Light Sheet 3D Printing

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Article

Xolography for linear volumetric 3D printing

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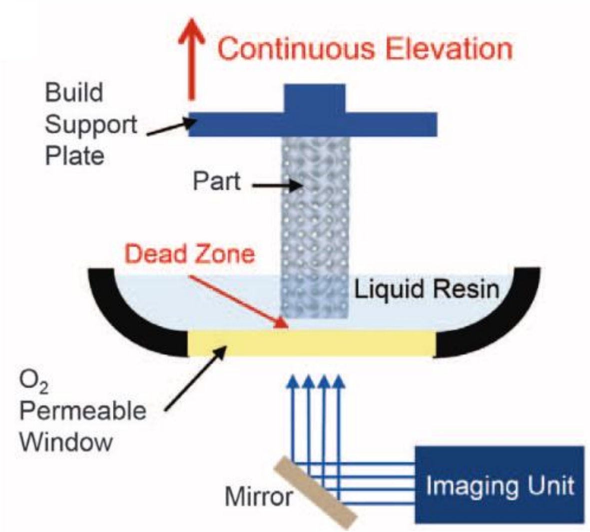
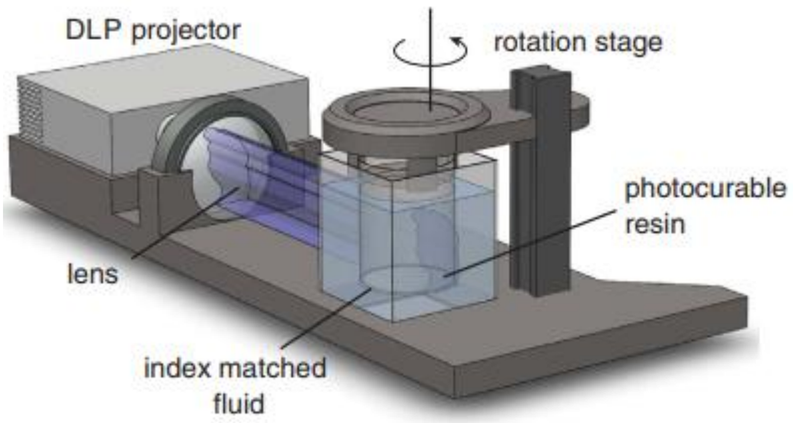
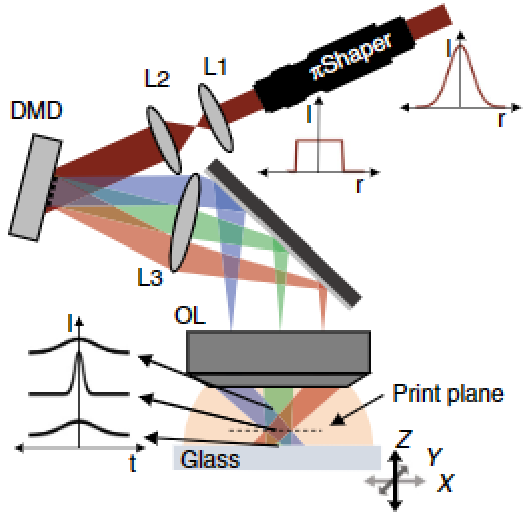
Issue to Address







stereolithography

Science 2015, 347, 1349

computed axial lithography

Science 2015, 347, 1349

two-photon lithographyhy

Light Sci. Appl. 2021, 10, 199

high speed

low resolution (~100 μm)

high resolution (~1 μm)

low speed & high cost

new 3D printing method both with high resolution and high speed?

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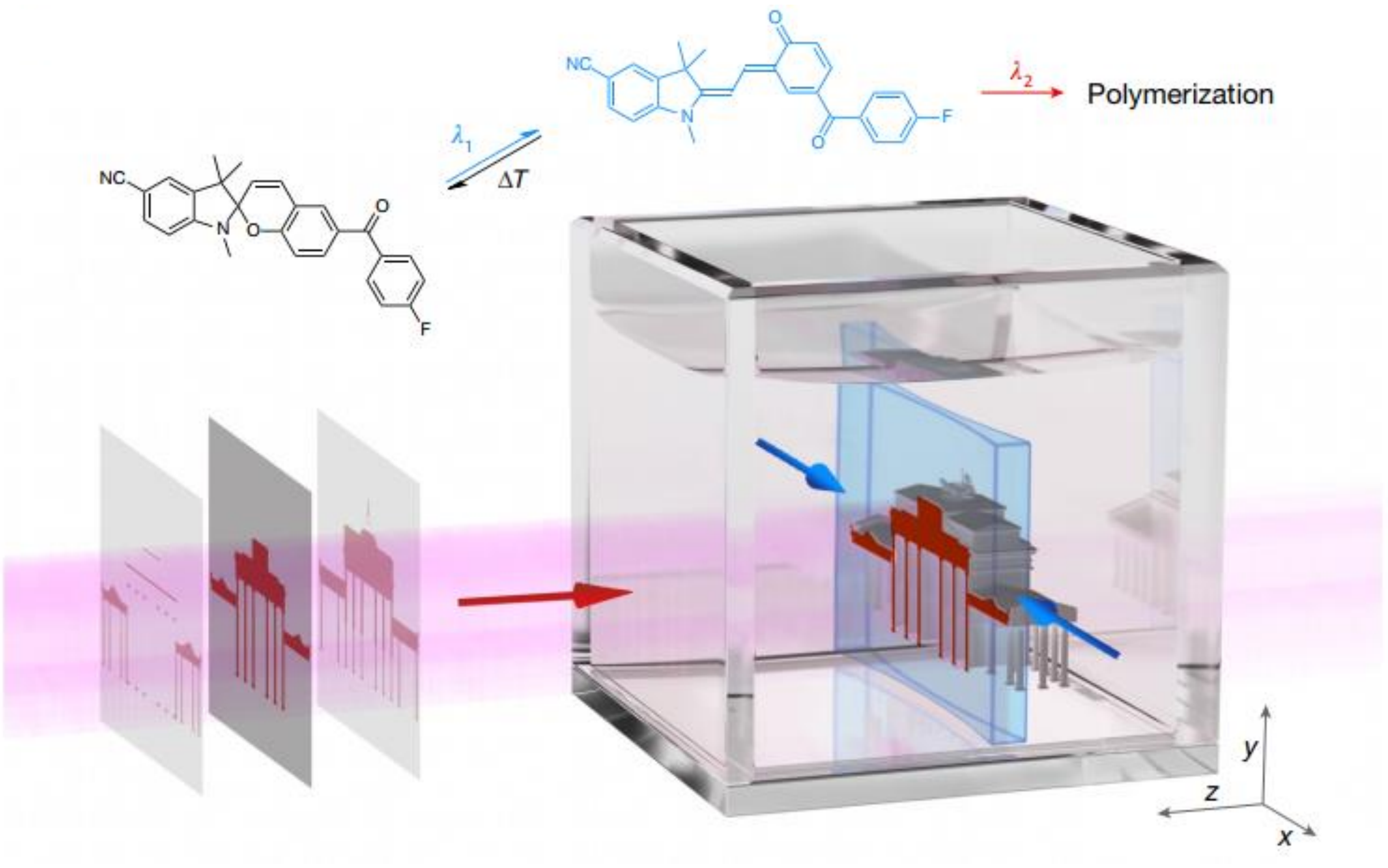
Illustration of Xolography

