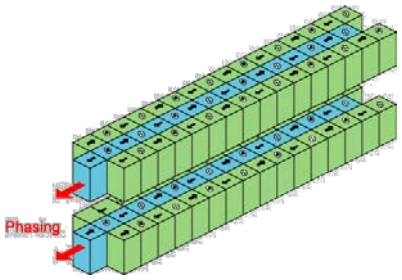
Element Strategy Initiative Advisory Council (ESIAC) 2019、
December 13 (Friday), 2019 @ Yokohama

Synchrotron Radiation Facility

Masaki Takata
Tohoku University
Photon Science Innovation Center

Application of magnetic materials

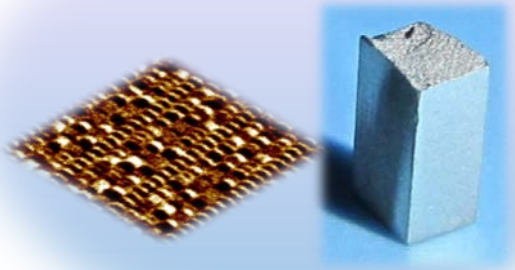


Insertion devices

HEV,EV cars

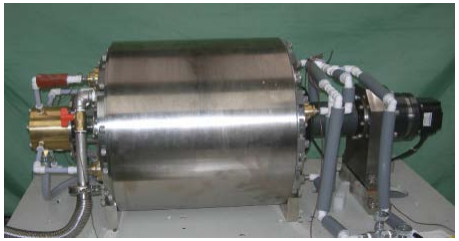
Wind power generators

Information Technologies

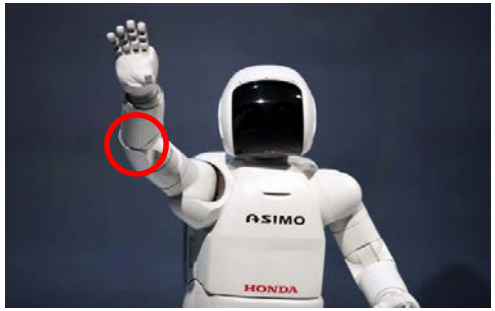


Magnetic thin films,

Permanent magnets



Magnetic refrigerator



Arthro of Robots

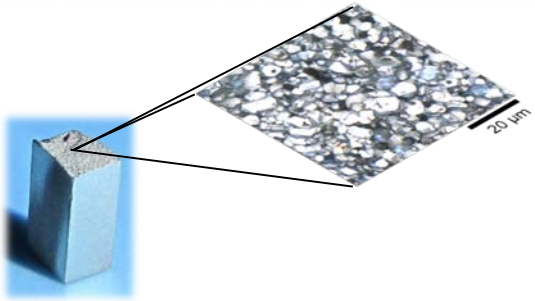
ESICMM embarked innovative upgrade of BL25SU toward nano visualization of magnetism.

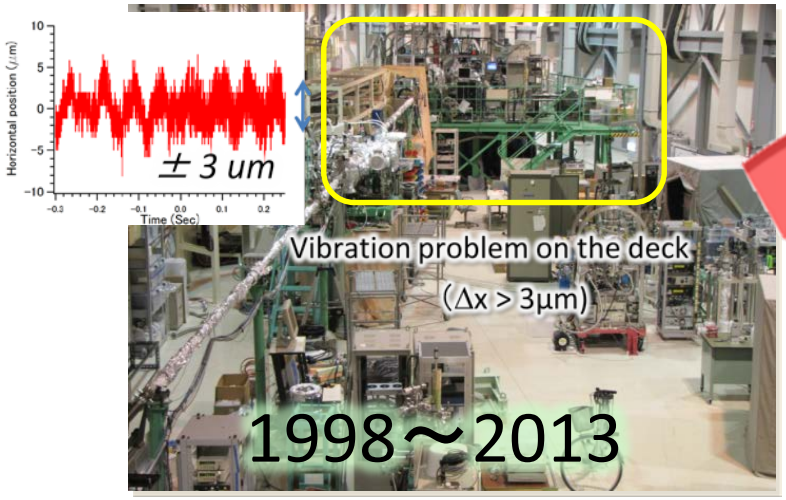
To uncover the coercivity mechanism via soft X-ray nano-beam



Y. Senba H. Ohashi S. Goto

Coercivity relates to the microstructure causing inhomogeneity of the local magnetism.





BL25SU was installed in 1998.

