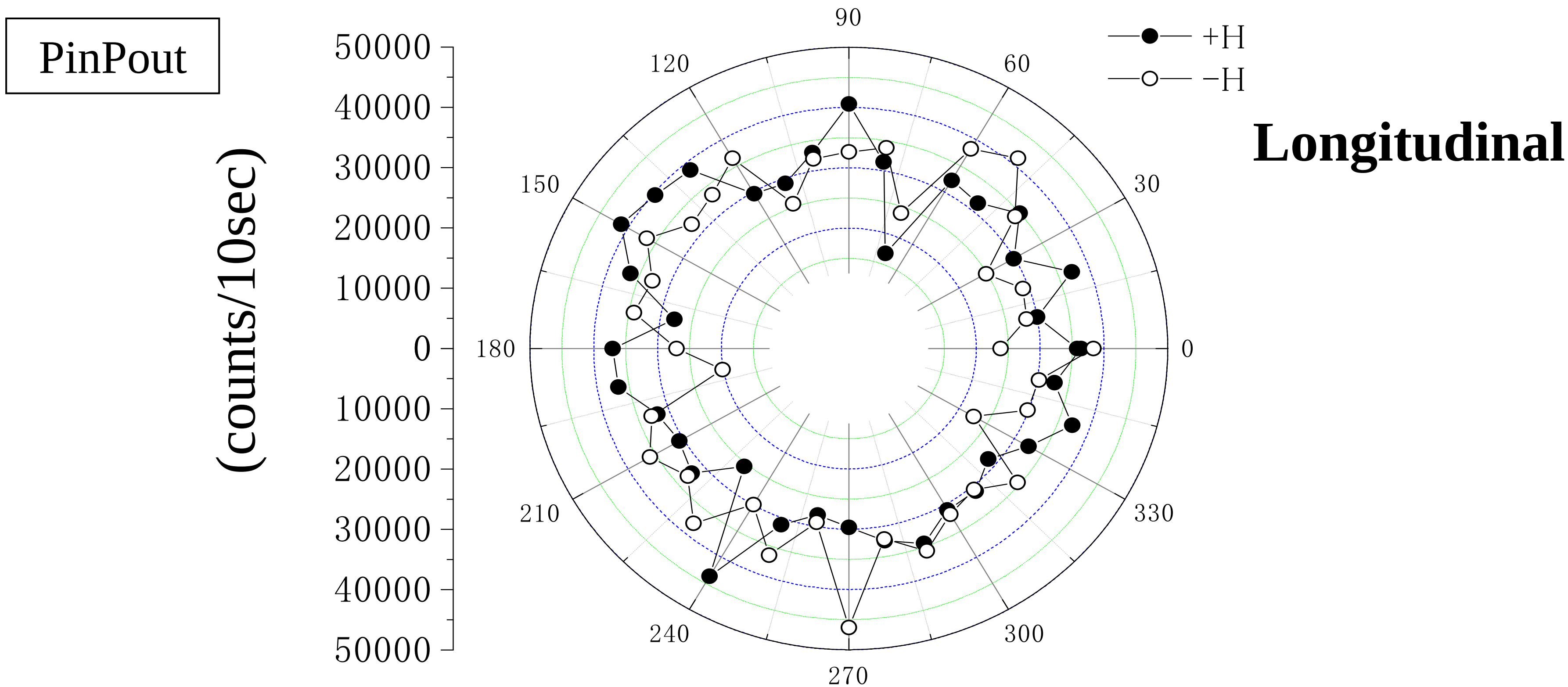


Longitudinal Kerr
configuration

Polar Kerr configuration



Azimuthal angle dependence of SHG from unpatterned permalloy film

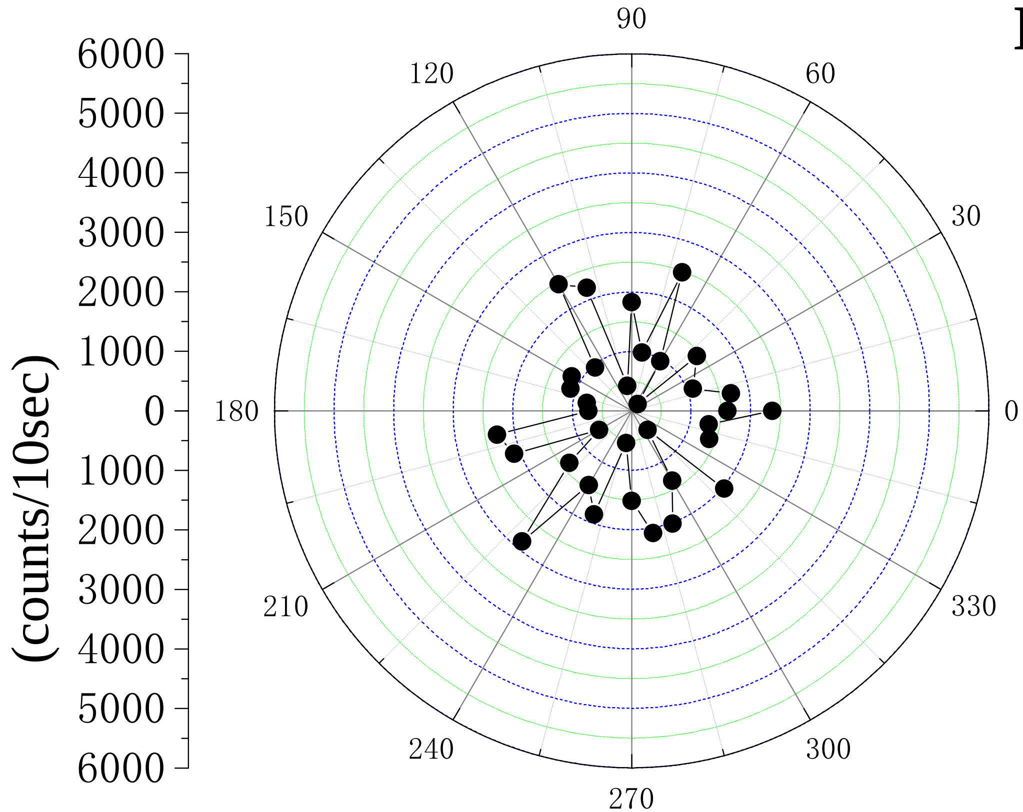


Unstructured permalloy film: H=±2.5kOe

Azimuthal angle dependence of SHG from unpatterned Si wafer

