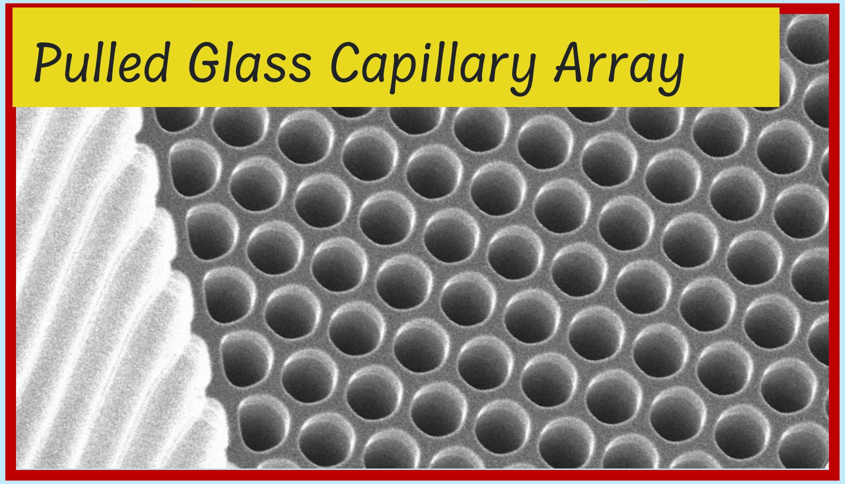
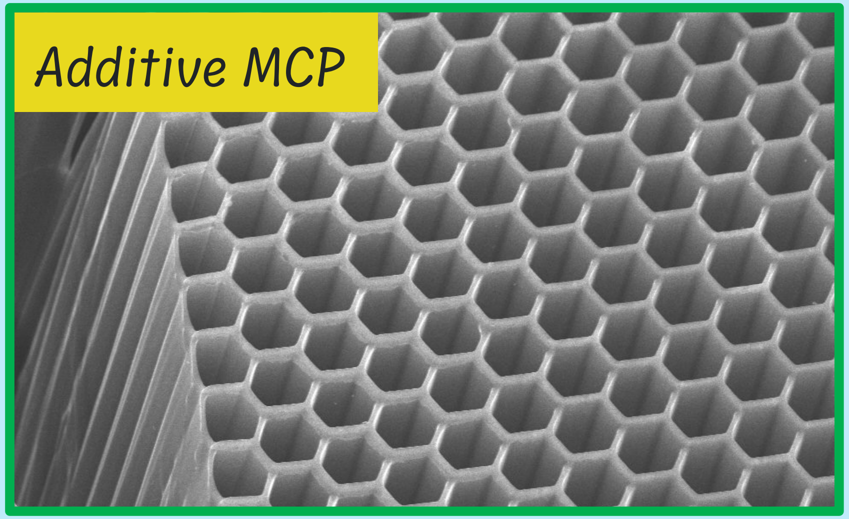
Additive Manufacturing of Microchannel Plates

Phase II SBIR (DE-SC0019535)

DOE-NP SBIR exchange meeting, Aug 15 2024

SEM comparison





- Microchannel plates (MCPs) provide high gain with low background and noise for light and particle detection
- Creating MCPs with **additive manufacturing (3d printing)**
- Why?
  - Cheaper; no foundry required
  - Arbitrary structures (helical pores for B field tolerance)
  - Large open area ratio
  - Wider range of materials
- Challenges:
  - Requires a breakthrough in speed ($t \approx 1/\text{resolution}^3$)
  - Glass in traditional MCPs is a well understood material
  - Need to functionalize pores (resistance and secondary e−)

Technical Team

Robot Nose (RN)

- startup formed to translate DOE lab technology into detector and sensor applications

Jerome Moore: PI and Business Official

Michael Pellin: Photochemistry, Optics

Andy Moore: Software Engineering

Bob Wagner: MCP Validation[0]

Maram Alnahas: EE intern*

[0] also Argonne HEP

*now at NASA JSC

+also Moraine Valley CC

#now at Applied Materials

Argonne National Laboratory

Materials Science Division:

- Alex Martinson (ALD)
- Ashley Bielinski (ALD)
- Prabhjot Menon (Nanoscribe printing)+

Applied Materials Division:

- Jeff Elam (ALD)
- Anil Mane (ALD)#

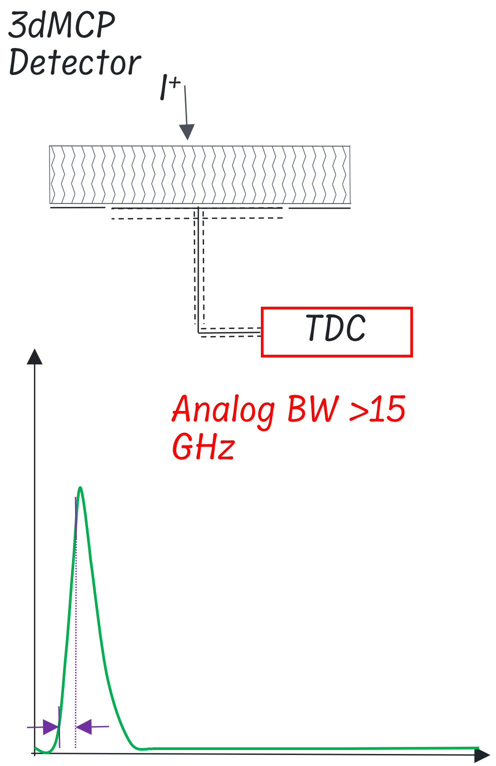
Physics Division

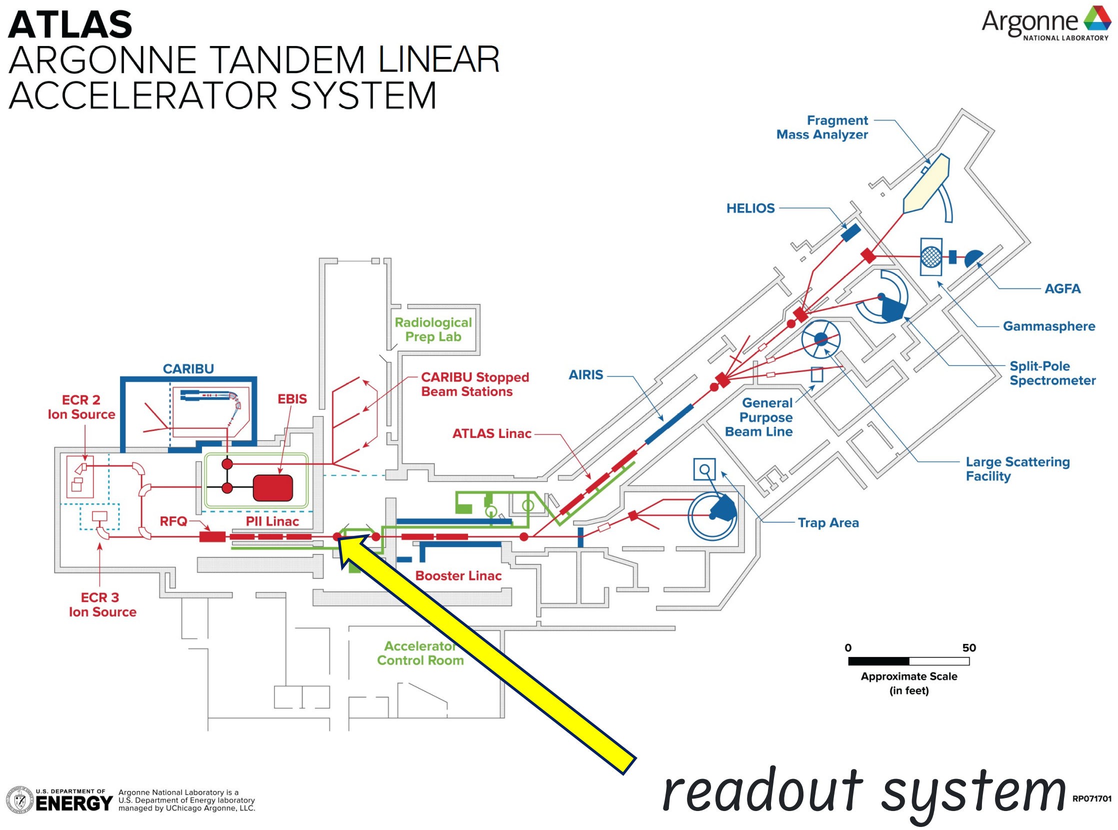
- Jerry Nolen, Numerous ATLAS Staff
- Junqi Xie (Photodetectors)

Extensive discussions:

