Neutron and Photon Detector Workshop

MCP Detector Development

Basic Energy Sciences
U.S. Department of Energy

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Outline

- Introduction – MCPs and their conversion into Neutron Detectors
- Examples of Current Neutron Applications
- Ongoing R&D
  - Large area MCP PSD detectors
  - Gamma rejection
- Summary
Microchannel Plate Formats

~1mm thick glass wafers with millions of microscopic channels – each channel an ‘independent photomultiplier tube’. Very widely used since ‘70s for e-, ion, UV and soft X-ray detection and imaging. Often used in space science. Mass produced for decades for commercial image intensifier tubes.
MCP Pores – typ. diameter 8µm, and 10µm c-c …this determines the ~10µm spatial resolution

MCP thickness is ~1mm
microchannel L/D ~ 120:1
Etched MCP Fabrication

Using a fiber optic draw technique, an outer 1” cladding tube is first mated with an acid-etchable solid glass core bar.

2nd draw

Solid glass cores require chemical etch of core glass.

Core/Clad Mono Draw

1st multifiber bundle

2nd stacked multifiber bundle, which is fused, cut into 1mm wafers and surface polished.

Final 1mm thick MCP wafer ready for surface activation.

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Microchannel Plate Operation

Typical MCP structure

Bias voltage ~ 1.5 kV across 1mm thick MCP for neutrons. Needs to operate at <10^{-6} torr
Various MCP imaging readouts exist:

RAE, W&S, ‘MAMA’ (Hubble Telescope), Cross Grid (CHANDRA Telescope), Cross-Strip, Cross-Delay Line, Medipix/Timepix
Conversion of MCPs
Into Neutron Detectors
$^{10}\text{B}$ (or Gd)-doped MCP Glass Provides Highly Effective Neutron Detection

Example MCP structure
Neutron-Sensitive MCP Approach

- $^{10}\text{B}$ (and/or Gd) incorporated into base glass (e.g., 10-15 mol% $^{10}\text{B}$) by Nova Scientific.
- Reactants create secondary electrons - reactant ranges matched to channel wall thickness
- Secondary e$^-$'s avalanche to large (>10$^6$ e-) output pulses (sub-ns)
- Thermal neutron absolute efficiency >50%
- but sensitivity/cm$^2$ > $^3\text{He}$ (3 atm.) by 1.7x
Measured Cold Neutron (5 meV) Efficiency ~70% (B/Gd-doped MCP, 0.8mm thick)

A. Tremsin et al., NIM 628 (2011) 415
Modeling: MCPs compared to $^3$He and $^{10}$B-lined tubes

Modeling supported by DNDO* to develop MCPs as small and medium format SNM detectors.

Assisted by N.J. Carron

*DNDO SBIR
HSHQDC-11-C-00130
Comparing MCP, $^3$He, and $^{10}$B-lined glass density

<table>
<thead>
<tr>
<th></th>
<th>Glass density</th>
<th>$^{10}$ B wt%</th>
<th>Gd wt%</th>
<th>Thermal neutron mean free path In solid glass</th>
<th>Thermal neutron mean free path In MCP ($f_{open} = 0.5$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCP NVN-7 10 cm diam</td>
<td>2.52</td>
<td>15.2</td>
<td>0</td>
<td>0.011 cm</td>
<td>0.022 cm</td>
</tr>
<tr>
<td>$^{3}$He tube 1” diam 12” length 3 atm</td>
<td></td>
<td></td>
<td></td>
<td>In 3 atm $^{3}$He</td>
<td>2.56 cm</td>
</tr>
<tr>
<td>$^{10}$B-lined tube 1” diam 12” length</td>
<td>Thickness of $^{10}$B layer</td>
<td></td>
<td></td>
<td>In solid $^{10}$B</td>
<td>3.6 μm</td>
</tr>
</tbody>
</table>

Parameters for calculating response as a function of neutron energy; thermal neutrons; also to a moderated spectrum.
### Comparison Results (calc.)

<table>
<thead>
<tr>
<th>Detector</th>
<th>Face-on area (cm²)</th>
<th>cts/sec at $E_{\text{thermal}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal incidence</td>
</tr>
<tr>
<td>NVN-7 MCP</td>
<td>78.5</td>
<td>60</td>
</tr>
<tr>
<td>He tube, 3 atm</td>
<td>76.2</td>
<td>37</td>
</tr>
<tr>
<td>B-lined tube</td>
<td>76.2</td>
<td>10</td>
</tr>
</tbody>
</table>

**Count rate in a planar thermal neutron flux of $1 \text{n/cm}^2/\text{sec.}$**

<table>
<thead>
<tr>
<th>Detector</th>
<th>1 mm</th>
<th>2 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVN-7. 10 cm diam. 76% charged particle escape efficiency</td>
<td>18.4</td>
<td>21.5</td>
</tr>
<tr>
<td>He tube. 3 atm. 1”D×12”L 90% charged particle detect efficiency</td>
<td></td>
<td>13.8</td>
</tr>
</tbody>
</table>

