3D Printing Enables Complex Manufacturing Processes for Sensors

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Outline

- 3D Printing Background & Rebranding- Ink Jet Printing & Ni LIGA on CMOS
- DMLS (Direct Metal Laser Sintering) Metal MEMS Wafers
- Adding Circuits onto 3D MEMS wafers

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Advantages of Additive Manufacturing- 3D Printing

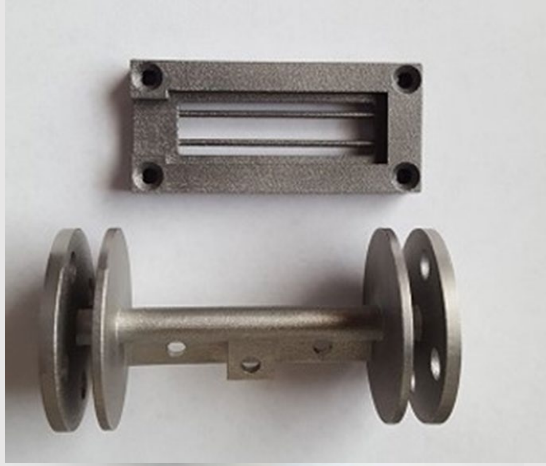
Material scrap is lower since it is a direct print additive process versus a subtractive machining or etching process – Think Micromachining.

By printing a single piece instead of using assembly steps, the manufacturing process can be simplified – large sensor or MEMS wafer

Unique features like weight reducing internal lattices can also be formed using AM (Additive Manufacturing) techniques.

AM is already used in Aerospace, Racing, Orthopedics, Dental- Low Volume, High Margins and for support of Remote Locations- naval ships, space stations…

Resonant Sensors



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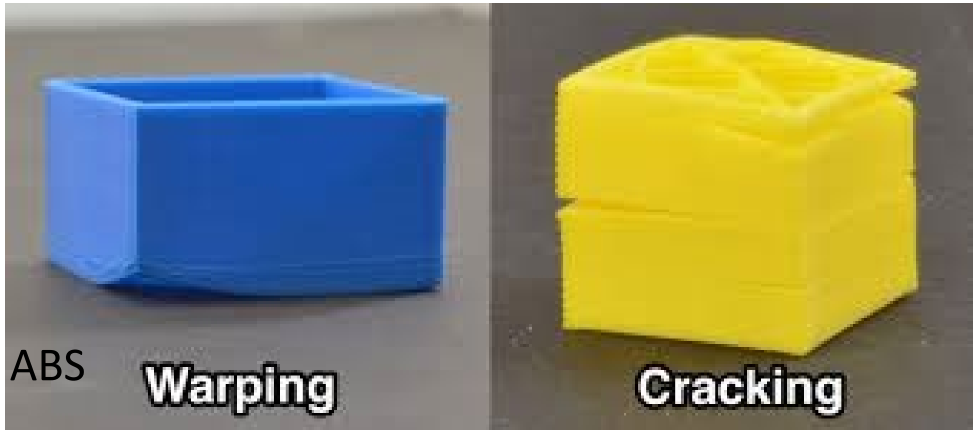
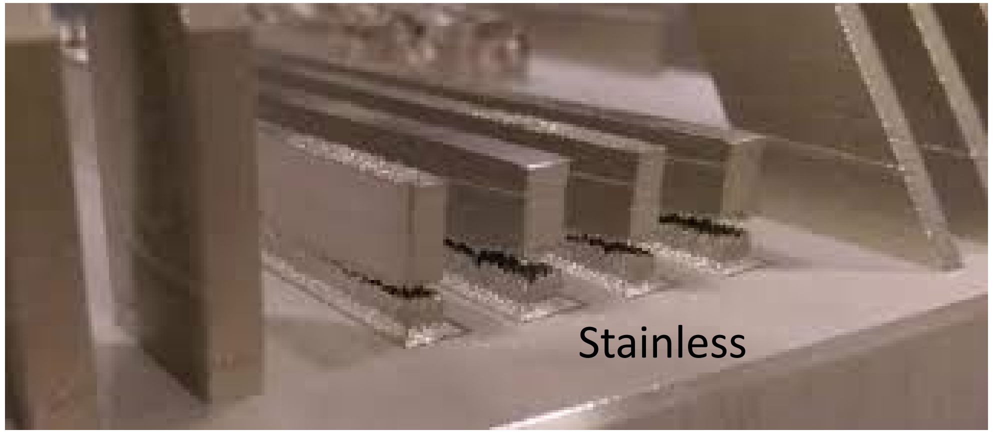
AM Problems- Cracking & Warpage

Full MEMS wafer printing can encounter these issues





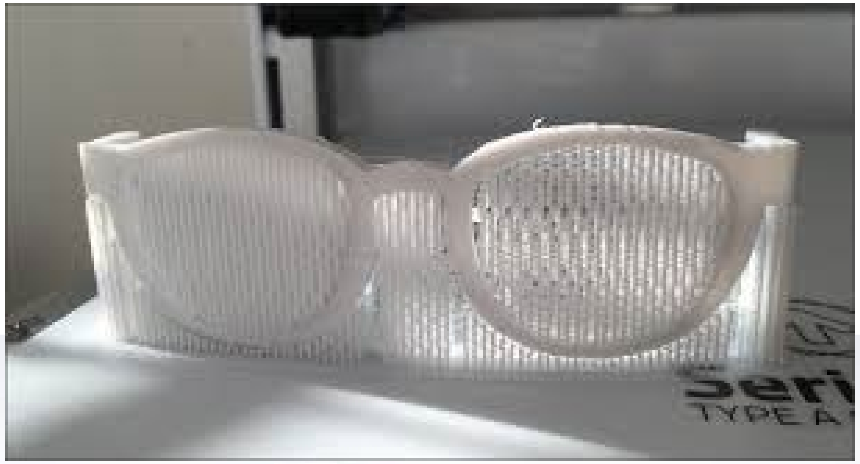
Cracked Metal

Design Rules Are Needed

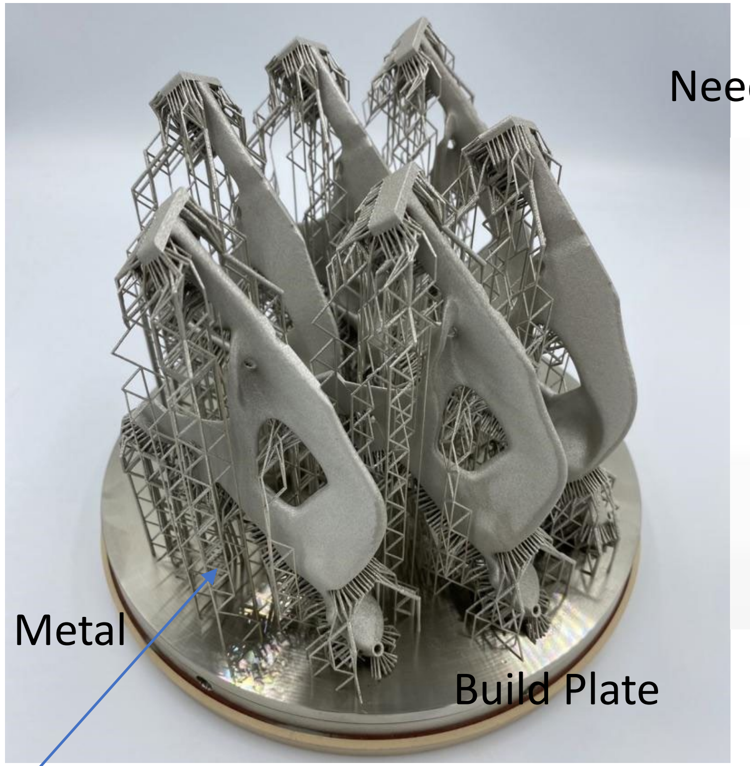
ProtoLabs Design Rules for Metal AM

Supports & Orientation During Printing

Temporary supports are key for structural stability & the prevention of wafer warpage during printed



Plastic



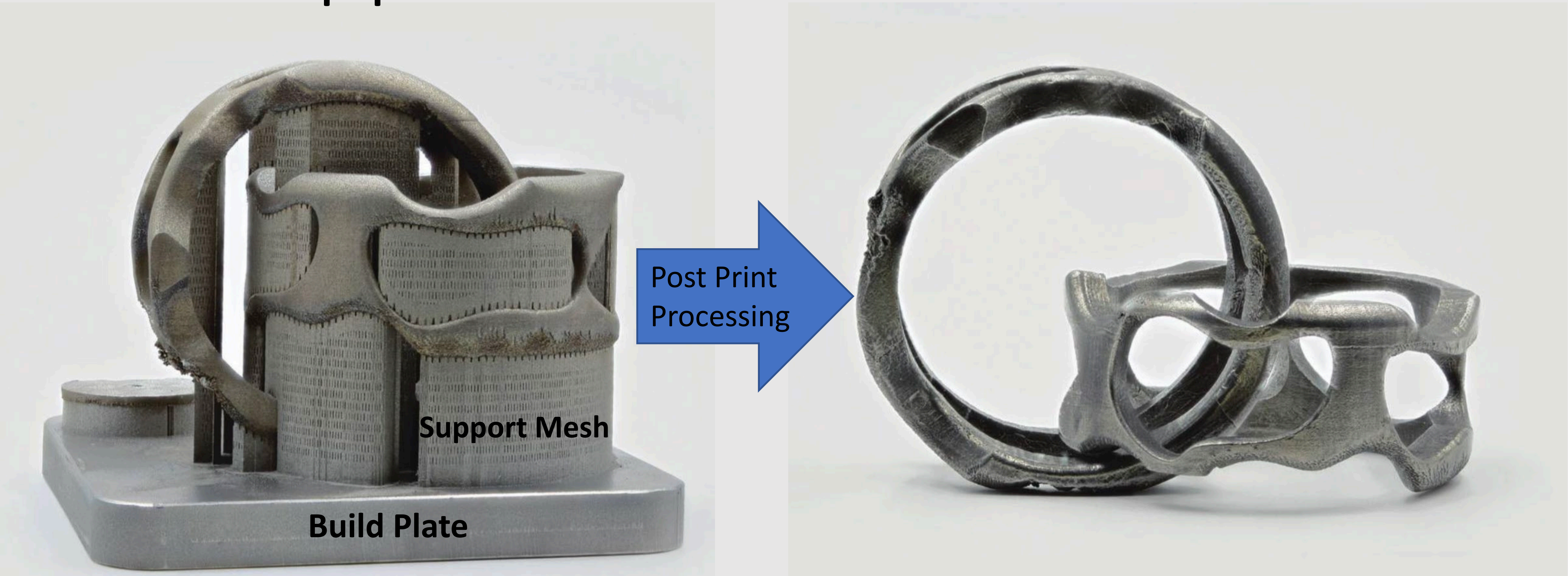
Metal

Needed for wafer and cantilever printing

Disc / Ring Print Orientation

After printing these thin supports must be removed & additional post processing is required

AM Supports Release- Sacrificial Etch



Supports are removed mechanically & chemically- wet etching, plasma etching, solvent vapor

The MEMS Wafer Processing Equivalent of the sacrificial etch- using vapor HF, XeF_2, Plasma O2, SF_6 or Wafer Dicing

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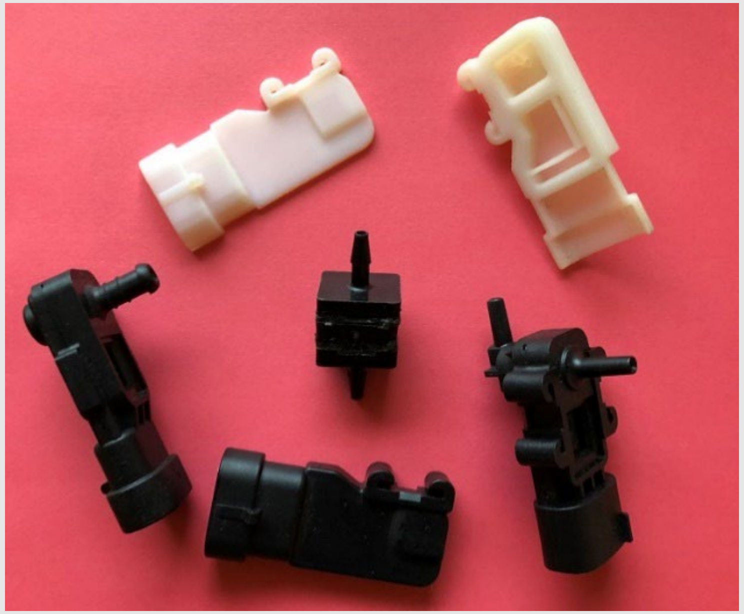
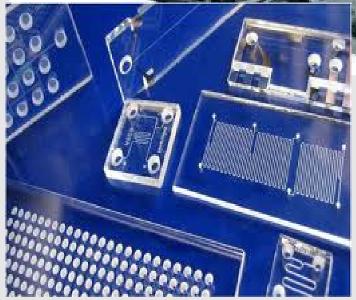
First AM Applications for Sensors: Packaging

