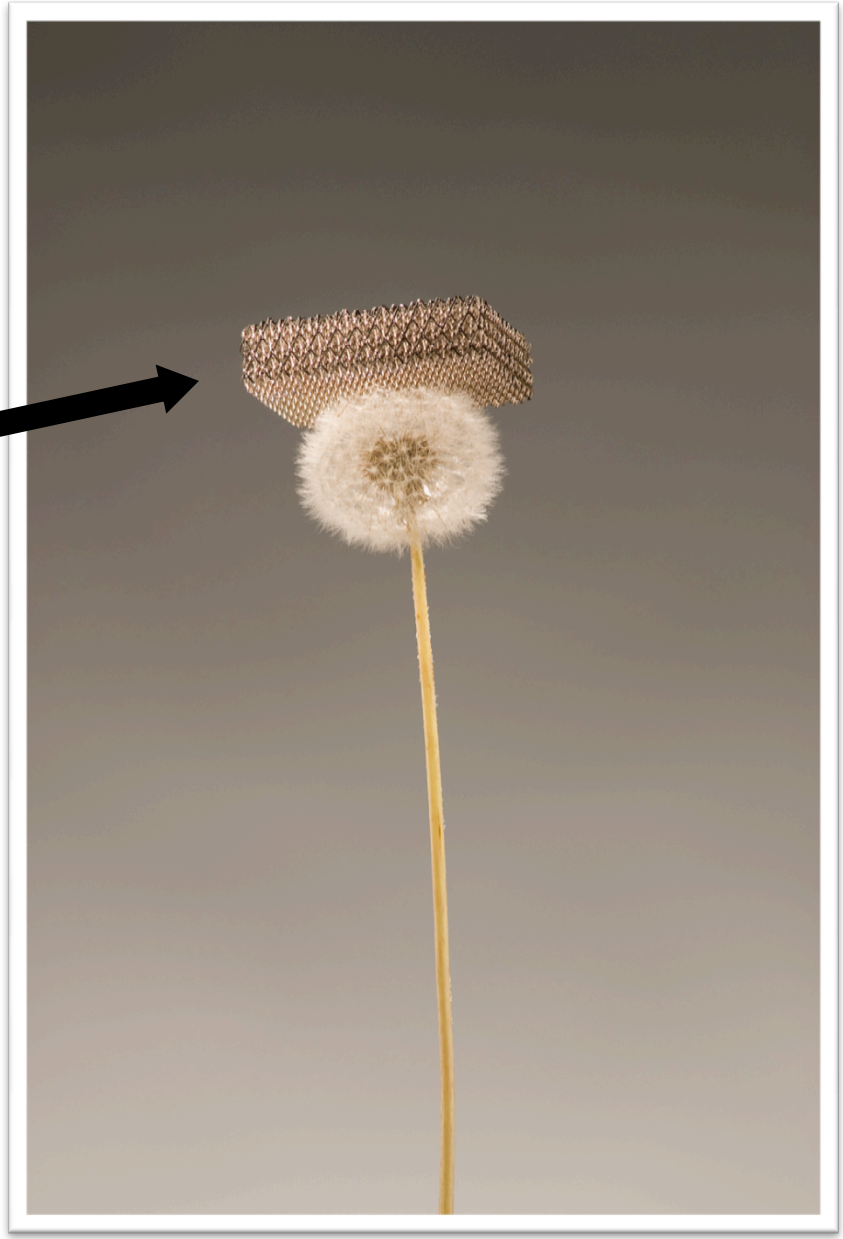
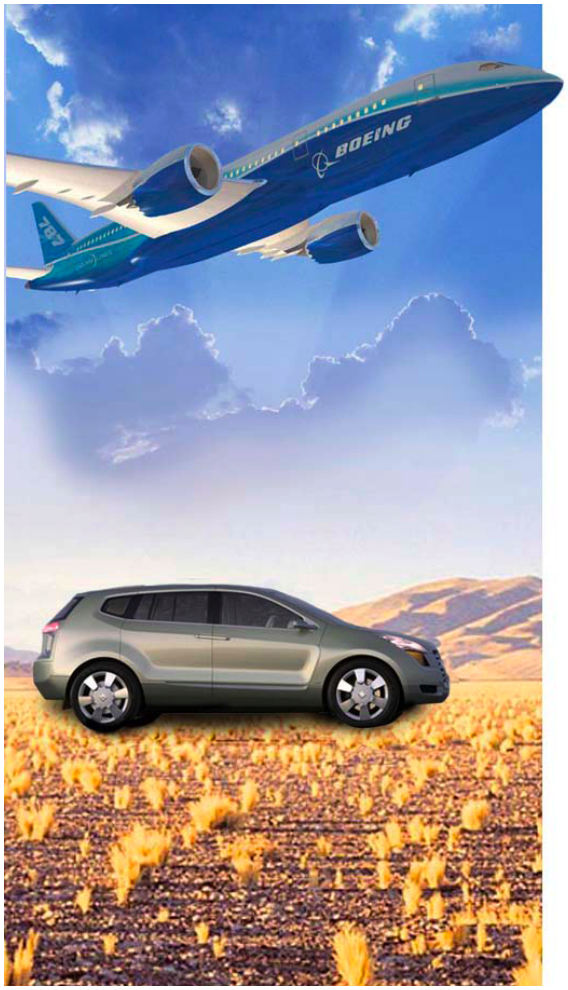
How did UV enable this?



Alan Jacobsen
jacobsen@hrl.com

HRL Laboratories, LLC
April 30, 2012

HRL Laboratories, LLC



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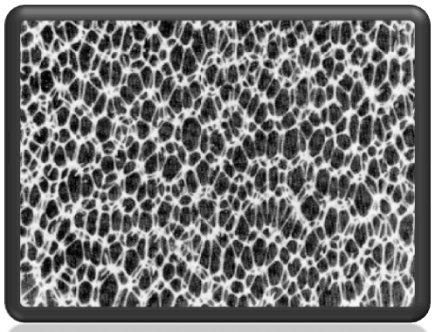
Governed by a Board of Directors – chaired by Dr. Paul Kaminski

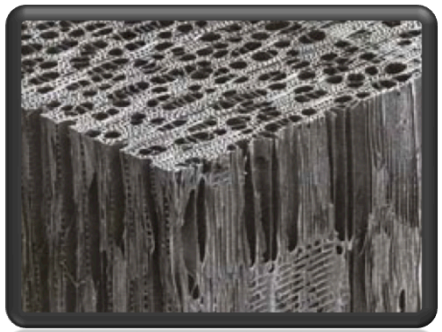
Government R&D contracts, subcontracts and commercial work make up more than half of HRL's research

