中性子ビーム利用基盤技術開発

加倉井和久
日本原子力研究開発機構　量子ビーム応用研究部門

1932 年、Chadwick による中性子の発見は、一方で、原子核物理の急速な発展と共に原子力技術や近代素粒子物理の創成を促した。他方で、短期間の間に中性子の質量、スピン、中性子磁気モーメント、中でも電荷が存在しないなどの中性子の本性が明らかにされると、中性子こそが物性物理（Condensed Matter Physics）のナノ構造を研究する為の理想的な道具であることが認識された。実際 1950 年以後、原子炉や加速器技術の急速な発展によって、研究用原子炉をはじめとする大強度の中性子ビーム源の施設が建設されて、中性子散乱による物性物理・化学の研究が一挙に花開いた。その後高束定常中性子源施設の建設、加速器を用いたパルス中性子源の開発、中性子ビームデバイスや検出技術の開発により、中性子利用は従来の固体物理のみではなく、ソフトマターを含む広い意味での物性研究、産業利用を含む材料研究、タンパク質の構造やダイナミックス等を対象とするバイオ研究において重要な観測子としての利用が拡大して来た。しかしこのように利用研究の領域が広がれば広がるほどに、定常中性子源或はパルス中性子源のみを所有する中性子利用研究施設では幅広い基礎研究や産業利用を含む利用研究からの需要に十分答えられる質的及び量的中性子データ収集及び解析力の実現が困難である事が明らかになって来た。

幸いに我が国では日本原子力研究開発機構　東海研究開発センター　原子力科学研究所の敷地内に世界でも稀な定常中性子源施設（JRR-3）とパルス中性子源施設（J-PARC/MLF）を備え持つ中性子量子ビーム利用環境の基盤が整った。この両中性子源の複合的ビーム利用の高度化を目標に、文部科学省の量子ビーム基盤技術開発プログラムの枠組みの中で高度化ビーム技術開発課題として「中性子ビーム利用高度化技術の開発」が採択され、偏極中性子、集光、検出技術を柱とするビーム利用技術の基礎基盤技術開発が行われている。

本講演ではこのプログラムの枠組みの中で得られた技術開発の成果を中心に、中性子ビーム技術の最新動向及びこれらの基盤技術を活用することにより可能となる新機能材料や創薬開発に向けた中性子利用研究の例を紹介したい。

文部科学省 量子ビーム基盤技術開発プログラム「中性子ビーム利用高度化技術の開発」は平成２０年度より幹事機関の日本原子力研究開発機構とネットワーク型研究開発拠点の北海道大学、東北大学、高エネルギー加速器研究機構、東京大学、京都大学との共同研究として行われております。各機関の研究代表者及び研究協力者の方々に謝意を表します。

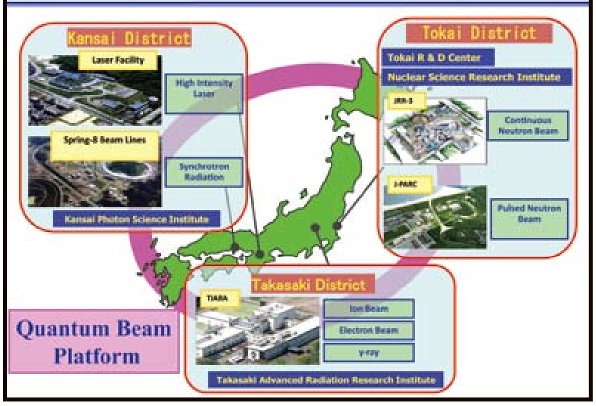
東北大学多元物質科学研究所・九州シンクロトロン光研究センター 合同シンポジウム
2012.7.30 仙台

中性子ビーム利用基盤技術開発

Neutron Beam Fundamentals Development

Kazuhisa Kakurai
Quantum Beam Science Directorate (QuBS)
Japan Atomic Energy Agency (JAEA)

Main Facilities of JAEA for Quantum Beam Science &Technology

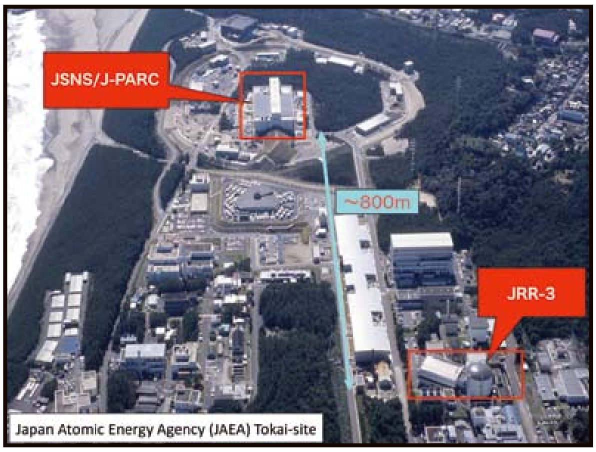


Outline

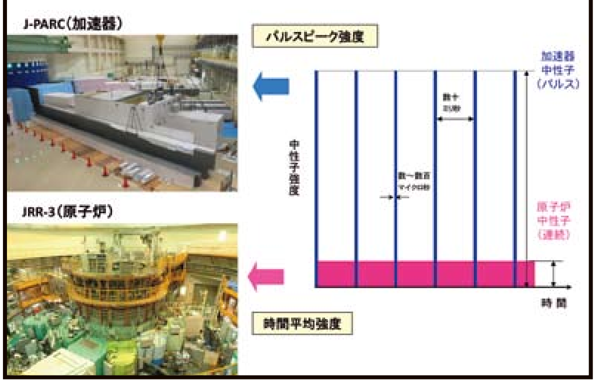
- Neutron Beam Fundamentals Development
- Development concerning the utilization of polarized neutrons
- Development of focusing devices
- Development of detecting devices

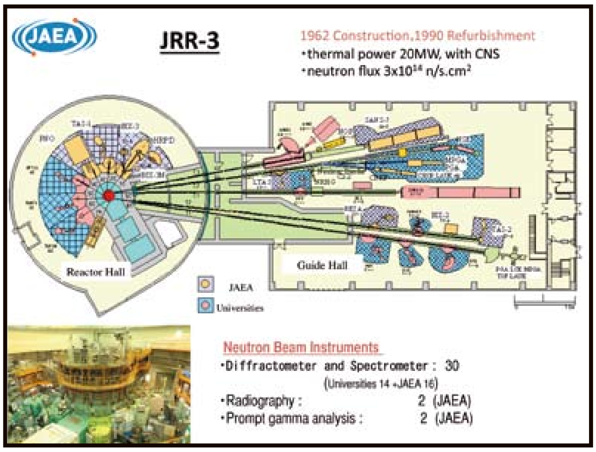
Outline

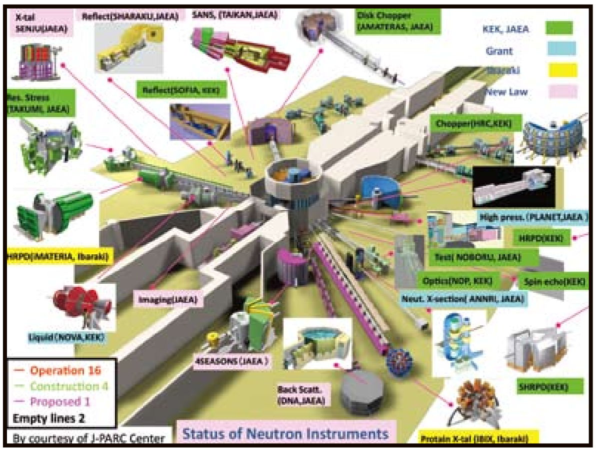
- Neutron Beam Fundamentals Development
- Development concerning the utilization of polarized neutrons
- Development of focusing devices
- Development of detecting devices

