MICRO 423 : ADVANCED ADDITIVE MANUFACTURING TECHNOLOGIES

3D printing using continuous wave light (single photon absorption)

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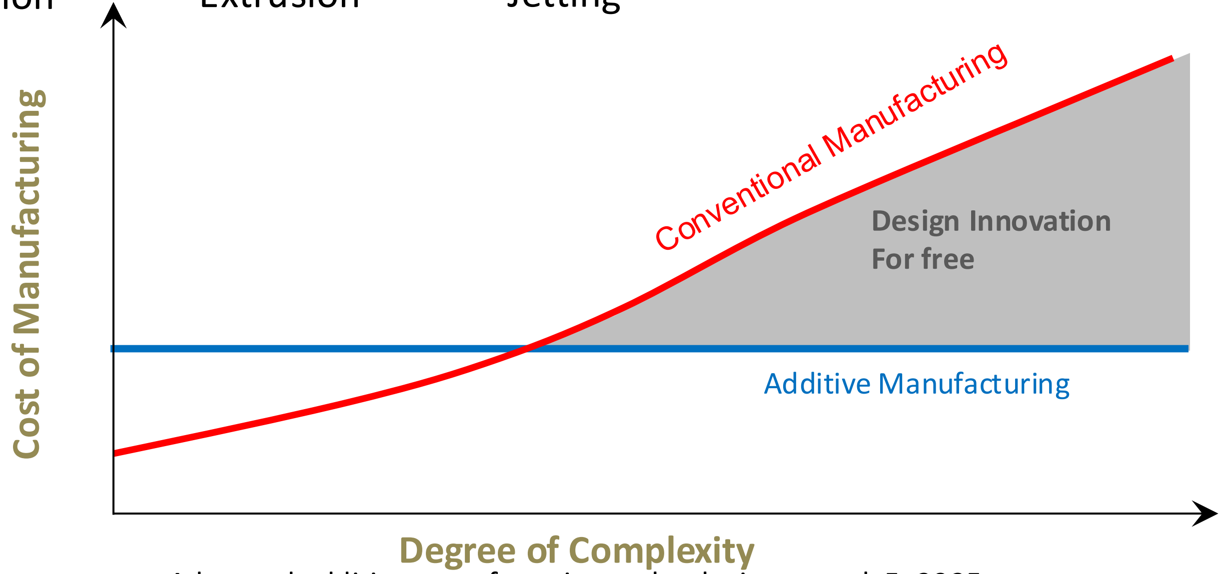
Modules of the 2025 course

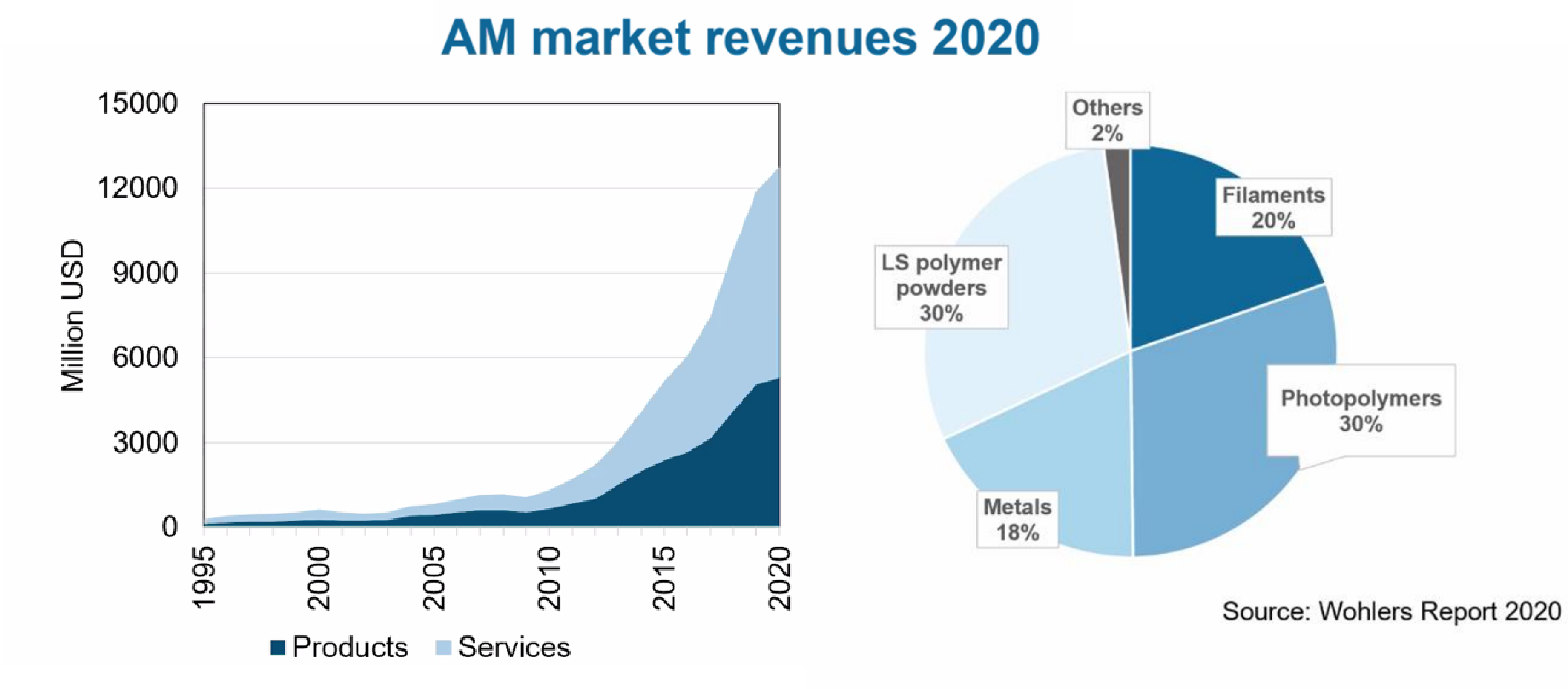
Topics covered	No	Lecture/Date
VAT Photo polymerization (history) – DLP printer – light engine – part I	5	20.03.2025
DLP printer – chemical components in a photoresin – role of oxygen – CLIP method– part II	6	27.03.2025
Tomographic Volumetric Additive Manufacturing (TVAM)	7	03.04.2025
Two photon Polymerization : nanoscale printing	8	10.04.2025
Two photon Polymerization : applications	9	17.04.2025
EASTER BREAK		22.04.2025
Prof. Paul Dalton, University of Oregon: Met Electro Writing (nanoscale)	10	1.05.2025
Gari Arutinov, Holst Center for AM: Mass transfer of microcomponents	11	08.05.2025
Julian Schneider: Scrona	12	15.05.2025
Patrizia Richner: Sonova (hearing aids). // **Design Competition**	13	22.05.2025

QUIZZ #2

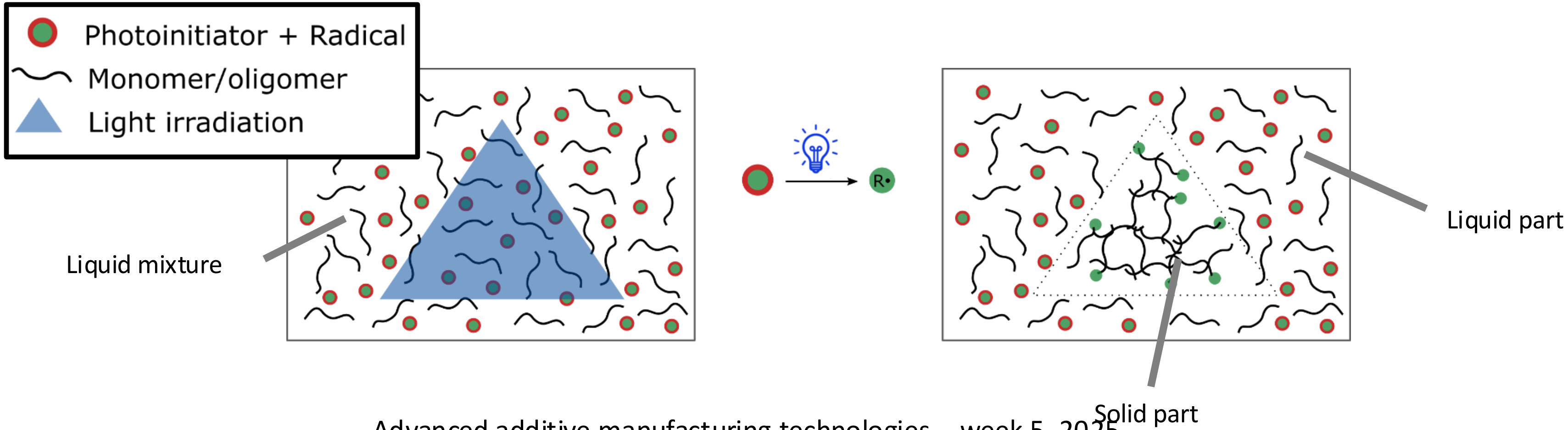
Vat photopolymerization | Material Extrusion | Material Jetting | Binder Jetting | Powder bed fusion



Are polymers important in AM ?