Existing porous (cellular) materials

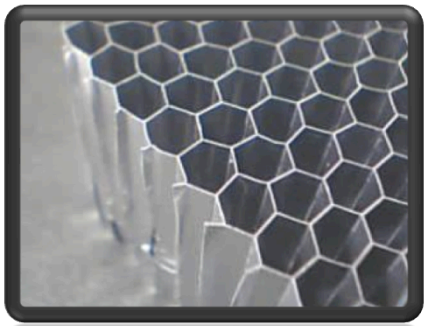
Foams



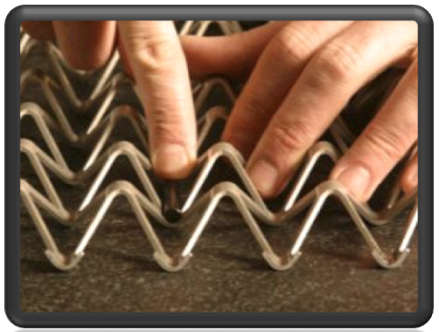
Wood



Honeycomb



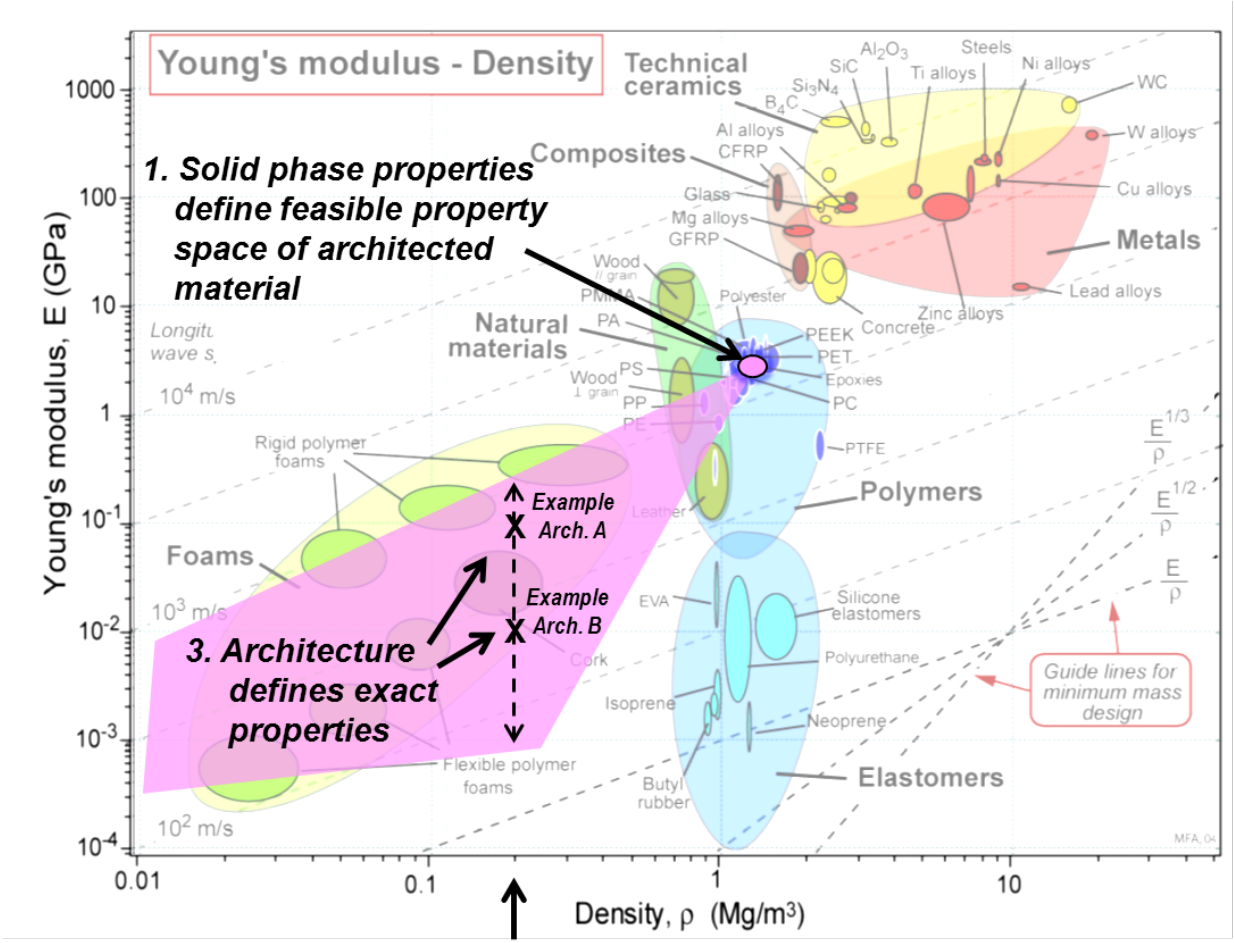
Formed metal



Material properties are defined by…

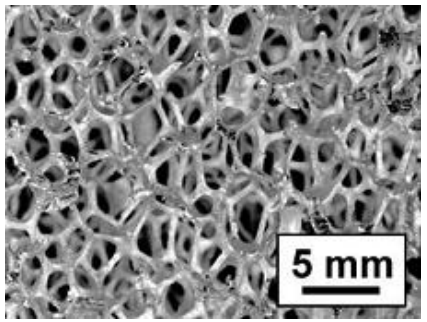
1. **Material properties of the solid phase (constituent)**
2. **Volume fraction of solid phase: *relative density***
3. **How the solid phase is organized: *material architecture***

Material architecture as a design parameter



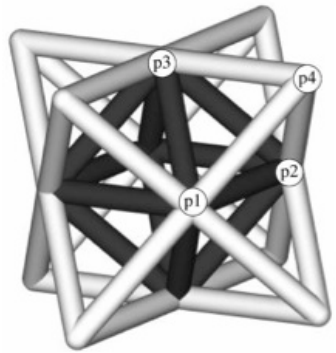
2. Volume fraction and density of solid phase define the density of the architected material

Stochastic



$$\frac{E}{E_s} = \bar{\rho}^2 \qquad \frac{\sigma}{\sigma_Y} = 0.25\,\bar{\rho}^{3/2}$$

Periodic Lattice



$$\frac{E_{33}}{E_s} = 0.2\,\bar{\rho} \qquad \frac{\sigma_{33}}{\sigma_Y} = 0.33\,\bar{\rho}$$

