Use of Microbeam at JAEA Takasaki

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1. Microbeam Production Systems at **TIARA** Facility

**Takasaki Ion accelerators for Advanced Radiation Application**

- **3MV Tandem Accelerator**
- **400kV Ion Implanter**
- **3MV Single-ended Accelerator**
- **K110 Cyclotron**

![Energy vs. Mass Number Graph]

- **AVF Cyclotron**
- **Tandem Accelerator**
- **Ion Implanter**
- **Several-MeV Light Ion Microbeam**
- **Several-Dozen-MeV Heavy Ion Microbeam**
- **Several-Hundred-MeV Heavy Ion Microbeam and Single-Ion Hit**
Production of Microbeam

- Primary beam
- Object slits
- Divergence-defining slits
- Quadrupole lenses
- Focal plane

Microbeam line

Heavy Ion Microbeam Line
- Several-dozen MeV

Light Ion Microbeam Line
- Several MeV
Spot Size of Light Ion Microbeam

Secondary electron mapping to measure the beam spot size

SEM (Scanning Electron Microscope) image of a silicon relief pattern

Scanning the microbeam

Intensity of Secondary Electrons

0.25 μm

0 0.4 0.8 1.2
Horizontal Position (μm)
2. Applications of the Microbeams

In-air Micro-PIXE Analysis Using 2 MeV Proton Microbeam

- Measurement System
  - In vacuum: X-ray detector for PIXE
  - In air: Microbeam, X-ray detector for PIXE, γ-ray detector for PIGE, Beam Scanner

- Cell: 2 dimensional distribution of elements in cattle blood vessel cell, 20μm x 20μm

- Tooth: Distribution of fluorine and calcium in tooth

Dental Sample

Graph: F Concentration (10^-6 ppm) vs. Position (μm)
Application of several-hundred-MeV heavy ion Microbeam

Beam spot size: $5 \sim 10 \mu m$

Single-ion hit rate: several hits/min

Elucidation of Cellular Radiation Response

- Investigation of cell-to-cell communications such as “bystander effects”
- Analysis of cellular spatial sensitivity, interaction of damages, dynamics of cellular repair and intra-cellular process like apoptosis
3. Development of a New High-Energy Heavy Ion Microbeam System

Several-hundred-MeV heavy ion beam ($\Delta E/E < 0.02\%$)
Preliminary Result

Observation of beam spot on a plastic scintillator

Fluorescence of beam spot

10 mm

Observation of beam spot on a plastic scintillator

High speed single-ion hit with targeting accuracy less than 1 μm

Several-hundred-MeV heavy ions applied to Mammalian cell

Cytoplasm

5~10 μm

Nucleus

Beam spot size

about 0.7 μm in diameter (achieved)

Single-ion hit rate

more than 600 hits / min (under development)
4. Generation of High Quality Beams by Upgrading Cyclotrons

Upgrade of AVF Cyclotron

- Flattop Acceleration System
  Energy Spread $\Delta E/E = 0.01 \sim 0.05 \%$

- Temperature Control System
  Magnetic Field Stability : $\Delta B/B < 0.001\%$

**TIARA Cyclotron Facility**

**Microbeam Applications**

Materials, Medical, Biological Sciences

**RCNP Cyclotron Facility**

**Ultrahigh Resolution Experiment**

Nuclear Physics
Development of Flattop Acceleration System

Superimposing the fifth harmonic voltage on the fundamental one

<table>
<thead>
<tr>
<th>Phase (degrees)</th>
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<td>-360</td>
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Relative Amplitude

-3.5 -3 -2.5 -2 -1.5 -1 -0.5 -0.25 0 0.25 0.5 1 1.5

Fundamental
Fifth harmonics

Pickup signal of V1+V5

-0.2 V

17.4 MHz
Single Turn Extraction

**Ordinary Acceleration**

Turn pattern before extraction

- Beam Current ($\mu$A)
- Probe Position (mm)
- $V_1 = 36.502$ kV
- $V_5 = 0.0$ kV

**Multiturn extraction**

Beam bunch for single-pulse injection

**Flattop Acceleration**

- Beam Current (nA)
- Probe Position (mm)
- $V_1 = 32.7$ kV
- $V_5 = 1.2$ kV

260 MeV $^{20}\text{Ne}^7+$
@ JAEA AVF Cyclotron

**Single turn extraction**

Beam bunch for single-pulse injection
Temperature increase caused by heat from coils: $\Delta t_{\text{yoke}} \approx 5$ °C

**Magnetic field stability:** $\Delta B/B \approx 3 \times 10^{-4}$

- Insertion of water cooled plate for heat shielding
  $\Delta t_{\text{yoke}} \approx 0.1$ °C
- Stabilization of cooling water temperature for coils
  $\Delta t_{\text{coolant}} \approx 0.5$ °C

$\Delta B/B \approx 1 \times 10^{-5}$
High Quality Beam at RCNP Cyclotron Facility

Energy Resolution
$\Delta E/E \sim 0.005\%$

Ring Cyclotron
$K=400$ MeV
$\Delta E/E \sim 0.01\%$
Since 1992

Stability of Magnetic Field
$\Delta B/B < 0.001\%$

Upgraded recently

Grand Raiden

AVF Cyclotron
$K=140$ MeV
$\Delta E/E < 0.1\%$
Since 1973
Ultrahigh Energy Resolution Experiment Using the High Quality Beam

Lateral and Angular dispersion matching between WS-beam line and Grand RAIDEN

Ultrahigh resolution of $\Delta E = 12.8$ keV

World record!!

Ordinary resolution $(p,n)$ measurement

Ultrahigh resolution $(^3\text{He},t)$ measurement

Comparison of resolutions

$$\Delta E = 12.8\text{ keV}$$

RCNP 2001

$^{58}\text{Ni}(^3\text{He},t)$

$E = 140$ MeV/u

$\Delta E = 35$ keV

$IUCF$

Ordinary resolution $(p,n)$ measurement

RCNP

$IUCF$
## 5. Summary

### Microbeams available at TIARA, JAEA Takasaki

<table>
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<th>Microbeam</th>
<th>Accelerator</th>
<th>$\Delta E/E$</th>
<th>Ion</th>
<th>Spot size</th>
<th>Applications</th>
</tr>
</thead>
</table>
| Light ion        | 3MV Single-ended     | $10^{-5}$    | 2~3 MeV H, He    | 0.25 $\mu$m | - Micro-PIXE analysis
                   |                      |              |                  |           | - PBW (Proton Beam Writing)                                                  |
| Heavy ion        | 3MV Tandem           | $10^{-4}$    | H ~ Au           | <1 $\mu$m  | - Analysis of single event phenomena in semiconductor devices               |
| High-Energy Heavy-ion | K110 AVF Cyclotron | $>10^{-3}$ (original) | H ~ Xe          | 5 ~ 10 $\mu$m (Collimation)         | - Elucidation of Irradiation effects to living cells |
|                  |                      | $10^{-4}$ (new) | 260 MeV Ne      | < 1 $\mu$m (Focussing)              |                                               |