- Good for plastic cavity packages -- out of date/manufacture parts, after market, low volumes
- Can also help startups



Pressure & Flow Sensor Packages

MAP Packages

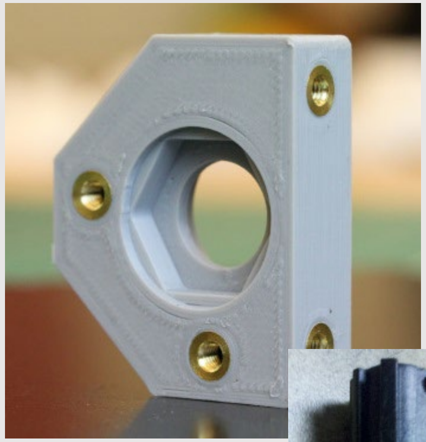


Microfluidics

Medical MEMS Sensor

Cavity Package PCB Drop-in- 2004

3D Printed Plastic with Hot Pressed Metal Inserts



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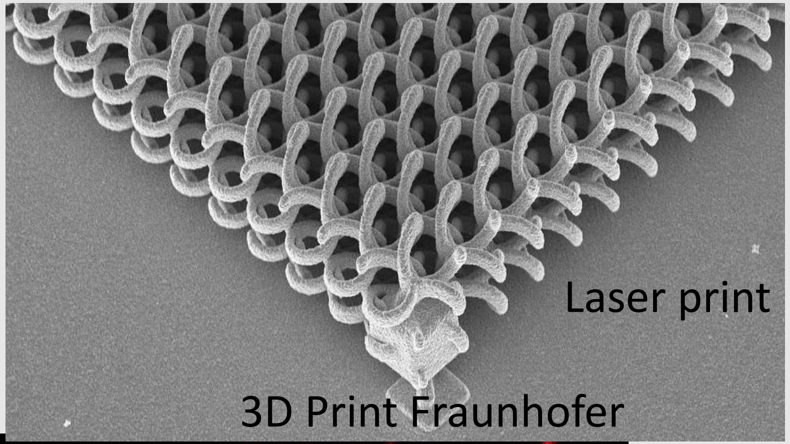
Micro 3D Printing: Polymers, Metals, Ceramics, Glass < 10mm Feature Sizes

BMF

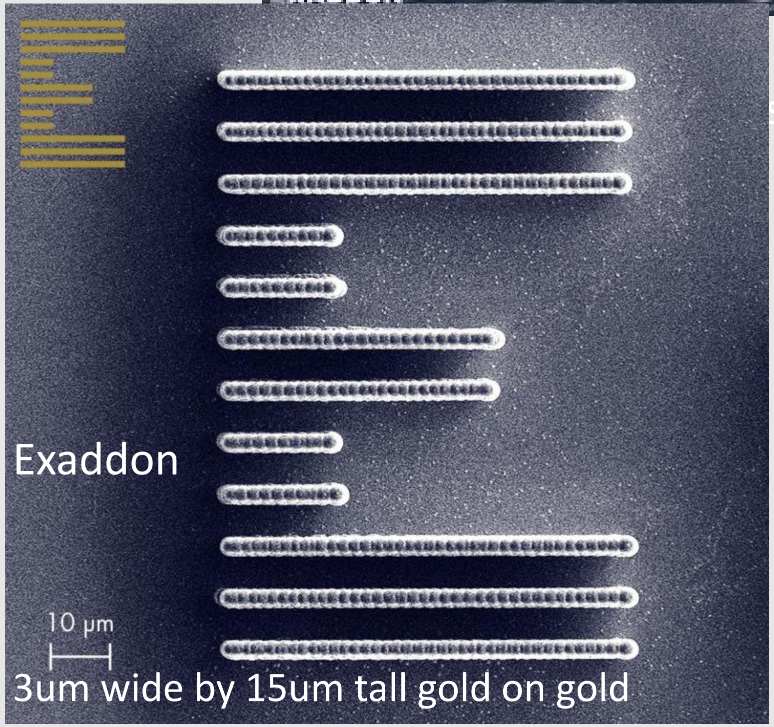
Femtika

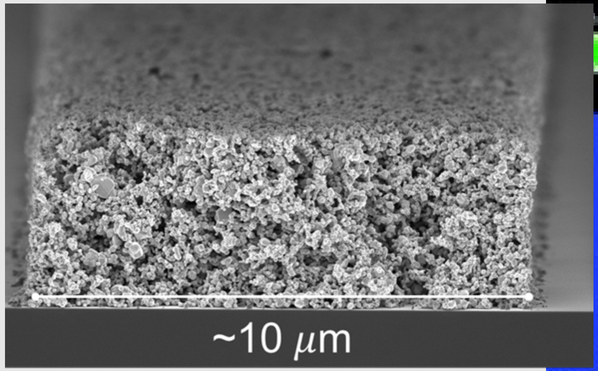
Mimotec

Incus



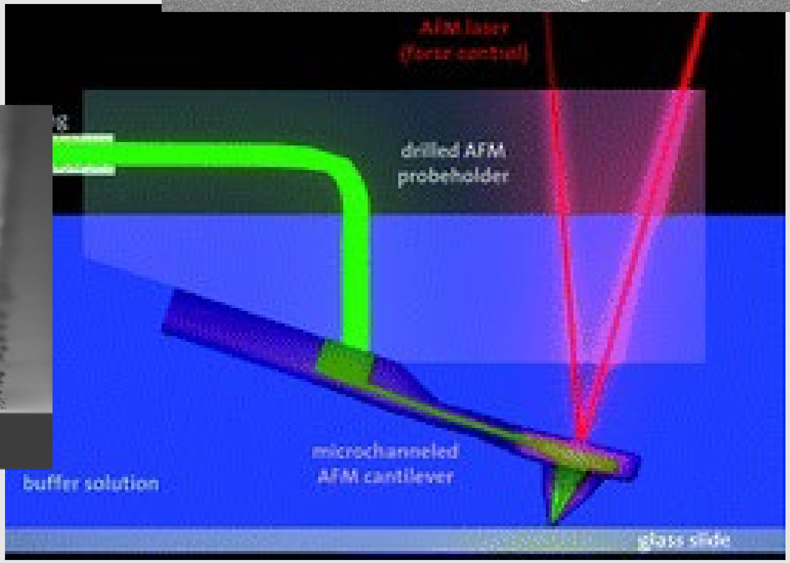
Upnano





Mesoline

ATLANT 3D – ALD Printing



AFM-Like Metal Electroprinting

Microfabrica

Micromaker3D

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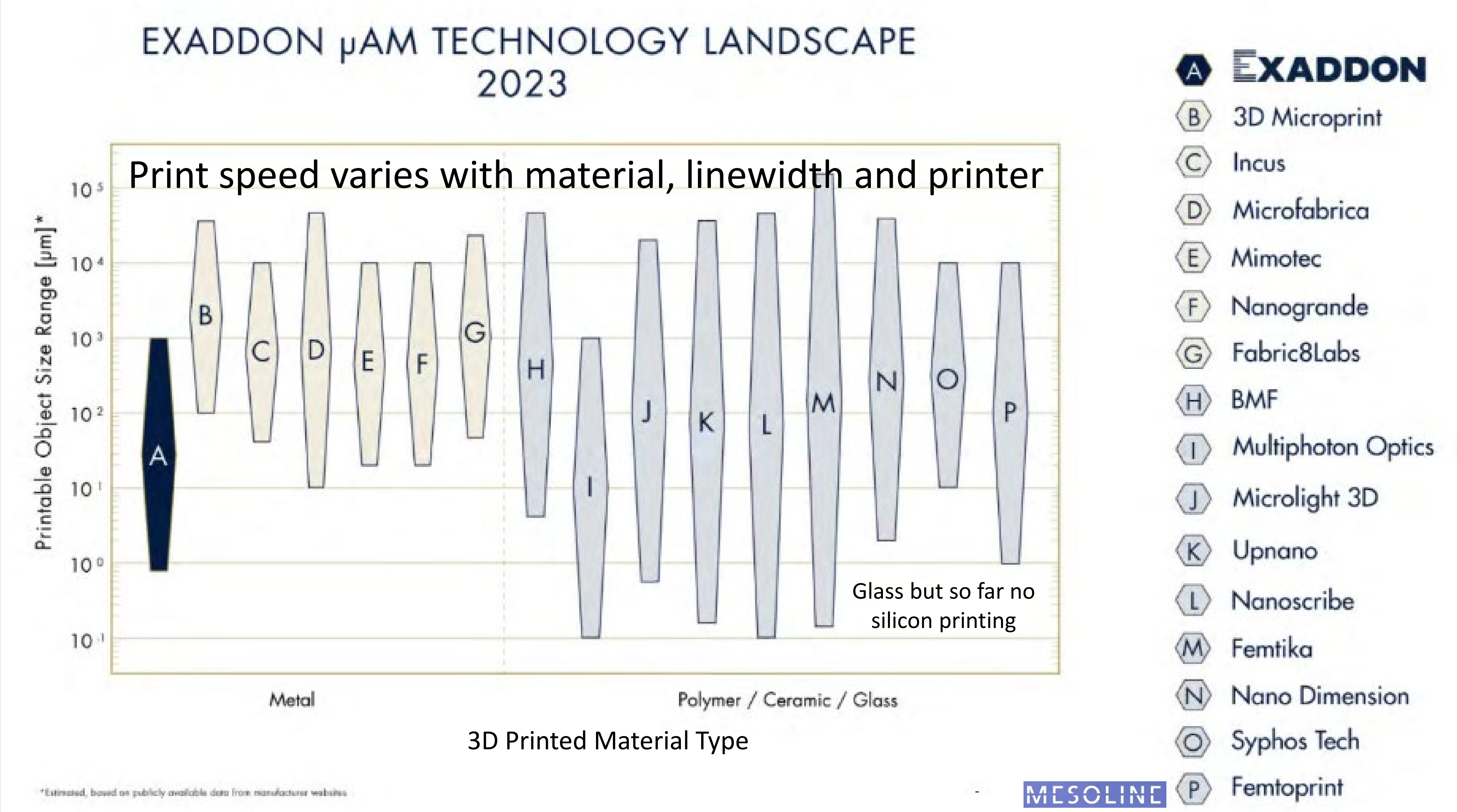
AM Micro Feature Size Competitive Space in 2023

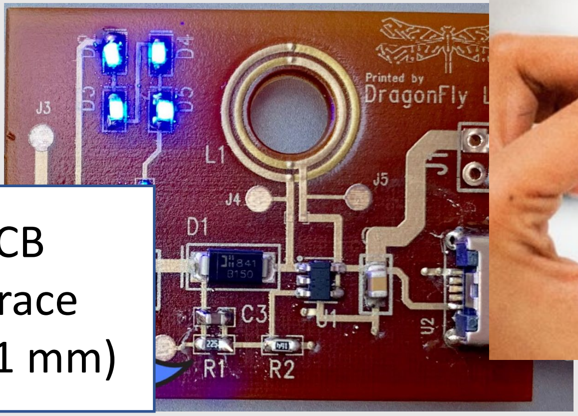


Rebranding- *Ink Jet Printing as 3D Printing*

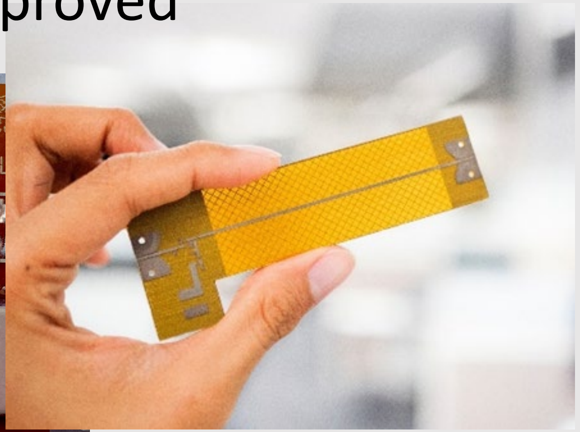
Ink jet printing (2D) for metal and dielectric layers was applied to metal hybrid PCBs in the late 1970’s-1990’s, as well as for passivation coating of PCBs using silicones and acrylics