- Camden Ertley (SwRI, Photodetectors)
- Zein-Eddine Meziani

GOAL: Bunch tuning for ATLAS or FRIB

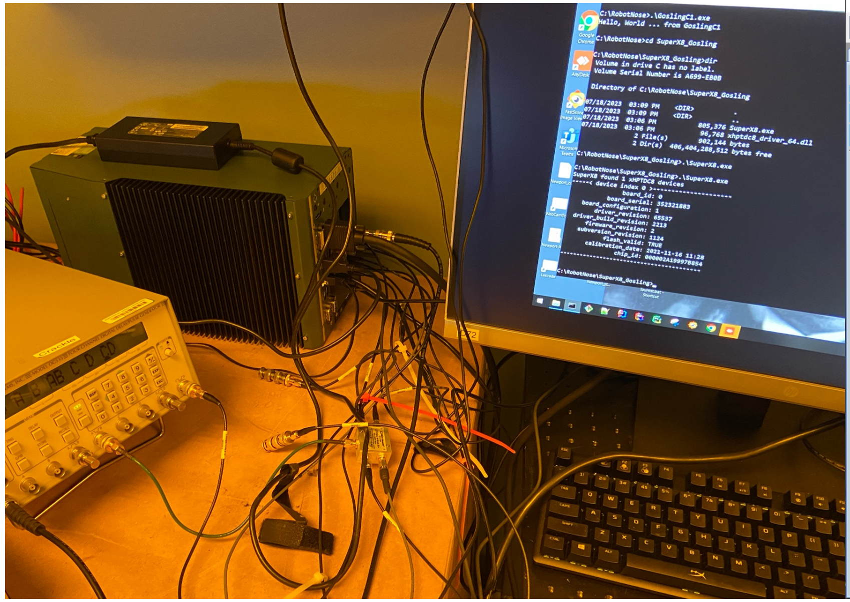


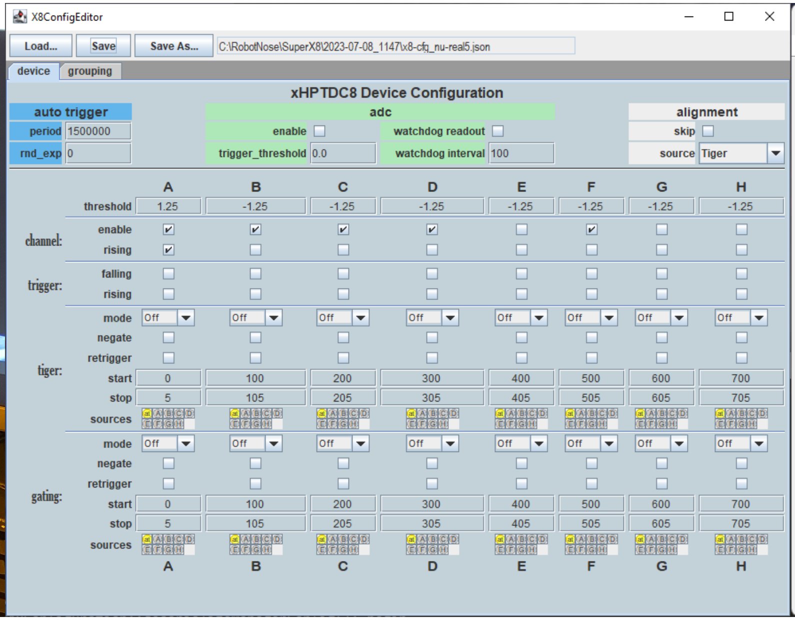


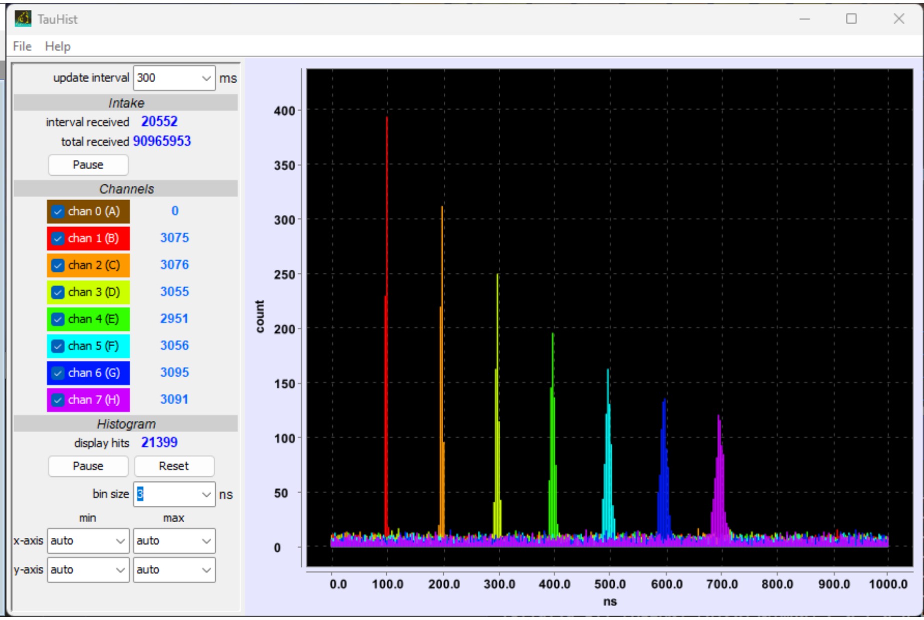
- *<70 ps rising edge (10%-90%) possible with proper channel geometry*
- *need high BW, high rate digitization and real-time display*

Acquisition System

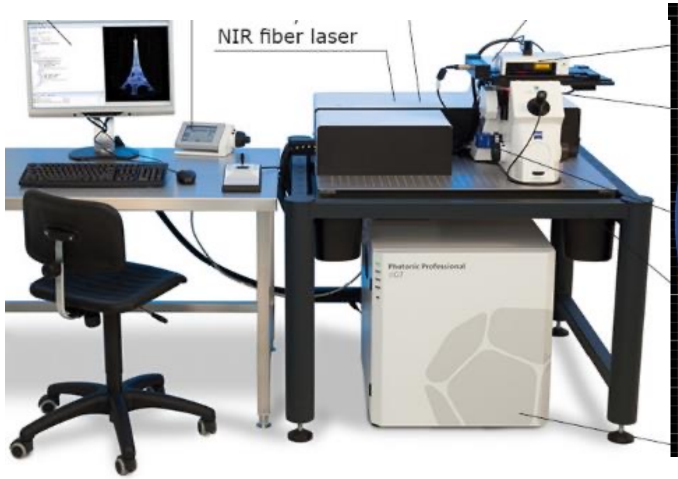
- TDC x8 from Cronologic: 13 ps timing resolution, 48 MHz hit rates
- Custom cabling + buffer amp
- Embedded computer – rad and electrical noise insensitive, long life components
- Software: robust code base in C#, Java; histograms hits at 3-10 Hz screen update rate
- Configuration of thresholds, gates, triggers with convenient user interface
- Remote monitoring via ethernet to control room

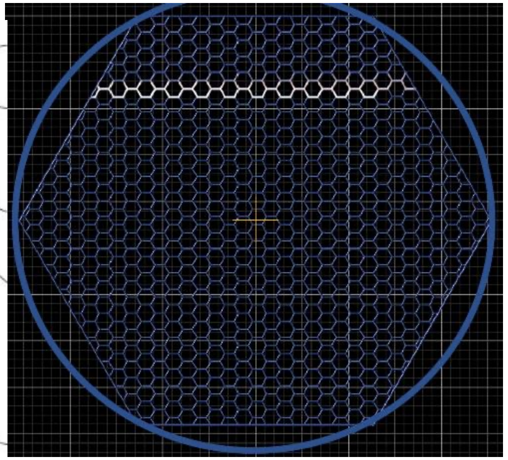




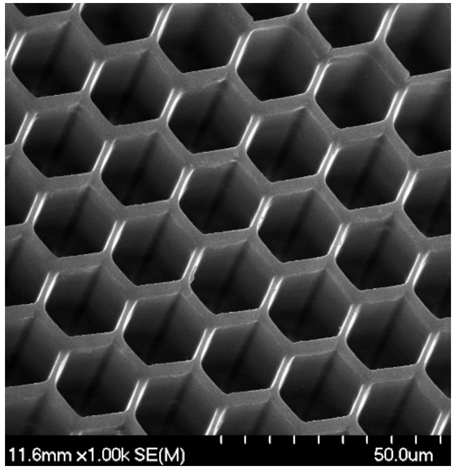


Proof of principle: additive microchannel plate (3dMCP)





10 μm



10 mm

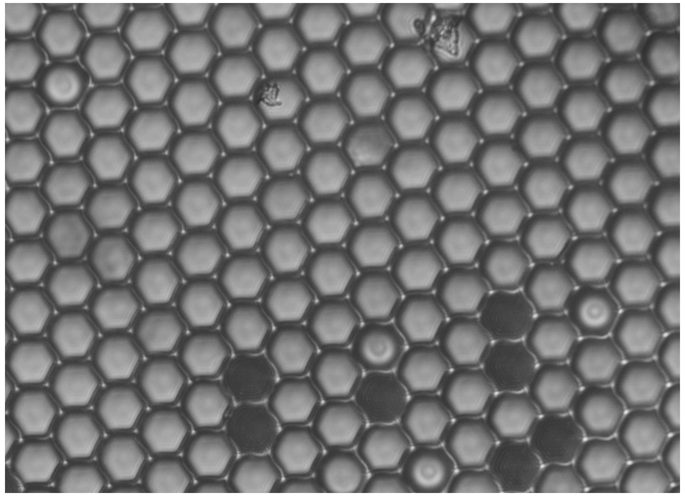
Nanoscribe (2-Photon Polymerization 2PP):

- $700k instrument (Argonne owned and operated)
- Throughput R^3 = 0.15 μL/hr
- Resolution r = 100 nm
- 10mm dia 0.6mm thick MCP takes >24 hours!