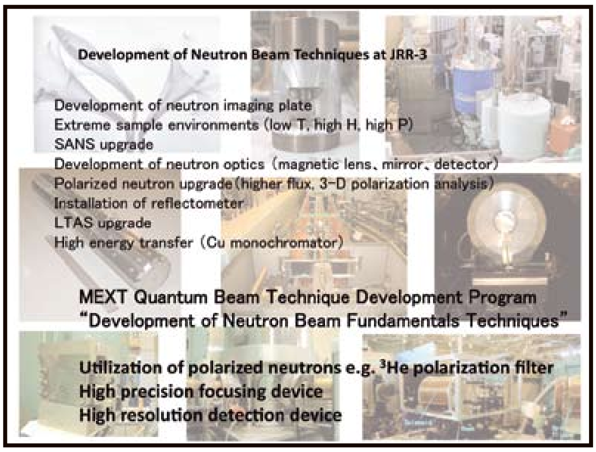


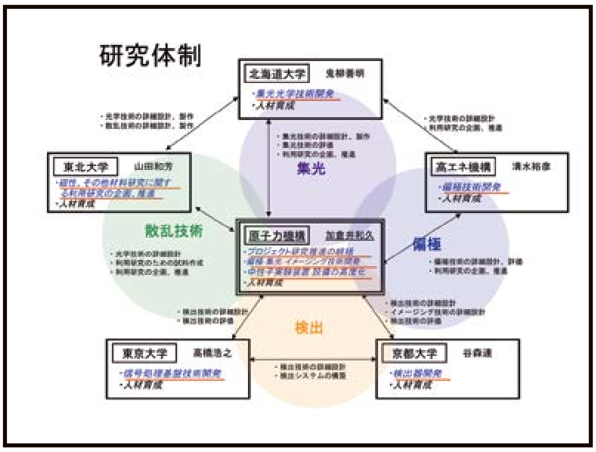
定常中性子源とパルス中性子源

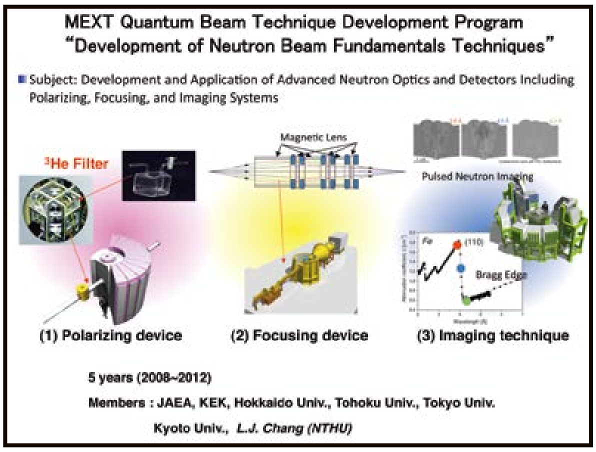










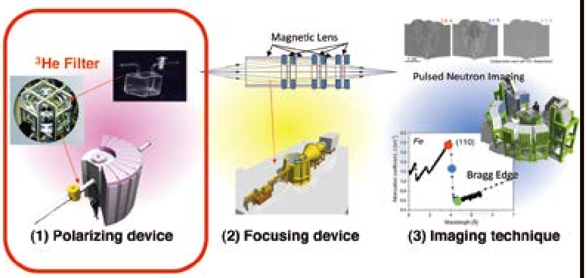


Outline

- Neutron Beam Fundamentals Development
- Development concerning the utilization of polarized neutrons
- Development of focusing devices
- Development of detecting devices

MEXT Quantum Beam Technique Development Program
"Development of Neutron Beam Fundamentals Techniques"

- Subject: Development and Application of Advanced Neutron Optics and Detectors Including Polarizing, Focusing, and Imaging Systems



Polarized neutron

Neutron spin 1/2

2 eigenfunctions for S_z=+1/2 and -1/2

$|\frac{1}{2},+\frac{1}{2}\rangle \equiv u$ 'spin up' state

$|\frac{1}{2},-\frac{1}{2}\rangle \equiv v$ 'spin down' state

If a beam of neutrons has a fraction f of neutron in the state u

Polarization **P** (in the quantization direction) with magnitude $P = 2f - 1$

Unpolarized beam P=0;
completely polarized beam with all the spins up P=1, with all the spins down P=−1

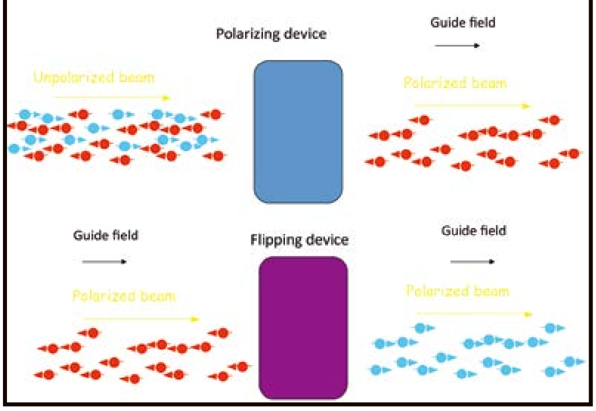
Polarization dependent cross section

$$\frac{d\sigma}{d\Omega} = NN^* + N^*\left(\vec{P}\cdot\vec{M}_\perp\right) + N\left(\vec{P}\cdot\vec{M}_\perp^*\right) + \vec{M}_\perp\cdot\vec{M}_\perp^* + i\vec{P}\cdot\left(\vec{M}_\perp^*\times\vec{M}_\perp\right)$$

Assuming collinear structure and inversion symmetry

$$\frac{d\sigma}{d\Omega} = N^2 + \boldsymbol{P}\,(2N\boldsymbol{M}_\perp) + (\boldsymbol{M}_\perp)^2$$

Utilization of polarized neutron



Polarization dependent cross section

$$\frac{d\sigma}{d\Omega} = NN^* + N^*\left(\vec{P}\cdot\vec{M}_\perp\right) + N\left(\vec{P}\cdot\vec{M}_\perp^*\right) + \vec{M}_\perp\cdot\vec{M}_\perp^* + i\vec{P}\cdot\left(\vec{M}_\perp^*\times\vec{M}_\perp\right)$$

Assuming collinear structure and inversion symmetry

$$\frac{d\sigma}{d\Omega} = N^2 + \boldsymbol{P}\,(2N\boldsymbol{M}_\perp) + (\boldsymbol{M}_\perp)^2$$

$$R = \frac{I_+}{I_-} = \left(\frac{N+M_\perp}{N-M_\perp}\right)^2$$ when N is known ⇒ $M_\perp$

Polarized Neutron Powder Diffraction Experiments on $Fe_{16}N_2$ Nano-Particles

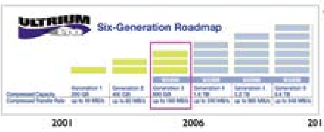
Y. Ishii[1], M. Takeda[1], T. Kikuchi[1], T. Shinohara[2], T. Oku[2], J. Suzuki[2], Y. Sasaki[3], M. Kishimoto[3], M. Yokoyama[4], Y. Nishihara[4] and K.Kakurai[1]

[1] *Quantum Beam Science Directorate, Japan Atomic Energy Agency (JAEA)*
[2] *Materials and Life Science Division, J-PARC Center*
[3] *Hitachi Maxell, Ltd.,*
[4] *Physics Department, Ibaraki University*

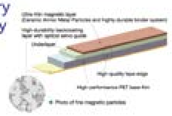
Magnetic Analysis of Fe-N nano-Particle

TU（5）2006, Hitachi Maxell Co. Ltd., Ibaraki Pref.

Magnetic tape has high memory density and high reliability.



Memory density



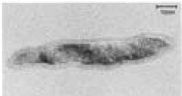
Memory density & storing speed of Tape and HDD

INSIC data

year	2001	2006	2011
Magnetic tape (TB)	0.1	1.0	10.0
HDD (TB)	0.03	0.3	3
Ratio of memory capacity (Tape/HDD)	3.3	3.3	3.3
Ratio of storing speed (Tape/HDD)	0.04	0.04	0.04

Goal of Generation 6 : 6.4TB

The most promising material is Fe-N nano-particle. (Hitachi Maxell Co. Ltd.)



$Fe_{16}N_2$

Large magnetic moment

Magnetic anisotropy

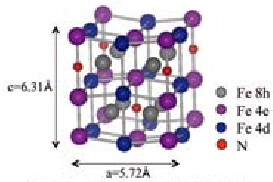
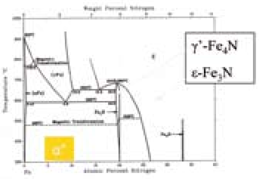


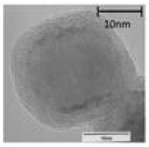
Figure was drawn with VENUS developed by Dilanian and Izumi.

α''- $Fe_{16}N_2$

bct (body-centred tetragonal)



$Fe_{16}N_2$ nano-particles diameter: 17nm

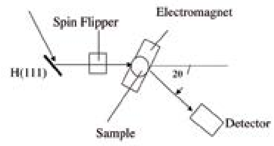


From the macroscopic measurement the magnetic moment for $Fe_{16}N_2$ cannot be determined.（difficult to estimate the non-magnetic anti-oxidizing layer, which is a proprietary material）

Core material is mainly $Fe_{16}N_2$, but may contain Fe_3O_4, α-Fe and Fe_4N

Information about the structure of the nano-particles:
PolSANS exp. by Oku et al.

