SAND2015-6651C

Exceptional service in the national interest

Sandia National Laboratories

Electrodeposition and Electroless Deposition for Additive Manufacturing

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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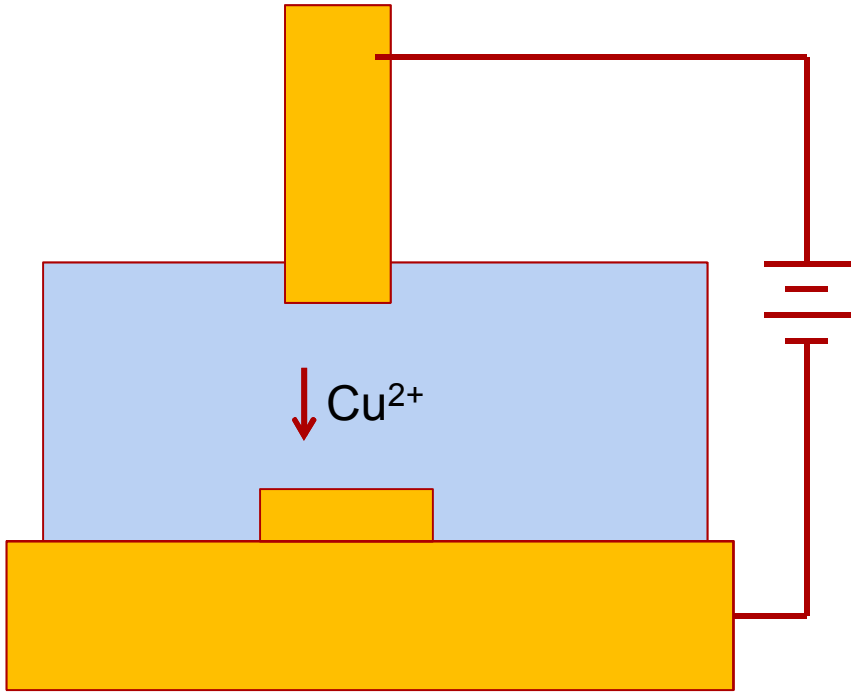
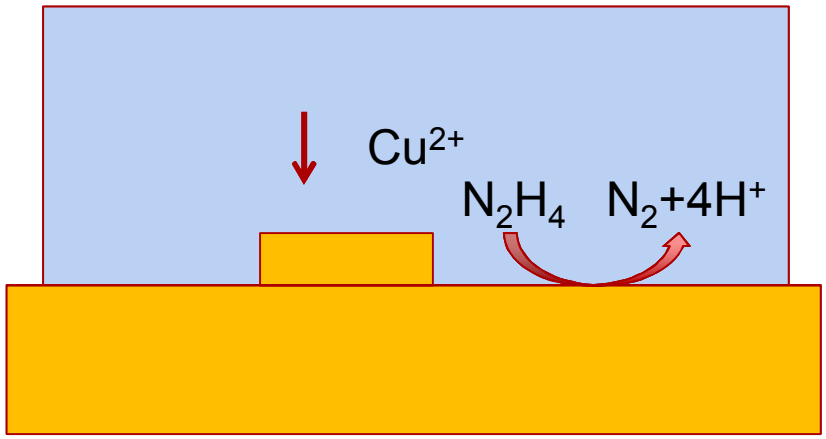
Electrodeposition

- Mixed electronic-ionic circuit
- Metal atoms become ions at sacrificial electrode
- Ions become metal atoms on part
- Electrons complete the circuit
- Ion concentration is low
- Ion transport is slow
- Challenge: spatial control



Electroless deposition

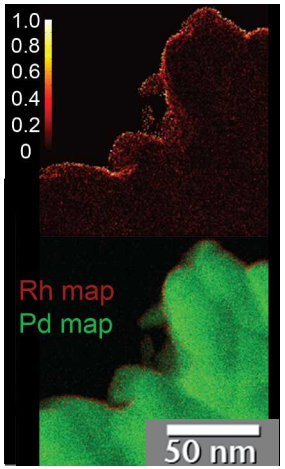
- Chemical reducing agent gives electrons to part
- Metal ions become atoms on part
- Charge balances in each phase
- Ion concentration is low
- Ion transport is slow
- Challenge: surface selectivity
- Challenge: spatial control
- Challenge: purity



Why?

- Spatial resolution: transcend scaling limits of laser sintering
- Dynamic range (part size : smallest feature size)
- Room temperature process
- No powder removal
- New ways to control microstructure
- New ways to control composition

nm scale



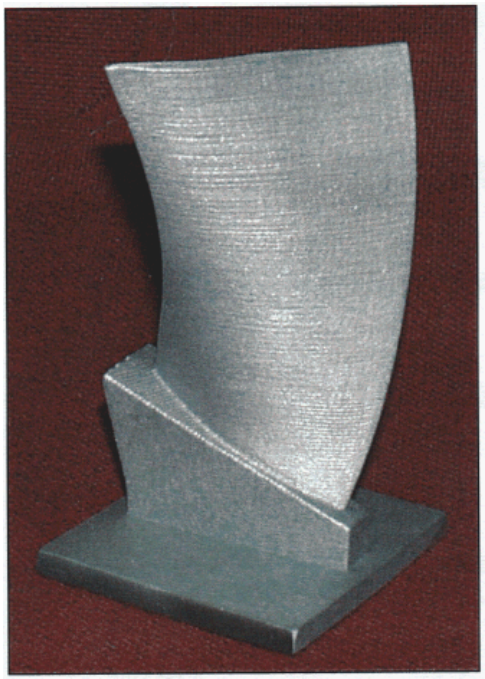
Cappillino et al., Langmuir 30 4820 (2014)