Self-propagating photopolymer waveguides

Nonlinear optical properties of photoresists for projection lithography

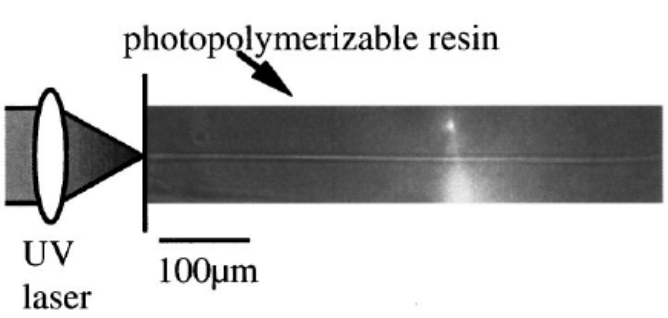
Anthony S. Kewitsch[a] and Amnon Yariv
Department of Applied Physics, California Institute of Technology 128-95, Pasadena, California 91125

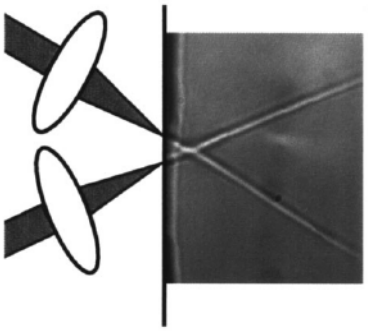
(Received 8 September 1995; accepted for publication 14 November 1995)

Optically-induced growth of fiber patterns into a photopolymerizable resin

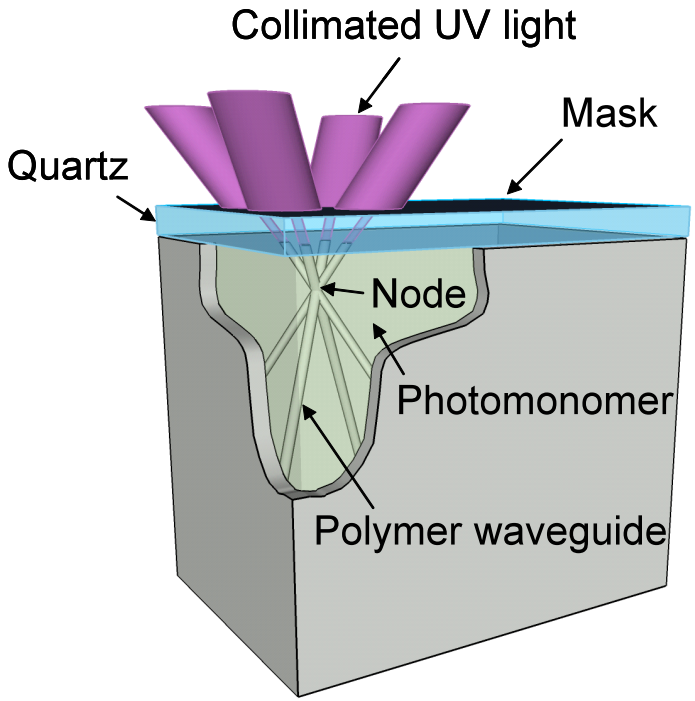
Satoru Shoji and Satoshi Kawata[a]
Department of Applied Physics, Osaka University, Suita, Osaka 565, Japan

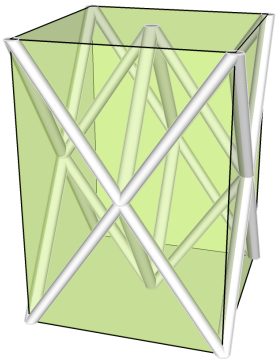
(Received 9 November 1998; accepted for publication 4 June 1999)

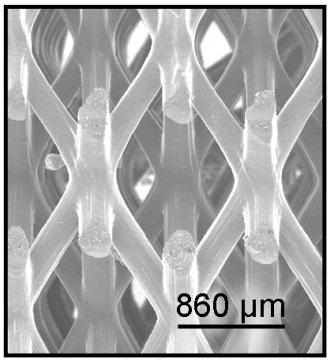




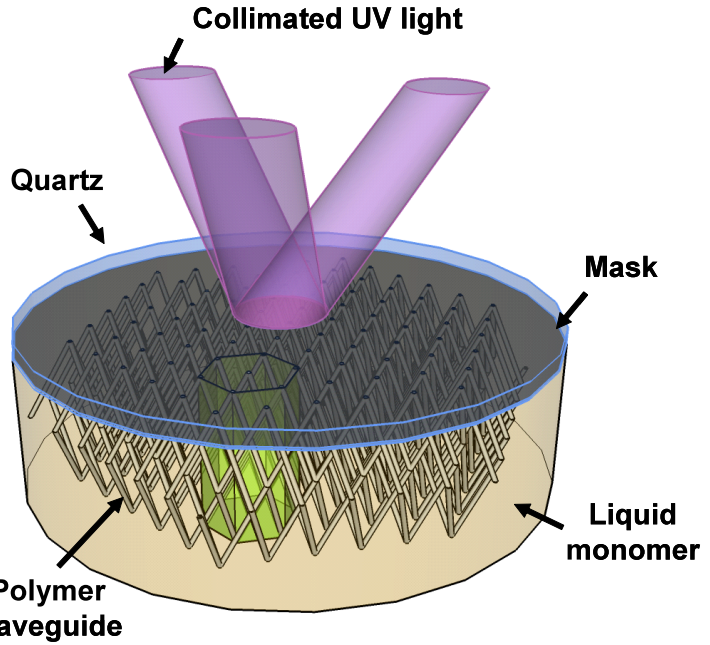
Fabrication of *microlattice* structures

