

General Atomic Target Fabrication Update

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Presentation to EUCALL
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General Atomics produces targets and target related equipment

- **Targets**
 - Hohlräume, capsules, flats, foams, high resolution 3D printed, ...
- **Diagnostics**
 - Fast x-ray diagnostics
- **Target fielding equipment**

GA's Target Fabrication and Characterization Advance Laboratory HED Science

- Many capabilities are needed to fabricate various classes of targets

Precision engineering
& design

Diamond & laser
machining

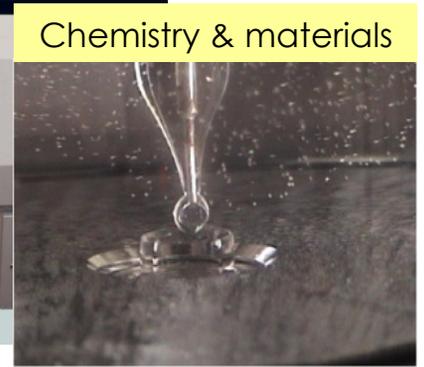
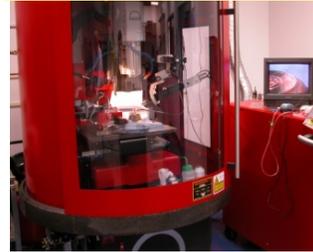
Femto second laser
Green and UV nanosecond laser

Precision assembly

Metrology

Coatings

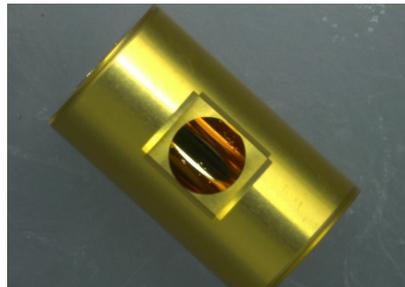
Chemistry & materials



- Multiple capabilities are used to make a single target



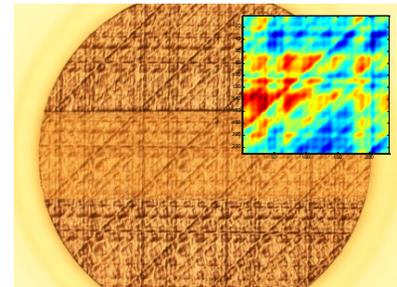
Capsules



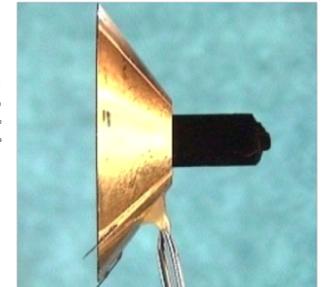
"Hohlraums"



Foams

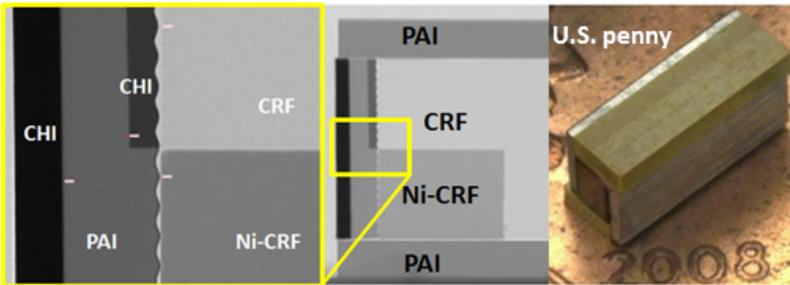
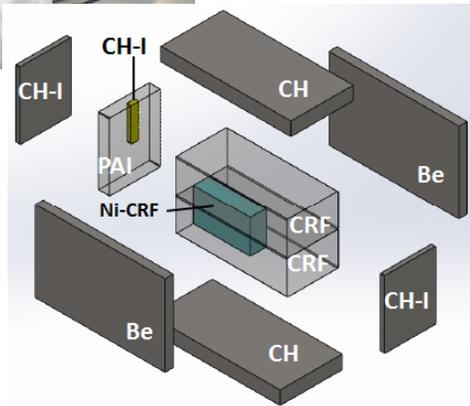


Complex planar



Assembly

Diverse Capabilities, Equipment, and Expertise at One Facility Improves Efficiency



Metal Coatings

CH/Glass Coatings

Electroplating

Chemistry/Material Science

Diamond Turning

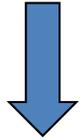
Milling

Laser Machining

Precision Assembly

Aerogels/Foams

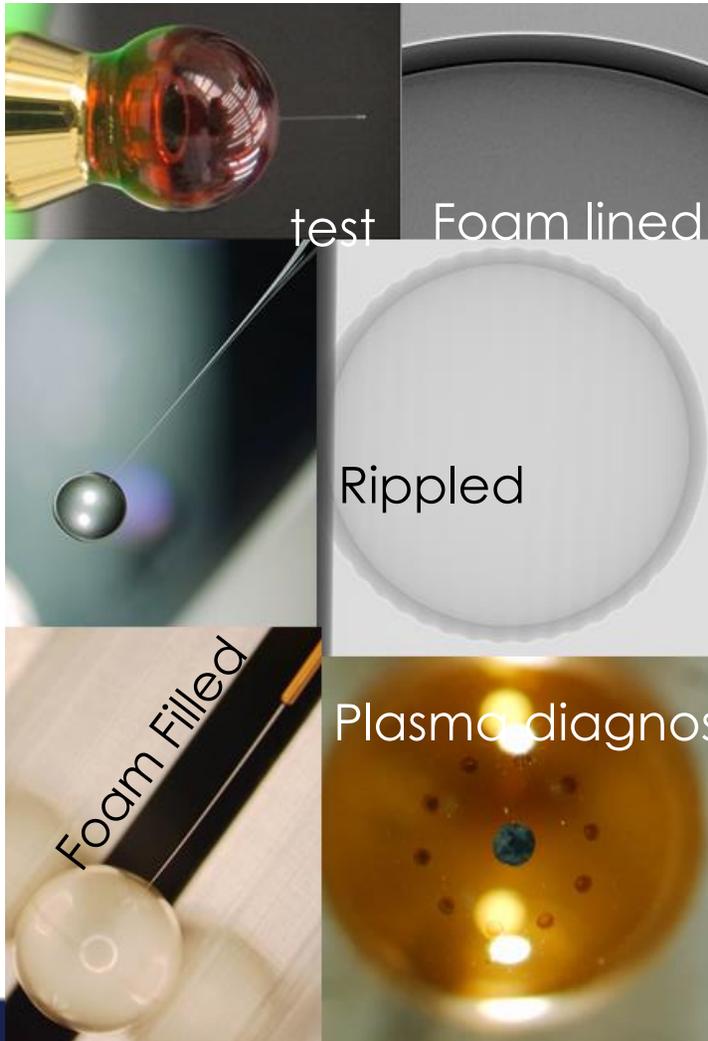
Characterization



- LLNL
- LANL
- SNL
- LLE
- **Others**

IFT fabricates high precision capsules in plastic, diamond, and beryllium

- Capsule variations are increasing



Capsule sectors can be used for focused proton beams



IFT uses a wide variety of coating techniques

- **Sputtering**
 - Multi-gun
 - Ag, Al, Al₂O₃, Au, AuB, Ge, B, Be, B₄C, BN, C, Cr, Co, Cu, Dy, Fe, Gd, Ir, Mg, Mn, Mo, Nb, Nd, Ni, Pd, Sc, Si, SiC, SiO₂, Sn, Ta, Te, Ti, TiO₂, U, V, W, Zn, Zr
- **Electroplating: Au, Ag, Cu, ...**
- **Spin coating**
- **Physical Vapor Deposition**
 - E-beam evaporator
 - Al, B, Cu, Fe, Ge, Si, Sn, Ta, V, Zr, ...
 - **In development Lithium**
- **Atomic Layer Deposition (ALD)**
 - 0.1 layer control, layer/15 sec, conformal
 - Pt, Al₂O₃, ZnO, TiN, TiO₂ ...
- **Diamond (HDC)**
- **Parylene-N**
 - Polymer
- **PE-CVD**
 - CH and CD polymer doped as requested with Ge, Si, ...



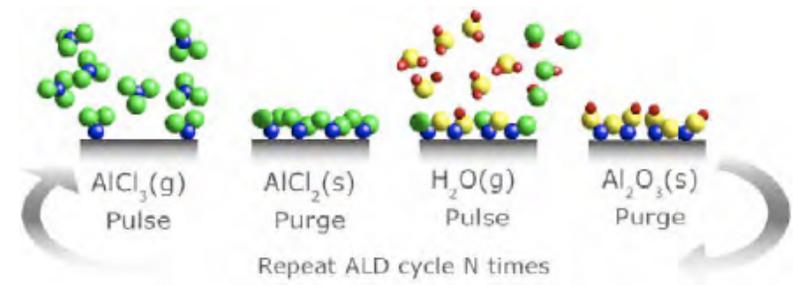
Sputter coating line



ALD system.



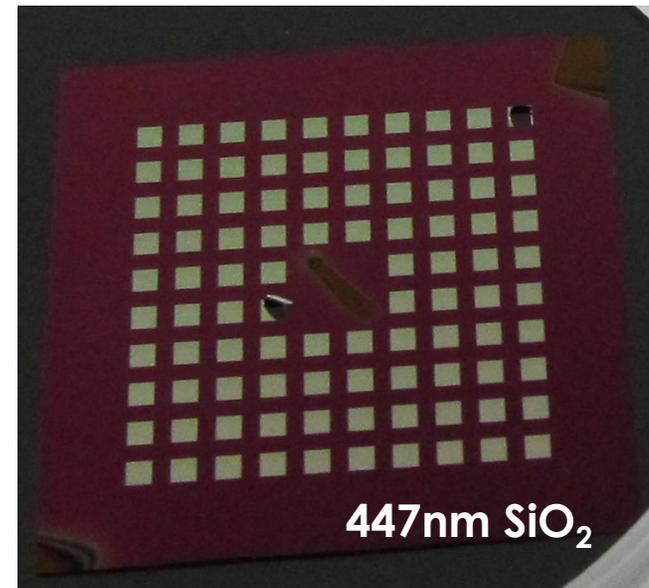
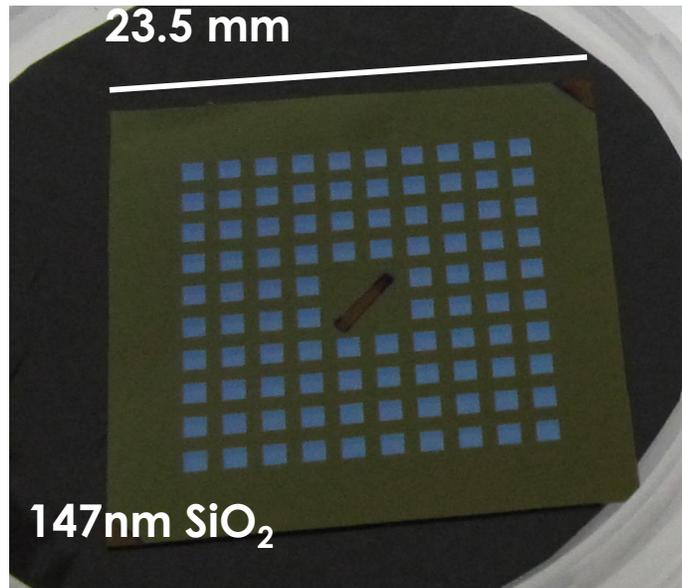
Various ALD pinhole-free coated samples.