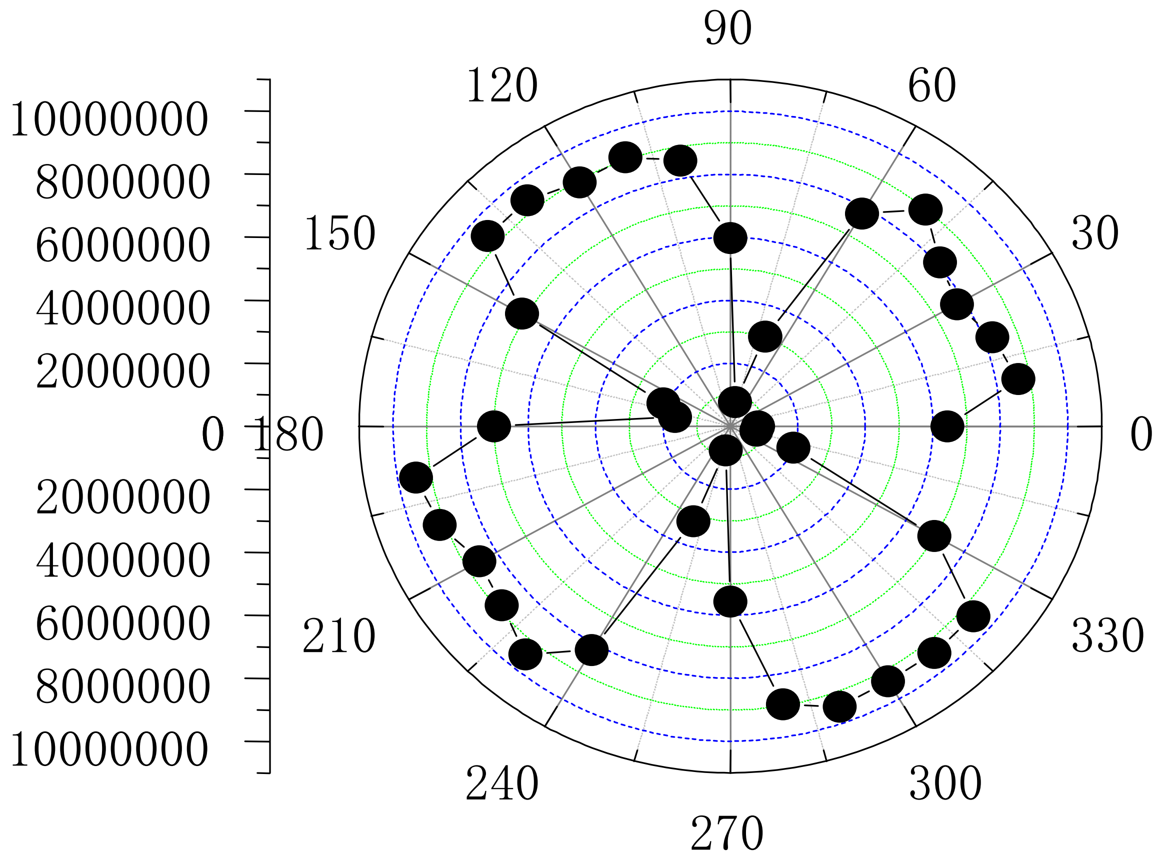
Longitudinal

PinPout



H=±2.5kOe

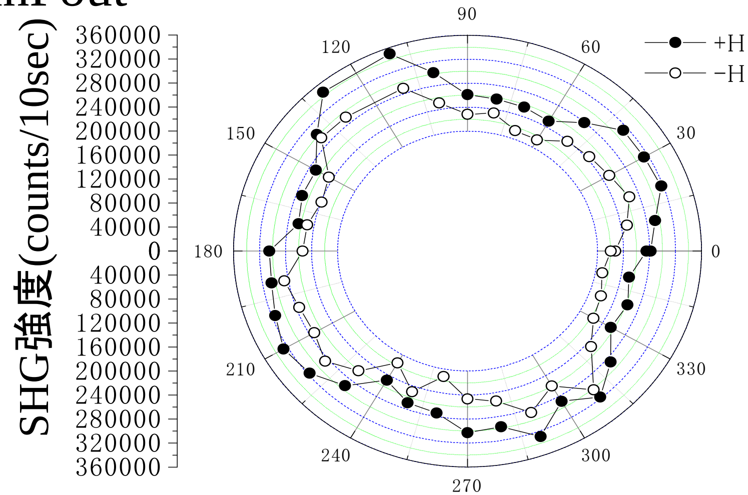
Azimuthal angle dependence of SHG from GaAs wafer



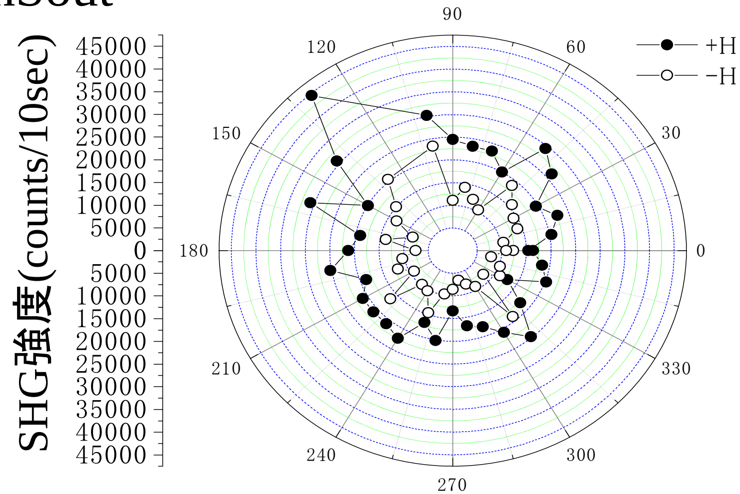
Azimuthal angle dependence of MSHG from the square dot array

