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RECENT RESULTS FROM ARGONNE MCP-PMT PROGRAM

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OUTLINE

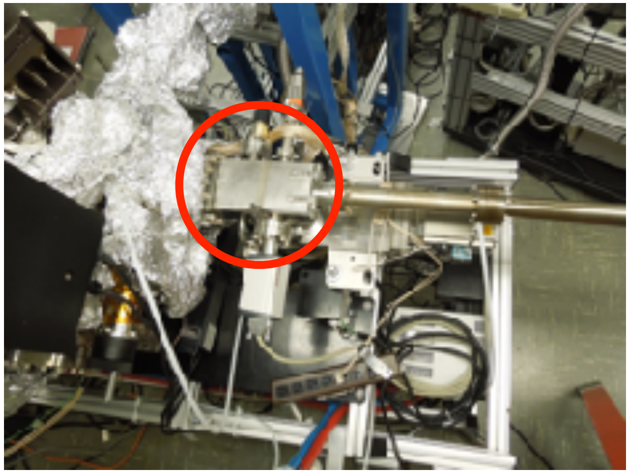
- Brief re-cap of MCP-PMT work at Argonne
- Recent results from study during spring/summer 2017 of MCP-PMT response in magnetic field
- Present early results from sub-micron resolution 3D printing of capillary arrays for MCP substrate
  - Patent application filed beginning of October, 2017
- Summary

BRIEF RE-CAP OF MCP WORK AT ARGONNE

- Argonne HEP group part of original LAPPD collaboration which began work in August, 2009 (UChicago, Space Science Lab/Berkeley, Incom, UHawaii, Fermilab, Arradiance)
  - Included collaboration with other Argonne divisions: Materials Science, Energy Systems ALD group, Argonne glass shop
- Use of atomic layer deposition and borosilicate glass MCP substrate reduced cost of MCPs, simplified fabrication, and improved gain and lifetime.
- Argonne developed thermopressure indium sealing technique for tubes and applied technique to produce 6cm × 6cm active area tubes in compartmentalized UHV transfer system. Incom, Inc. now supplies Argonne with 8” MCPs diced for 6cm production
- Small form factor tubes distributed to small number of early users as Incom developed LAPPD commercial manufacture (see talk by Alexey Lyashenko)
- Argonne program scaled down and focus is on better timing resolution and magnetic field performance.