Photopolymerization



Historical perspective

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First use of single photon polymerization in 3D printing

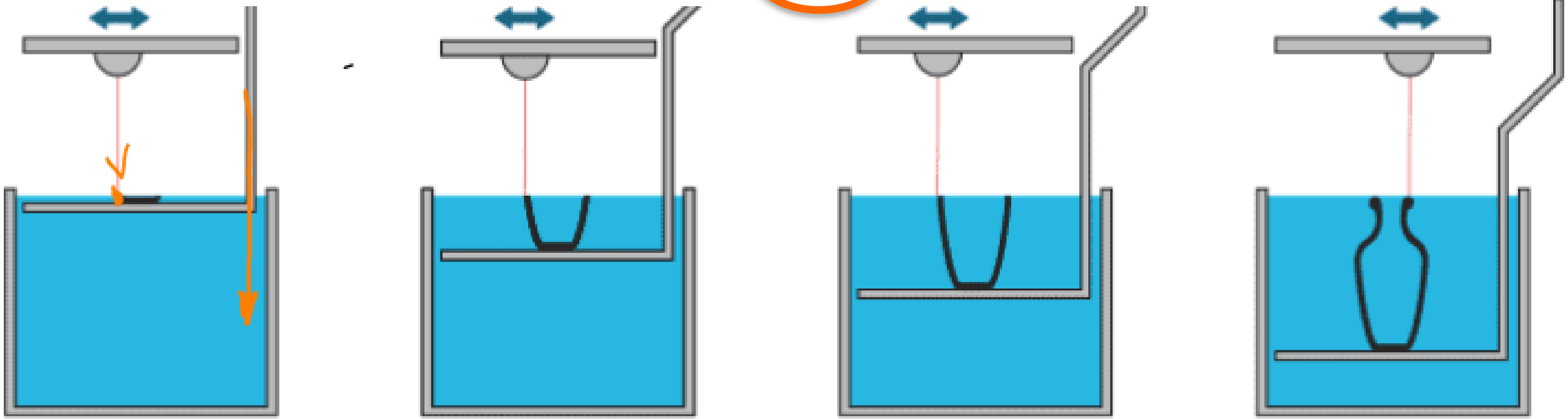
Automatic method for fabricating a three-dimensional plastic model with photo-hardening polymer

Hideo Kodama

Nagoya Municipal Industrial Research Institute, 3-24 Rokuban-cho, Atsuta-ku, Nagoya 456, Japan

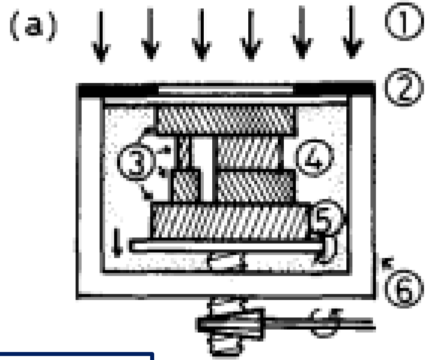
(Received 10 February 1981; accepted for publication 2 August 1981)

Review of Scientific Instruments, Vol. 52, Issue 11, Nov. 1981

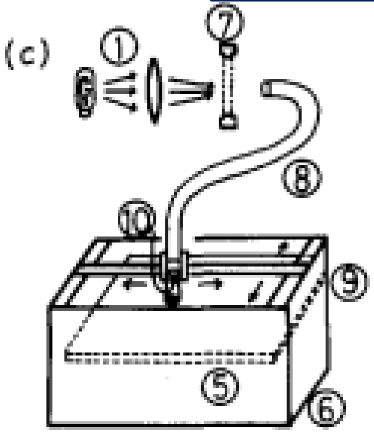


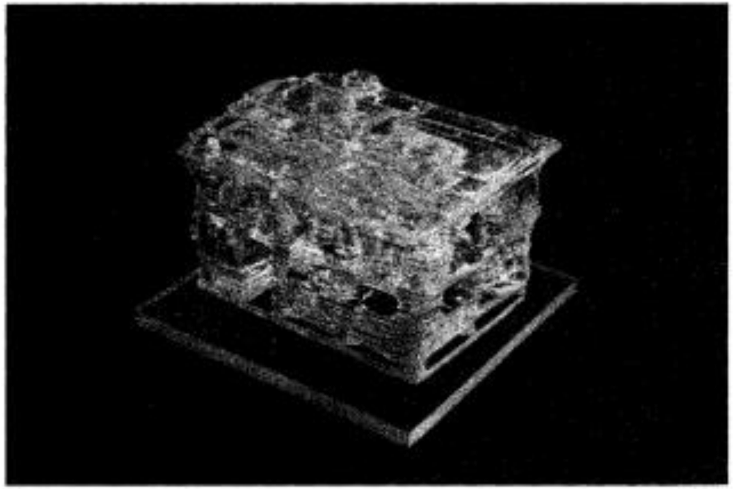
Historical perspective

Top-bottom

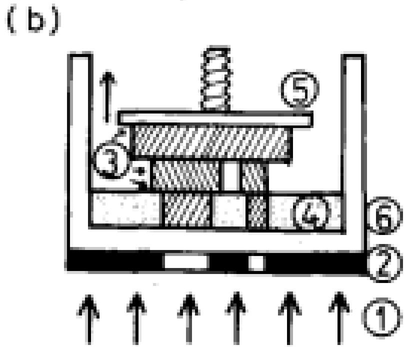


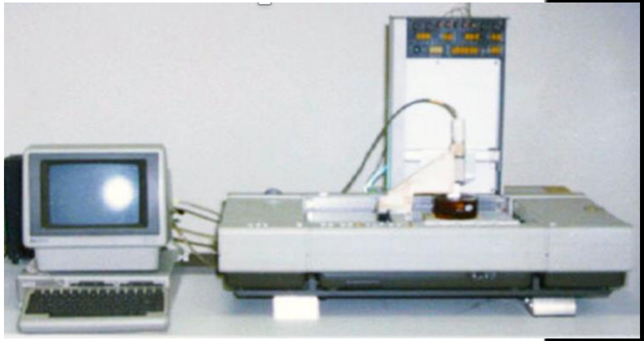
Point by Point

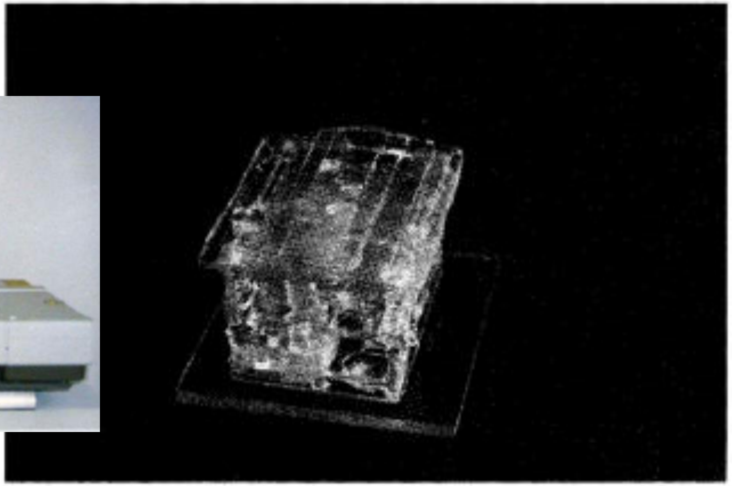




Bottom-up







Advanced additive manufacturing technologies

FIG. 7. A house model fabricated by the equipment *a*.