dormant state

latent state

dual-colour photoinitiator

orthogonally crossing(X) light

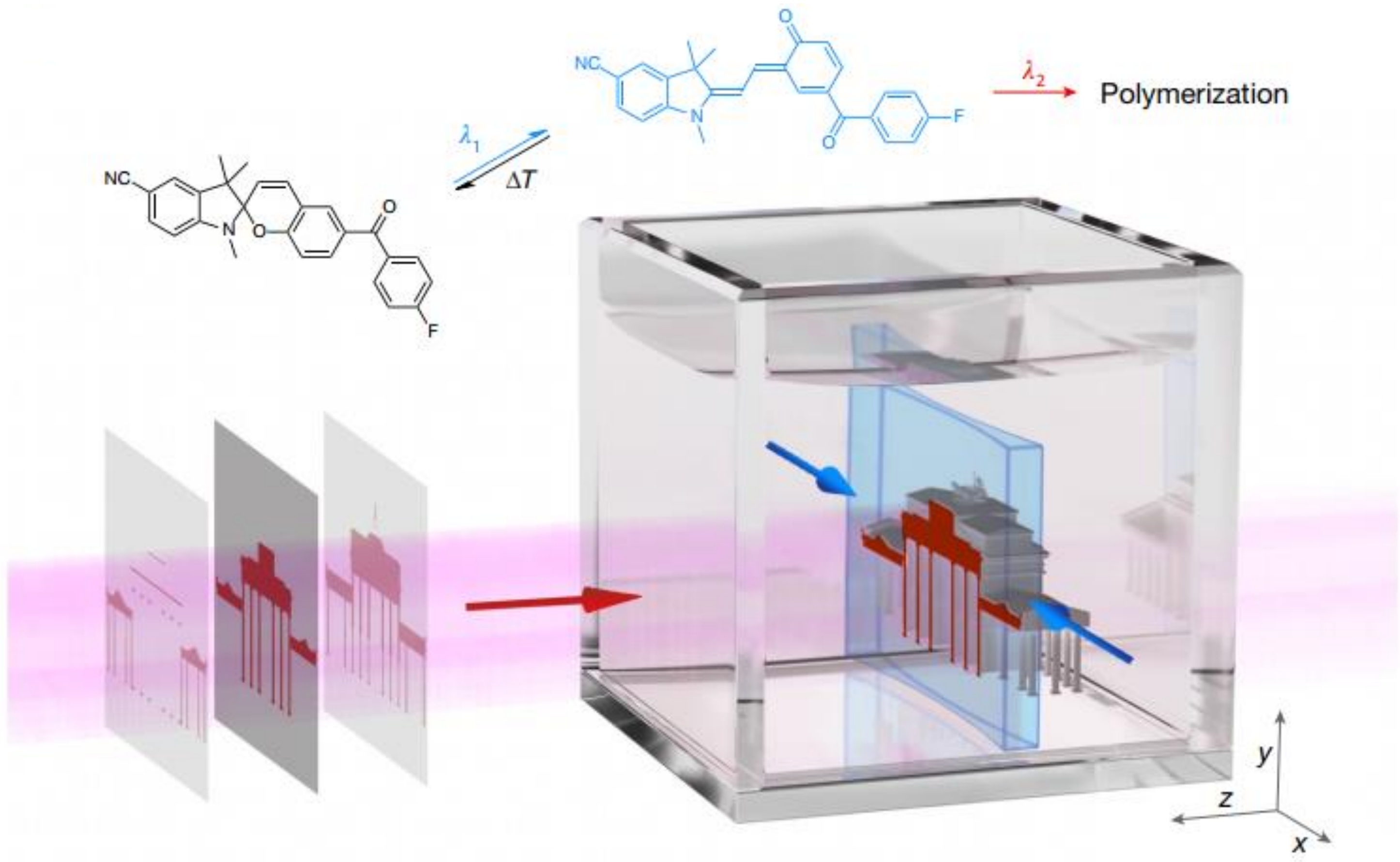


Requirements for Light-sheet Printing

dormant state

latent state

dual-colour photoinitiator



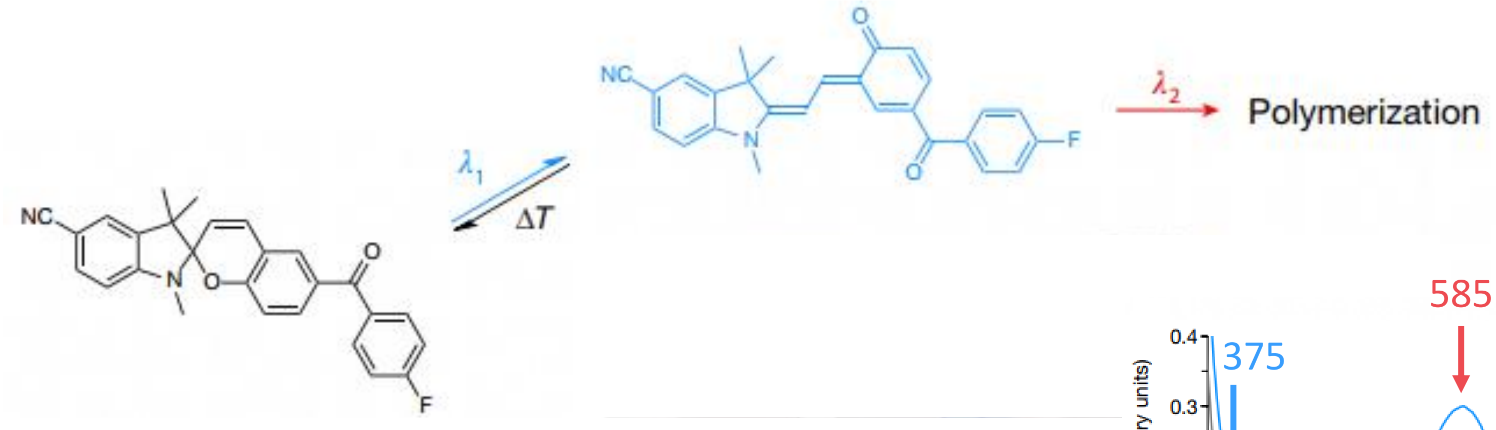
orthogonally crossing(X) light

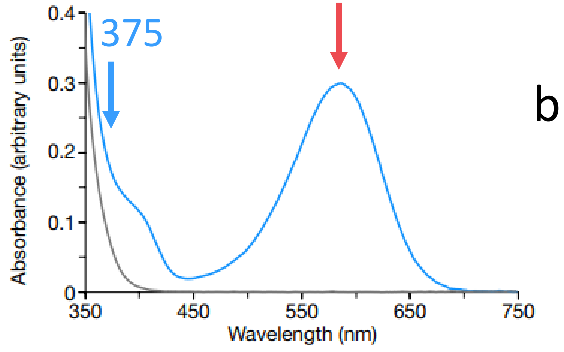
- Polymerization should be induced by λ_1 and λ_2 together, but by single light(non-overlapping adsorption regions)
- Photoinitiator in latent state decays back to the dormant state in due time
- Adsorption of dormant state should be sufficiently low for a large enough intensity through whole vessel

