The Development of Large-Area Thin Planar Psec Photodetectors

Henry Frisch,
Enrico Fermi Institute UC and HEPD, ANL

Arradiance ALD/Incom MCP Pair Test
Image - UV  2200v  Gain Map - UV

INCOM glass substrate

~150 20μm pores

Herve Grabas

10/5/2010
The Large-Area Psec Photo-detector Collaboration

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John Andersen, Karen Byrum, Gary Dredge, Edward Moy, Alexander Parmaroucz, Mayly Sanchez, Robert Stalke, Hendrik Weerts, Matthew Weststein¹, Zikri Yusuf

High Energy Physics Division
Argonne National Laboratory, Argonne, Illinois 60439

Bernhard Adams, Klaus Attenecker
Advanced Photon Source Division
Argonne National Laboratory, Argonne, Illinois 60439

Zeke Isaevov
Mathematics and Computer Sciences Division
Argonne National Laboratory, Argonne, Illinois 60439

Jeffrey Elam, Joseph Liberta
Energy Systems Division
Argonne National Laboratory, Argonne, Illinois 60439

Michael Pollin, Igor Veryovkin, Hau Wang, Alexander Zhizhe
Materials Science Division
Argonne National Laboratory, Argonne, Illinois 60439

David Desalvo, Neal Sullivan, Ken Stenton
Armstrong Inc., Sudbury, MA 01776

Mirea Bogdan, Henry Frisch¹, Jean-Francois Genat, Mary Heintz, Richard Northrop, Fukum Tang

Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637

Erik Kaelberg, Anatoly Rotzlin, Greg Sellberg
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

James Kennedy, Kurtis Nishimura, Marc Rosen, Larry Buckman, Gary Vaner
University of Hawaii, 2505 Correa Road, Honolulu, HI, 96822

Robert Abrams, Valentin Ivanov, Thomas Roberts
Muons Inc 552 N. Balania Avenue, Balania, IL 66510

Jerry Ya’ara
SLAC National Accelerator Laboratory, Menlo Park, CA 94025

Oswald Siegrum, Anton Tremblin
Space Sciences Laboratory, University of California, Berkeley, CA 94720

Dmitri Roudievitch
Syskern Technologies Inc., Longmont, CO 80501

David Forbush, Tianchi Zhao
Department of Physics, University of Washington, Seattle, WA 98195

¹ Joint appointment Argonne National Laboratory and Enrico Fermi Institute, University of Chicago

3 National Labs, 6 Divisions at Argonne, 3 US small companies, 3 universities
Goal of 3-year R&D-commercializable modules.
Three Goals of a New (1 yr-old) Collaborative Effort:

1. Large-Area Low-Cost Photodetectors with good correlated time and space resolution (target 10 $/sq-in incremental areal cost)

2. Large-Area TOF particle/photon detectors with psec time resolution (< 1psec at 100 p.e.)

3. Understanding photocathodes so that we can reliably make high QE, tailor the spectral response, and develop new materials and geometries (QE > 50%, public formula)
Parallel Efforts on Specific Applications

Explicit strategy for staying on task

LAPD Detector Development
Drawing Not To Scale (!)

PET
(UC/BSD, UCB, Lyon)

Collider
(UC, ANL, Saclay)

Muon Cooling
Muon, Inc (SBIR)

K->πνν
(UC(?))

DUSEL
(Matt, Mayly, Bob, John, ..)

Mass Spec

Security
(TBD)

All these need work - naturally tend to lag the reality of the detector development
Application 1 - Colliders

At colliders we measure the 3-momenta of hadrons, but can’t follow the flavor-flow of quarks, the primary objects that are colliding. 2-orders-of-magnitude in time resolution would all us to measure ALL the information => greatly enhanced discovery potential.

A real top candidate event from CDF- has top, antitop, each decaying into a W-boson and a b or antib. Goal- identify the quarks that make the jets. (explain why...)

Specs:
- Signal: 50-10,000 photons
- Space resolution: 1 mm
- Time resolution: 1 psec
- Cost: <100K$/m^2
Application 2 - Neutrino Physics

- Spec: signal single photon, 100 ps time, 1 cm space, low cost/m² (5-10K$/m²)*
Can we solve the depth-of-interaction problem and also use cheaper faster radiators?

Simulations by Heejong Kim (Chicago)

Alternating radiator and cheap 30-50 psec planar mcp-pmt's on each side

Depth in crystal by time-difference

Depth in crystal by energy-asymmetry
Application 4-
Cherenkov-sensitive Sampling Calorimeters

A picture of an em shower in a cloud-chamber with $\frac{1}{2}$" Pb plates (Rossi, p215- from CY Chao)

A `cartoon' of a fixed target geometry such as for JPARC's KL-> pizero nunubar (at UC, Yao Wah) or LHCb

Idea: planes on one side read both Cherenkov and scintillation light- on other only scintillation.
1. MCP’s loaded with Boron or Gadolinium are used as neutron detectors with good gamma separation (Nova Scientific).