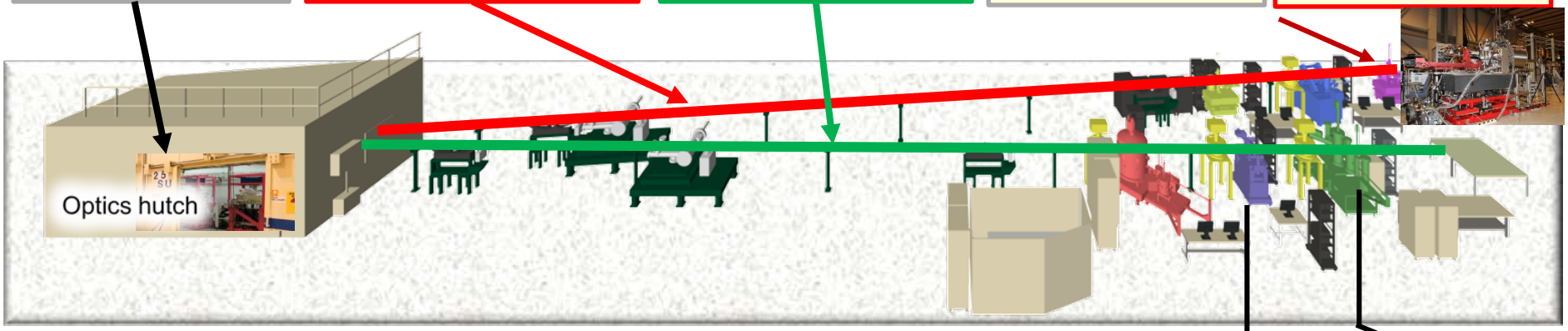
Vibration problem has become serious.

We uninstalled the original beamline in Dec. 2013, and built the new BL with the couple of branches.

The matching funds were source of beamline upgrade

ESICMM collaboration with RIKEN and JASRI

RIKEN	ESICMM	JASRI	JASRI	ESICMM
Optics Hutch Mirror system (M_0, M_{1a}, M_{1b})	Nano-beam branch Monochromator Refocusing mirror	Micro-beam branch Monochromator Refocusing mirror	Nano-beam Scanner unit	Scanning soft XMCD apparatus



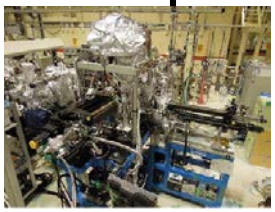
Retarding Field Analyzer

Grand-in Aid for Scientific Research on Innovative Area

Prof. H. Daimon

Micro-ARPES

Photon and Quantum Basic Research Coordinated Development Program

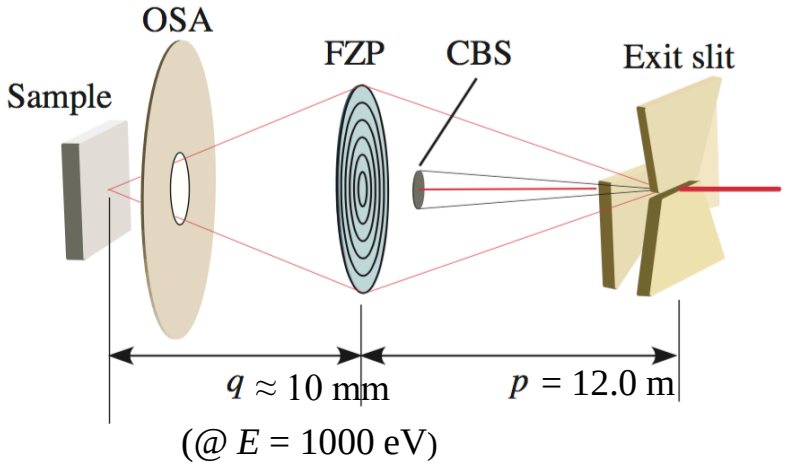


Prof. S. Shin

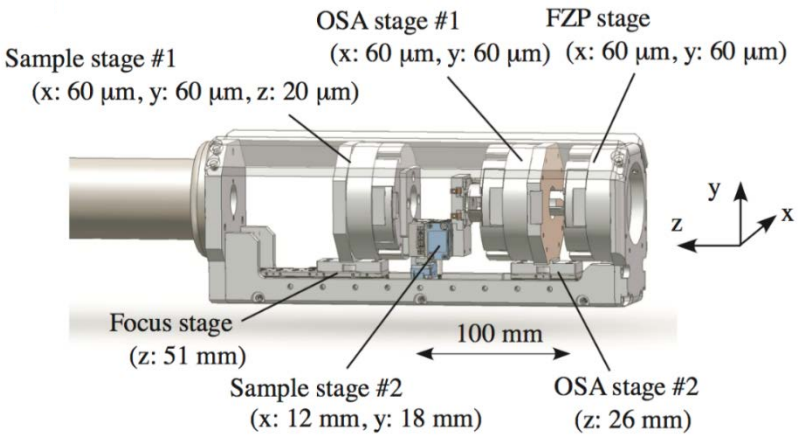
ESICMM also ignited new challenges of SX instruments technology.

