Development and Applications of “Mössbauer Cameras”

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Mössbauer Group at SIST

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“Mössbauer camera” to study microstructures in materials

CCD camera

Mössbauer camera

Readout time is too slow in X-ray camera (30ms)
“Mössbauer Camera” using PIAS + FOS

Mössbauer Driver + $^{57}$Co source

sample

Camera lens

PIAS

FOS + CsI (TI)

5cmx5cm / 500x500 pixels
Imaging by PIAS + FOS
“Mössbauer Camera” using a mapping Technique
Main program with LabVIEW
Mössbauer camera: mapping by focusing 14.4keV γ-ray

Shimazu H. Soejima

14.4keV γ-ray emitted from a $^{57}$Co-in-Rh source (50mCi) are focused on a sample by MCX lens (Soejima-Kumakov lens)

- focal distance: 58mm
- entrance diameter: 4mmφ
- spot size: 265μmφ
- transmission: 41% for 14.4keV

H. Soejima, Japan Patent 2014379(1986); 2001797(1988)
A mapping technique for Mössbauer spectroscopy

A measurement position is varied with a step size between 250 μm and 25 μm
Three stage MCP with a center hole and a grid
Hamamatsu Photonics K.K.

Space resolution: 50~100μm
The images are distorted at boundaries!
Instrumental set-up

- SEM
- MCX
- XY stage
- sample
- MCP
- Si-detector
- $^{57}$Co

Vac ~ $10^{-5}$ Pa
Mössbauer Camera using a mapping Technique

How to select an observation area by FE-SEM?
Mössbauer Camera

How to proceed the microscope operation corresponding three different input?
$^{57}\text{Fe}$ Mössbauer Effect

$^{57}\text{Fe}$ Mössbauer Effect

$^{57}\text{Fe}$

$^{14.4}\text{keV}$

$^{57}\text{Co}$

$^{14.4}\text{keV}$

$^{57}\text{Fe}$ 14.4 keV $\gamma$-ray: 1

$^{14.4}\text{keV} \gamma$-rays: 0.1

Conversion & Auger Electrons: 2

$^{6.4}\text{keV}$-X-rays: 0.27

E. Murad and J. Cashion 2004
Image Simulations for $100\text{nm}^{57}\text{Fe}+50/100\text{nm-Ag}$ in the case of conversion and Auger electrons mapping.

emission (Counts = 1±1)

emission (Counts = 10±3)
Image Simulations for 100nm$^{57}$Fe+50/100nm-Ag in the case of transmitted 14.4keV-$\gamma$-rays mapping

Transmission
(Counts=50000±224)

Transmission
(Counts=10000±100)
PHA spectra from MCP which depend on the energy of electrons?
Simultaneous measurements of mapping images using transmission and emission geometry

$^{57}$Fe deposited mc-Si

$^{14.4}$keV-$\gamma$-rays

electrons

$^{57}$Fe enriched FeNi alloy
A mapping image of electrons and FE-SEM picture
PHA spectrum of MCP corresponding to the measuring points
Mapping picture of SUS304
Observed image of $^{57}\text{Fe} + \text{Ag}$ deposited FZ-Si

3D mapping may be possible!

$^{57}\text{Fe}$ thickness: 50nm

Ag thickness: 20nm~210nm

FZ-Si (2.7×10^{15} \text{B/cm}^3)
Application for Fe contamination in mc-Si solar cell

Low efficiency due to defects
Mc-Si wafer contains a region with low minority carrier life time

150x150 mm mc-Si wafer

Lowτ region

High τ region

1.6 μs

42 μs
Mössbauer spectra of $^{57}$Fe doped FZ-Si, mc-Si

Atomistic information on $^{57}\text{Fe}$ through Hyperfine interactions between $^{57}\text{Fe}$ nucleus and electrons

Fe impurities in mc-Si solar cells

$^{57}\text{Mn}/^{57}\text{Fe}$ in Si

![Graph showing normalized counts vs velocity at different temperatures](image)
FINAL LATTICE SITES AND CHARGE STATES OF $^{57}\text{Mn}/^{57}\text{Fe}$ GeV- IMPLANTATION INTO Si


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Direct Observation of Fe states in the p-n junction of solar cells during operation under light illumination.

- Sun light: 100 mW/cm²
- Thickness ~200 mm
- Single Fe atom implantation deeply into p-n junction
- Direct observation of the carrier trapping process by Fe atoms
- $^{57}$Mn/$^{57}$Fe beam from RIPS

Diagram showing the p-n junction with labels for n-type, p-type, $P^+$, and Ag electrode.
Observed images of 1.5 nm-\textsuperscript{57}Fe deposited mc-Si (intentionally contaminated with \textsuperscript{57}Fe)

-3 \leq V_D \leq 3 \text{ mms}^{-1}

Clearly shown is that \textsuperscript{57}Fe distribute differently in different crystal grains
Different resonance conditions provide different images

All $^{57}$Fe components

- $-3 \leq V_D \leq 3 \text{ mms}^{-1}$

$V_D = 0 \text{ mms}^{-1}$

The image mainly corresponding to substitutional $^{57}$Fe component

The image mainly corresponding to interstitials and other clusters
Comparison with the results from minority carrier life-time & FTIR

Life time

FTIR mapping for isolated $O_{int}$
Observed images of mc-Si as received without intentional $^{57}$Fe contamination

$-3 \leq V_D \leq 3 \text{ mms}^{-1}$

$V_D = 0 \text{ mms}^{-1}$

Interstitial Fe and clusters

Substitutional Fe
pn-junction Si as received

-3 ≤ V_D ≤ +3 mms⁻¹

V_D = 0 mms⁻¹
A running project to achieve submicron spot size

**Fresnel Zone Plate**: \( \varnothing 250\mu m, \text{Ta thickness}=2.5\mu m, \text{width of most outer zone}= 250\text{nm}, \text{membrane}: \text{SiN } 2.0\mu m \)
Fresnel Zone Plate combined with MCX

Beam spot size: 250 nm transmission = 16% for 14.4keV

FZP (ATN/FZP-200/206) focal distance = 483mm

MCX beam = 265μmφ
Transmission = 35%
PHA spectrum of MCX+FZP at focal point

- **14.4keV-γ**
- **6keV-X**
The spot size reaches down to 3 μm.
Beam focus by FZP and other elements

- 1st order diffraction
- 2nd order diffraction
- Direct beam
- Pin hole collimator
- FZP
- γ-rays
Summary: “Mössbauer Camera”

1. **Imaging** by PIAS+FOS
   - Monochromometer for 14.4 keV $\gamma$-rays

2. **Mapping** by MCX: spatial resolution of 50 $\mu$m
   - Distortion of image

3. Applications for Fe impurity in Si-solar cells
   - Mapping under light illumination

4. **Mapping** by MCX + FZP: spatial resolution of 3 $\mu$m
   - Vibration of the set-up
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