Londitudinal

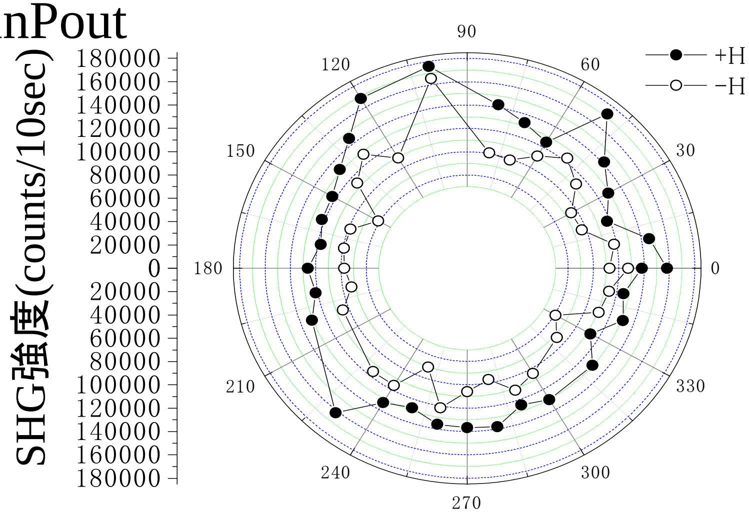
PinPout



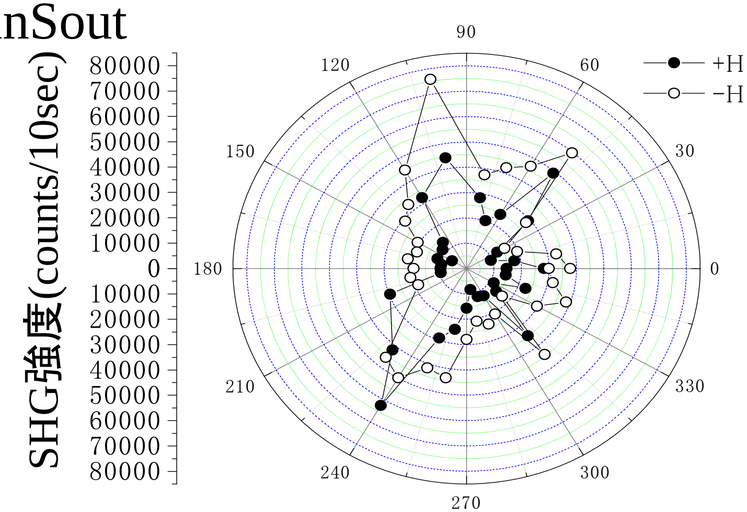
PinSout

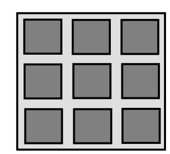


SinPout



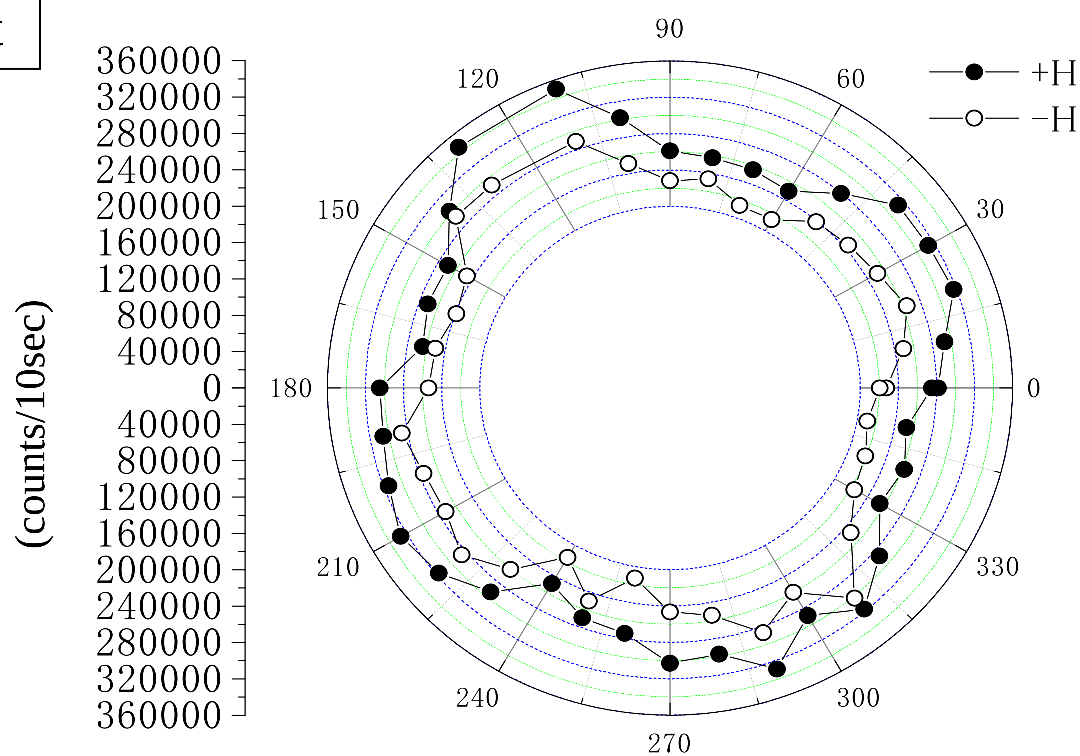
SinSout





Azimuthal angle dependence of MSHG from 1μm square dot array

PinPout



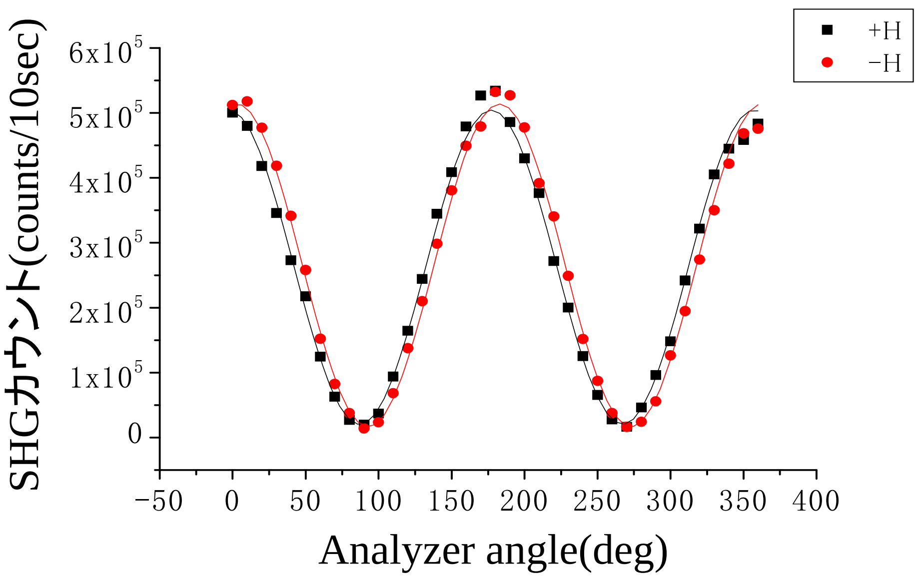
H=±4kOe

Longitudinal Kerr configuration