Ultra thin coatings on multiple pane silicon window frames is parallel production method

Isochoric Heating Targets

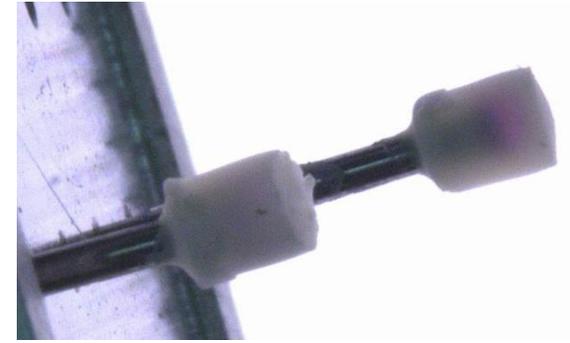
- Micro-crystalline SiO_2 on 50 nm silicon nitride with silicon frame



- 96 targets per frame
- Facilitates a variety of thin coatings

We have a new formulation for low density C, H foam ("GACH")

- Densities as low as a few mg/cm³
- Sub-micron pore size
- Has also been deuterated (C, D)
- Can be laser machined
- Can be doped (e.g. chlorine)



GACH cast on sticks,
first step to
machining spheres



Deuterated



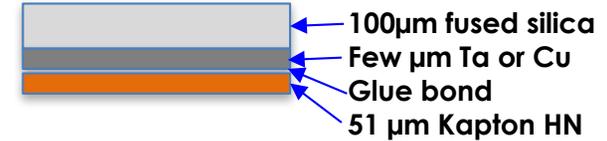
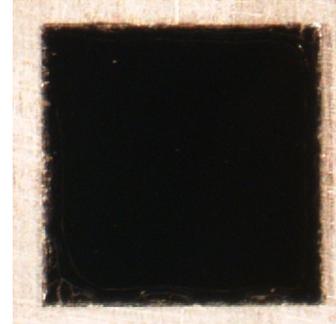
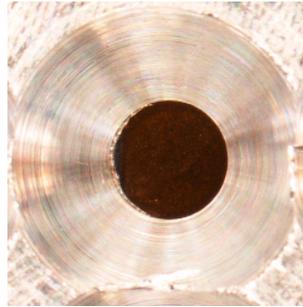
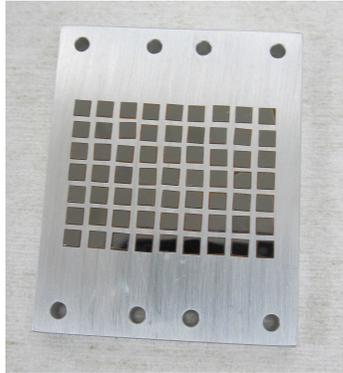
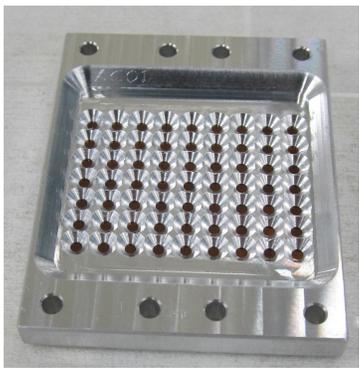
Chlorine doped



Bromine doped

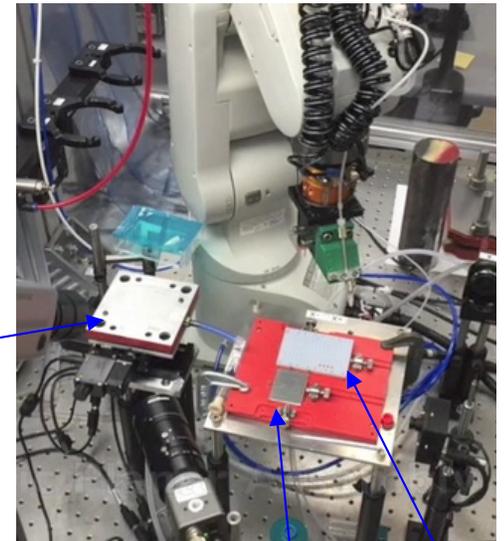
- All metal foams can also be produced: Copper or Nickel

Robotic automation has been used to glue together flats and to mount targets



- **Used Robot Assembly station to handle quantity**
- **Metal coated fused silica chips supplied by customer (2.5x2.5x0.1mm)**
 - Supplied ~3 1/2 weeks prior to shot
 - Supplied with edge delamination of metal layer
- **50 µm thick Kapton ablators laser cut**
 - Over or under size to miss delamination burr on chip
- **Glued ablators (967) and mounted (1003) targets with**
 - Combined UV and heat cure with Dymax 605
 - Opaque target need secondary cure

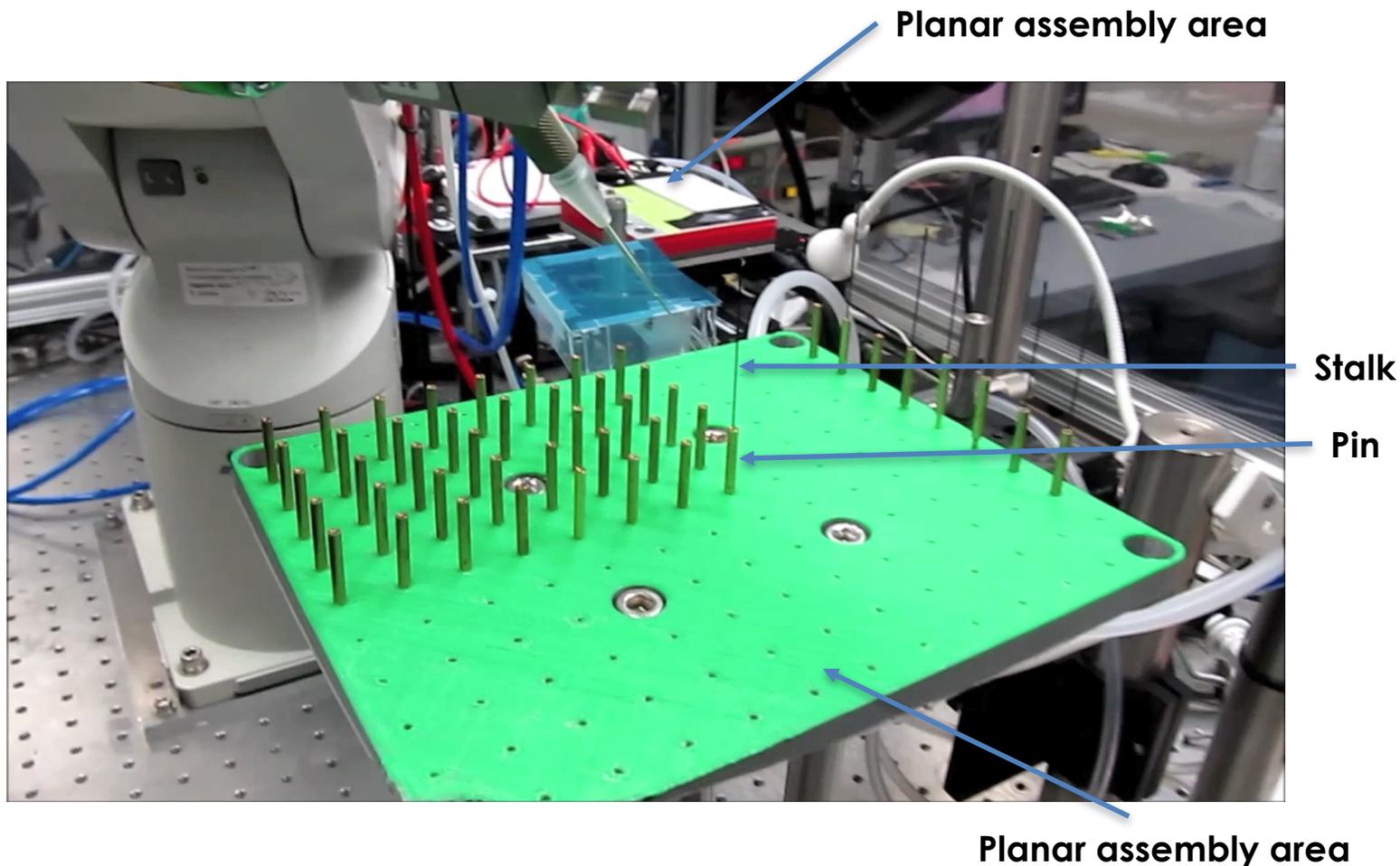
Assembly Location



Parts Tray

Mounting Plate Location

Planar assembly robot has been upgraded to assemble stalks to pins



- One robot handles both planar and stalk assembly

Machining learning combined with robotics to cull and classify defects automatically

Built 2017
For NIF size
(2mm) shells

2018,
upgrade for
OMEGA size
(1 mm shells)



Find and pick up



Coating tray

"Good"

Good/Bad
Classifier

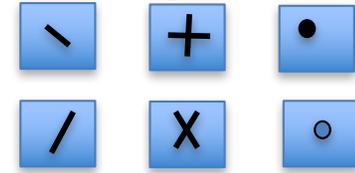
"Bad"