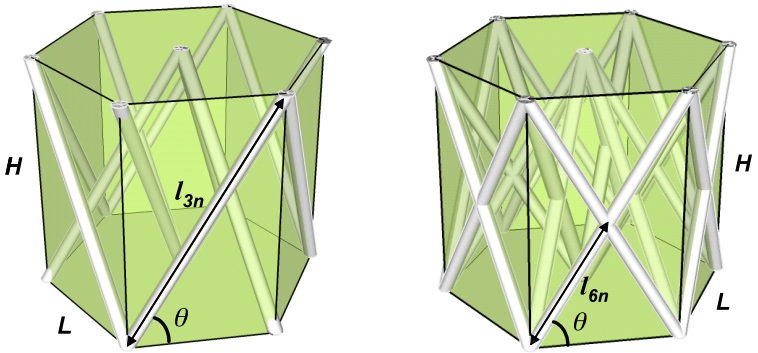






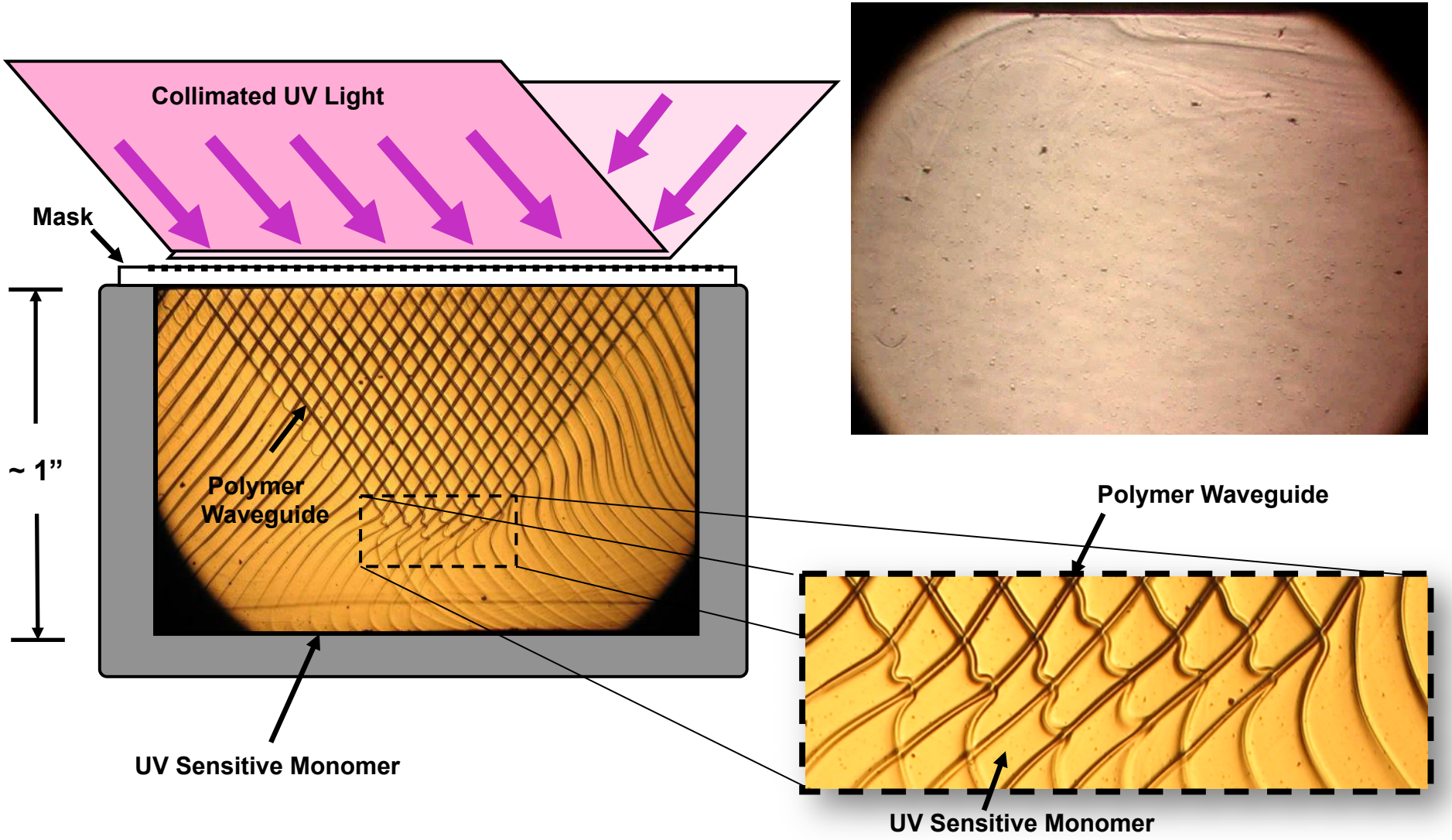
[Jacobsen et al., *Adv. Mat.,* 2007]





[Jacobsen et al., *Acta Mat.,* 2008]

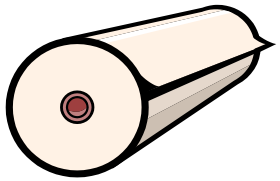
Real-time imaging of intersecting photopolymer waveguide formation



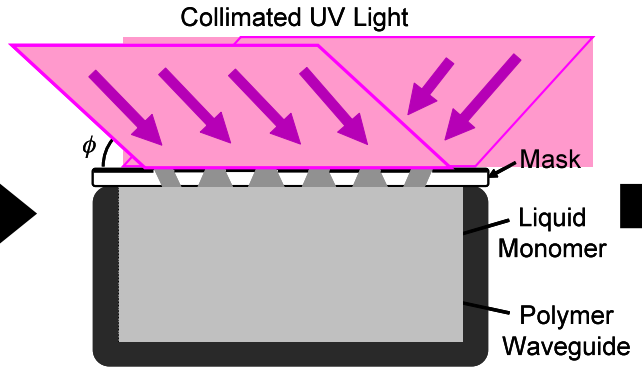
2D UV Processing for 3D Structures

FABRICATION PROCESS

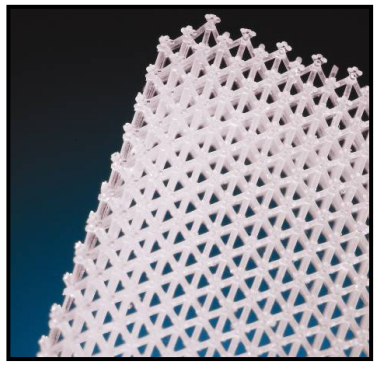
2-D UV Processing and Materials for Films and Coatings