Experiment on TAS-1

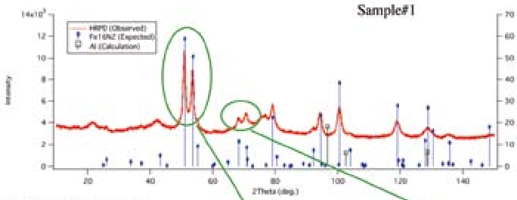


Polarizing monochromator : magnetized Heusler (111)
Incident neutron energy : 14.7 meV(λ = 2.356 Å)
Polarization of the incident beam : 90%

TAS-1 in half-polarizing operation mode

Electromagnet

Sample#1

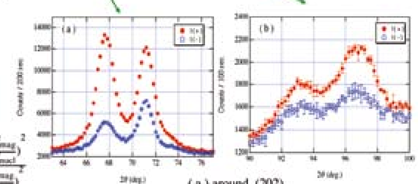


Use of polarized neutrons

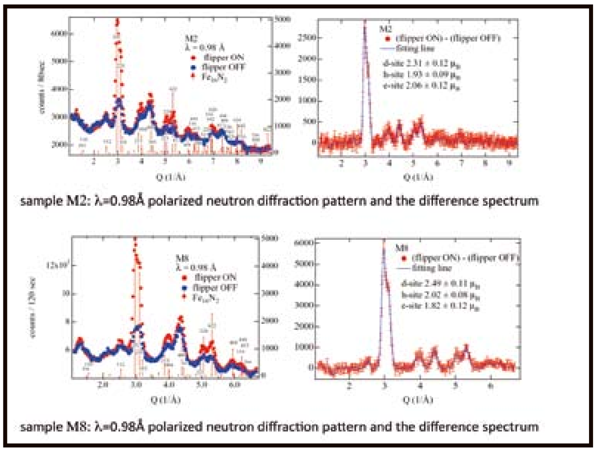
$I_+ = (F_{nucl} + F_{mag})^2$

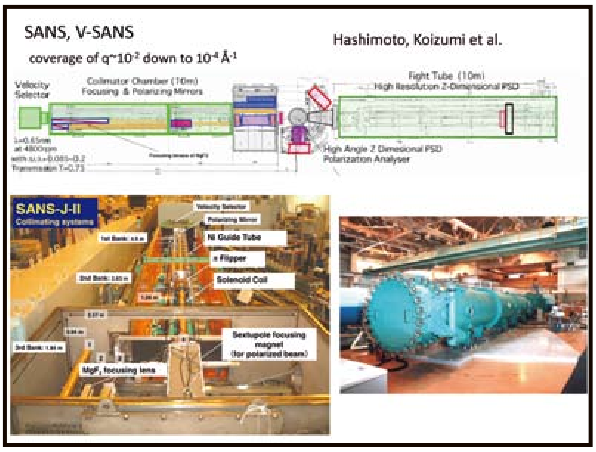
$I_- = (F_{nucl} - F_{mag})^2$

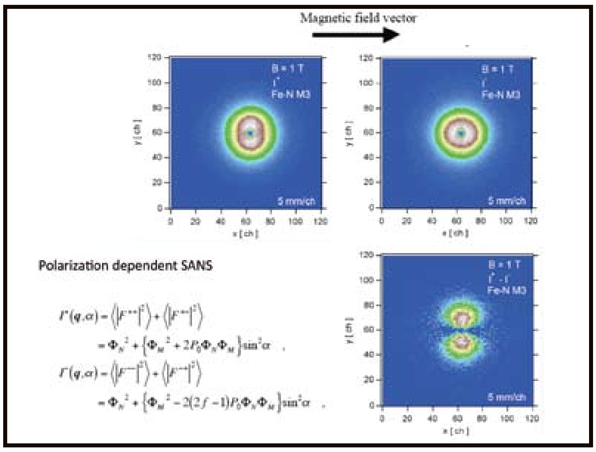
$$\frac{I_+}{I_-} = R = \frac{(F_{nucl}+F_{mag})^2}{(F_{nucl}-F_{mag})^2} = \frac{\left(1+\frac{F_{mag}}{F_{nucl}}\right)^2}{\left(1-\frac{F_{mag}}{F_{nucl}}\right)^2}$$

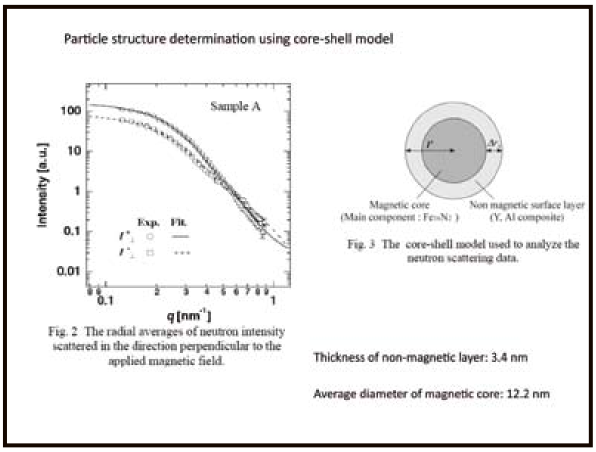


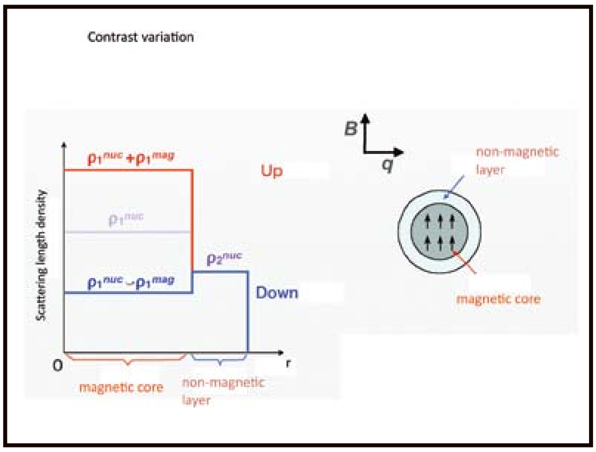
(a) around (202)
(b) around (004)

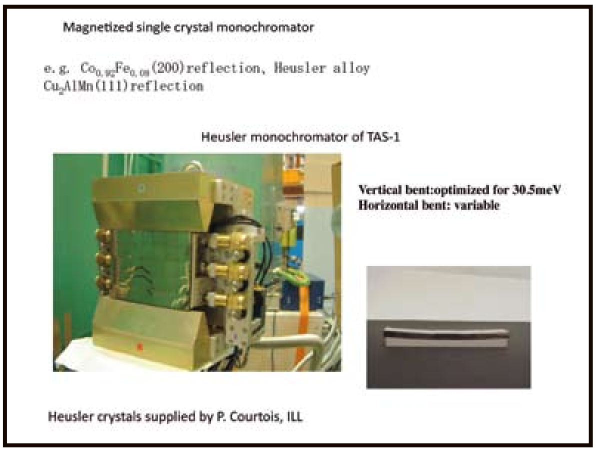

M2
λ = 0.98 Å
flipper ON
flipper OFF
(flipper ON) - (flipper OFF)
fitting line
Q (1/Å)
sample M2: λ=0.98Å polarized neutron diffraction pattern and the difference spectrum
M8
λ = 0.98 Å
flipper ON
flipper OFF
(flipper ON) - (flipper OFF)
fitting line
Q (1/Å)
sample M8: λ=0.98Å polarized neutron diffraction pattern and the difference spectrum

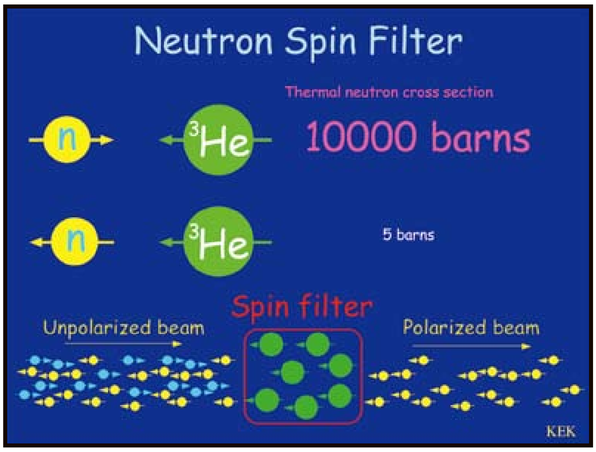

SANS, V-SANS
Hashimoto, Koizumi et al.
coverage of q~10^-2 down to 10^-4 Å^-1
Velocity Selector
Collimator Chamber (10m)
Focusing & Polarizing Mirrors
Fight Tube (10m)
High Resolution 2-Dimensional PSD
High Angle 2 Dimensional PSD
Polarization Analyser
SANS-J-II
Collimating systems
Velocity Selector
Polarizing Mirror
Ni Guide Tube
π Flipper
Solenoid Coil
Sextupole focusing magnet (for polarized beam)
MgF2 focusing lens