Property of Photoinitiator

dormant state

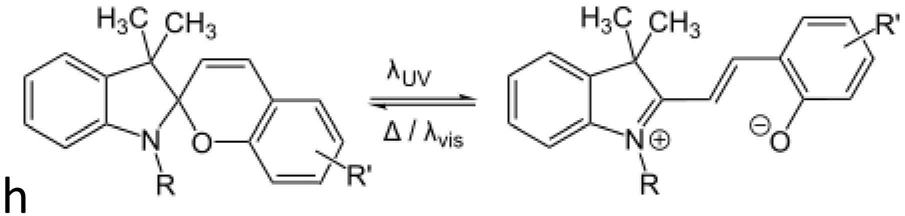
latent state





black: dormant state
blue: latent state

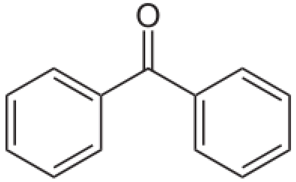
spiropyran
classical photoswitch

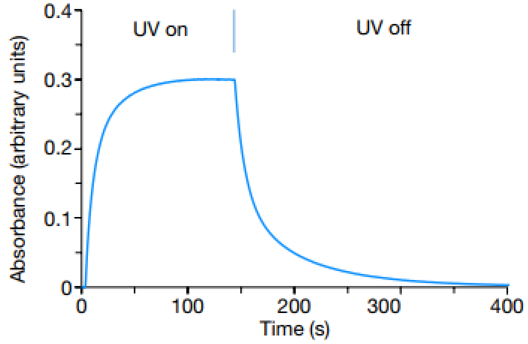


1