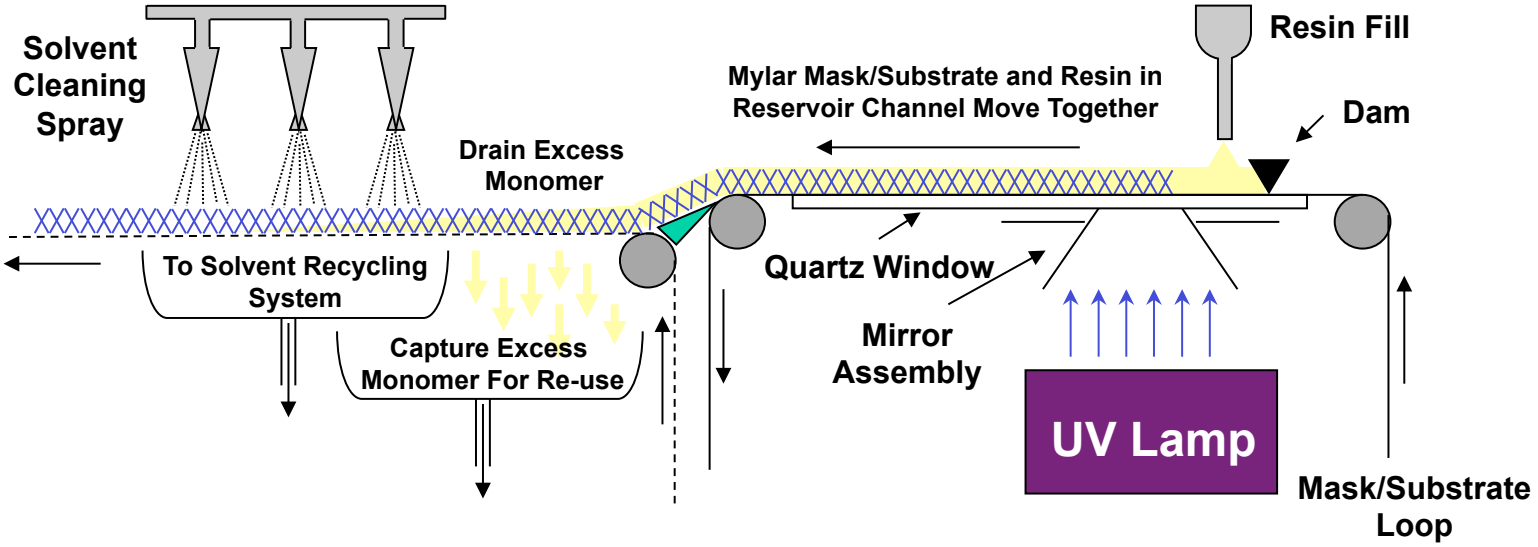
2-D ➔ 3-D



2-D UV Processing and Materials for 3-D structures



ROLL-TO-ROLL CONCEPTS

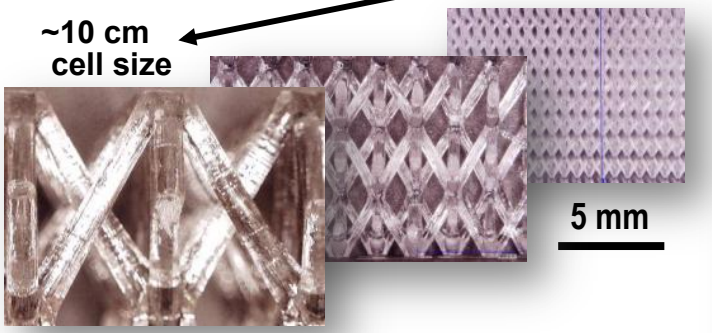


One process – many possible architectures

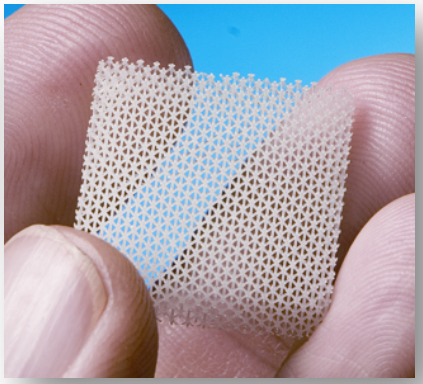
Large cell size range

~100 μm cell size

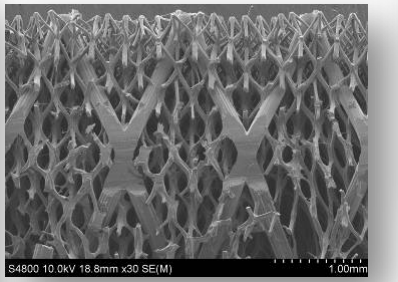
~10 cm cell size

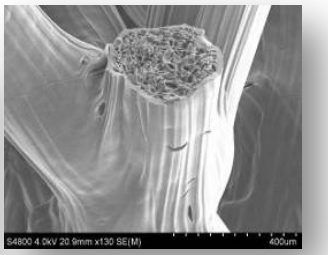


HRL Microlattice



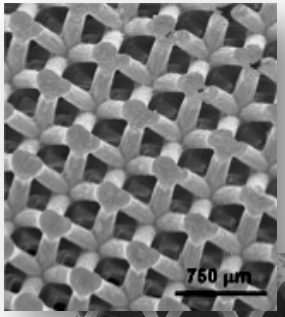
Multi-level trusses

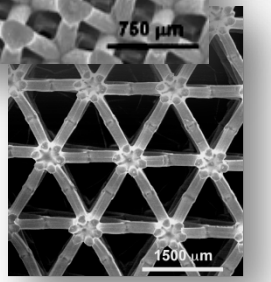




Porous trusses (similar to bone)

