Fermilab

Physics Department
Mechanical Department Engineering Note

Number: MD-ENG- *DRAFT* Date: 3/10/09

Project Internal Reference: LAPPD Burle MCP

Project: Large-Area Picosecond Photo-Detectors Project

Title: 4096 channel pads w/Ag Epoxy Technique to PC Board Read-Out

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Reviewer(s): Henry Frisch,

Key Words: Burle MCP, Pico-Second,

Abstract Summary: A group from The University of Chicago, Argonne, Fermilab and Berkeley are interested in the development of large-area systems to measure the time-of-arrival of relativistic particles with (ultimately) 1 pico-second resolution, and for signals typical of Positron-Emission Tomography (PET), a resolution of 30 pico-seconds (sigma on one channel). These are respectively a factor of 100 and 20 better than the present state-of-the-art. This would involve development in a number of intellectually challenging areas: three-dimensional modeling of photo-optical devices, the design and construction of fast, economical, low-power electronics, the `end-to-end' (i.e. complete) simulation of large systems, real-time image processing and reconstruction, and the optimization of large detector and analysis systems for medical imaging. In each of these areas there is immense room for creative and innovative thinking, as the underlying technologies have moved faster than the applications. We collectively are an interdisciplinary (High Energy Physics, Radiology, and Electrical Engineering) group working on these problems, and it's interesting and rewarding to cross the knowledge bases of different intellectual disciplines. (http://psec.uchicago.edu/)

Concept

Since Photocathode and Photomultiplier technology is a well know technology from early development cia; 1930's, we will not describe this technique in this Engineering Note. Refer to: http://en.wikipedia.org/wiki/Photomultiplier

MCP BASICS

For over thirty years, PHOTONIS (formerly Philips Photonics, Galileo and Burle) has consistently set the standard in electron multipliers and related products. Today, an extensive R&D program coupled with unsurpassed expertise in micro channel plate (MCP) technology continues to deliver a succession of product and process improvements that push aside previous technology limits. This expertise is used to mass-produce MCPs for our image intensifier tubes as well as for a variety of custom scientific applications. This, plus the ability to meet your product requirements, makes Photonis/Burle the preferred choice of professionals the world over.
A microchannel plate (MCP) is an electron multiplier for detecting X-rays, ultraviolet radiation and charged particles. The output is a two-dimensional electron image which preserves the spatial resolution of the original input radiation, but with a linear gain up to 1000. This may be used for exciting a phosphor screen placed close to the output, giving a visual representation of the radiation pattern. Alternatively, the electron image can be read out by, for example, a wedge-and-strip or fast delay-line anode array.

Each plate consists of an array of tiny glass tubes fused together to form a thin disc. Both faces of the disc are metal-coated to provide parallel electrical connections to all channels. In a vacuum, and with a potential difference (usually 800 to 1400 V) across the plate, each channel becomes a continuous dynode electron multiplier, operating on the same principle (electron avalanche) as its cousin - the single-channel electron multiplier.

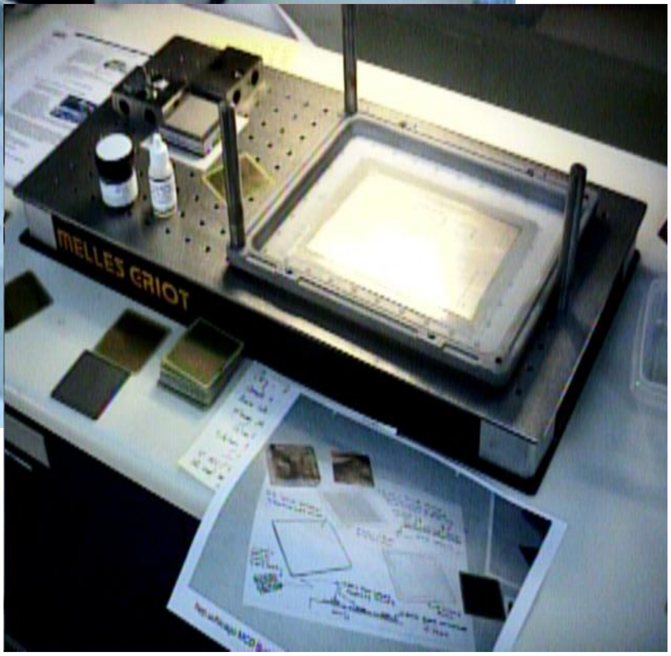
Information courtesy: http://www.photonis.com/en/content/133-ism-mcp-reference-list

1st Iteration

Problem of accurately placing a drop of conductive epoxy of exact amounts consistently on 4096 individual pads was a daunting task.

A silk screen *mask* was first suggested since this is an industrial accepted method, to mass produce PC Boards with this technique.

The time and money to obtain a costly item as a silk screen was dropped and we turned to a company that can solder parts like these together.



Application of 4096 individual Ag Epoxy drops

Since a Silk Screen Mask was not feasible, we turned to MicroDetector Groups CNC controlled 9 x 16” Encapsulation stage. System is set up with a pneumatic activated syringe that is positioned beneath the Nikon microscope field of view. To allow CNC programed positions and dispersion of Ag Epoxy, to the 4096 pads.