6CM SMALL SINGLE TUBE PROCESSING SYSTEM

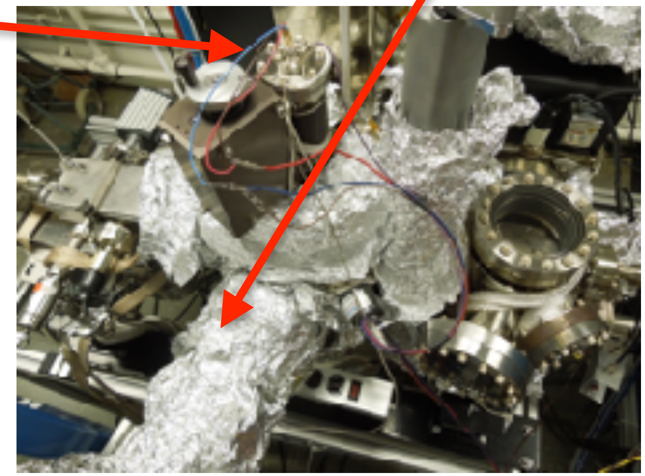
SMALL SINGLE TUBE PROCESSING SYSTEM CHAMBERS



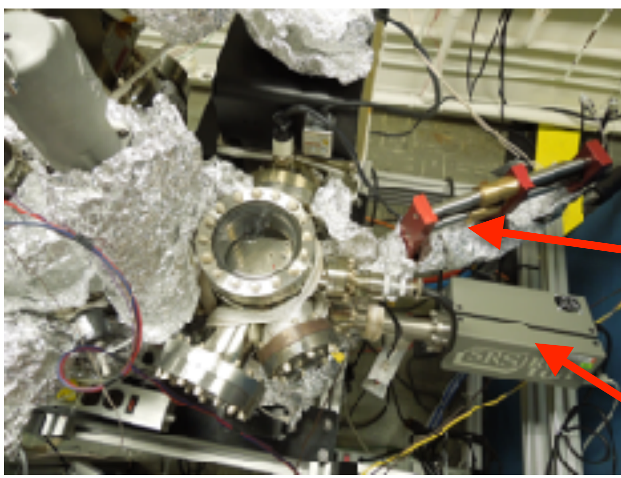
Loadlock

electron gun

connection to sealing chamber



Bake & Scrub Chamber

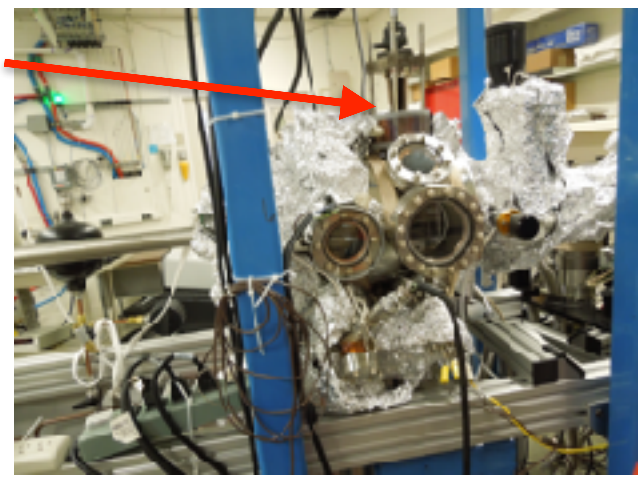


QCM for deposition monitoring

RGA for monitoring baking

Deposition Chamber

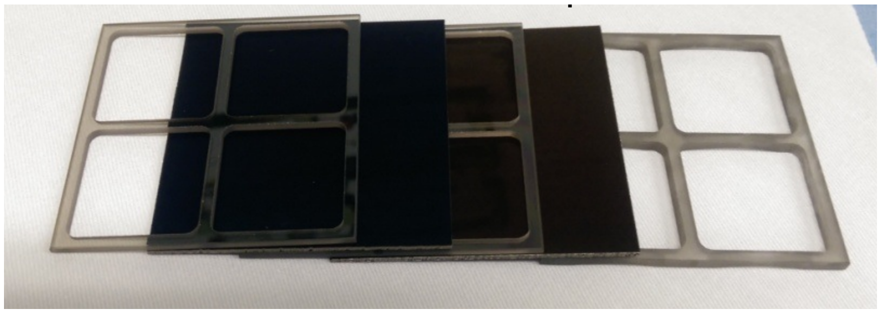
hydraulic press for indium seal

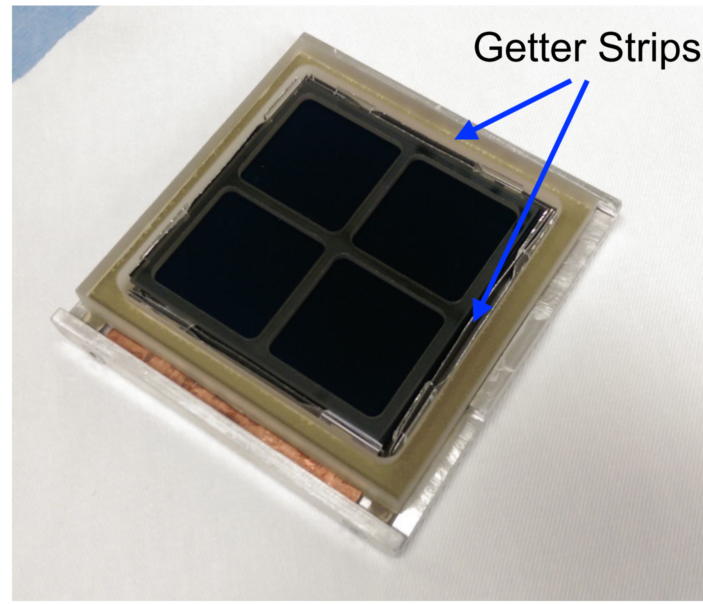


Sealing Chamber

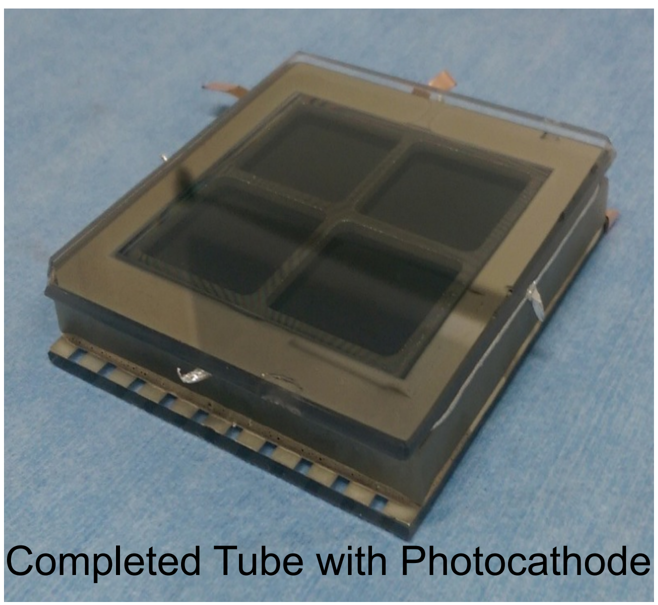
6×6CM^2 MCP PHOTODETECTOR COMPOSITION

MCP & Grid Spacer Stack





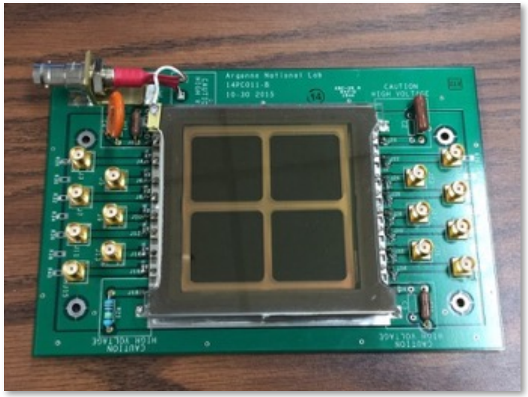
Stack in Glass Lower Tile Assembly



Completed Tube with Photocathode

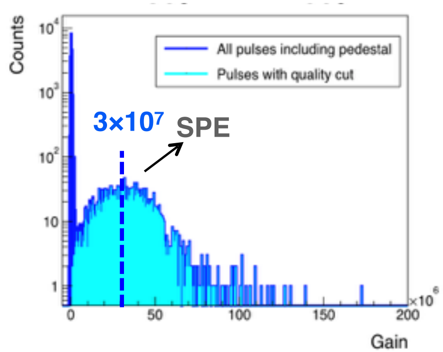
SUMMARY OF 6CM TUBE CHARACTERISTICS

- Argonne routinely producing 6X6 cm^2 functional detectors with K_2CsSb photocathode
- New IBD-1 design allows HV optimization, as biasing individual components possible
- In addition to assembly of photo-detectors, laser testing facility available and photocathode research ongoing.
- Performance:
  - Gain $> 10^7$
  - Quantum efficiency ~ 15%
  - Time resolution including the laser jitter: σ ~ 35 ps
  - Position resolution along anode strip: < 1 mm
  - Rate capability > 1 MHz/cm^2 for single photoelectrons



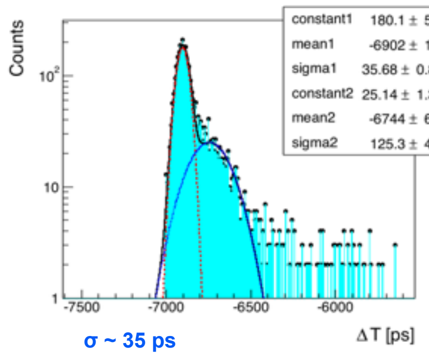
Argonne 6X6 cm MCP-PMT on custom readout board

Gain distribution



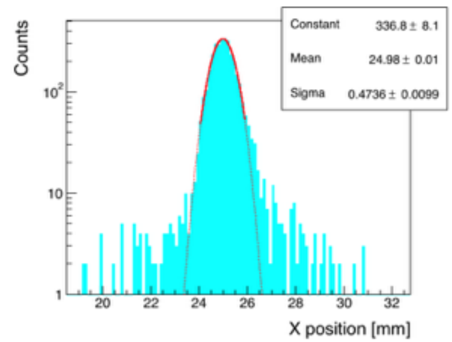
Gain > 10^7

Timing distribution



σ ~ 35 ps for SPE, including Laser jitter

Position resolution



σ < 1 mm for SPE

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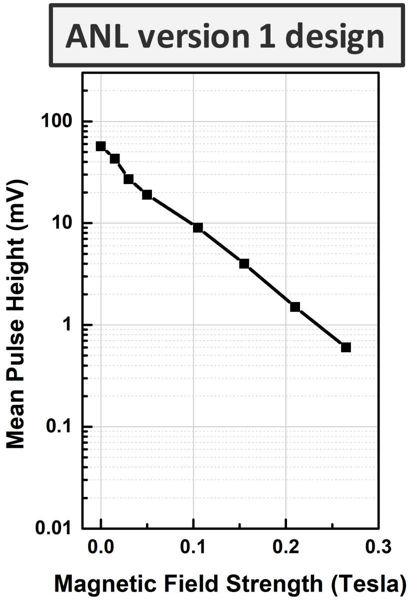
SETUP FOR MAGNETIC FIELD RESPONSE MEASUREMENT

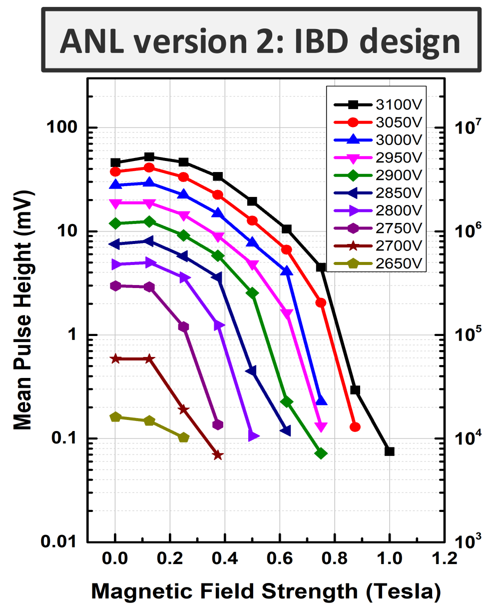
Uniform 1.4T field inside MRI solenoid (main use is g-2 NMR calibration)
Field varied by moving detector along solenoid axis in fringe field
MCP-PMT illuminated with pulsed 405nm LED
Readout via Caen DT5742 16-ch DRS4

PERFORMANCE OF 6×6CM² MCP-PMT IN MAGNETIC FIELD & COMPARISON TO COMMERCIAL DEVICE

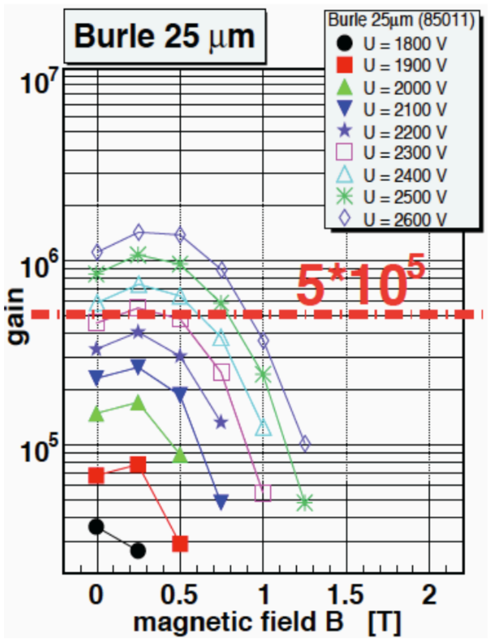
Field ⊥ MCP plane; 8° bias angle of pores w.r.t. MCP plane