2

benzophenone
common phothoinitiator





thermal half-life 6 s
at 25 °C

3D Printer Assembly

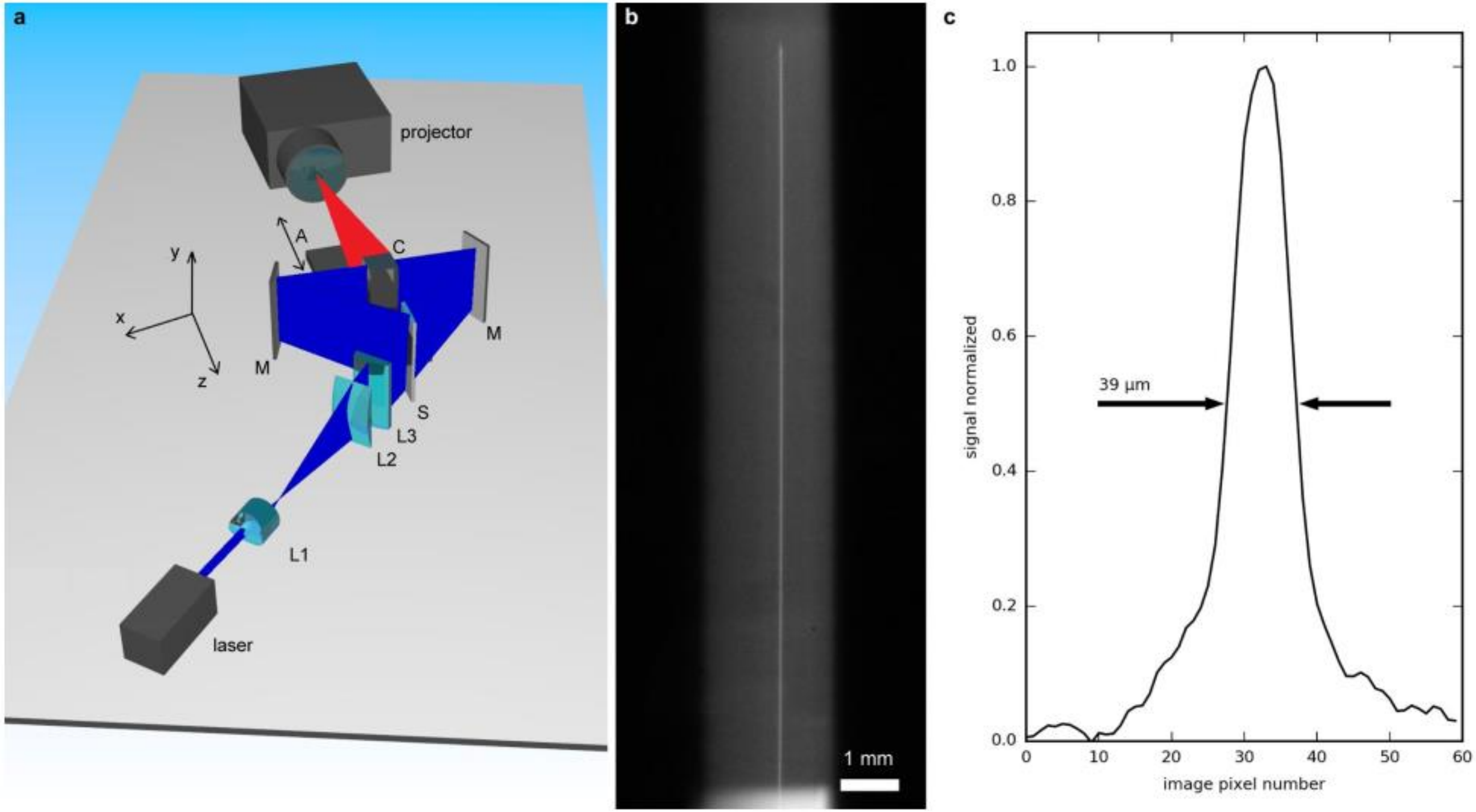
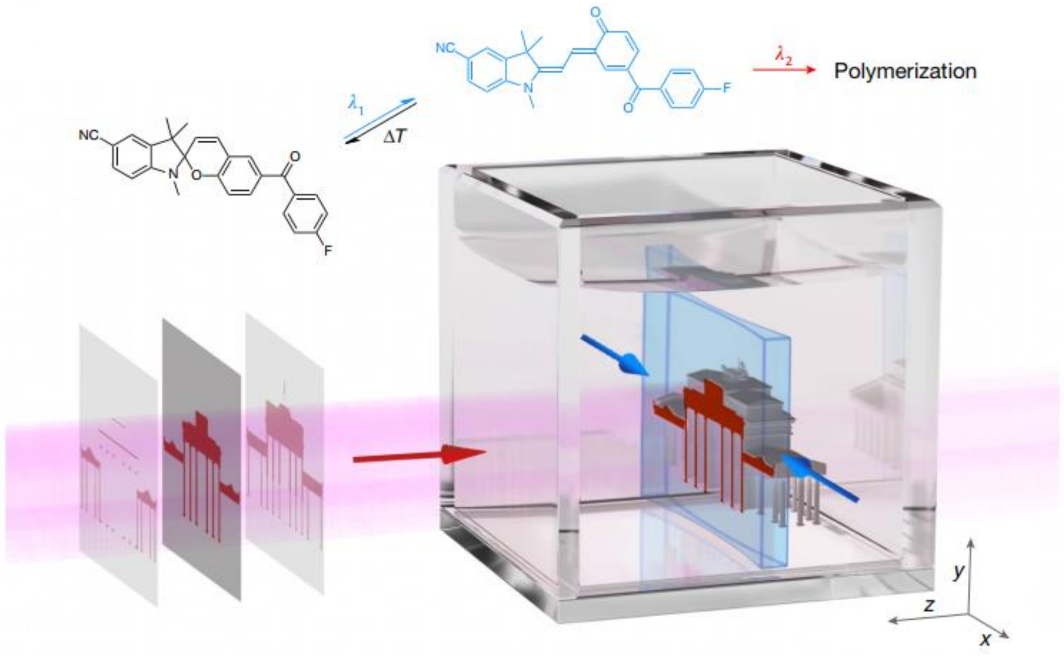
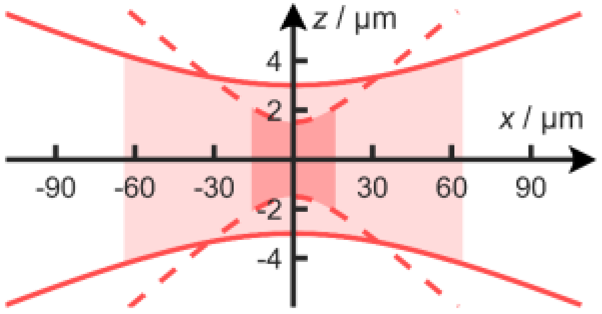
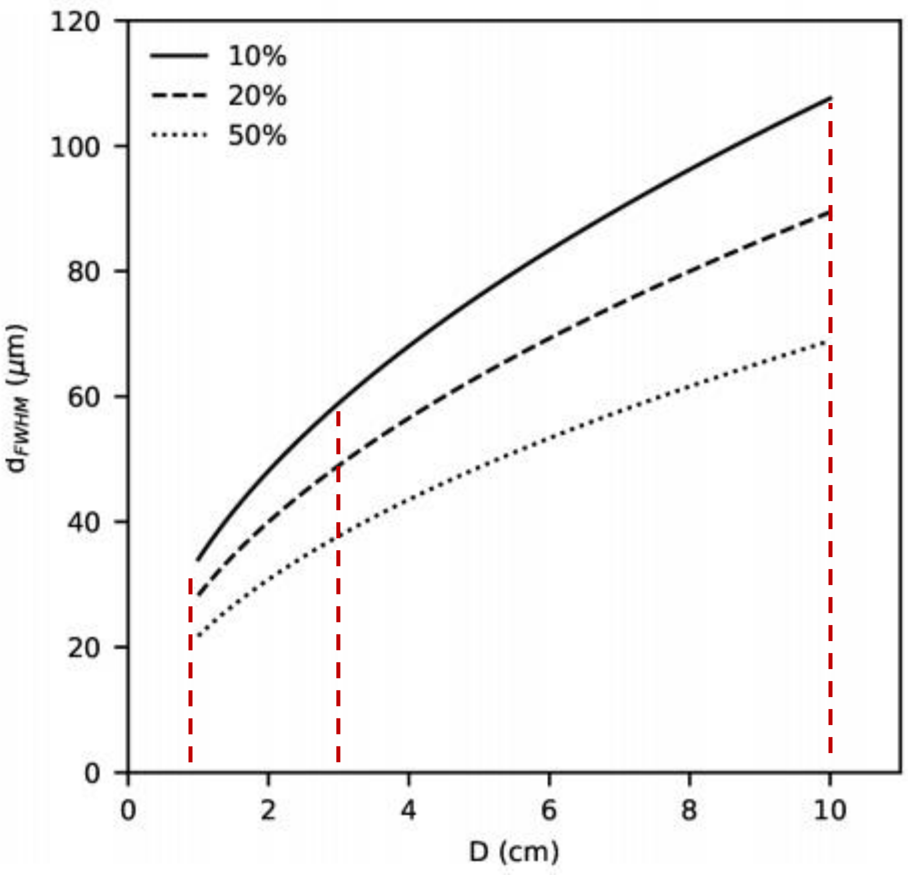