Waste Basket

2017 Did
not exist

2018, Add
this
capability

Defect example
training set



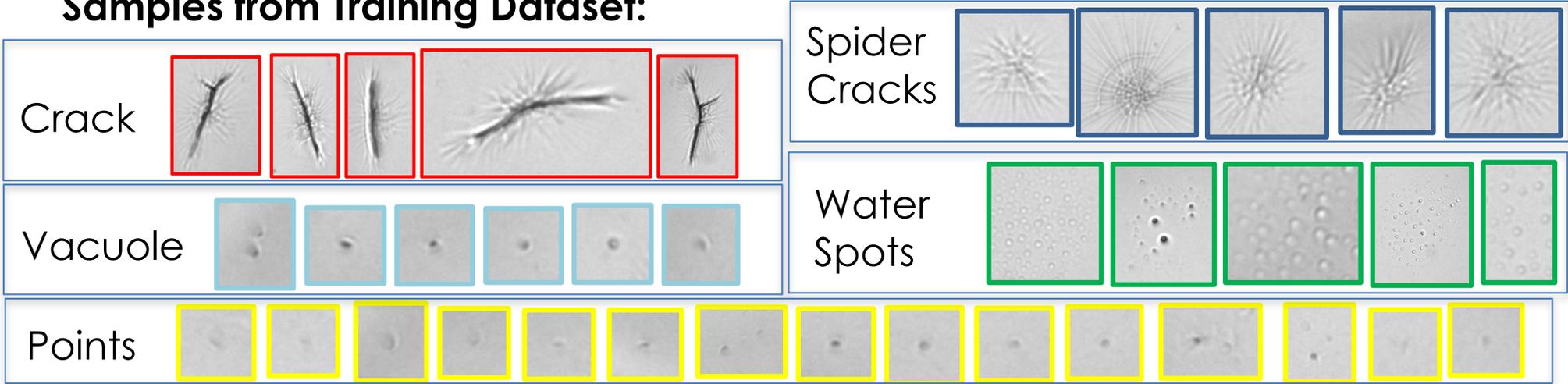
Defect Type
Classifier

Image plus
co-ordinates
of each
defect's
center

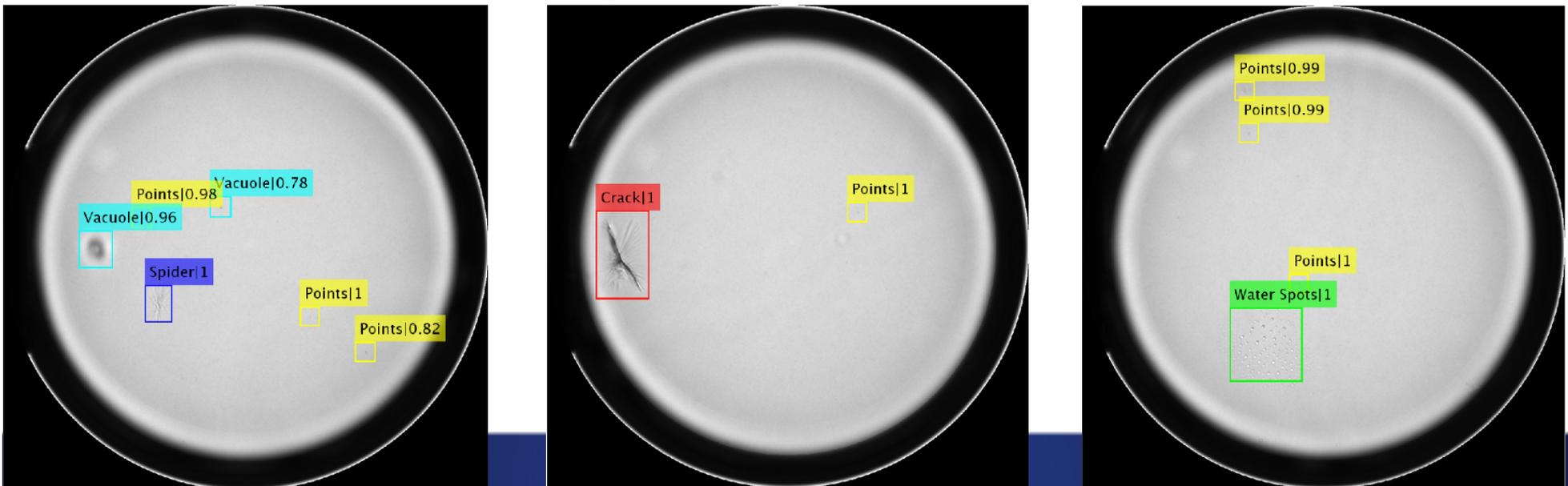
Defect Type Statistics
by Shell Report

Defect recognition reaches >90% accuracy

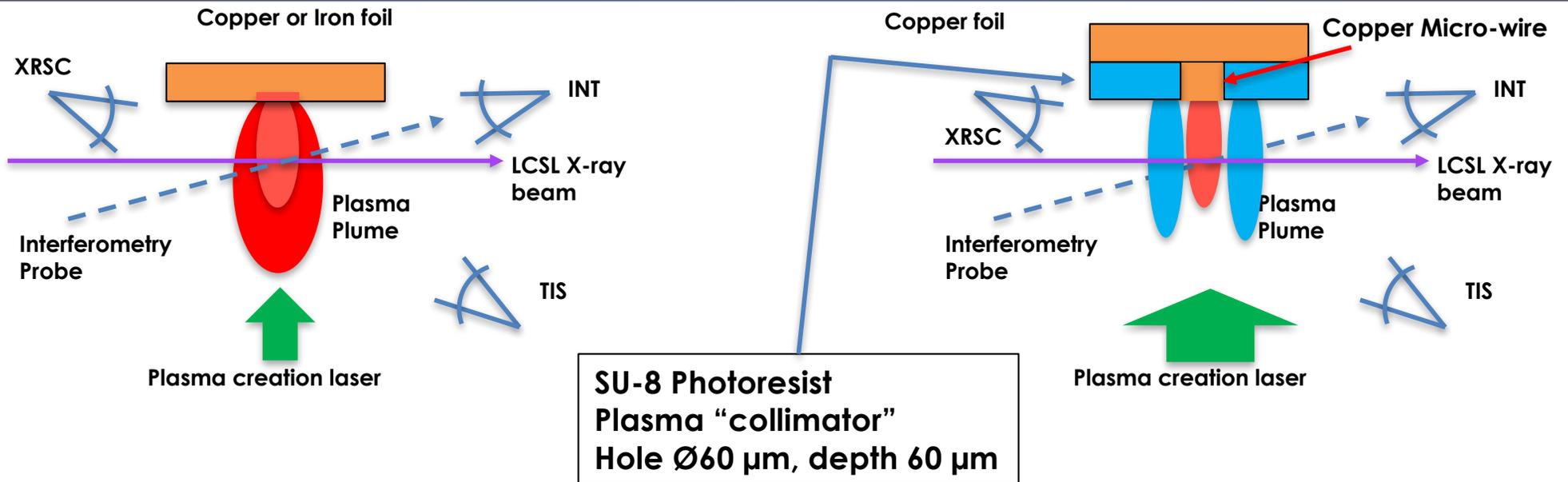
Samples from Training Dataset:



Example results from running the code

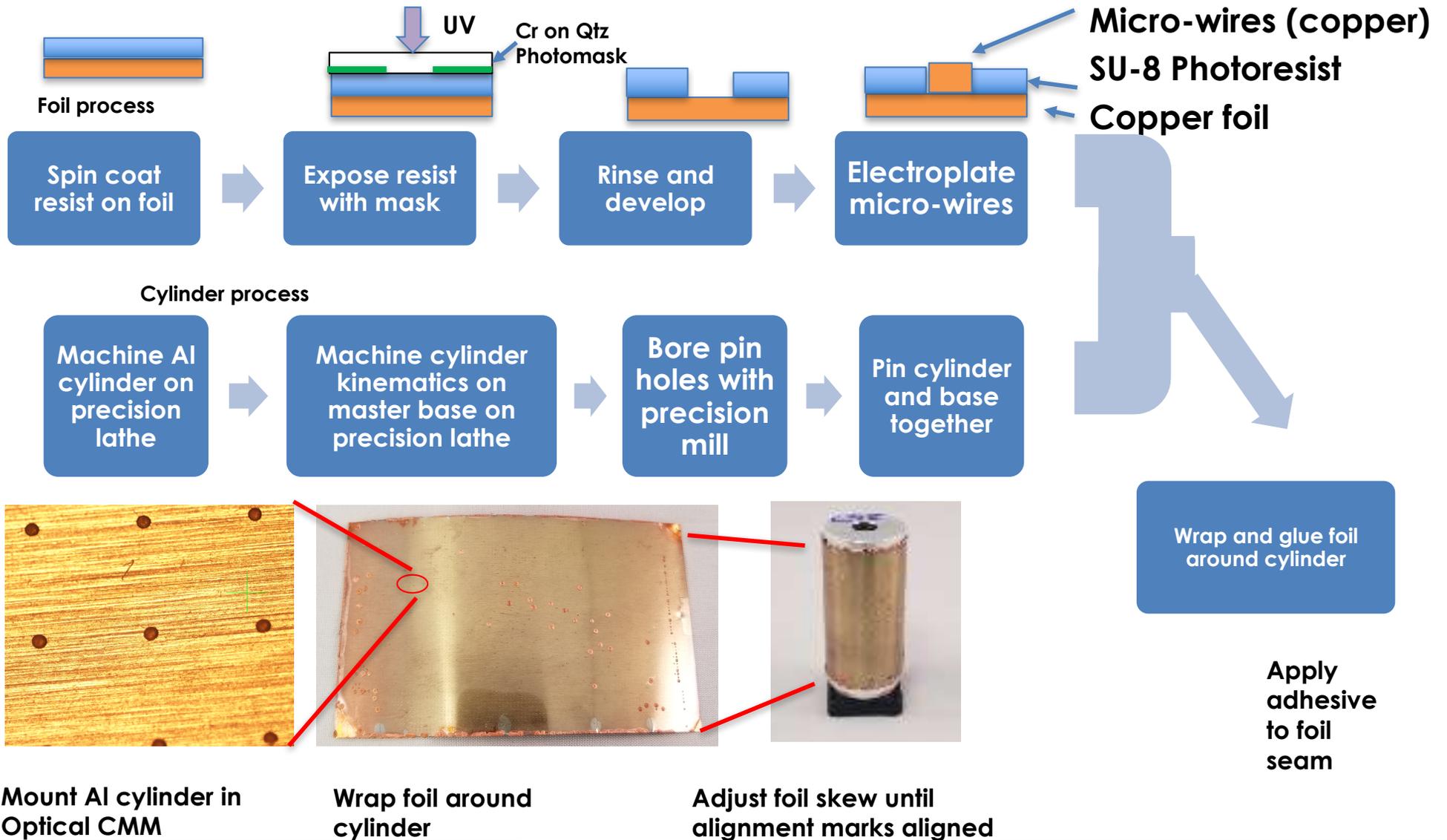


>10,000 encased micro-wire targets produced on cylindrical holders for LCLS experiments this past April



- **X-ray beam probes Copper plasma just above target surface**
- **Target foils mounted on cylinders for diagnostic access**
 - 3 Cylinders each with >3400 "collimator" micro-wire targets
 - Lithographic process
 - 9 Cylinders with plain foil – Copper
 - 3 Cylinders with plain foil – Iron