- Initial test done at JLab
- Internal bias chain thru resistive grid spacers & MCPs; little control over individual MCP bias
- Very sensitive to B-field
- **Essentially lose response by 0.2T**



- Latest test results from Argonne MRI magnet
- Individual MCP bias design w/external resistor chain
- Significantly improved response
- **Use gain up to 0.8T**



- Burle Planacon response for similar size pore
- Lower gain tube initially but somewhat less gain drop with field
- **Useful gain 1-1.2T**

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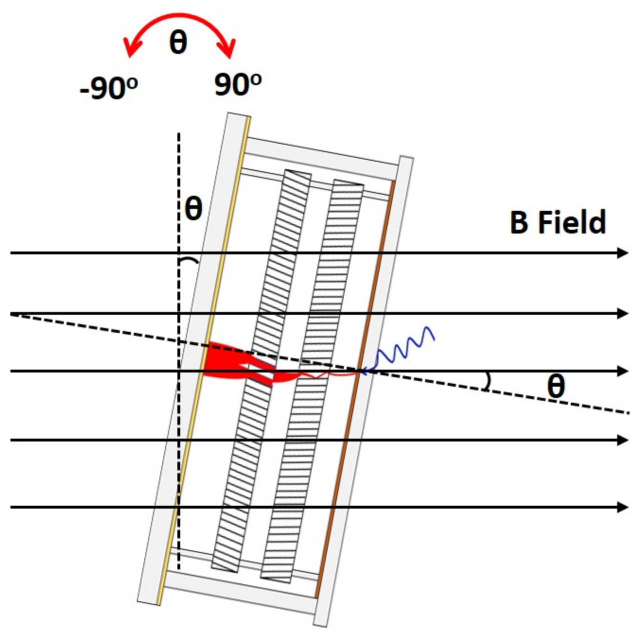
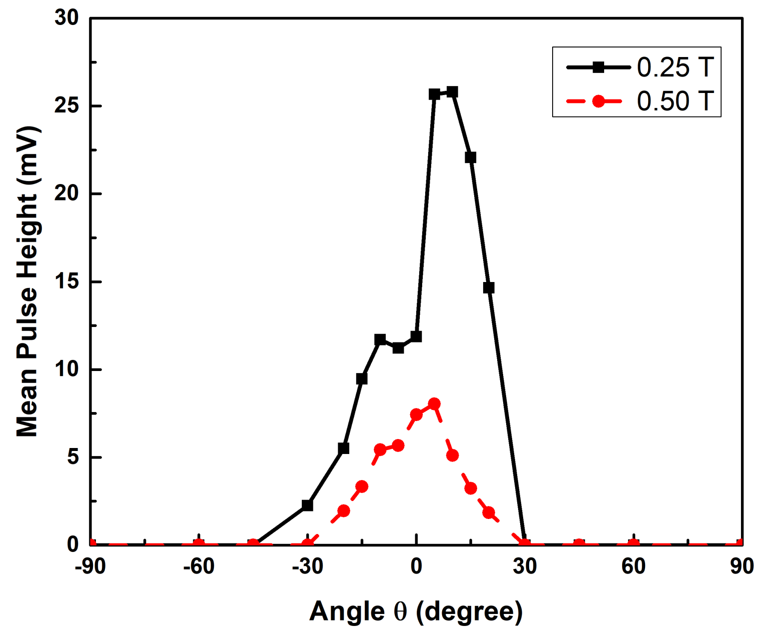
ANGULAR DEPENDENCE OF MAGNETIC FIELD RESPONSE

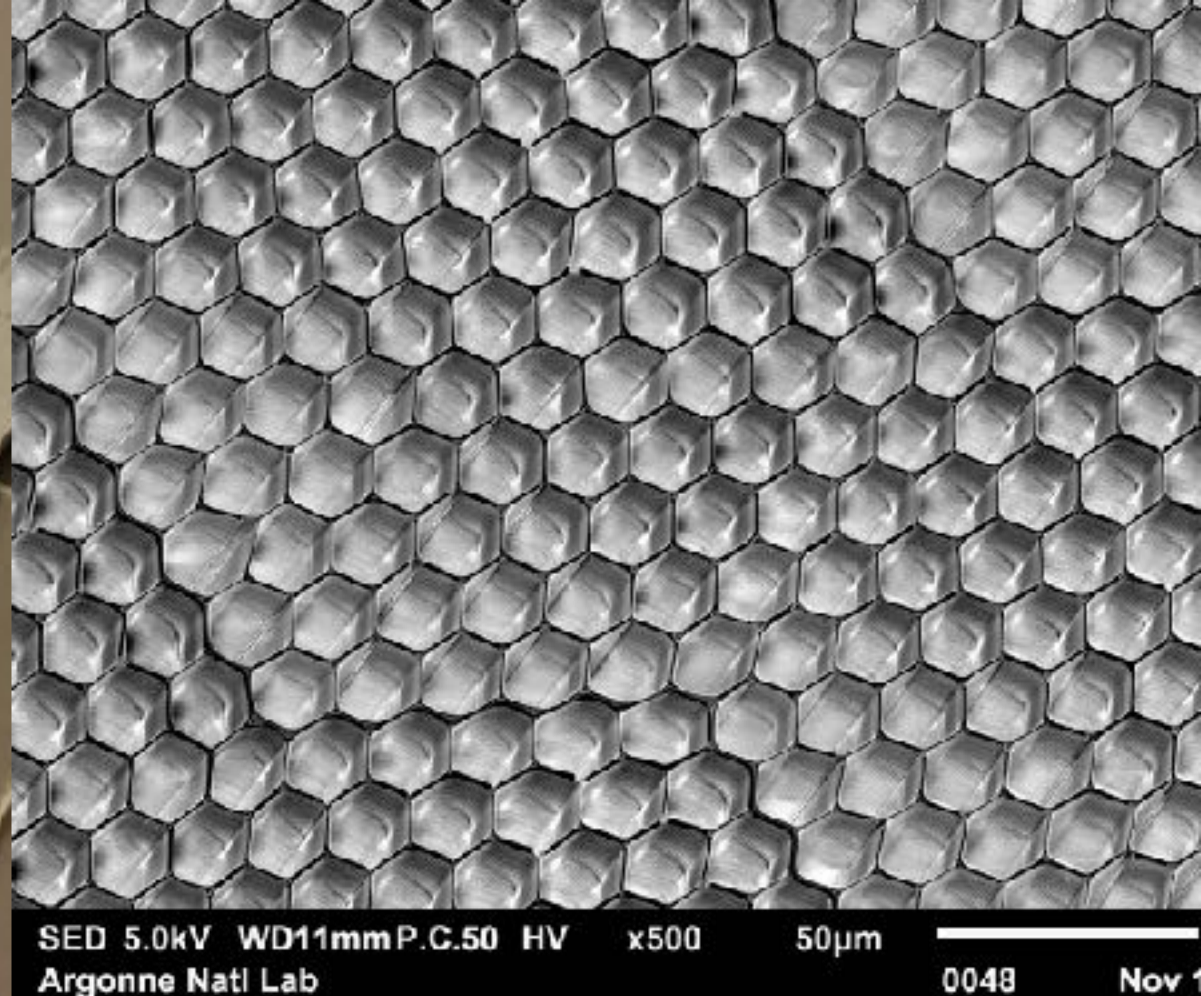




Pores have 8° bias w.r.t. MCP surface, so peaking of response at ±8° is unsurprising. Secondary electrons spiral around field as they traverse pores. Asymmetry is not understood at present (difference whether 1st or 2nd MCP pores align with field?). Response rapidly goes to zero at larger angles.