70m electrodeposited, post-processed aluminum

Wikipedia PD

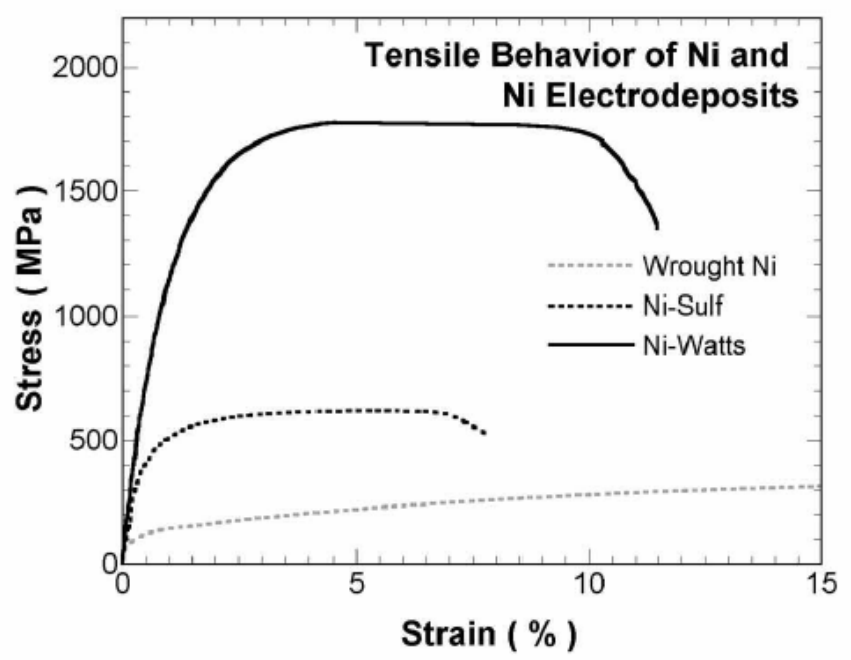
cm scale
Laser sintered part

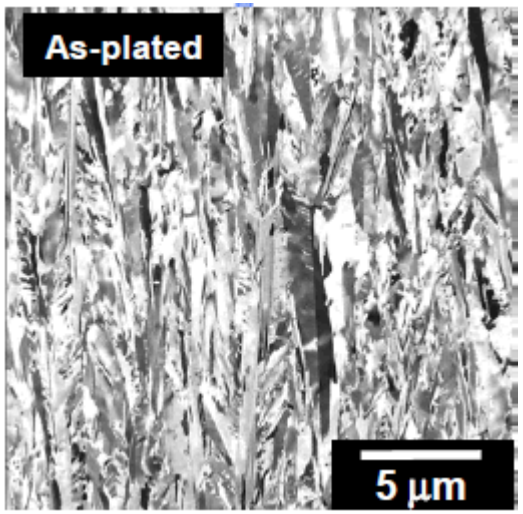
T. Ensz, SAND 2002-0574P



Materials

- Electrodeposition: Ni, Cu, Pd, Au, Fe, Co, Mn, Cr
  - Alloys; stainless steel
- Electroless: P or B impurities
- Multilayers
- Unique grain sizes, orientations





Ni + trace Mn

Ni
600 °C anneal

G. Kubiak / S. Goods / N. Yang, SAND2004-5590C

Strategies

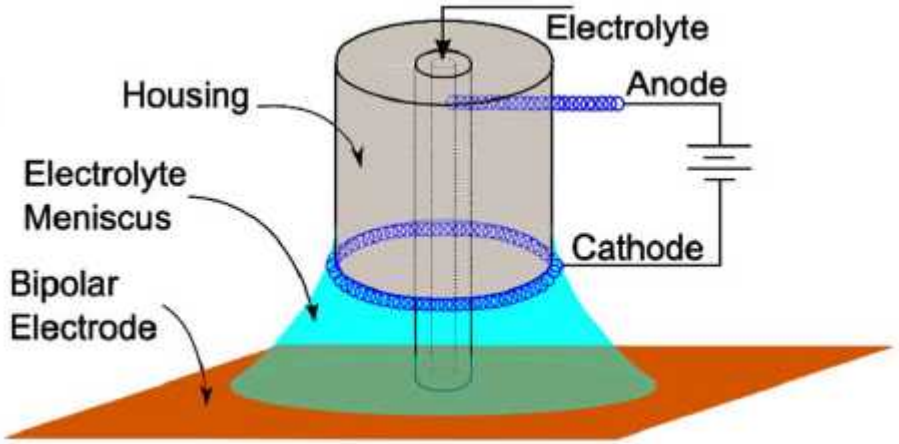
- Scaling: large areas
- Plating rate: convection; jet electrodeposition
- Spatial selectivity: photoresist, laser assistance, convection
- 3D: layering; electroforming; stacking, folding post-process

Wikipedia PD

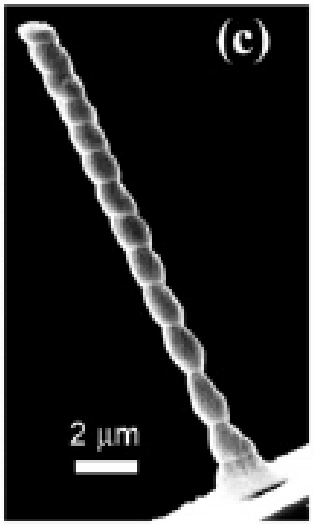
Other practical large-area, slow-growth technologies

Jet electrodeposition

- High convection, low conductivity: fast, local plating
- Large-area scalability is lost



Braun and Schwartz, J. Echem. Soc. 2015, 162, D180
Creative Commons



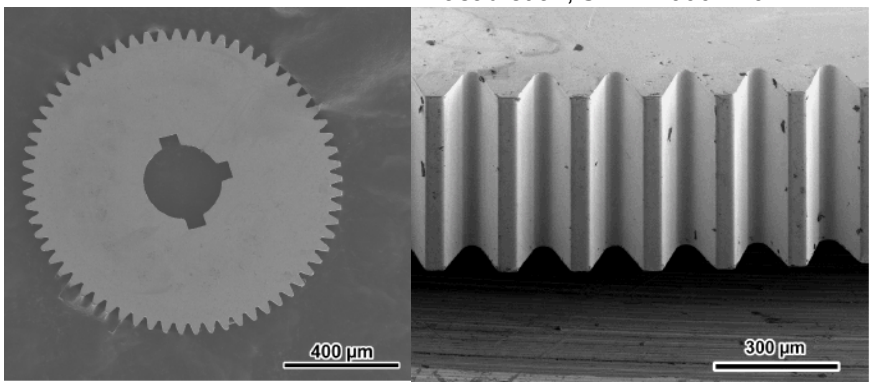
Suryavanshi and Yu
Nanotech. 2007, 18, 105305
Fig. 2 (IOP Journals)

