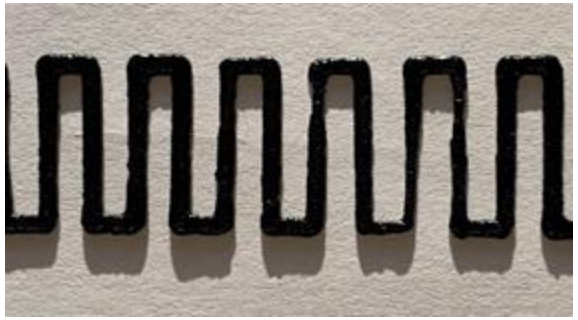
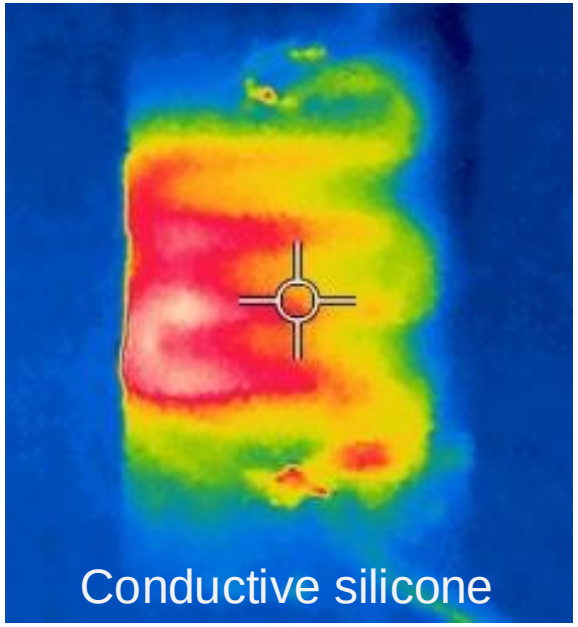
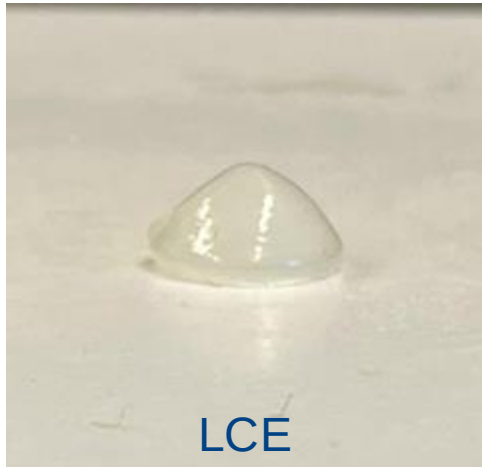
3D printing: new design space

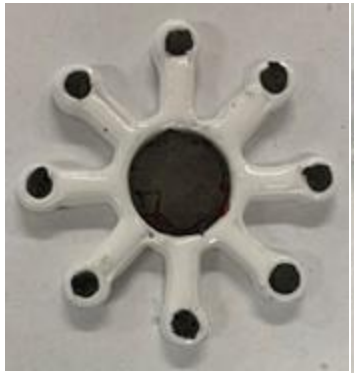


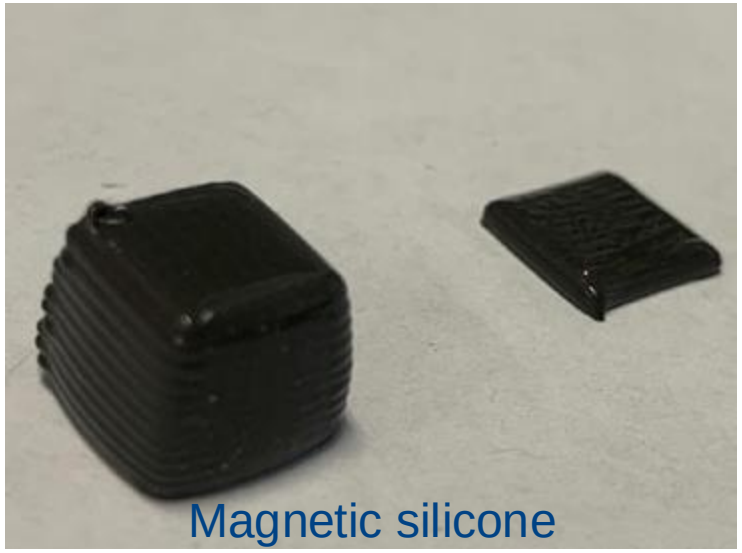


Conductive silicone rubber



LCE





Magnetic silicone rubber

Materials: Fiber reinforced silicone rubbers, Conductive silicone rubbers, Magnetic silicone rubbers, LCEs, epoxy, hydrogels, liquid metal…