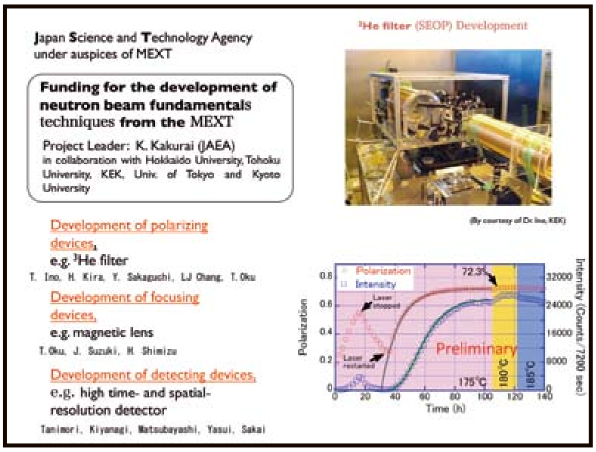

Magnetic field vector
B = 1 T
Fe-N M3
5 mm/ch
x [ch]
y [ch]
Polarization dependent SANS

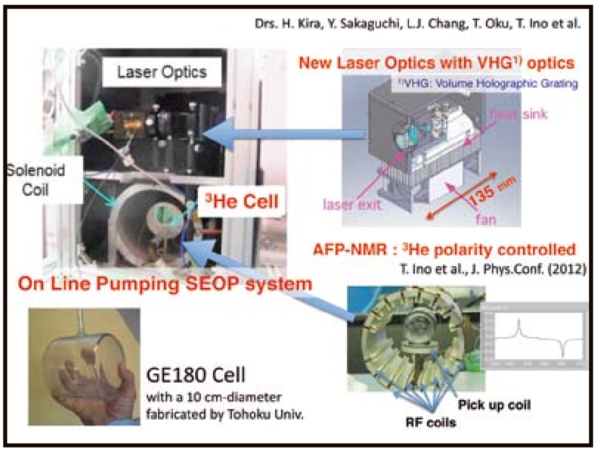

Particle structure determination using core-shell model
Sample A
Intensity [a.u.]
q [nm^-1]
Exp.
Fit.
Fig. 2 The radial averages of neutron intensity scattered in the direction perpendicular to the applied magnetic field.
Magnetic core
Non magnetic surface layer
(Y, Al composite)
Fig. 3 The core-shell model used to analyze the neutron scattering data.
Thickness of non-magnetic layer: 3.4 nm
Average diameter of magnetic core: 12.2 nm

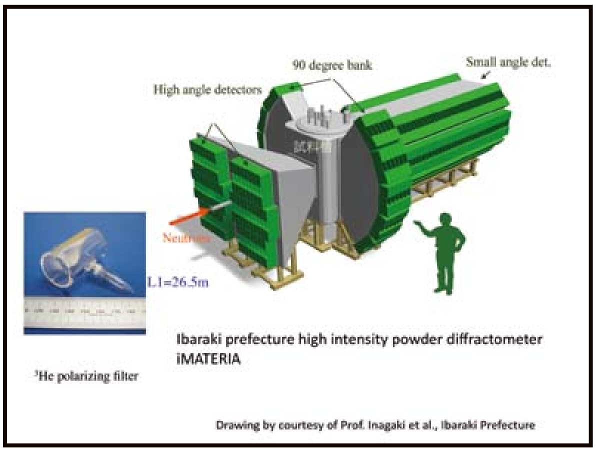

Contrast variation
B
q
Up
Down
non-magnetic layer
magnetic core
Scattering length density
r
0
magnetic core
non-magnetic layer

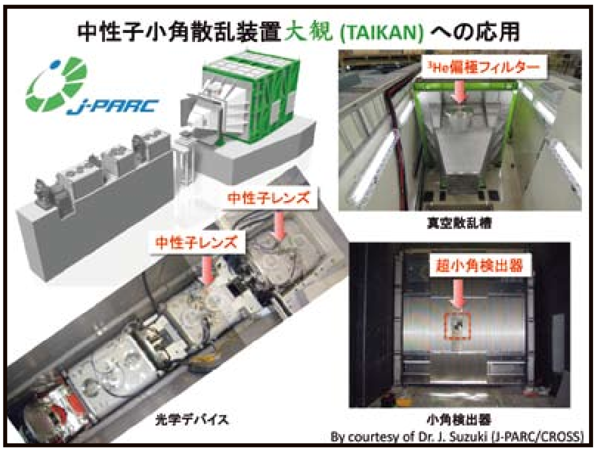

Magnetized single crystal monochromator
e.g. Co0.92Fe0.08(200) reflection, Heusler alloy Cu2AlMn(111) reflection
Heusler monochromator of TAS-1
Vertical bent: optimized for 30.5meV
Horizontal bent: variable
Heusler crystals supplied by P. Courtois, ILL

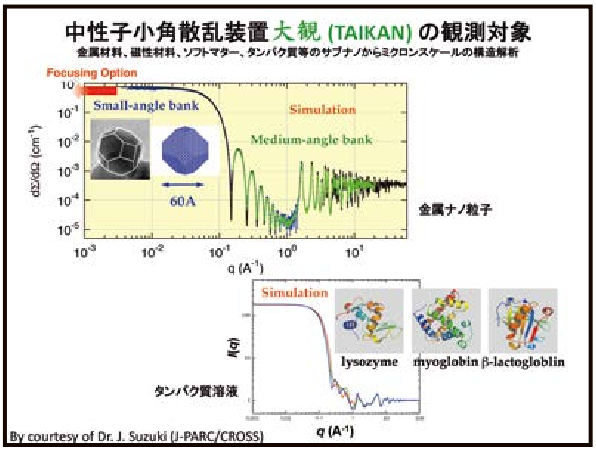

Neutron Spin Filter
Thermal neutron cross section
n
3He
10000 barns
n
3He
5 barns
Spin filter
Unpolarized beam
Polarized beam
KEK

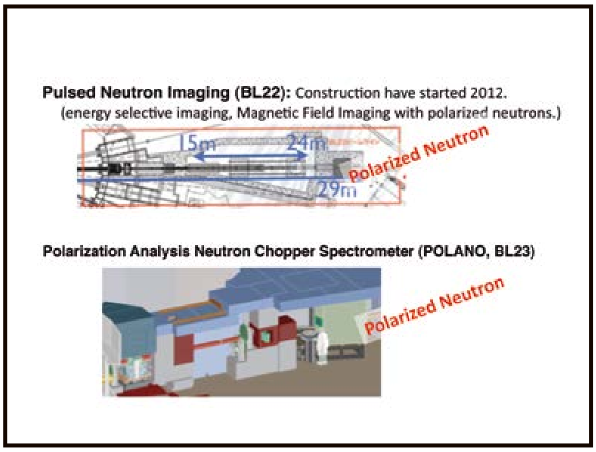

Japan Science and Technology Agency
under auspices of MEXT
3He filter (SEOP) Development
Funding for the development of neutron beam fundamentals techniques from the MEXT
Project Leader: K. Kakurai (JAEA)
in collaboration with Hokkaido University, Tohoku University, KEK, Univ. of Tokyo and Kyoto University
(By courtesy of Dr. Ino, KEK)
Development of polarizing devices,
e.g. 3He filter
T. Ino, H. Kira, Y. Sakaguchi, LJ Chang, T. Oku
Development of focusing devices,
e.g. magnetic lens
T. Oku, J. Suzuki, H. Shimizu
Development of detecting devices,
e.g. high time- and spatial-resolution detector
Tanimori, Kiyanagi, Matsubayashi, Yasui, Sakai
Polarization
Intensity
72.3%
Laser stopped
Laser restarted
Preliminary
175°C
180°C
185°C
Polarization
Time (h)
Intensity (Counts / 7200 sec)