1980: First patent by Japanese Dr. Kodama for Rapid Prototyping : "***a vat of photopolymer material is exposed to a UV light that hardens the part and builds up the model in layers***".

Not enough 

... the full patent was not filed within the 1-year deadline !

1984: 3 French scientists at CNRS independently discover the same thing, file at patent application on July 16, 1984.

Alcatel – Cilas drop the application "**for lack of business perspective**" !!

1984: In the US, Chuck Hulls independently discovers the same thing, file a patent application on Aug. 8, 1984.

EPFL

(12) **DEMANDE DE BREVET D'INVENTION** A1

(22) **Date de dépôt :** 16 juillet 1984.

(30) **Priorité :**

(43) **Date de la mise à disposition du public de la demande :** BOPI « Brevets » n° 3 du 17 janvier 1986.

(60) **Références à d'autres documents nationaux apparentés :**

(71) **Demandeur(s) :** *COMPAGNIE INDUSTRIELLE DES LASERS CILAS ALCATEL, société anonyme.* — FR.

(54) **Dispositif pour réaliser un modèle de pièce industrielle.**

(72) **Inventeur(s) :** Jean-Claude André, Alain Le Mehauté et Olivier De Witte.

(73) **Titulaire(s) :**

3D SYSTEMS

$ 600 Million/year

United States Patent [19]

Hull

[11] **Patent Number:** **4,575,330**

[45] **Date of Patent:** **Mar. 11, 1986**

[54] **APPARATUS FOR PRODUCTION OF THREE-DIMENSIONAL OBJECTS BY STEREOLITHOGRAPHY**

[75] Inventor: **Charles W. Hull, Arcadia, Calif.**

[73] Assignee: **UVP, Inc., San Gabriel, Calif.**

[21] Appl. No.: **638,905**

[22] Filed: **Aug. 8, 1984**

4,252,514	2/1981	Gates	425/162
4,288,861	9/1981	Swainson et al.	365/127
4,292,015	9/1981	Hritz	425/162 X
4,329,135	5/1982	Beck	425/174
4,333,165	6/1982	Swainson et al.	365/127 X
4,374,077	2/1983	Kerfeld	264/22
4,466,080	8/1984	Swainson et al.	365/127 X
4,471,470	9/1984	Swainson et al.	365/127

Primary Examiner—J. Howard Flint, Jr.

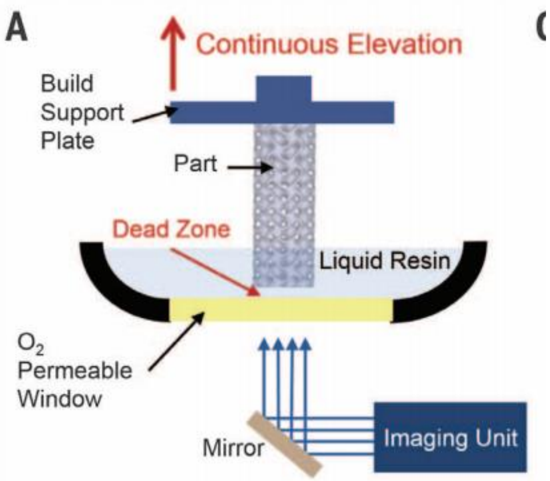
Science

ADDITIVE MANUFACTURING

Continuous liquid interface production of 3D objects

2015
1200 citations

John R. Tumbleston,[1] David Shirvanyants,[1] Nikita Ermoshkin,[1] Rima Janusziewicz,[2] Ashley R. Johnson,[3] David Kelly,[1] Kai Chen,[1] Robert Pinschmidt,[1] Jason P. Rolland,[1] Alexander Ermoshkin,[1*] Edward T. Samulski,[1,2*] Joseph M. DeSimone[1,2,4*]

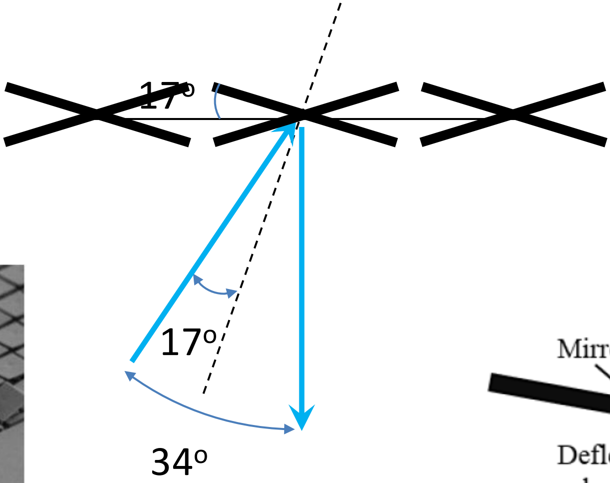


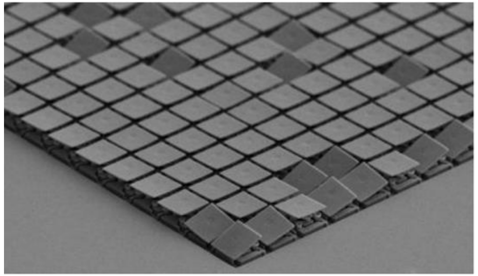
Carbon 3D

Founded 2013: Raised $422 M.

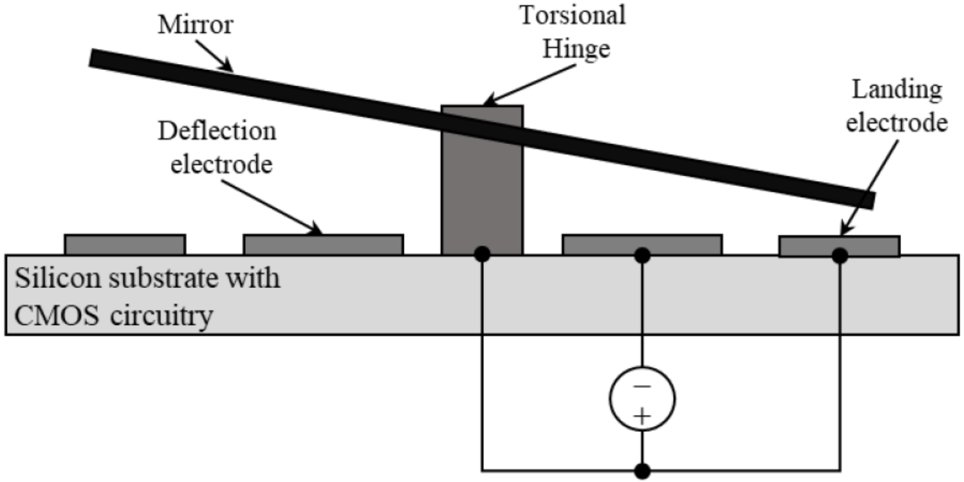
- light engine for DLP printing
- Experiments with DLP
- Resin chemistry

Digital MicroMirror Array (DLP™)