Techniques: bi-material printing, rotating nozzle…

3D printing processes

"1D" processes:

Typically involves movement of a single point in a direction

1. Extrusion based (moving of a nozzle)
   - Fused Deposition modeling (FDM)
   - Direct Ink Writing (DIW)
2. Inkjet printing IJP (moving of an inkhead)
3. Vat photopolymerization (moving of a light source)
   - Stereolithography (SLA)
   - Two-photon lithography (TPP)
4. Powder bed fusion (moving of a heat source)
   - Selective laser melting (SLM)
   - Electron beam melting (EBM)
   - Multi-jet fusion (MJP)

- Process largely driven by material:
  - FDM: glass transition of thermo-plastic
  - DIW: shear thinning behavior of complex fluids
  - SLA/TPP: photo reactivity of photo-polymers
  - PBF: melting and thermal fusion of powers (metals/polymers)

"2D" processes:

A single process can generate 2D structures

1. Digital light processing (DLP)
2. Multimaterial multinozzle (MM3D) 3D printing

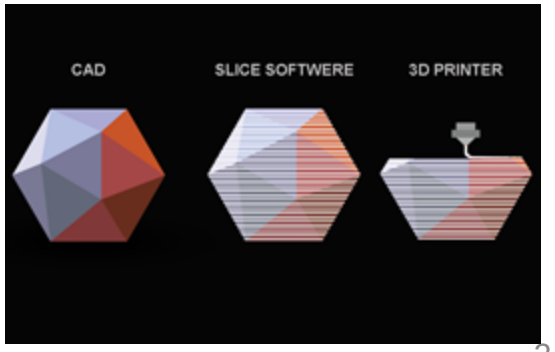
"3D" processes:

A single process can generate 2D structures

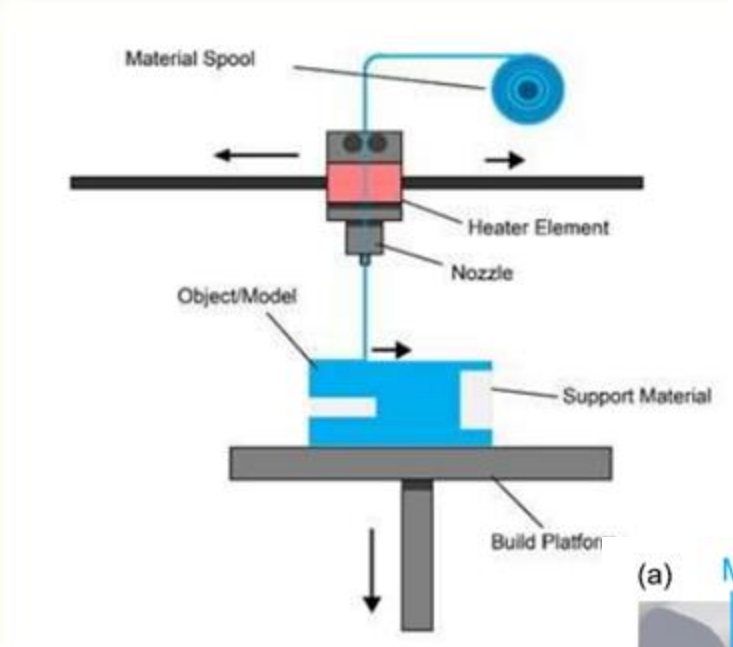
1. Computed axial lithography (CAL)

For 1D processes:

Model → Slicer → Gcode → Machine



Fused deposition modelling (FDM)



Process parameters:

- Nozzle temperature
- Bed temperature
- Printing speed (v)
- Filament diameter (d)
- Layer height (h)
- Extrusion width (w)
- Extrusion multiplier (EM)