Lithography and micro-machining techniques used for production

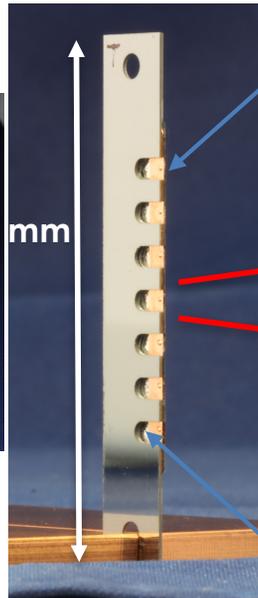


Targets for laser generated proton isochoric heating of target foils

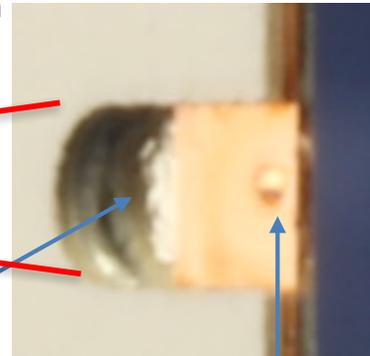


Target Assemblies on shipping restraints

48 mm

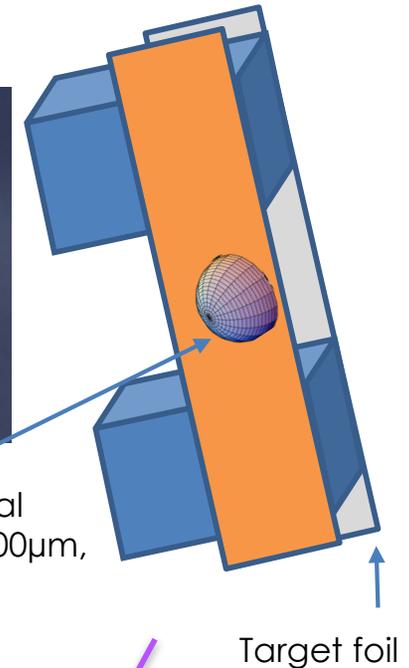


Dimpled copper strip, 4 μm thick, clamped between two silicon wafers

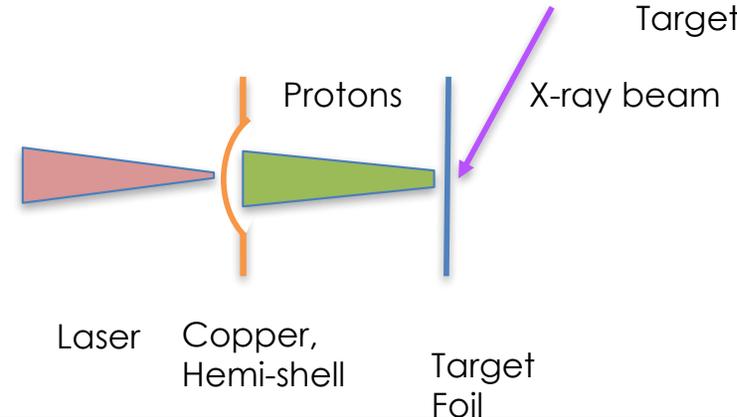


Target foil, Aluminum foil, 0.65 μm thick, attached to back side of silicon wafer

Hemispherical dimple, SR 300 μm , $\text{\O}400 \mu\text{m}$



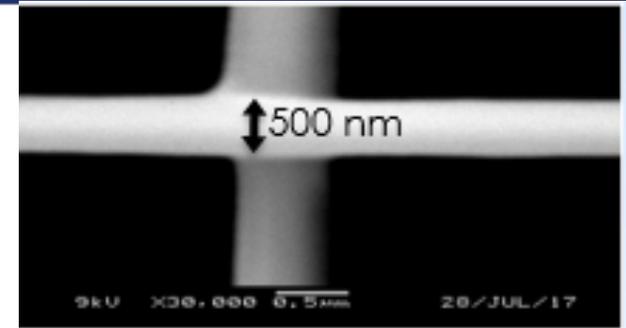
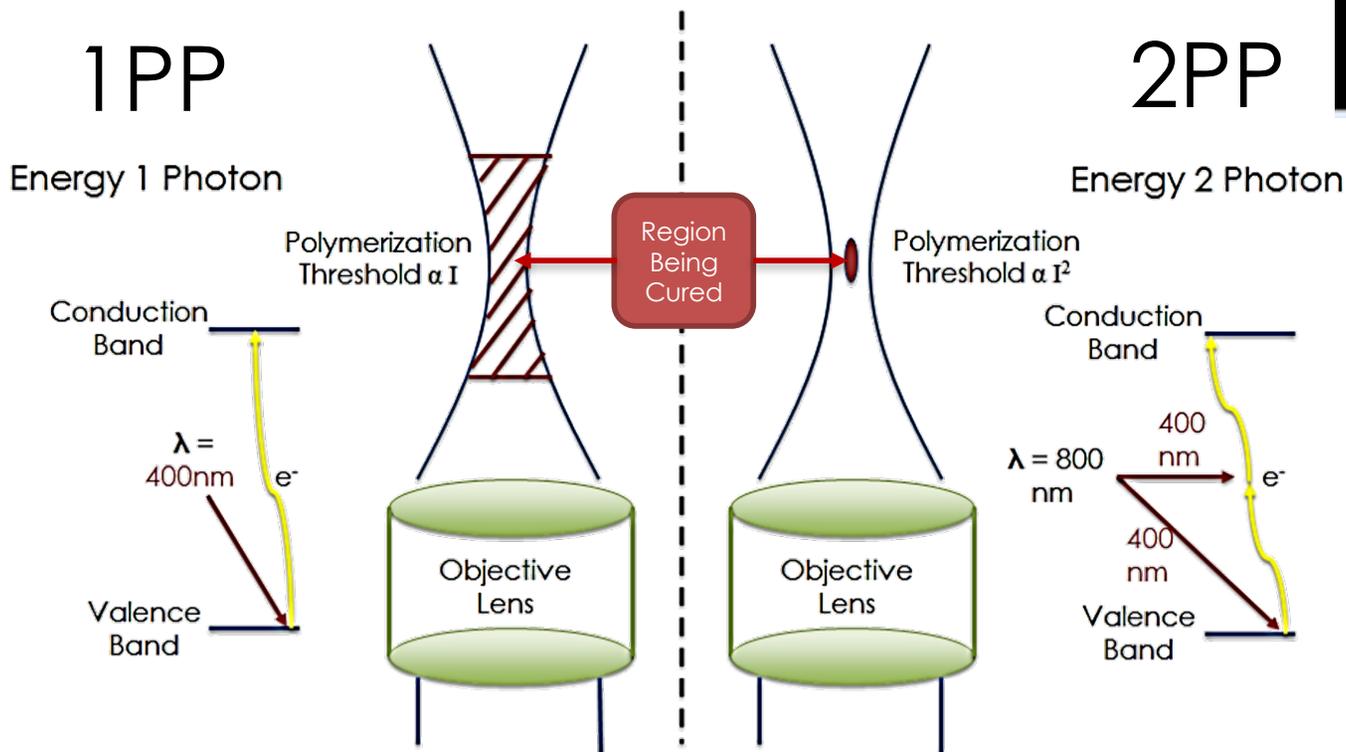
Target foil



- **500 targets delivered**

Additive manufacturing system using 2 photo polymerization (2PP) has sub micron resolution

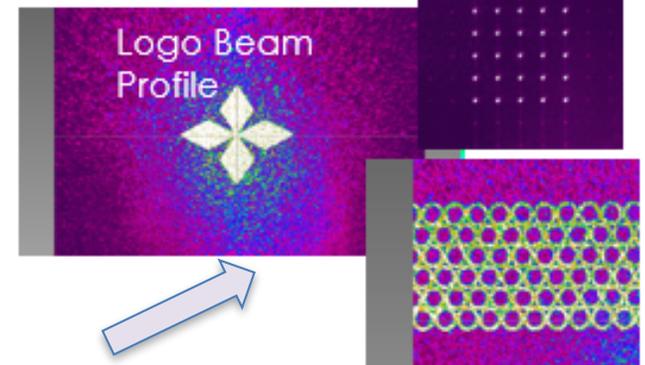
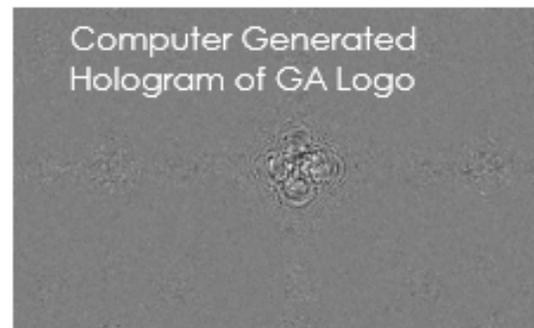
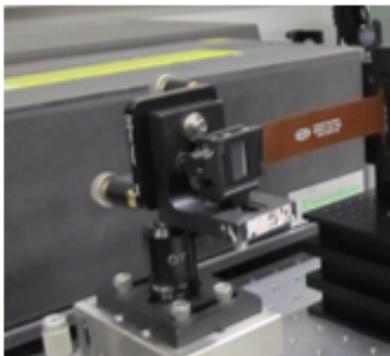
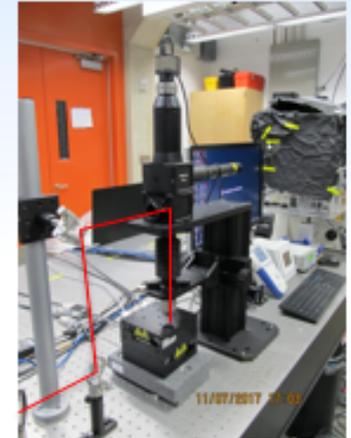
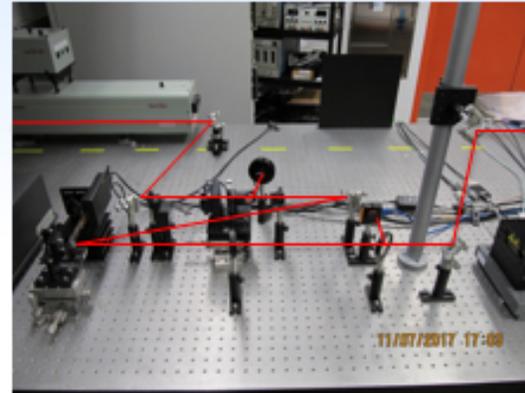
2 Photon Polymerization versus 1 Photon Polymerization



- Pulsed lasers peak powers are intense enough to trigger 2 photon absorption
- Pulsed laser average powers are low enough to not destroy the sample