Drs. H. Kira, Y. Sakaguchi, L.J. Chang, T. Oku, T. Ino et al.
Laser Optics
New Laser Optics with VHG1) optics
1)VHG: Volume Holographic Grating
heat sink
Solenoid Coil
3He Cell
laser exit
135 mm
fan
AFP-NMR : 3He polarity controlled
T. Ino et al., J. Phys.Conf. (2012)
On Line Pumping SEOP system
GE180 Cell
with a 10 cm-diameter
fabricated by Tohoku Univ.
Pick up coil
RF coils


90 degree bank
Small angle det.
High angle detectors
Neutron
L1=26.5m
Ibaraki prefecture high intensity powder diffractometer
iMATERIA
3He polarizing filter
Drawing by courtesy of Prof. Inagaki et al., Ibaraki Prefecture

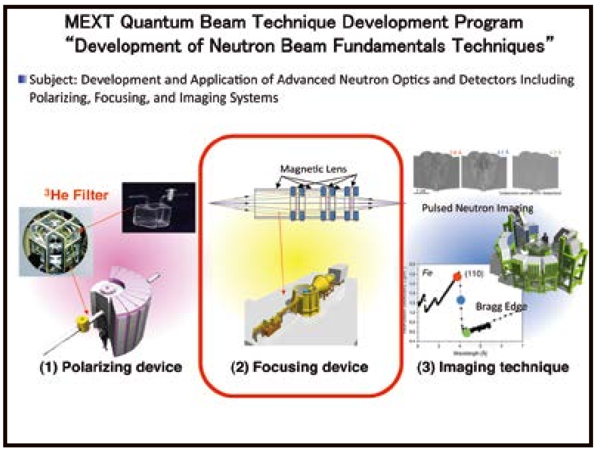

中性子小角散乱装置大観 (TAIKAN) への応用
J-PARC
3He偏極フィルター
真空散乱槽
中性子レンズ
中性子レンズ
超小角検出器
光学デバイス
小角検出器
By courtesy of Dr. J. Suzuki (J-PARC/CROSS)

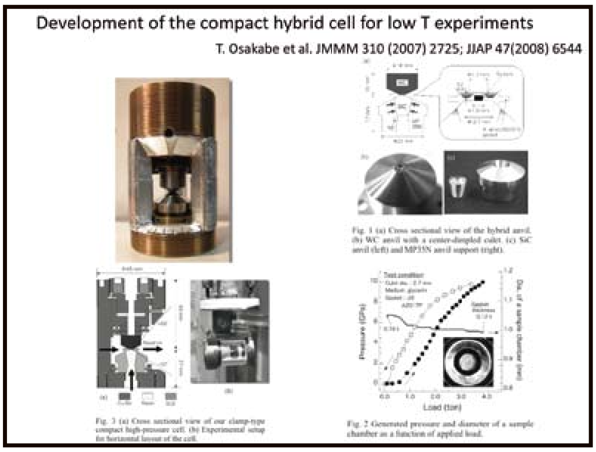

中性子小角散乱装置大観 (TAIKAN) の観測対象
金属材料、磁性材料、ソフトマター、タンパク質等のサブナノからミクロンスケールの構造解析
Focusing Option
Small-angle bank
Simulation
Medium-angle bank
60A
金属ナノ粒子
q (A-1)
Simulation
lysozyme
myoglobin
β-lactogloblin
タンパク質溶液
q (A-1)
By courtesy of Dr. J. Suzuki (J-PARC/CROSS)

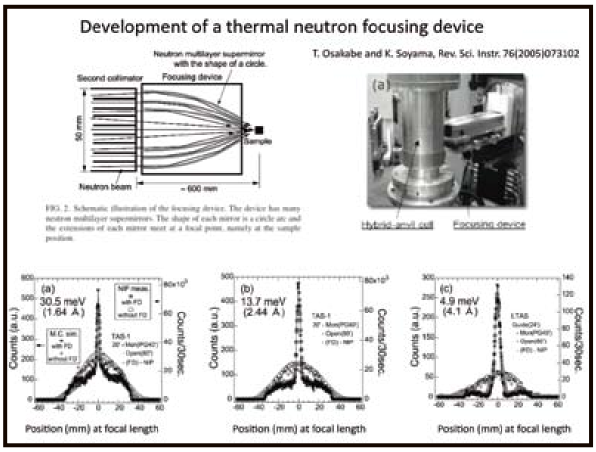


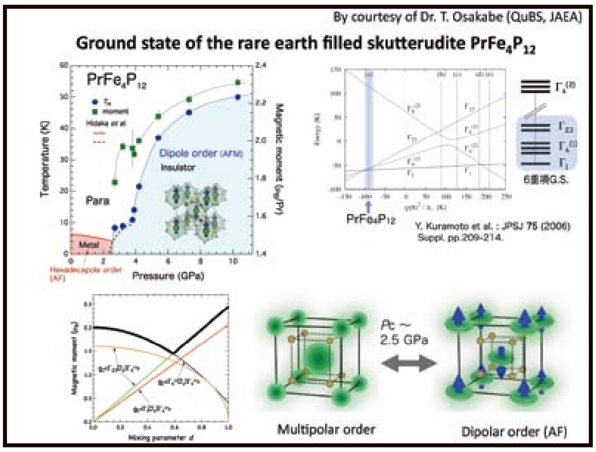
Outline

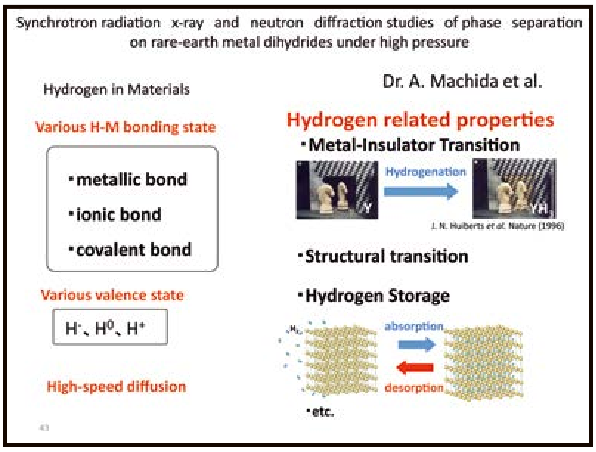
- Neutron Beam Fundamentals Development
- Development concerning the utilization of polarized neutrons
- **Development of focusing devices**
- Development of detecting devices