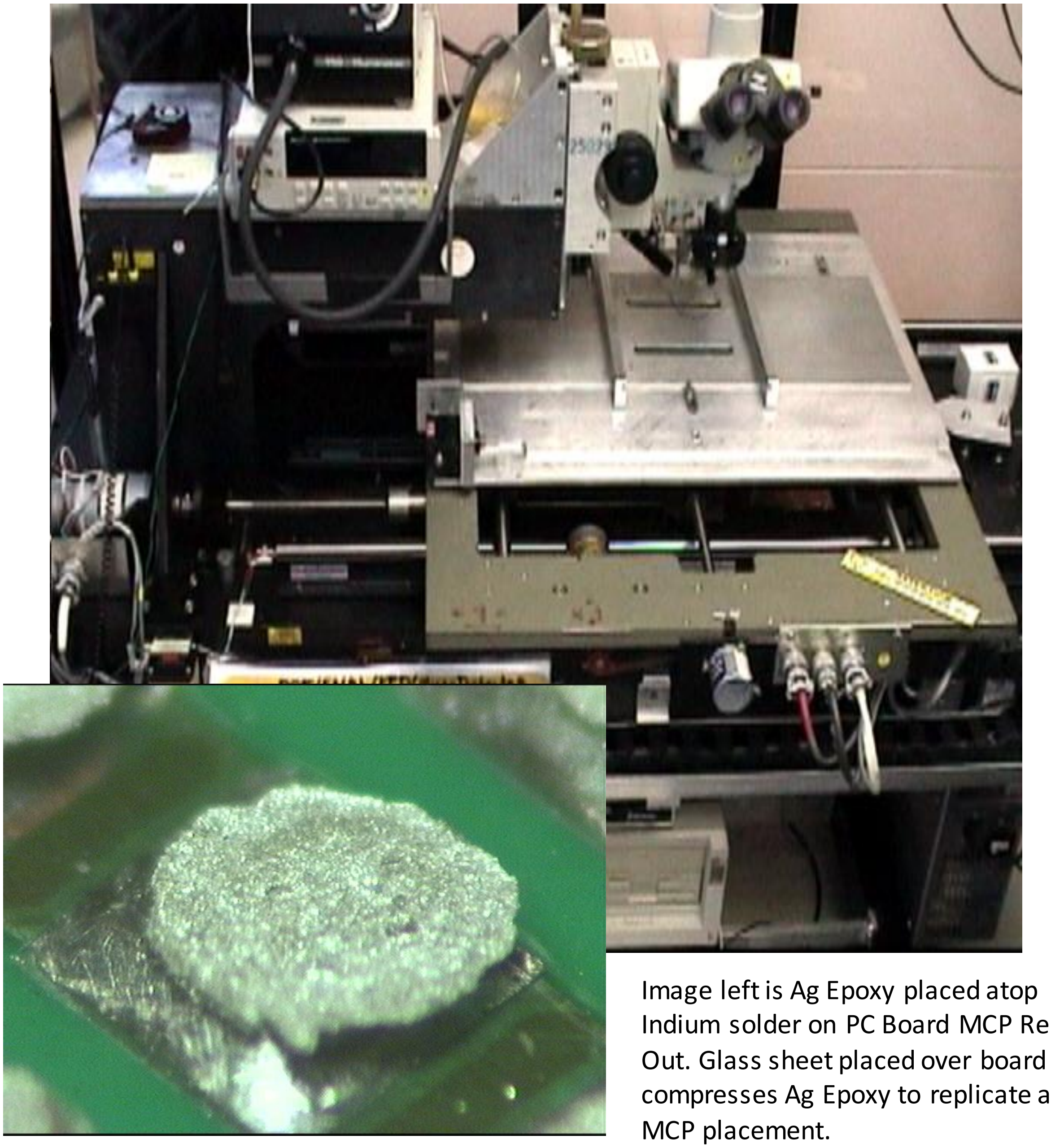
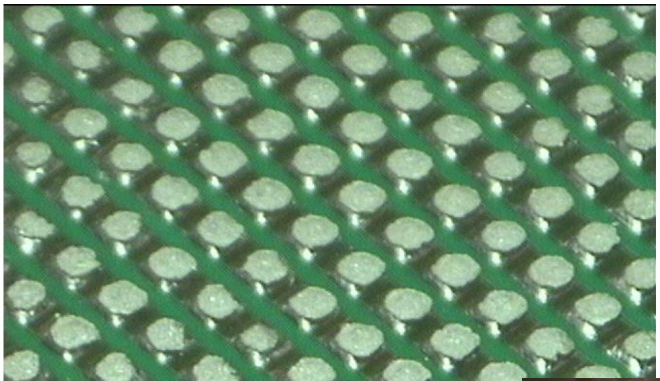
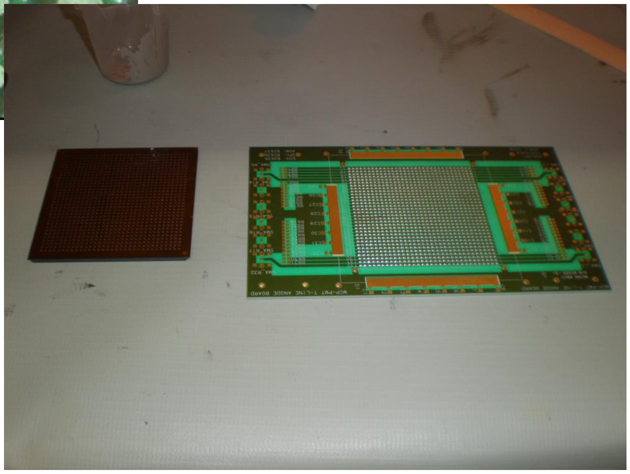


Image left is Ag Epoxy placed atop Indium solder on PC Board MCP Read Out. Glass sheet placed over board compresses Ag Epoxy to replicate a MCP placement.

Application of 4096 individual Ag Epoxy drops



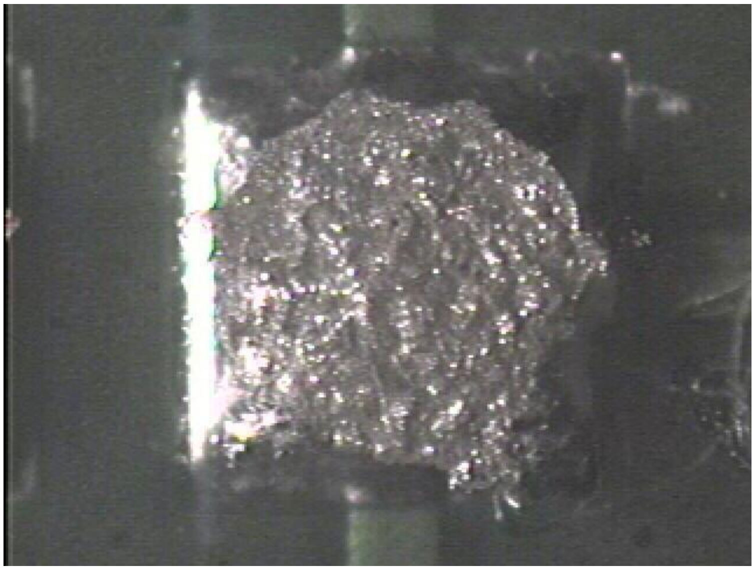
PC Board with glass placed over Ag Epoxy to reproduce pressure excreted by a MCP during cure cycle.
This sampling was inspected for over flow and consistency of volume uniformity, during application of un-cured epoxy.



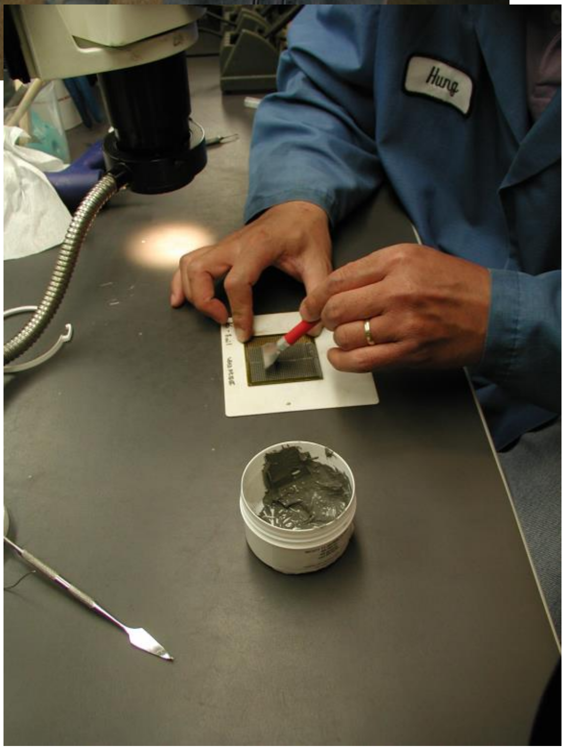
Several test iteration were performed to insure application consistency with inspected under microscope and tested for electrical continuity also. Different PC Board designs were made for specific testing.

This method is showing promising potential, However very time consuming application method.

Image right shows cured Ag Epoxy beneath glass sheet.
Adhesion of 4096 individual epoxied pads show extremely desirable mechanical along with electrical properties.