image pixel size of 21 µm × 21 µm at the focus position (resolution in x and y direction)
39 µm FWHM light sheet waist size can be realized for printing in 10-cm-sized vessel

Optimal Light Sheet Waist Widths

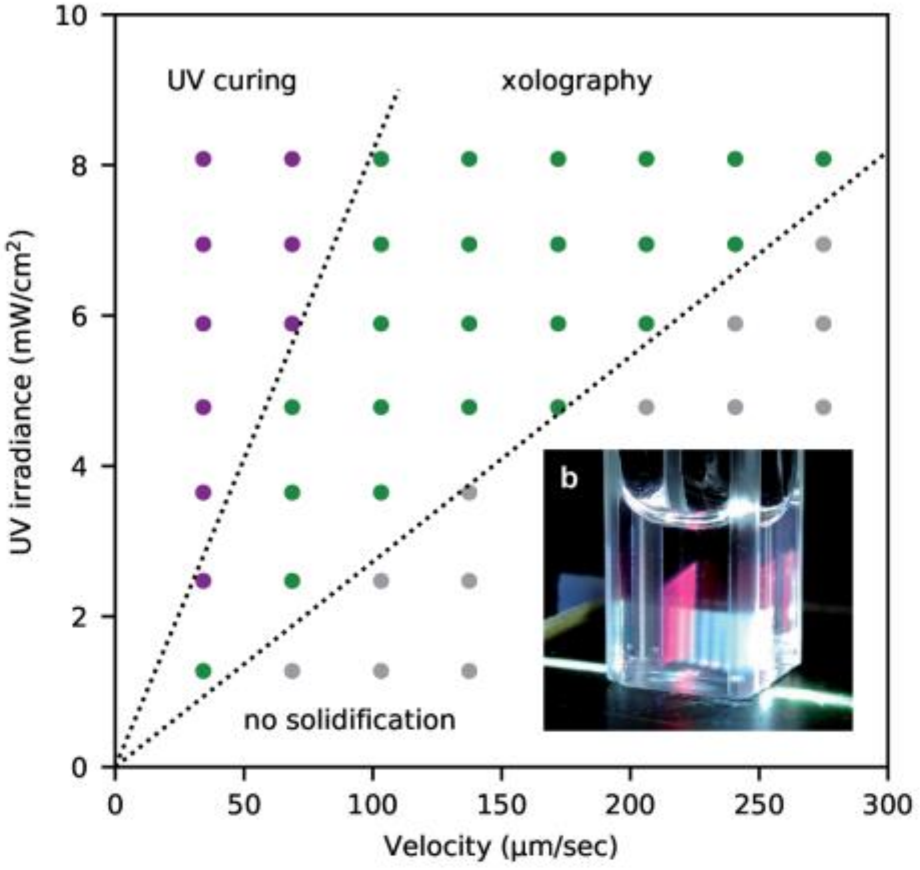


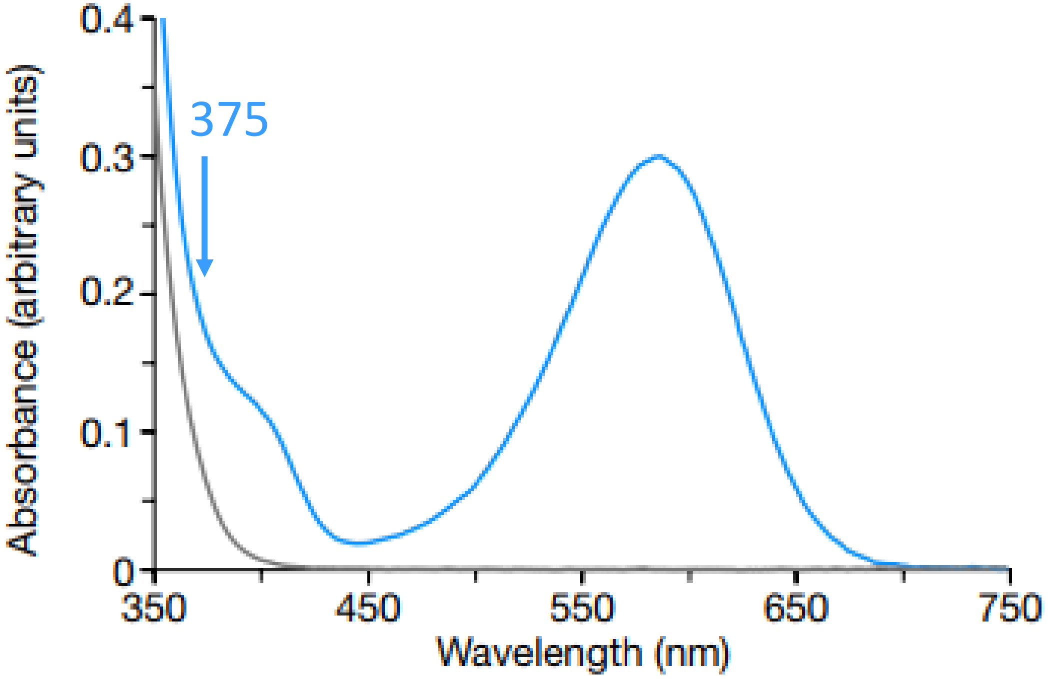




FWHM waist sizes against volume depth
34 µm for 1 cm, 59 µm for 3 cm,108 µm for 10 cm
(resolution in z direction)