We see the similarities in NanoDimension’s Dragonfly PCB 3D Printer
 Its very similar to ink jet printed hybrid circuits

Materials, nozzles and X-Y controls have improved



3D Printed PCB
Larger Metal Trace
Dimensions (>0.1 mm)



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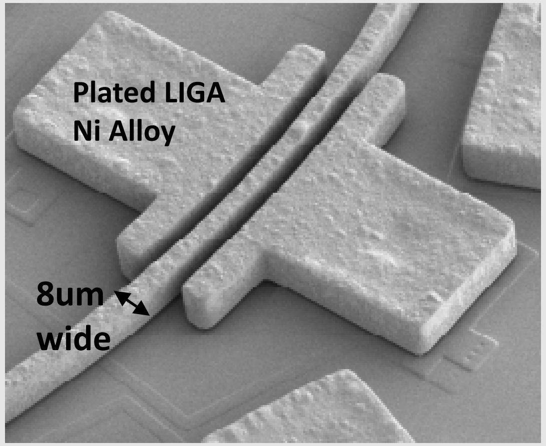
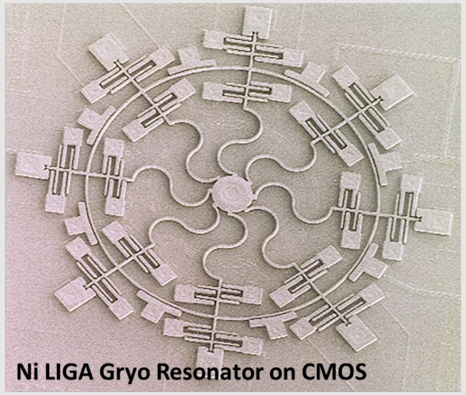
Rebranding- LIGA as Wafer Level 3D Printing
3D Electro-Printing: Lessons Learned from LIGA

LIGA = Lithographie, Galvanoformung, Abformung



SEM Close-Up of LIGA Resonator on CMOS circa 1999-2001

- Plated, softer metals that easily plastically deform
- LIGA printed on a CMOS silicon wafer
- Drop Test and Shock Failures
- Work hardening & cyclic fatigue of micro-resonators
- Alloying for increased hardness
- Ferromagnetic? May need Mu metal shielding



UV-LIGA is offered at 3D printing by Mimotec

See: Sparks, Transducers 1997

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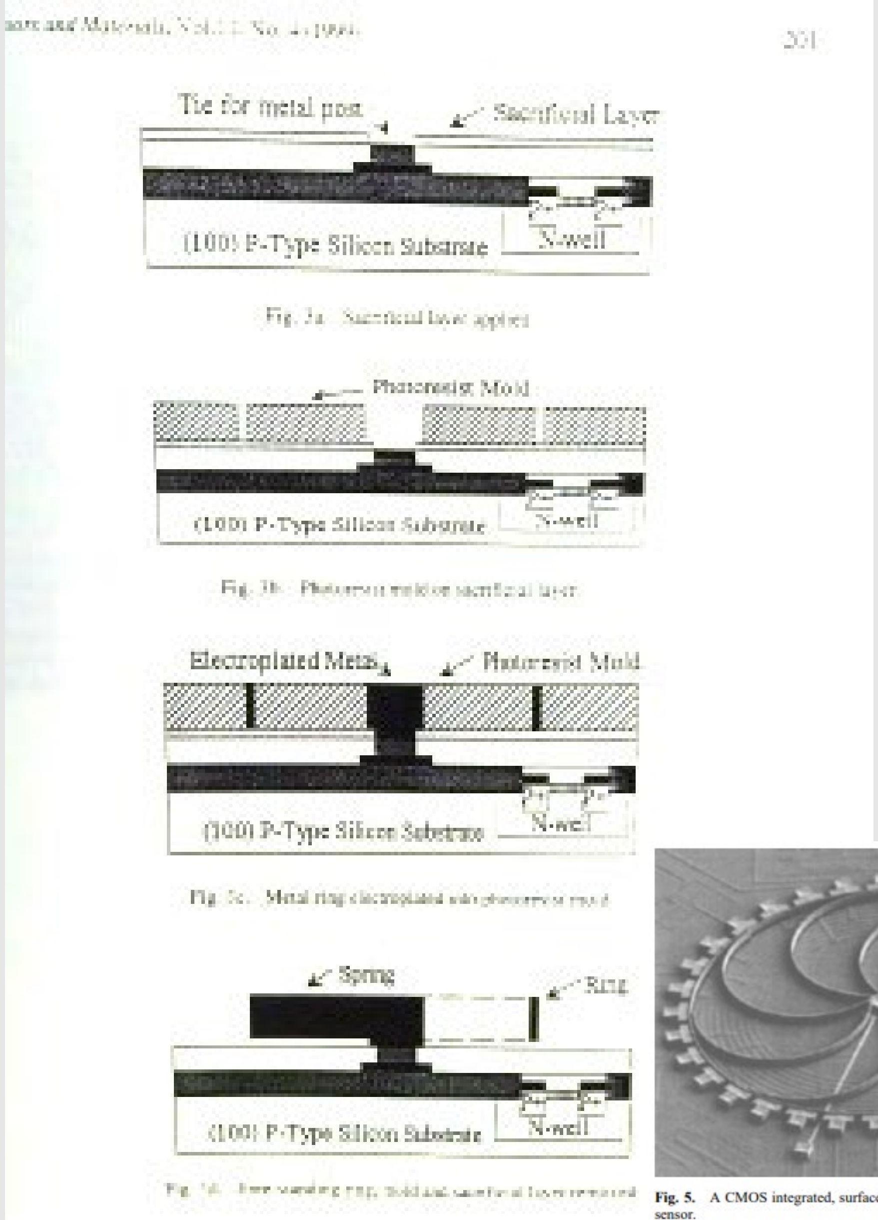
3D Ni LIGA on CMOS Wafer Process Flow

- Deposit the sacrificial layer on the CMOS wafer- Polyimide, Aluminum… This includes a plating seed layer, electrically tied to the CMOS circuits
- Spin or spray the thick photoresist mold, UV expose and develop
- Electroplate the nickel alloy
- Remove the resist mold and sacrificial layer



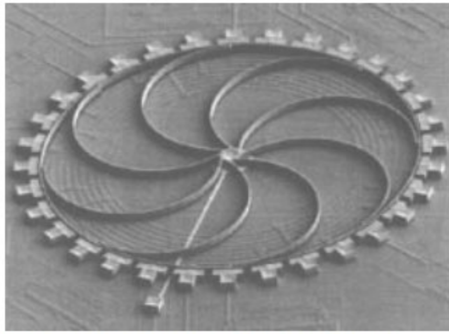
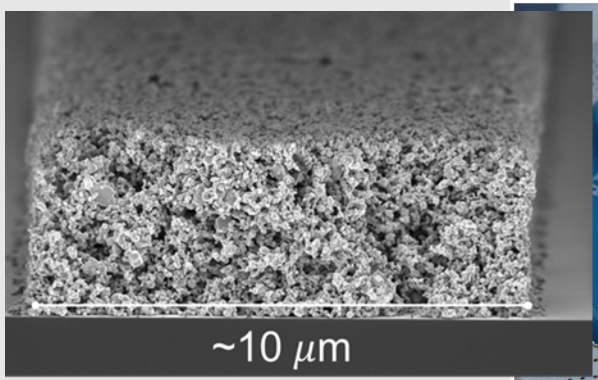
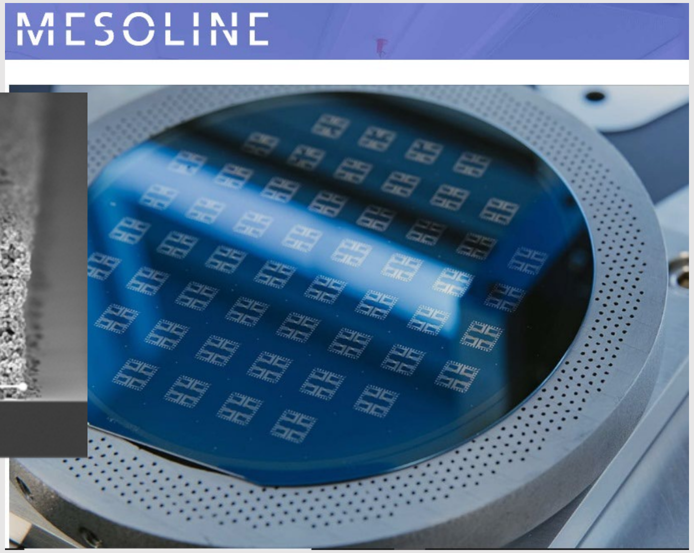


Fig. 5. A CMOS integrated, surface-micromachined angular rate sensor.