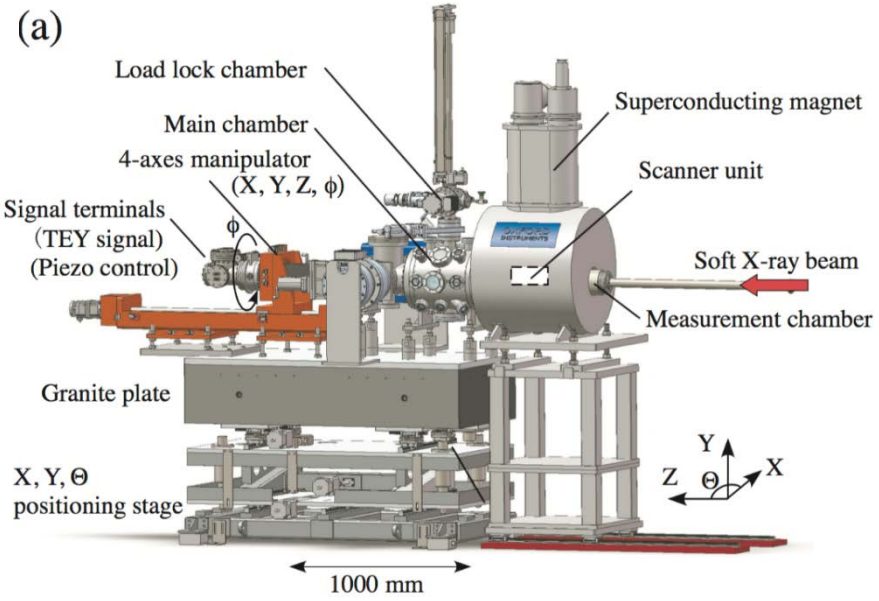
Development of Scanning Soft X-ray Magnetic Imaging

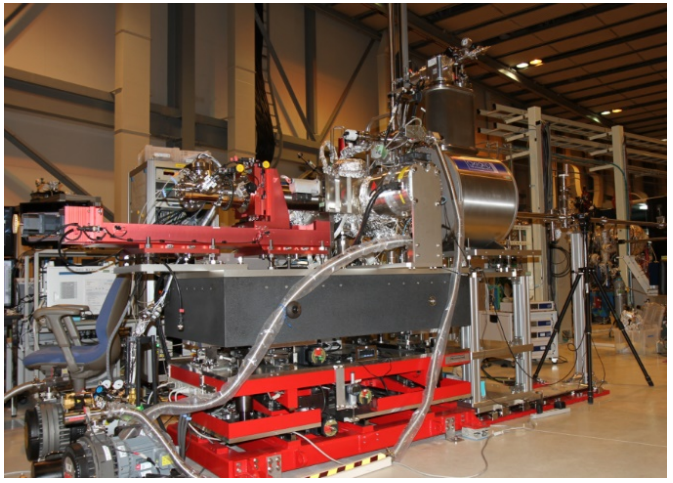
Optics for a <100 nm soft X-ray beam



11 axes piezo-drives scanner unit



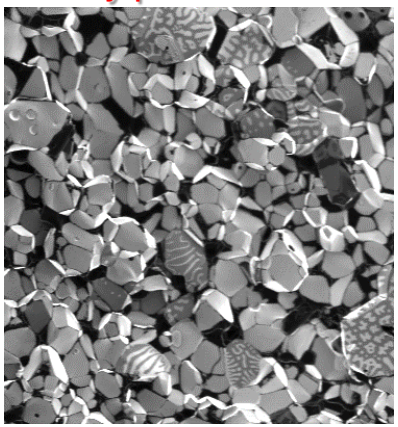




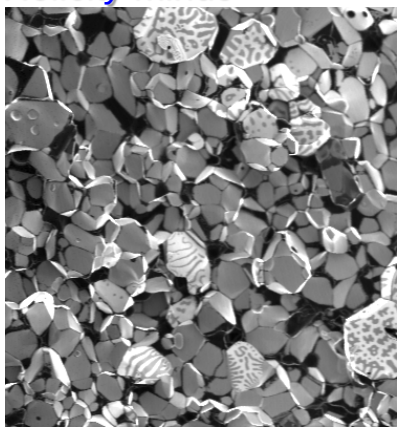
Y. Kotani *et al.*, J. Synchrotron Rad. **25**, 1444 (2018).

Magnetic and Morphologic Contrast imaging has achieved.