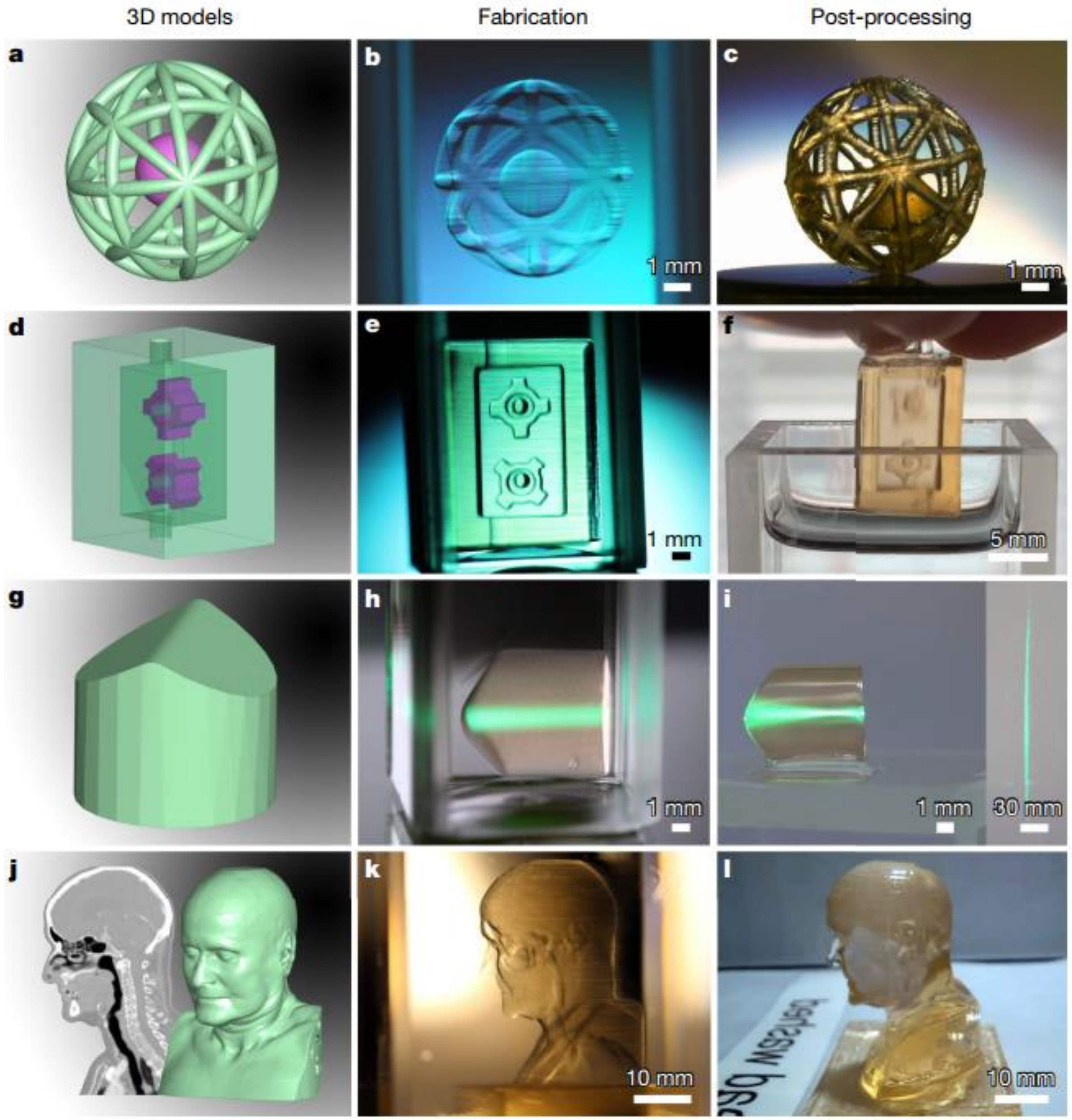
Suitable UV Power and Velocity

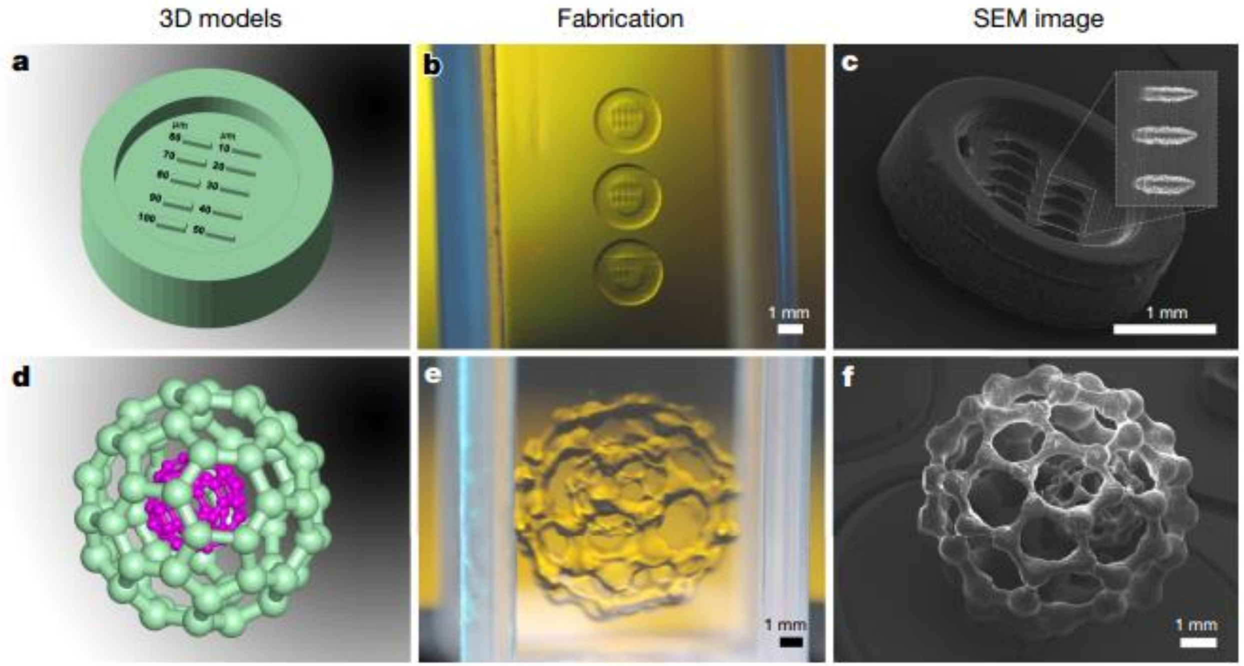




UV power too high: undesired solidification
velocity too high: not enough solidification
final choice: 136.8 μm/s with 7 mW/cm^2

Various Printed Structures





resolution can reach 25 µm in the x and y directions
and 50 µm in the z direction

printing speed can reach 55 mm^3/s
one minute in 10 mm cuvettes

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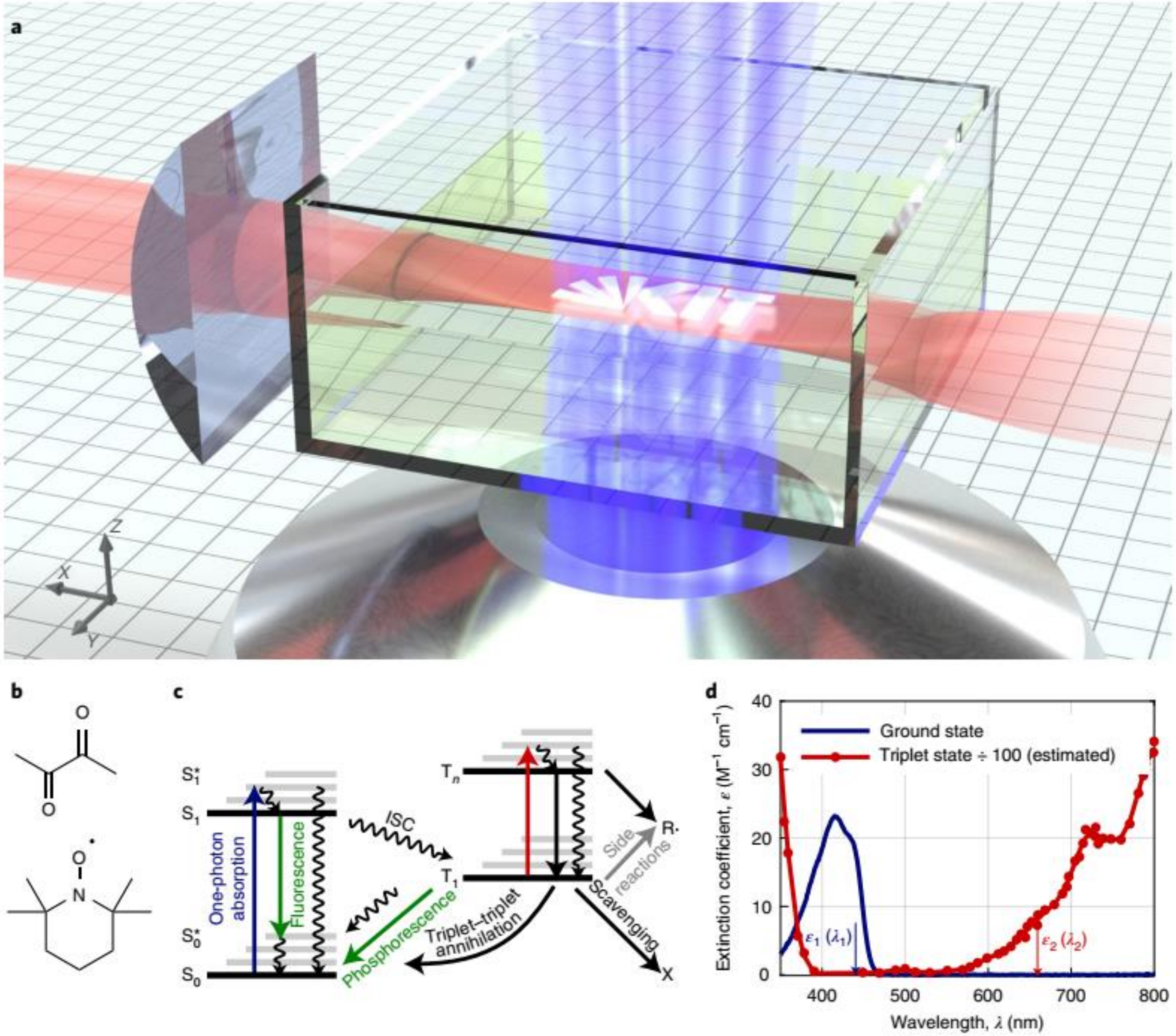
Light Sheet by Two-colour Two-step Absorption