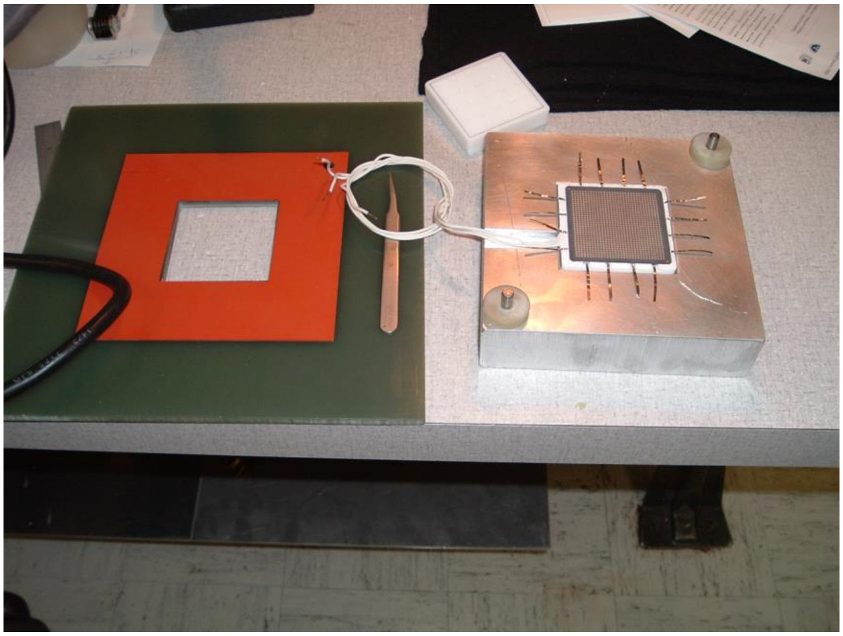


Solder Assembly Method



Best Electronics, Rolling Meadows, IL a local vendor was chosen to try the solder method. Since the vacuum sealed MCP vessel is actually sealed with low temperature Indium (In) solder, the vacuum seal need attention.
A fixturing jig was constructed after several phone calls with this vendor to fit into the equipment that Best utilize.
The low temperature of the MCP's In solder vacuum seal was a challenge with this method since the PC Board and bottom of MCP needs to be at an elevated temperature to fuse the two together, a cooling plate was added to this fixture.
Best built Kapton Masks that was laser drilled to have 4096 circular opening that match the MCP pads.
Indium solder is applied to both surfaces prior to solder re-flow machine.

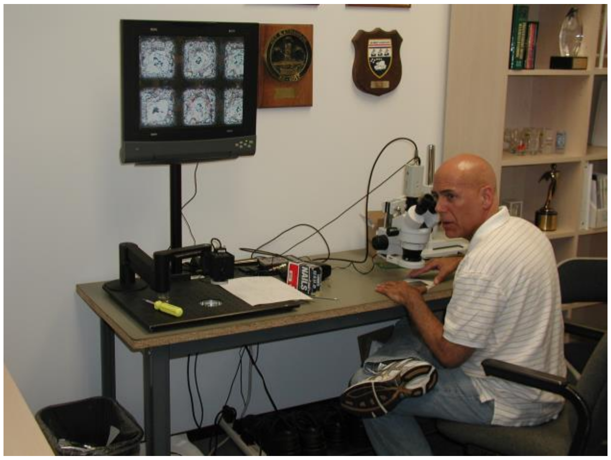
Solder Assembly Method



The heat sink used for this was an aluminum block with a pocket milled into it to ‘nest’ the MCP during this procedure.

The MCP is placed up-side down to keep the vacuum sealed side away from the heat used to melt the In Solder.
A FR-4 plate and high temperature silicon rubber was also fabricated to aid in focusing the heat energy into the PC Board that is placed over the MCP. Alignment of the PC Board to the MCP is the two pins seen above image. FR-4 Board has matching holes keyed to locate the window in FR-4 plate above the ‘nested’ MCP in aluminum heat sink.

After several attempts with the Indium solder attachment technique our sample MCP’s vacuum was broken.



Ag Epoxy Low Temperature Cure Method

University of Chicago Electrical Engineering Group was tasked with reading out the signals expected below 10 Pico-seconds.

A PC-Board was finally designed to attach a Burle MCP w/25 micron pore glass tubes, as the first attempt to start exploring this new electronics speed frontier.

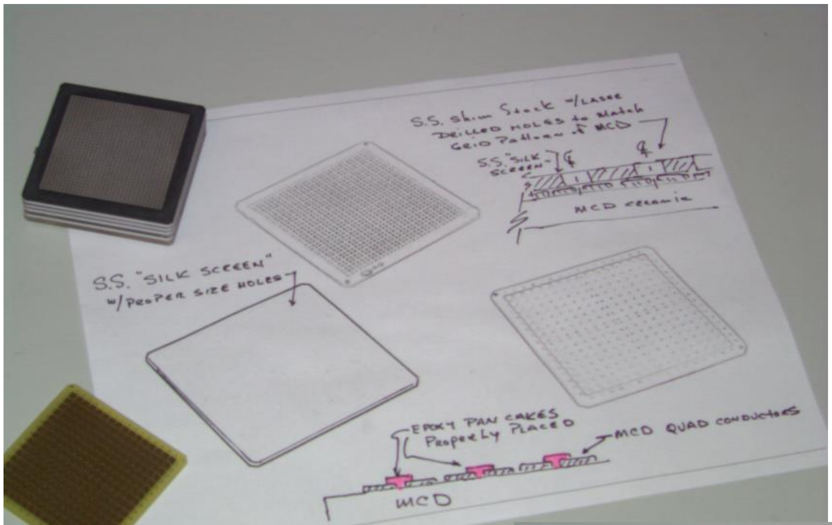
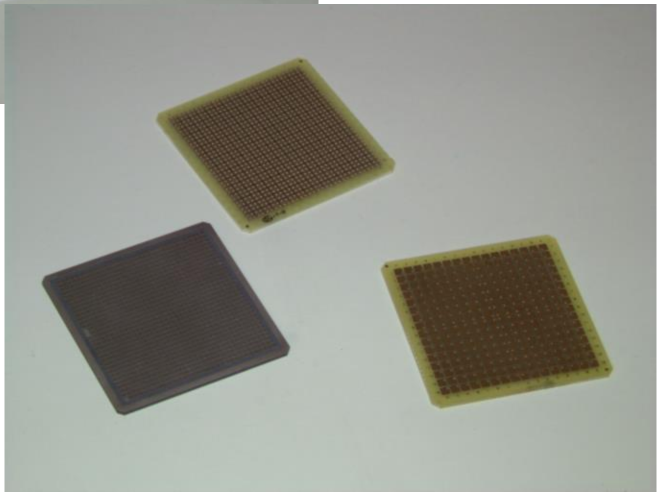


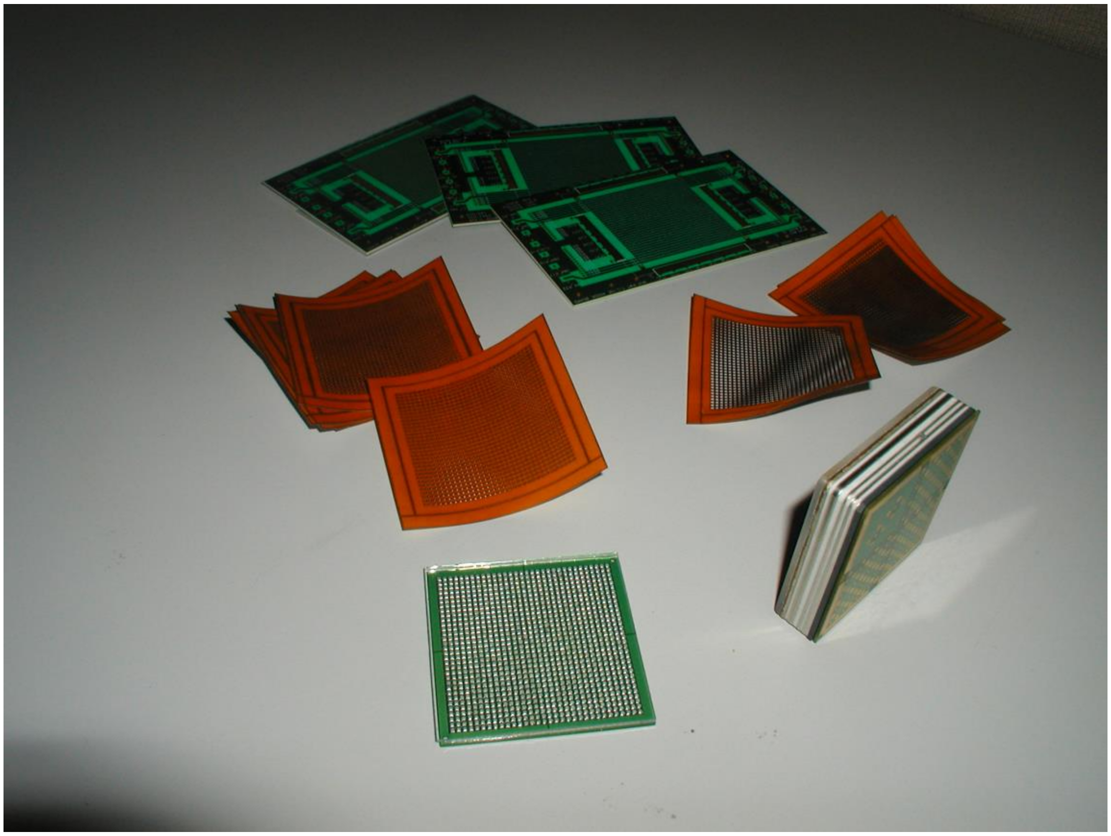
Image left shows early attempt to see if Silver (Ag) Epoxy can even be applied to MCP 4096 individual pads.