SUMMARY & PLANS FOR IMPROVING RESPONSE IN MAGNETIC FIELD

- Introduction of independent biasing of MCPs allows better optimization of individual MCP gain and improved magnetic field performance
- Useful signal maintained up to ~0.8T for $\perp$ orientation of B-field w.r.t. MCP-PMT
- Alignment of pores along field improves response. Larger angle of field w.r.t. MCP rapidly degrades response
- Expect performance in B-field could be improved with smaller pore size (current size is 20μm) and possibly reduced spacing of MCP/support spacers.
  - Recently received 10μm pore MCPs with MgO SEE coating from Incom, Inc.
  - Current photocathode-MCP gap is 3mm, MCP-MCP gap 2mm, MCP-anode gap 2mm
  - Plan to reduce gap spacing to determine if this improves response.

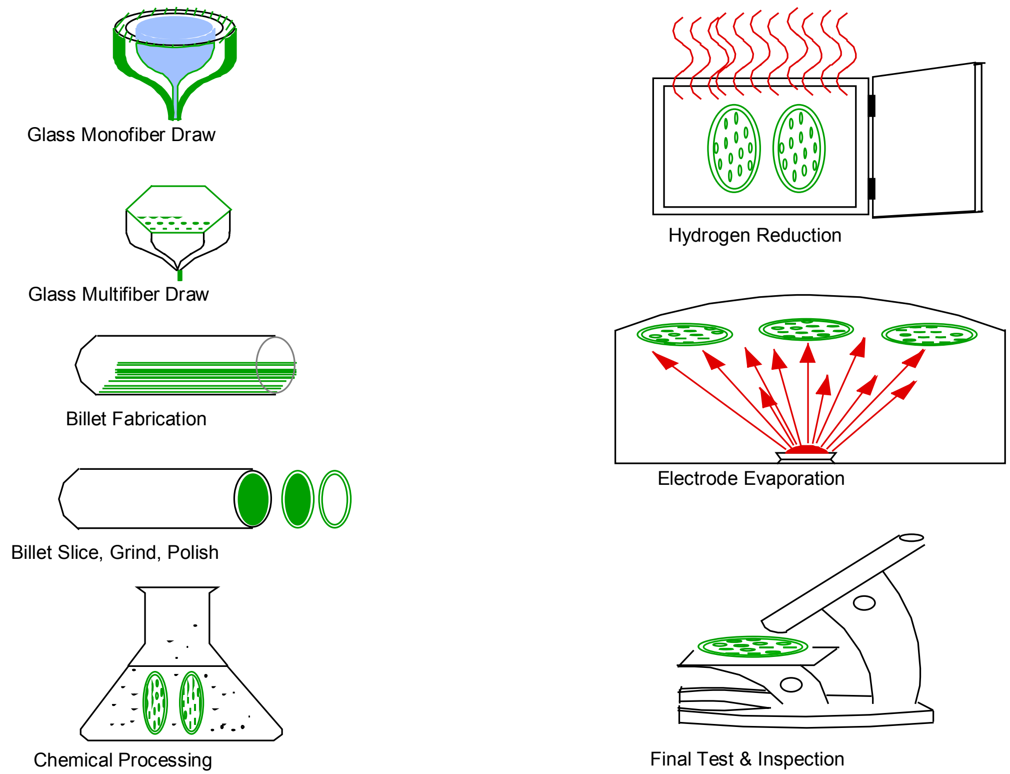


3D PRINTING OF CAPILLARY ARRAYS FOR MICROCHANNEL PLATES

WHY 3D PRINT CAPILLARY ARRAYS? (I)

Hollow core borosilicate capillary arrays and atomic layer deposition of resistive and emissive coatings have transformed MCP fabrication: lower cost and better performance

- Use of hollow core borosilicate as opposed to lead glass reduced cost and eliminated some chemical processing



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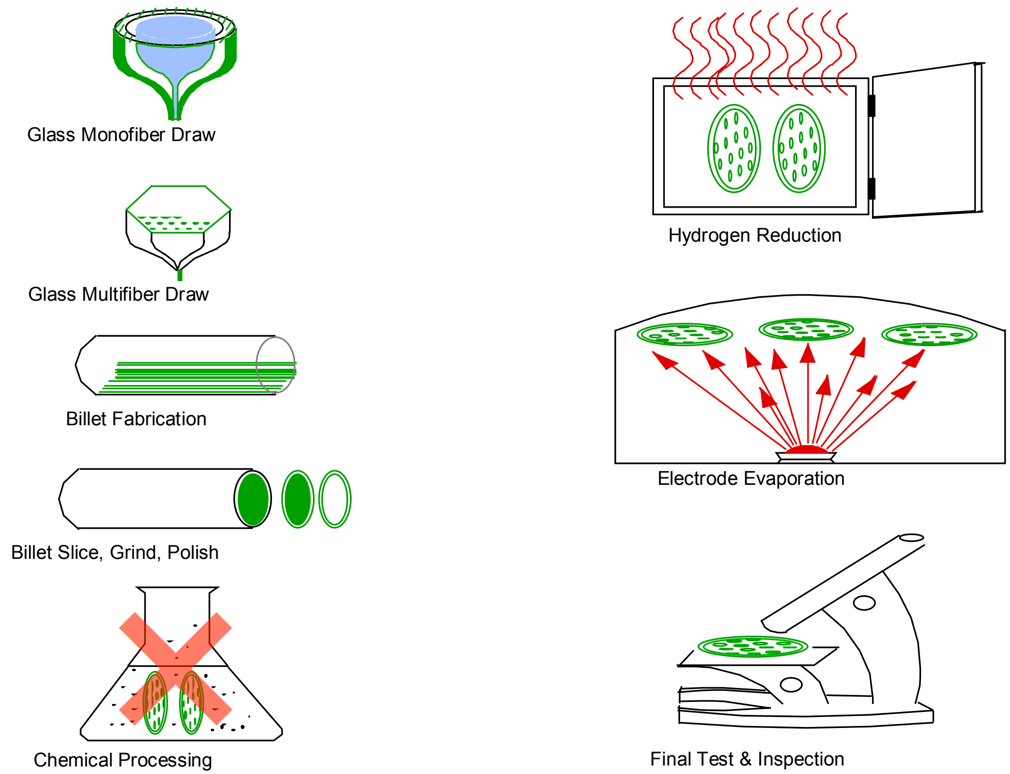

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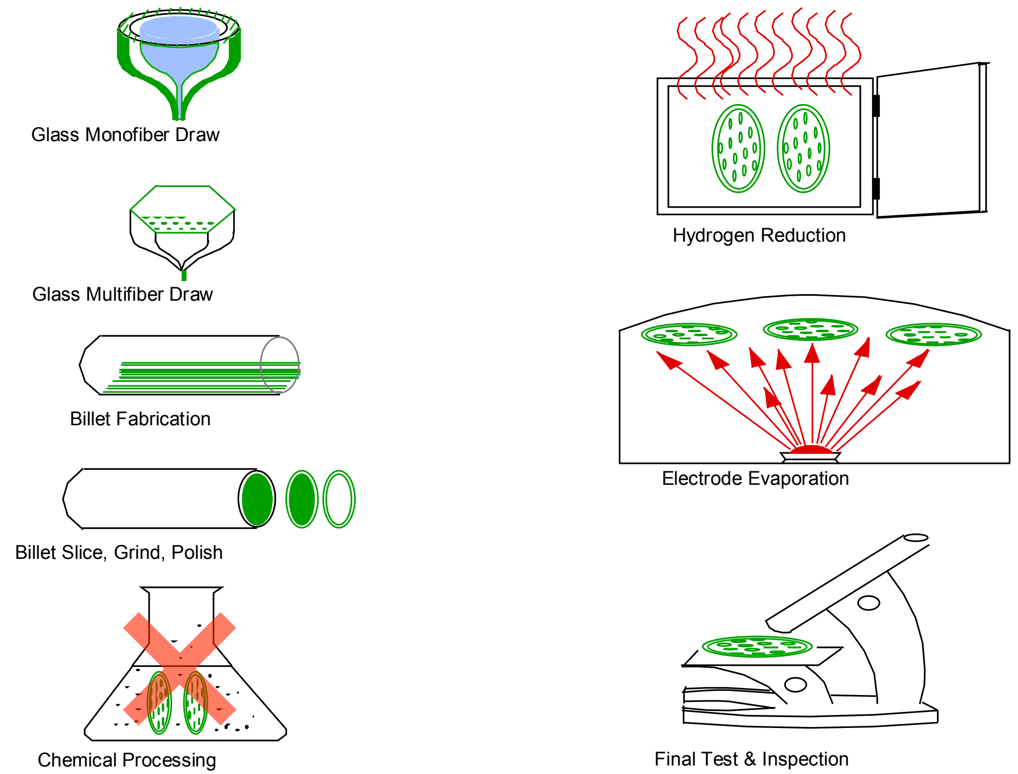