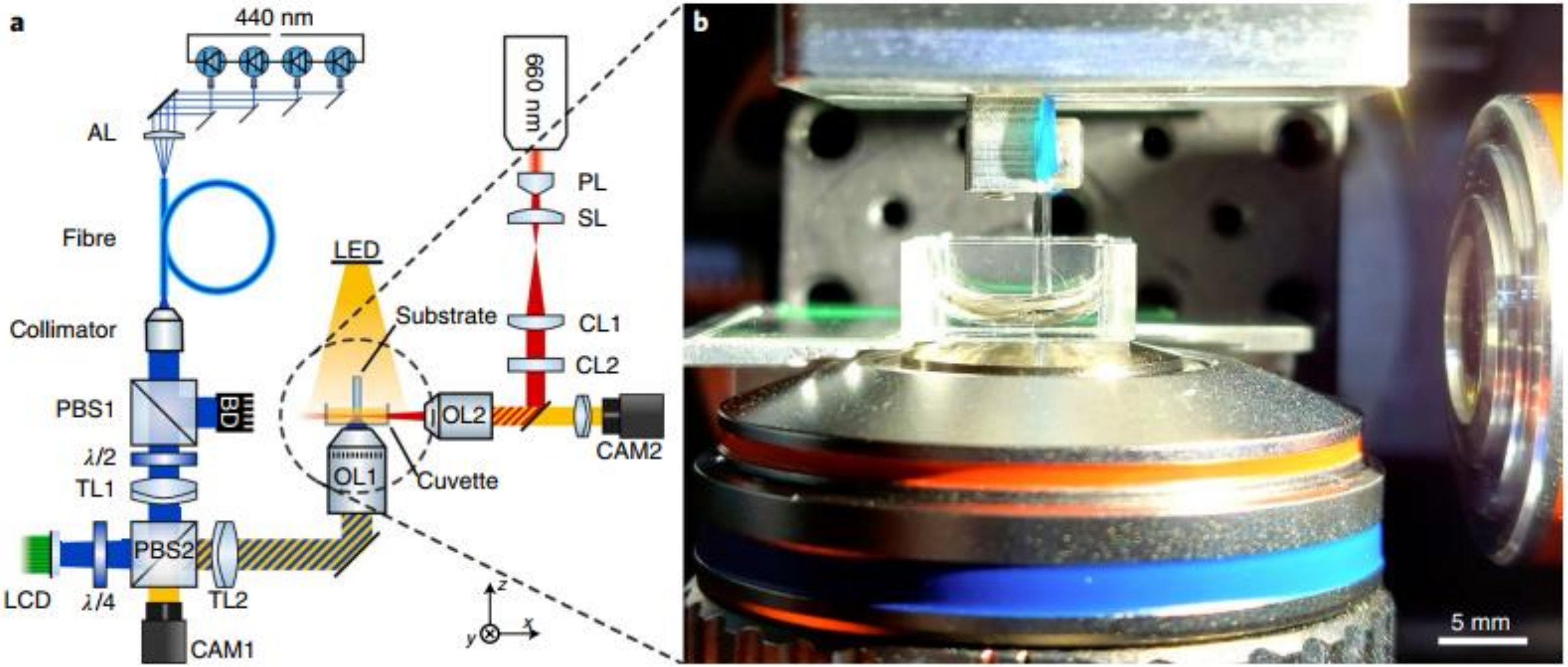
2,3-butanedione (BA)
photoinitiator

TEMPO
radical scavenger

non-overlapping
adsorption regions

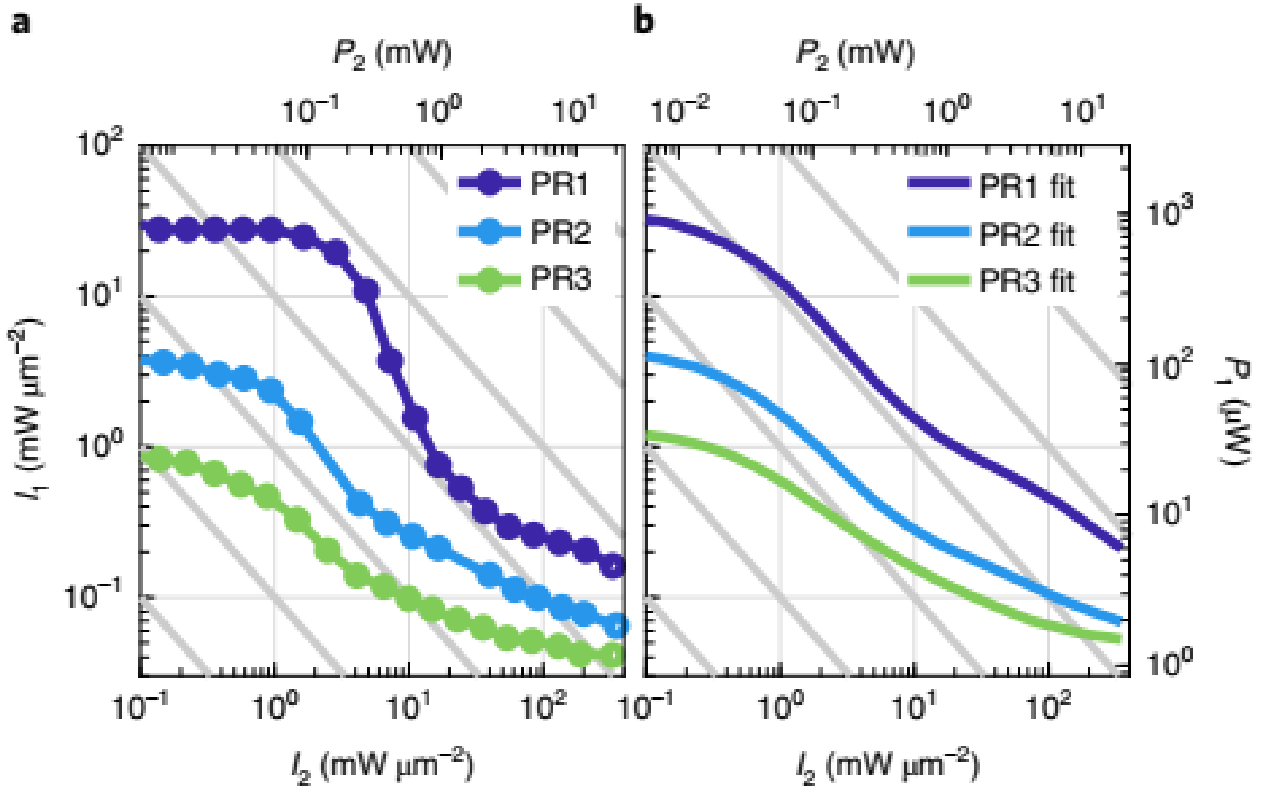
intermediate-state
lifetime 100 µs

3D Printer Assembly



LCD has 1,920 × 1,080 pixels
stationary light sheet and projected light

Threshold Intensity for Solidfication



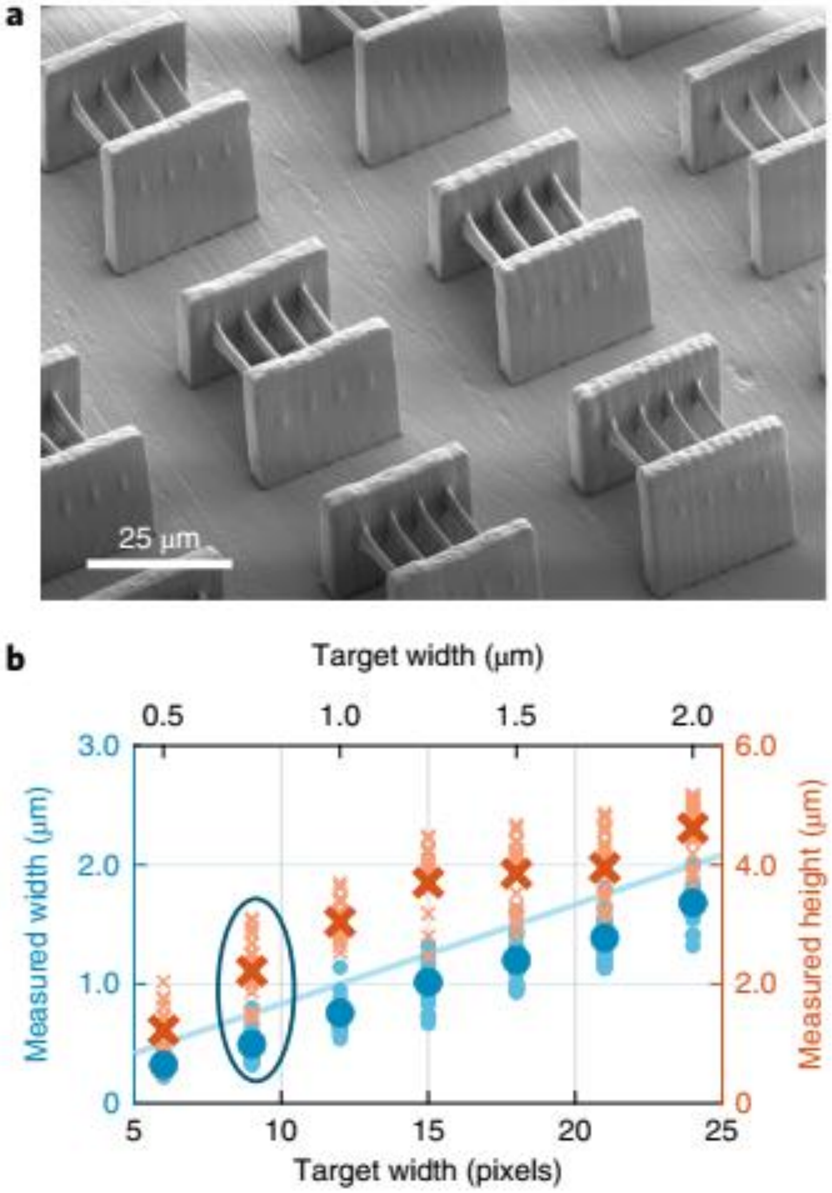
Name	Monomer	[BA]	[TEMPO]	Viscosity
PR1	TMPTA	0.11 M (1.1 wt.%)	0.011 M (0.2 wt.%)	0.1 PaS
PR2	PETA	0.11 M (1.1 wt.%)	0.011 M (0.2 wt.%)	1.0 PaS