Examples of 3D Printing on Wafers

ATLANT 3D Nanosystems
ALD 3D Printing- Runners



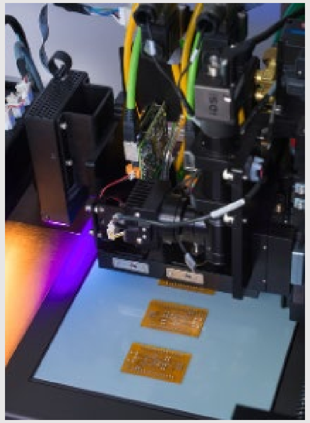


Mesoline

Northeastern University

Sciperio

PCB circuit printing
of nanoparticles



NanoDimensions

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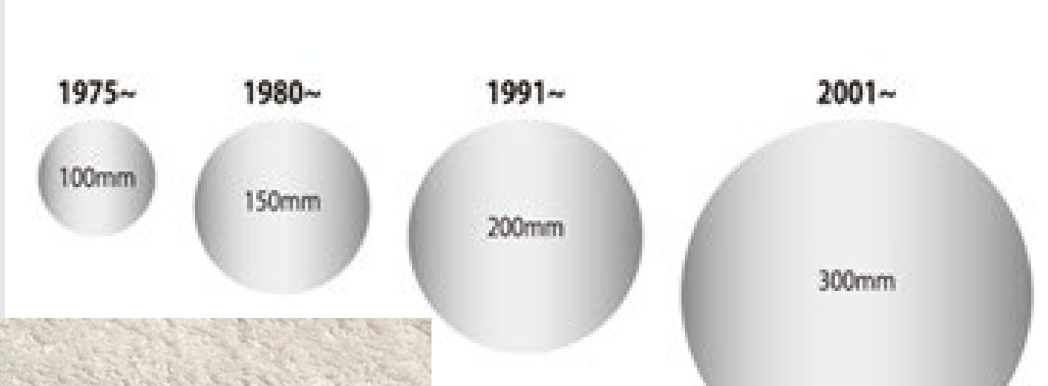
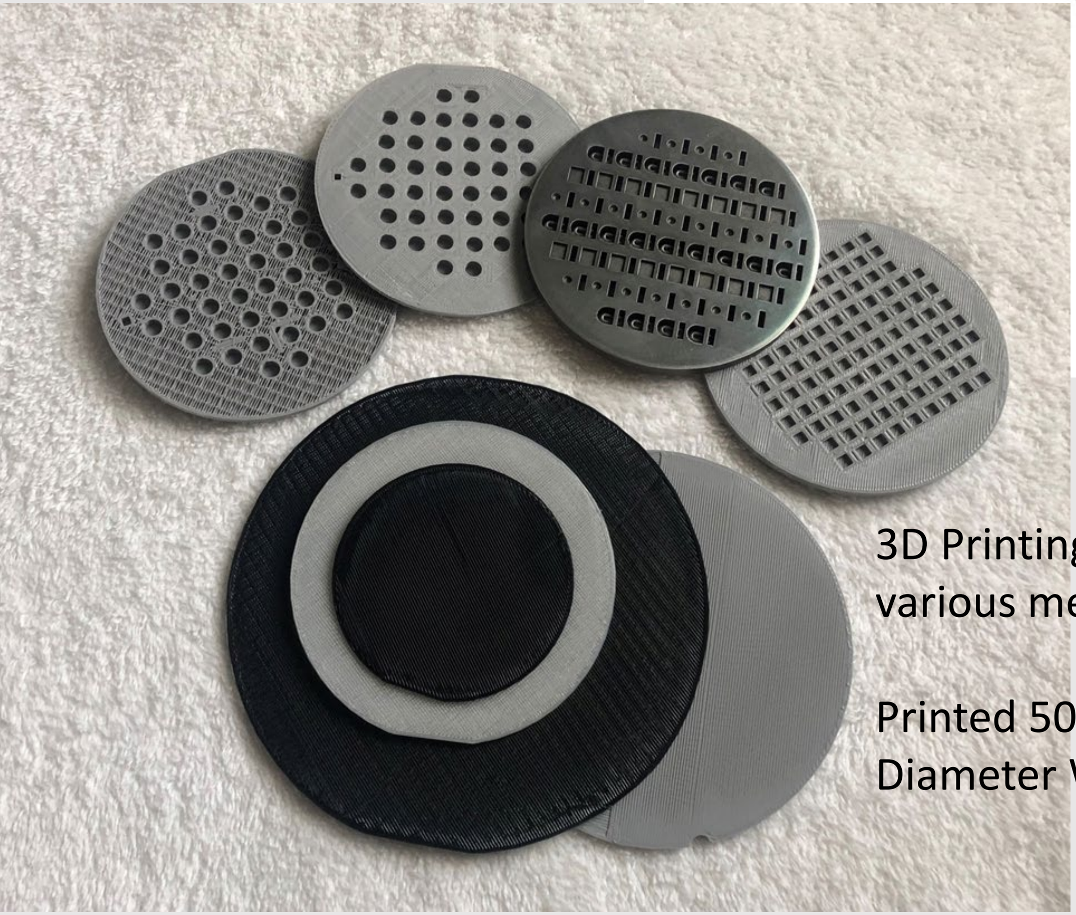
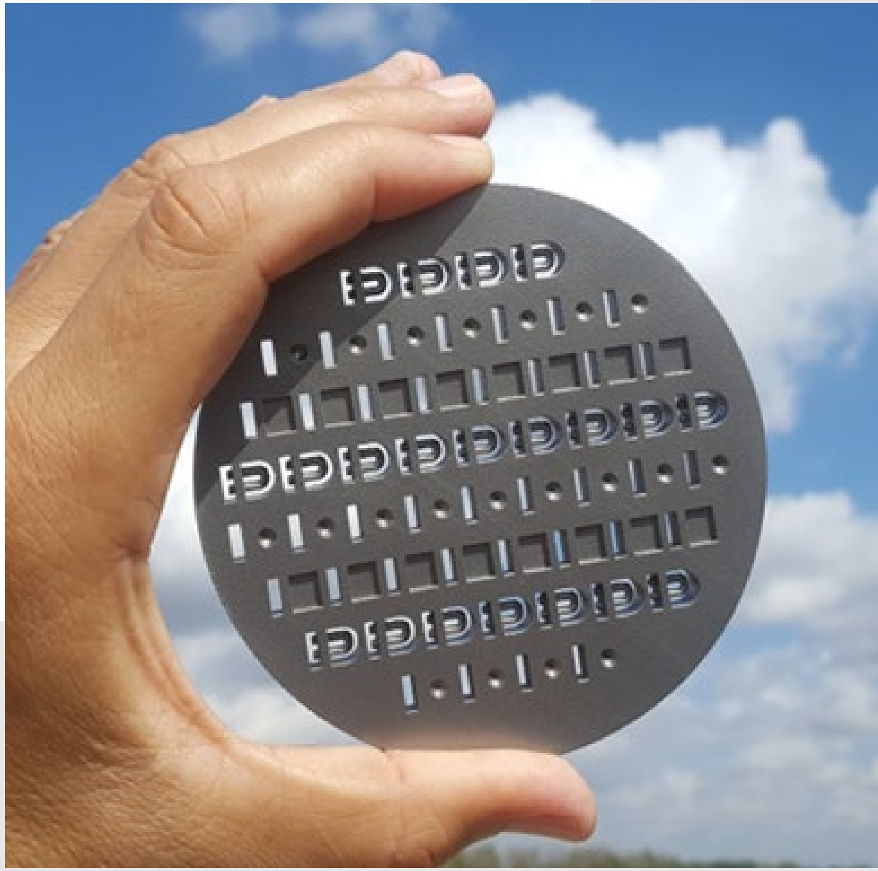
DMLS (Direct Metal Laser Sintering) of the Entire MEMS Wafers



Si MEMS wafers are typically 100 to 200mm in diameter





3D Printing micromachined wafers using various metals & plastics

Printed 50, 75, 100, 125, 150mm Diameter Wafers

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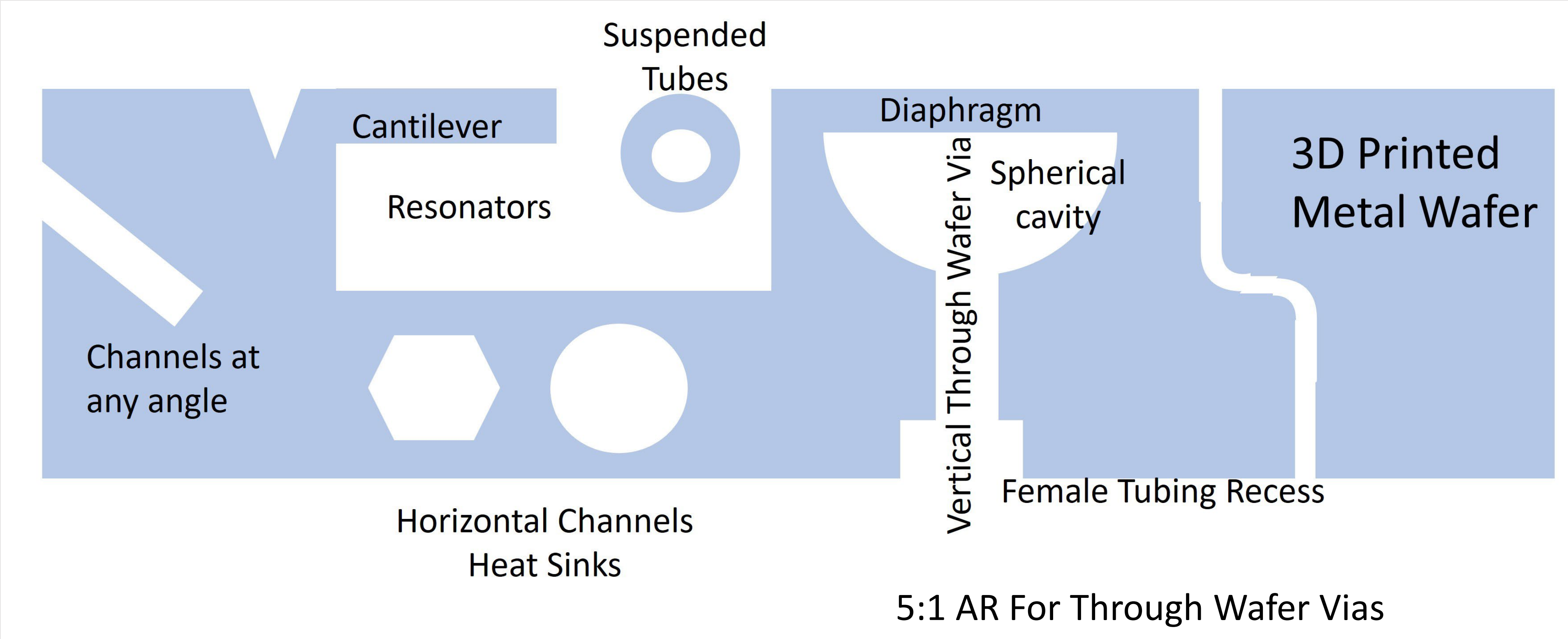
All these MEMS structures can simultaneously fabricated in one print



With a much wider variety of materials.

No DRIE, etch or bond development needed

Reduce MEMS wafer processing by 100's of steps

DLMS 3D Printed MEMS Wafer Cross-Section

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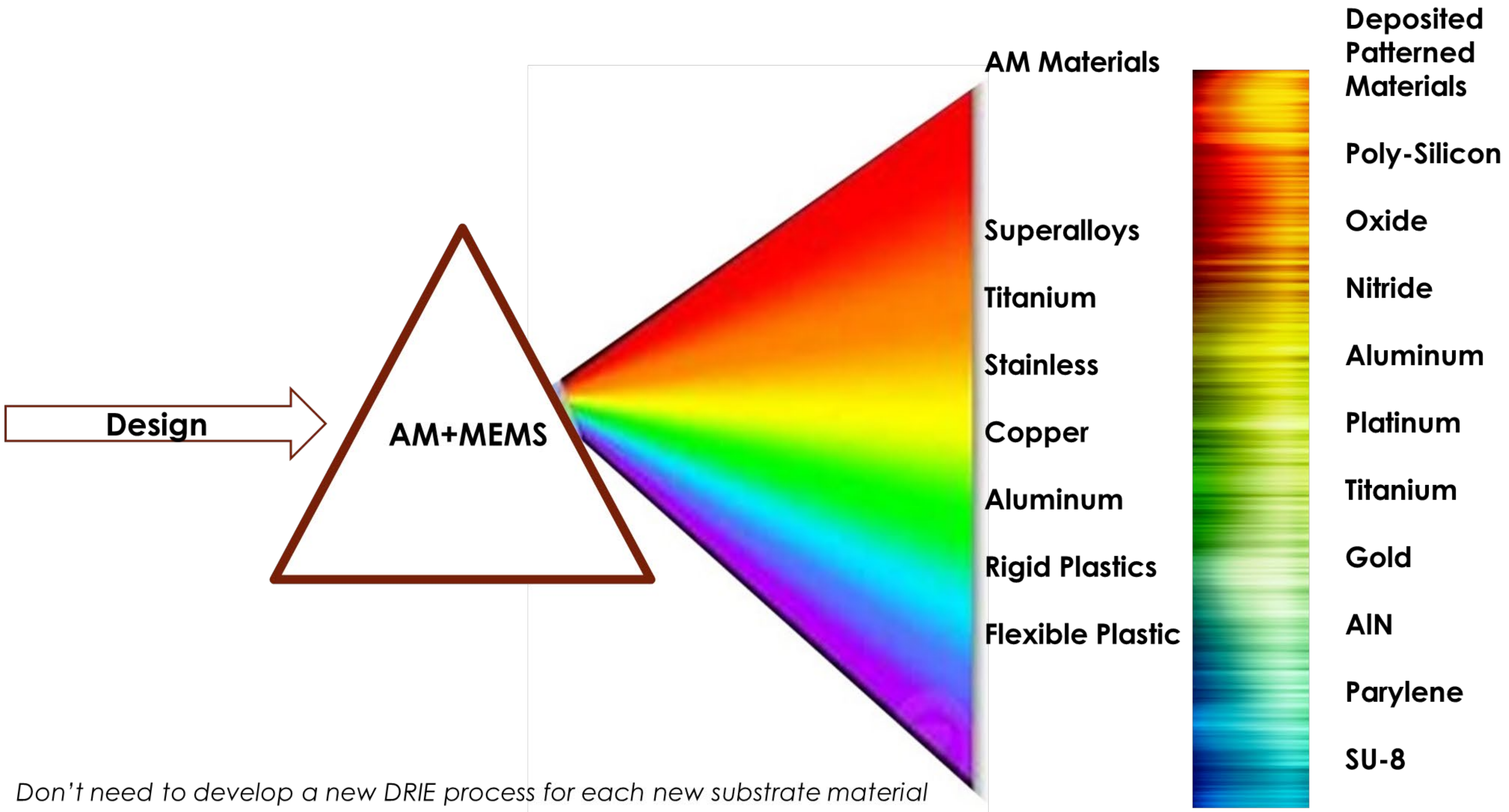
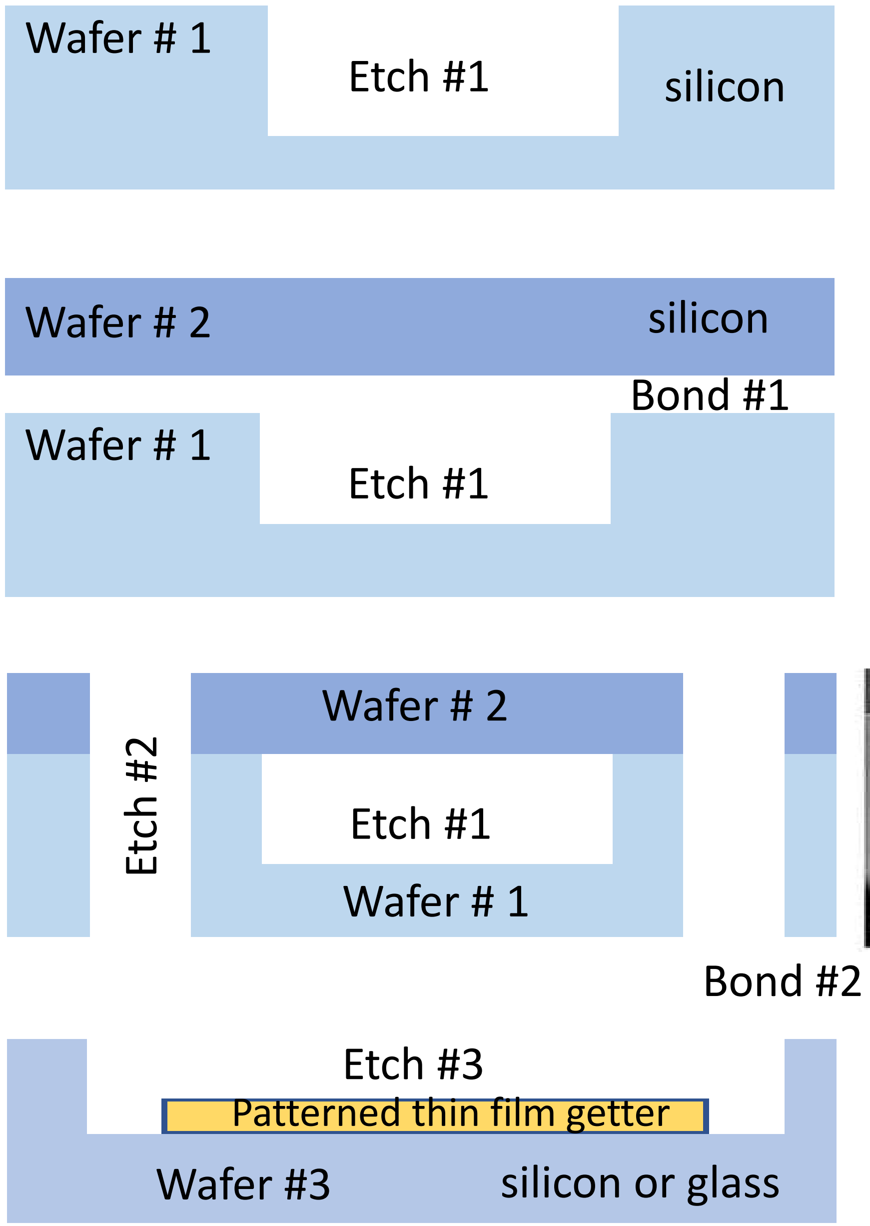
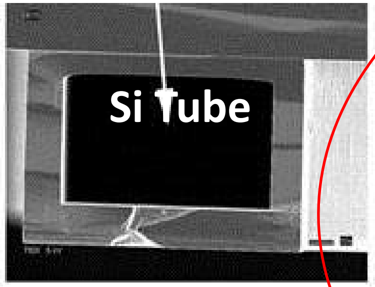
AM+MEMS Expands the Material Spectrum for MEMS and Microfluidics