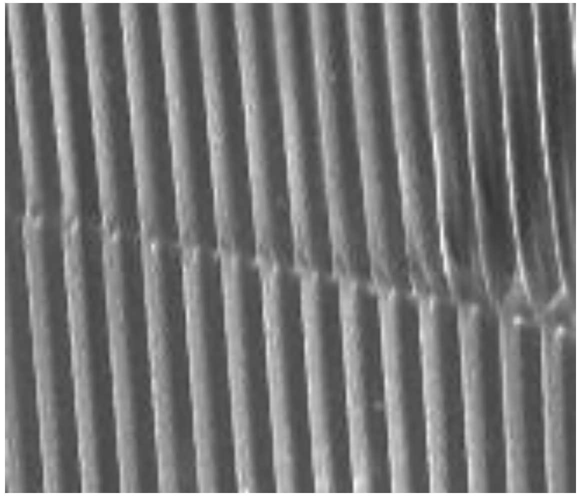
Hundreds of samples were printed 2019-2023

3dMCP blanks: Scanning Electron Microscopy (SEM) analysis

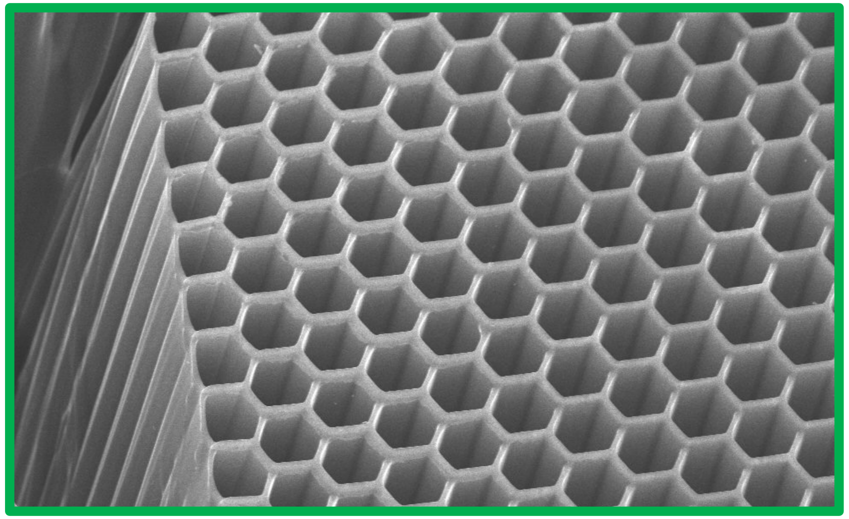
Three example prints shown



Top view:
blocked pores
FAIL



Cross section:
misaligned pores
FAIL



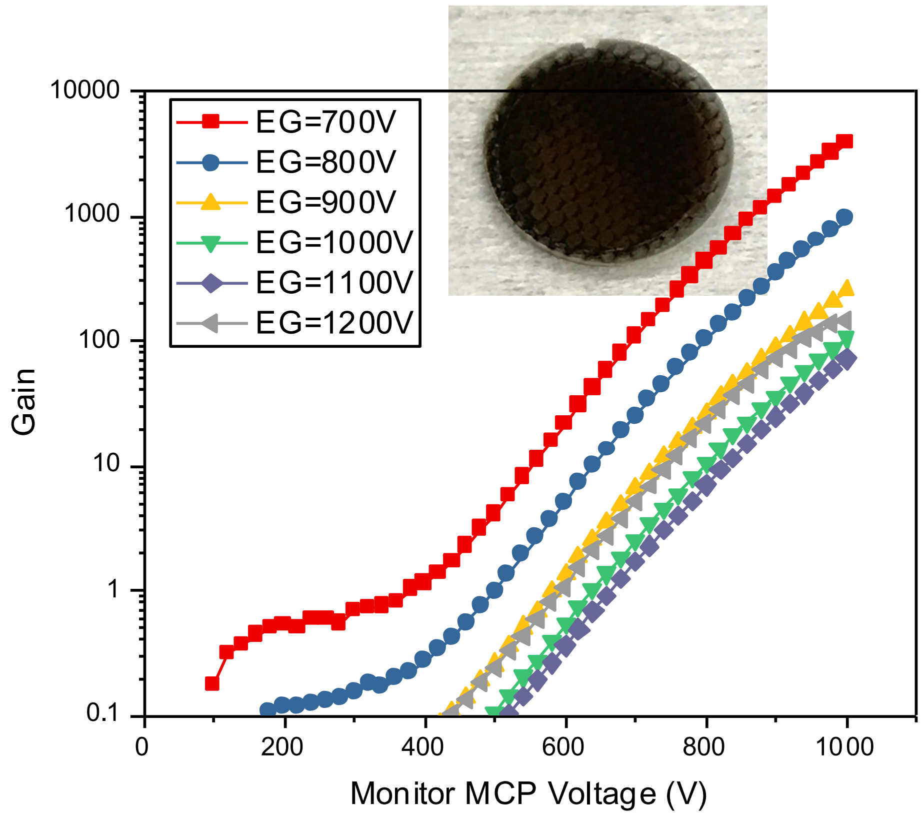
Isometric view:
ideal sample
PASS

22 parameters to adjust to achieve ideal 3dMCP blanks

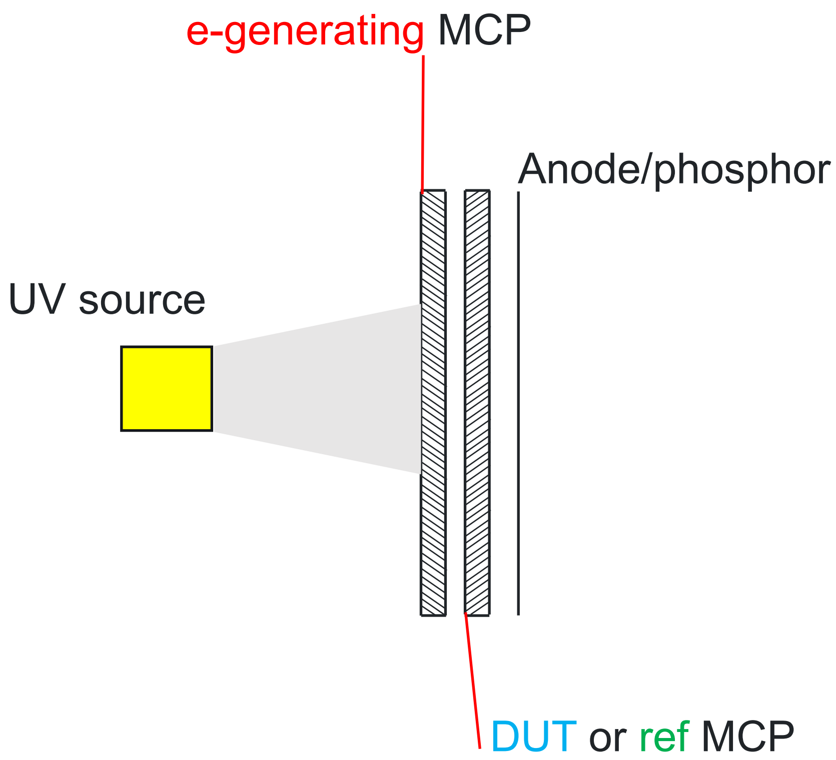
Can we make it generate gain? (1 MCP = 1000x)

Thermal ALD ChemX type coating

- $Mo:Al_2O_3$ = 1:7 cycle ratio
- Deposition at 150ºC is a breakthrough!



Gain measured; but how real is it?



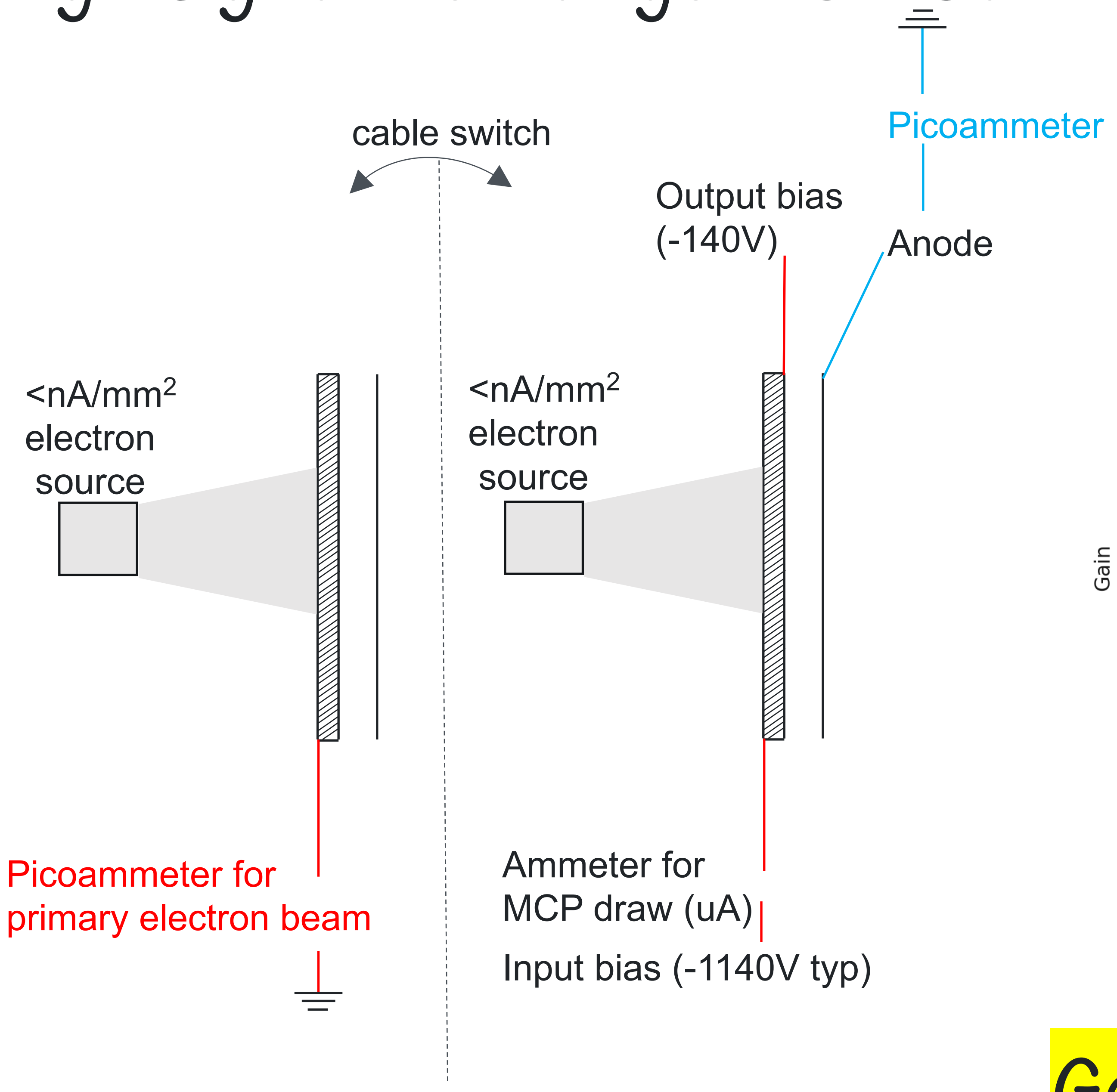
Typical MCP gain measurement is prone to error:

$G = (MCP_{DUT}/E\text{-}gen1) / (MCP_{ref} / E\text{-}gen2)$

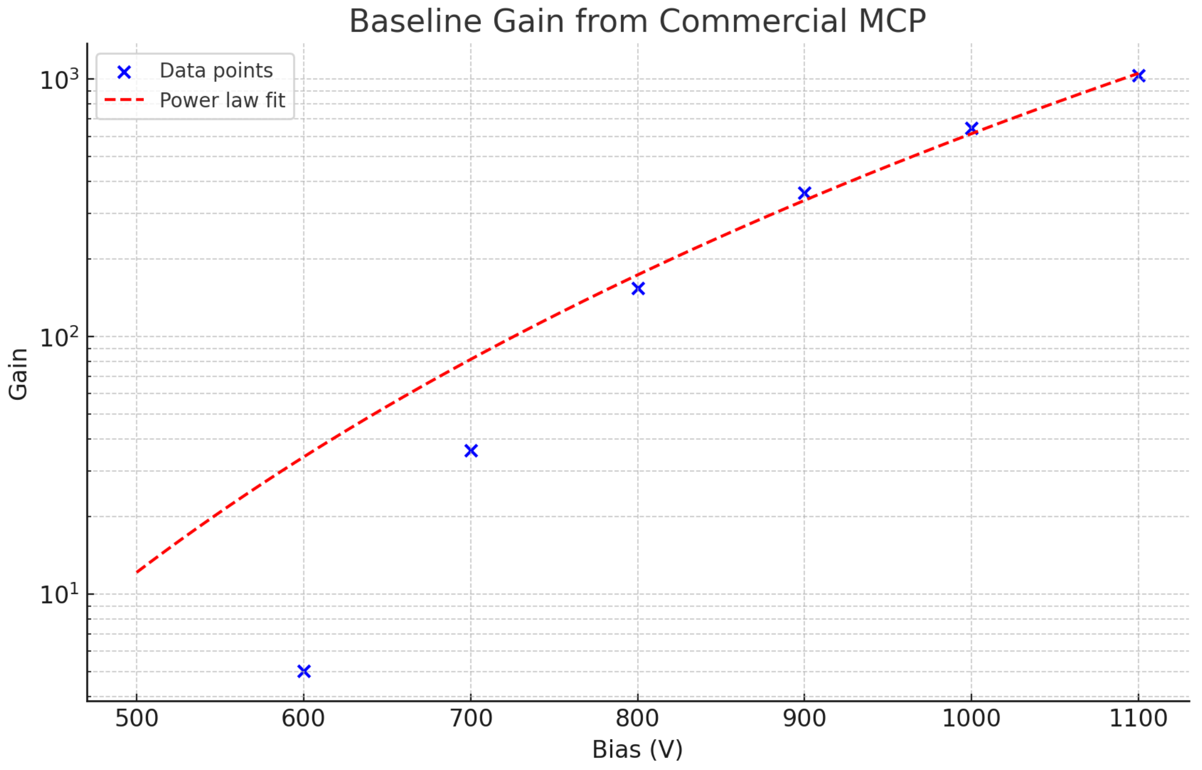
(must hold e-gen, UV flux constant through two sets of measurements and vent between)

field emission can cause misleading background

High Dynamic Range MCP Gain measurement



G = (Anode / Primary)



Gain = e- out/ e- in

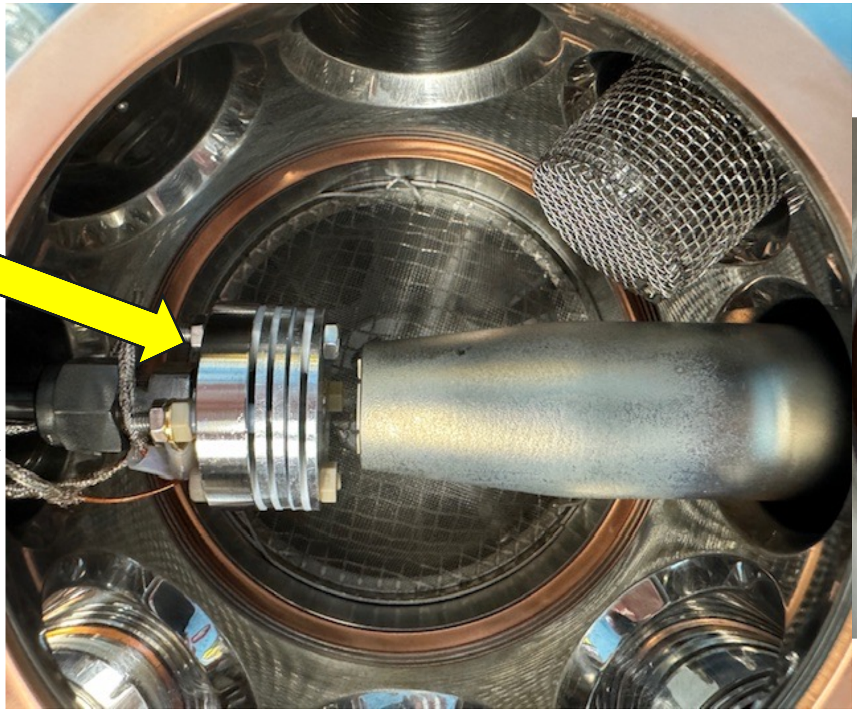
HDR MCP Gain measurement system

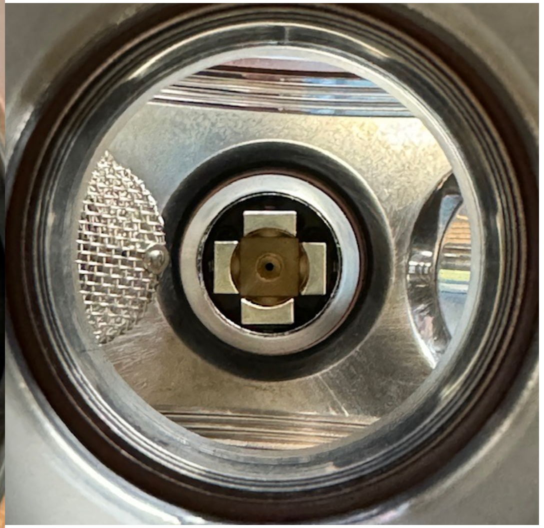
top view

RGA

e- gun
front view

MCP test
assembly
(retractable
w/airlock)



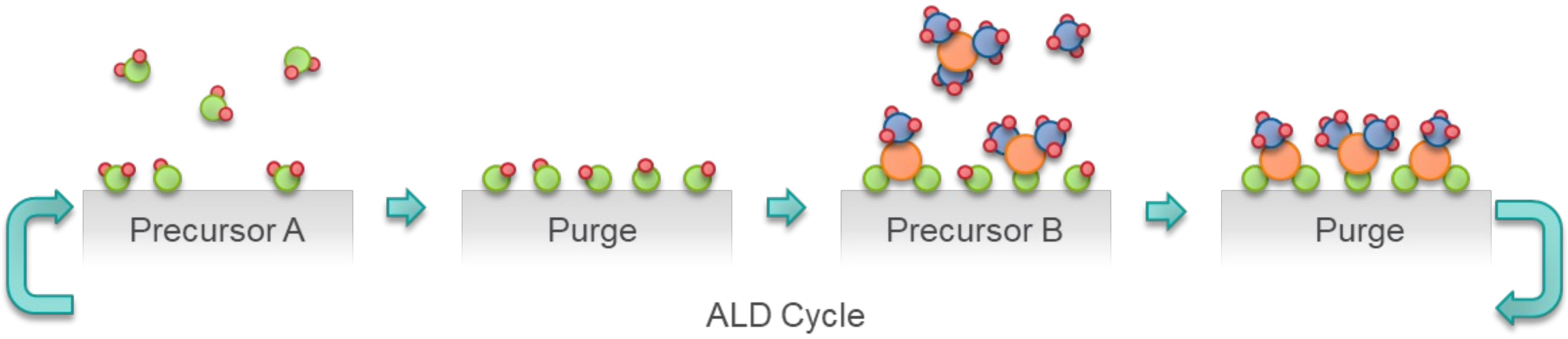


power
supplies,
picoammeters

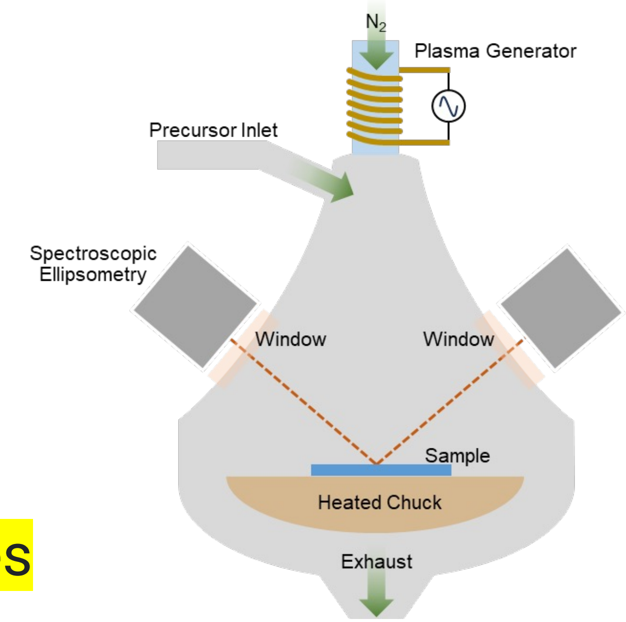
high vacuum high
conductance pumping
for conditioning MCPs