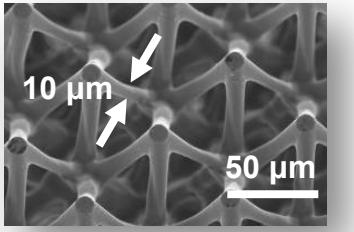
Octahedral unit cell



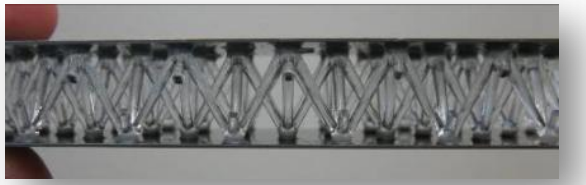


Hexagonal unit cell

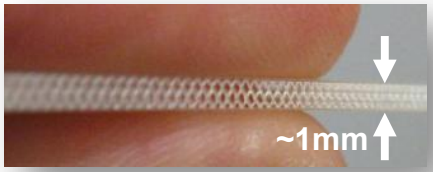
Range of strut sizes



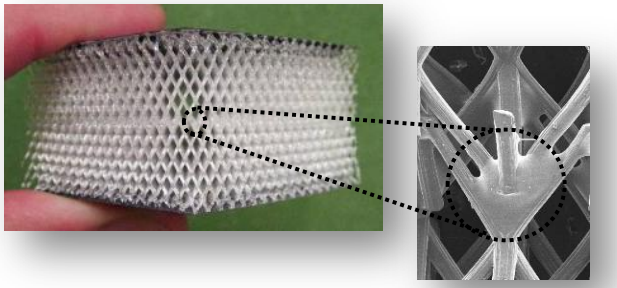
Sandwich structures



Micro-sandwich structures

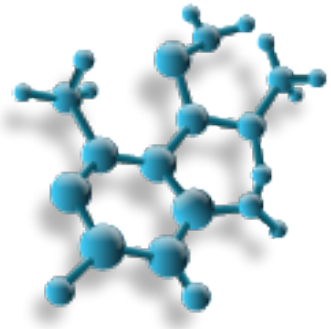


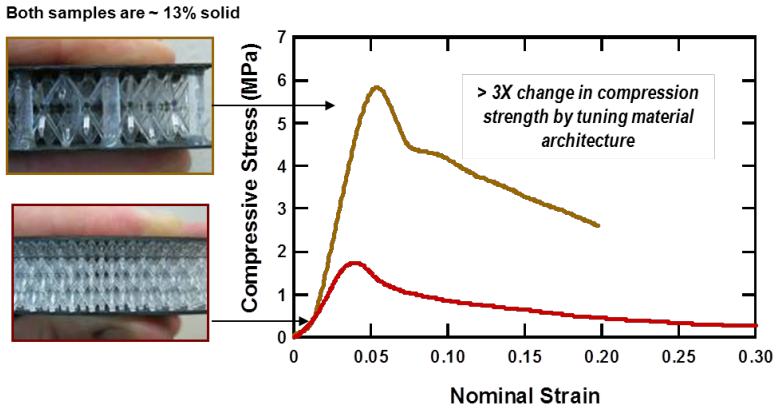
Multi-layer thick trusses

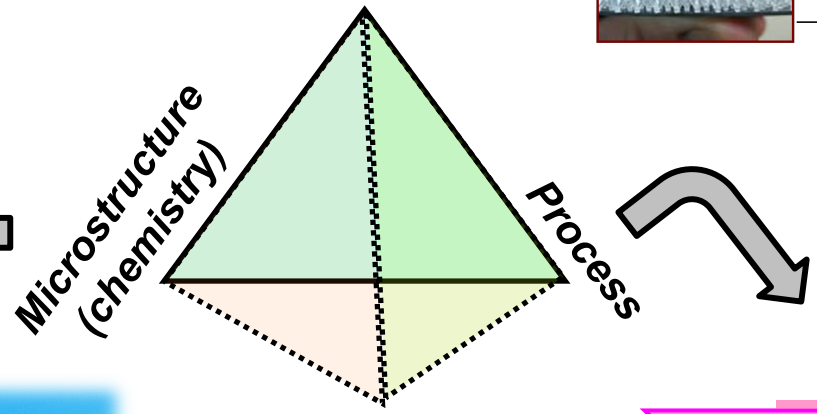


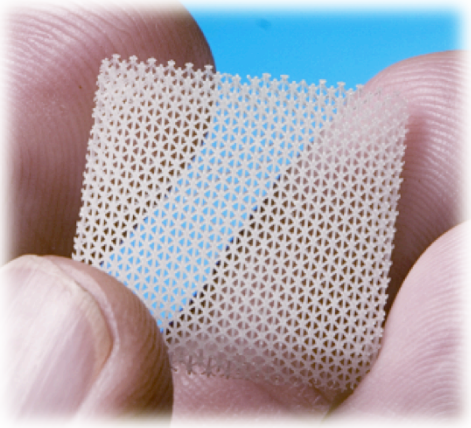
Large area

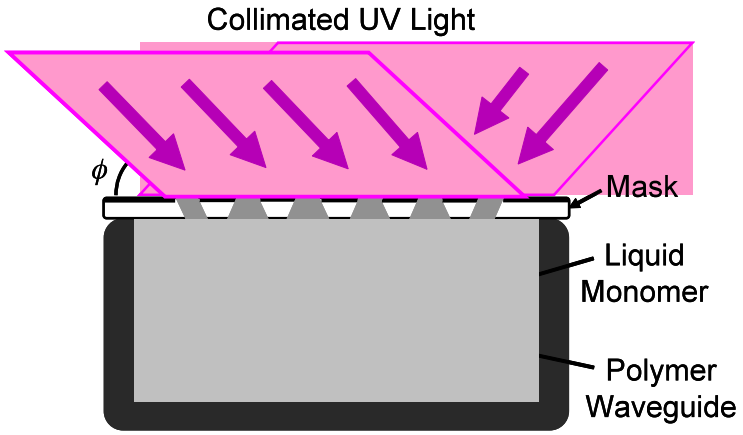
The "*new*" materials science triangle



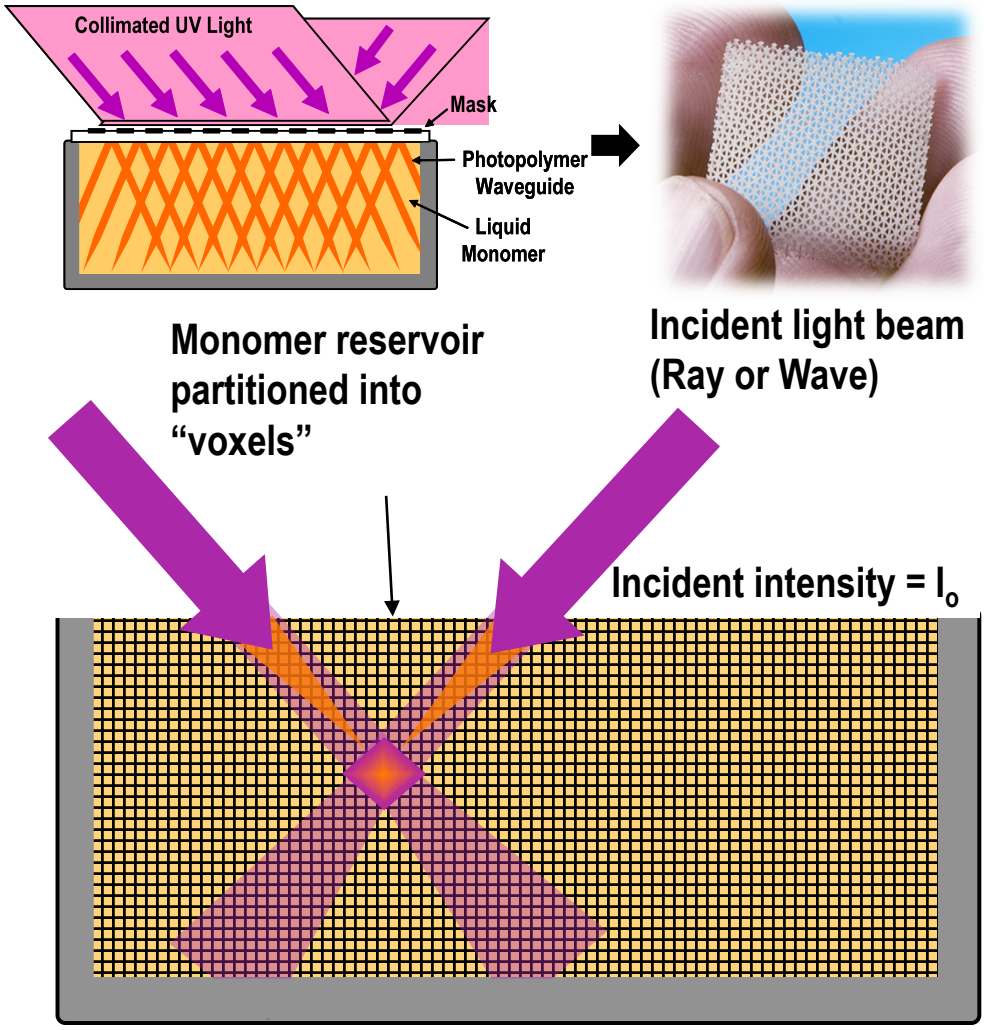




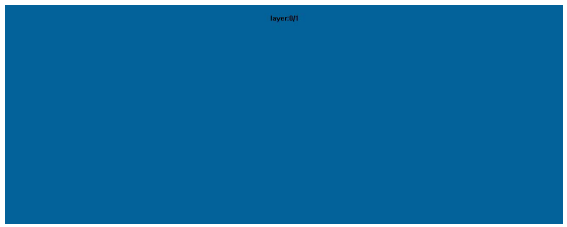




Overview of Photopolymerization Model