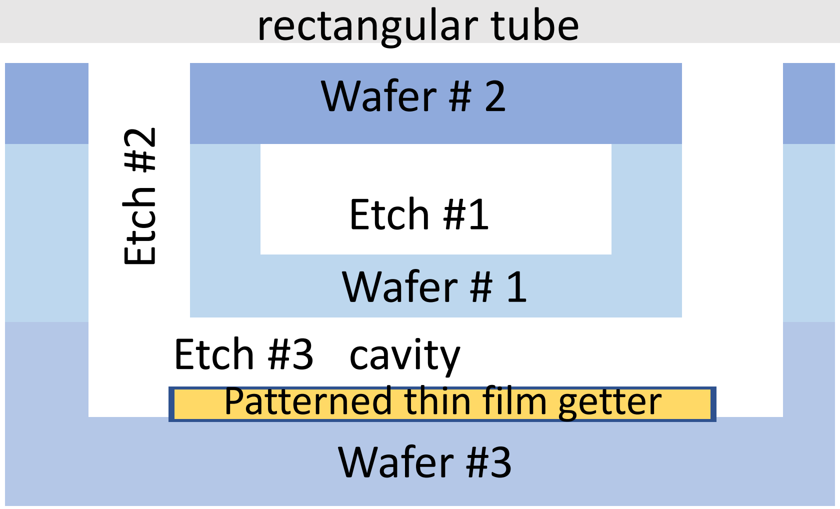


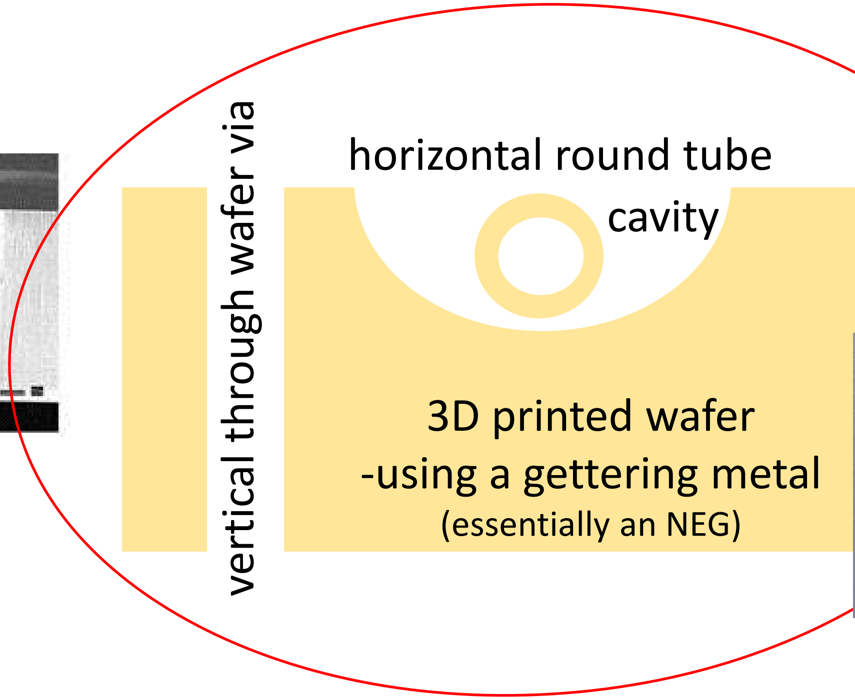
Don't need to develop a new DRIE process for each new substrate material

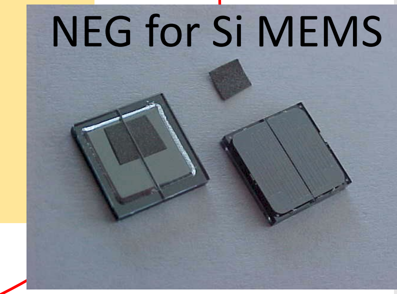
Example: Si MEMS Versus AM Microtube Process





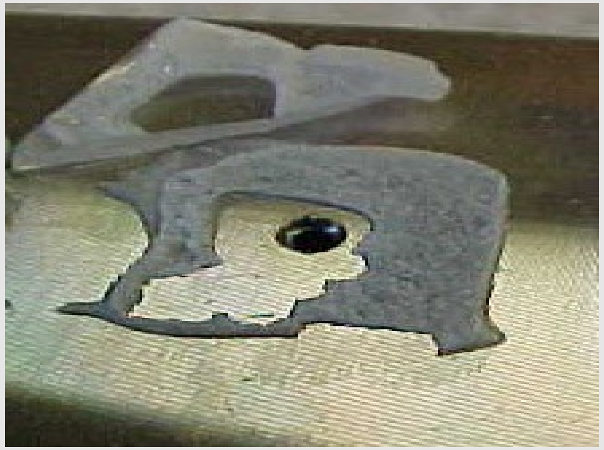




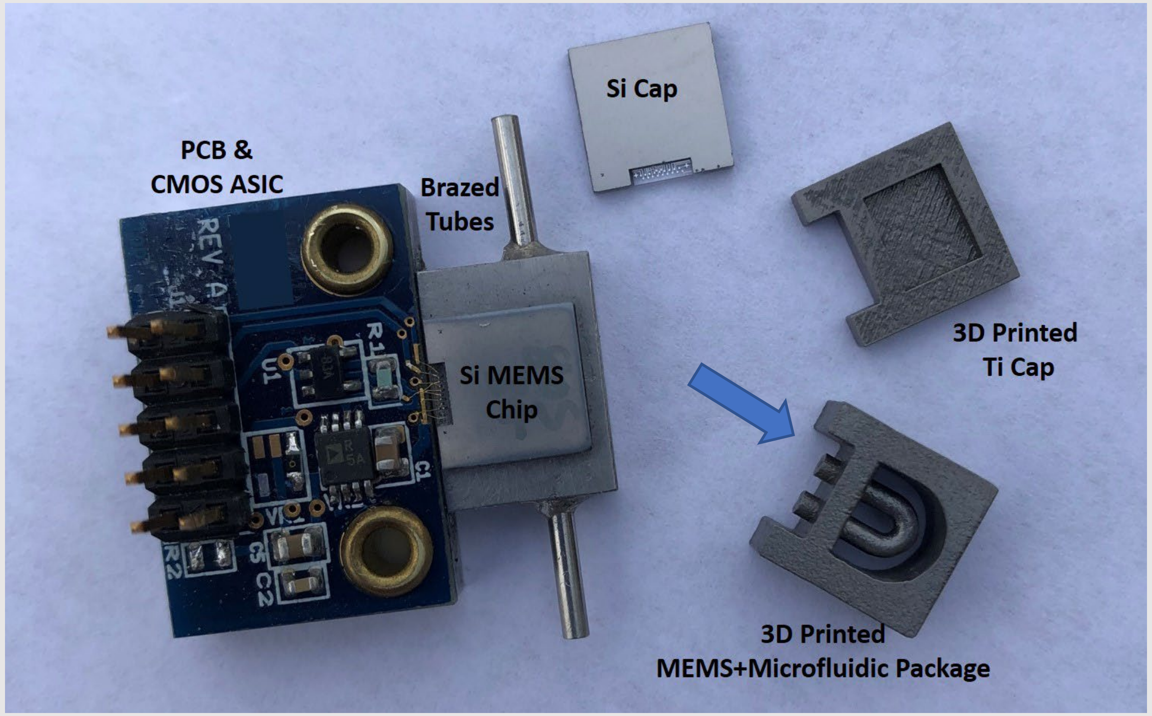


Silicon microfluidic failure modes can be avoided with Additive Manufacturing

Silicon Diaphragm Rupture



Epoxy Adhesion Failure



Titanium and stainless have superior fracture toughness to silicon

Combining the sensor chip and microfluidic interface eliminates weak epoxy or silicone die attachment