Nonlinear Kerr rotation
In 1μm square dots

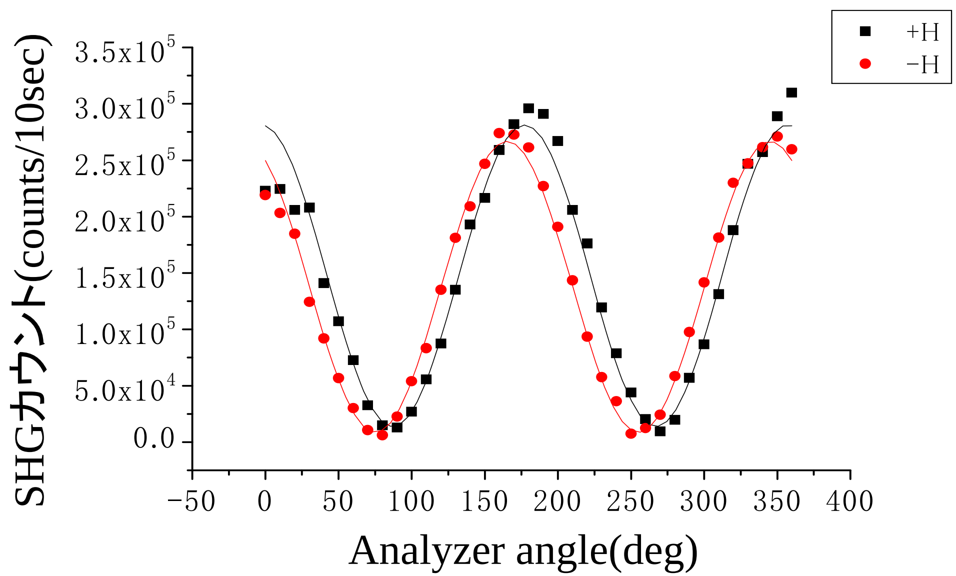
Longitudinal

Nonlinear Kerr rotation 2.80°

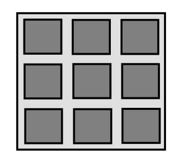


〈Pin〉

Nonlinear Kerr rotation 6.00°



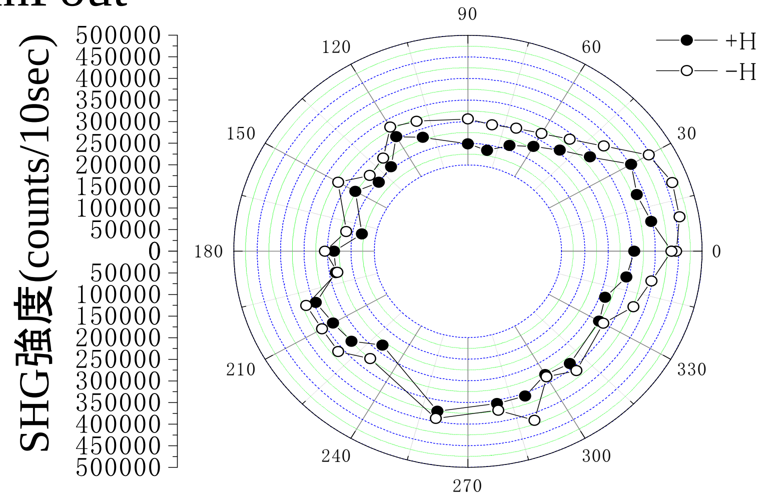
〈Sin〉



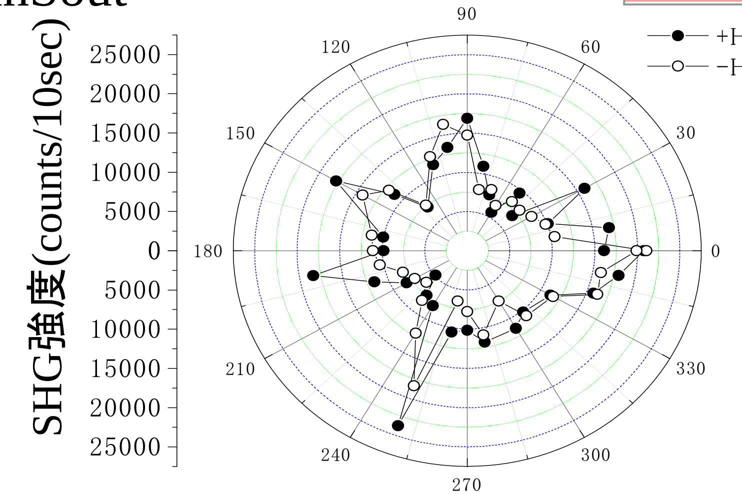
Azimuthal angle dependence of rectangular dots

