Performance of a µPIC-based Neutron Imaging Detector

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Outline

- Prototype detector
- Performance of FPGA DAQ
- Neutron/gamma separation
- Position resolution
- Demonstration measurements
  - SANS
  - Resonance absorption
  - Bragg edge transmission
Neutron imaging detector prototype

- 10 × 10 cm² μPIC.
- Gas mixture: Ar-C₂H₆-³He (up to 2 atm total pressure).
- Gas gain < 1000 for neutron imaging.
- Detection efficiency: up to ~30% for thermal neutrons.
- Position resolution: < 0.4 mm; time resolution: ~1 µs (for each neutron event).
Simultaneous measurement of position and energy deposition at high rates.
Test experiments at J-PARC

- JSNS beam power ~120 kW.
- Ar(63%)-C\textsubscript{2}H\textsubscript{6}(7%)-\textsuperscript{3}He(30%) at 2 atm (detection efficiency ~28%).
- Same gas filling used for both experiments (separated by 8 months).

NOBORU beam line

- Pressure decreased by ~1%.
- Gain decreased by ~33%.
- Gain recovered by increasing anode voltage.
Neutron pulses and DAQ rate

- Data rates from 100 kHz ~ 4.5 MHz.
- Live time from 15 ~ 60%.
- External TOF gate to reduce dead time.

**DAQ bottlenecks**
- Encoder output buffer (limits DAQ rate).
- VME-to-PC data transfer (limits DAQ live time).

**Preliminary**

- ~16000 pulses
- Single pulses
- Time (ms) 0 10 20 30 40 50 60 70 80 90 100
  - 30 MHz
  - 100 MHz
  - External gate
  - Output buffer
  - LVDS
  - VME-to-PC
  - VME memory
  - Output buffer (limits DAQ rate).
  - VME-to-PC data transfer (limits DAQ live time).
Neutron/gamma separation

* Neutrons selected by cuts in total energy deposition and 3D track length.
* Fraction of γ’s surviving cuts < $6 \times 10^{-5}$.
Position resolution with PID

Position from mid-point of p-t track.
 Resolution: $960 \pm 105 \, \mu m$ ($\sigma$)

Beam setup

- Slits 1,2: $6 \times 6 \, cm^2$.
- 1-cm Polyethylene degrader.

Resolution from edge:
$349 \pm 36 \, \mu m$ ($\sigma$)
(Includes beam divergence)
Position resolution

Beam setup

* Slit 1: 0.3×0.3 cm².
* Slit 2: 6×6 cm².
* Rotary collimator (1×1 cm²).
* Two 2.54-cm Bi monocrystal filters.
Position resolution from grid

Fit function
Gaussian resolution convoluted with step function.

\[ I(x) = \frac{1}{2} A \left[ \text{erf} \left( \frac{a - \mu + x}{\sigma \sqrt{2}} \right) + \text{erf} \left( \frac{a + \mu - x}{\sigma \sqrt{2}} \right) \right] \]

Preliminary

\[ \sigma = 315 \pm 15 \text{ \( \mu m \)} \]

(includes beam divergence)
Small-angle neutron scattering

Spherical SiO$_2$ nanoparticles
Diameter: ~200 nm.
Sample distance: 1666 mm.
Beam size: 4 × 4 mm$^2$.
DAQ rate: 520 kHz.
Exposure time: 35.0 min.

Distance from beam center

q vs Neutron wavelength

q projection
(6 < $\lambda$ < 10 Å)
Resonance imaging

- Known resonance at 132 eV (TOF = 90.9 µs).
- Observed at 90.86 ± 0.23 µs.

Assorted metals
- DAQ rate: 1.48 MHz
- Exposure time: 5.5 min

Neutrons at resonance energy for selective imaging.

Transmission for $^{59}$Co

- Known resonance (TOF = 90.9 µs).
- Observed at 90.86 ± 0.23 µs.

$^{59}$Co (TOF = 90.9 µs)

$^{23}$Na (TOF = 19.6 µs)
Resonance imaging

- Bismuth filter
  - Absorption peaks at 800 eV (37 µs) and 2310 eV (22 µs).
  - Dip on high side due to event pile-up.
Resonance imaging

Indium
Tantalum
Gold
Molybdenum
Copper
Manganese

Sample thicknesses between 5 and 1000 µm.
Bragg edge transmission

78 × 40.5 × 10 mm³ TIG welded 316L stainless steel plate

* Edge spacing consistent with FCC crystal structure.
Strain from transmission

- Strain from variation in edge position.
- Transmission gives strain component along beam.
- Full strain tensor requires measurements at multiple angles.

‘Pixel’ size of 4.8 \( \times \) 4.8 mm\(^2\).

Edge positions by fit procedure from Santisteban, et al. (2001).

\[
\begin{align*}
\text{Edge position (Å)} & \quad \text{(111)} \\
\text{Preliminary} & \\
\text{Weld center-line} & \\
\text{Edge position (Å)} & \quad \text{(200)} \\
\text{Preliminary} & \\
\text{Edge position (Å)} & \quad \text{(220)} \\
\text{Preliminary} & \\
\text{Edge position (Å)} & \quad \text{(311)} \\
\text{Preliminary} & \\
\end{align*}
\]
Transmission spectra

Pixels in the weld region.

Some edges are not clear.

Fit function

\[ Tr(t) = e^{-n_w \sigma_0} \left[ e^{-n_w \sigma_{hkl}} + \frac{1}{2} \left(1 - e^{-n_w \sigma_{hkl}}\right) \right. \]
\[ \times \text{erfc} \left(-\frac{t - t_{hkl}}{\sigma \sqrt{2}}\right) \]
Lattice parameter and strain

* For cubic crystal:

\[ a = d_{hkl} \sqrt{h^2 + k^2 + l^2} \]

* Component of strain along beam direction:

\[ \varepsilon = \frac{a - a_0}{a_0} \]

* To measure complete strain tensor, measurements of several different directions are required.
Summary

- TPC based on micro-pattern gaseous detector and FPGA DAQ system.
  - Position resolution of ~0.3 mm; time resolution of ~1 µs.
  - DAQ with high data rates, external TOF gate.
  - Strong rejection of background gammas and fast neutrons.

- Detector operation remains stable over long time.
  - Annealing to reduce outgassing for increased long-term gain stability.
  - Gas filtration system might extend operation almost indefinitely.

- Third detector test at J-PARC in 2011.
  - Position resolution with shorter drift cage.
  - Bragg edge transmission with simpler sample.

- µPIC system is available in 10×10 cm², 20×20 cm², and 30×30 cm².
  - Second 10-cm system built for JAEA.
  - Now setting up 20-cm neutron imaging detector for use at Kyoto University.