Helium leaks through most wafer bonding interfaces

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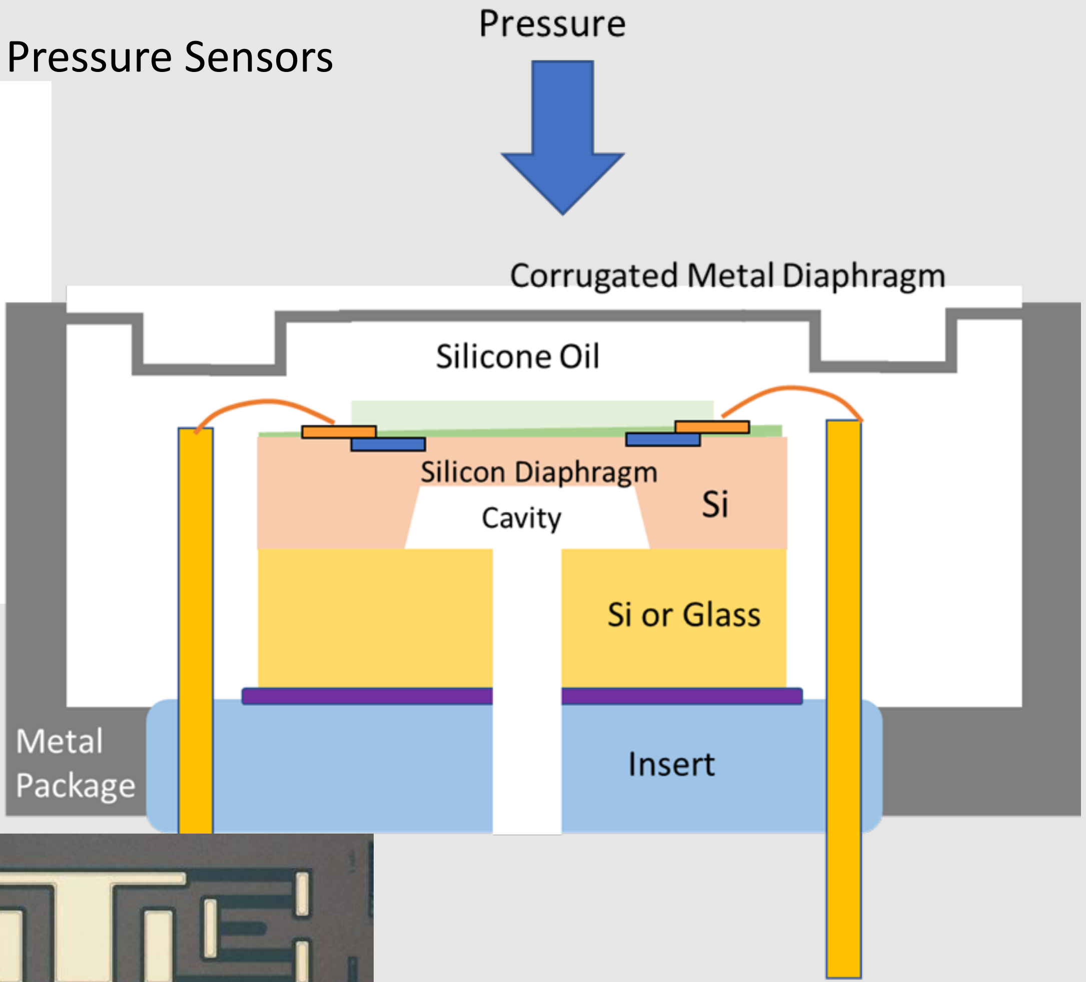
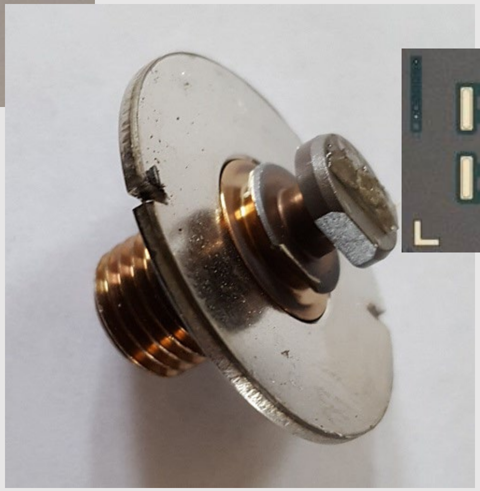
Typical Si MEMS Pressure Sensor Failure Mode Solutions

Industrial MEMS Pressure Sensors

Oil Filled





Pressure Snubbers

Corrosive fluid only touches the metal diaphragm, not the silicon chip

Backside Sense- Si Strain Gauge Glass Bonded to a machined metal diaphragm- laser assembled

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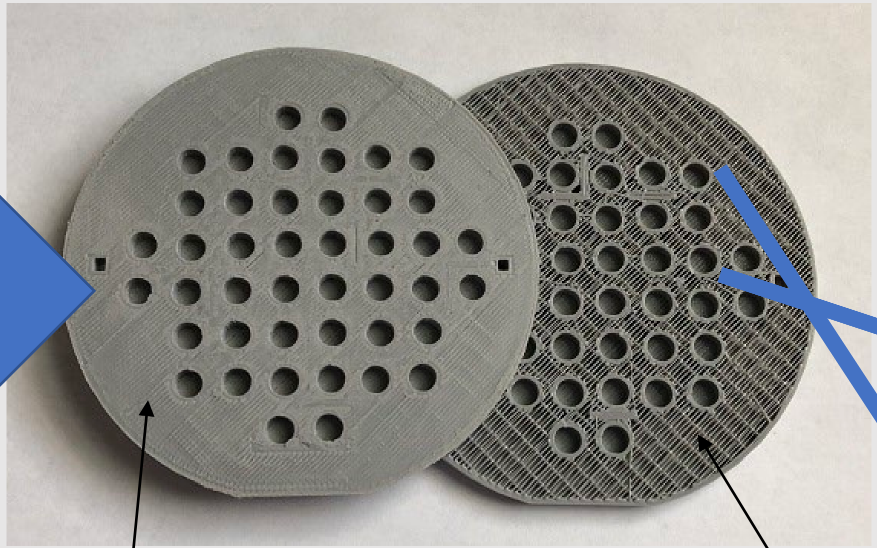
AM Supports and Internal Lattices Applied to MEMS Wafers

AM Supports

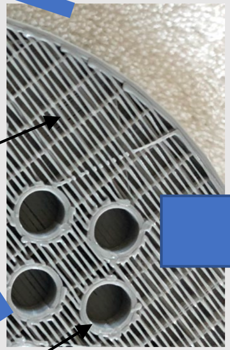
Density/Mass Lowering AM Lattice

MEMS AM Wafer



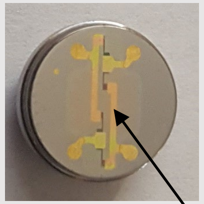
Smooth Surface Finish – Interior Wafer Lattice

Interior Wafer Lattice



Back-side cavity

Singulated Metal MEMS Chip



Front-side Circuits

Challenges for DLMS MEMS AM Wafer Fabrication

- Reducing minimum printed feature size below 50 microns
- Thin wafer warpage
- Support structure removal and associated surface roughness

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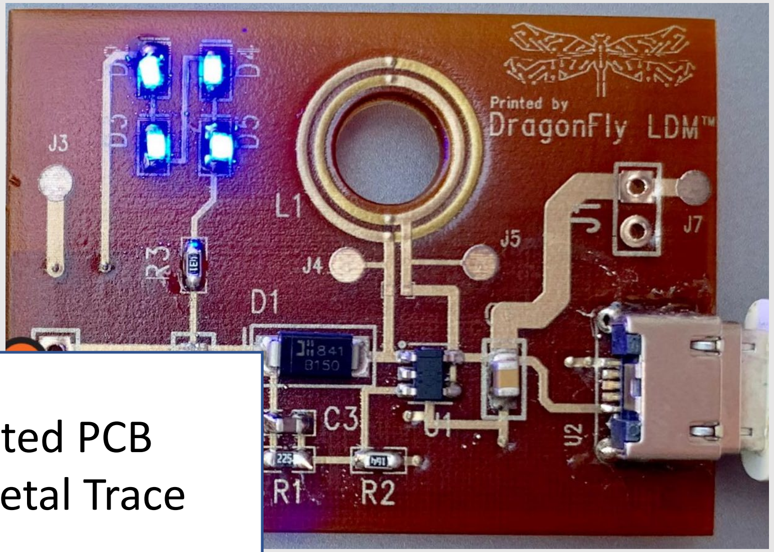
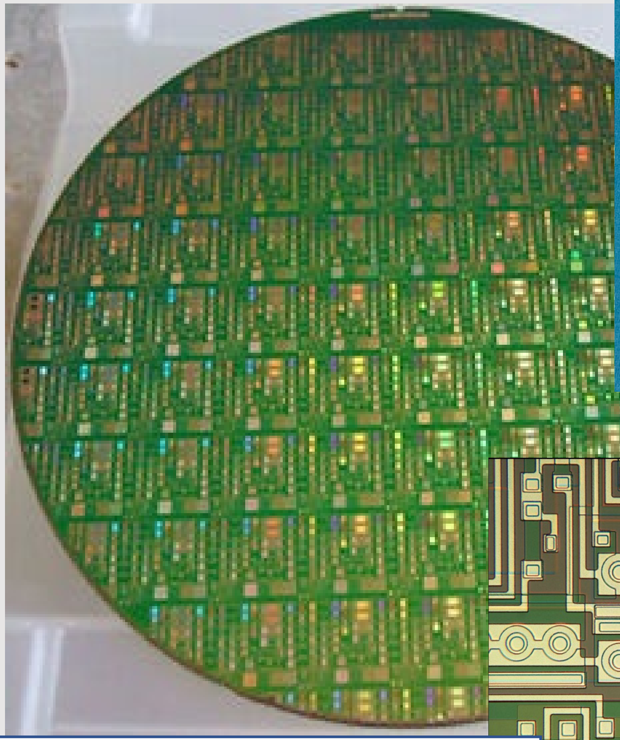
Circuit Options: 3D Printed Circuits versus Circuit formed with Traditional Fab Lithography on AM+MEMS wafers

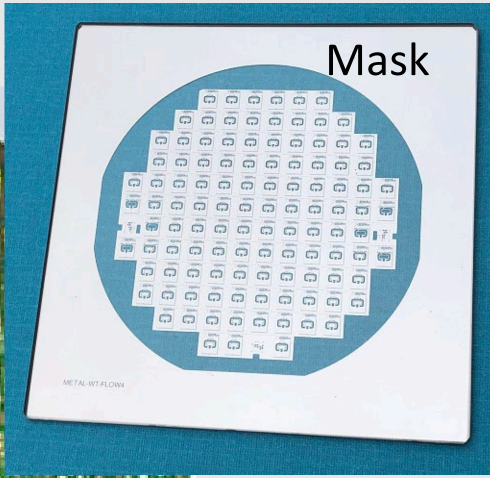


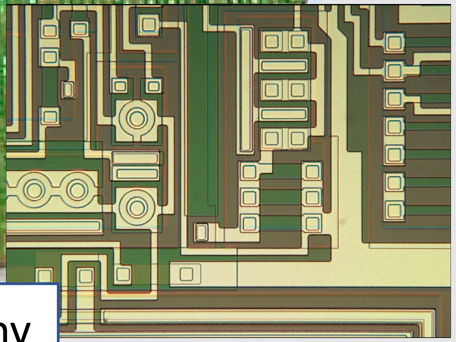
3D Printed PCB
Larger Metal Trace

NanoDimension's PCB 3D Printer
Dimensions are >0.1mm (100 microns)

or







Leverage Wafer Photolithography for micron or nanometer-linewidths on the AM+MEMS® wafer