To read out, it was decided to apply Ag epoxy to four pad groups first.



U. of Chicago acquired a MCP ceramic back plane from Burle. This back plane could be used that had the pad densities to test for interconnection shorting with the Ag epoxing proposal.

1st Iteration Proving Epoxy Mask

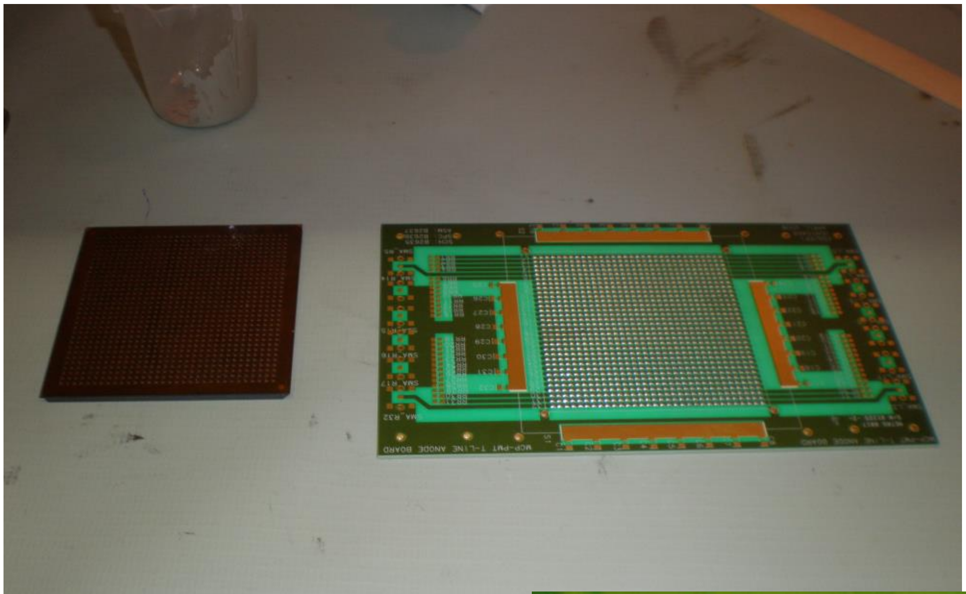


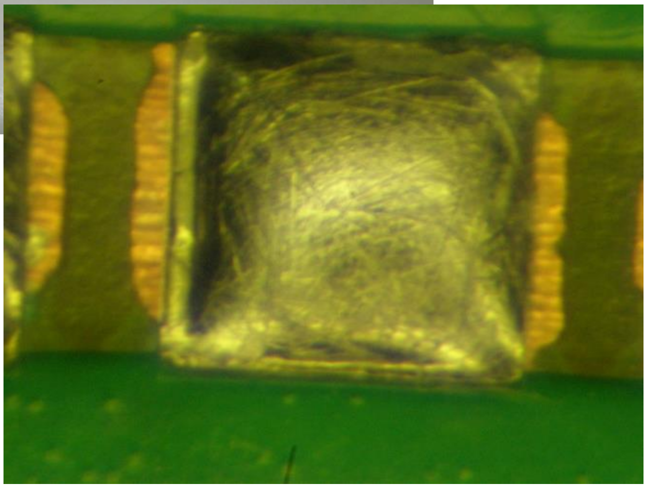
While Indium Solder was being explored to join the MCP to a read out PC Board we contacted Best to provide us with Kapton Laser drilled Masks to experiment this assembly method.

Our first iteration was to visually inspect the application after elevated temperature cure cycle.
A temperature of 80'c was agreed upon after the Indium solder seal failure at Best, was dialed in to the vacuum oven and noted on the thermal control panel.

Glass sheet cut to area of test PC Boards were used for this series of testing, that was completed on the 9 x 16" CNC controlled table, to verify requirements.

1st Iteration Proving Epoxy Mask
Preparation of surfaces



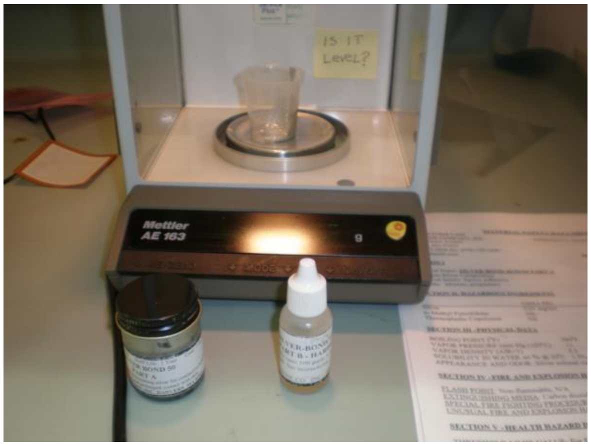


Preparation is key to ensure epoxy to adhere to these small surfaces.

MCP Back Plane and in this case Indium Solder was scuffed up with a 3M Scotch red pad. This opens more surface are for epoxy to 'grab'.

Follow up with 200% Ethanol, wipe surfaces until cloth shows a clean residue free result. This may require multiple cloths to insure residue free surfaces.

1st Iteration Proving Epoxy Mask



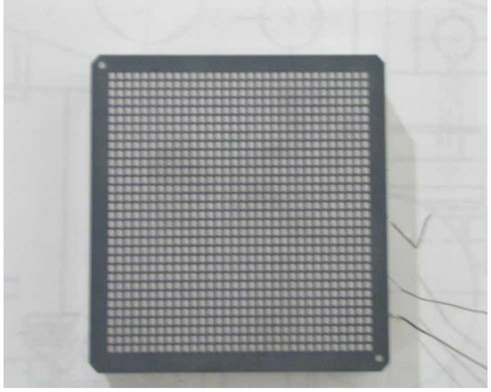
Ag Epoxy:
http://www.transene.com/silver_bond.html

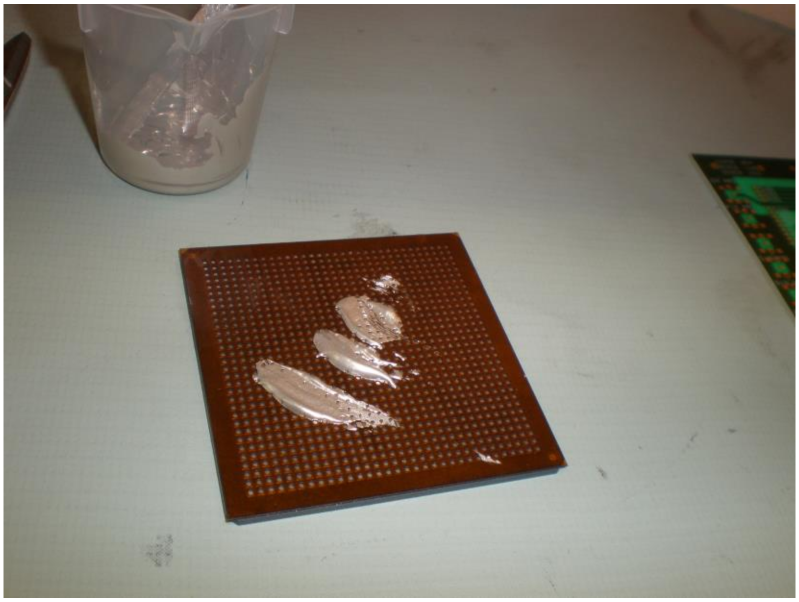
SILVER-BOND - TYPE 50

Standard low-temperature cure, high electrical conductivity.