longitudinal

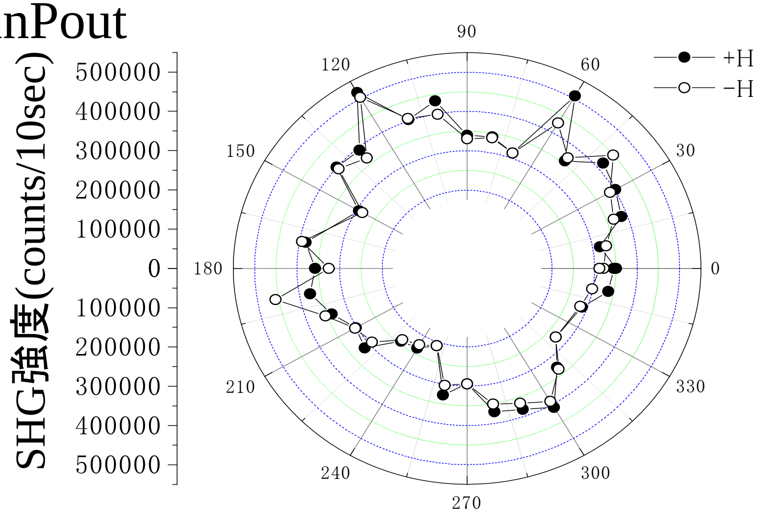
PinPout



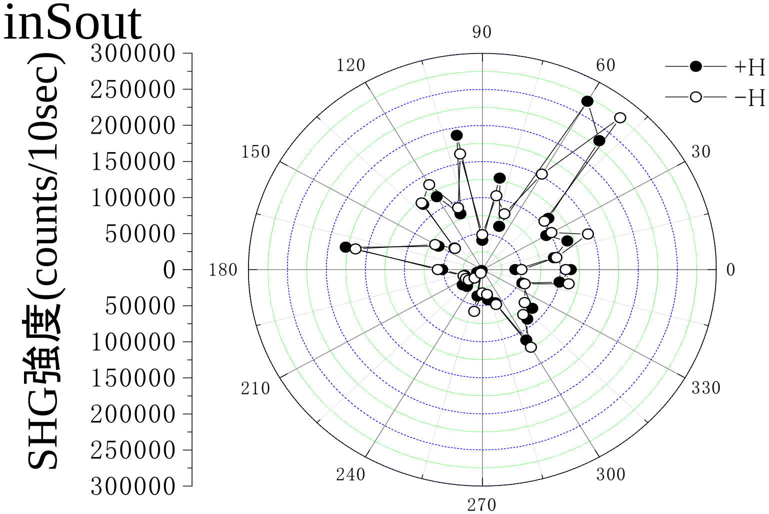
PinSout

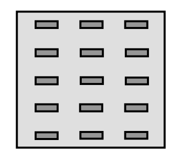


SinPout



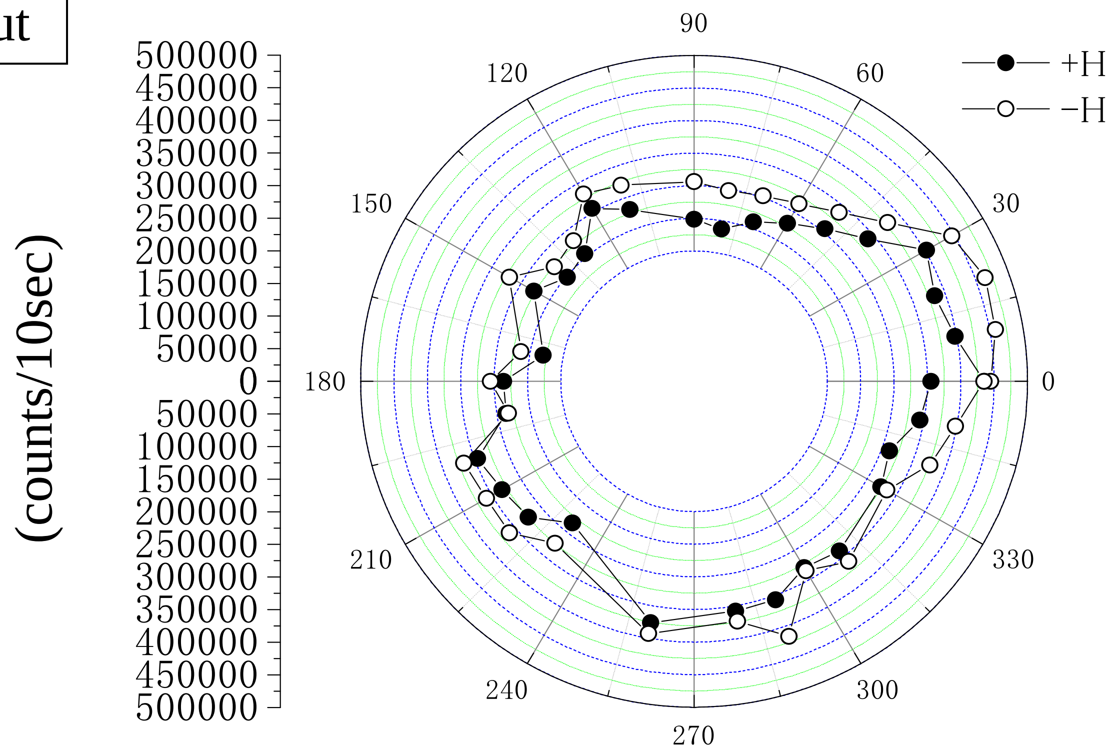
SinSout





Azimuthal angle dependence of MSHG from 300nm x 100nm rectangular dot array (Longitudinal)