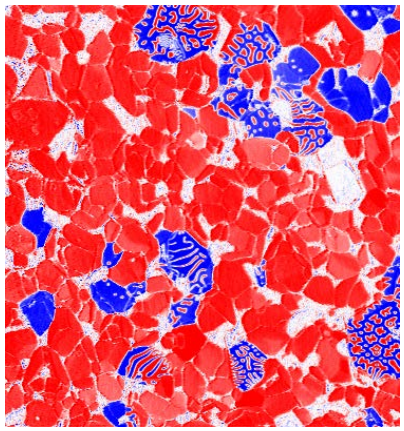
$\mu^{+}_{\mathrm{Fe},L_3}(x,y)$ Helicity plus

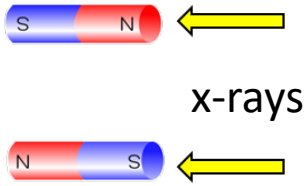


$\mu^{-}_{\mathrm{Fe},L_3}(x,y)$ Helicity minus



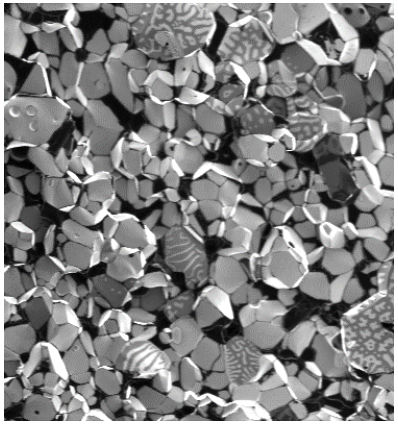
$\Delta\mu_{\mathrm{Fe},L_3}(x,y) = \left[\mu^{+}_{\mathrm{Fe},L_3}(x,y) - \mu^{-}_{\mathrm{Fe},L_3}(x,y)\right]$

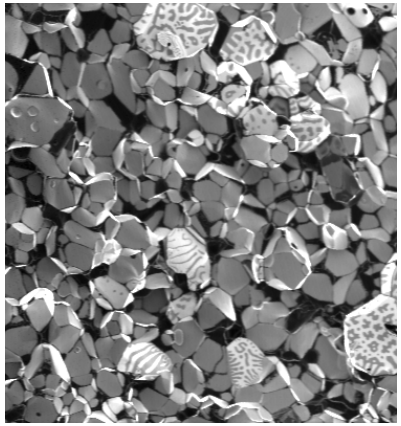


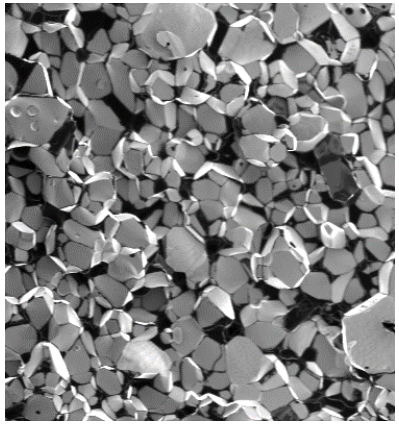


x-rays

$\mu_{\mathrm{Fe},L_3}(x,y) = \left[\mu^{+}_{\mathrm{Fe},L_3}(x,y) + \mu^{-}_{\mathrm{Fe},L_3}(x,y)\right]/2$



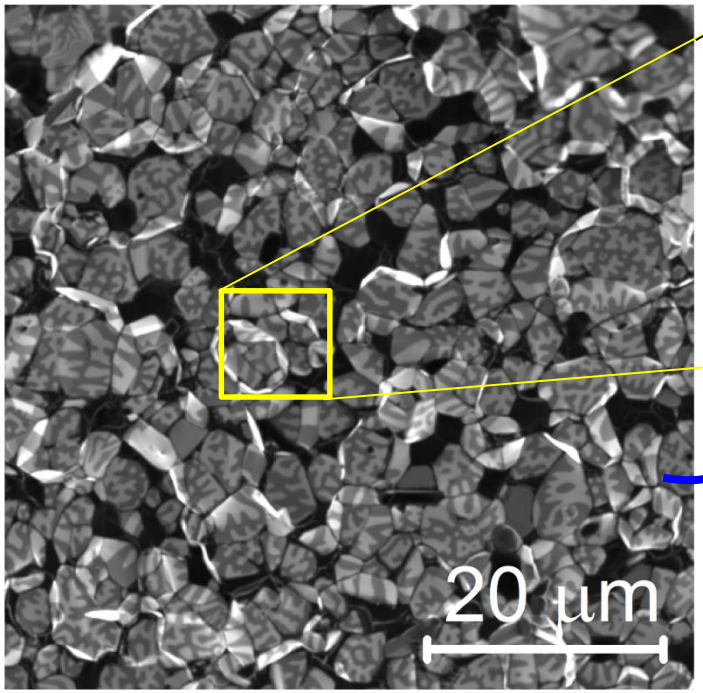




Challenge of the fast scan imaging as practicable tool.