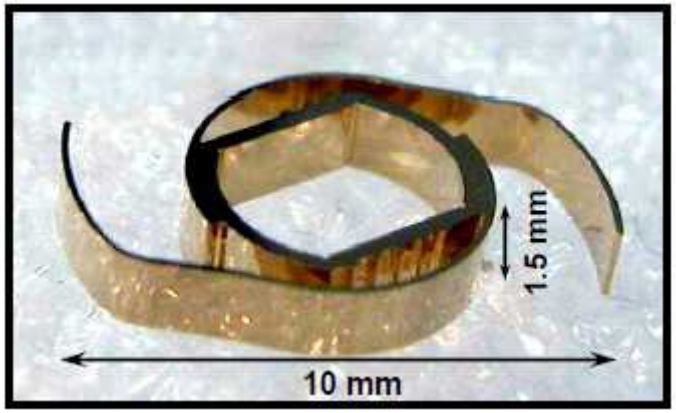
Also Dover et al., SFF Symp. 1996; Sundaram et al., J. Manuf. Sci. Eng. 2015, 137, 021006-1

Deposition through photoresist

- LIGA
- UV LIGA

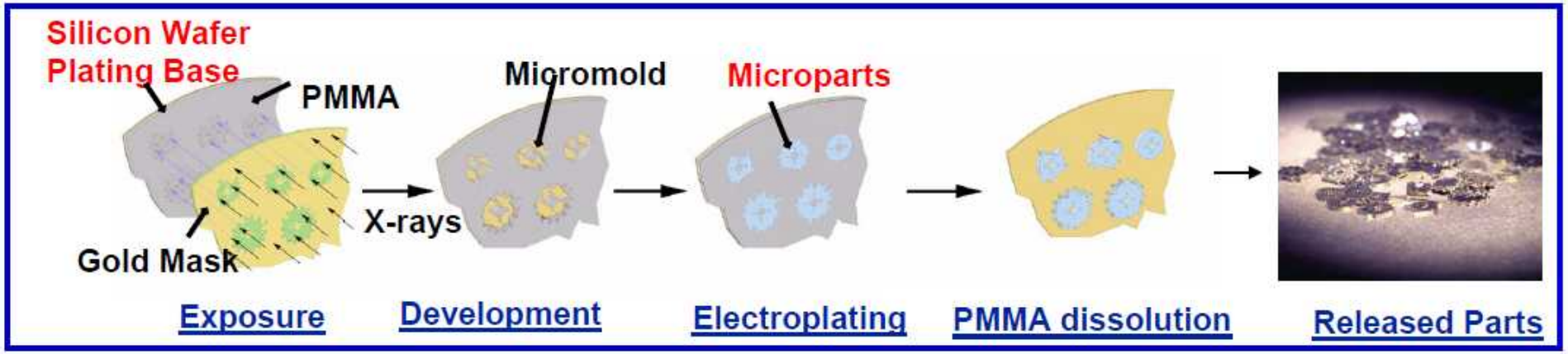
Prasad et al., SAND2000-1702



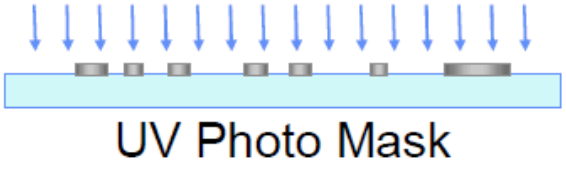


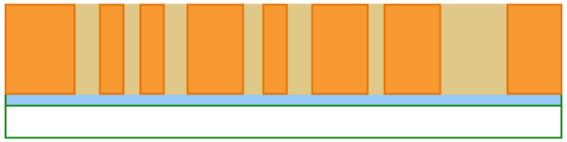
G. Kubiak, SAND2004-5590C

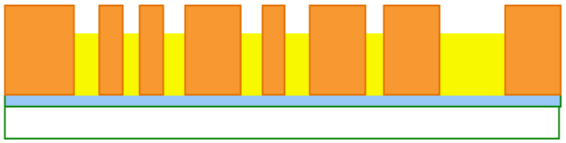
A. Morales, SAND2005-2039C

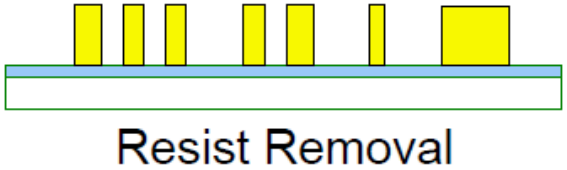


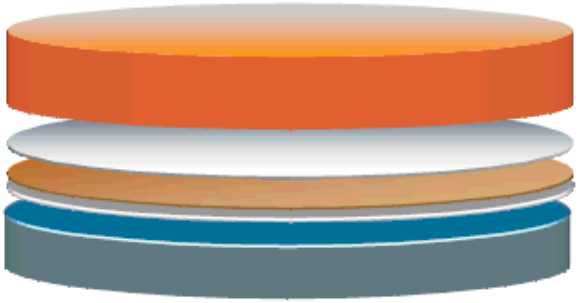
Deposition through photoresist