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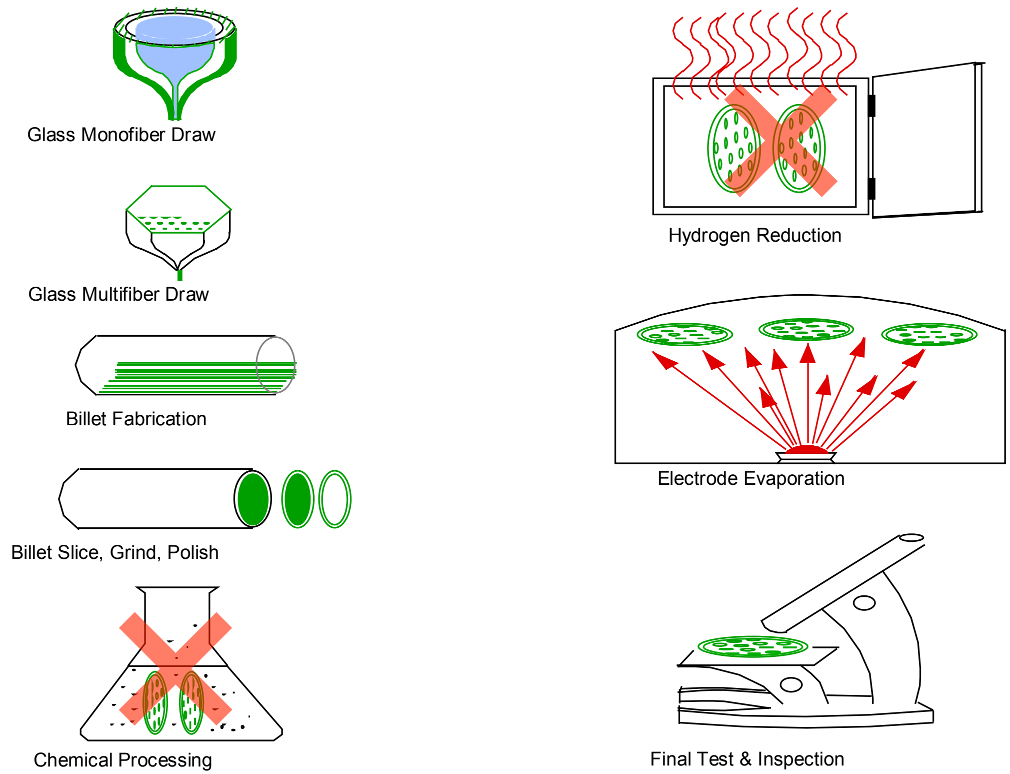

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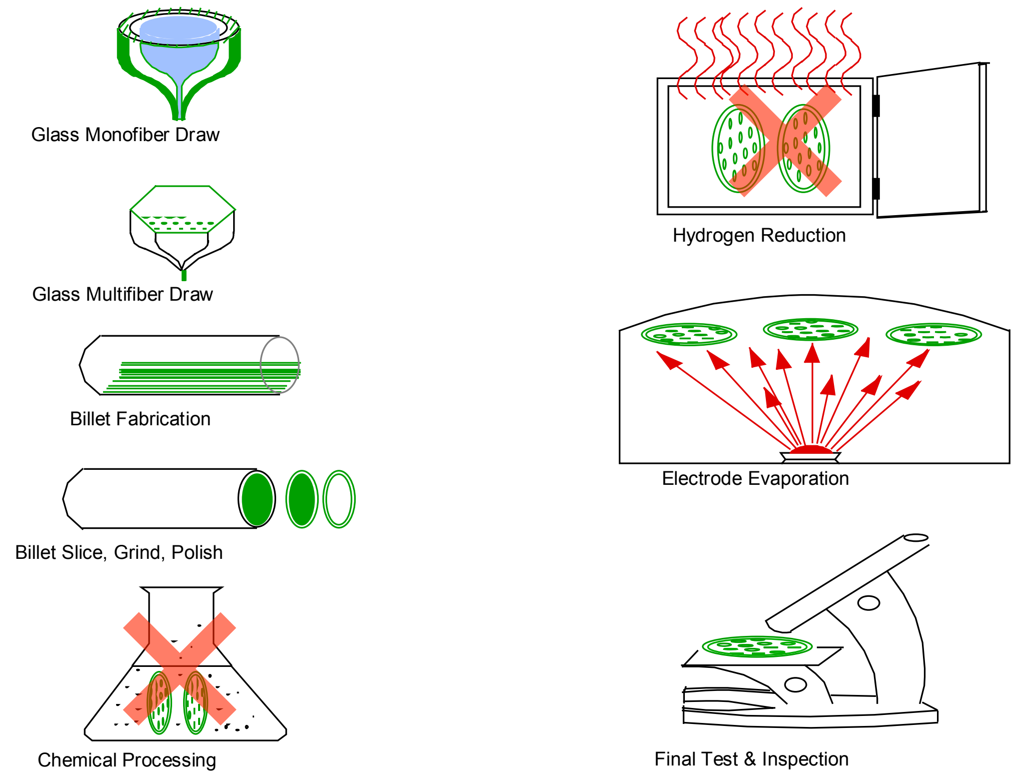
- Overall cost much less but large capillary array plates (20×20cm^2) still ~$1000 and require substantial labor to make



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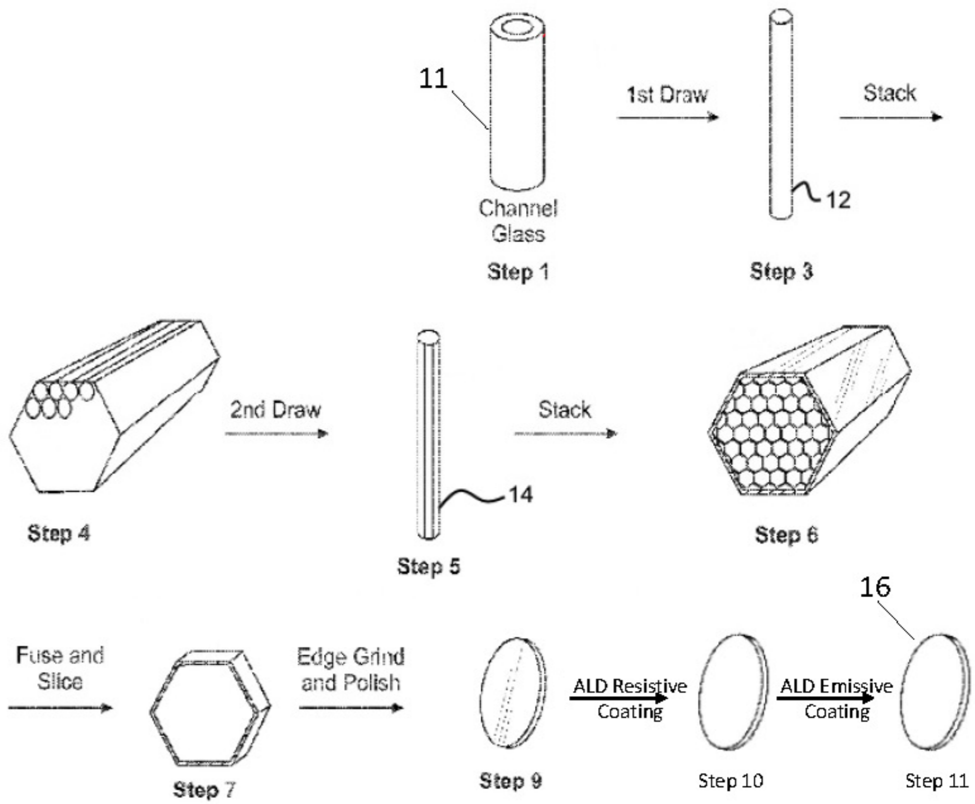