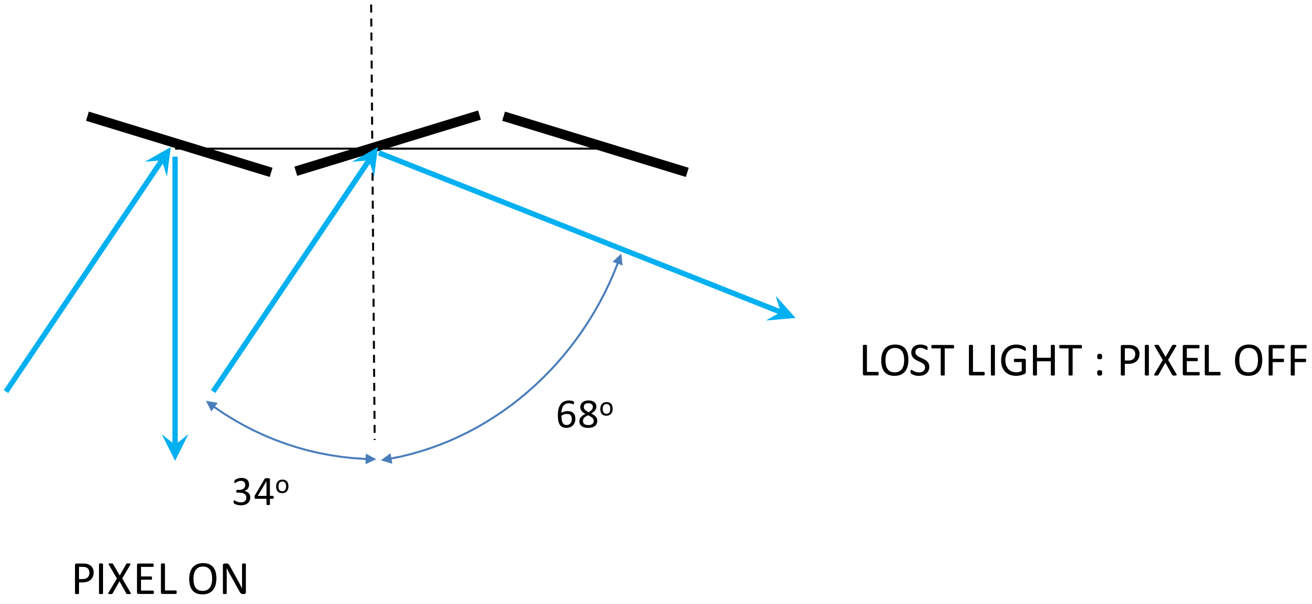




Pixel size.
5.4 x .5.4 um
1920 x 1080 pixels



Digital MicroMirror Array (DLP™)



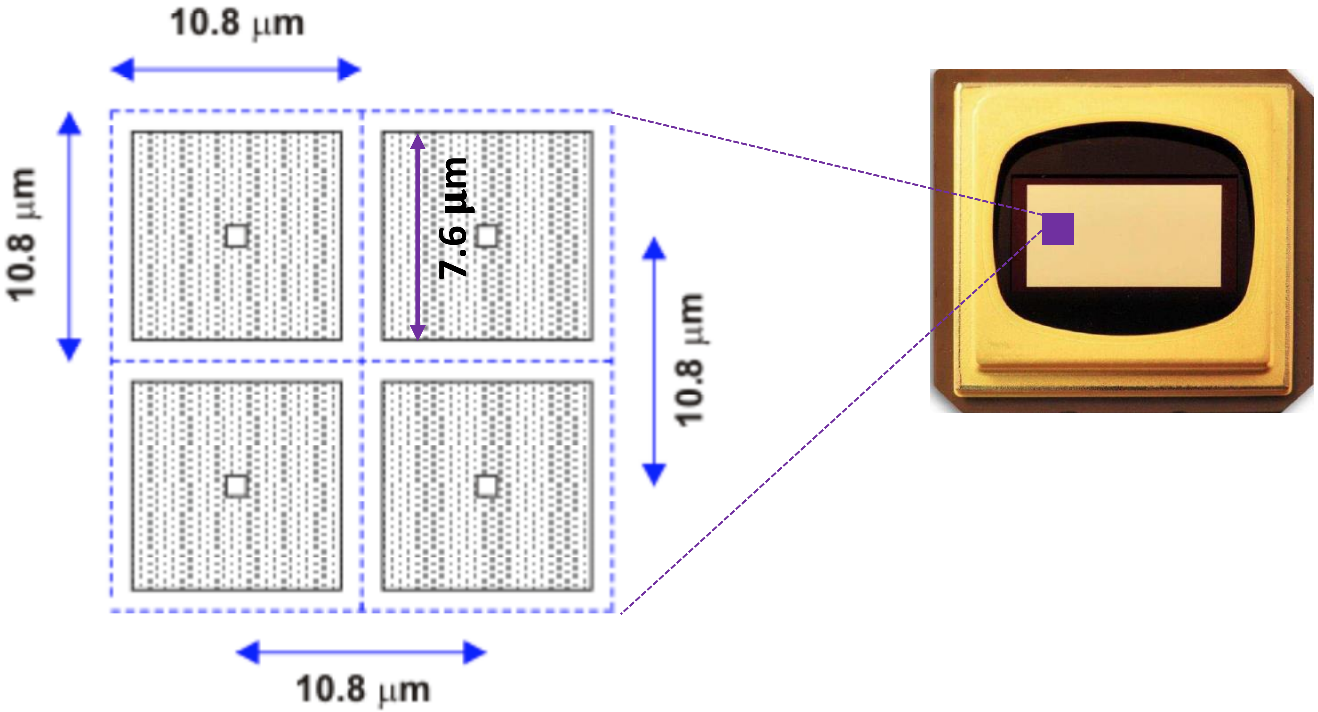
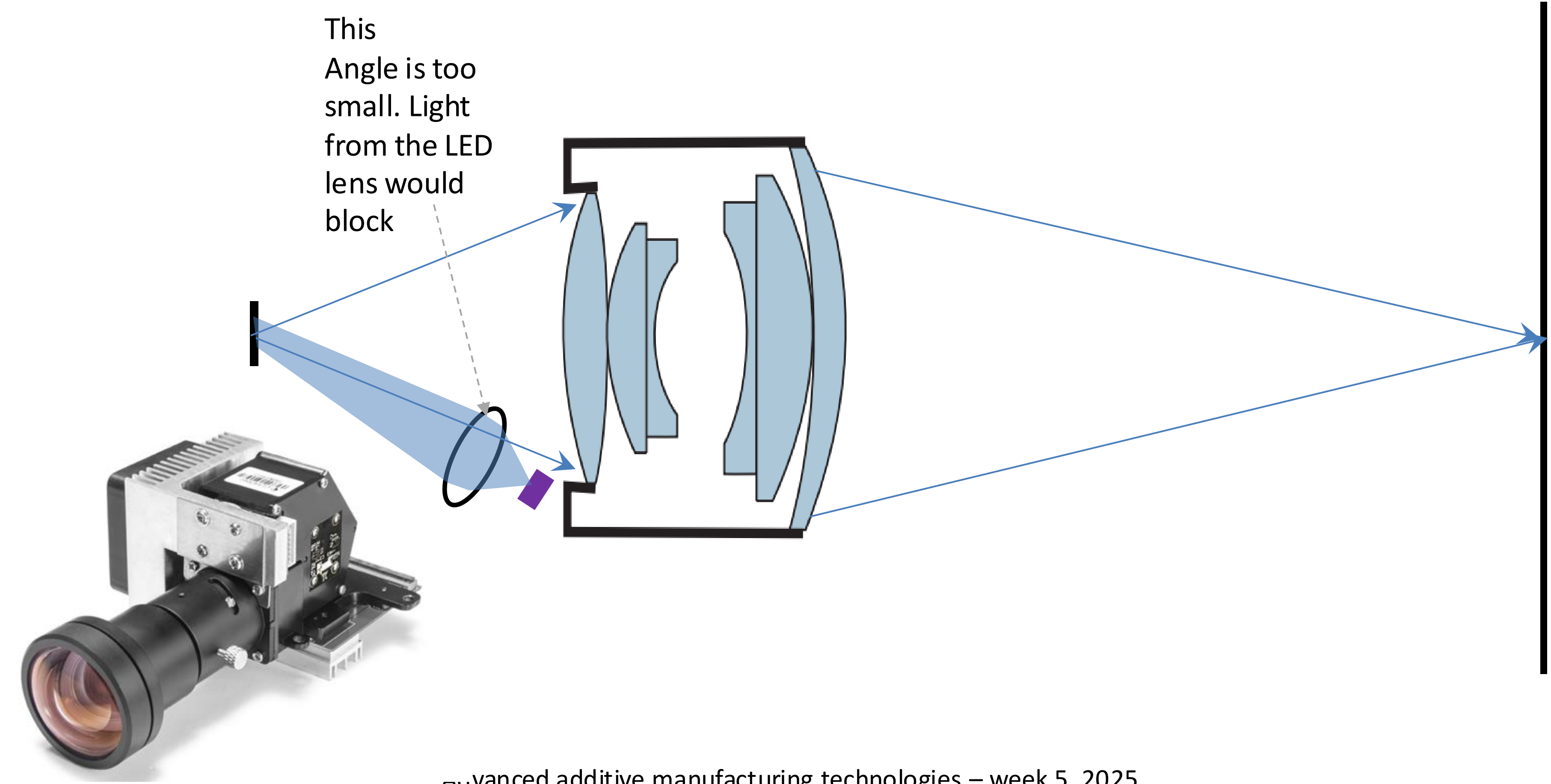
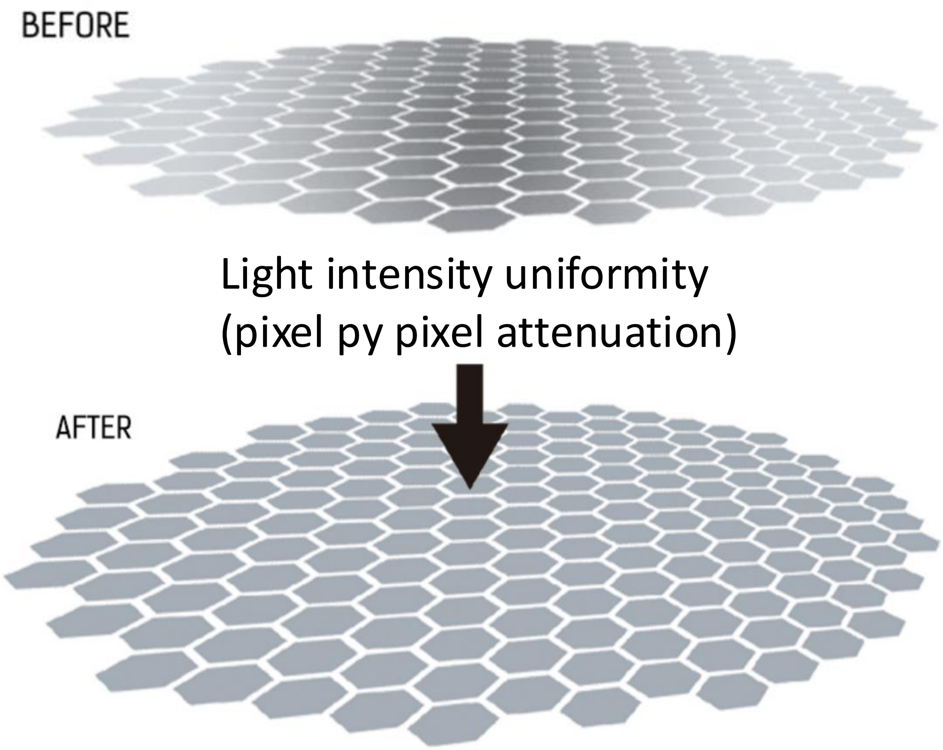