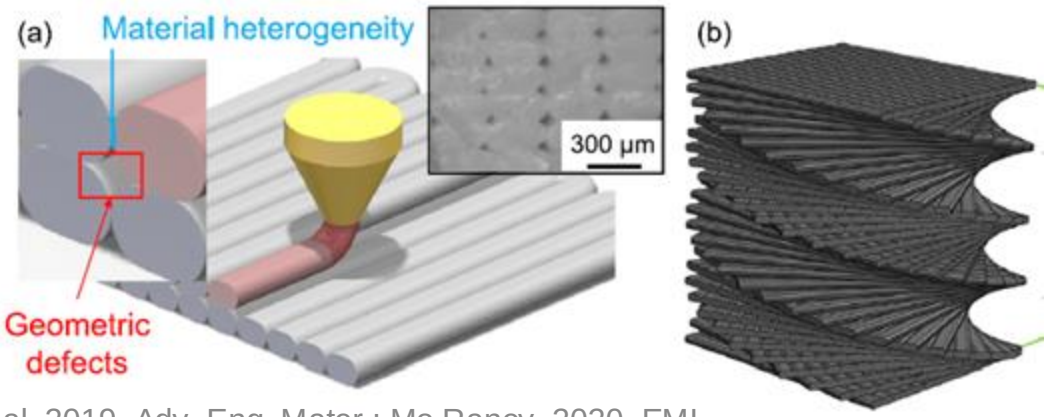
```
G1 X19.753 Y1.650 E0.0253
G1 X0.248 Y1.650 E1.0947
G1 X0.248 Y2.100 E0.0253
G1 X19.753 Y2.100 E1.0947
G1 X19.753 Y2.550 E0.0253
G1 X0.248 Y2.550 E1.0947
G1 X0.248 Y3.000 E0.0253
G1 X19.753 Y3.000 E1.0947
G1 X19.753 Y3.450 E0.0253
G1 X0.248 Y3.450 E1.0947
G1 X0.248 Y3.900 E0.0253
```

G-code

$$E = \frac{h * w * l * EM}{\frac{\pi}{4} d^2}$$

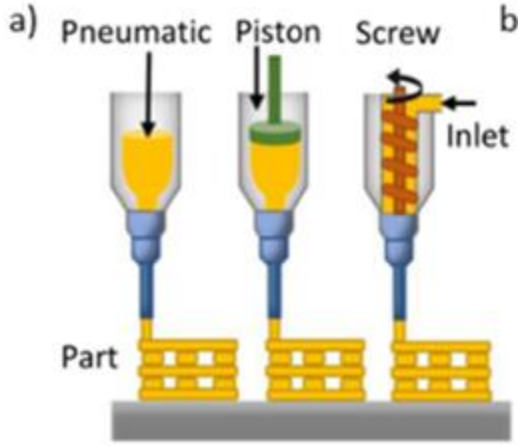
Commonly used materials:

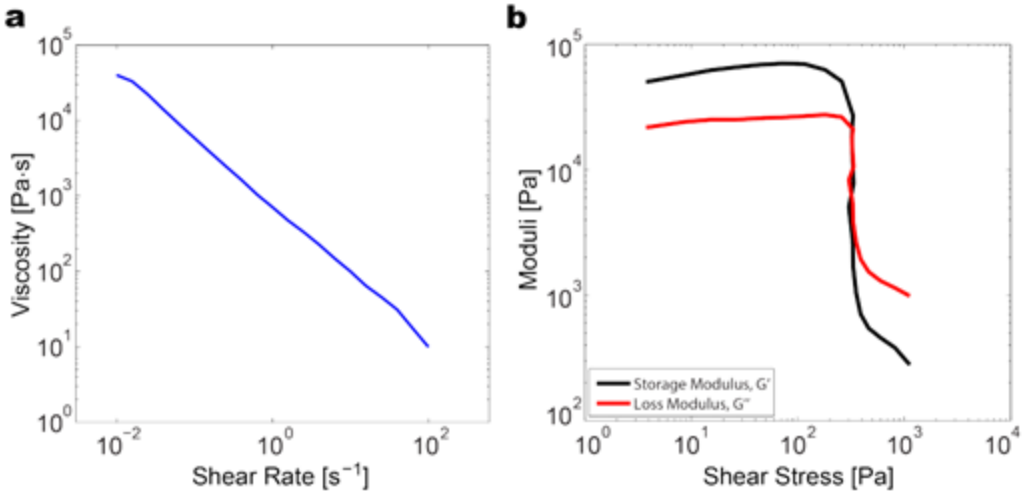
- Poly-lactic acid (PLA)
- Acrylonitrile butadiene styrene (ABS)
- Polyethylene (PET)
- Nylon



Surjadi et al. 2019, Adv. Eng. Mater.; Mo Raney, 2020, EML

Direct Ink writing (DIW)





Process parameters:

- Extrusion pressure
- Printing speed
- Nozzle diameter
- Layer height

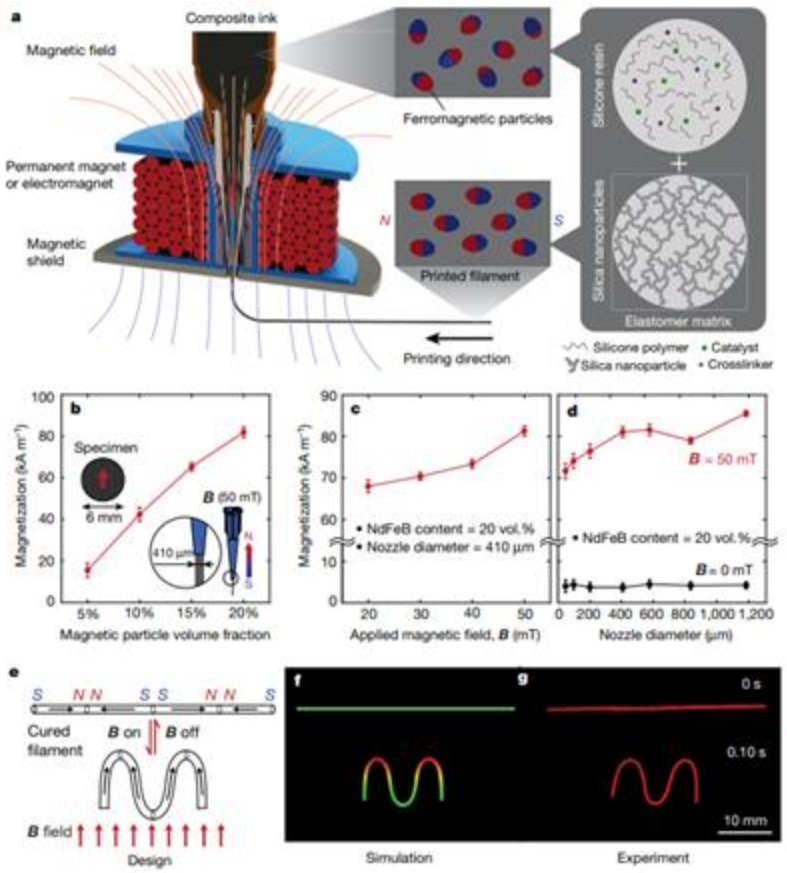
Active material 3D printing:

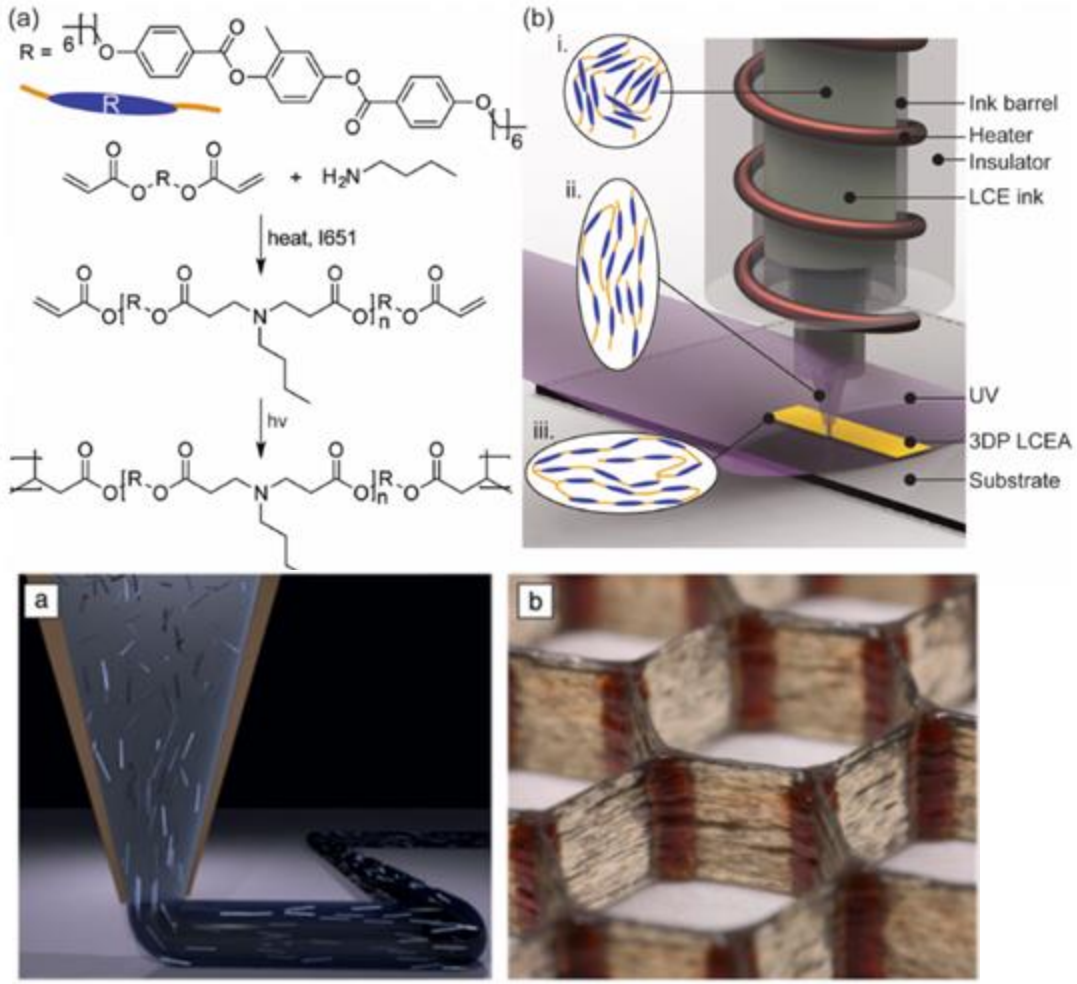
- Liquid crystal elastomer
- Composites
- Magnetic soft composites