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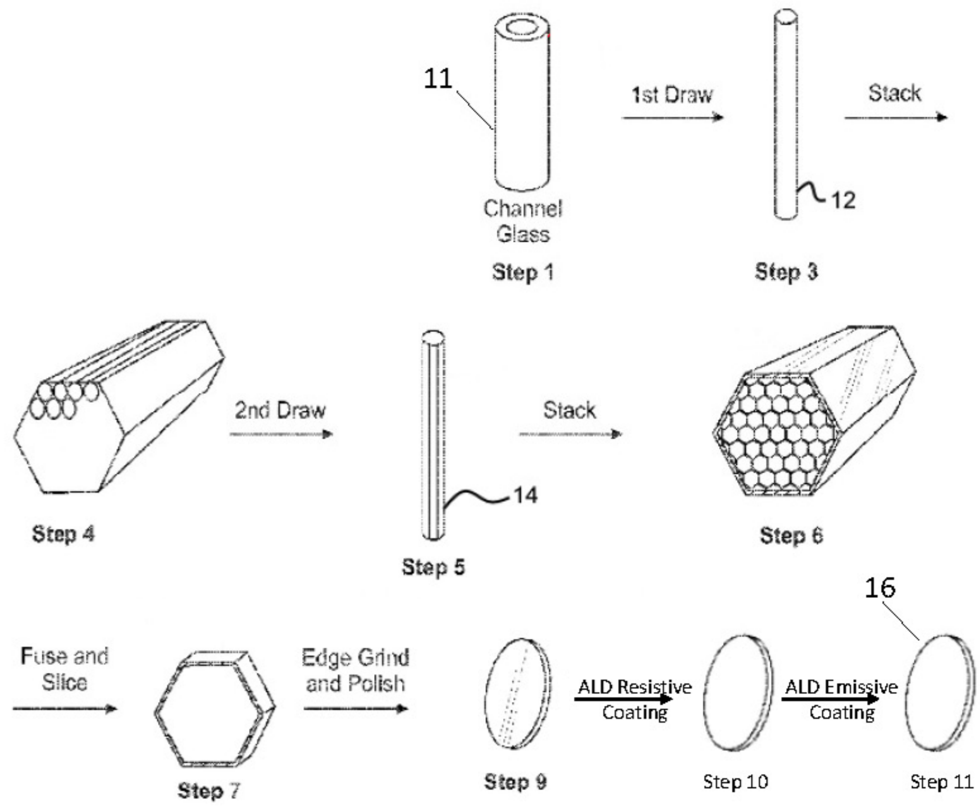
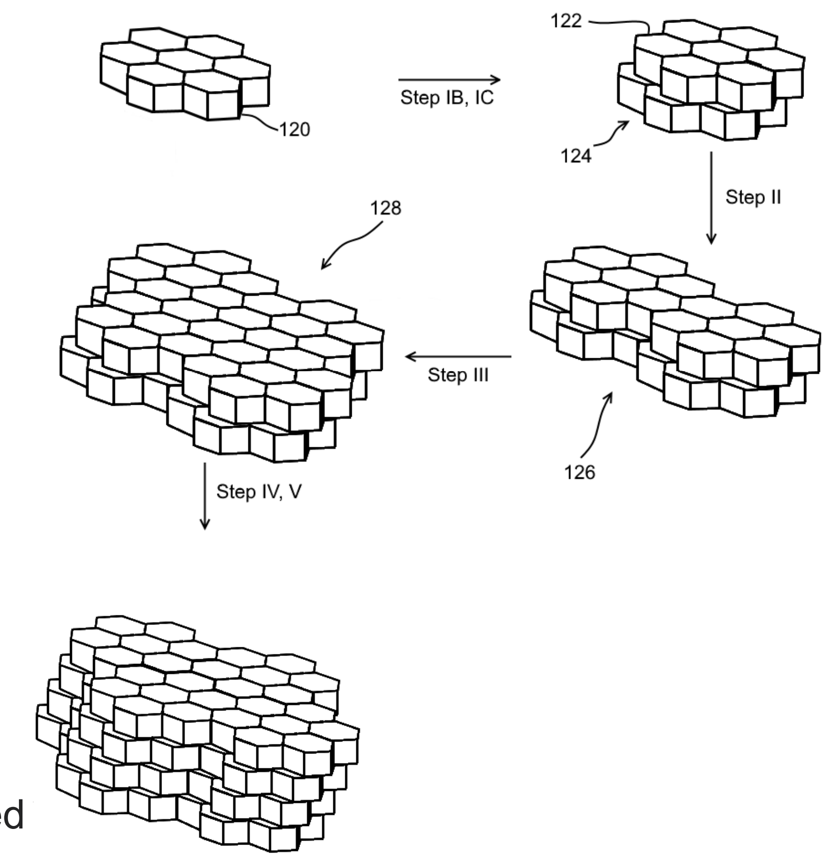


3D printing capillary arrays could reduce cost another ×10+, allow novel geometries and maybe eliminate some ALD steps

WHY 3D PRINT CAPILLARY ARRAYS? (II)

3D printing eliminates many steps in capillary array fabrication

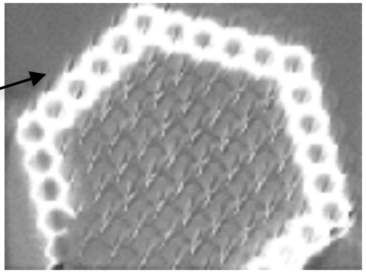
- No glass to draw, bundle, draw, bundle, fuse, slice, grind, and polish.
- Array is fabricated as series of identical element draws
  - Current print limitations require making in ~400μm × 400μm × 1μm blocks
- Can make essentially any desired pattern
- Material is viscous monomer that is polymerized to form substrate
  - Photoresist is relatively cheap: few dollars/cm^2 or less
  - Can perfect structure in software and print technique with small samples for little cost, then scale up
  - Can add compounds to photoresist to customize: e.g. resistive material to eliminate ALD resistive coating
- Imperfections in capillary array largely eliminated



SO, HOW DOES ONE PRINT AN MCP?

- Use Two Photon Polymerization (TPP) of photoresist to make structure
  - First shown by Maruo & Kawata "Two-photon absorbed near-infrared photopolymerization for three-dimensional microfabrication", J. MEM. Sys **7**, 411 (1998).
  - Infrared laser (780nm) focused to small spot where power is sufficient to produce TPP. Resolution is ~0.1-1μm.
    - Varying laser power ranges effect from no polymerization, to useful polymerization, to blistering
  - Write the structure by moving laser from point-to-point