Figure 4. DLP5500 Micromirror Pitch

1920 x 1080 pixels
16:9 ratio
(1.78)

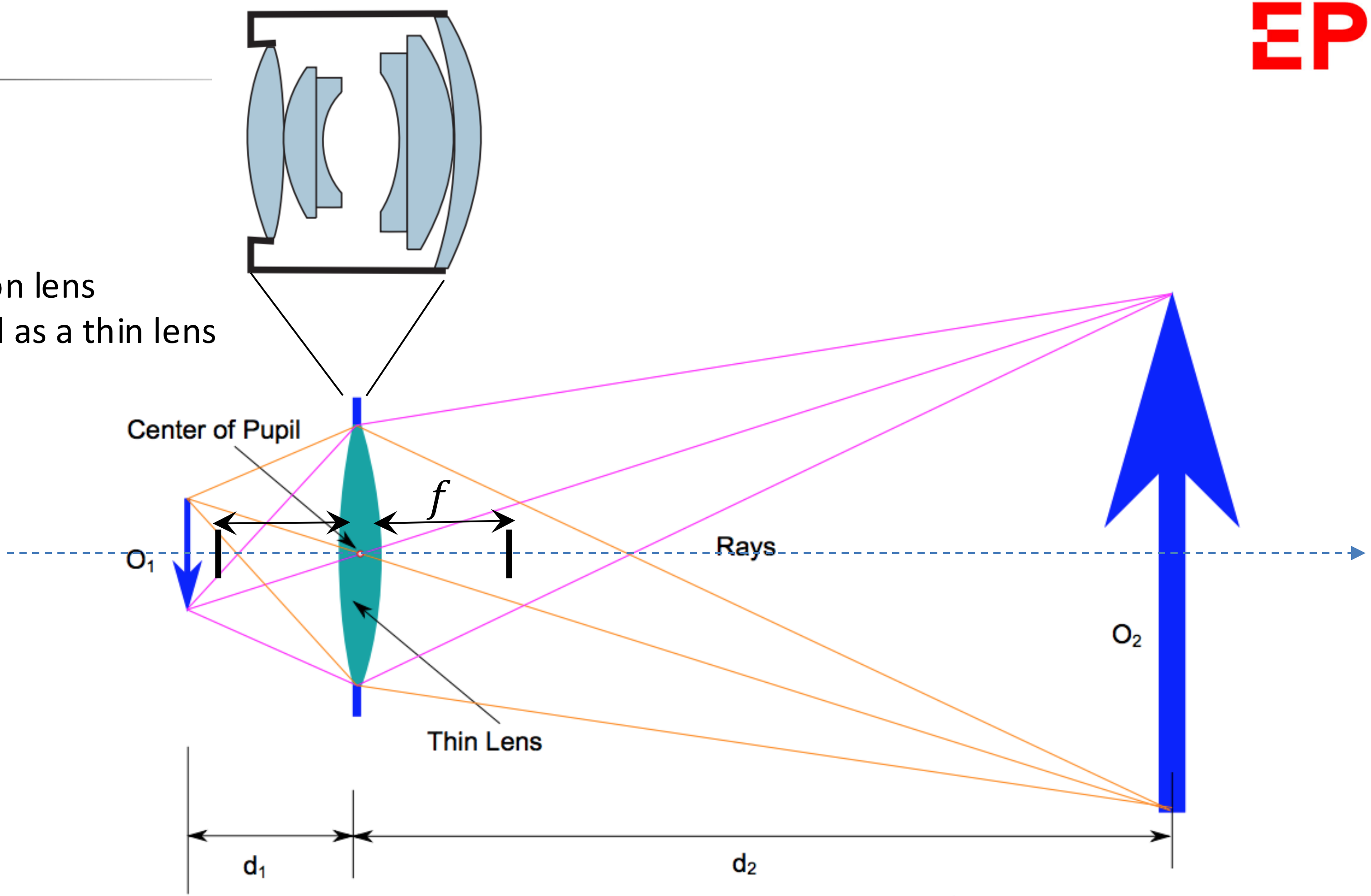

This
Angle is too
small. Light
from the LED
lens would
block

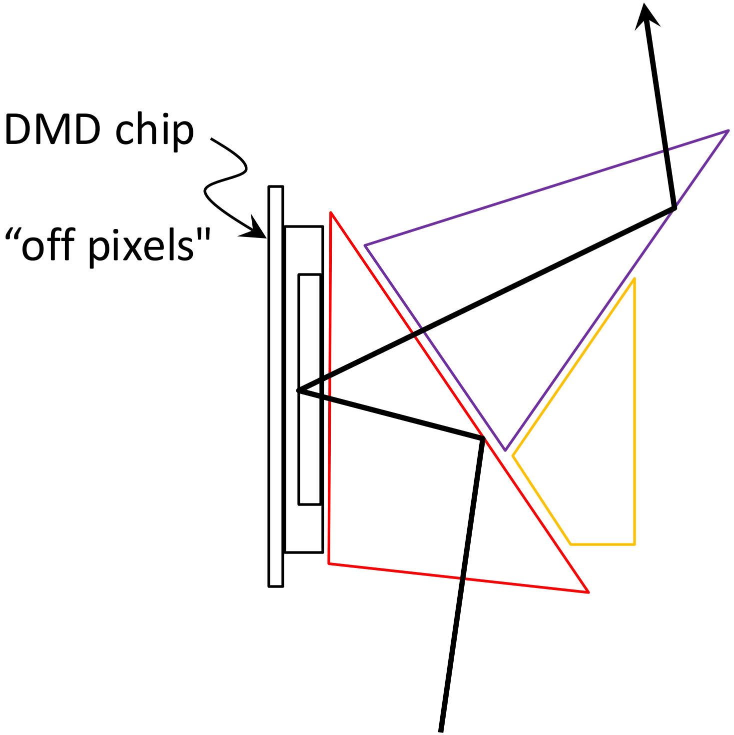


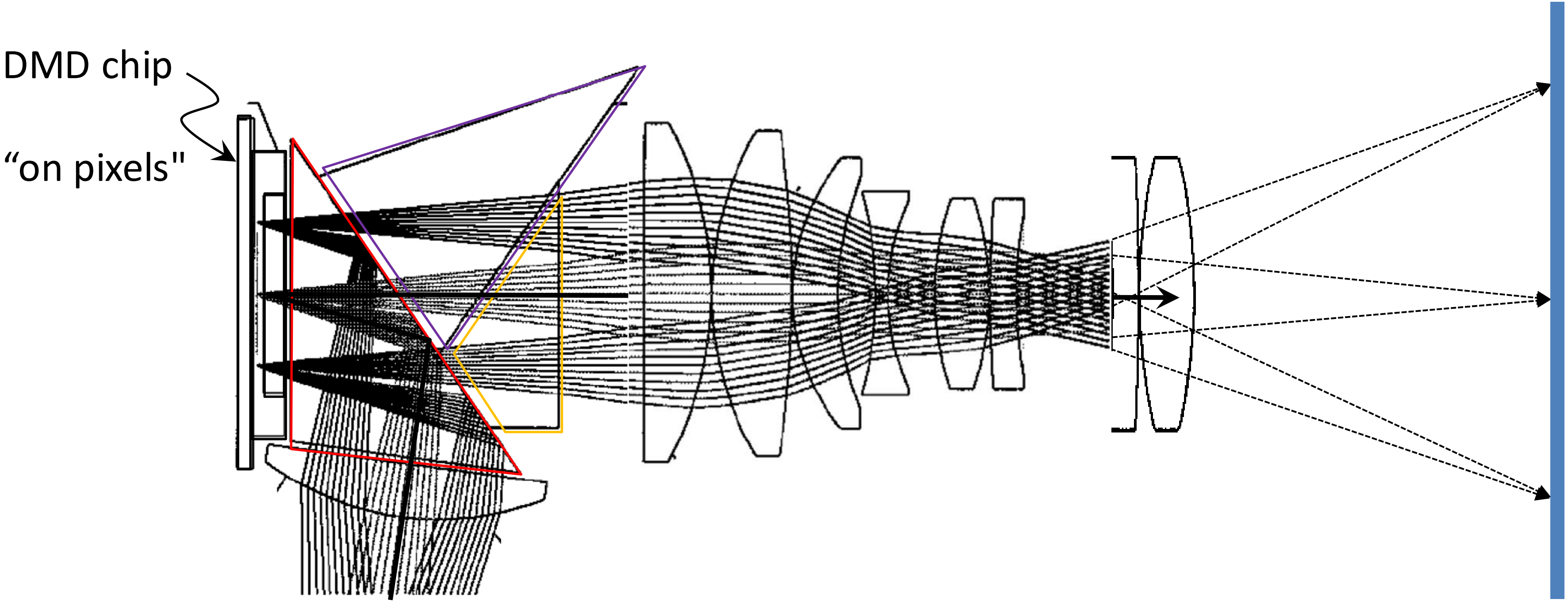
Light intensity uniformity
(pixel py pixel attenuation)