3D printing system being upgraded for taller structures and faster writing

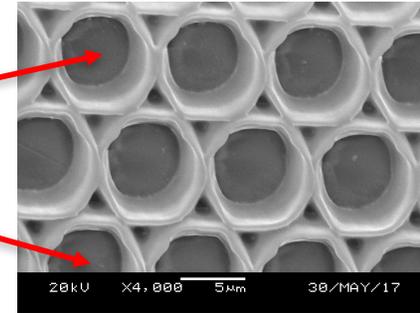
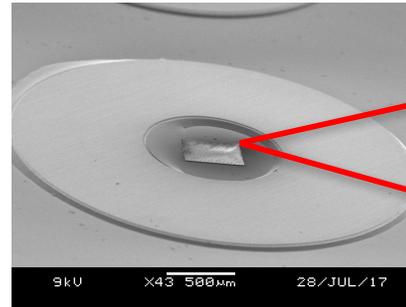
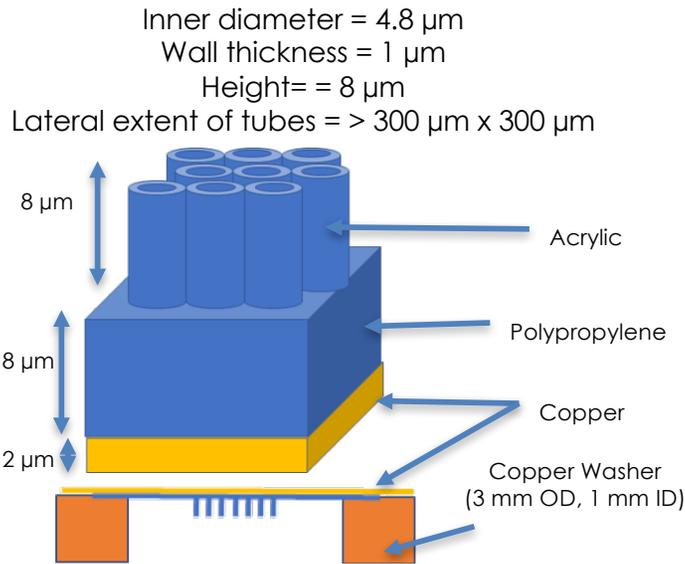
- Top down illumination allows tall structures
- Extreme beam shaping profiles will allow parallel writing of voxels or z slices
- Long travel, fast positioning stage allow parts without stitching defects



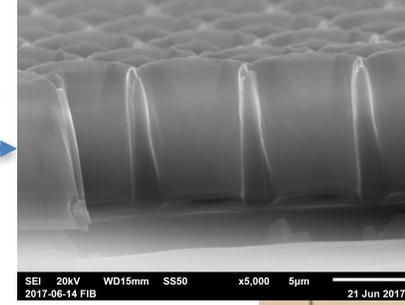
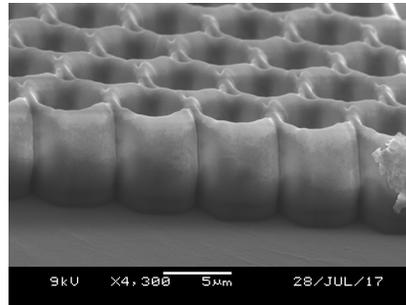
Arbitrary laser beam profiles will allow entire Z-slice to be written at once with enough laser pulse energy. Currently can write 5 spots at once. (examples next slides were written with one spot)

Grazing incidence/plasma focusing/multi-tube array targets have been made by high resolution 3D printing/additive manufacturing

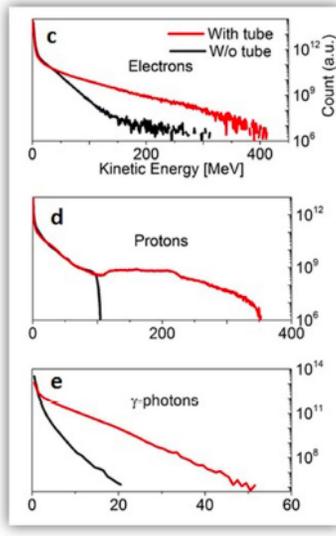
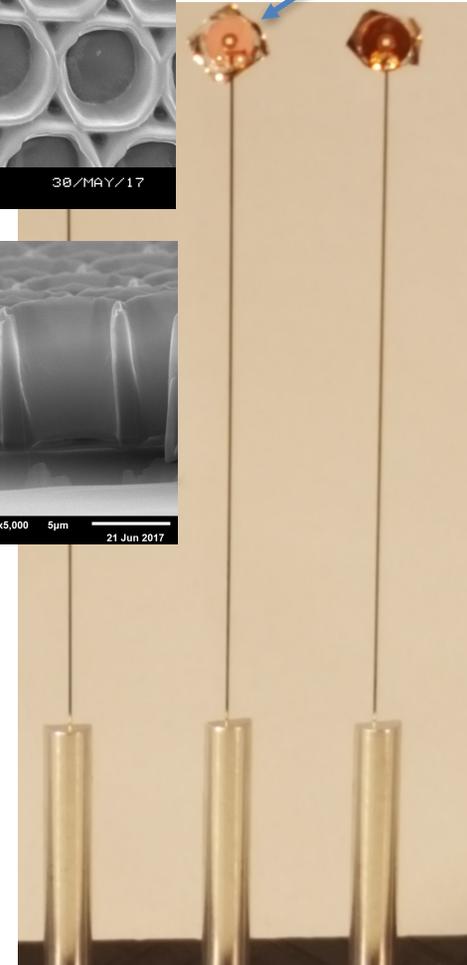
Micro-Tube Array Target¹



SEM Characterization



Ø3mm

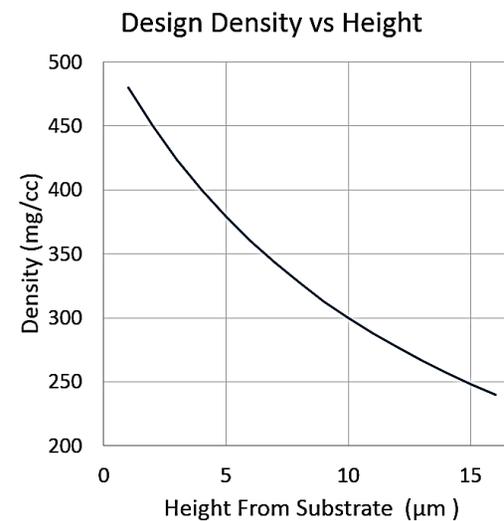
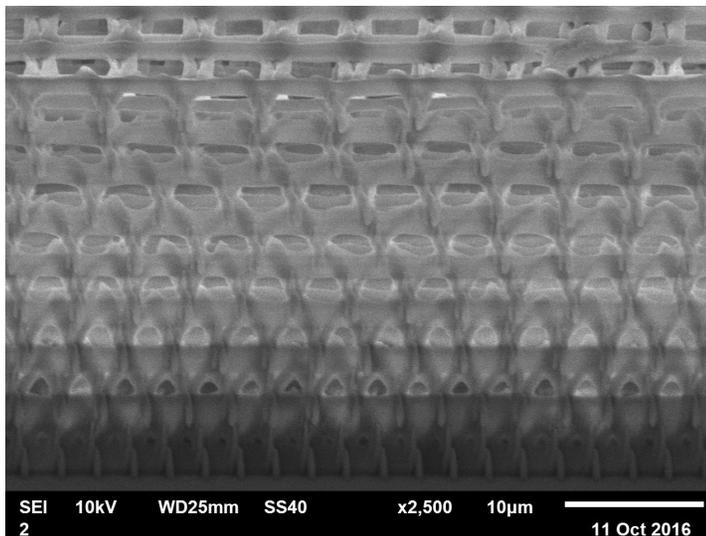
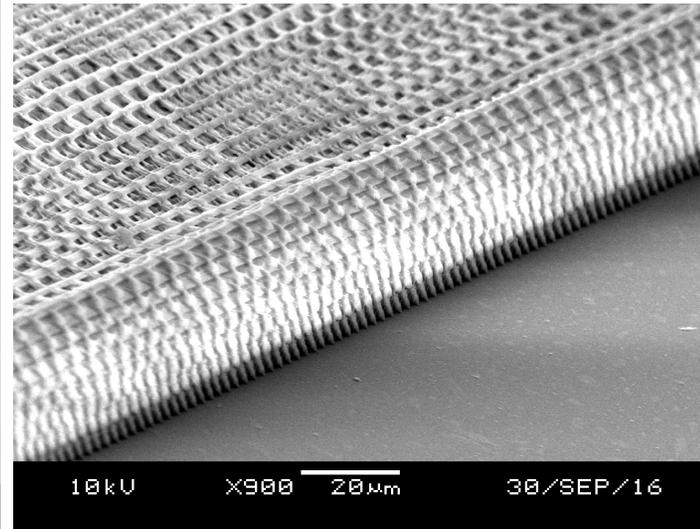
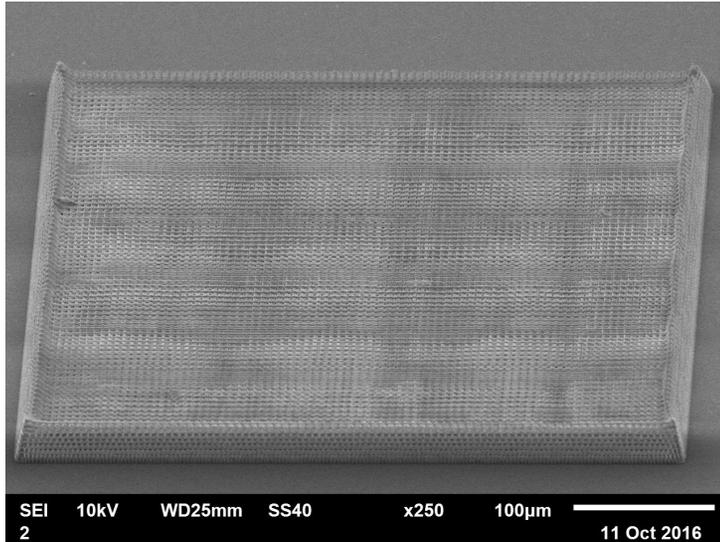


Micro-tube arrays have been written on:

- 4 μm and 8 μm polypropylene film
- 1 μm cobalt foil
- 1 μm gold foil

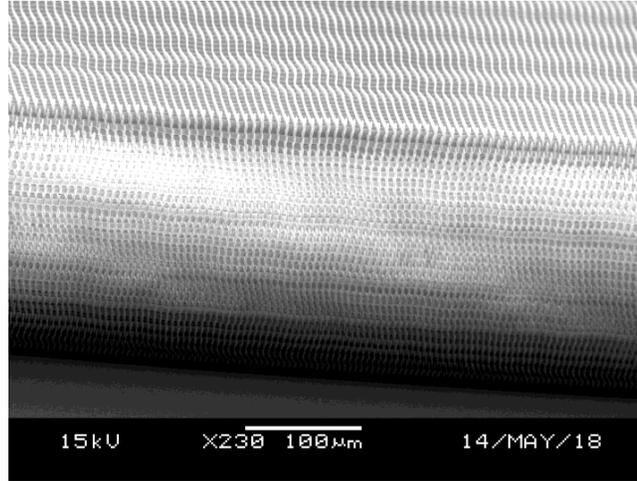
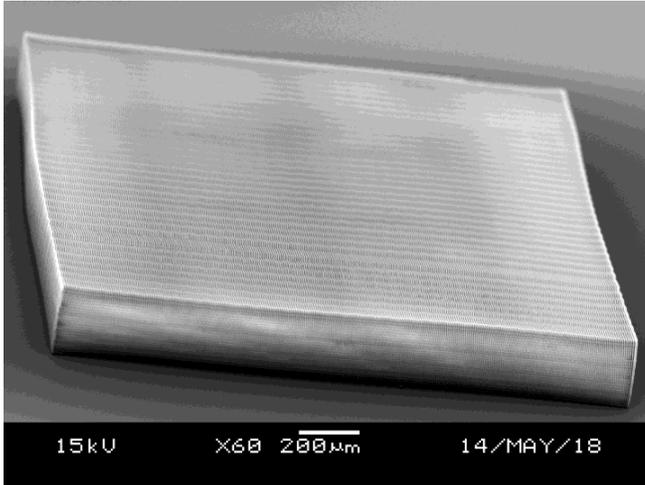
1. L. L. Ji, J. Snyder, A. Pukhov, R. R. Freeman, and K. U. Akli, Towards manipulating relativistic laser pulses with micro-tube plasma lenses, Nature Scientific Reports | 6:23256 | DOI: 10.1038/srep23256, 16 March 20

Gradient density foams have been made of large areas without stitching



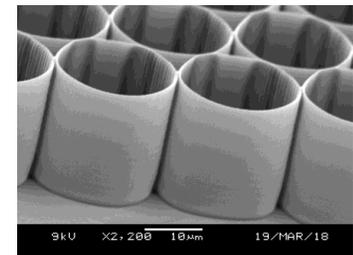
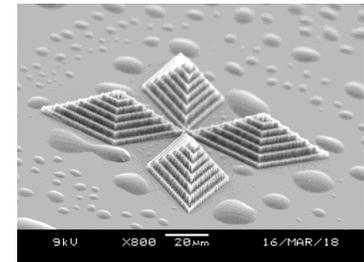
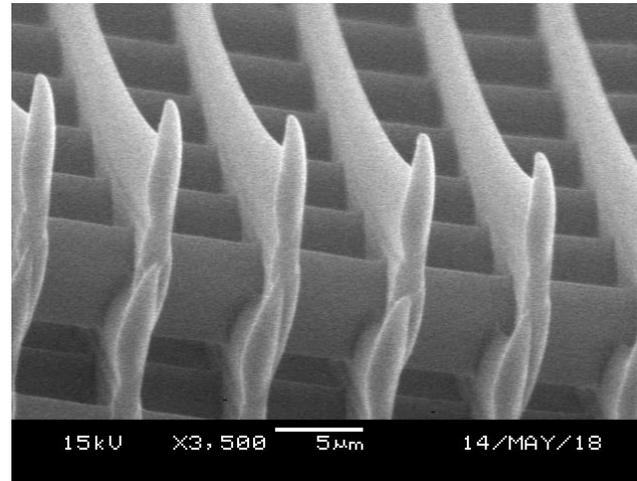
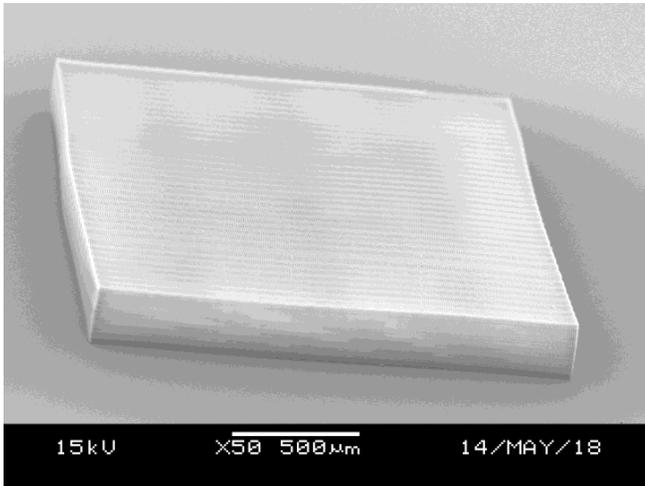
No stitching defects

Milli-meter sized parts have been made



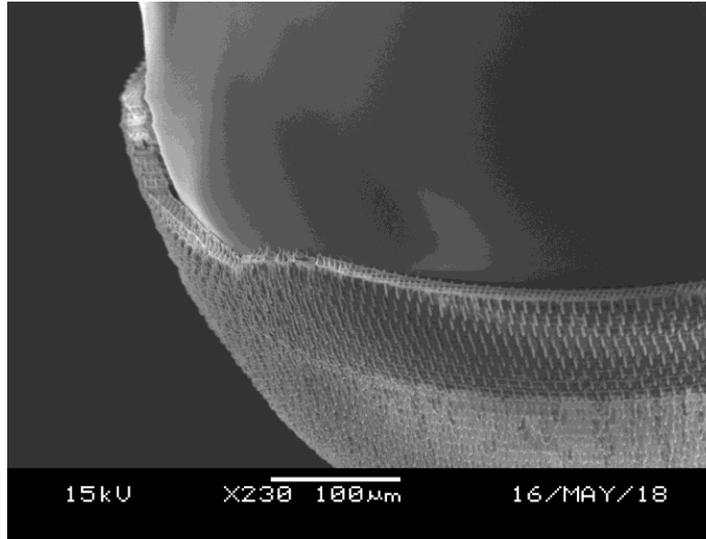
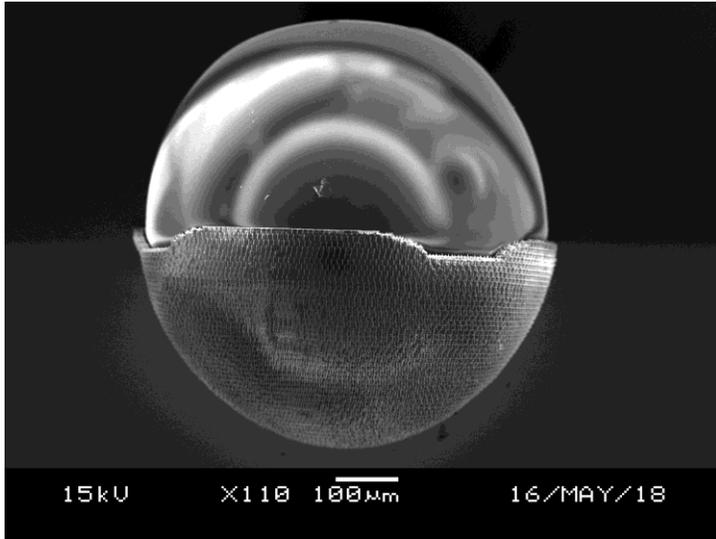
No stitching defects

(Nanoscribe galvo limited to 140x140µm; large areas are stitched together)

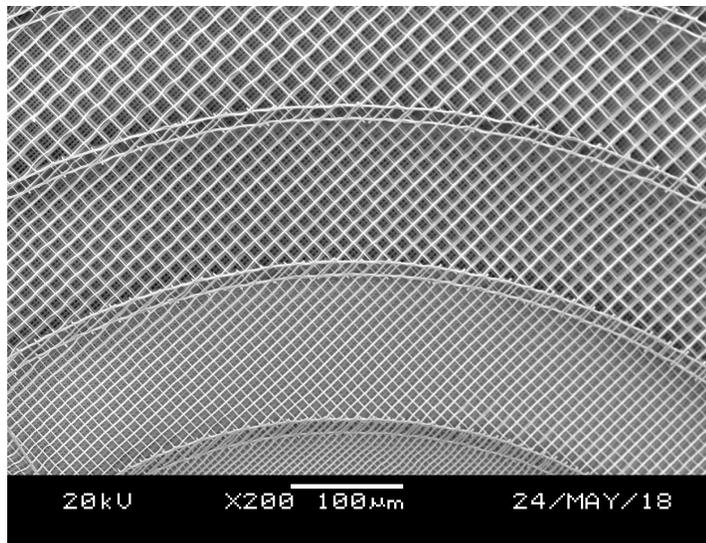
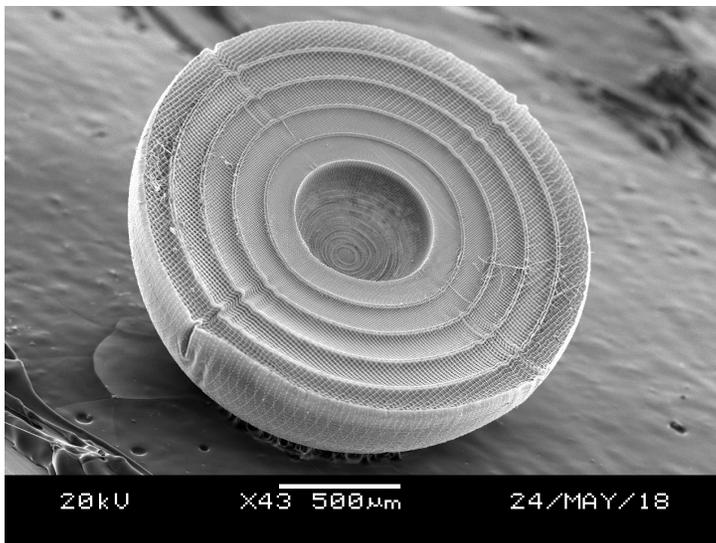