laser draw as shown by monitor camera



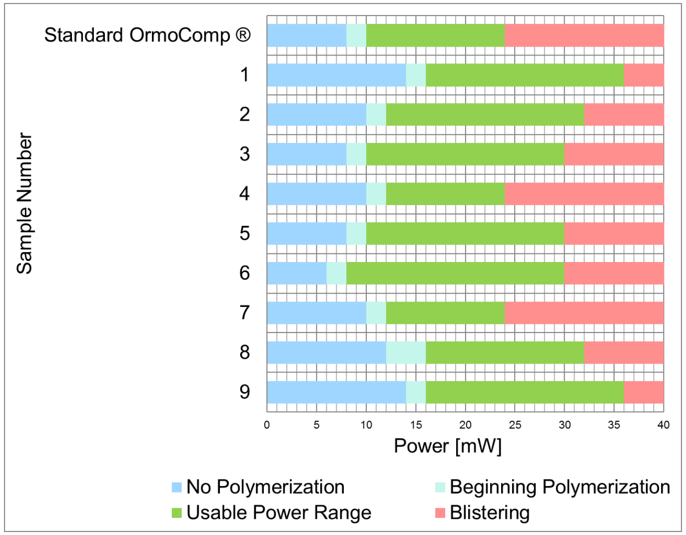
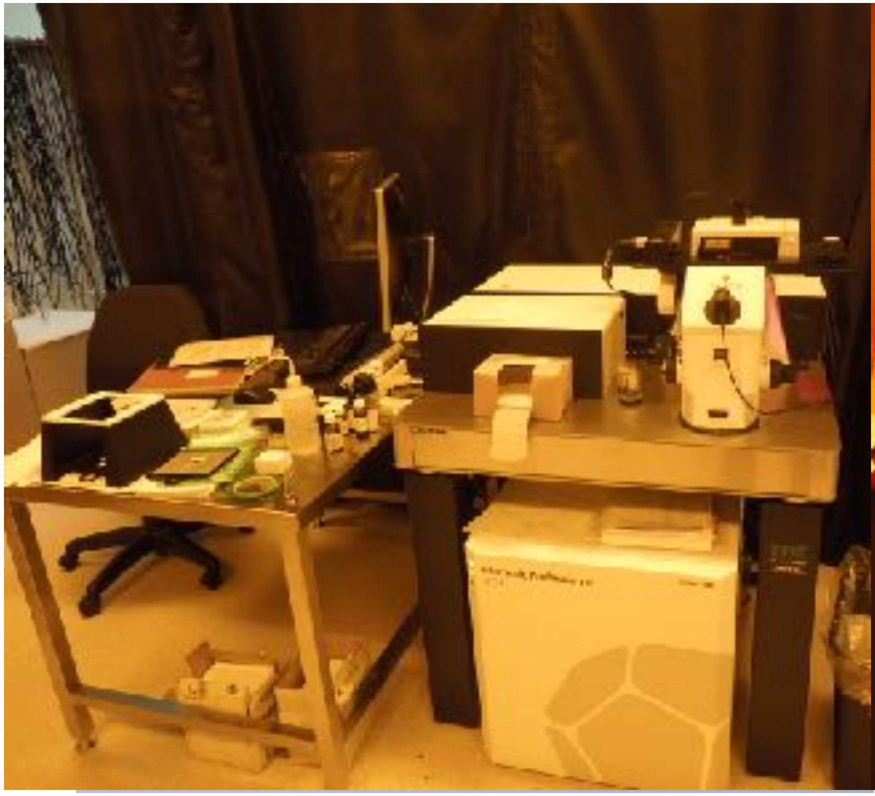


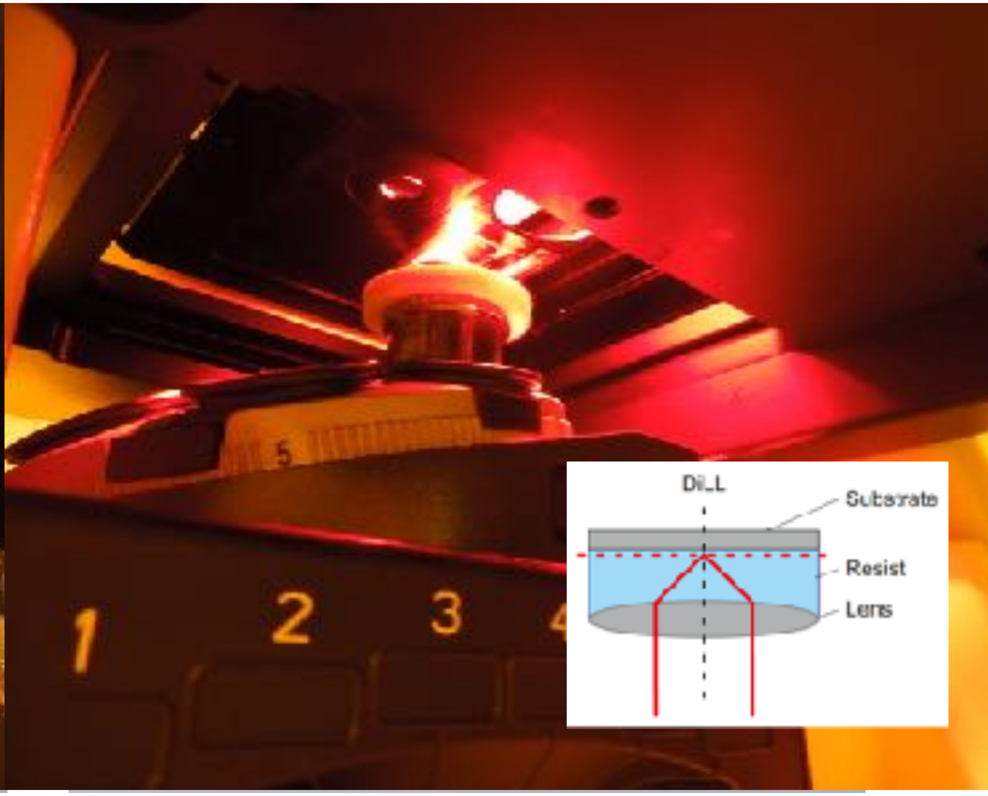
figure credit: Harnisch & Schmitt, SPIE (2017)

  - Complete process with developer and UV illumination
- 3D TPP printers commercially available
  - We use Nanoscribe Photonic Professional (GT)

NANOSCRIBE 3D PRINTER SPECIFICS



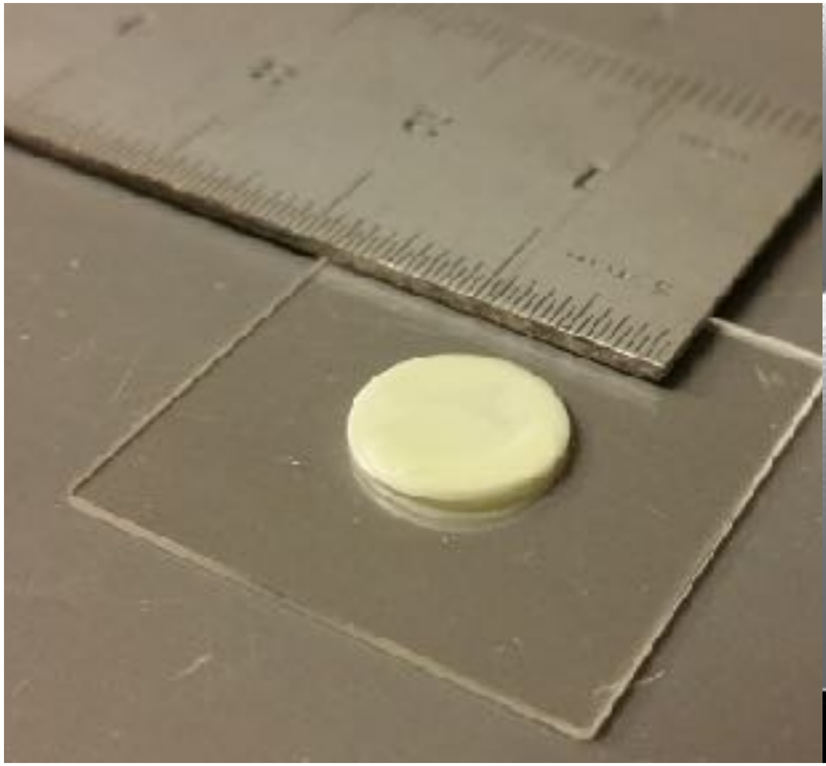
Printer is “table-top” device consisting of
- Floating optical table
- Laser and focussing optics
- Microscope and autofocus system
- Motorized stage: stage (cm movement), piezo (300µm), galvo (100nm-400µm)