PR3	DPEHA	0.11 M (1.1 wt.%)	0.011 M (0.2 wt.%)	6.0 PaS

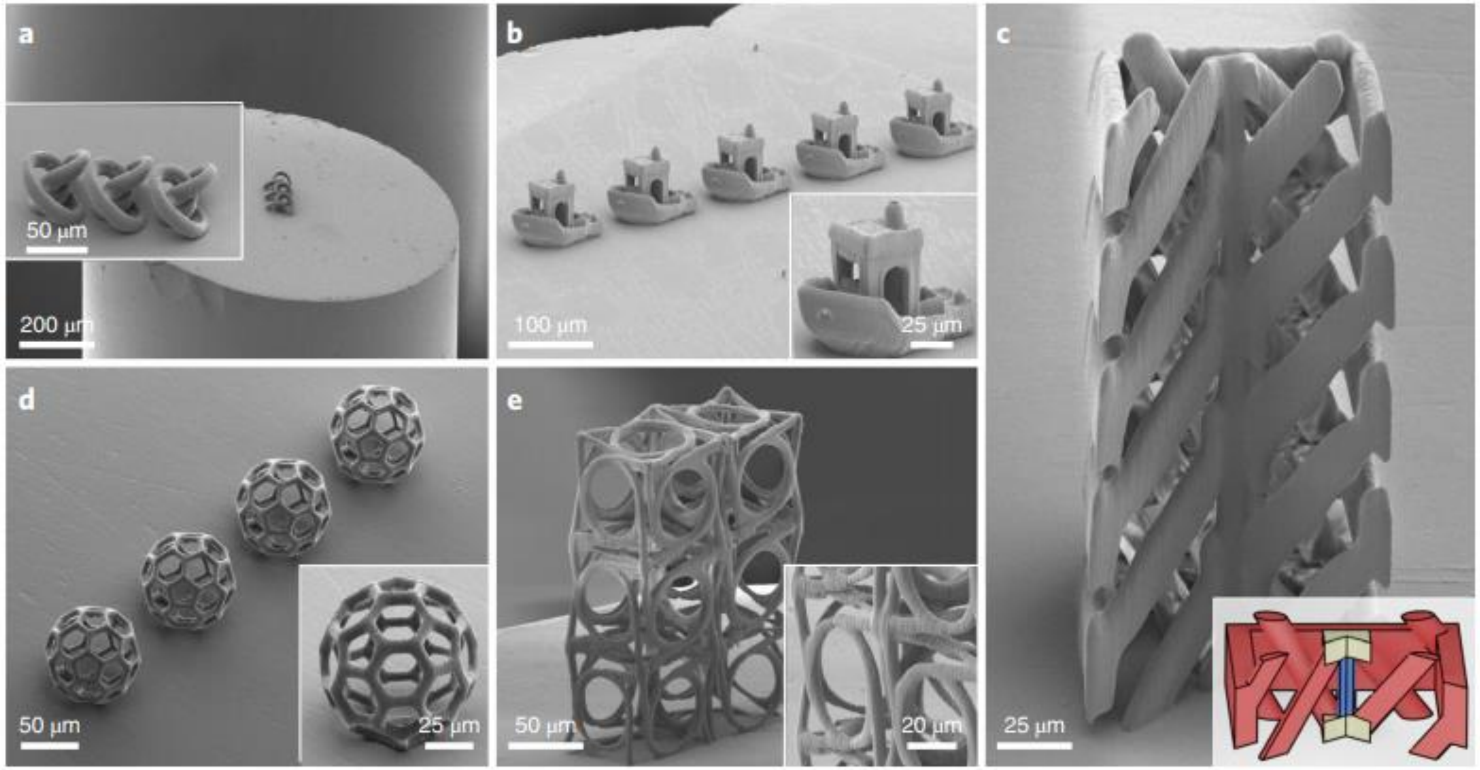
threshold intensity of bule light I_1 vs different I_2

PR1-3: photoresin with different monomer

final choice: PR3(little change in refractive index), I_1 = 0.16 mW/μm^2, I_2 = 3 mW/μm^2

Printed Various Structures





100% yield for the nine-pixel-wide lines

resolution can reach 0.5 μm in width and 2.2 μm in height

1,920 × 1,080 pixels corresponds to 3.3×10^4 voxels

printing speed can reach 7×10^6 voxels/s, 3.85×10^6 $\mu m^3/s$

Comparison of Different Methods