Build Volume: 4.72″ x 2.66″ x 5.91″
(120 x 67.5 x 150mm)
L x W x H
Pixel Size X, Y: 0.0025″ (62.5µm)

Complex
Projection lens
Modeled as a thin lens

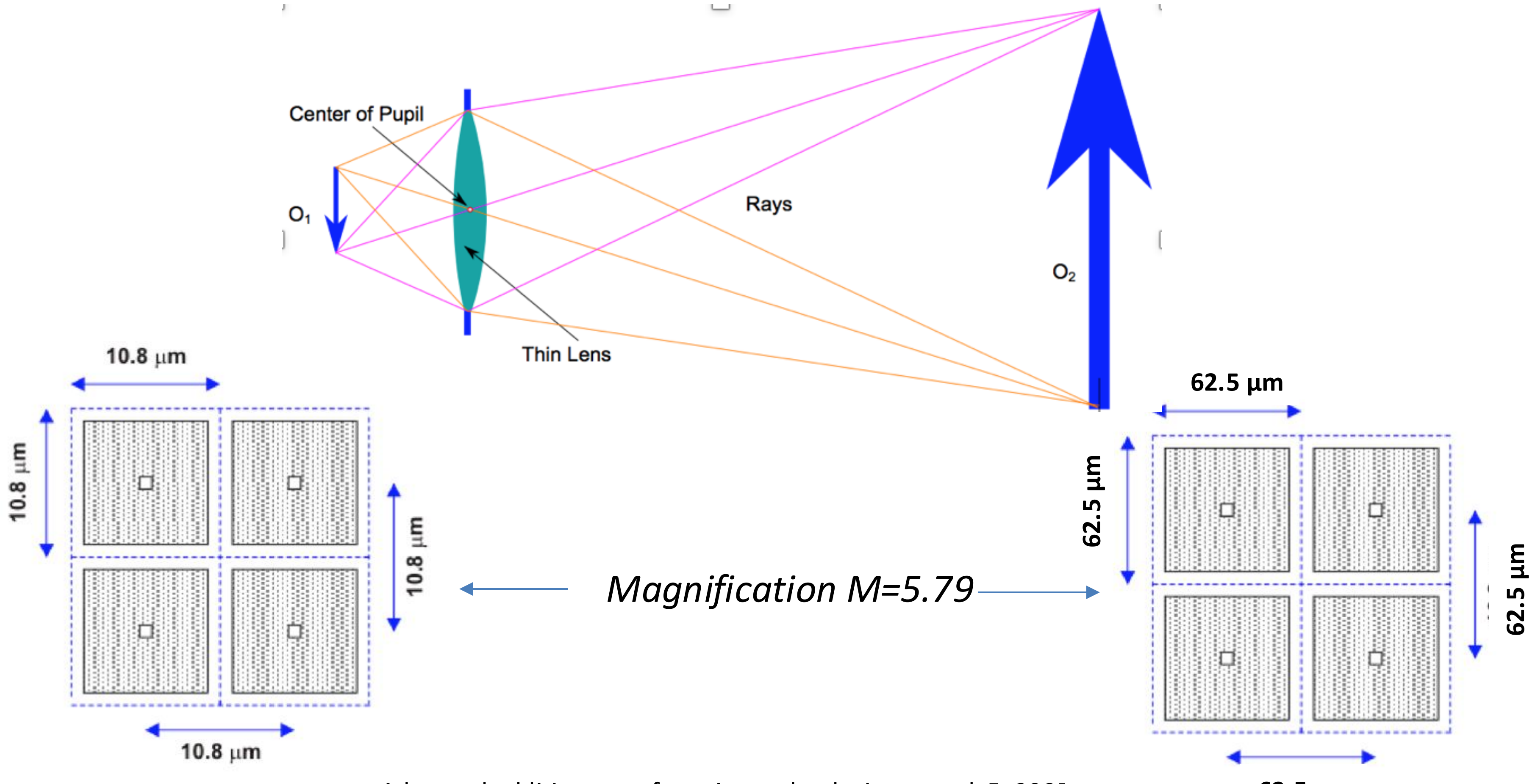



DMD chip
“off pixels"


DMD chip
“on pixels"

Draw a sketch of how the components are positioned (light source& board, DMD, lens) based on the system below