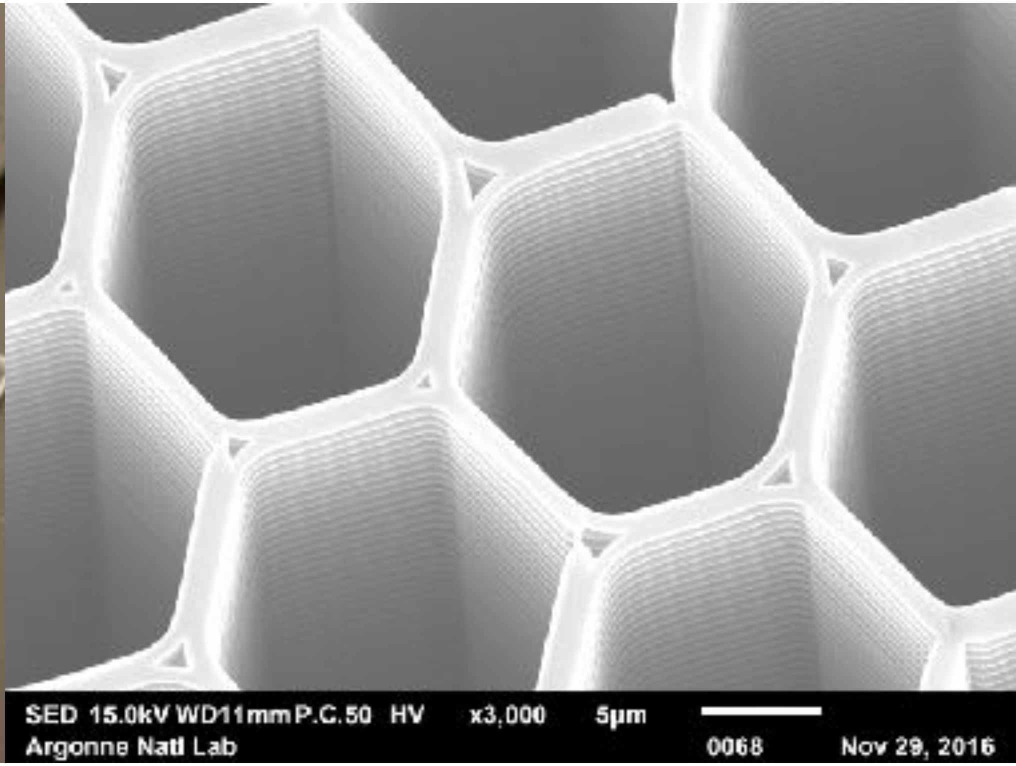


Photoresist applied to glass plate which is inverted and inserted into stage.

Microscope lens is dipped into photoresist to focus laser spot onto print voxel. Dip-In Laser Lithography (DiLL)
Printing starts at just inside glass/resist interface to adhere structure to glass

1CM CAPILLARY ARRAY WITH HEXAGONAL PORES



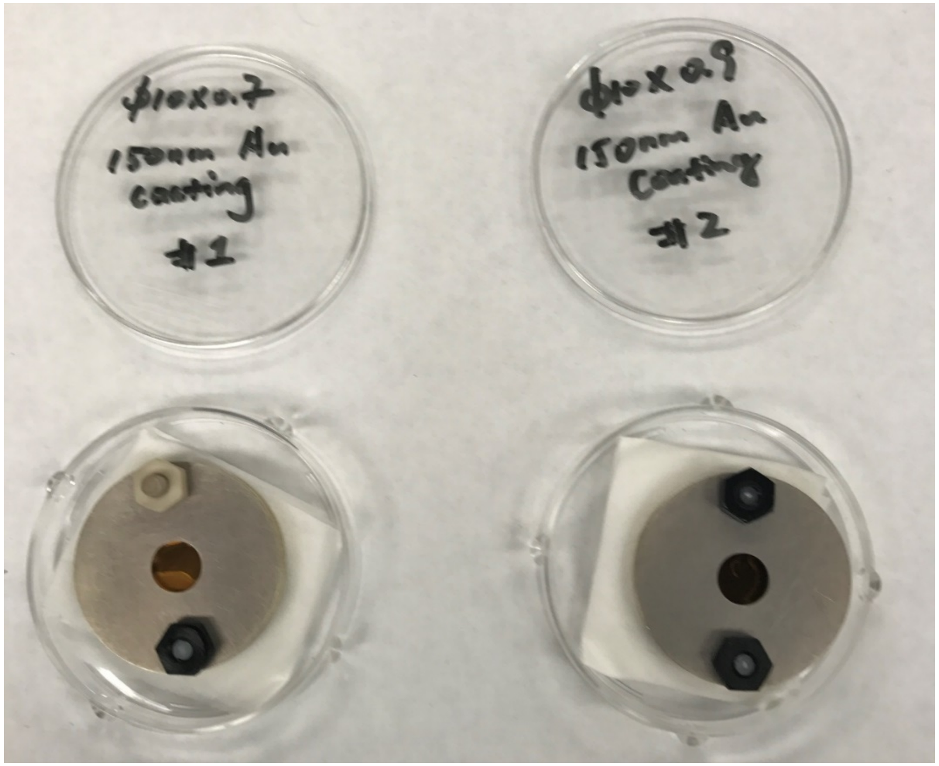


Completed capillary array
- Resist stabilized after print with developer
- Wash with isopropanol
- Exposure to UV lamp for 15 minutes completes any polymerization

SEM image of earlier capillary array
- Laser write speed too fast causes breaks in structure at vertices

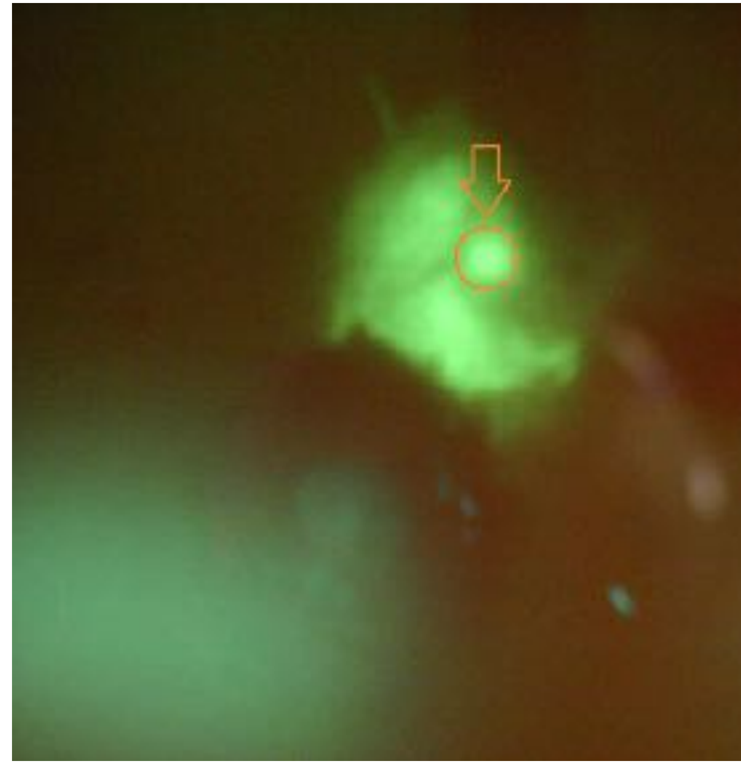
Overall size of capillary array that can be printed **currently** limited by writing speed: 1cm x 0.9mm array takes 39 hours

FUNCTIONALIZATION OF 3D PRINTED MCP VIA ALD AND DEMONSTRATION OF GAIN PRODUCTION



1cm MCP with 10µm pores after ALD coating

- Resistance ~2GΩ; high but usable
- SEE layer — Al_2O_3



1cm MCP image in phosphor chamber

- Illuminated with UV lamp to ionize electrode
- Gain produced in 1cm MCP further amplified by second 8” MCP

SUMMARY

- Production of 6cm × 6cm active area MCP-PMTs continues with small number distributed.
  - Lifetime testing, magnetic field studies, photocathode fabrication improvement,…
- Observed improved performance in B-field with current design
  - Looking to improve response with smaller pore MCPs, reduced spacing of components
- Have produced first 3D printed MCPs and demonstrated gain production
  - Hexagonal pores with thin walls give large open-area ratio
  - MCP size limited by print time with single beam laser
  - Technique appears scalable to multiple laser beams for reasonable print times of larger area
  - 3D printing allows geometries not possible with conventional fabrication

Evolutionary: Continue to improve MCP-PMT performance with incremental changes to pore size, geometry, ALD materials

Revolutionary: Change once again how MCPs are produced through sub-micron resolution 3D printing