Sample turnaround in <24h
helps ALD optimize runs

Plasma Enhanced Atomic Layer Deposition (ALD)



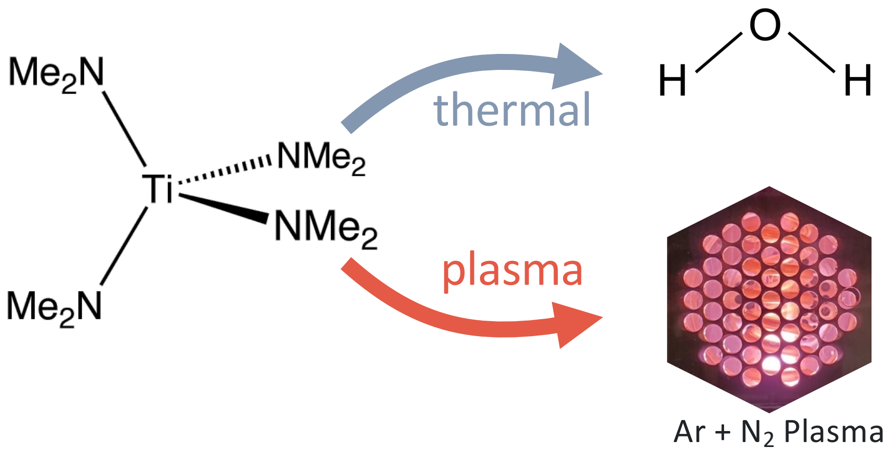
- Sequential surface synthesis
  - Self-limiting reactions between precursor molecules and a substrate surface
- Desirable attributes:
  - Å-scale thickness control
  - Tunable composition
  - Uniform growth on complex 3D substrates

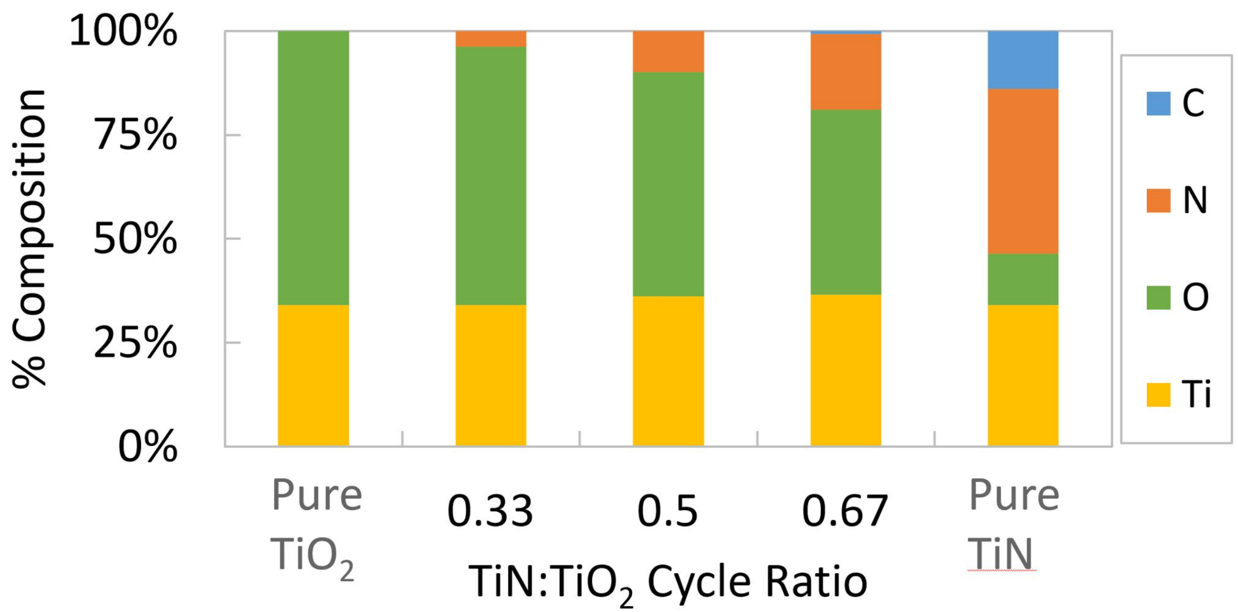


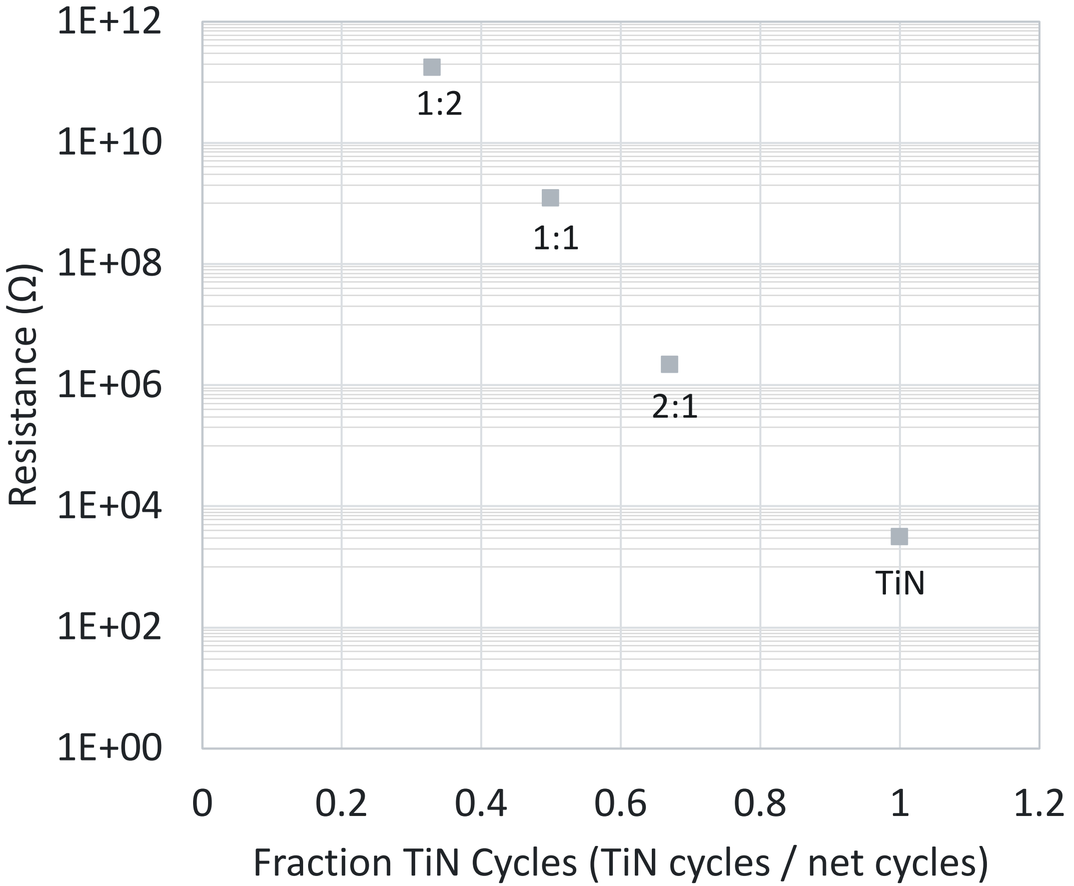
Ashley Bielinski, Argonne MSD

Metal Oxynitrides: ALD TiOxNy

Tunable O:N Ratio for Programmable Resistance







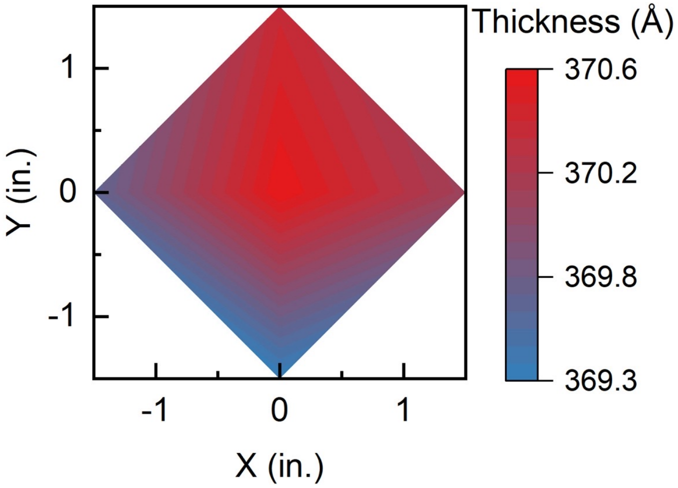
480 net cycles (TiO_2 + TiN) measured diagonally across 1″ × 1″ fused silica substrate

PE-ALD Film Uniformity

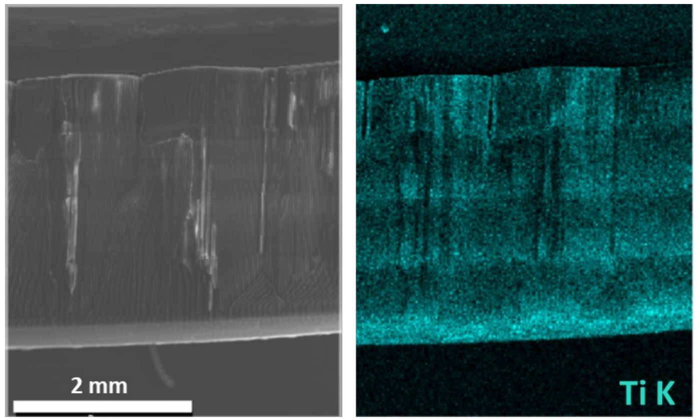
- Lateral and through-pore uniformity
  - Loss of reactive plasma radicals due to surface recombination can limit high growth in high aspect ratio structures