Geometrical Optics



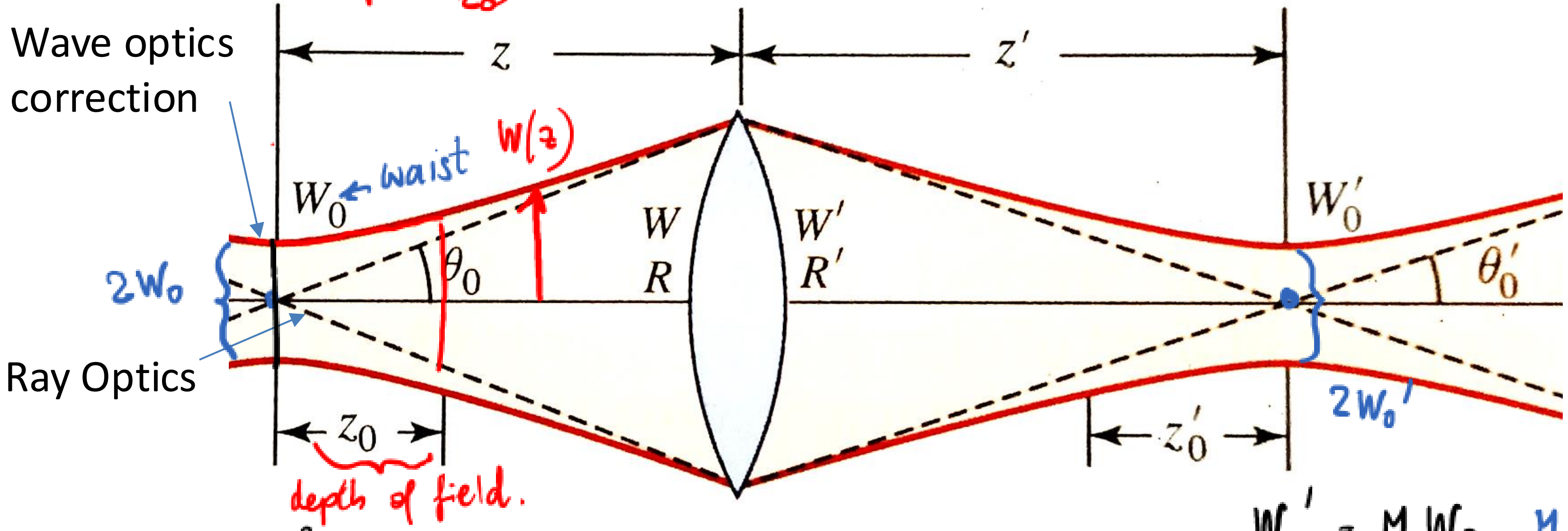
Wave Optics

EPFL

NOT TO SCALE

$\lambda = 400\,nm$

$$W(z) = W_0\sqrt{1+\left(\frac{z}{z_0}\right)^2}, \quad W(z=z_0) = \sqrt{2}\cdot W_0$$



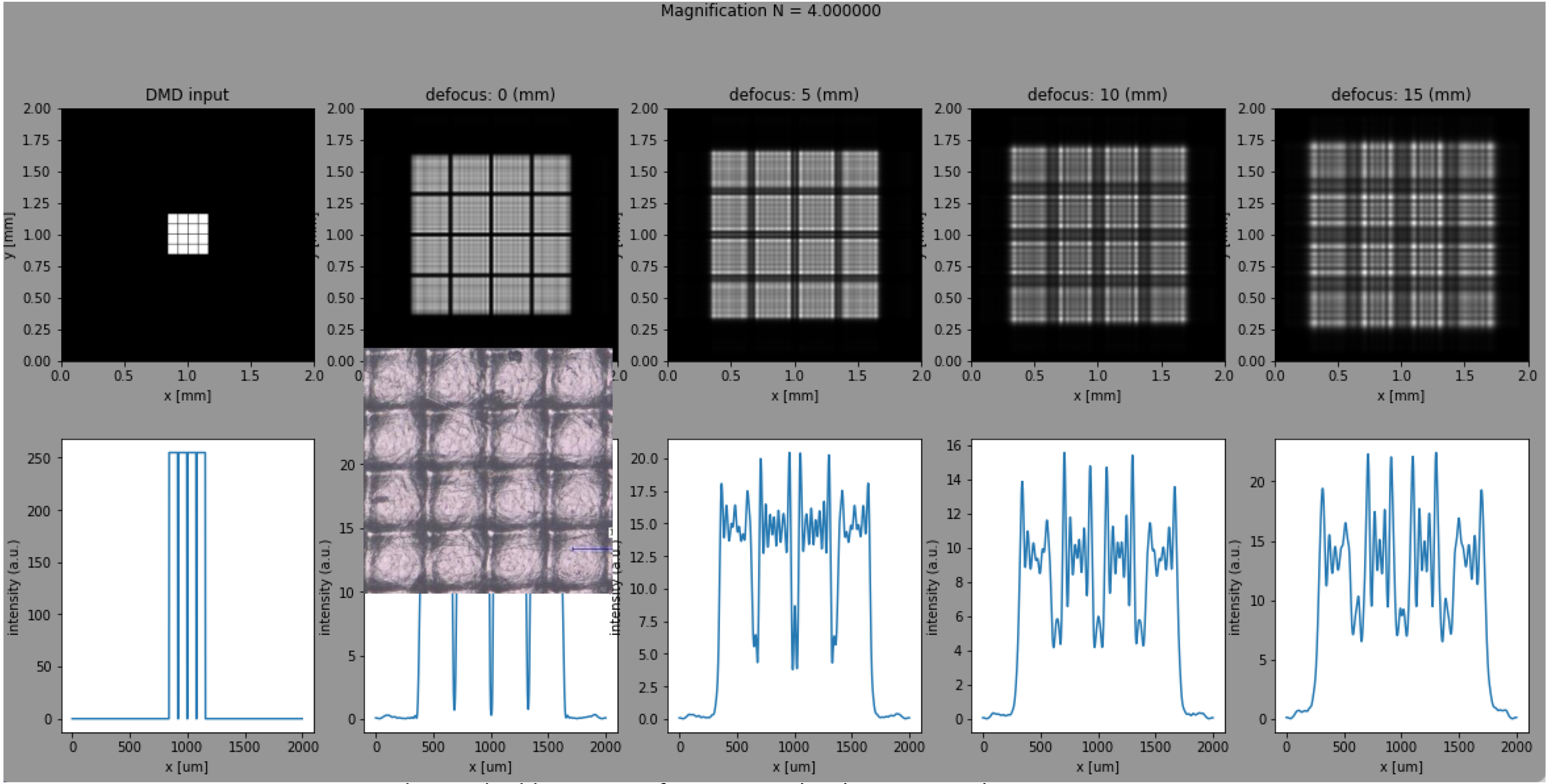
$W_0' = M\,W_0 \quad M = 5.79$

$z_0 = \frac{\pi W_0^2}{\lambda} \Rightarrow z_0 = 183\,\mu m.$

$z_0' = M^2 z_0 \Rightarrow z_0' = 6.13\,mm.$

pixel size: $5.4\,\mu m = W_0$

Simulation

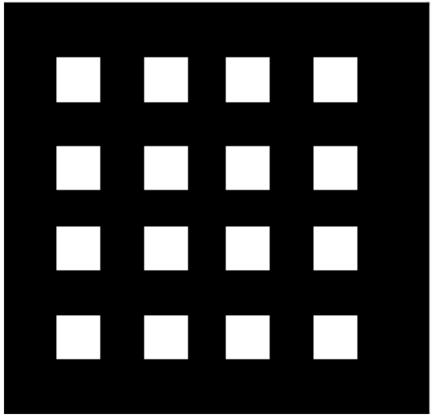


Magnification N = 4.000000
DMD input
defocus: 0 (mm)
defocus: 5 (mm)
defocus: 10 (mm)
defocus: 15 (mm)
y [mm]
x [mm]
intensity (a.u.)
x [um]

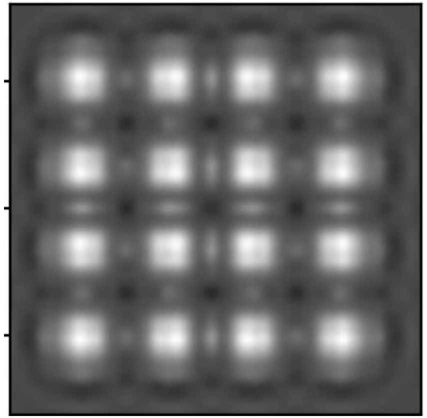
Simulation

Image plane

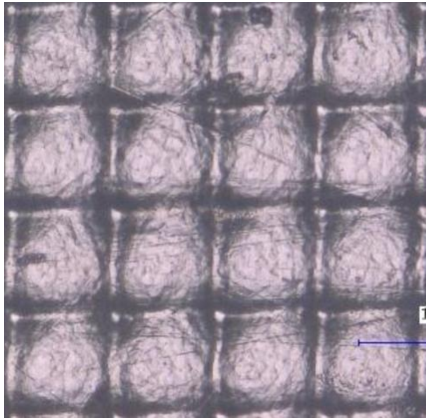
Input



Output



Real surface measurement



(exercise)

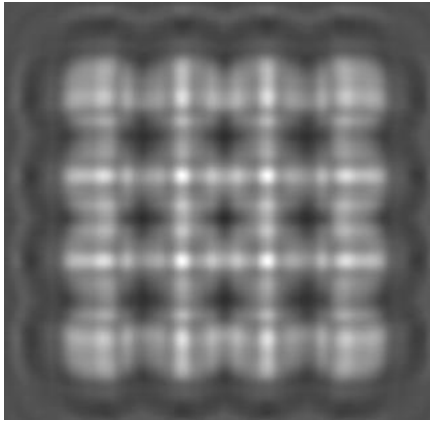


Image plane + 2mm

Example

Design a DLP printer projector for microlithography i.e we are interested in making small but high resolution structures. Assume we want to achieve 10 um spatial resolution with a build volume of 15 x 15 x 15 mm.