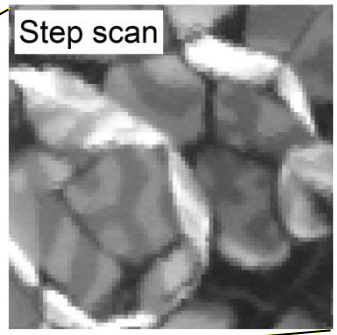
10 hours → 10 min.

➡ XMCD mapping using the quick scan has been developed instead of the step scan mode.

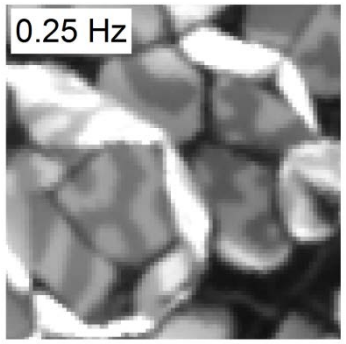


Sampling time=30 ms

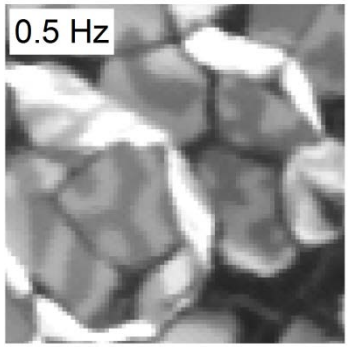
60 × 60 μm² (100 nm-step) :
400 × 400 pix.