- Test of pure TiN
  - Confirm lateral uniformity
    - Spectroscopic ellipsometry
  - Confirm deposition through pore structure
    - Cross-section SEM + energy dispersive x-ray spectroscopy (EDX) mapping

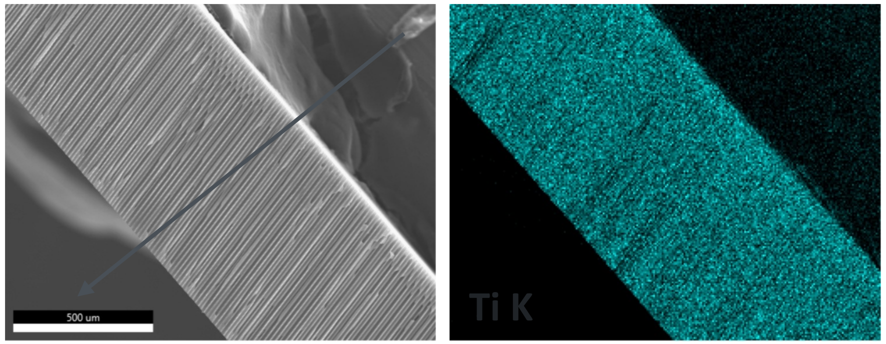
4” Si Wafer Map



SEM and EDX:



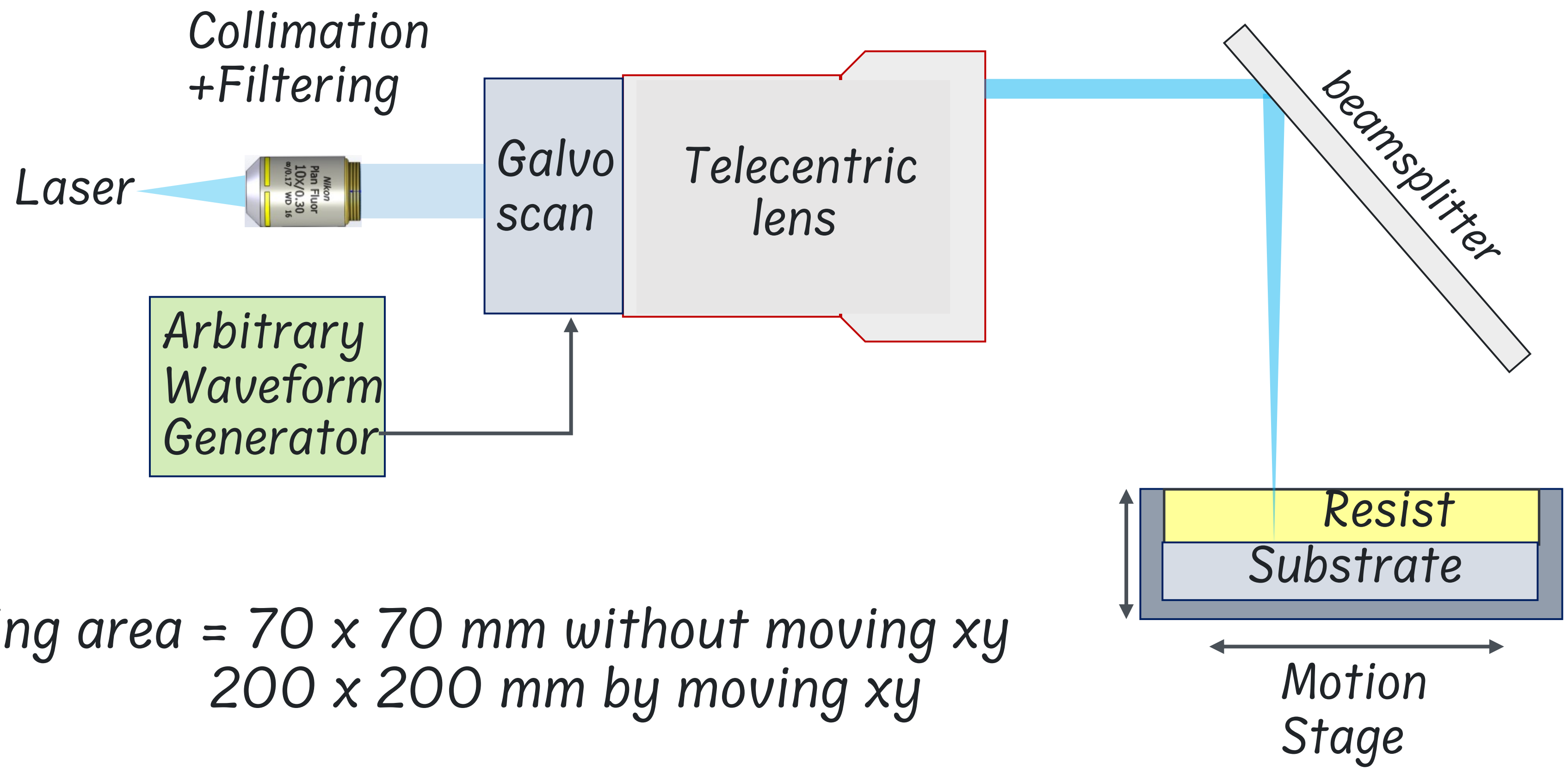
3D Printed MCP



Commercial glass MCP

Optics layout of tool for writing 3dMCP structures

built via DE-SC0020940 (NNSA SBIR 2021-2024)