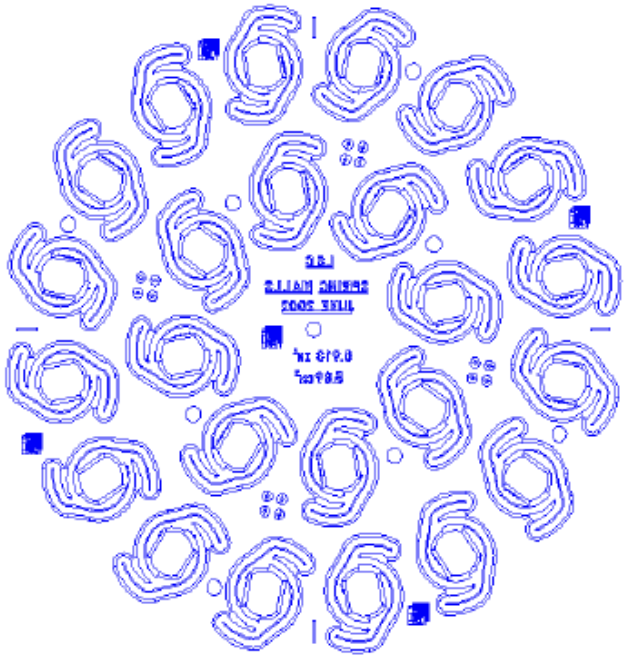


SU-8 Resist (DKS; 140 μm)

Adhesive Layer (0.75 μm)

Ti/Cu/[Ti]; (100/1000/[100] A)

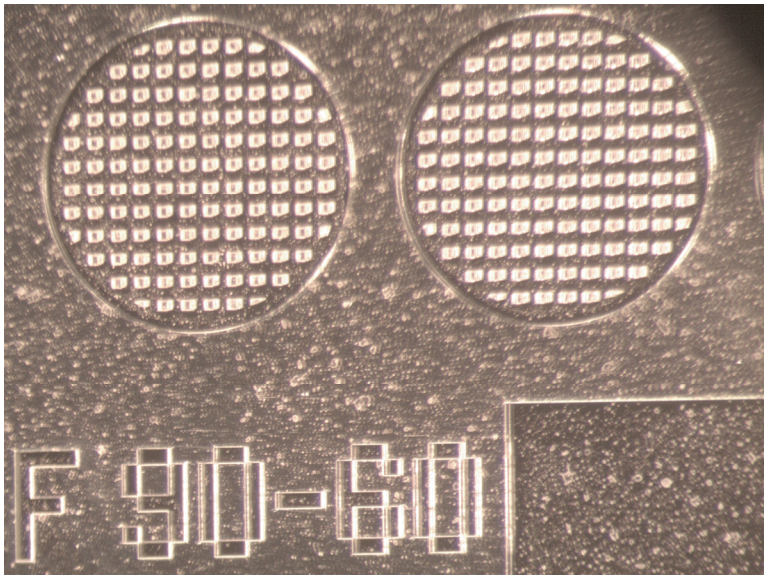
Silicon (100 μm; 75 mm)



G. Kubiak, SAND2004-5590C

Scalability

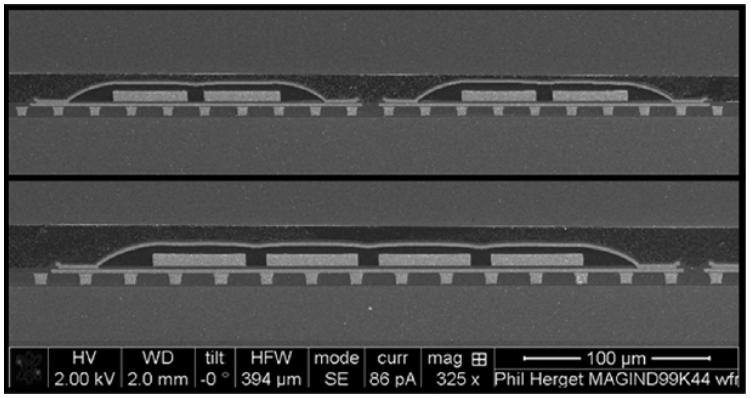
- Low-cost, large-area, stackable electroplated films
- Thick dry film UV photoresist (SUEX, DJDevCorp)
  - Printed circuit board technology applied to MEMS manufacturing
- Flexible electronics substrates (DuPont Pyralux Cu on polyimide)
- Plate, then release through Cu etch