Shear-thinning behavior is key for direct ink writing

Surjadi et al. 2019, Adv. Eng. Mater.; Shan et al. 2015, Adv. Mater.

Direct Ink writing (DIW)





Yuk et. al. 2018, Nature; Kotikian et. al. 2018, Adv. Mater.; Raney, Lewis, 2015, MRS Comm.

Digital light processing (DLP)

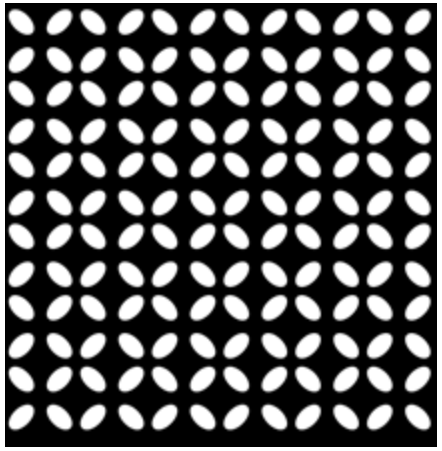
A job file includes following items:

1. Build list (exposure time per layer)
2. Data processing info (build process)
3. Job info (printer setup)
4. Exposure images (1920x1080 pixels)

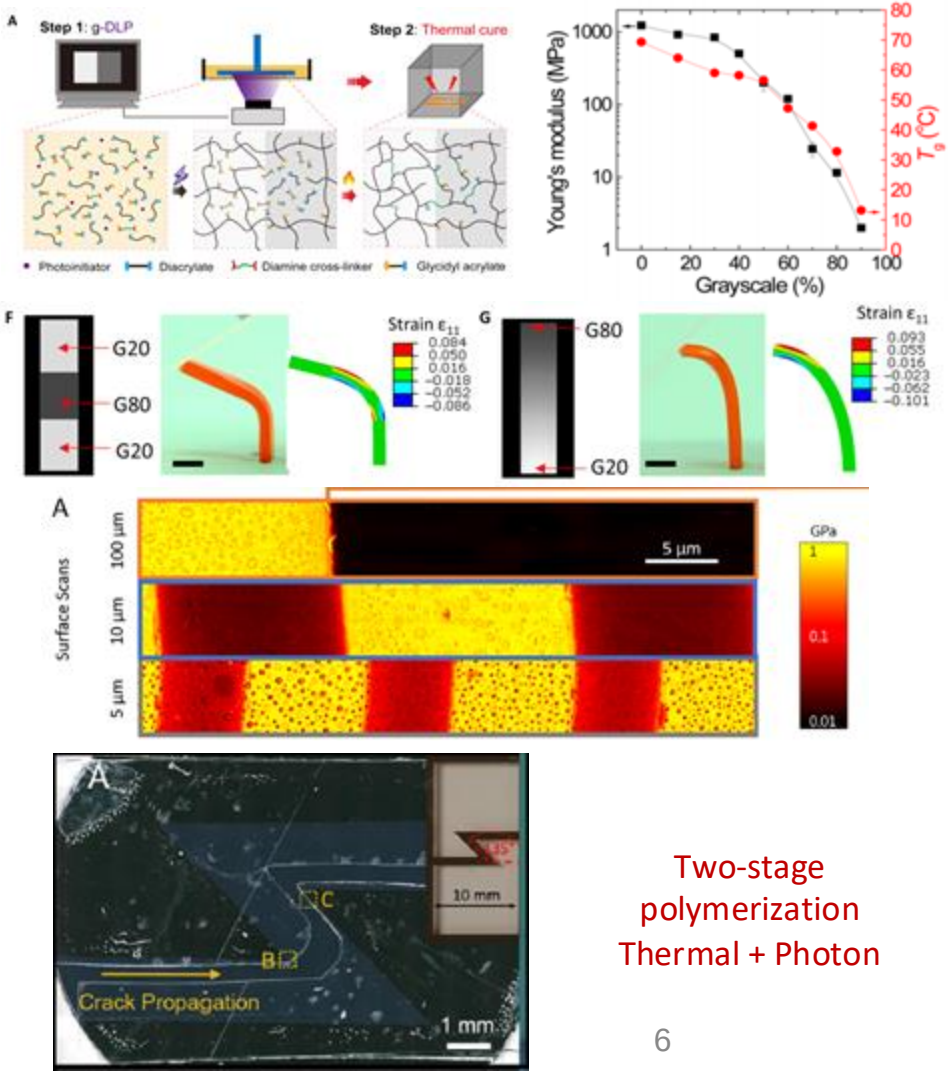
Image properties:

8-bit depth black and white images

Highly accurate and allow overhang structures

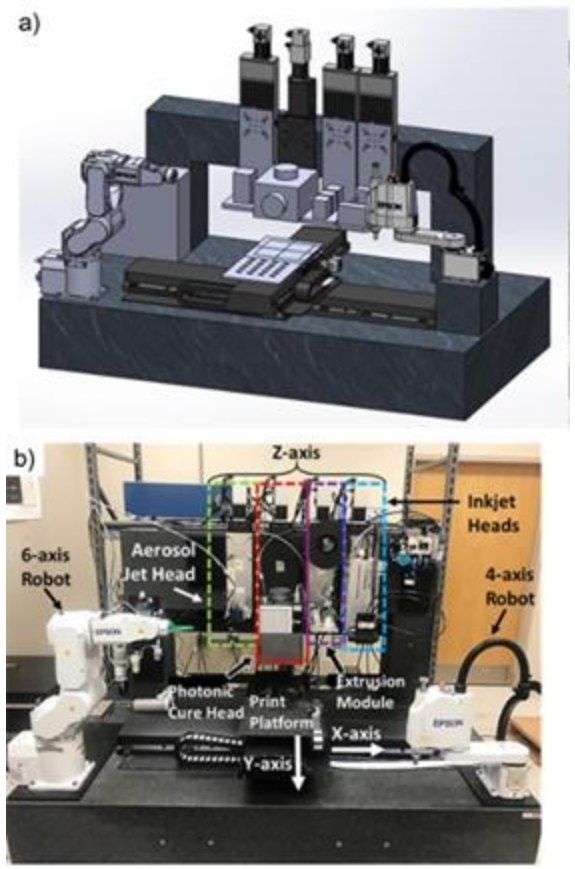


Cox et. al. 2019, Adv. Eng. Mater.; Huang et al. 2019, Sci. Adv.



Two-stage polymerization
Thermal + Photon

Multi-process 3D printer



The m⁴ 3D Printer: A multi-material multi-method additive manufacturing platform for future 3D printed structures

Digital LED Light

Devin J. Roach, Craig Hammel, Conner Dunn, Xiao Kuang, H. Jerry Qi

Georgia Institute of Technology

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Soft Pneumatic Actuator

Devin J. Roach, Craig Hammel, Conner Dunn, Xiao Kuang, H. Jerry Qi

Georgia Institute of Technology

Roach et al. 2019, Additive Manufacturing

Ships today

1		Borosilicate Glass Sheet 10" x 10" 8476K21 Thick. ✓ 1/4"	1 Each	$36.80 Each	$36.80
2		Borosilicate Glass Sheet 4" x 4" 8476K14 Thick. ✓ 1/4"	1 Each	$9.34 Each	$9.34