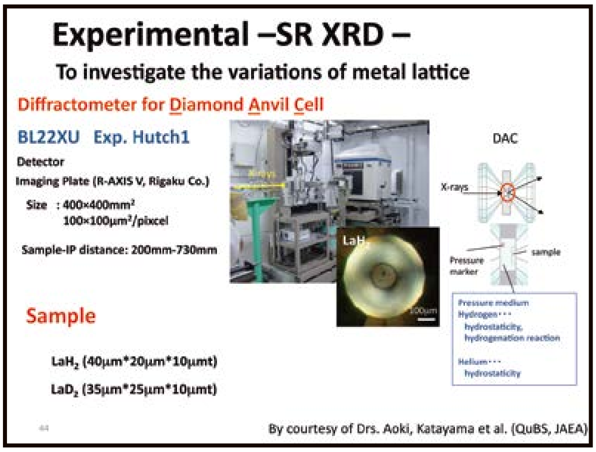


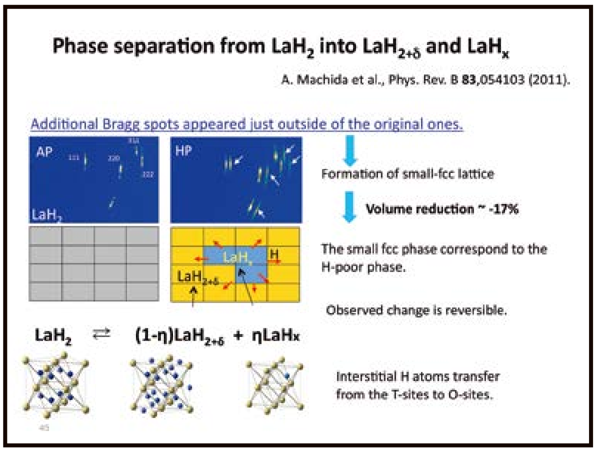


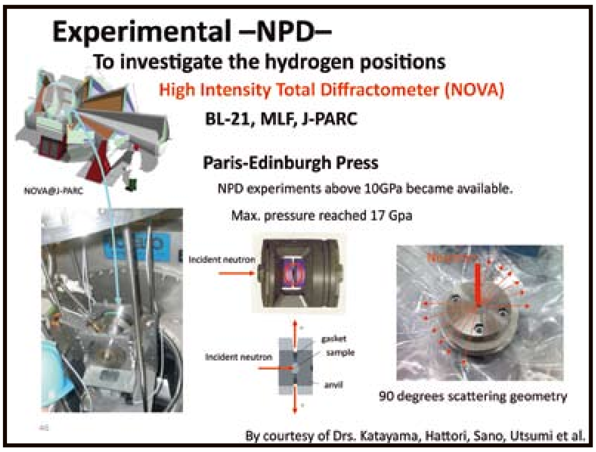


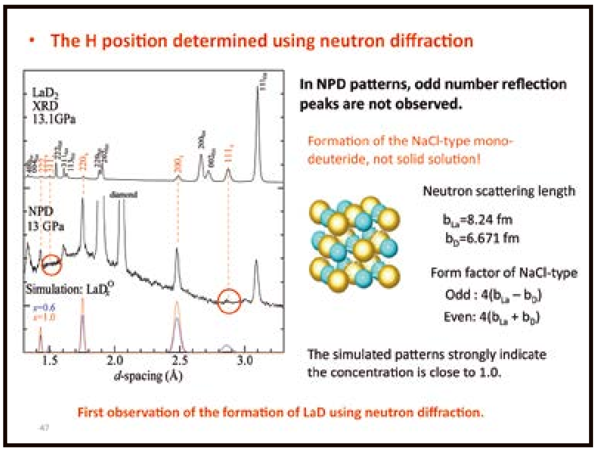


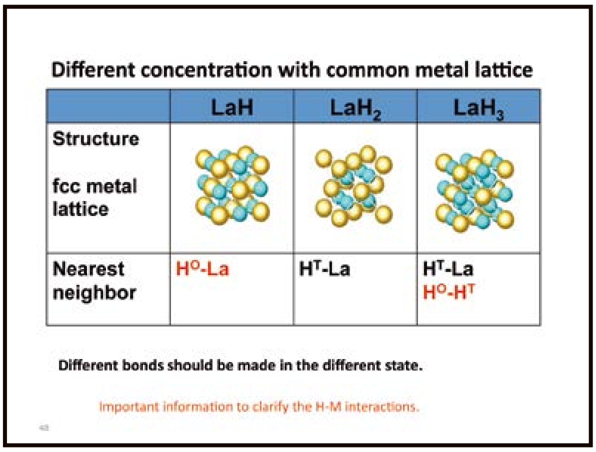

Synchrotron radiation x-ray and neutron diffraction studies of phase separation on rare-earth metal dihydrides under high pressure
Dr. A. Machida et al.
Hydrogen in Materials
Various H-M bonding state
・metallic bond
・ionic bond
・covalent bond
Various valence state
H⁻、H⁰、H⁺
High-speed diffusion
Hydrogen related properties
・Metal-Insulator Transition
Hydrogenation
J. N. Huiberts et al. Nature (1996)
・Structural transition
・Hydrogen Storage
absorption
desorption
・etc.

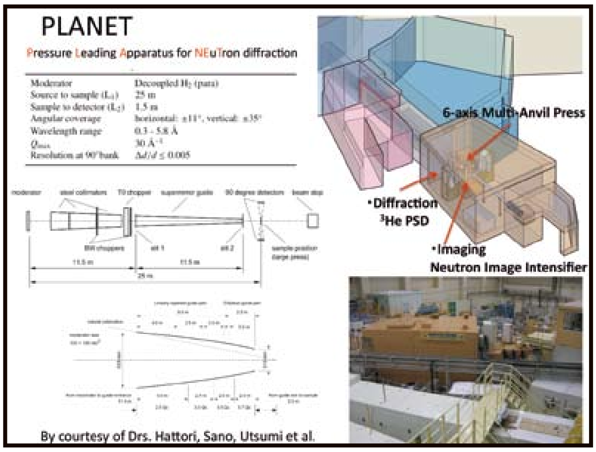

Experimental –SR XRD –
To investigate the variations of metal lattice
Diffractometer for Diamond Anvil Cell
BL22XU Exp. Hutch1
Detector
Imaging Plate (R-AXIS V, Rigaku Co.)
Size : 400×400mm²
100×100μm²/pixcel
Sample-IP distance: 200mm-730mm
Sample
LaH₂ (40μm*20μm*10μmt)
LaD₂ (35μm*25μm*10μmt)
DAC
X-rays
sample
Pressure marker
LaH₂
Pressure medium
Hydrogen・・・ hydrostaticity, hydrogenation reaction
Helium・・・ hydrostaticity
By courtesy of Drs. Aoki, Katayama et al. (QuBS, JAEA)

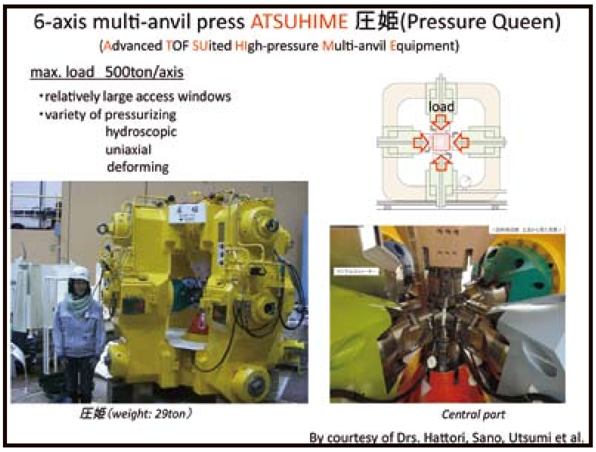

Phase separation from LaH₂ into LaH₂₊δ and LaHₓ
A. Machida et al., Phys. Rev. B 83,054103 (2011).
Additional Bragg spots appeared just outside of the original ones.
AP
HP
LaH₂
Formation of small-fcc lattice
Volume reduction ~ -17%
The small fcc phase correspond to the H-poor phase.
Observed change is reversible.
LaHₓ
LaH₂₊δ
H
LaH₂ ⇄ (1-η)LaH₂₊δ + ηLaHx
Interstitial H atoms transfer from the T-sites to O-sites.

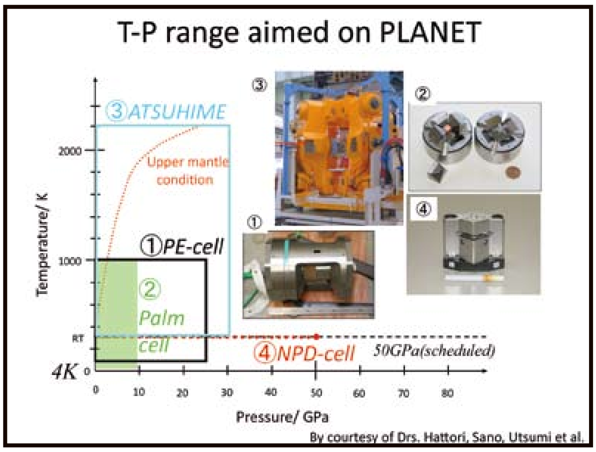

Experimental –NPD–
To investigate the hydrogen positions
High Intensity Total Diffractometer (NOVA)
BL-21, MLF, J-PARC
Paris-Edinburgh Press
NPD experiments above 10GPa became available.
Max. pressure reached 17 Gpa
NOVA@J-PARC
Incident neutron
gasket
sample
anvil
90 degrees scattering geometry
By courtesy of Drs. Katayama, Hattori, Sano, Utsumi et al.

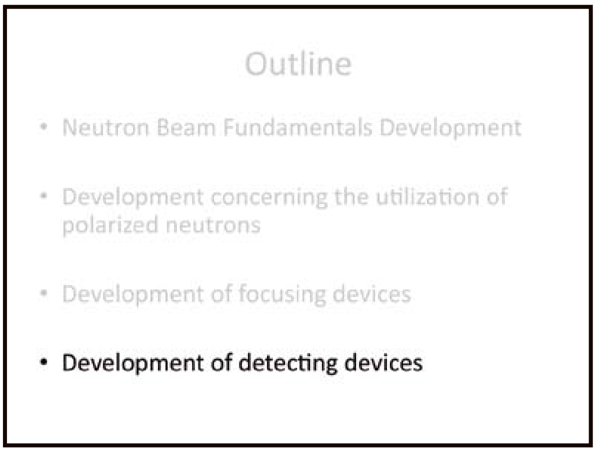

・ The H position determined using neutron diffraction
LaD₂
XRD
13.1GPa
NPD
13 GPa
diamond
Simulation: LaDₓᴼ
1.5
2.0
2.5
3.0
d-spacing (Å)
In NPD patterns, odd number reflection peaks are not observed.
Formation of the NaCl-type mono-deuteride, not solid solution!
Neutron scattering length
b_La=8.24 fm
b_D=6.671 fm
Form factor of NaCl-type
Odd : 4(b_La − b_D)
Even: 4(b_La + b_D)
The simulated patterns strongly indicate the concentration is close to 1.0.
First observation of the formation of LaD using neutron diffraction.