2. Large-area means could scan trucks, containers

3. Time resolution corresponds to space resolution out of the detector plane IF one has a $t_0$ – i.e can do 3D tomography of objects

Specs: TBD

An area for possible applications- need a counterpart to form an application group. (ANL an obvious place)
Detector Prescription (Generic)

- **Small feature size** $\ll 300$ microns (1 inch = 1 nsec, 300 microns = 1 psec)

- **Homogeneity** — the ability to make uniform large-areas (think solar-panels, floor tiles, 50”-HDTV sets)

- **Intrinsic low cost**: although application specific, all need low-cost materials and robust batch fabrication. Needs to be simple.
Detector Development - 3 Prongs

MCP development - use modern fabrication processes to control emissivities, resistivities, out-gassing

Use Atomic Layer Deposition for emissive material (amplification) on cheap inert substrates (glass capillary arrays, AAO). Scalable to large sizes; economical; pure – i.e. chemically robust and (it seems- see below) stable

Readout: Use transmission lines and modern chip technologies for high speed cheap low-power high-density readout.

Anode is a 50-ohm stripline. Scalable up to many feet in length; readout 2 ends; CMOS sampling onto capacitors - fast, cheap, low-power (New idea - make MCP-PMT tiles on single PC-card readout - see below)

Use computational advances - simulation as basis for design

Modern computing tools allow simulation at level of basic processes - validate with data. Use for `rational design’ (Klaus Attenkofer’s phrase).
Detector Development- 3 Prongs
Progress since last DOE visit (6 mo)

MCP development-
Received first 8” plates; installed Beneq ALD Prod. Facil; measured gain > $10^6$ in multiple plates with multiple chemistries, measured lifetime, uniformity, characterized prime secondary-emitting layers, established baseline 8”x8” design at SSL in ceramic and 16”x24” design in glass at ANL, constructed hermetic base seals, started a top seal program, constructed multiple test facilities at SSL and ANL and (almost) fabrication facility at SSL, made multiple photocathodes at SSL, made our first photocathode with ANL folks, acquired space for the Tile Factory and Photocathode Growth Facility, started designs.

Readout:
Submitted 2nd and 3rd gen sampling chips, simulated anode, baseline design of SuperModule Tray, design of analog/digital/test board, simulation of analog bandwidth and signal generation.

Simulation as basis for design
Developed modular end-to-end MCP simulation framework, defined canonical plots, first comparisons of testing and sim
ANL-UC Glass Hermetic Packaging Group

- Proceed in 3 steps: 1) hermetic box; 2) Add MCP’s, readout, (Au cathode); 3) Add photocathode

Box

Box + 8” MCPs
Possible Au anode

Box + MCP + PC

Yr 1  Yr 2  Yr 3
LAPPD Year 2 ARRA Funding Milestones

Milestones for the ARRA funding from July 1, 2010 to June 30, 2011

1. Demonstration of gain of $10^6$ and aging performance comparable to or better than that of commercial plates with a pair of capillary MCP plates functionalized by ALD;
   • **Done**

2. Development of an MCP test facility capable of handling 8” plates in tiles;
   • **Almost - 2 mo.? ANL and SSL**

3. Functionalization of an 8” × 8” glass capillary substrate with ALD;
   • **Almost - 2 mo.?**

4. Observation of gain from an ALD-functionalized 8” × 8” MCP plate;
   • **3-6 mo.?**

5. Design and costing of a photocathode characterization facility;
   • **Done**

6. Design and costing of an 8” glass tile assembly facility. • **3-4 mo.?**

• These are my estimates- godparent reviews in progress
Micro-channel Plates PMTs

Satisfies small feature size and homogeneity

Photon and electron paths are short - few mm to microns => fast, uniform Planar geometry => scalable to large areas
Sample both ends of transmission line with Photonis MCP (not optimum)

Position Resolution at 158PEs

<table>
<thead>
<tr>
<th>HV (kV)</th>
<th>Std</th>
<th>640μm</th>
<th>140μm</th>
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<tbody>
<tr>
<td>2.3 kV</td>
<td>12.8ps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 kV</td>
<td>2.8ps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 kV</td>
<td>2.2 ps</td>
<td>110μm</td>
<td></td>
</tr>
<tr>
<td>2.6 kV</td>
<td>1.95 ps</td>
<td>97μm</td>
<td></td>
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2 picoseconds; 100 microns measured
Chemically produced and treated Pb-glass does 3-functions:

1. Provide pores
2. Resistive layer supplies electric field in the pore
3. Pb-oxide layer provides secondary electron emission

Separate the three functions:
1. Hard glass substrate provides pores;
2. Tuned Resistive Layer (ALD) provides current for electric field (possible NTC?);
3. Specific Emitting layer provides SEE
Where we are with glass substrates

- Hexagonal bundle of capillaries is called a ‘multi’. Each multi has ~15,000 capillaries.
- Many many multis in an 8”-square plate.