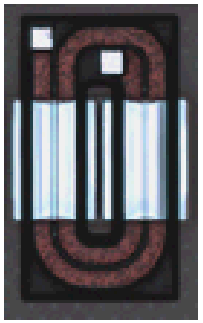


C. Arrington, P. Finnegan, M. Bartsch, SNL, 2015

Multilayers

- IBM
  - Interconnects
  - HD write heads





Cu
Ni-Fe alloy

Wang et al., J. Appl. Phys. 2012, 111, 07E732
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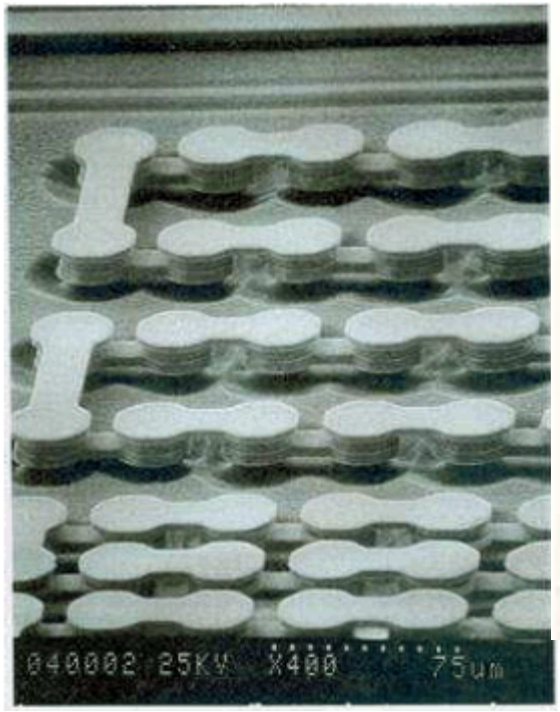
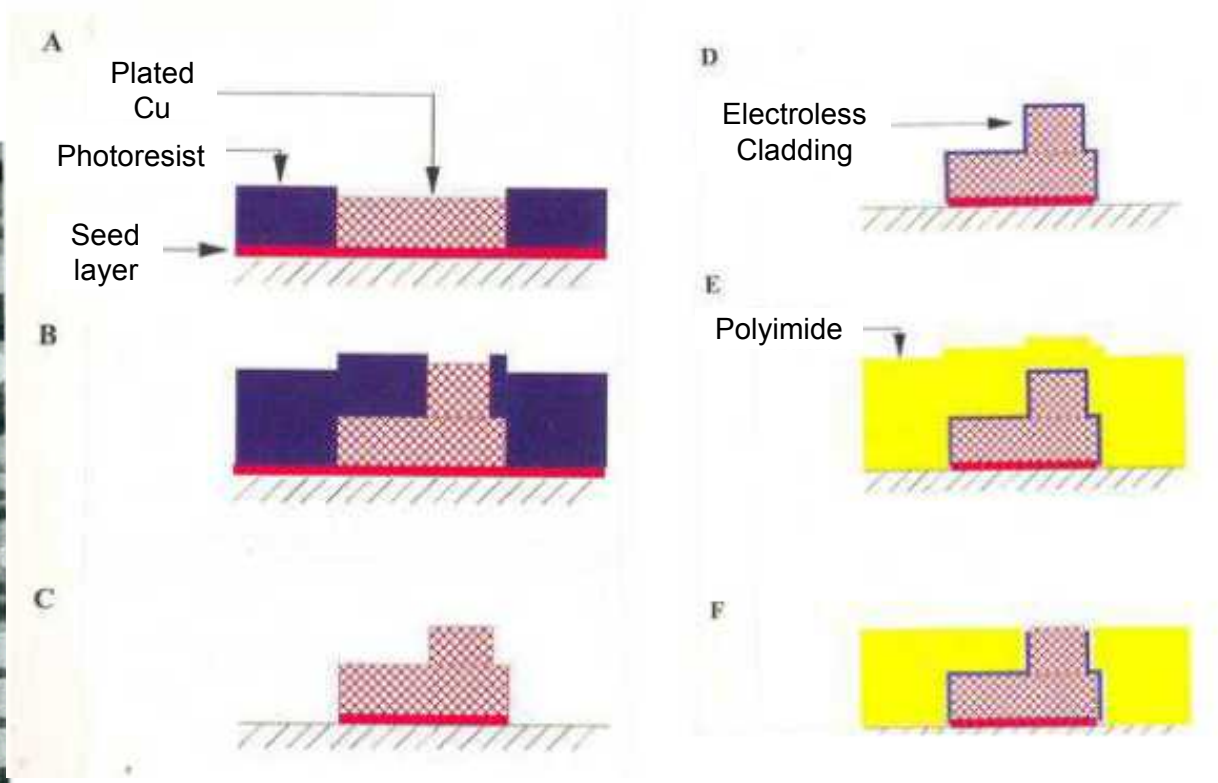
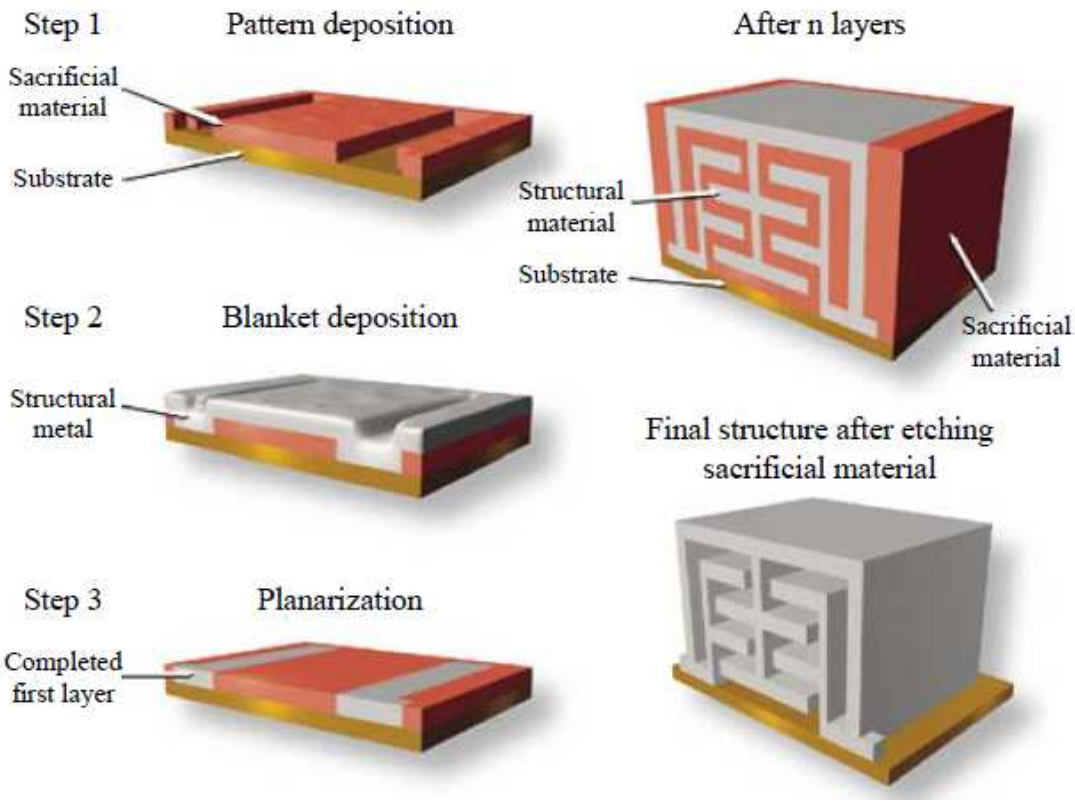




Krongelb and Romankiw, ECS Trans 2015, 64, 1.
Reproduced by permission of the Electrochemical Society.