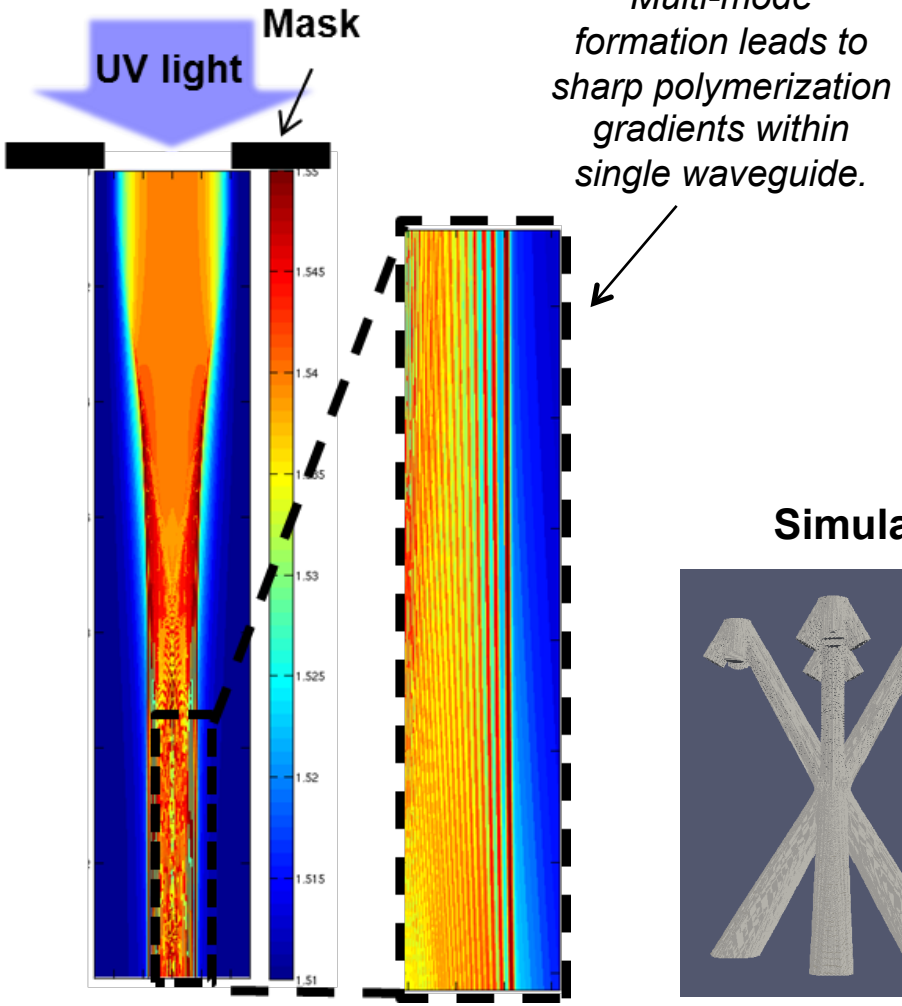


- **Step 1: Light beam is "directed" into monomer reservoir**
  - Ray Model
  - Wave Model
- **Step 2: Incident light drives local chemical reaction at each voxel**
- **Step 3: Local refractive index is updated based on % conversion from liquid monomer to solid polymer**
- **Step 4: Light is redirected through reservoir with updated refractive index at each voxel**



Wave propagation model can simulate formation of complex micro-truss features

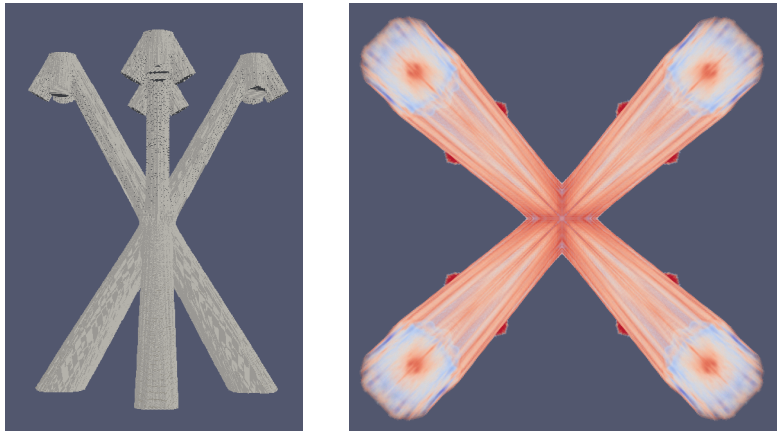
Single Waveguide Simulation



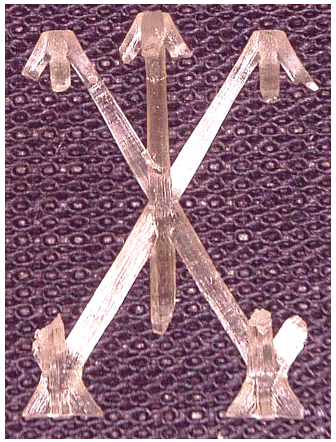
Multi-mode formation leads to sharp polymerization gradients within single waveguide.