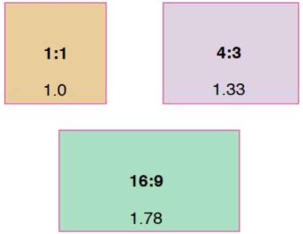
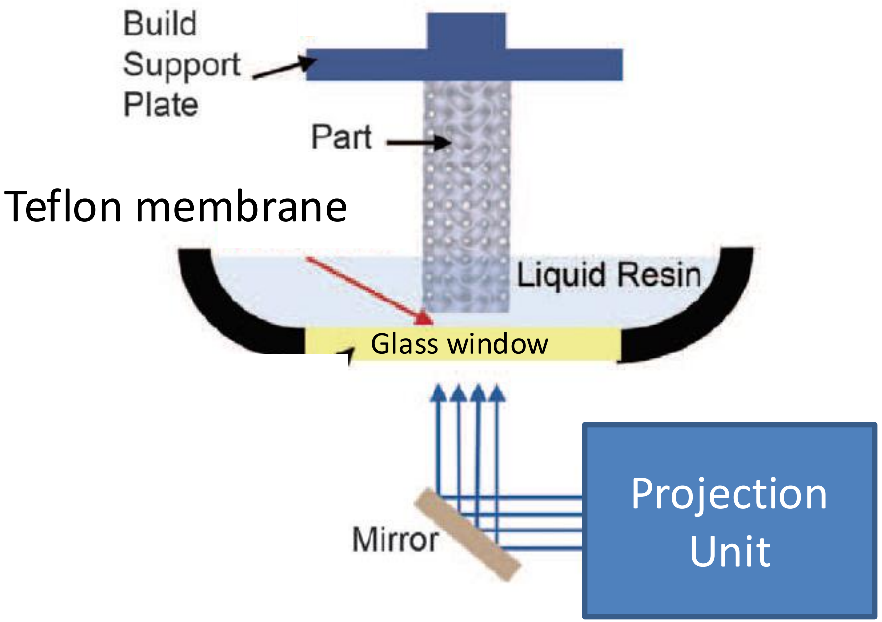


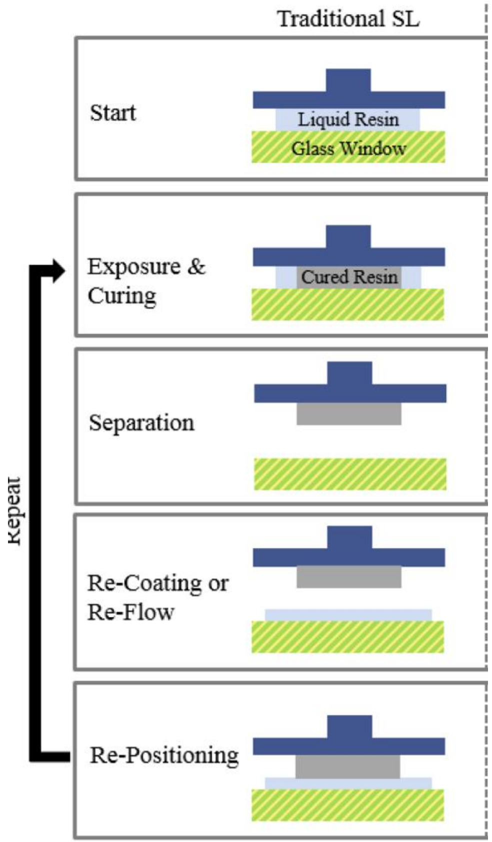
Figure 1. Aspect Ratios

Figure 2. DLP DMDs With Their Aspect Ratios

i.e Find the lens, the distance of the DLP chip to the lens , distance of the image plane from the lens (i.e where the resin container is located)

DLP 3D printing



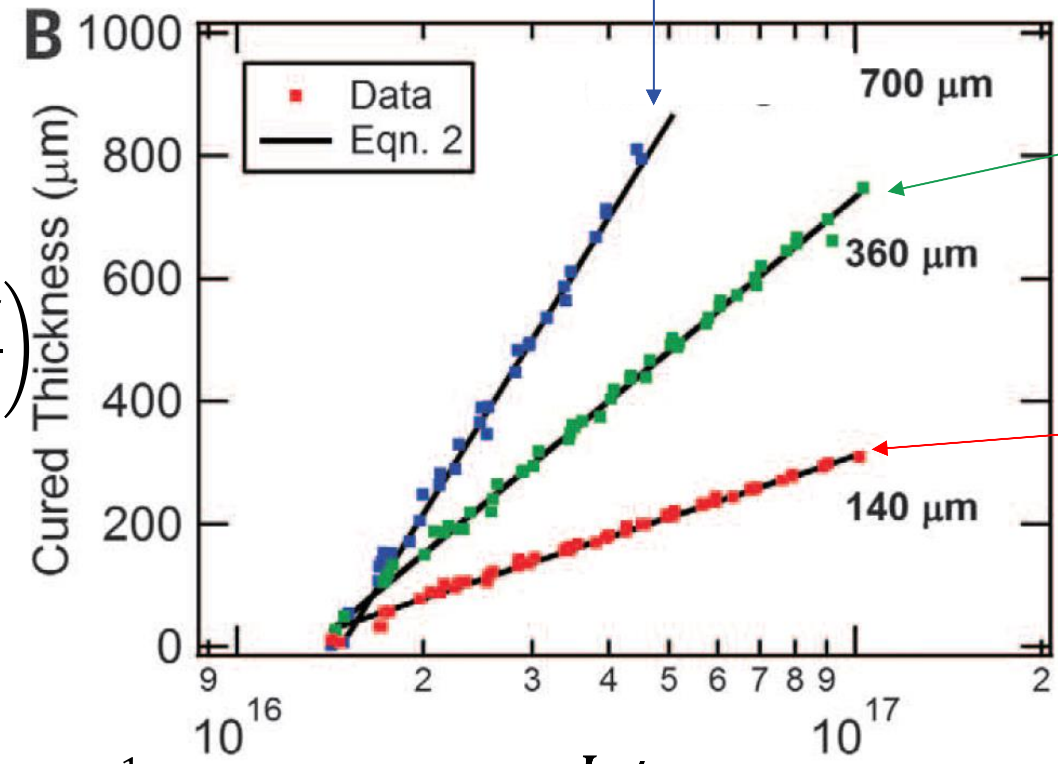


$$\alpha_3 = \alpha_{PI} + \alpha_{3,dye}$$

$$\alpha_2 = \alpha_{PI} + \alpha_{2,dye}$$

$$\alpha_1 = \alpha_{PI} + \alpha_{1,dye}$$

$$z_{ct} = \frac{1}{\alpha_i} ln\left(\frac{\alpha_i I_0 t}{D_c}\right)$$



$$I_0 t$$

Penetration depth $h = \frac{1}{\alpha_i}$

RESIN PARAMETERS

FH1100 STANDARD RESIN

Appearance	Gray
Density (g/cm^3)	1.14
Viscosity (cps)	350 cps (25°C)
Critical Exposure Ec (mJ/cm^2)	12 mJ/cm^2
Penetration Depth (dp)	0.2 mm

As comparison
Water has a viscosity of 1 cps at 20°C