Multilayers

- Microfabrica
  - Pd, Ni-Co alloy
  - Medical devices



Cohen et al., Rapid Prototyping J., 2010, 16, 209
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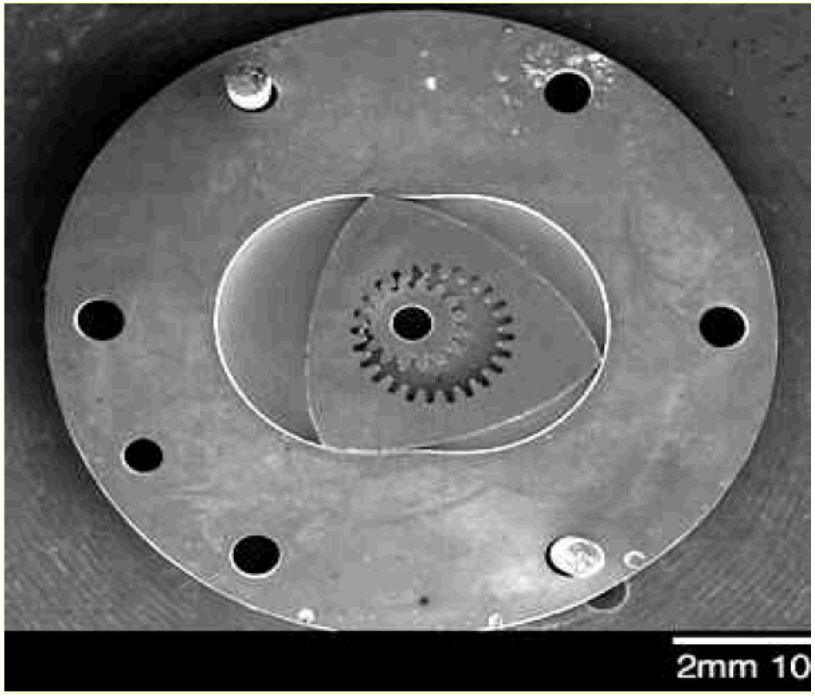
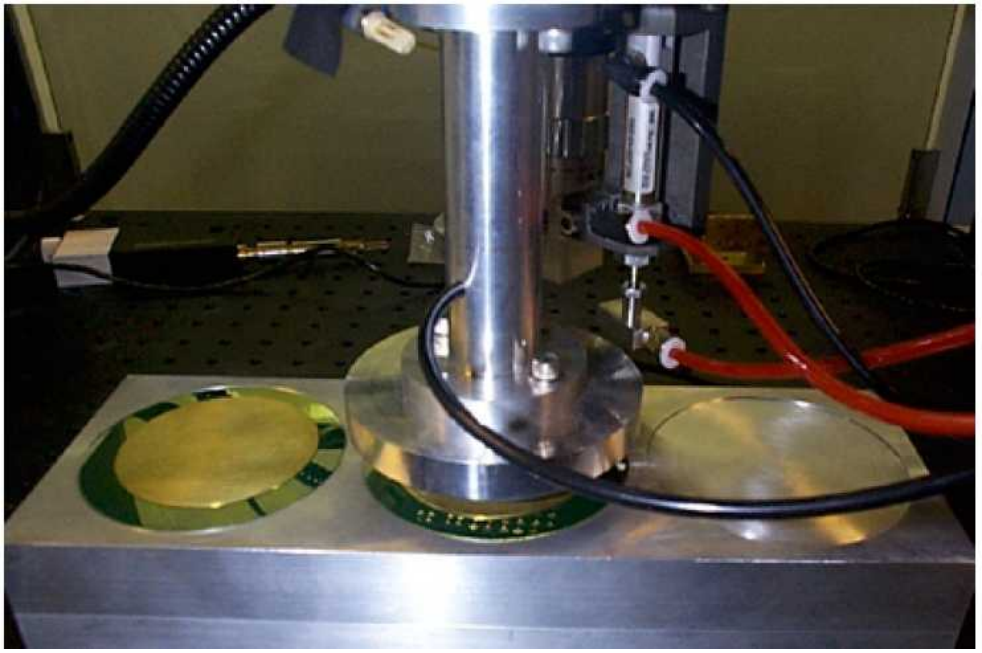
Assembly

- Robotic tweezers
- Parallel stacking of parts
- Diffusion bonding

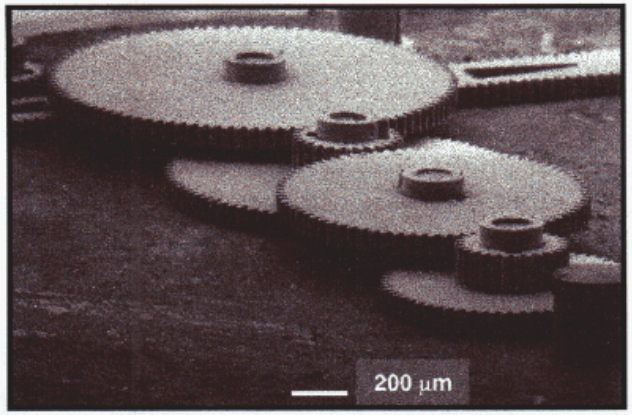
G. Kubiak, SAND2004-5590C





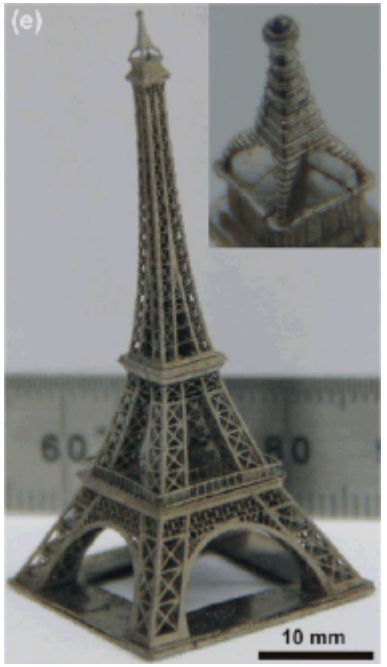
Feddema et al., SAND99-0746

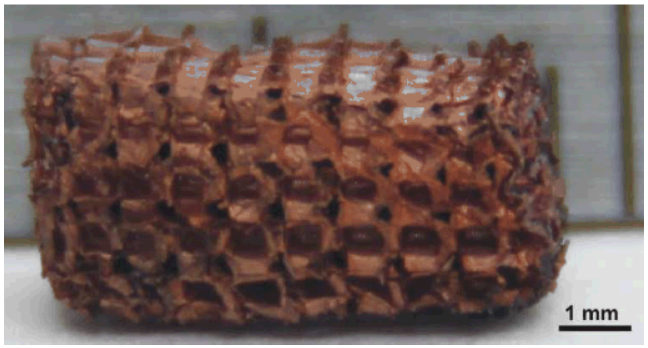
Prasad and Christenson, SAND2002-0536P



Electroforming

- 3D print plastic parts
- Chemical activation of plastic
  - Harsh chemicals such as chromic acid
  - Polymer functionalization
- Electroless deposition
- Further electrodeposition