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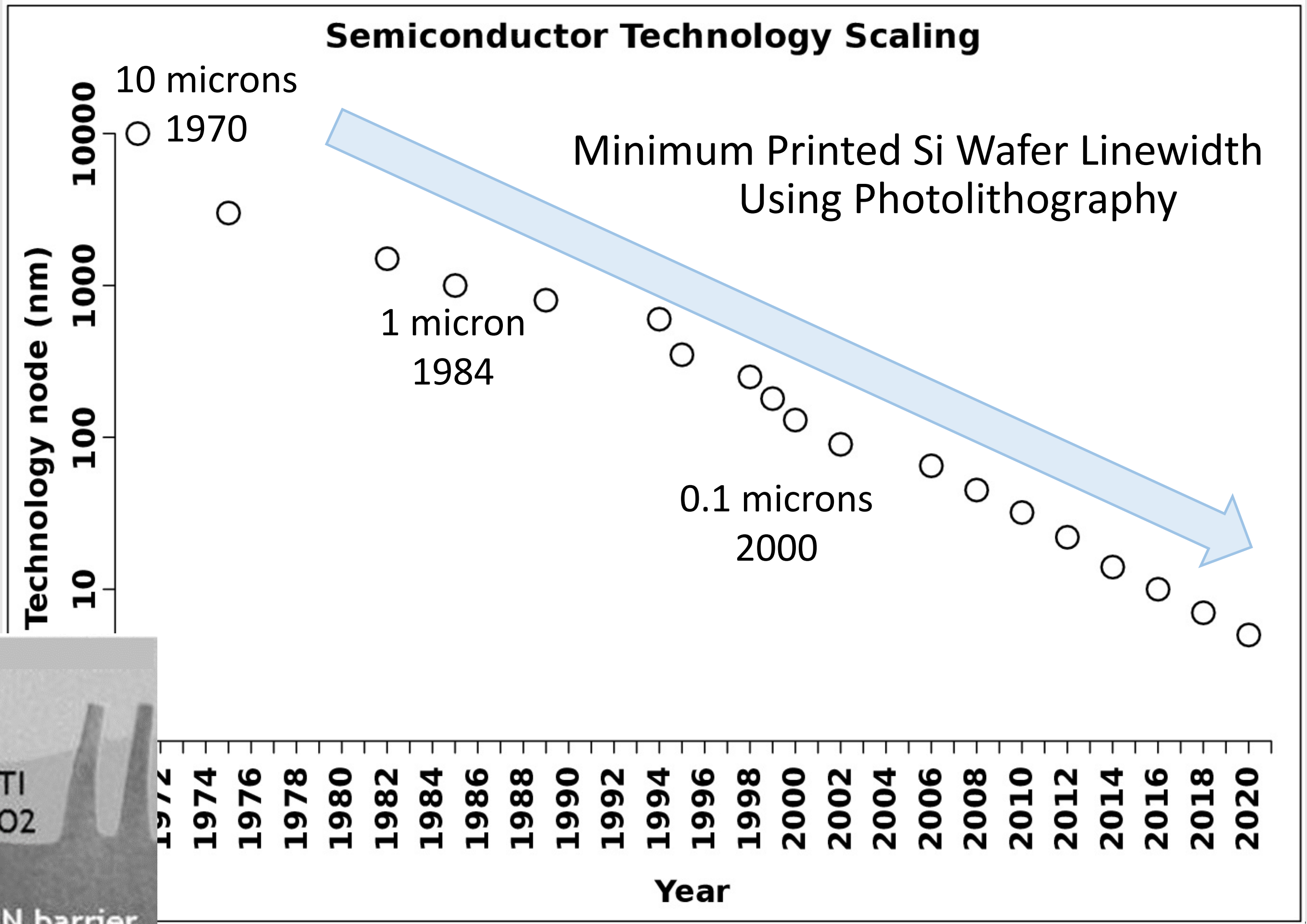
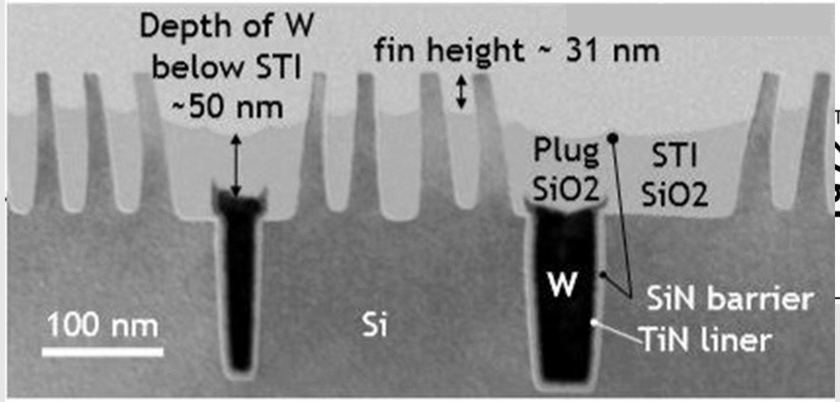
AM+MEMS Can Leverage Moore's Law on the 3D Printed Wafer Surface - *Convergence*

AM minimum 3D print linewidth varies with print method and material and has also been shrinking over the last 5 years.

Currently AM linewidths varies from > 100 microns down to < 1 micron



EUV Photolithography is already below 3 nm



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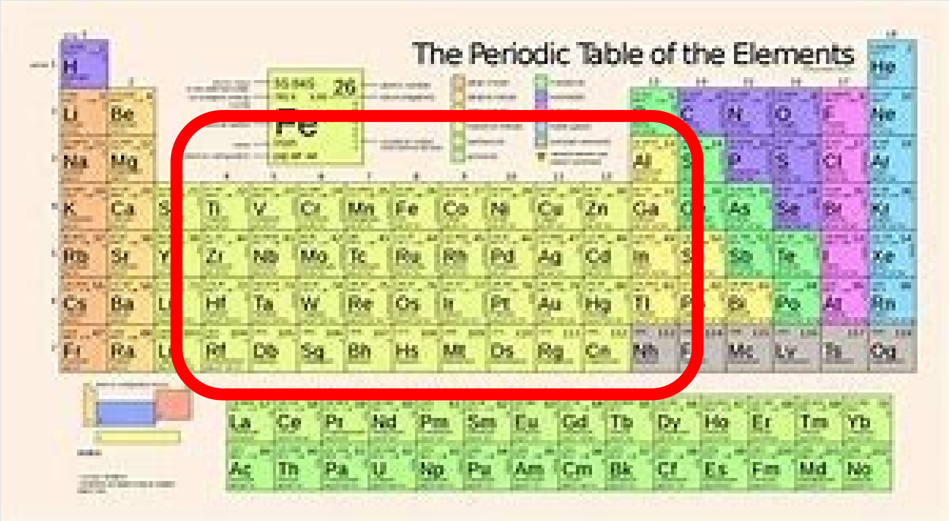
Forbidden BiCMOS Front End Fab Materials

- Transition metals (Fe, Ti, Sc, Co, Cu, Au…) can cause diode leakage, emitter-collector pipes, lower minority carrier lifetimes and gate oxide defects in BiCMOS devices.
- Frontend BiCMOS fabs will not allow these metals near high temperature fab tools- furnaces, RTP, CVD
- Dedicated MEMS fabs, without CMOS frontend processing can safely process these 3D printed materials

Transition Metals



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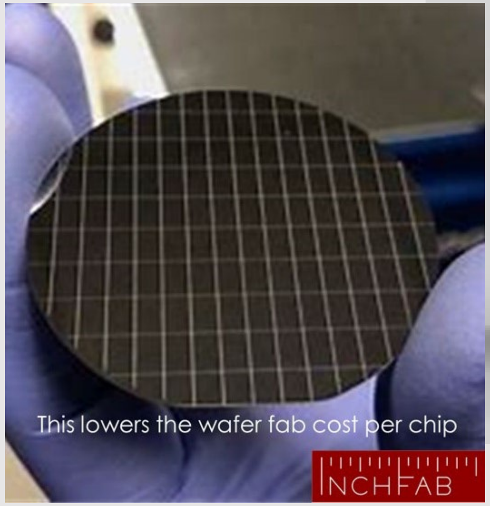
Modular Foundry for 3D Printed MEMS Wafer: InchFab

InchFab has developed a modular MEMS foundry system that lowers the CAPEX and material cost fabricating wafers.

Smaller diameter wafers are used to lower the cost of wafer processing.

This is ideal for adding circuits to 3D printed MEMS wafers

2" Silicon, GaN or AM Metal Wafer



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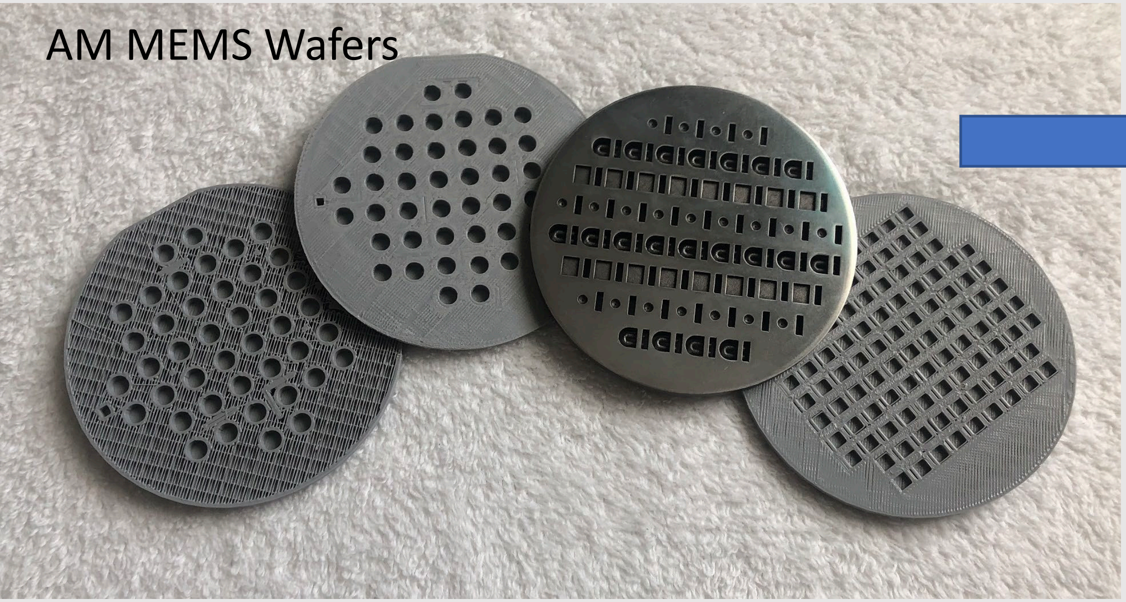
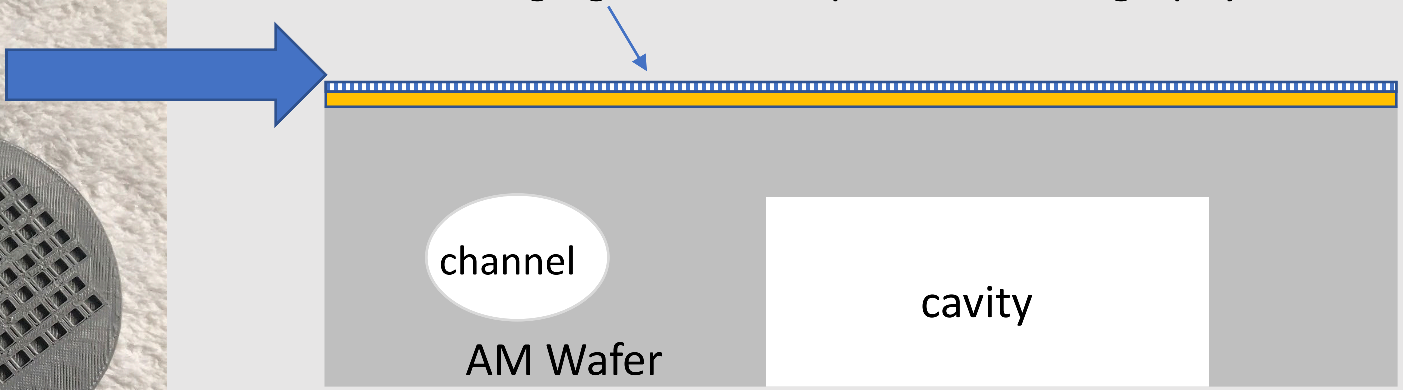
Planar Photolithography on Additive Micro Machined Wafers

Retain one planar wafer surface for
photolithography steps with spin or spray on resist

Thin Films On Steel Top Surface



Deposited & Patterned Thin Films
Leveraging 2nm to 1+ µm Photolithography



Incorporate existing and future nanometer lithography availability for 200 and 300mm silicon wafers

Pattern thin films- conductive, dielectrics, piezoelectrics, thin film transistors, resistors, etc.