- **2x2x0.25 mm gradient density foam block**

CAD translator for printing more complicated parts

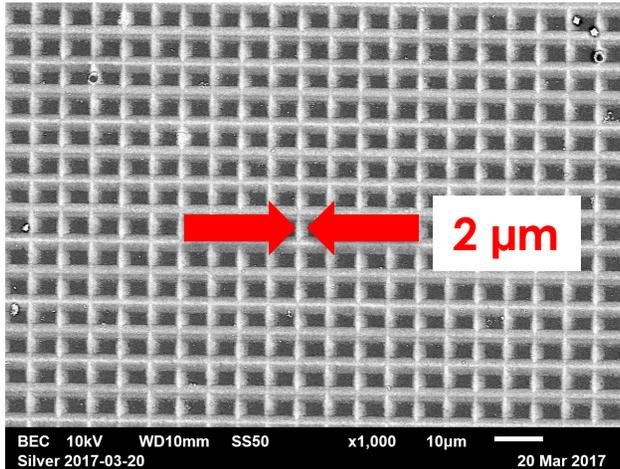


Foam hemi-shell
Ø865 µm x 30 µm wall
~230 mg/cm³

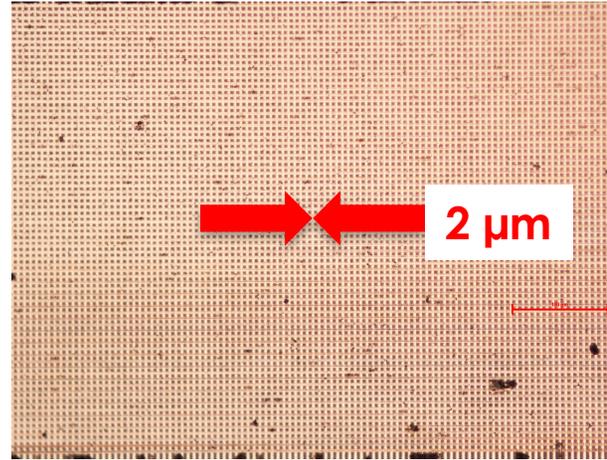


Stepped graded
density hemi-shell
OD982 µm ID290 µm
~50 to ~200 mg/cm³

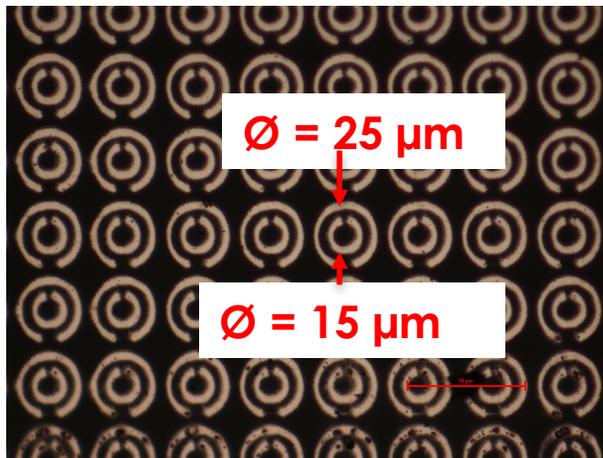
Gold and silver can be directly written on thin polymer films and other substrates in 2D



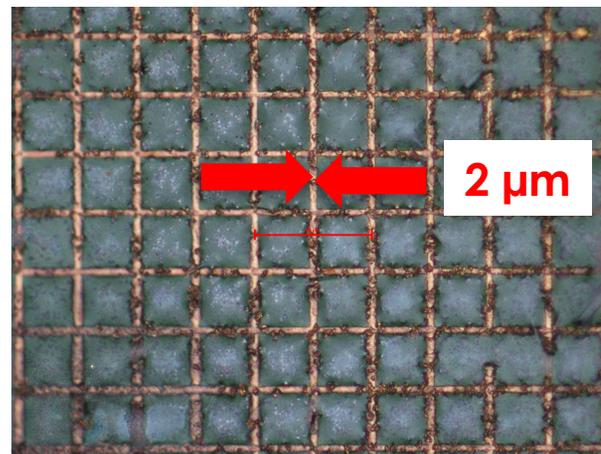
Silver Grid



Silver Grid



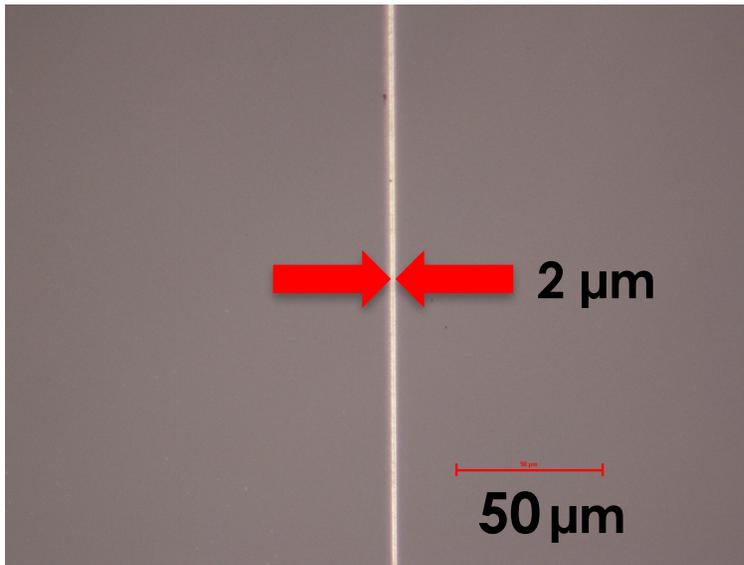
Split Ring Resonators



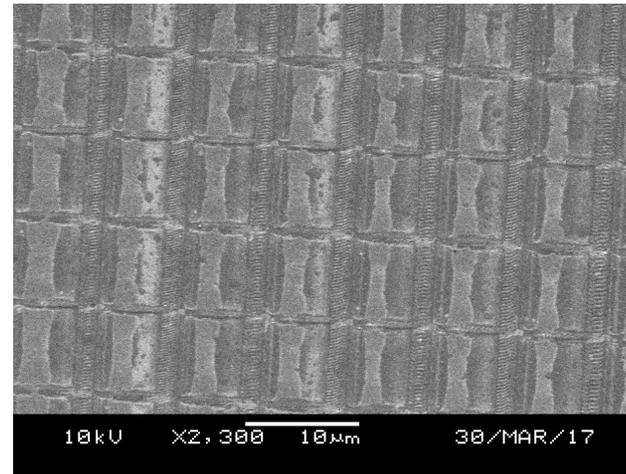
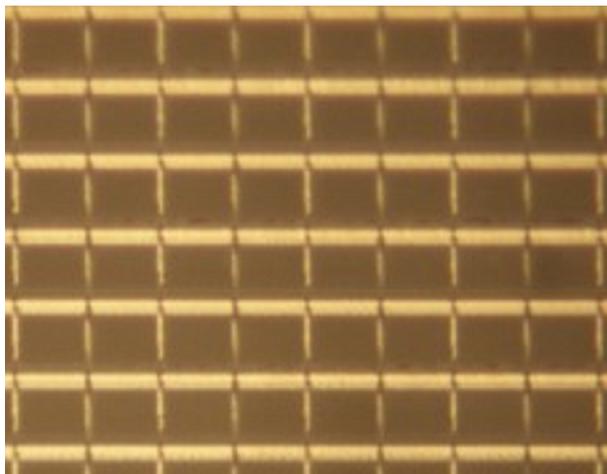
Gold Grid

Working on 3D

Pure Carbon Hydrogen polymer (CH) printing in development



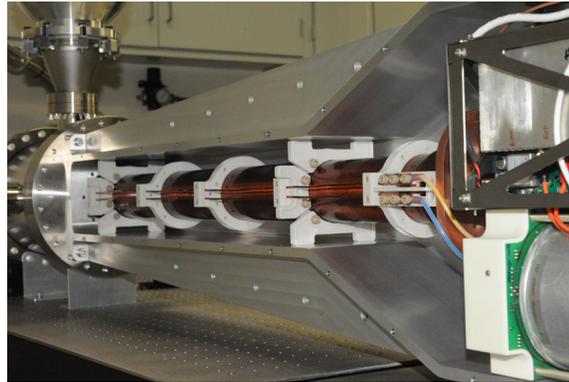
- In Development
- 2 Micron Linewidth
- Attractive material for HEDP experiments



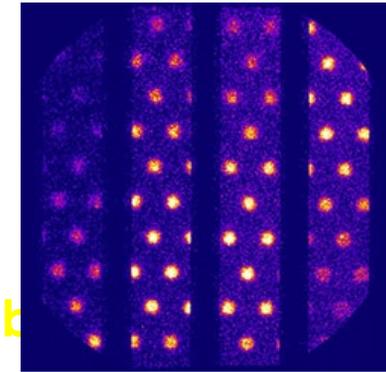
GA on team that developed fastest x-ray imager (10ps gate)



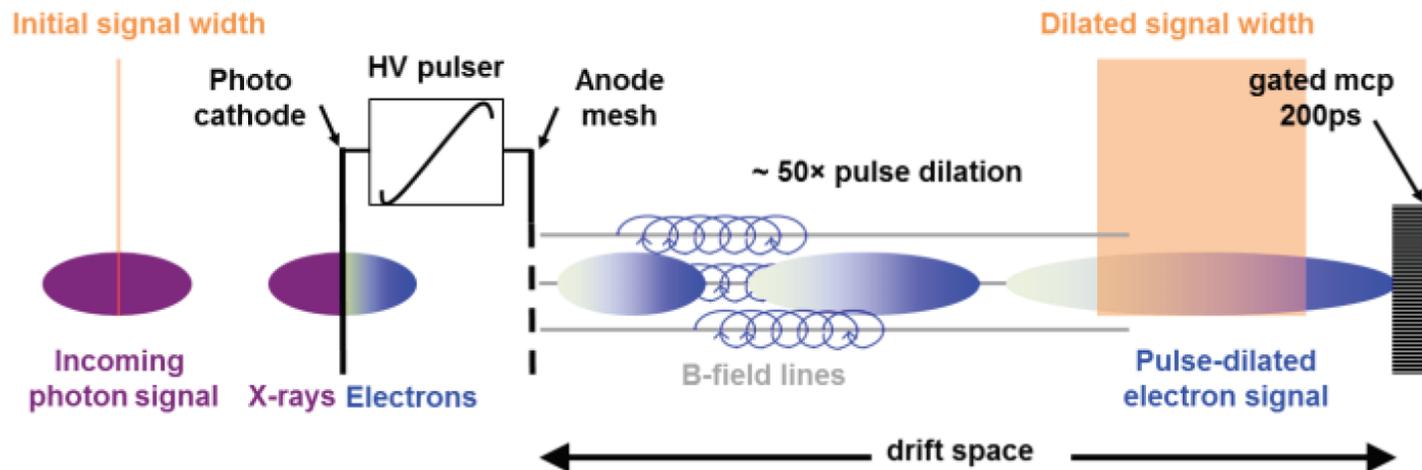
Dilation X-ray Imager (DIXI)



Magnetic coils of drift tube



Capsules images



We also make precision pinhole arrays for xray and penumbral imaging in W and Ta

- Electron pulse from photocathode drift in magnetic field to stretch out (dilate) in time for read out by slower MCP

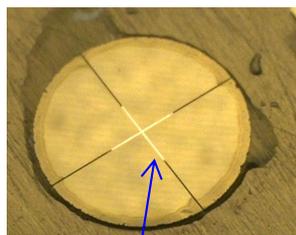
GA with affiliate Umwelt- und Ingenieurtechnik GmbH Dresden (UIT) are developing a supply system for targets for Europe

- **UIT (GA affiliate) and GA are forming a partnership**
- **The future intended contact for target orders for Europe will be :**
 - Dr Jens Schubert of UIT, GmbH
 - www.uit-gmbh.de
- **Buy in Euro**