Wang et al.,
ACS Appl. Mater. Interf. 2014, 6, 2583.
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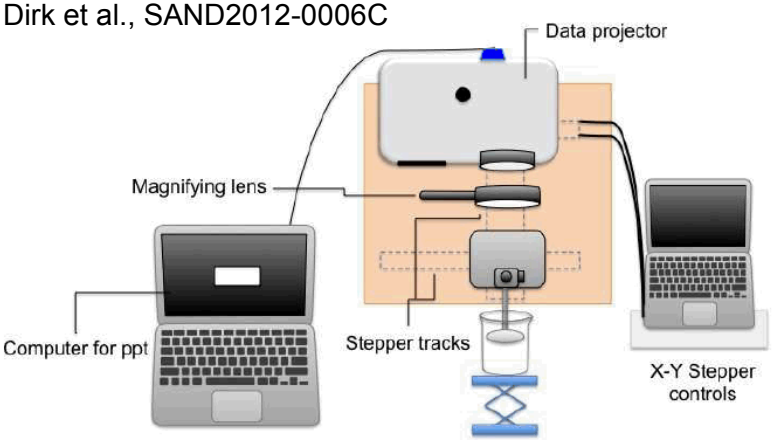
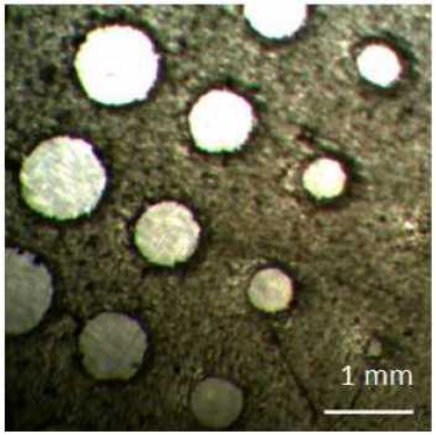
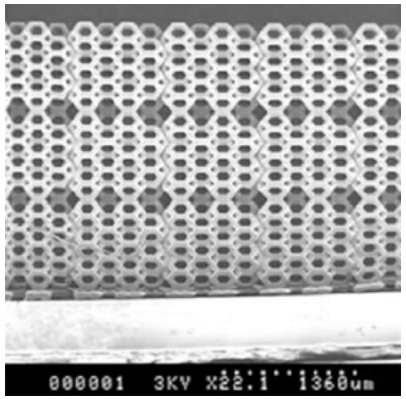
Electroforming

- Hughes, LLNL: metallization of sub-millimeter structures
- SNL: conducting polymers

Dirk et al., SAND2012-0006C







Zheng et al., Rev. Sci. Inst. 2012, 83, 125001
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From Schaedler et al., Science 2011, 334, 962.
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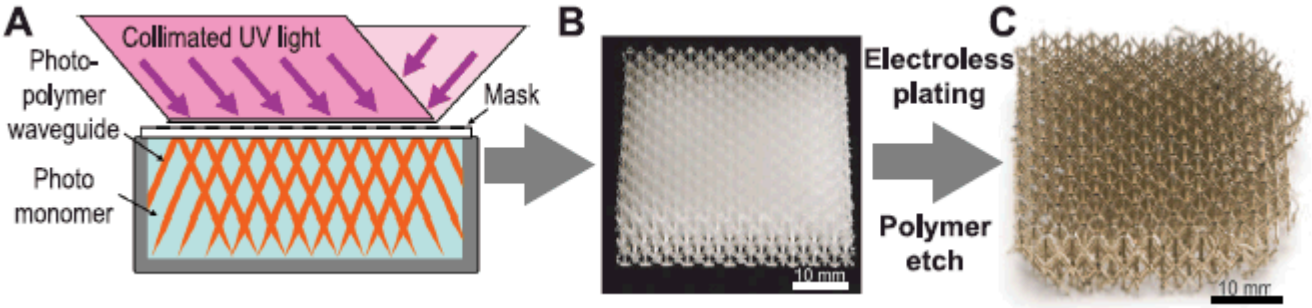
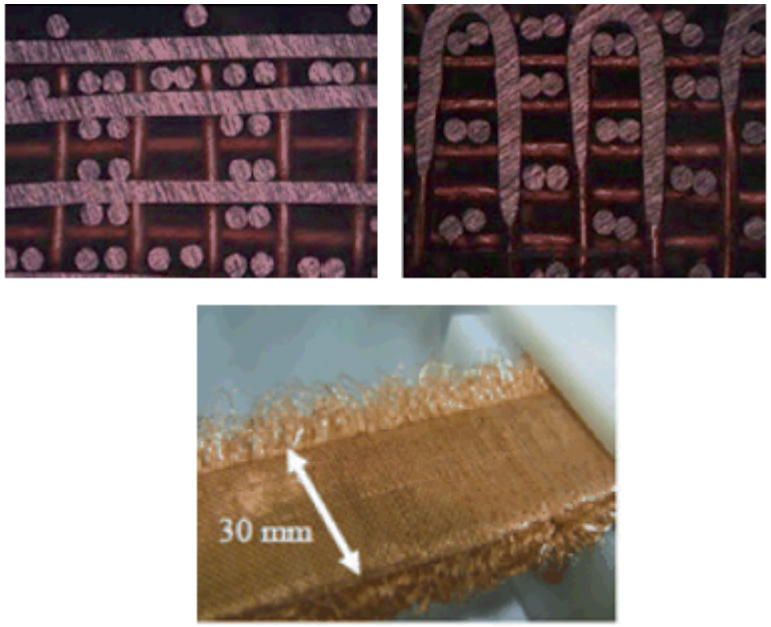
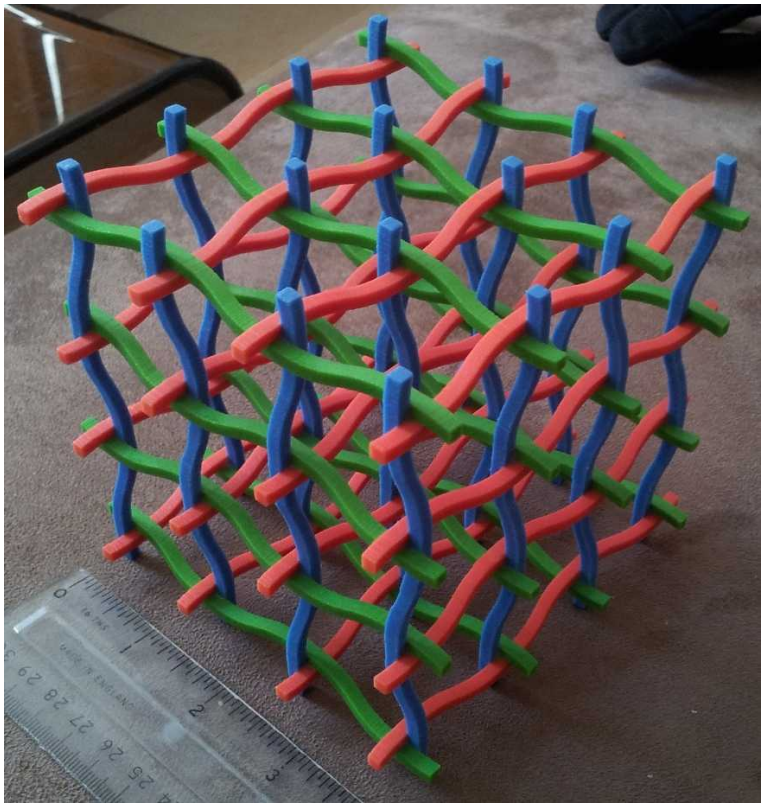