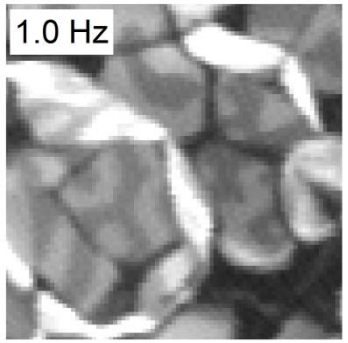
~ 567 min



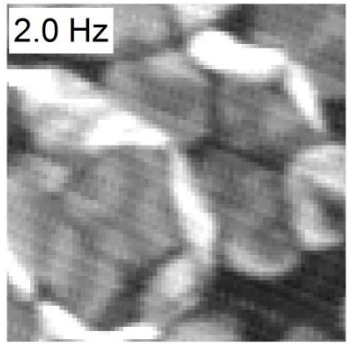
85 min



20 min



10 min

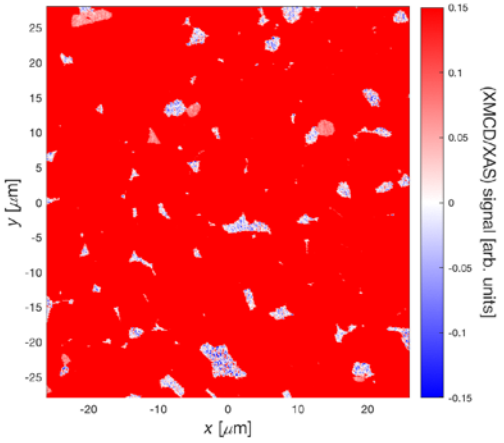


5 min

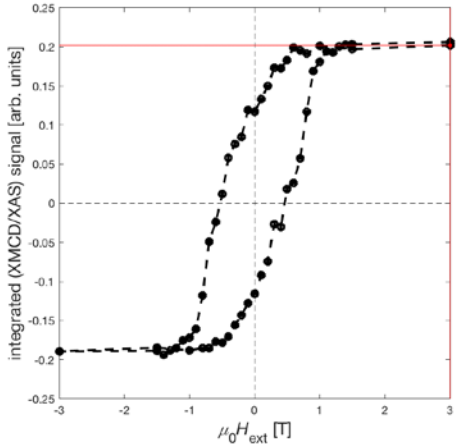
60 times faster

Unmasking the interior magnetic domain structure and evolution

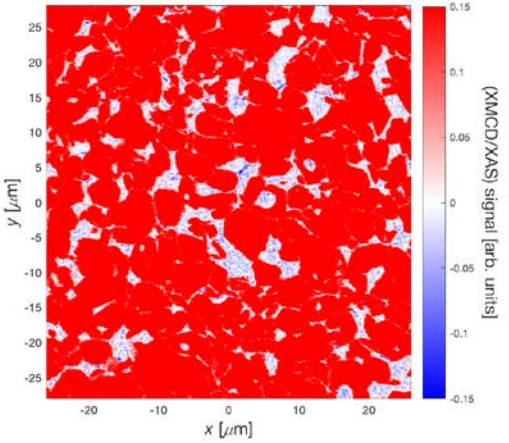
Polished

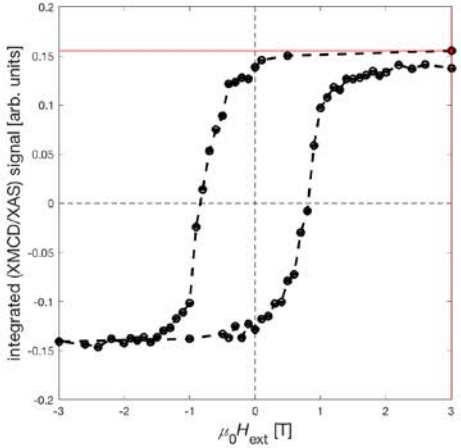


Integrated XMCD intensity



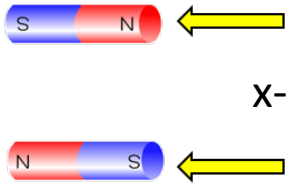
Fractured

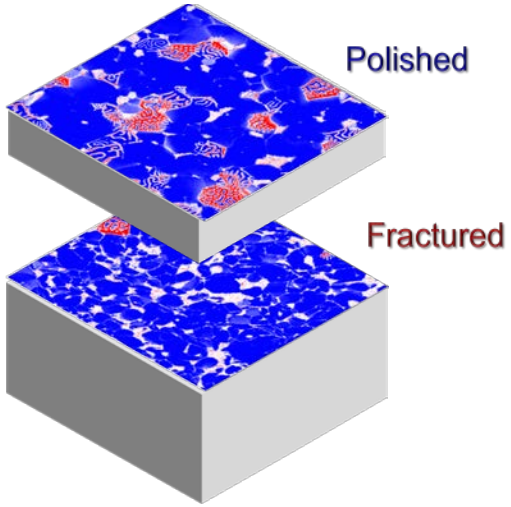




D. Billington, Phys. Rev. Mater. 2, 104413 (2018)

(Selected as "Editors Suggestion")



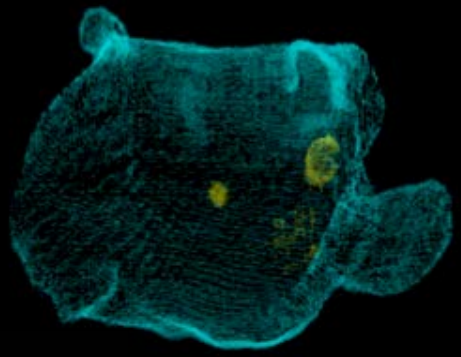


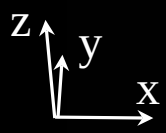
Magnetic domains in the remanence states for polished and fractured surfaces.

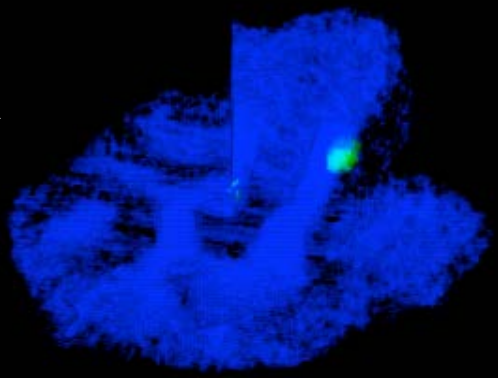
Fractured surface imaging allows investigation of realistic magnetic domains.

3D visualization has further been developed.