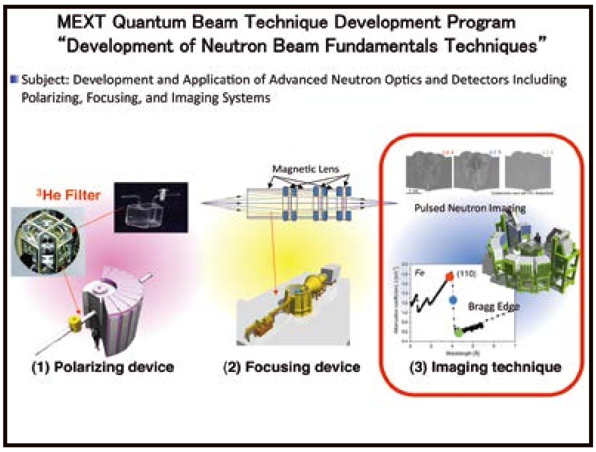

Different concentration with common metal lattice
LaH
LaH₂
LaH₃
Structure
fcc metal lattice
Nearest neighbor
Hᴼ-La
Hᵀ-La
Hᵀ-La
Hᴼ-Hᵀ
Different bonds should be made in the different state.
Important information to clarify the H-M interactions.

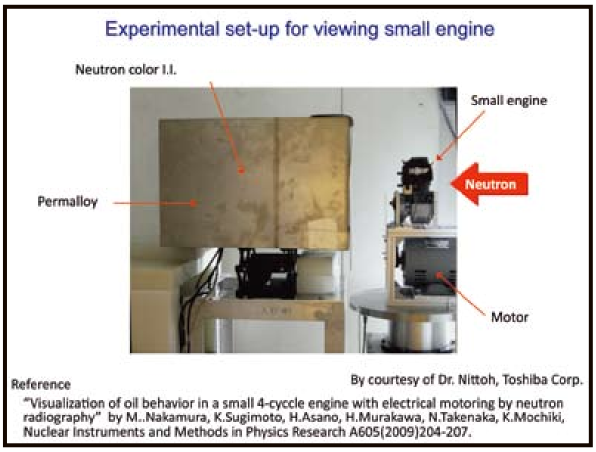

PLANET
Pressure Leading Apparatus for NEuTron diffraction
Moderator Decoupled H2 (para)
Source to sample (L1) 25 m
Sample to detector (L2) 1.5 m
Angular coverage horizontal: ±11°, vertical: ±35°
Wavelength range 0.3 - 5.8 Å
Qmax 30 Å-1
Resolution at 90° bank Δd/d ≤ 0.005
6-axis Multi-Anvil Press
•Diffraction
3He PSD
•Imaging
Neutron Image Intensifier
By courtesy of Drs. Hattori, Sano, Utsumi et al.

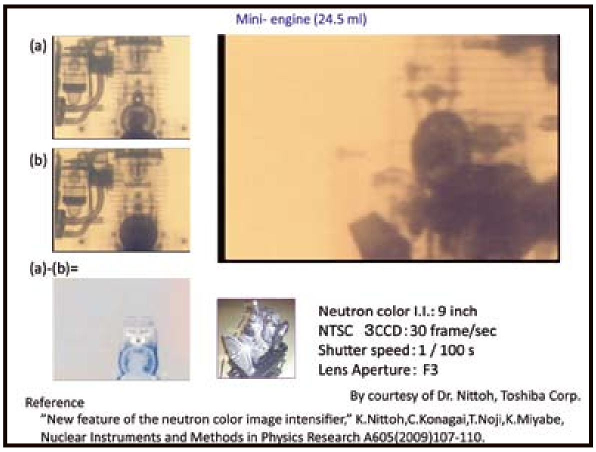

6-axis multi-anvil press ATSUHIME 圧姫(Pressure Queen)
(Advanced TOF SUited High-pressure Multi-anvil Equipment)
max. load 500ton/axis
•relatively large access windows
•variety of pressurizing
hydroscopic
uniaxial
deforming
load
圧姫(weight: 29ton)
Central part
By courtesy of Drs. Hattori, Sano, Utsumi et al.

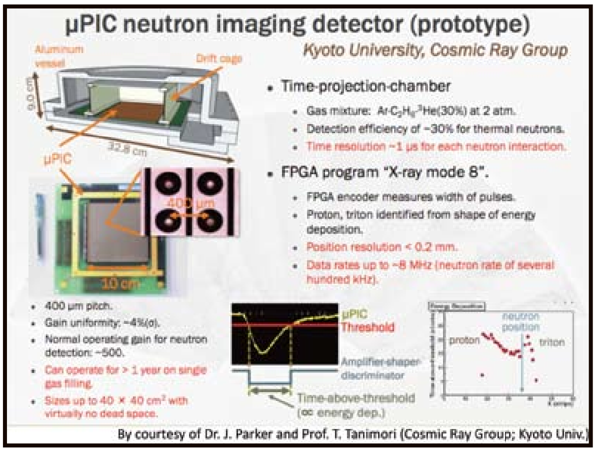

T-P range aimed on PLANET
③ATSUHIME
Upper mantle condition
①PE-cell
②Palm cell
④NPD-cell 50GPa(scheduled)
Temperature/ K
Pressure/ GPa
4K
By courtesy of Drs. Hattori, Sano, Utsumi et al.

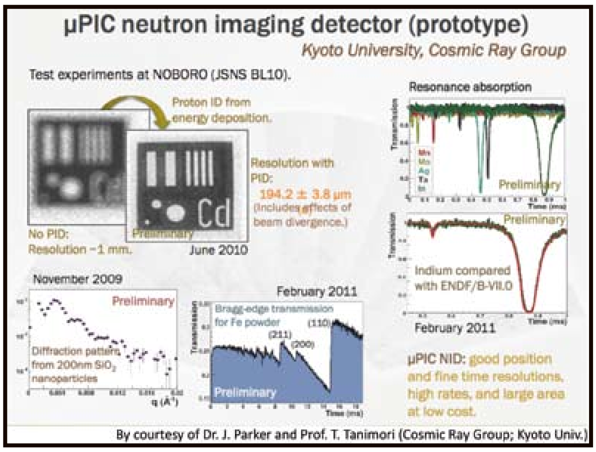

Outline
• Neutron Beam Fundamentals Development
• Development concerning the utilization of polarized neutrons
• Development of focusing devices
• Development of detecting devices

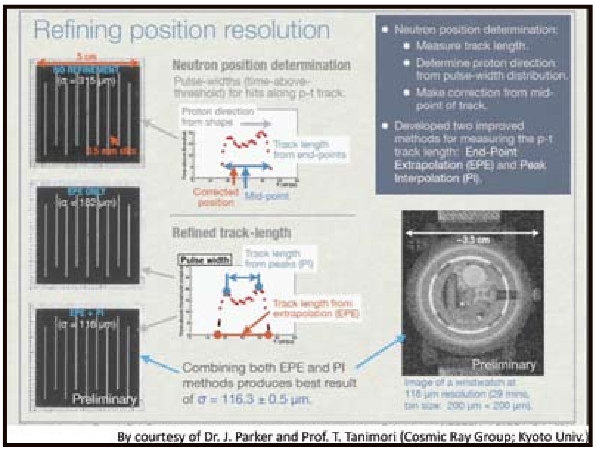

MEXT Quantum Beam Technique Development Program
"Development of Neutron Beam Fundamentals Techniques"
Subject: Development and Application of Advanced Neutron Optics and Detectors Including Polarizing, Focusing, and Imaging Systems
3He Filter
Magnetic Lens
Pulsed Neutron Imaging
Bragg Edge
(1) Polarizing device
(2) Focusing device
(3) Imaging technique

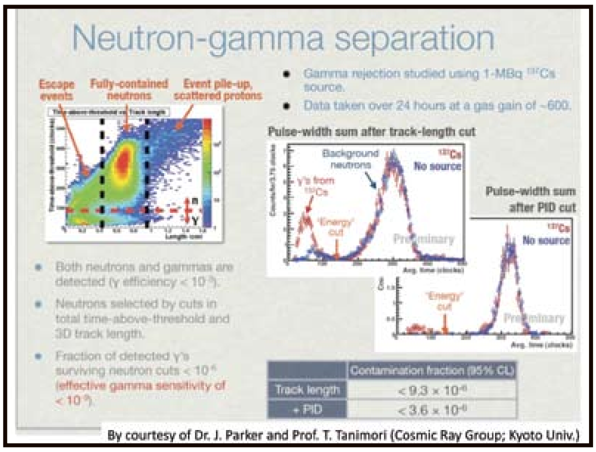

Experimental set-up for viewing small engine
Neutron color I.I.
Small engine
Neutron
Permalloy
Motor
Reference
By courtesy of Dr. Nittoh, Toshiba Corp.
"Visualization of oil behavior in a small 4-cycle engine with electrical motoring by neutron radiography" by M..Nakamura, K.Sugimoto, H.Asano, H.Murakawa, N.Takenaka, K.Mochiki, Nuclear Instruments and Methods in Physics Research A605(2009)204-207.