Vacuum processing on polymer AM wafers is a challenge due to outgassing

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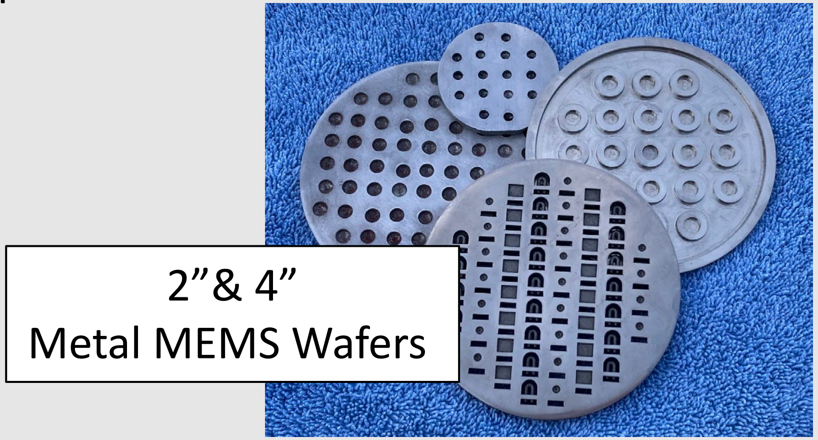
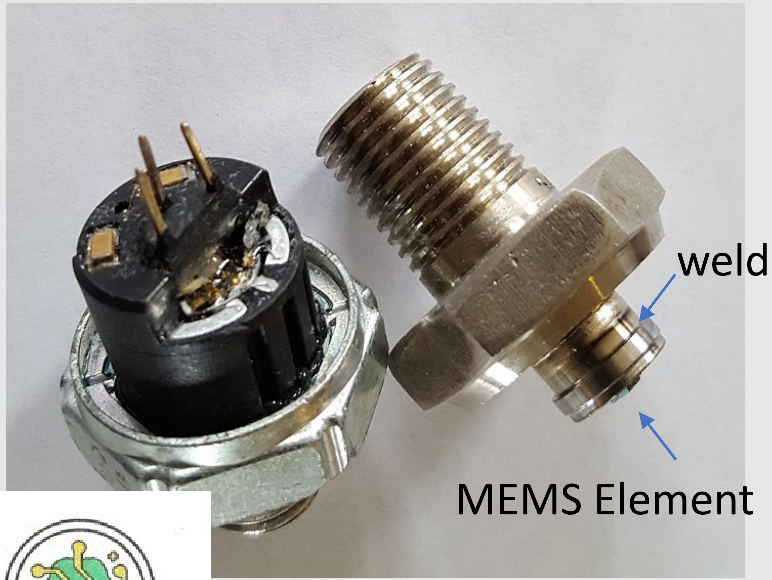
Pressure Sensors & Strain Gauges on 3D Printed Metal Wafers

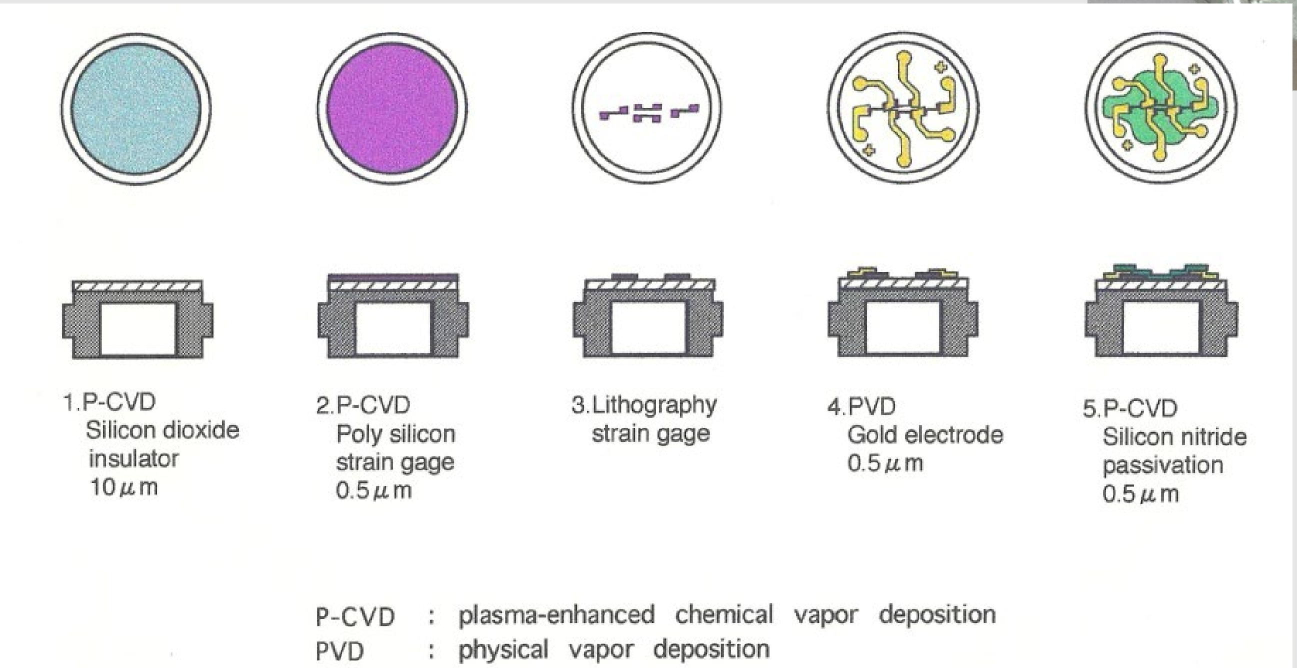
CVD Wheatstone Bridge on Metal





Pressure Sensor Package Steel Chip Welded to Package for industrial & automotive applications

MEMS on Metal Wafer Process



Biocompatible titanium can be used for medical biosensor applications

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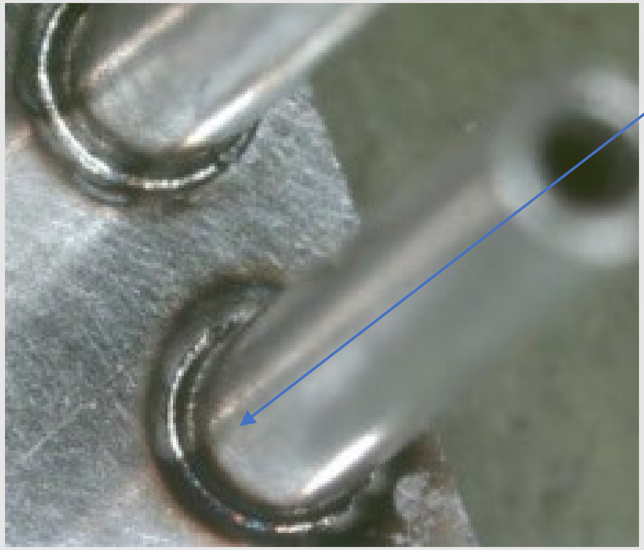
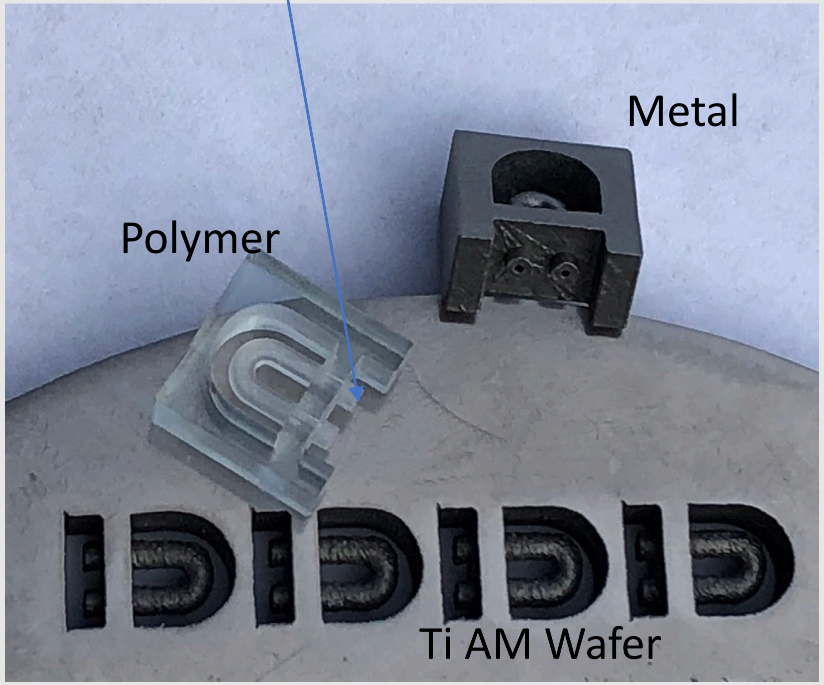
Post Dicing Packaging Microfluidic Interfaces 3D Printed or Laser Welded Tubing

3D Printing enables the combining of the MEMS sensor element with the fluidic packaging interface

After wafer dicing the microfluidic chip can have bottom or side metal tubing connections.





- Dual stainless tubing laser welded to the bottom of the chip
- 3D Printed female tubing inset ports

3D printed metal and plastic side tubing inlets and outlets on each chip

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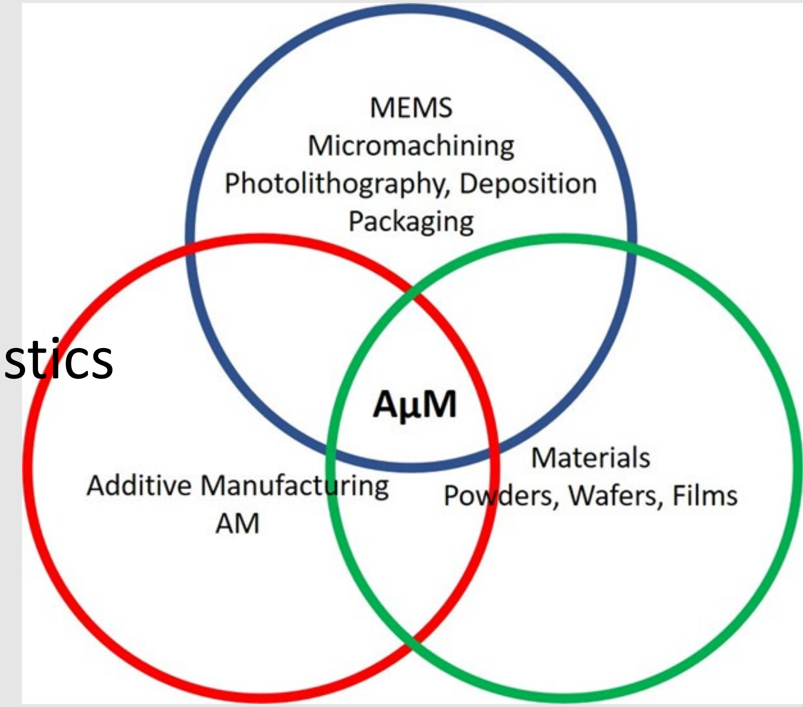
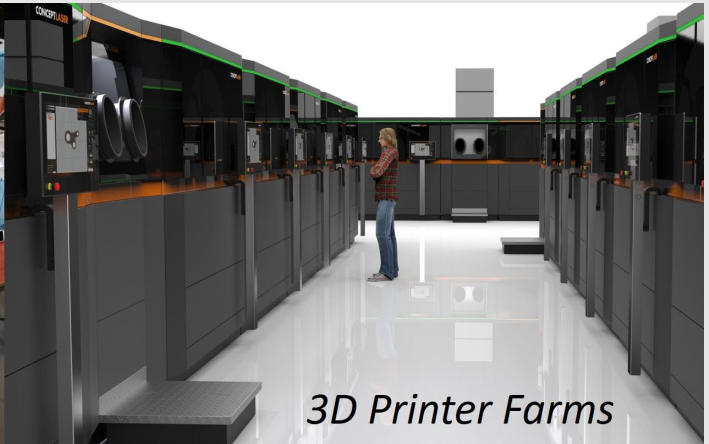
Convergence-Will MEMS Fabs have 3D Printers?

Wafer fabs have photo, thermal, plasma etch bays

Will they have an AM bay in the future?

- Can use them for maintenance- fast replacement parts for fab equipment- virtual warehouse
- Quick MEMS prototype packages
- Print MEMS wafers from metals, alloys like stainless steel and plastics





3D Printer Farms

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Conclusions

3D Printed MEMS wafers can be a new platform for fabricating sensors and can broaden the material and structural micromachining capability over conventional silicon and Pyrex wafer processing, while reducing processing & development time

These 3D printed MEMS substrate materials include materials like stainless steel, super alloys and titanium for industrial, aerospace, automotive and medical implant applications

The convergence of conventional sub-micron photolithography and AM+MEMS wafers offers significant advantages over traditional silicon MEMS devices by adding micron and even submicron circuit and feature dimensions for high-volume, low-cost manufacturing, ideal for harsh environments.

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