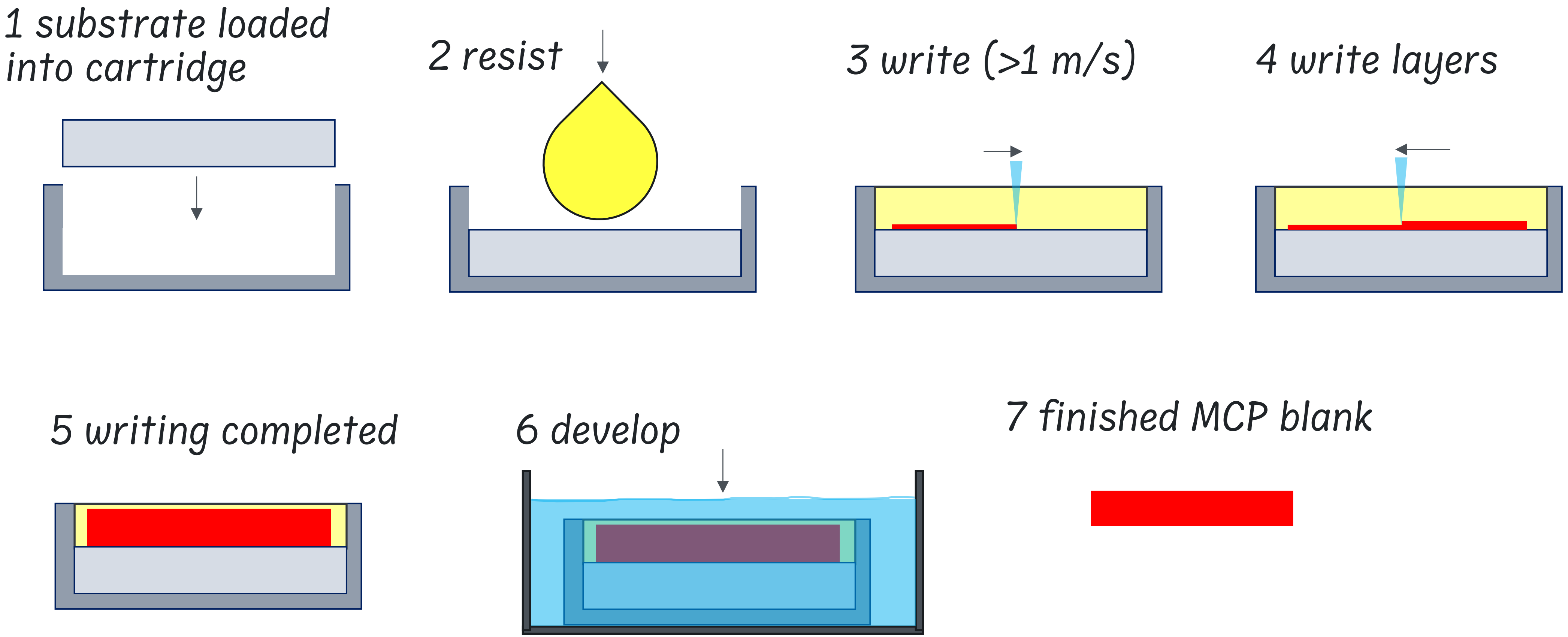


Writing area = 70 x 70 mm without moving xy
200 x 200 mm by moving xy

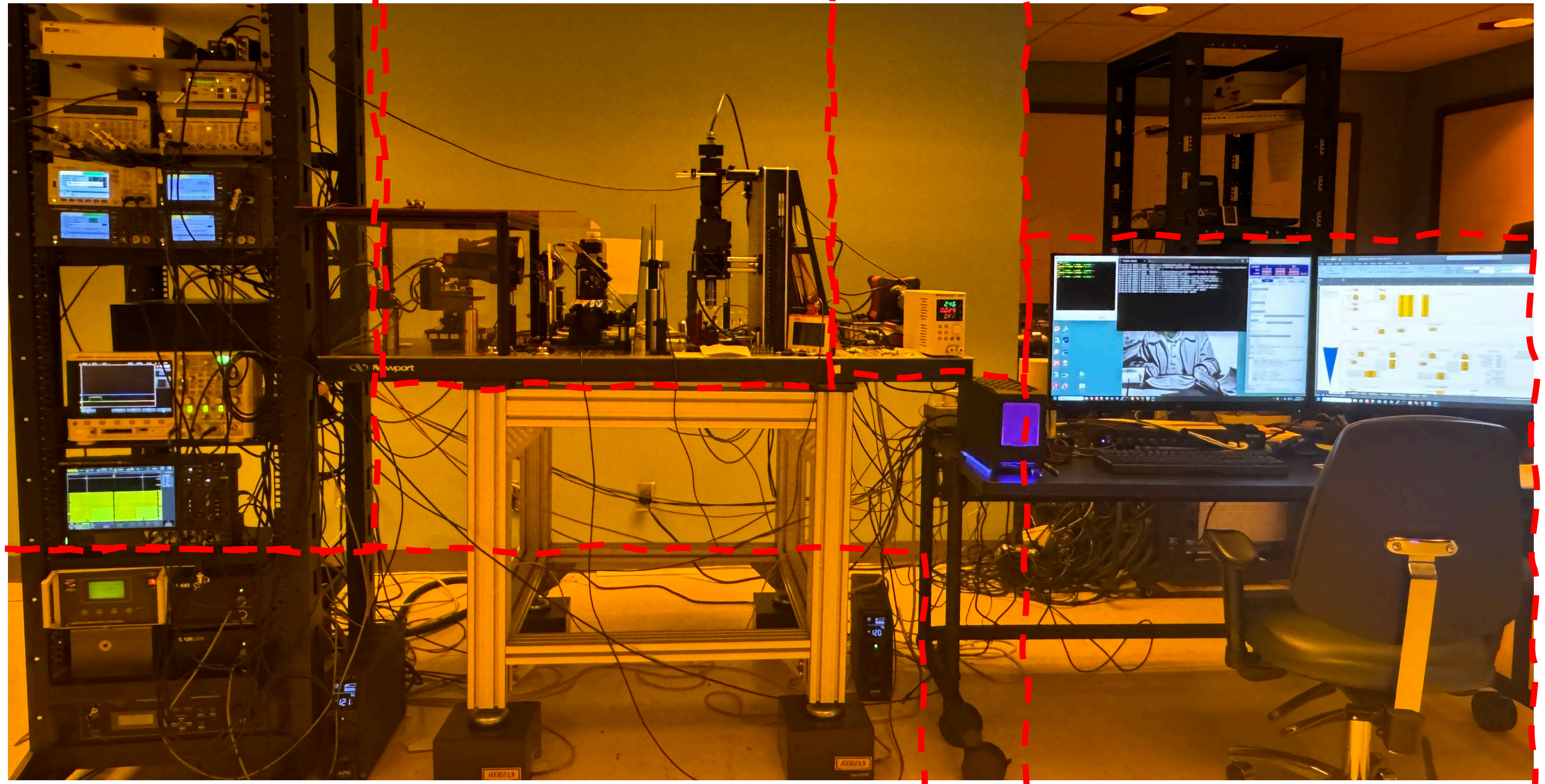
throughput (R^3) > 5 mL/hr solidified
resolution (r) < 1.4 μm

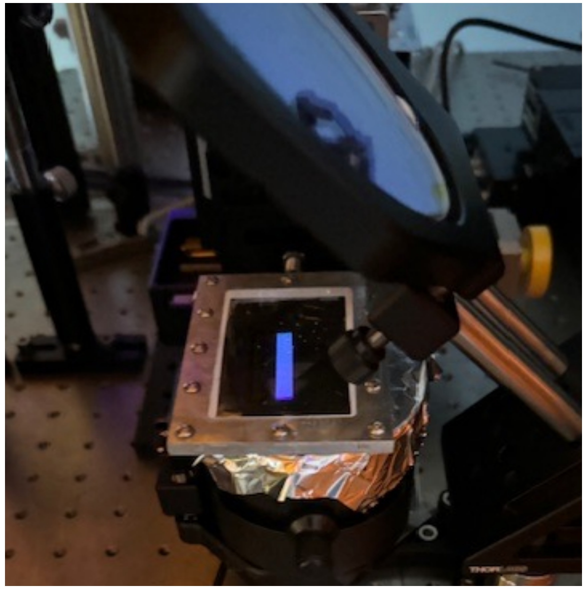
20x demagnification through objective possible

Process for 1-photon additive manufacturing of MCP blanks



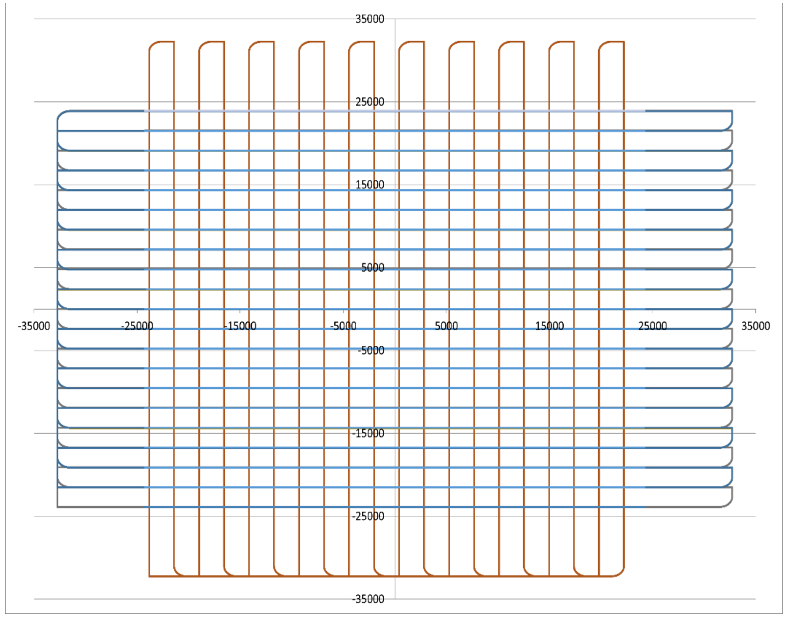
Rapid High Resolution AM System (DE-SC0020940, 2021-2024)



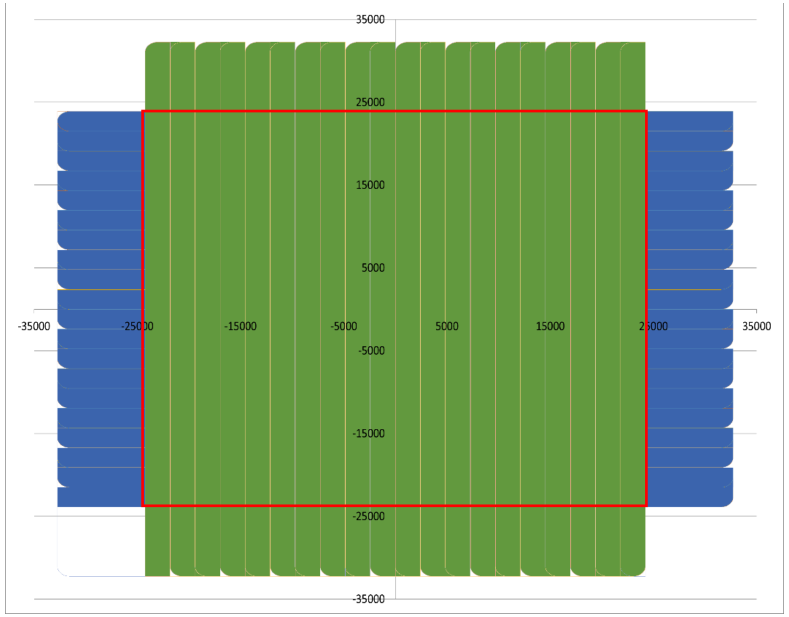


cartridge with print in progress

Creating the scan path : square pores, square MCP



first pass



many passes ; one layer

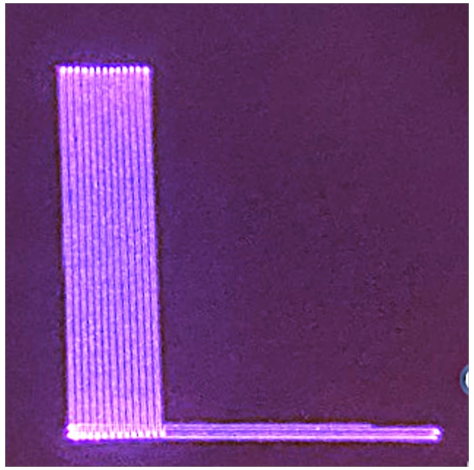
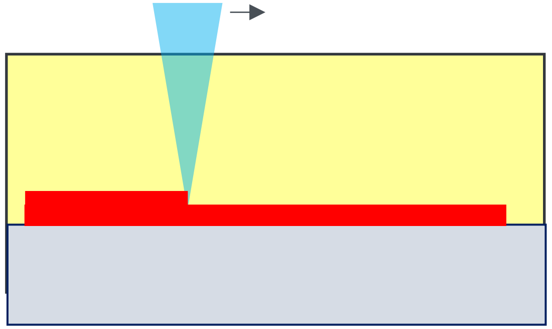


photo of laser sweep



**there are 10^{13} voxels (µm^3) in a 100mm x 100mm x 1mm MCP!

absorption: A → A*

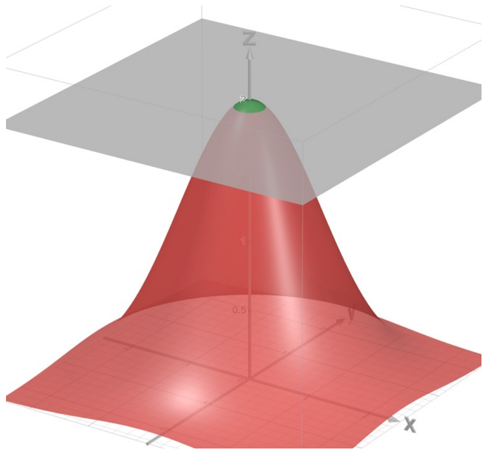
branching: A* → monomer rxn or A* → quenched $_{[t]}$ → A