**Counts/sec in an isotropic moderated spectrum of $1 \text{n/cm}^2/\text{sec.}$**
Recent Neutron Science Applications with MCPs
Tomographic Reconstruction:
MCP Neutron Imager, ~1 µs time resolution
(ICON beamline at PSI, 2009)

Cold neutrons
L/D 350:1, ~$10^7$ flux
MCP/Timepix readout
55 µm pixels
201 projections/150 sec

DOE STTR: Nova Scientific / UCal-Berkeley
#DOE DE-FG02-07ER86322
Tomography Animations

Raw data obtained by Anton Tremsin and UCal-Berkeley high resolution MCP detector group. FRM-II/ANTARES beamline at Technical University Munich, 1/09. A. Kaestner, image reconstruction; M. Muehlbauer, 3D visualization.
Recent DOE and NIST-Supported Neutron Science Experiments

- Very high resolution real-time radiography (~10 µm) and tomography
- Energy-resolved imaging at a pulsed source
- Time-of-flight transmission diffraction
- Material strain measurements
- Dynamic magnetic field measurements through neutron spin interaction with magnetic fields
- MCPs as collimators
- Collaboration with UCal-Berkeley SSL MCP group.
MCP Detector with Medipix/Timepix Readout

DOE STTR: Nova Scientific + UCal-Berkeley,
#DOE DE-FG02-07ER86322

- 256 x 256 array of 55 μm pixels
- 100 kHz/pixel
- Frame rate: 1 kHz
- Low noise (<100e⁻) = low gain operation
- ~1 W watt/chip, abutable
- Developed at CERN
Energy Resolved Imaging

MCP time resolution ~1 µs for thermal neutrons

Inherent MCP time resolution is ~150ps, for front surface detection (electrons, UV, soft X-rays, etc.)

For thermal neutrons, 1mm MCP thickness and uncertainty of neutron Interaction in MCP bulk, limits Δt to ~1 µs. But Δt ~100 ns for epithermal

Bragg edge (thermal) strain mapping at ISIS. Also did NRAI (epithermal)

A. Tremsin
Transmission images of the belt mount at the resonance energy of Ag and away from it, same area as highlighted. (a) Transmission image obtained with neutrons around 1.63 eV. (b) Image obtained at 5.3 eV at the silver resonance. Both images are normalized by the open beam and represent the spatial variation of transmission coefficient at the corresponding neutron energy.

IEEE NSS, October 2011, Valencia, Spain
Phase Contrast Imaging, Dynamic Magnetic Field Imaging


Some Recent Publication Collaborators….
with A. Tremsin (Berkeley SSL) and NOVA Scientific

University of California at Berkeley, CA, USA
J. B. McPhate, J. V. Vallerga, O. H. W. Siegmund

Rutherford Appleton Laboratory, ISIS Facility, UK
W. Kockelmann, A. Paradowska, S. Y. Zhang, E. Schooneveld, J. Kelleher

Paul Scherrer Institute, Switzerland
E. Lehmann, L. Josic, A. Kaestner

Technische Universität München, Forschungs-Neutronenquelle
FRM-II, Germany
M. Muehlbauer, B. Schillinger

Spallation Neutron Source, Oak Ridge National Laboratory, USA

European Spallation Source Scandinavia
A. Steuwer

Helmholtz-Zentrum Berlin für Materialien und Energie GmbH
N. Kardjilov, M. Dawson, M. Strobl, I. Manke
Just underway: Neutrons in Biology.
NIH myelin study using MCPs

Diffractometer D16 at ILL, where benchmark murine PNS and CNS myelin diffraction data was obtained from a recording of intensity in 2010 (w/D.Kirschner), using $^3$He PSD setup. At NIST’s NCNR, (also with Kirschner) we will test an MCP imaging detector with CNS myelin.
NIH SBIR Ph.I
Ongoing MCP R&D
MCPs must operate under high vacuum (<10^{-6} torr)

Vacuum Sealed ‘Tube’ Enclosures
Examples of ‘Old Style’ Sealed Round MCP Tubes

Custom tube produced for Nova’s DNDO SBIR program, by Sensor Sciences (Walnut Creek, CA).

Image intensifier tubes volume production 8 -12 tubes per production station (e.g., ITT, old Litton).

DNDO SBIR #HSHQDC-11-C-00130
Square Tube Format

2” square sealed MCP tube shown – the ‘Planacon’ from Photonis. Hamamatsu has a similar product, but neutron-sensitive MCPs have never been sealed and used by either. Current development program (ORNL SNS/Nova) will produce 8” square sealed MCP PSD ‘modules’ for neutron applications.
Sealed Tube Schematic

No photocathode necessary for neutrons
Electroded 8” substrate ~2000Å Inconel on both sides for HV bias.

Still under development for DOE’s LAPPD HEP program by Incom, currently 20 µm pores, need 8 µm for neutrons, plus $^{10}$B doping of the raw MCP glass melt.