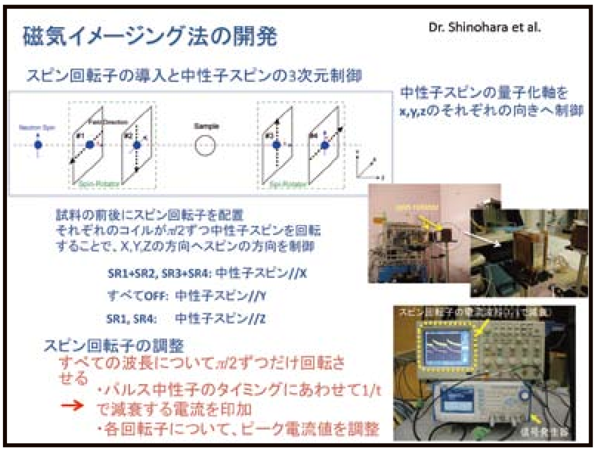

Mini- engine (24.5 ml)
(a)
(b)
(a)-(b)=
Neutron color I.I.: 9 inch
NTSC 3CCD : 30 frame/sec
Shutter speed : 1 / 100 s
Lens Aperture : F3
By courtesy of Dr. Nittoh, Toshiba Corp.
Reference
"New feature of the neutron color image intensifier," K.Nittoh,C.Konagai,T.Noji,K.Miyabe,
Nuclear Instruments and Methods in Physics Research A605(2009)107-110.

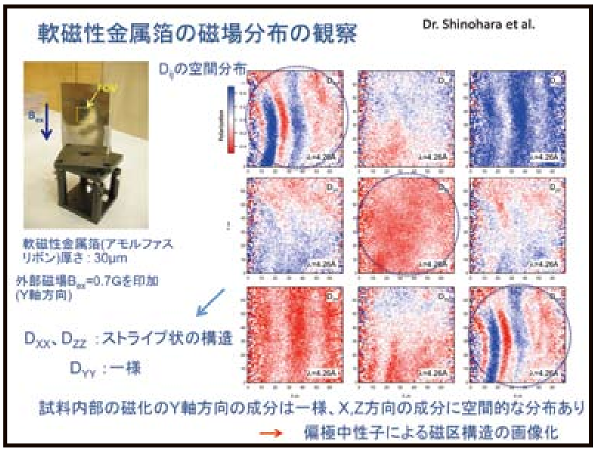

μPIC neutron imaging detector (prototype)
Kyoto University, Cosmic Ray Group
Aluminum vessel
Drift cage
9.0 cm
32.8 cm
μPIC
400 μm
10 cm
Time-projection-chamber
Gas mixture: Ar-C2H6-3He(30%) at 2 atm.
Detection efficiency of ~30% for thermal neutrons.
Time resolution ~1 μs for each neutron interaction.
FPGA program "X-ray mode 8".
FPGA encoder measures width of pulses.
Proton, triton identified from shape of energy deposition.
Position resolution < 0.2 mm.
Data rates up to ~8 MHz (neutron rate of several hundred kHz).
400 μm pitch.
Gain uniformity: ~4%(σ).
Normal operating gain for neutron detection: ~500.
Can operate for > 1 year on single gas filling.
Sizes up to 40 × 40 cm2 with virtually no dead space.
μPIC
Threshold
Amplifier-shaper-discriminator
Time-above-threshold
(∝ energy dep.)
neutron position
proton
triton
By courtesy of Dr. J. Parker and Prof. T. Tanimori (Cosmic Ray Group; Kyoto Univ.)


μPIC neutron imaging detector (prototype)
Kyoto University, Cosmic Ray Group
Test experiments at NOBORO (JSNS BL10).
Proton ID from energy deposition.
Resolution with PID:
194.2 ± 3.8 μm
(Includes effects of beam divergence.)
No PID:
Resolution ~1 mm.
Preliminary
June 2010
November 2009
Preliminary
Diffraction pattern from 200nm SiO2 nanoparticles
q (Å-1)
February 2011
Bragg-edge transmission for Fe powder
(110)
(211)
(200)
Preliminary
Time (ms)
Resonance absorption
Mn
Mo
Ag
Ta
In
Preliminary
Preliminary
Indium compared with ENDF/B-VII.0
February 2011
μPIC NID: good position and fine time resolutions, high rates, and large area at low cost.
By courtesy of Dr. J. Parker and Prof. T. Tanimori (Cosmic Ray Group; Kyoto Univ.)


Refining position resolution
5 cm
Neutron position determination
Pulse-widths (time-above-threshold) for hits along p-t track.
Proton direction from shape
Track length from end-points
Corrected position
Mid-point
Refined track-length
Pulse width
Track length from peaks (PI)
Track length from extrapolation (EPE)
Combining both EPE and PI methods produces best result of σ = 116.3 ± 0.5 μm.
Preliminary
Neutron position determination:
Measure track length.
Determine proton direction from pulse-width distribution.
Make correction from mid-point of track.
Developed two improved methods for measuring the p-t track length: End-Point Extrapolation (EPE) and Peak Interpolation (PI).
~3.5 cm
Preliminary
Image of a wristwatch at 116 μm resolution (29 mins, bin size: 200 μm × 200 μm).
By courtesy of Dr. J. Parker and Prof. T. Tanimori (Cosmic Ray Group; Kyoto Univ.)


Neutron-gamma separation
Escape events
Fully-contained neutrons
Event pile-up, scattered protons
Gamma rejection studied using 1-MBq 137Cs source.
Data taken over 24 hours at a gas gain of ~600.
Pulse-width sum after track-length cut
Background neutrons
γ's from 137Cs
'Energy' cut
137Cs
No source
Preliminary
Pulse-width sum after PID cut
137Cs
No source
'Energy' cut
Preliminary
Both neutrons and gammas are detected (γ efficiency < 10-3).
Neutrons selected by cuts in total time-above-threshold and 3D track length.
Fraction of detected γ's surviving neutron cuts < 10-6 (effective gamma sensitivity of < 10-9).
Contamination fraction (95% CL)
Track length < 9.3 × 10-6
+ PID < 3.6 × 10-6
By courtesy of Dr. J. Parker and Prof. T. Tanimori (Cosmic Ray Group; Kyoto Univ.)


磁気イメージング法の開発
Dr. Shinohara et al.
スピン回転子の導入と中性子スピンの3次元制御
中性子スピンの量子化軸を
x,y,zのそれぞれの向きへ制御
Sample
試料の前後にスピン回転子を配置
それぞれのコイルがπ/2ずつ中性子スピンを回転
することで、X,Y,Zの方向へスピンの方向を制御
SR1+SR2, SR3+SR4: 中性子スピン//X
すべてOFF: 中性子スピン//Y
SR1, SR4: 中性子スピン//Z
スピン回転子の調整
すべての波長についてπ/2ずつだけ回転させる
→
・パルス中性子のタイミングにあわせて1/tで減衰する電流を印加
・各回転子について、ピーク電流値を調整



Summary

The continuous development efforts on neutron beam fundamentals , such as polarized neutrons, focusing devices, etc. for both the continuous and pulsed source are essential for advanced neutron scattering investigations to realize state-of-the-art experiments such as magnetic structure determination, experiments under novel and extreme sample conditions .

Acknowledgement

MEXT(JST) Quantum Beam Technique Development Program
“Development of Neutron Beam Fundamentals Techniques”

and all members of this program
from JAEA incl. QuBS, J-PARC/MLF, KEK, Hokkaido Univ., Tohoku Univ., Tokyo Univ. and Kyoto Univ.