Since very small amounts are actually used, precise weighing scales are required. We used a Mettler AE 163 type. Weighing capacity: 30 mg to 160 g. Readability: 0,01

Note two circular targets in opposite corners of MCP Back Plane. These will be used as alignment features with PC Board.

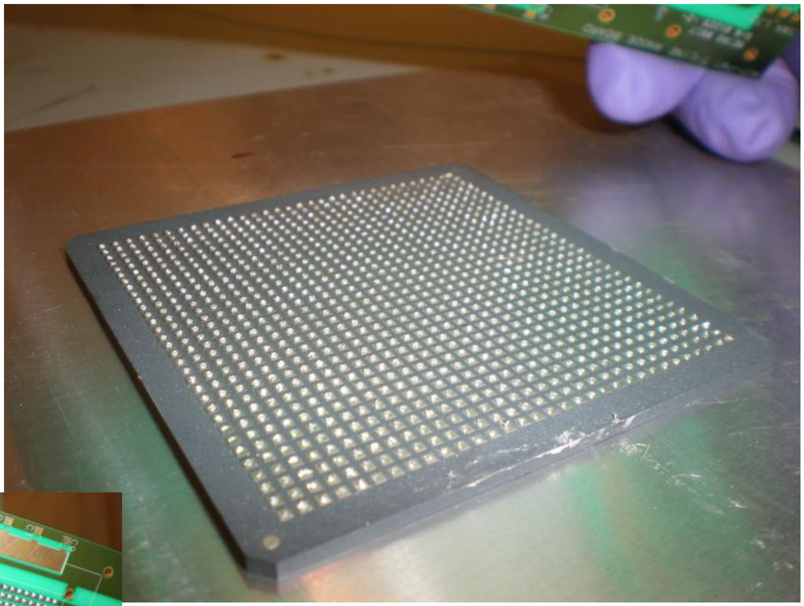


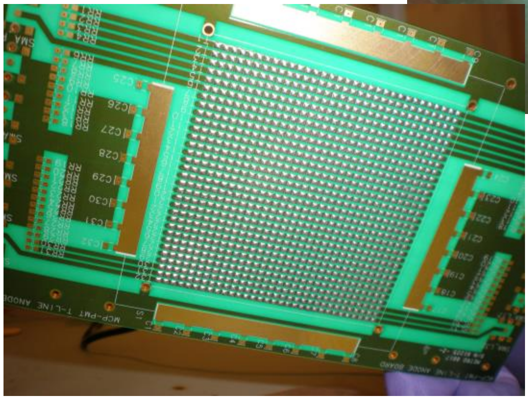


With 4096 Pad Kapton aligned over a Burle MCP electrical Back Plane. Ag Epoxy is weighed out and placed on assembly. During course of discovering true amount of Ag Epoxy is needed, a cup was used and reweighed to trim down bulk to a more conservative mix, for future applications.

1st Iteration Proving Epoxy Mask

Kapton Mask is then removed to revile Ag Epoxy placed on the 4096 pads of the MCP Back Plane. This is the first attempt and it looks like desirable results will be had with this technique.





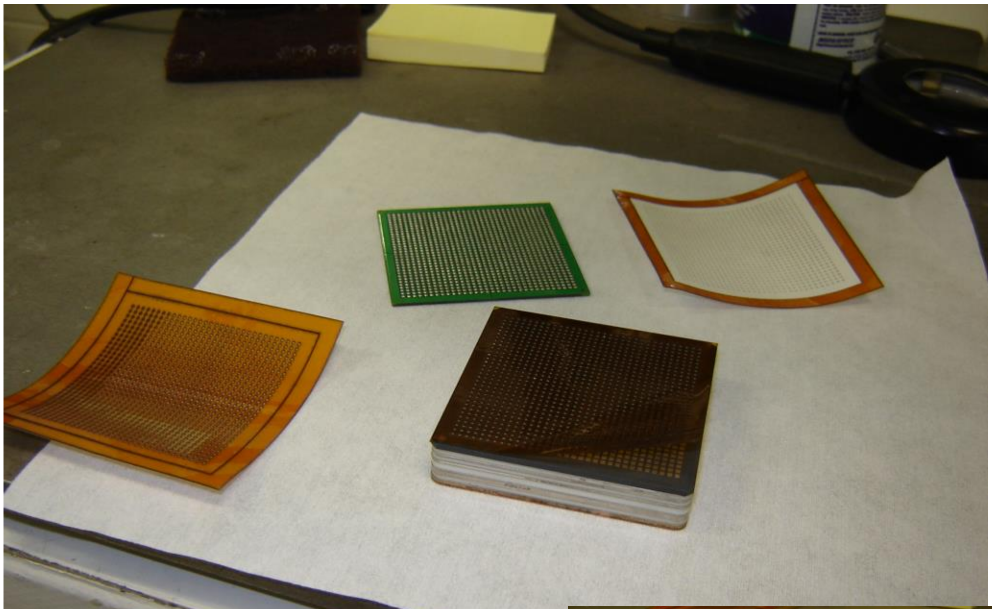
PC Board fabricated to read out each 4096 channels. This board has In Solder applied to each pad. Surface was roughed up with 3M Scotch and cleaned in previous detail.

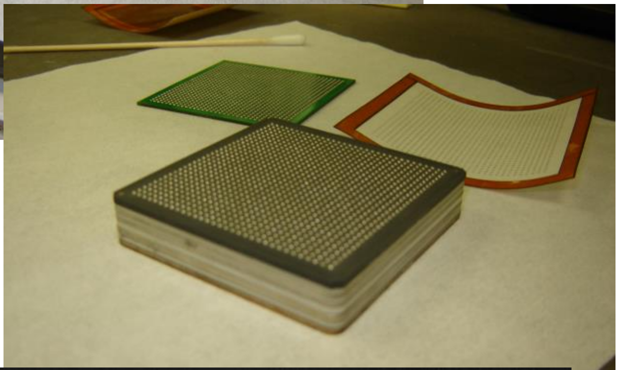
Two thru holes opposite corners will be aligned to Burle MCP's Back Plane's features.

Alter cure pad continuity was measured to prove assembly techniques. Mechanical Twist off test displayed strong properties as per manufactures data sheet.

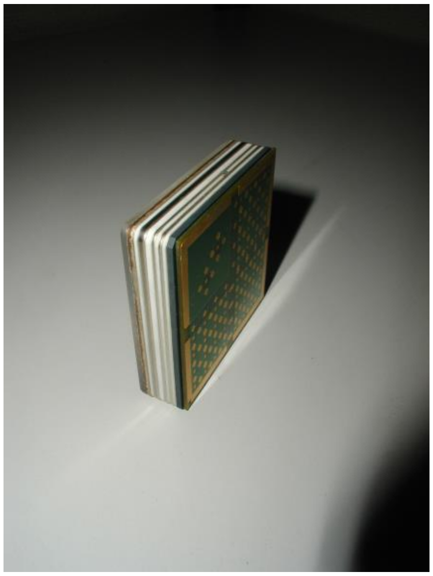
Next test was to learn how to twist MCP Back Plane off PC Board and be able to learn how to clean the two parts to near original conditions and re-apply epoxy, to insure functional MCP's can be recovered.