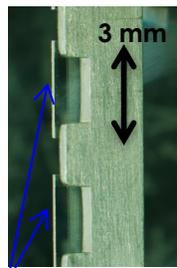


Many types of targets, shields, and fiducials have been built for LCLS; most are 2D or 2 1/2 D in nature

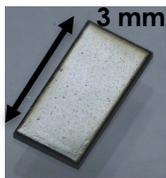
- Examples of items supplied for LCLS experiments



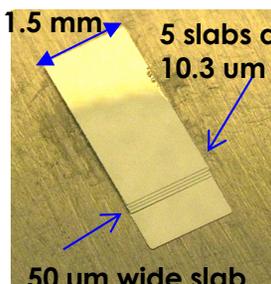
Ø3mm, 50 µm thick fused silica coated with aluminum



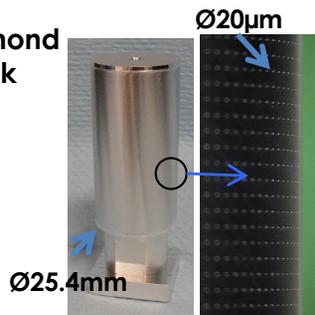
Quartz Targets w/ 100nm Al coating on laser facing thin edge



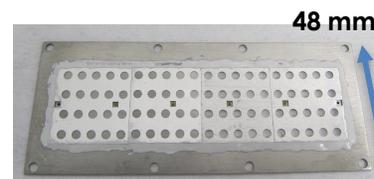
Al/parylene coated carbons (CRF, Glassy, Rigid, pyrolytic)



Diamond multi-step, glued

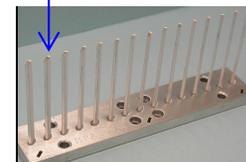


Cylinders with >10,000 micro-dots (holes in resist on aluminum)

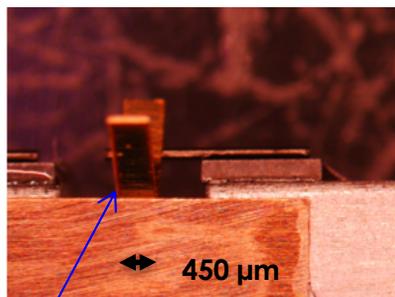


Array of polypropylene film windows above Mg (left), and MgO (right) chips

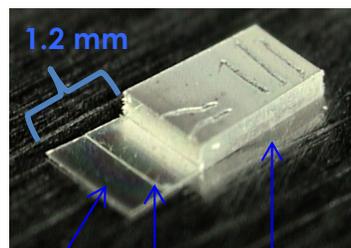
1.5 x 3 mm cross section



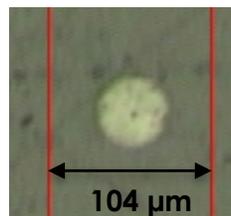
15 Al and parylene coated polystyrene pillars have total of 750 shot locations



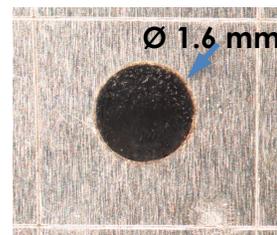
Edge mounted gold shield



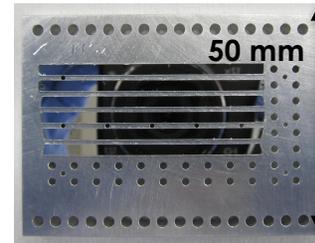
10 µm thick Mg and Aluminum steps
20 µm thick
400 µm thick handle



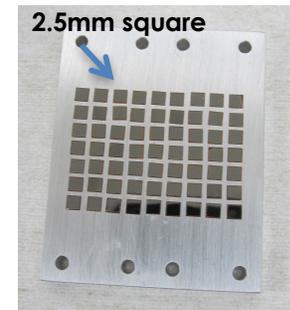
Embedded Al micro-dot arrays



Iron oxide powder target array



Ti/Cr alloy targets, 5 layer



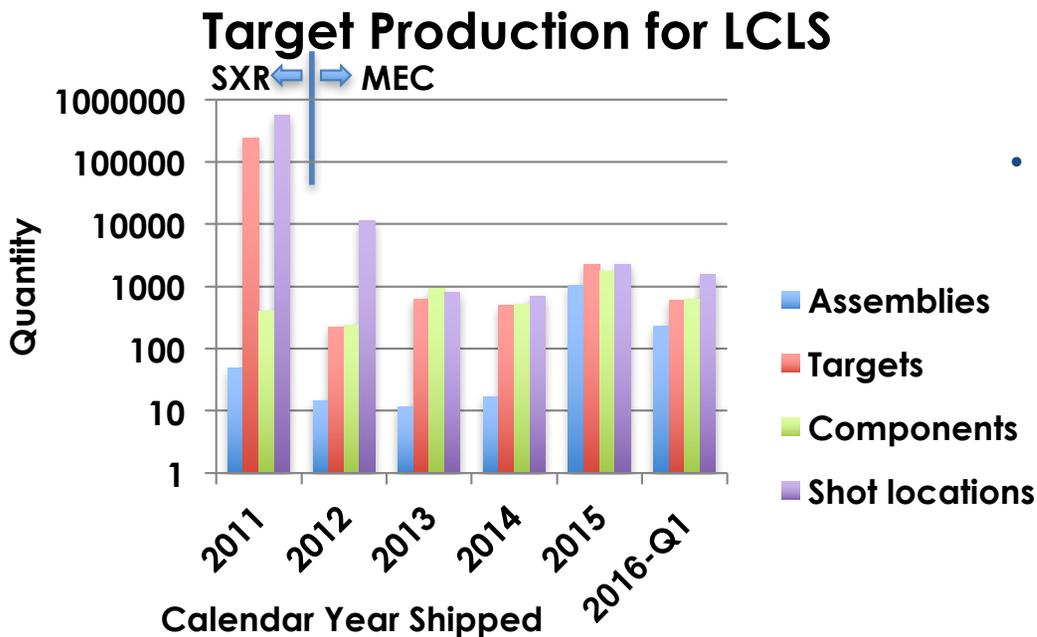
Robot Assembled and mounted targets

BACKUPS

- **Questions?**

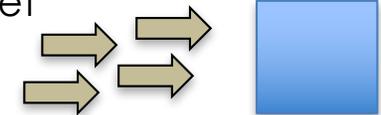
Rep-rated facilities, like LCLS and HiBEF, use many targets in an experiment

- **Rep-rated: less than 10 min./shot can use hundreds to thousand targets in experiment**
- **To keep shot rate up, avoid pumping down chamber for each target**
 - Load locks
 - Put in arrays of targets onto target positioner in chamber
- **MEC at LCLS typically uses arrays of targets**
 - Design consideration: target design to reduce fratricide (one target shot damaging another)



- **A “Target” is at least a defined feature**

- 1 plain foil shot 4 places counted as 1 target

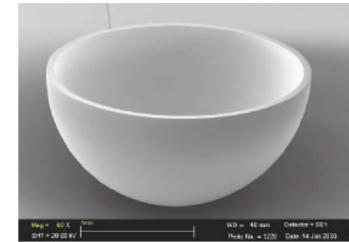
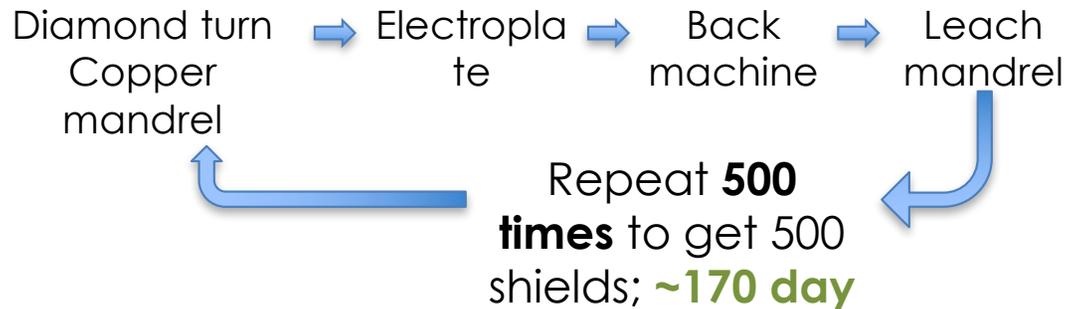


- 1 foil with 4 features shot 4 places counted as 4 target



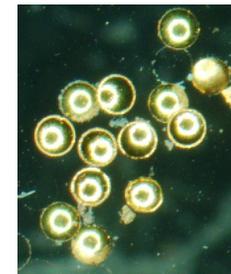
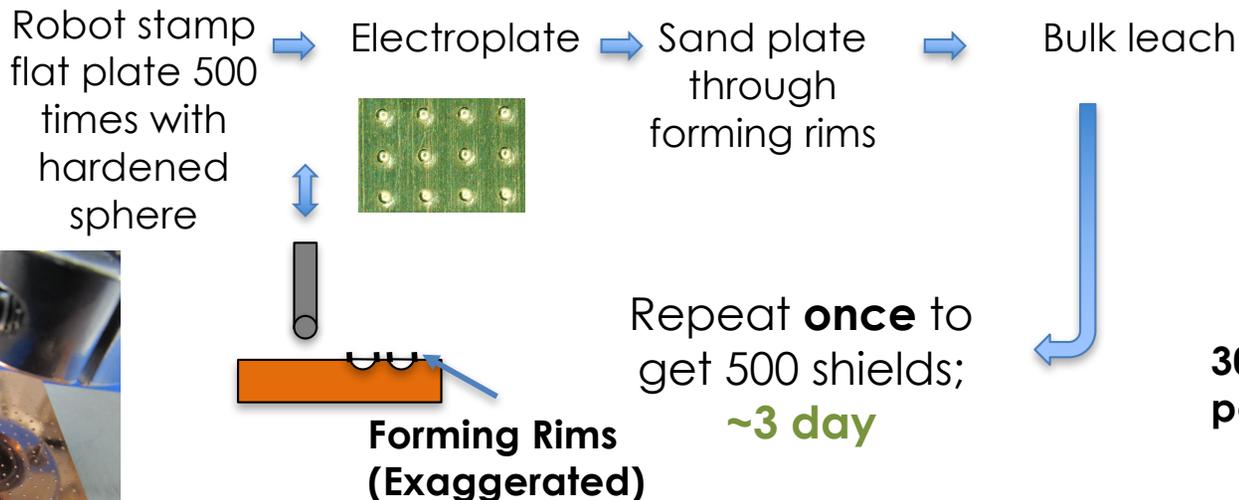
TSNA Proton focusing targets made by robotic metal forming of mandrels allows many partial gold hemi-shells to be produced

- In hemi machining process, one is made at a time



Machined hemi shell.

- In Robotic forming process, many are made at once



300 μm diameter, 5 μm thick partial gold hemi shells