3D weaving

- 50 µm features, 100 mL-scale parts



Sharp et al., Procedia Mater. Sci. 2014, 4, 15
SAERTEX USA, Creative Commons



Derck van Schuylenburch, isoweave.com
US patent 5263516

Synergy with metal powder sintering

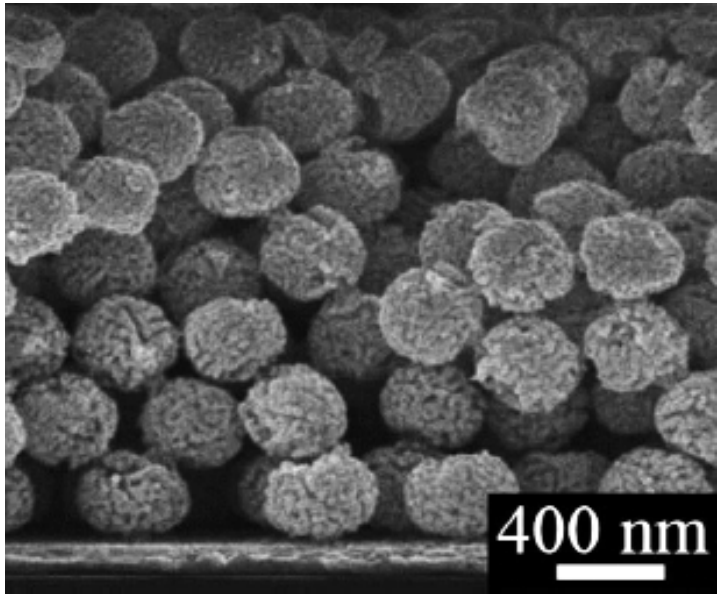
Sandia National Laboratories

- Electroforming
- Electropolishing
- Precise powder production

Electrochemical powder fabrication

- Uniform, tunable particle size
- High surface energy for low-temperature sintering

Au powders by electrodeposition
Chae et al.,
ACS Appl. Mater. Interf. 4 3973 (2012)



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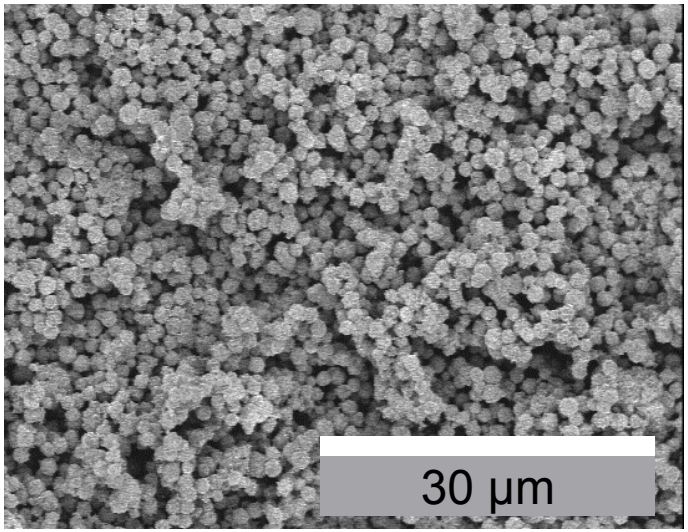
Electroless growth of
Cu and PdCu powders



Jones et al., Powder Tech. 267 95 (2014)

How electrochemistry fits in

Sandia National Laboratories

- New length scale and material options
- Dimensions: x,y: good; z: bad
- Z strategies:
  - multilayer resists
  - inspection, stacking, bonding
  - 3D substrates
- Post processing
- Precise powder production

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