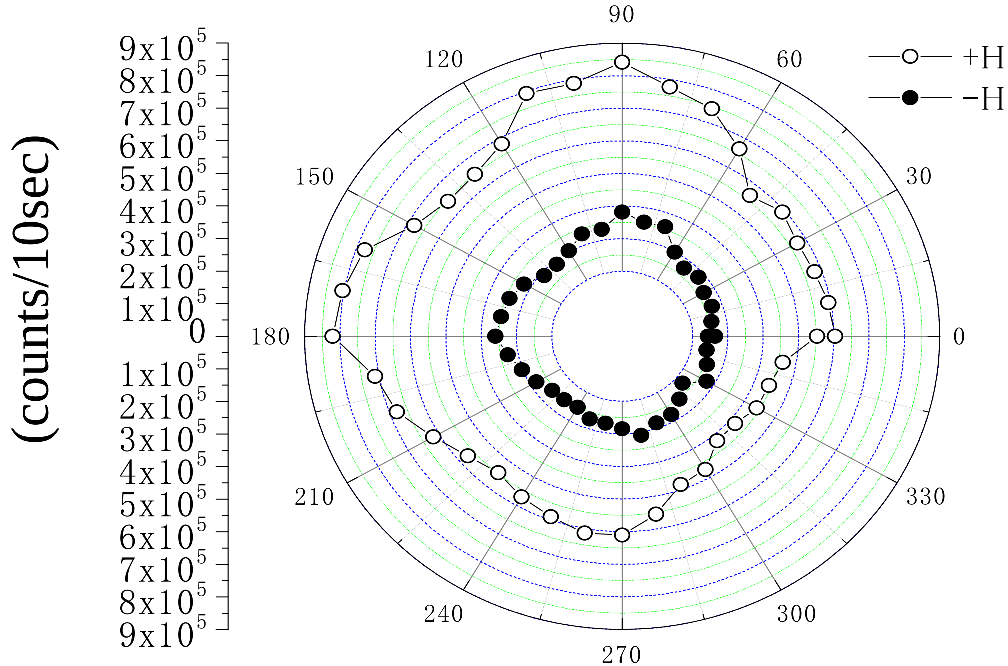
PinPout



H=±4kOe

Azimuthal angle dependence of MSHG from 300nm x 100nm rectangular dot array (Polar)