Optical Microscope inspection edge view



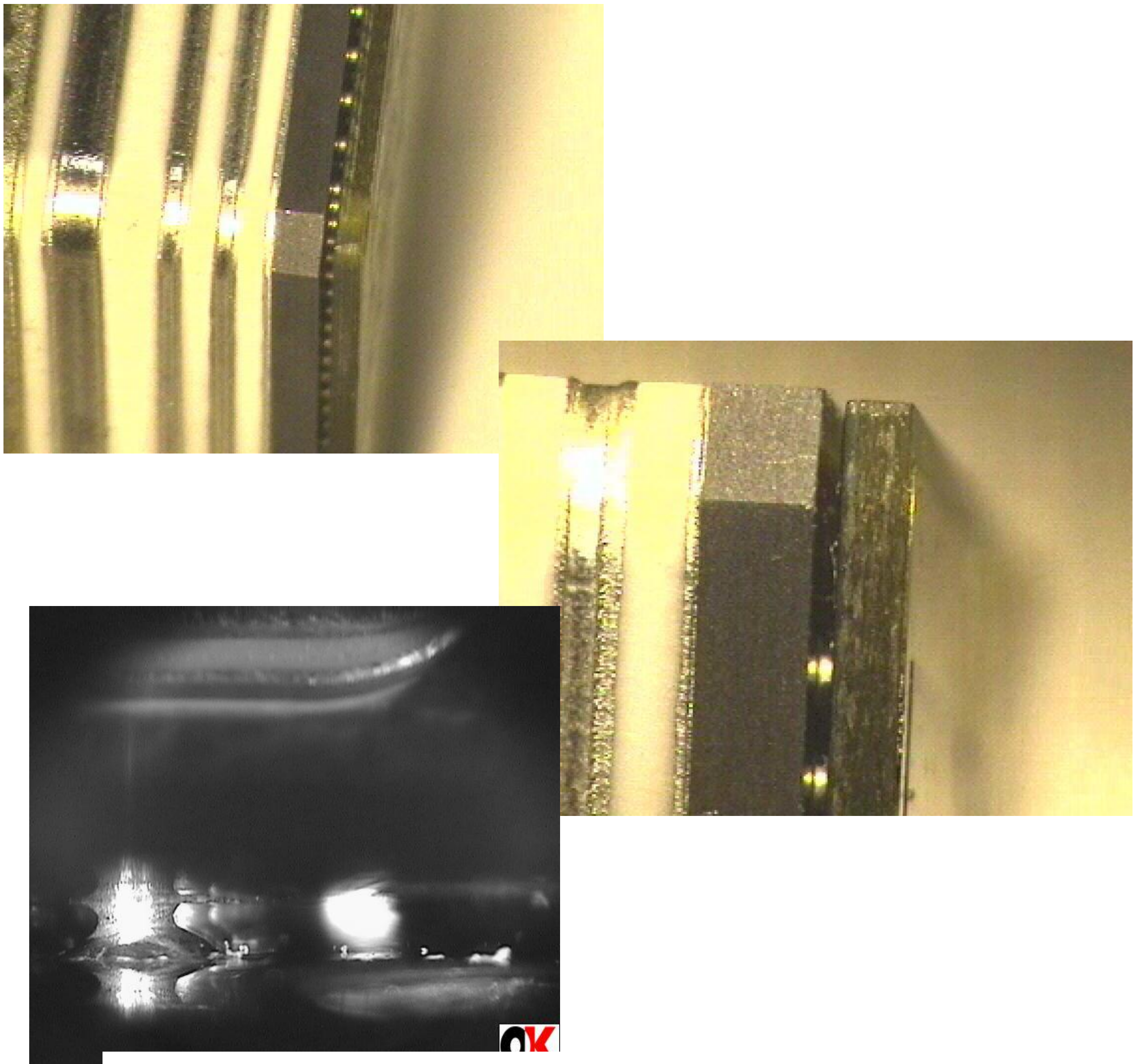


A mechanical grade MCP was obtained along with a simple 4096 Pad PC Board to be used to test weight application during oven cure.



Ag/In Solder pad check with microscope on edge view.

Optical Microscope inspection edge view

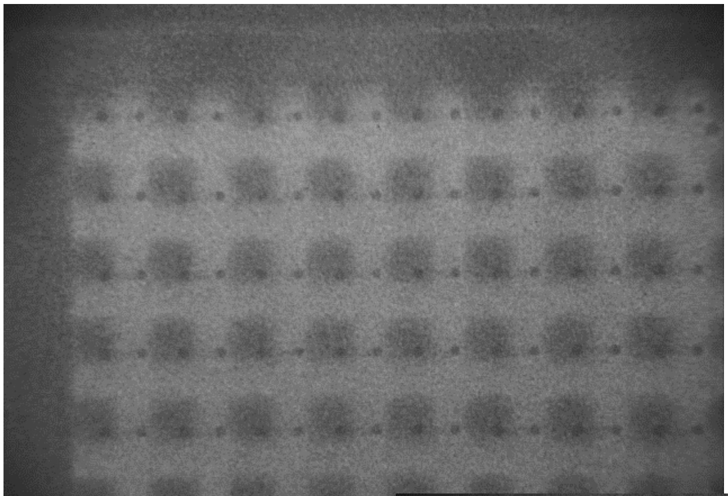


Edge view inspection can only penetrate a few rows of pads. But unlike a 2D X-Ray image does not show form of individual columns of Ag Epoxy.

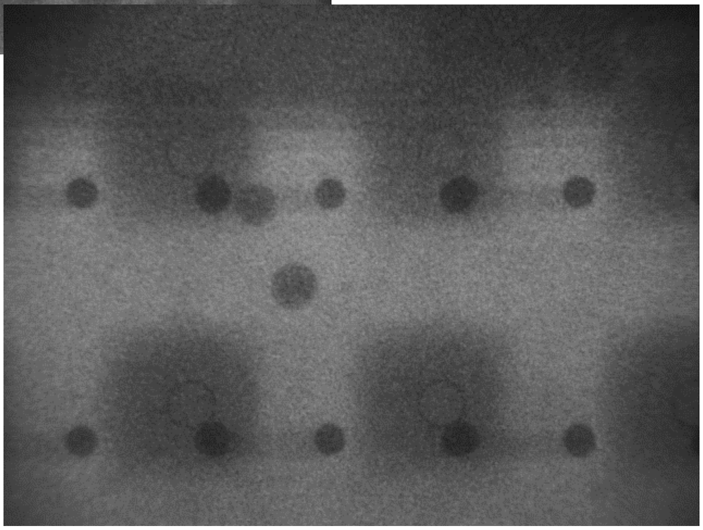
Images demonstrates flow of 90,000 cps Ag Epoxy spread; due to two distinct surface conditions, showing two flow out surfaces and narrowing center shape as surface tension consumes droplets of Ag Epoxy during its 'pot-life' and does not over flow to cause shorting with adjacent pads.

X-Ray inspection will be done at FNAL/Computing Electrical Engineering Lab next.

X-Ray Inspection of mechanical grade MCP w/In Epoxy to test board



X-Ray images provided by FNAL/Computing Electrical Engineering Lab.



X-Ray 2D imaging is a science into itself in interpolation of imagery display.

Square Pads are easily recognizable, but tiny dots lay at a different level which 2D X-Ray does not indicate their location in 3rd dimension, however a side view did show features internal to MCP assembly which are proprietary and will not be displayed.