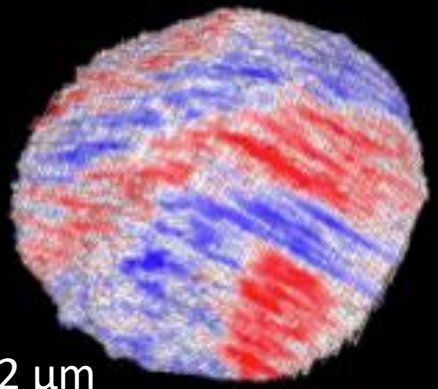
Nd-Fe-B sintered magnet

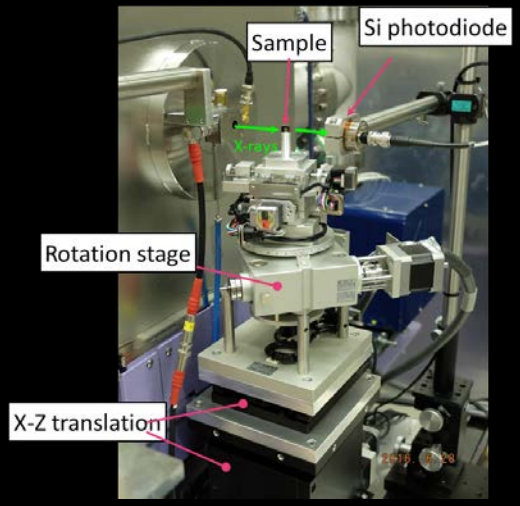






Gd-Fe-Co thick disk

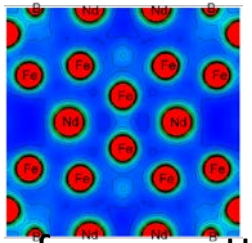




M. Suzuki *et al.*, APEX **11**, 036601 (2018).

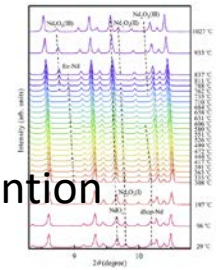
SPring-8 has ushered critical magnetic materials strategy!

H. Okazaki *et al.*,
Acta Materialia,
181, 530 (2019)

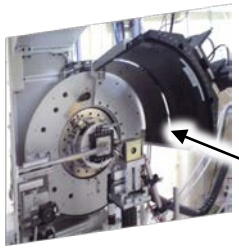


Electron Density

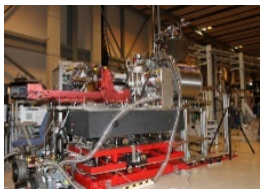
N. Tsuji *et al.*,
Acta Materialia
154, 25 (2018).



Secondary
phases



XRD



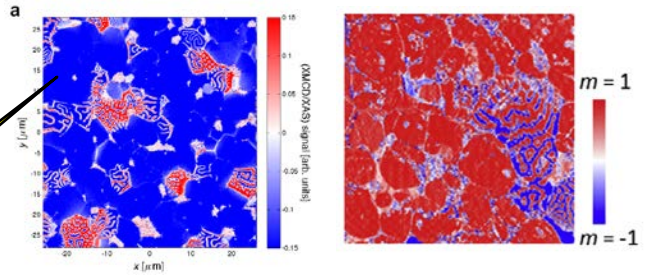
Development of
Soft X-ray MCD microscope

Y. Kotani *et al.*,
J. Synchrotron Rad.
25, 1444 (2018).

Soft X-ray
nano-beam

D. Billington *et al.*,
Phys. Rev. Mater.
(2018), *in print*

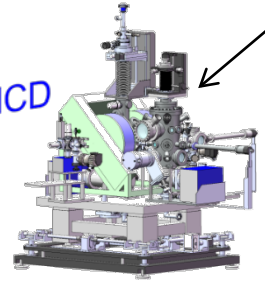
K. Miyazawa *et al.*,
Acta. Materialia
162, 1 (2019).



Vivid & high resolution magnetic imaging

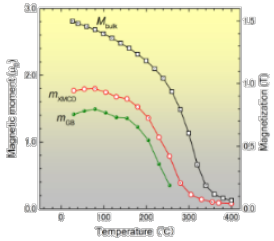
SPring-8

XMCD

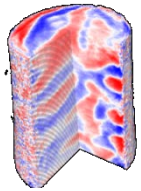


Hard X-ray
nano-beam

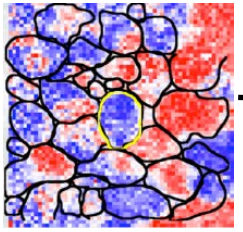
T. Nakamura *et al.*,
Appl. Phys. Lett.
105, 202404 (2014).



GB magnetism using
Soft XMCD



3D Magnetic CT



M. Suzuki *et al.*,
Acta Materialia
106, 155 (2016).

M. Suzuki *et al.*,
In preparation

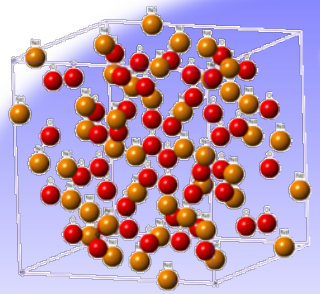
Magnetic domain Imaging
using Hard X-ray MCD

Materials Mag!c
Hitachi Metals

More than 5 companies use the technique.

k you for your attention

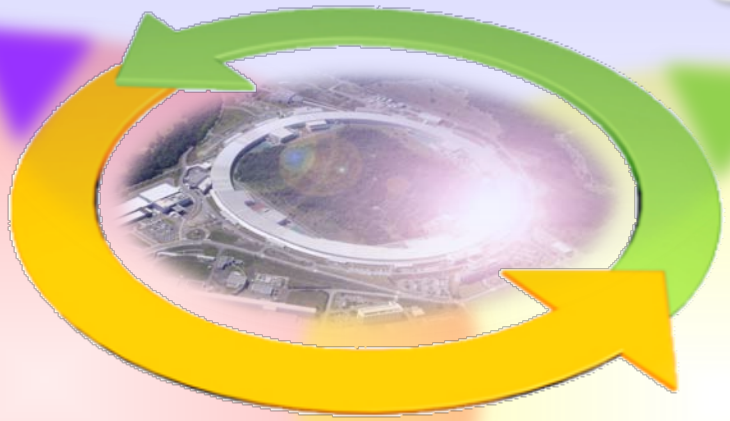
Thank you for your attention.