Waveguides Intersecting in Single Plane

Simulation of 3D Unit Cell

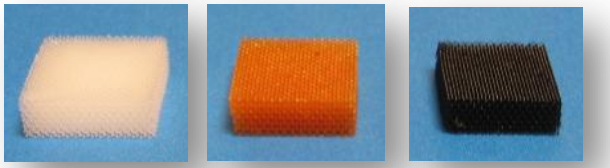


Experiment

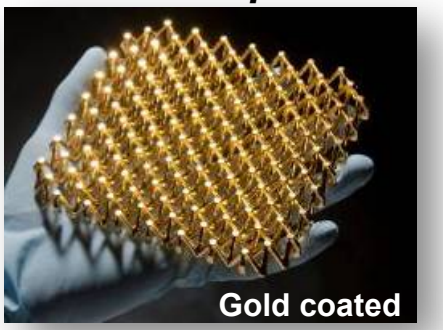


Post-processing approaches for other materials – polymers, metals, and ceramics

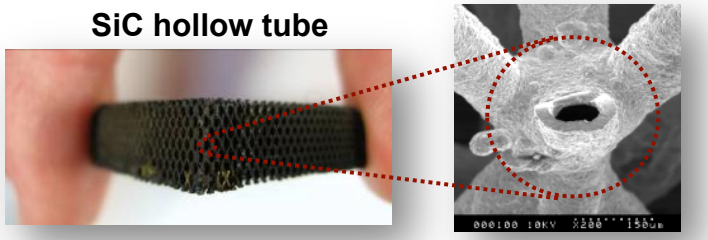
Thermal oxidation



Polymer Microlattice
as template

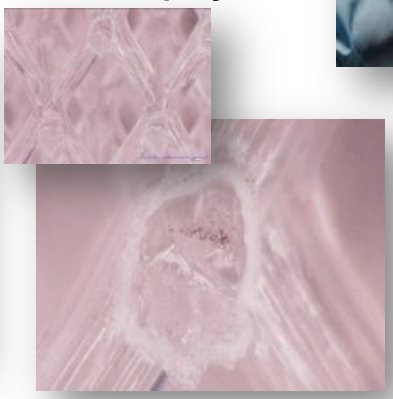


SiC hollow tube

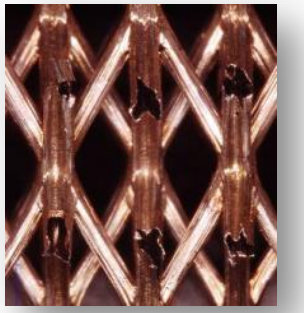


Vitreous carbon

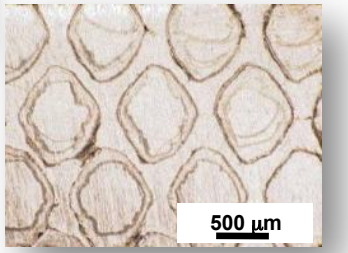
Hollow parylene



Ultralight Ni-P

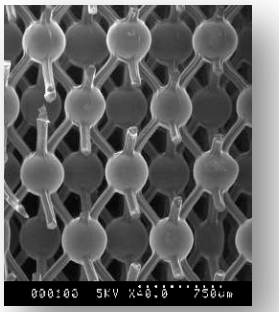


Al – SiC composite

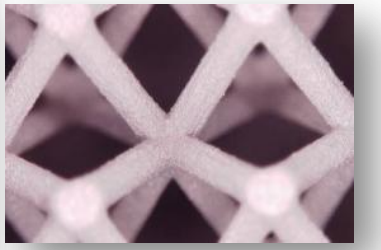


Alumina

Carbon balloons



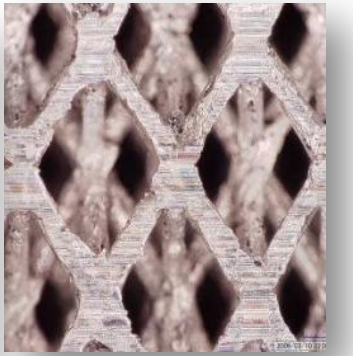
Aluminum coated



Ni hollow tube

Copper plated

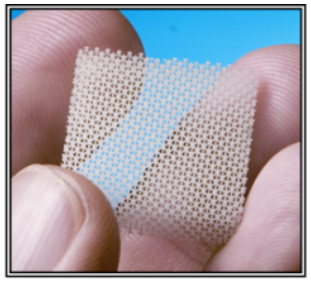
Cast aluminum



World's Lightest Structure… or Material?

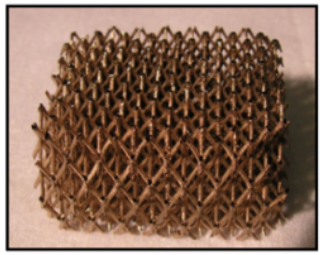
DARPA MCMA Program

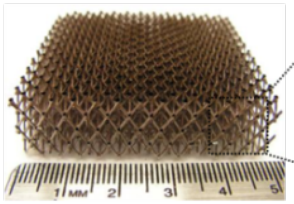
Utilize material architecture to achieve "white space"



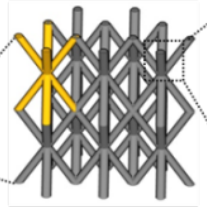
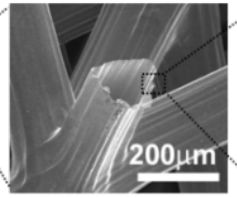
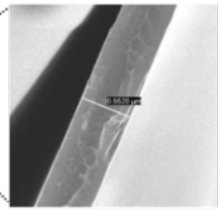
Electroless plating Ni-P coating

Polymer etch





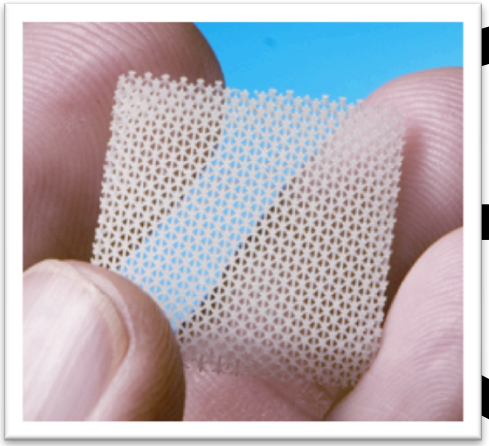
Architectural parameters

	Lattice-based unit cell	Hollow-tube lattice member	Constituent material
			
Size Scale	~ mm - cm	~ μm - mm	~ nm - μm
Controllable architectural features	Unit cell symmetry, spatial location of lattice members	Diameter, wall thickness, node geometry	Composition, microstructure, multilayer

Reference: T.A. Schaedler, A.J. Jacobsen, A. Torrents, A.E. Sorensen, J. Lian, J.R. Greer, L. Valdevit, W.B. Carter, *Science* **334**, 964 (2011)

Commercial Opportunities

Custom Comfort



Energy Dissipation

Shock Attenuation

Breathable, Air Flow

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