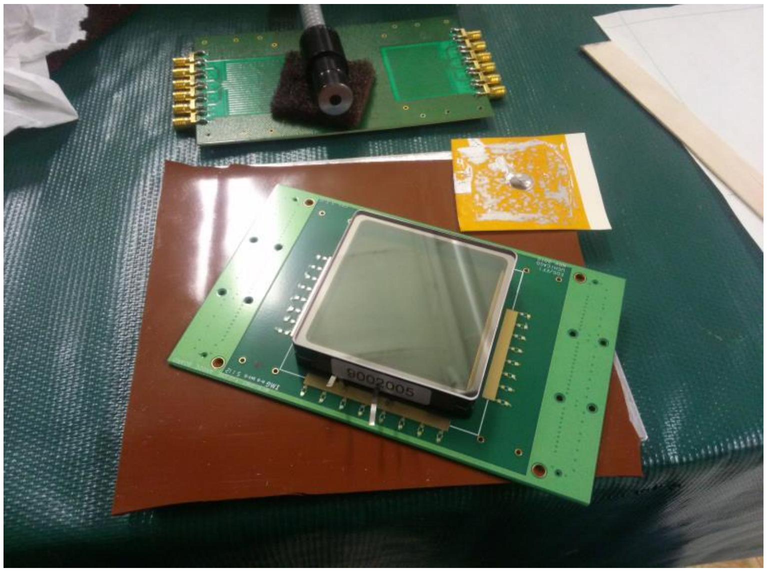
2D Image does show no excessive flow of epoxy deep within the 4096 pad areas.

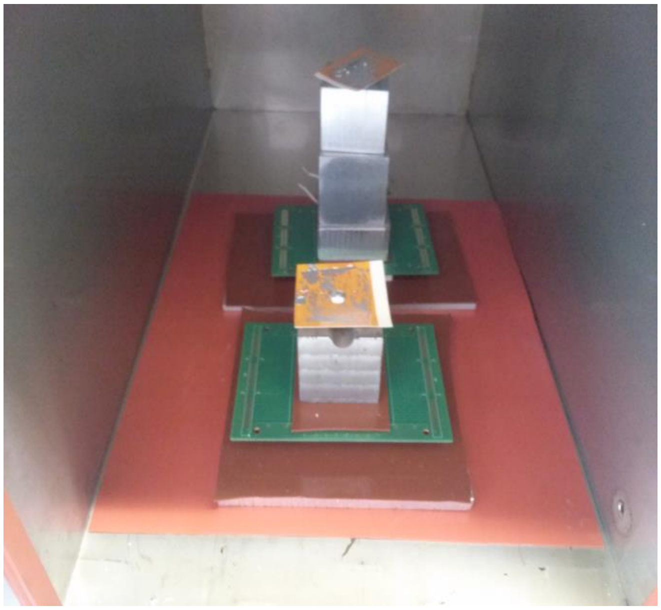
Success now can be claimed with this assembly technique.

Assembly of Electrical Grade MCP to Readout Card

Following preceding assembly techniques electrical grade MCP was attached to Read Out Card.
Aluminum plate and high temperature silicon rubber is beneath Read Out Card to aid in CTE expansion and oven floor irregularities.

Epoxy mixing sheet also acts as a ‘witness’ that will travel with assembly into curing oven.





Large sheet of High Temperature Silicon Rubber again is used at base of curing oven which the individual aluminum plates used to transfer assemblies into the cure oven.

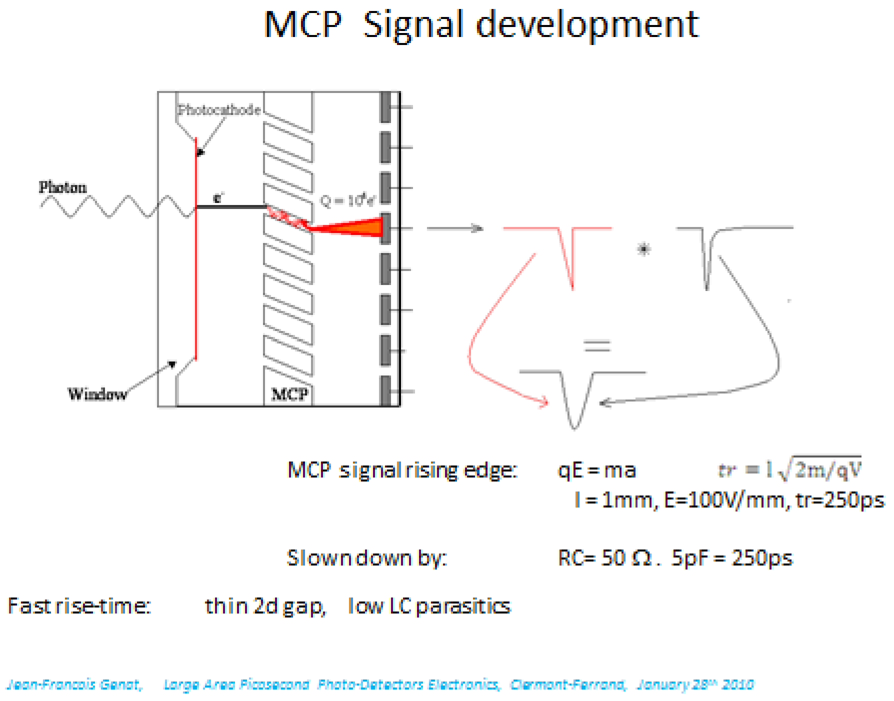
A smaller sheet of silicon rubber is placed over the MCP’s glass surface to protect the surface during the cure and a weight is then placed on top of assembly to provide proper pressure to flow Ag epoxy

Electronic Testing Argonne National Labs

Efficiency, Dark noise, and Baseline fluctuations with Burle-Photonis MCP-PMT's

Jean-Francois Genat and Edward May

Dec 2009 –Jan 2010



MCP Signal development

MCP signal rising edge: $qE = ma$ $tr = l\sqrt{2m/qV}$

$l = 1mm$, $E=100V/mm$, $tr=250ps$

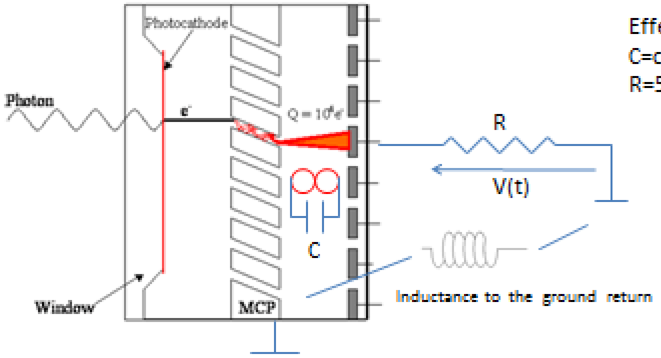
Slown down by: $RC= 50\ \Omega\ .\ 5pF = 250ps$

Fast rise-time: thin 2d gap, low LC parasitics

Jean-Francois Genat, Large Area Picosecond Photo-Detectors Electronics, Clermont-Ferrand, January 28th 2010

MCP Signal development

MCP signal rising edge: $qE = ma$ $tr = l\sqrt{2m/qV}$
Example: l = 1mm, E=200V/mm, tr=250ps



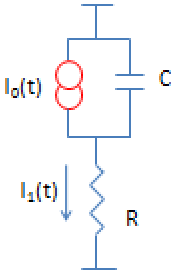
Effect of passive elements:
C=capacitance of the detector
R=50 Ω

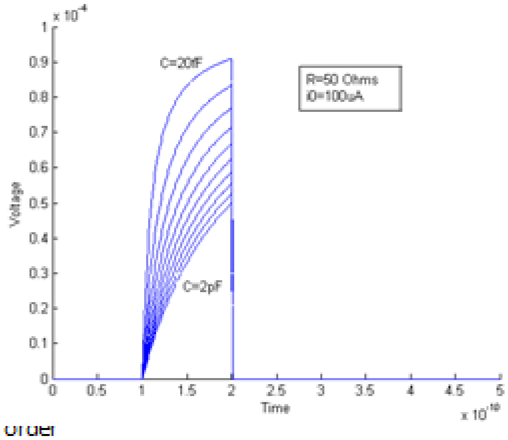
Fast rise-time: thin 2d gap, low RLC elements