Mount MCPs in tandem, for gain levels of $>10^6$ e-/pulse
Bottle Fusion vs. Block Press

- Bottle Fusion
- Block Press
- Core
- Clad
- Mono
- Multi
- Finished Bottle
- Fusion Billet
- Finished Block
- Press Billet

NOVA Scientific, Inc. August 1, 2012
The evacuated MCP detector housing (sketch), constructed by the ORNL/SNS Detector Group, to be implemented in a Phase II DOE STTR. Pins pass through the casing walls for electrical connections to MCP and ‘hybrid’ RAE/DLA SNS readout.
Concept Sketch of Proposed MCP Neutron PSD ‘Card’
The ‘MCP Mosiac’ Concept – 2014-15 (?)
MCP Gamma Rejection

As a bulk ‘solid-state’ detector, MCPs also are inherently gamma ray sensitive, with
~1-2% absolute detection efficiency

A first generation (‘Gen 1’) solution* that worked:
~10 ns ultrafast coincidence with a surrounding gamma scintillator

*supported by DTRA SBIR HDTRA1-5-C0023; DNDO SBIR HSHQDC-11-C-00130
Initial gamma rejection scheme
MCP Inside NaI scintillator Block

10-30 ns coincidence counting window requires both a neutron event and a simultaneous 478 keV ($^{10}$B) and/or Gd gamma event.
Neutron Verification Logic

- MCP
- Fast Scintillator

478 keV

Coincidence Unit

yes (if < 10 ns)
no (if > 10 ns)
## Results

### Gamma Rejection Ratio

*252*Cf source at 2.15 meters  
(DNDO Ph.II SBIR)  

<table>
<thead>
<tr>
<th></th>
<th>MCP (coincidence)</th>
<th>3He (LND 25193, 4&quot;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 ns window</td>
<td>$1 \times 10^{-5}$</td>
<td>$2 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

Further reductions in the coincidence window length, down to 1-10 ns, might further improve the rejection ratio by 10x.

“OK”, but $10^{-7}$ gamma/n rejection ratio would be much more in line with other ‘alternative’ detectors.
A Second Generation Approach
‘All-Electronic’ MCP Gamma Rejection

- Bulky, complex scintillator/PMT is eliminated
- Much reduced package size & volume
- Utilizes the *induced* MCP electrode pulses
- Major differences recently seen between neutrons and gammas
- Ongoing further tests and refinement
Side Bonus: MCPs as Neutron Collimators

- Multiple experiments have been carried out with $^{10}$B or Gd-doped MCP collimators having highly aligned and parallel microchannels. Rocking curves as narrow as $\pm 0.1^\circ$ can be obtained with 5 mm thick MCPs, with 8 µm pores – a very compact structure with very high efficiency of collimation.

- Extensive modeling done w/A. Tremsin (Berkeley SSL), tests carried out, for both neutron beam shaping and scatter rejection.

- Test campaigns at pulsed and continuous beamlines:
  - ORNL SNS and HFIR(SNAP, CG-1)
  - PSI (Neutra, FunSpin)
  - ISIS (ROTAX)
  - FRM-11 (Antares)

DOE STTR #DE-FG02-08ER86333
Nova Scientific and UCal-Berkeley
Tests with PSI Imaging Resolution Target

Closed position to the detector (~1 cm away from the active area)  
NO COLLIMATOR

Aperture = 1cm  
Flux 1e7 n/cm²/s

Aperture = 2cm  
Flux 3.2e7 n/cm²/s

Aperture = 42mm  
Flux 4.5e7 n/cm²/s
Image Improvement Even at Close Positioning

Closed position to the detector (~1 cm away from the active area) WITH COLLIMATOR

Aperture = 1cm  
Flux 5.8e5 n/cm²/s

Aperture = 2cm  
Flux 1.2e6 n/cm²/s

Aperture = 42mm  
Flux 1.72e6 n/cm²/s
Better Yet: Sample Is Placed Further from Detector

32 mm to the detector cover (~42 mm to the active area)

NO COLLIMATOR

Aperture = 1cm
Flux 1e7 n/cm²/s

Aperture = 2cm
Flux 3.2e7 n/cm²/s

Aperture = 42mm
Flux 4.5e7 n/cm²/s
Considerable Image Improvement Observed

32 mm to the detector cover (~42 mm to the active area) WITH COLLIMATOR

Aperture = 1cm
Flux 5.8e5 n/cm²/s

Aperture = 2cm
Flux 1.2e6 n/cm²/s

Aperture = 42mm
Flux 1.72e6 n/cm²/s
MCPs in small format (up to 50mm dia.) have already demonstrated unique and powerful neutron detection capabilities, enabling a variety of applications, especially in areas where high spatial and timing resolution (~10 µm and ~1 µs) is critical.

Work is underway to provide large area (10x10cm, 20x20cm) MCP neutron detectors, offering very high spatial and timing resolution, with matching electronic readout, enclosed in robust vacuum sealed housings.

Considerable effort and increasing success in reducing intrinsic MCP gamma ray sensitivity by several orders of magnitude, to attain levels comparable to the other ‘alternative’ neutron detectors.

Effective neutron collimation has been demonstrated with thick, $^{10}$B or Gd-doped MCPs, due to the extremely high parallelism of microchannels resulting from the glass fiber draw process.