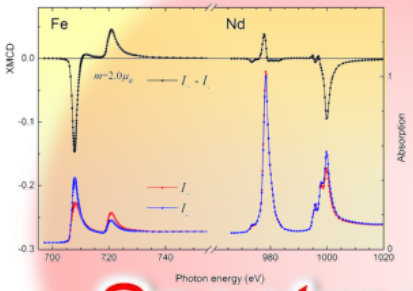


Structural analysis

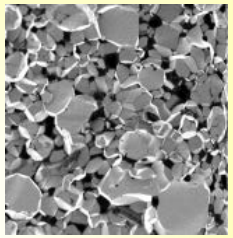
Site-specific spectroscopy

Scale seamless structural analysis





Spectroscopy



Imaging

Functional imaging

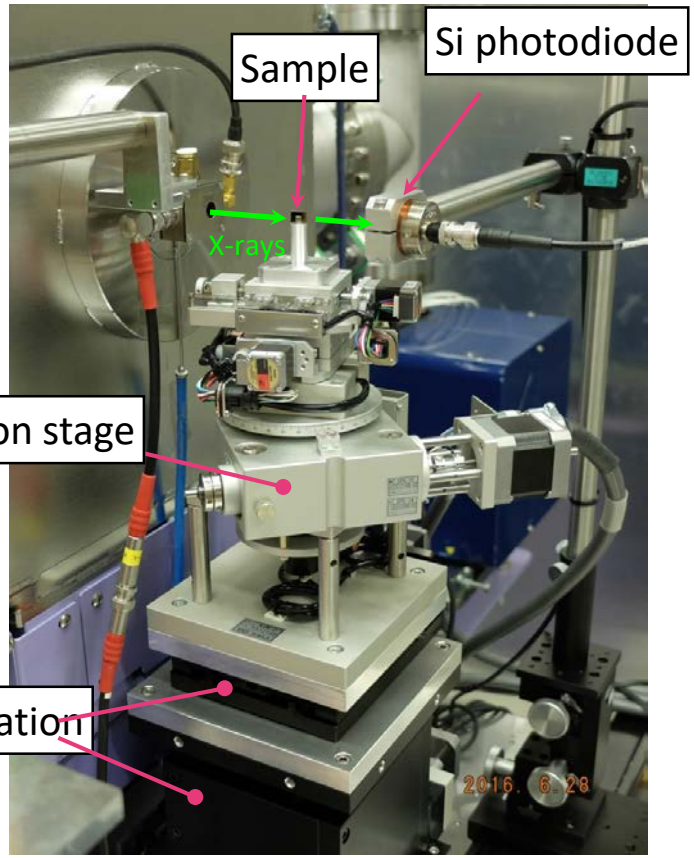
以下、参考

Feasibility of XMCD-CT using hard X-rays

Scanning X-ray magnetic CT setup

SPring-8 BL39XU

M. Suzuki



Focused beam size : 130(H) × 140(V) nm^2

X-ray energy : 7.247 keV (Gd L_3)

Polarization modulation at 37 Hz with diamond X-ray phase plate

On the Fly Scan + Lock-in detection

M. Suzuki et al., Appl. Phys. Express **11**, 036601 (2018).

Magnetic domain observation techniques

Methods	Specimen	Magnetic fields	Resolution	Lab./ Facility
Kerr microscopy	*Flat surface*	~ 25 T	*200 - 1,000 nm*	Labo.
MFM	*Relatively flat surface*	< 1 T	*10 - 50 nm*	Labo.
Lorenz TEM	*Transmittable thin film (~100 nm)*	< 1 T	*~1 nm*	Labo.
Spin SEM	*Surface (irregular surface)*	< 0.1 T	*~10 nm*	Labo.
STXM, TXM	*Transmittable thin film (~100 nm)*	Currently, < 0.5 T	*10 - 100 nm*	SR X-rays
PEEM	*Surface*	< 0.05 T	*20 - 100 nm*	SR X-rays
SXM by TEY mode (This work)	*Surface (irregular surface)*	8 T	*50 - 100 nm*	SR X-rays

Only this work makes possible to observe the magnetic domain structure in the irregular surface under high magnetic fields.