MCP Signal development

First order model:

$$i_1(t) = i_0 t/(t + RC)$$





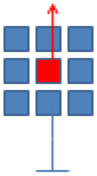
Rise time is RC dependent at the first order

Experimental conditions

10 and 25 µm 2" x 2" Burle-Photonis MCP tested

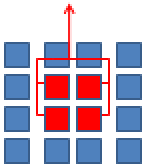
- 25 µm MCP HV: 1.7-2.0 kV

Signals taken on one anode pad, all other pads grounded:



- 10 µm MCP HV: 2.2-2.5 kV

Signals taken on one anode pad, all other pads grounded:

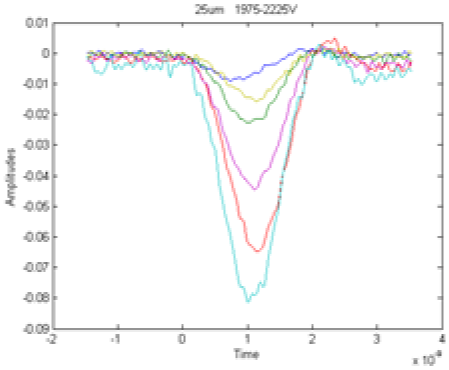


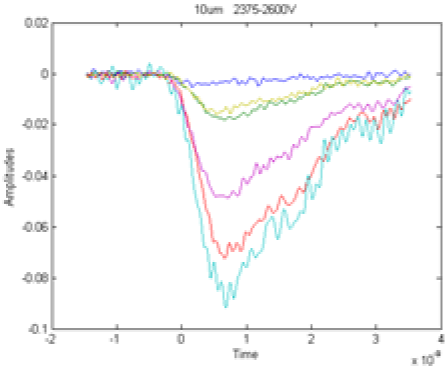
Use Ed May's calibrated laser test setup at Argonne

- 408nm light set at 100 Photo-Electrons
- TDS 6154C 18GHz bandwidth from Tektronix

Measured Signals

408nm 70ps laser
100 Photo-Electrons
Cable bandwidth: 3.5 GHz

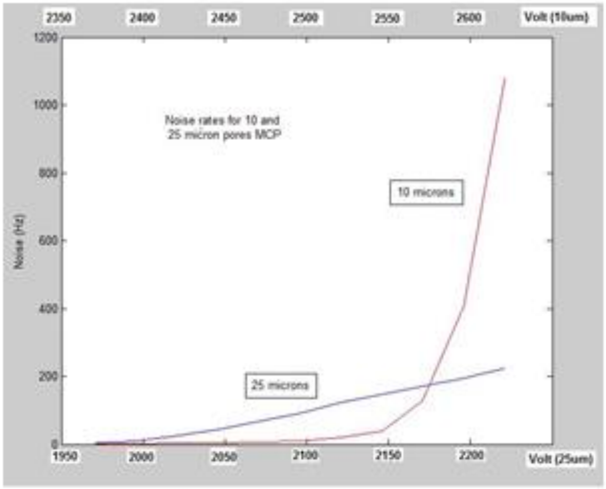




Conclusions:

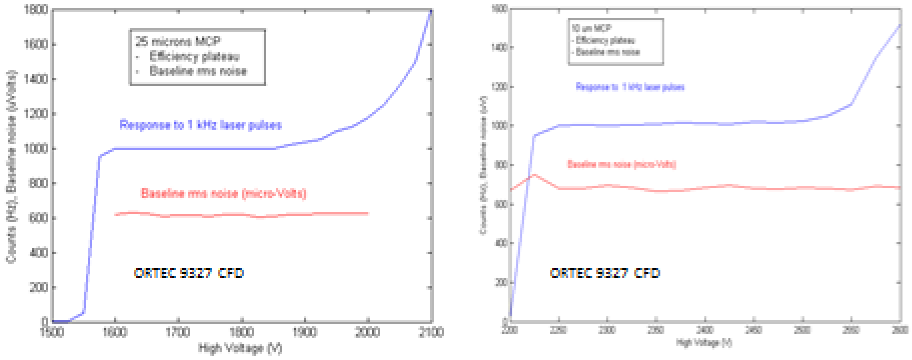
- Gain is 40mV/100 = 0.4mV/PE (25µm) at 2100 V
  5mV/100 = 50 µV/PE (10µm) at 2500V
- 10µm somewhat faster rise time, longer trailing edge, presumably due to 4 pads connected together.
- The rise time does NOT depend upon the amplitude

Impulse dark noise vs HV



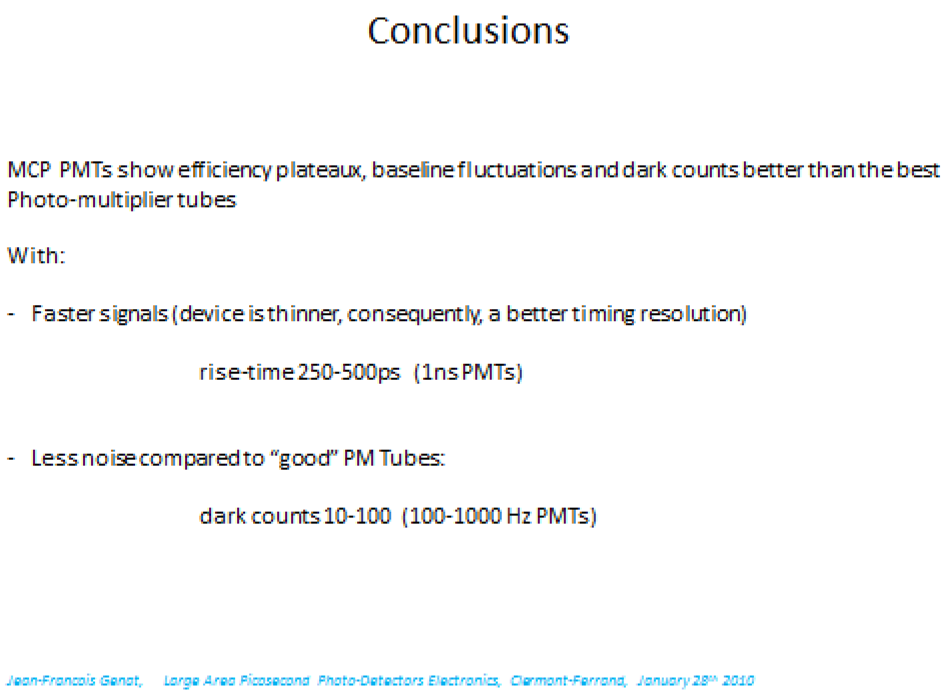
Conclusion: At full efficiency (25µm 2000V, 10µm 2500V), dark counts rates are:
25Hz (25µm)
80Hz (10µm)

MCPs Efficiency and Baseline noise



Efficiency plateau and baseline noise (left: 25 µm, right 10 µm)
Plateaux are 300V wide for both MCPs
Baseline rms below 1 mV rms (system noise), no dependence with the High Voltage

10 µm MCP showed double and triple after-pulses (not included in the count rates)



Conclusions

MCP PMTs show efficiency plateaux, baseline fluctuations and dark counts better than the best Photo-multiplier tubes

With:

- Faster signals (device is thinner, consequently, a better timing resolution)

  rise-time 250-500ps (1ns PMTs)

- Less noise compared to “good” PM Tubes:

  dark counts 10-100 (100-1000 Hz PMTs)