- Have received multiple samples of 10-micron, 20-micron, 40-micron glass substrates from Incom in 3/4”-sq and 33 mm round formats – will show results after ALD below.
- Two developments at Incom (our glass folks)- 1) 8” plates are being fabricated and the process improved, and 2) replacement of some multis with solid islands (‘pads’) for installation of mechanical spacers. Idea is low cost amplification section - so far so good (hesitate to quote a # yet).
Sealed Tube (Tile) Construction

- All (cheap) glass
- Anode is silk-screened
- No pins, penetrations
- No internal connections
- Anode determines locations (i.e. no mech tolerancing for position resolution)
- Fastens with double-sticky to readout Tray: so can tile different length strings, areas
- Tile Factory in works (ANL)
The 24”x16” `SuperModule
## Glass Package Component Costs

<table>
<thead>
<tr>
<th>Glass Package Component Costs</th>
<th>Quotations</th>
<th>Cost estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
<td>1000</td>
</tr>
<tr>
<td>Window (1@)</td>
<td>$18</td>
<td>13</td>
</tr>
<tr>
<td>Side wall (1@)</td>
<td>$78</td>
<td>55</td>
</tr>
<tr>
<td>Base plate (1@)</td>
<td>$20</td>
<td>13</td>
</tr>
<tr>
<td>Rod Spacers (75@)</td>
<td>$7</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>$641</td>
<td>$306</td>
</tr>
</tbody>
</table>

The above prices are for water jet cut B33 glass, tol. +/- 0.010, except rod spacers +/-0.004

Glass components are a small percentage of the proposed 8 x 8 MCP
Atomic Layer Deposition (ALD) Thin Film Coating Technology

- Atomic level thickness control
- Deposit nearly any material
- Precise coatings on 3-D objects

• Lots of possible materials => much room for higher performance

Jeff Elam pictures
Conventional MCP’s:  Alternative ALD Coatings: (ALD SiO₂ also)

- Many material possibilities
- Tune SEE along pore

Conventional MCP’s: SiO₂

Al O
(MgO)

(ALD SiO₂ also)

ZnO

Many material possibilities
Tune SEE along pore

Jeff Elam, Zeke Insepov, Slade Jokela
MCP and Photocathode Testing

Fred Borcherding HEPD Visit

10/5/2010

Large Area Photodetector Development Collaboration

- Conventional lead-oxide MCPs have single composition for resistive/emissive material
  - Functionalized in H-furnace requiring long “scrubbing” time (removal of volatiles)
- ALD allows separate control of resistive and emissive layers
  - Separately optimize each layer for best overall performance
  - Precise control over composition; tunable resistance
- Arradiance coatings on Incom plate - Scrub time reduced by up to ×10 (!) (SSL)
- Have functionalized several pairs with newly developed resistive layer plus Al₂O₃ secondary emissive layer (ANL)

Signal from MCP pair coated with new resistive layer Al₂O₃ emissive layer
First measurements of gain in an ALD SEE layer at the APS laser test setup (Bernhard Adams, Matthieu Cholet, and Matt Wetstein)

LAPPD
Preliminary
(very)
First-ever test of an ALD pair (Ossy, SSL)

Electron pattern (not a picture of the plate!)- SSL test, Incom substrate, Arradiance ALD. Note you can see the multi’s in both plates => ~50 micron resolution

Note- at high gain the boundaries of the multi’s go away
Simulation (crosses all groups)
Valentin Ivanov, Zeke Insepov, Zeke Yusof, Sergey Antipov

Spoiled end. Color: field angle

Trajectories
TTS simulation, $E_{sec} = 2\ eV$, direct channel, Gain = 14
- Crossing mode

TTS simulation, $E_{sec} = 2\ eV$, tilted 7.5°, Gain = 143
- Switching to hopping mode

TTS simulation, $E_{sec} = 2\ eV$, tilted 10° channel, Gain = 3730
- Well-defined hopping mode

Funnel (!)