PinPout

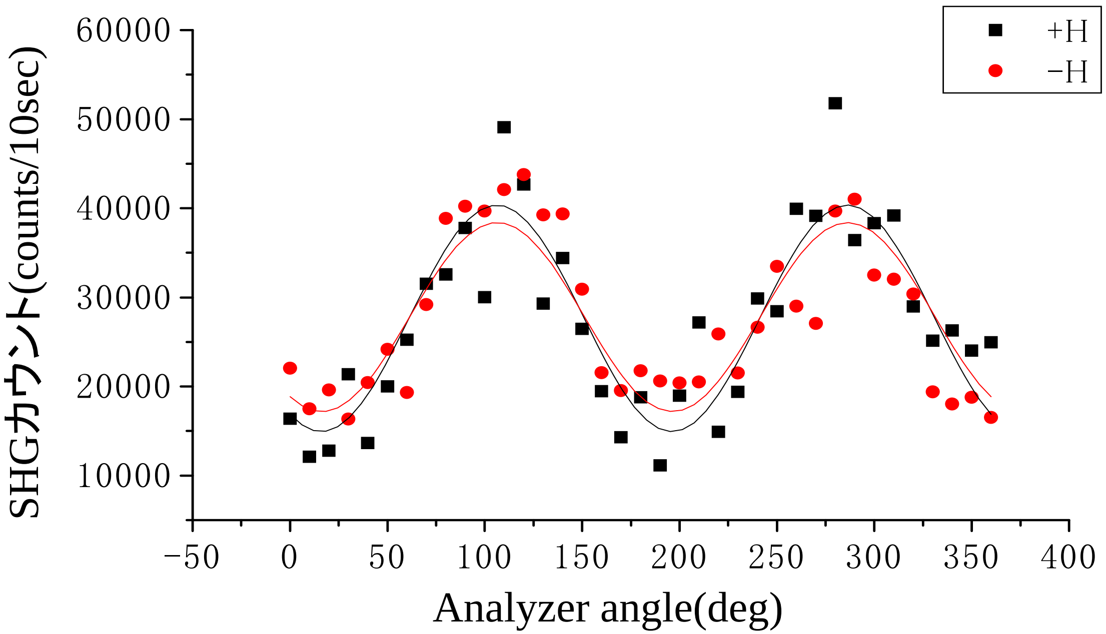


H=±6kOe

Nonlinear Kerr rotation in rectangular dot array

longitudinal

Nonlinear Kerr rotation 0.25°

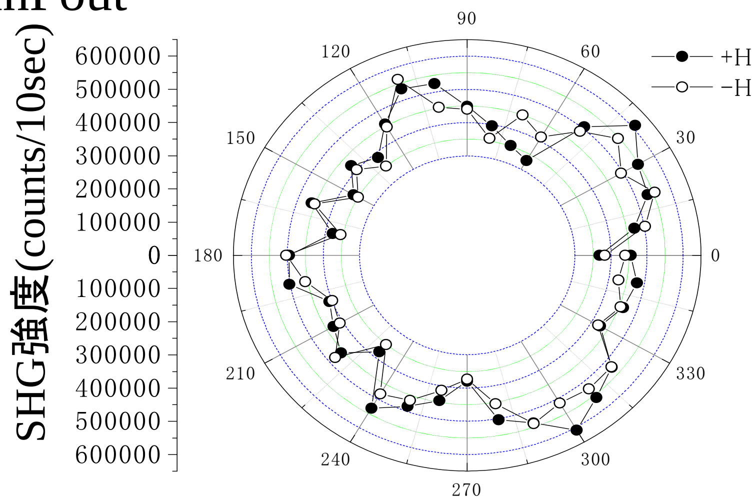


〈Sin〉

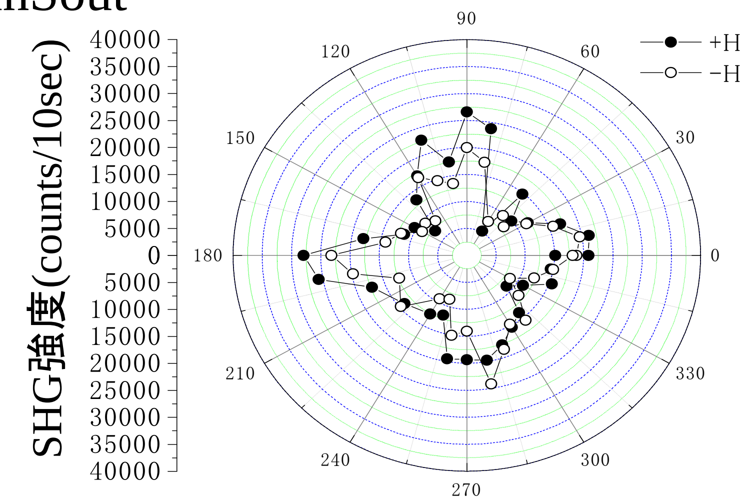
Azimuthal angle dependence of MSHG in circular dots

longitudinal

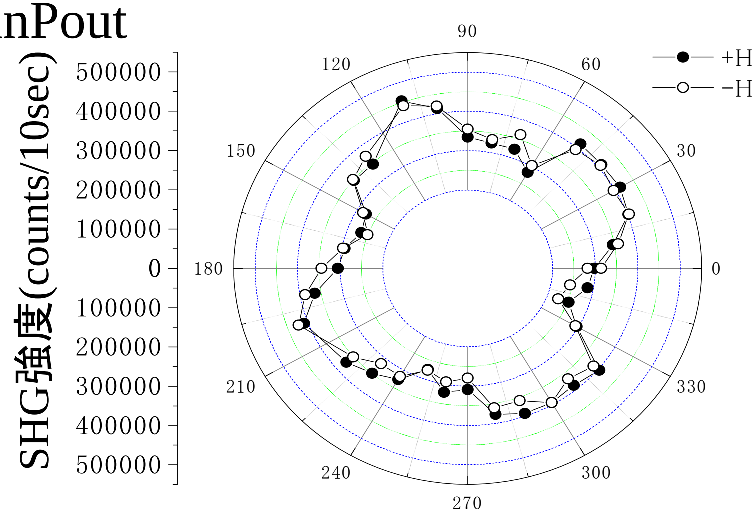
PinPout



PinSout



SinPout



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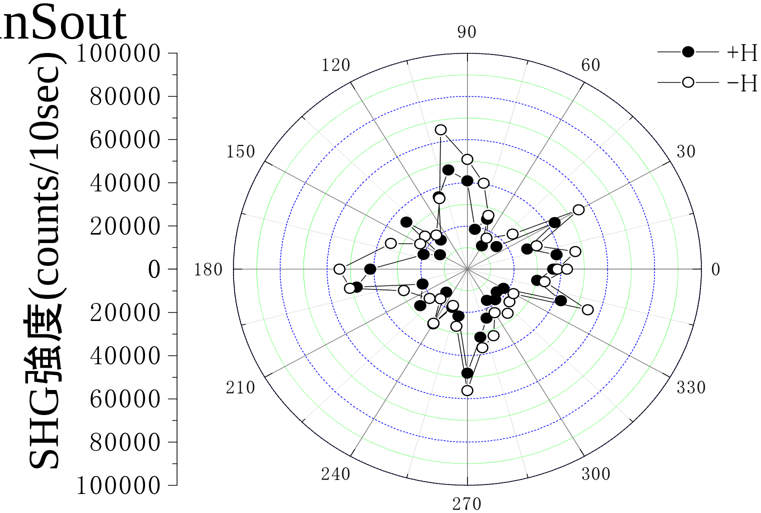

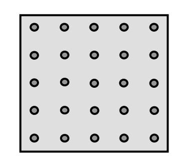

Summary

- Square, rectangular and circular dot arrays of 0.1-1 μm in dimension buried in Si wafer have been successfully obtained by Damascene technique using EB lithography
- MFM observation in square dot clearly shows closure domain pattern.
- MFM images of smaller dots show influence of magnetic field from the probe tip
- MSHG reflects symmetry of dot-arrangements