Positron Probe Microanalyzer (PPMA) and other accelerator based slow positron facilities at AIST

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Smolenice Castle, Slovakia, 7th Sept 2011
AIST LINAC-based Slow Positron Beam

PPC10 Slovakia, 7th Sept 2011
AIST LINAC-based Slow Positron Beam

Positron / Ion combined Beamline

PPMA
PALS

TOF-PAES

Linear Storage Section

Pair Production

Positron

Sample

Bremsstrahlung

Ion

Sample

W moderator
RI-based PALS

$^{22}\text{Na} 1 \text{ GBq}$
Counting rate $\sim 4,000$ cps
Time resolution $< 200$ ps

Time resolution $\sim 250$ ps

Best resolution: 155 ps

Commercially available from FUJI IMVAC Inc.
Positron Probe Microanalyzer (PPMA)

http://www.aist.go.jp/aist_j/press_release/pr2008/pr20080828_2/pr20080828_2.html
PALS System for Positron Microbeam

Intense e\(^+\) microbeam

Microchannel plates

Bellows

Vacuum chamber

Objective lens

\(\gamma\)

Ba\(_2\)F\(_2\) scintillation detector

PAL spectra with micro beam

Resolution < 200 ps
Diameter: <30 \(\mu\)m

Counting rate:
1-3k cps for 30 um
Positron Probe Microanalyzer (PPMA)

http://www.aist.go.jp/aist_j/press_release/pr2008/pr20080828_2/pr20080828_2.html

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Brightness Enhancement System

Beam diameter vs. Energy (eV)

Magnetic guide (~20m)

Extraction Coil

Focusing Lens

Positron Source (Moderator)

Spiral Orbit

Gathing Center Orbit

Virtual Positron Source

2r0

2r

α

Zmin

RF


Pulsing system

Moderator

~ keV

Reemission of positrons

~ eV

0.25 or 0.5 m

MCP

Electrodes

WD=10mm

Remoderator

Yoke

Vacuum Wall

0.1 m

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NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)
Beam Diameter / Time Width of Bunch

- **Beam Diameter**:
  - Pulser Width: 5 - 10 ns

- **Beam Size**:
  - ~10 mm (FWHM) in solenoid
  - ~1 mm (FWHM) at remoderator
  - ~25 μm (FWHM) at sample

- **Intensity**:
  - 48 mm x 7 mm

- **Counts**:
  - 2-3 kcps for PALS

- **Materials**:
  - Ta
  - SiO₂

References:

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3-D Mapping of Defects

- **Diameter:** <30 μm
- **Resolution:** ~200 ps
- **Counting rate:** 1-3k cps for 30 μm


Defects created by Ar⁺ and H⁺

- **H⁺ ion beam**
  - (50 keV, 10¹⁶ cm⁻²)
- **Ar⁺ ion beam**
  - (150 keV, 10¹⁸ cm⁻²)

- **Sample**
  - 1 pixel: 50 μm x 50 μm (≈1 s/pixel)
  - total: 3500 pixels

- **Mean impl. Depth (Energy)**
  - 200 nm (4.7 keV)
  - 350 nm (6.4 keV)
  - 500 nm (7.8 keV)

- **Depth**
  - 600 nm
  - 200 nm

- **Lifetime**
  - short
  - long

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PPMA – Ductile Fractured Iron Sample

nominal strain

$\varepsilon = 0 \% \quad 0.5 \% \quad 0.5 \% \quad 2.9 \% \quad 14.7 \%$

(PPMA parameters)

Beam energy : 25 keV
Beam diameter : 50 $\mu$m
Scanning step : 50 $\mu$m$^2$ (gauge area)
100 $\mu$m$^2$ (chuck area)
$\gamma$-ray counts : 5000 / pixel
Measurement points : 10,000 / image

average positron lifetime

130 ps 180 ps
Extraction of Slow Positrons to Air

N. Oshima et al., Appl. Phys. Express 4, 066701 (2011)
Nanotechnology shared infrastructure

IBEC Innovation Platform

Nano Characterization

Nano Processing Facility (NPF)

Manufacturing Center

Electron Microscope

Research Support

Technical Training

HR-NMR

MEMS Foundary

http://www.open-innovation.jp/ibec/
AIST Electron Accelerator Facility

300 MeV e⁻ LINAC (1979– )

New e+ beamline (PPMA, PALS)

Existing e⁺ facilities (PALS, PPMA, PAES)

Slow e⁺ beamline (1988– )

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Goal:

To increase the speed and efficiency and volume of our PALS and PPMA measurements.

Current Situation:

Under construction. Should be ready for tests with electrons soon and first positrons within this fiscal year (March 2012).
New Positron Beamline

RF Buncher (125 MHz)

RF Buncher (125 MHz)

Re-moderator

Linear Storage Section

Concrete Wall

Positron Converter & Moderator

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AIST Electron Accelerator Facility

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Superconducting Accelerator (SCA)

- CW or high duty operation
- 24 h operation
- Energy gain 7.5 MeV
- High power (> 10 kW)
Current Situation at AIST

Current LINAC

SCA Module 1 (Present Position)

Positron Experimental Room

10 m
Monte Carlo Simulation

Step 1: Calculate energy and angular emission distributions of fast $e^+$

Step 2: Calculate the depth distribution profile of $e^+$ absorbed in W

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Slow Positron Production

\[
\gamma_N = 0.28(E_e - 3)^{1.35} - 0.4
\]

\[
\gamma_N = 0.28(E_e - 3)^{1.35} - 0.4
\]

\[
\frac{\gamma_s(5\,\text{MeV})}{\gamma_s(70\,\text{MeV})} = 0.4\%
\]

\[
\frac{\gamma_s(10\,\text{MeV})}{\gamma_s(70\,\text{MeV})} = 3\%
\]

Maximum Slow Positron Yield

Beam Heating of the Converter

\[ P_w = \frac{(T_b - T_w)2\pi\lambda l}{0.5 + \ln(r_2/r_1)} \]

\[ P_r = 2e\sigma \left( \int_0^{r_2} (T(r)^4 - T_0^4)2\pi r dr \right) \]

\[ E_d I_e = P_w + P_r \]
Maximum Slow Positron Yield

Electron Current, $I_e$ (μA)

Electron Energy, $E_e$ (MeV)

$T > 3270$ K

SCA: 5 – 15 MeV

70 MeV LINAC

Summary

• **PPMA:**
  - PALS measurements possible with a microbeam (30μm)
  - 2-D and 3-D defect imaging (Beam Energy 0 – 30 kV)
  - Extraction of positron microbeam to air

• **New Positron Beamline:**
  - Currently under construction (scheduled completion this fiscal year Mar 2012)
  - Vertical beamlines for PALS and PPMA
  - Initially operated using existing LINAC (70 MeV), in future will be synchronous with SCA

• **Superconducting Accelerator (SCA)**
  - High pulse repetition rate, no e+ pulse stretching and chopping
  - Low energy but high current, beam heating in the converter/moderator will be a challenge
THANK YOU

and thanks to our collaborators;

• Positron Probe Microanalyzer
  M. Fujinami (Chiba Uni.)
  A. Uedono (Tuskuba Uni.)

• New Positron Beamline
  Vacuum Products Inc.

• Superconducting Accelerator
  N. Hayashizaki (Tokyo Inst. Tech)
  E. Minehara (Wakasa-Wan Energy Res. Centre)
  TIME Inc.