Previous calculations

Large Area Photodetector Development Collaboration
Photocathode Group

Klaus Attenkofer, Zikri Yusof, Ossy Siegmund, Junqi Xi, Sasha Paramonov, Seon Wu Li, Slade Jokela, Ryan Dowdy (UIUC), Jim Buckley (WashU, Dan Leopold (WashU)

- III-V have the potential for high QE, shifting toward the blue, and robustness i.e. they age well, high-temp
- Opaque PC’s have much higher QE than transmission PC’s- we have the geometry
- Many small factors to be gained in absorption, anti-reflection- see papers by Townsend and talk by Fontaine on our web site
- Quantum Effic. Of 50% have been achieved in multi-alkalis
- Basic understanding is missing- we think we can make major contributions here to applications

Big payoff if we can get >50% QE robust Photocathodes, and/or more robust (assembly). Also want to get away from ‘cooking recipes’ to rational design.
SSL Photocathodes: Large Process Chamber – our backup (Ossy Siegmund)

Glass Window

UV Transmissive Window

Photo-Cathode

Manipulators

Forming Well Flange

18” ID Chamber

Ion Pumps

UHV valves

Forming Well Flange

16.5” Detector Loading Flange

Ion Pump supply
SSL Photocathodes: Processing Oven, Cathode Deposition

• Oven accommodates Large Format Inside Envelope: 36” x 30” x 25” High
• Defines Large Chamber Limits

• Cathode station controls alkali metal deposition, and monitors cathode response

• Ossy Siegmund
Purchase of Burle Photocathode Facility (LDRD money)

Our System

All wrapped up ready to ship

Alkali Metals (K, Cs) Deposition

Making electrical contacts to the various electrodes. A "white" light source is also installed over the tube to monitor the photocurrent during deposition.

The oven cover was then lowered. The temperature was set to 150 C, which was the deposition temperature for the alkali metals.
MCP/Photocathode Development-Test setup at APS laser

Bernhard Adams, Klaus Attenkofer, (APS), Matt Wetstein (HEP), Matthieu Chabon
New Femtosec Laser Lab at APS

LAPPD Collaboration: Large Area Picosecond Photodetectors

• Bernhard Adams, Matthieu Chabon, Matt Wetstein
Design Status
- So far two chips have been made:
  psTDC_01   psTDC_02

ASIC Evaluation Card (Analog) [A.K.A. "AC card"]
- 1.9 mil (48.26 micron) trace/spacing
  - laser etching
- Fairly $$$ PCB fabrication
- 4x SMA input
- 2x high density Samtec connectors
- Pluggable Mezzanine card
- NP-175 dielectric

Testable structures
The structures that could be separately tested in the chip were:
- Comparator
- Sampling cell
- Token Readout
- Ring oscillator
- Ramp generator
Psec2 ASIC

- 130nm IBM 8RF Process
- This chip 4 channels, 256 deep analog ring buffer
- Sampling tested at 11 GS/sec
- Each channel has its own ADC - 9 bits eff (?)
- The ADCs on this chip didn’t work due to leakage (silly, didn’t simulate slow easy things) - resubmitted, and test card out for fab with external ADC - will use 1 of 4 chnls
- We’re learning from Breton, Delagnes, Ritt and Varner (Gary is of course a collaborator)
Many configurations are possible from very simple to complicated. Simulation and test can only tell which one will be the best.
Summary

• Glass substrates with ALD looks viable - still some questions and evolution, but looks good.

• Basic questions on SSE materials are answered and are solid.

• The necessary test and development facilities have been developed at SSL and ANL.

• We have developed a `frugal' 16”x24” design at ANL and a conservative but very solid 8”by 8” design at SSL; both places are close to making full-size proto-types

• Multi-alkali photocathodes have been made at SSL and at Burle by ANL folks - we are much more confident than 6 months ago

• We have attracted excellent young talent, less-young talent, interest from industry and applications - it’s a really good, highly-motivated group.
Concerns

• Funding- 4,3,1 vs 4, 2,2

• SuperModule design has led to larger area goal at 3-year end- goal now is enough SuperModules to engage industrial production (a step beyond `commercializable’) - Tile Factory wasn’t in the Proposal

• We had requested strategic LDRD funds for the Photocathode Growth and Characterization Facility at ANL- just turned down (not unexpected) -

• Missing an engineer/manager for the Tile Factory; photocathode effort still something of a pick-up ball game (but these can be the best, but a concern)
THE END

Thanks to everybody in the LAPPD collaboration, esp. the young ones.

Making electrical contacts to the various electrodes. A "white" light source is also installed over the tube to monitor the photocurrent during deposition.

The oven cover was then lowered. The temperature was set to 150 C, which was the deposition temperature for the alkali metals.
Varner, Ritt, DeLanges, and Breton have pioneered waveform-sampling onto an array of CMOS capacitors.
SSL Tube Processing Facilities

Sealed tube facilities and oven

UHV detector/cathode processing station
SSL Sealed tube detectors Pre-process assembly

Planacon, with fiber optic window and cross strip anode (signal vias straight through substrate), in assembly with MCPs installed (above) ready to process.
SSL: Alkali Photocathodes

Emission spectrum of Cherenkov in water compared with bialkali response.

UCB SSL cathode compared with commercial product.

Quantum Efficiency (%) vs. Wavelength (nm)

Fran Jean-Francois Genat