Laser power, NA (focus), sweep rate and photoresist kinetics are crucially linked

Threshold writing

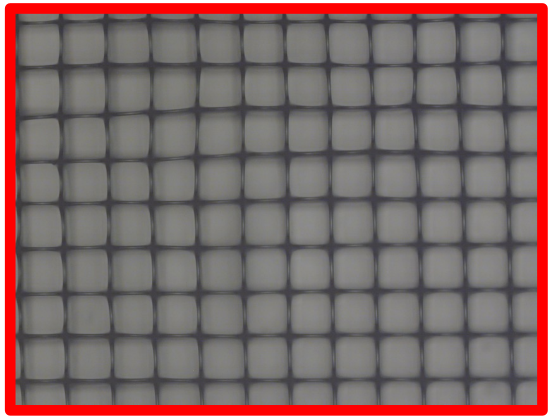
absorption of near UV: A → A*

branching: A* → Initiate Polymerization
or A* → $\text{Quenched}_{[t]}$ → A



Gaussian width: 30 μm
resolution (r): 1.4 μm

20 μm pores
in 50x50mm MCP blank
printed in 1 hour



Demonstration of writing in 3d with extraordinary spatial dynamic range

70 mm/1.4 um = 50,000:1
...path to 10^6 in future

The work goes on!

M+

Additive Z-Channel MCP
DE-SC0019535

Phase III private capital in negotiation

Staffing; facilities

Will return to ATLAS!

e- [any]

Printer for Large-Area MCPs
DE-SC0020940 (NA-22)

>100x faster (bigger)

MCPs in photodetector assemblies

Y

Cherenkov Detectors w/Argonne MEP (NP Phase I)
DE-SC0024829

$, mm resolution, ps timing

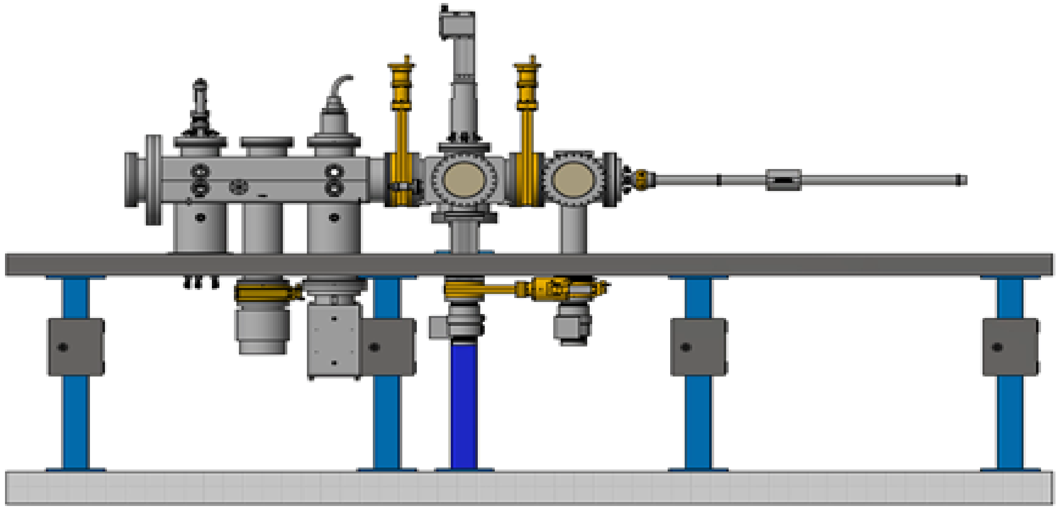
Y

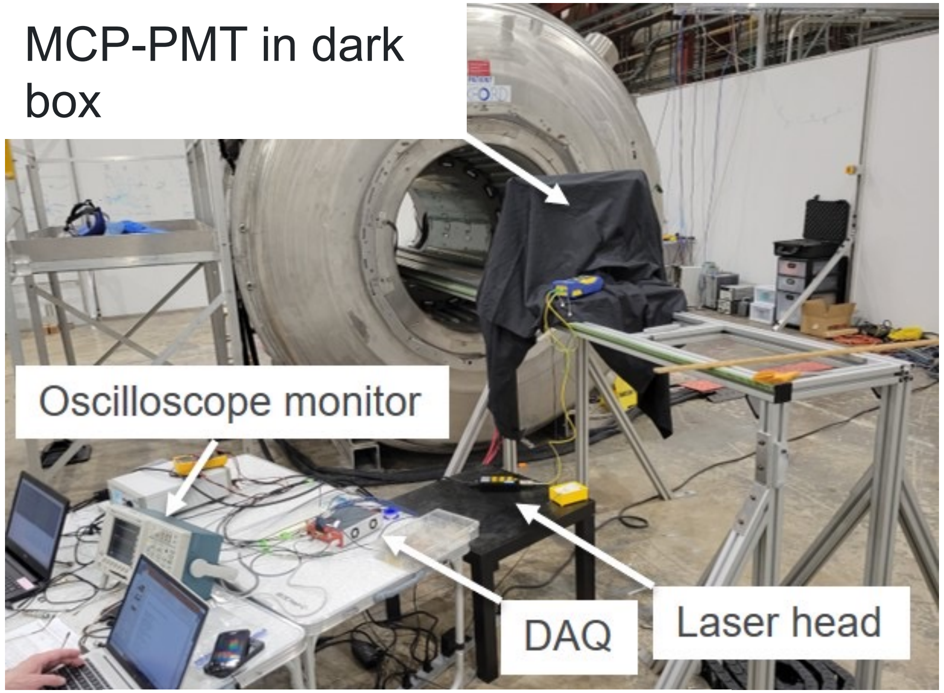
Space instrumentation w/SouthWest Research Inst.

$$$, um resolution, ns timing

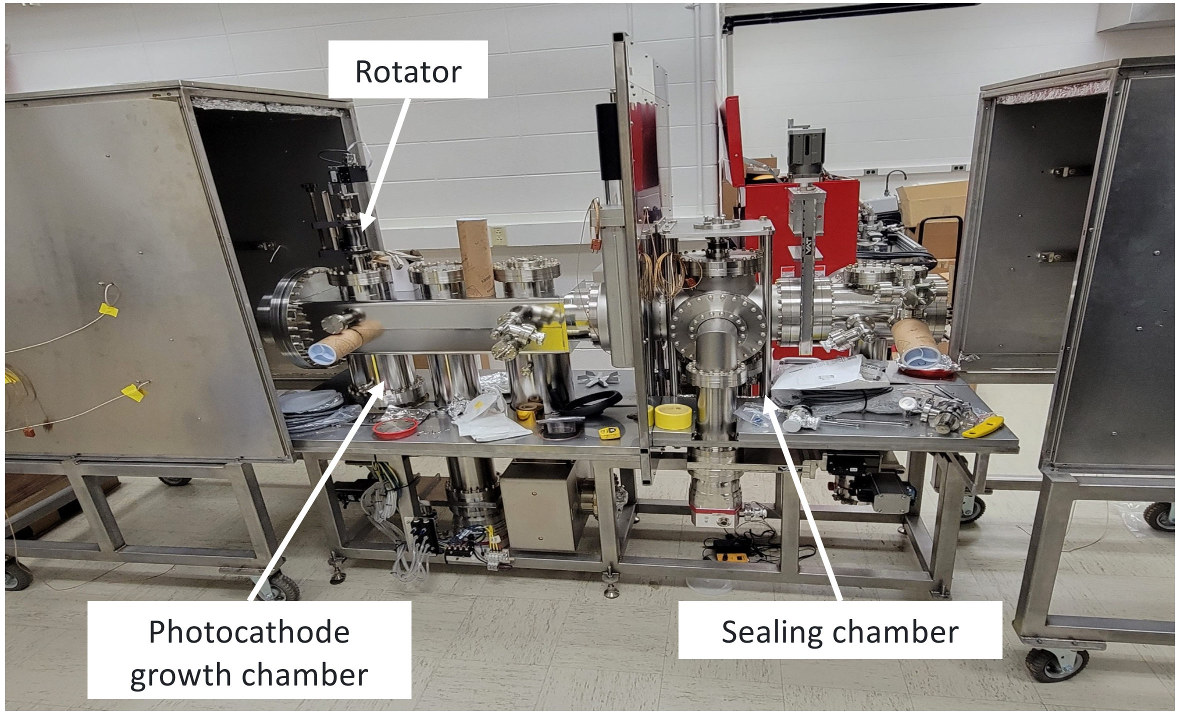
Lab Facility: 10x10 cm^2 MCP-PMT Fabrication Facility Argonne PHY Division; Junqi Xie

- Capable of fabricating 10x10 cm^2 device size
- Recently built
- Completing commissioning currently





Magnetic field test station



Accomplishments during DE-SC0019535

1. Optimized MCP blank printing via creation of >100 1 cm diameter MCP blanks
2. Coated blanks with thermal ChemX ALD process at lowest temperature yet
3. Coated blanks with new plasma enhanced ALD of TiO_xN_y films
4. Characterized MCPs and coatings with optical, SEM, composition analyses
5. Measured resistivity and gain from MCPs; made new high DR gain system
6. Created MCP precision pulse measurement system with Ga^+ primary beam (BIJOU)
7. Built multiple acquisition systems with sophisticated software for display of timing
8. Designed and built MCP assemblies for use at heavy ion accelerator facilities

9. (DE-SC0020940) >100x faster 1-photon additive tool

Gratitude to NP funding, Michelle Shinn, and DOE SBIR/STTR office!