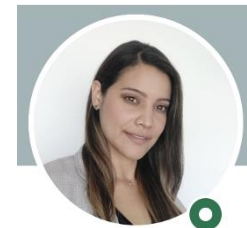


MICRO 423 : ADVANCED ADDITIVE MANUFACTURING TECHNOLOGIES

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

Prof. Christophe Moser

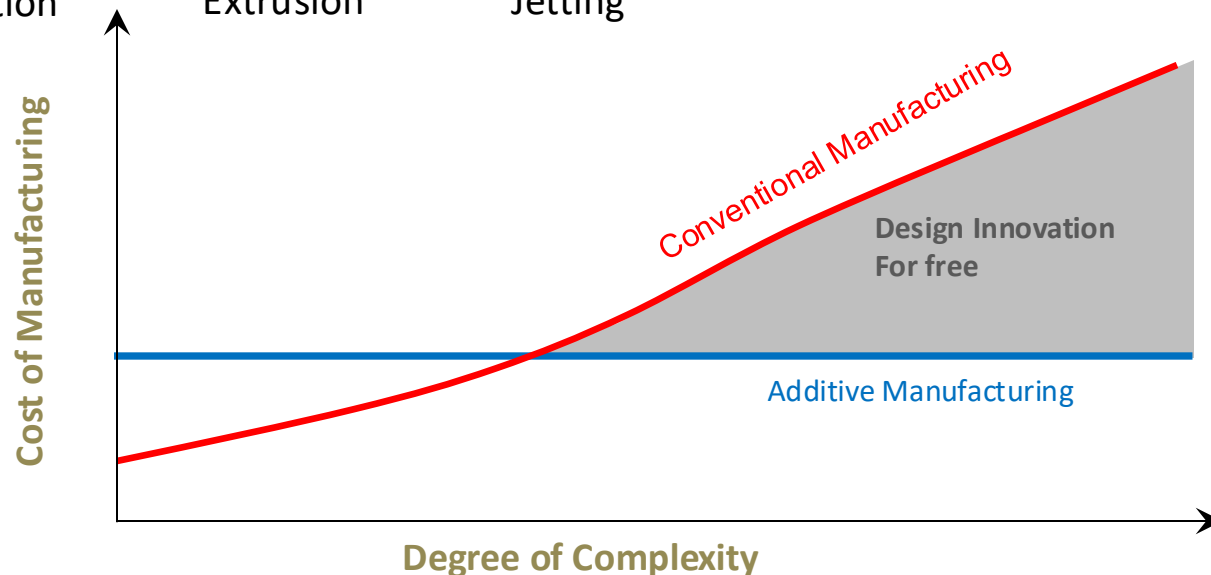
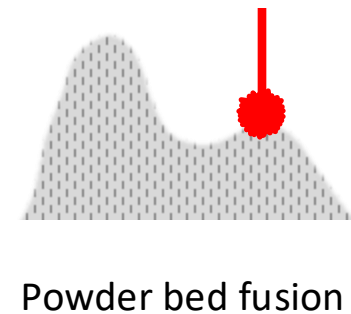
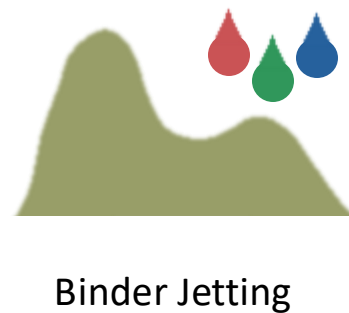
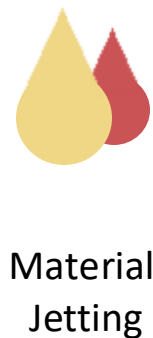
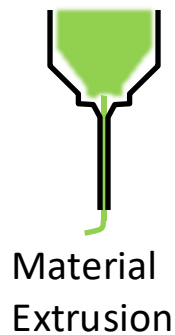
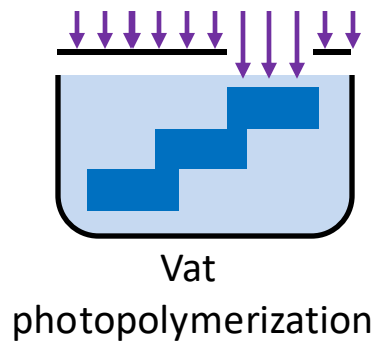
Maria Alvarez Castaño
maria.alvarezcastano@epfl.ch



Modules of the 2025 course

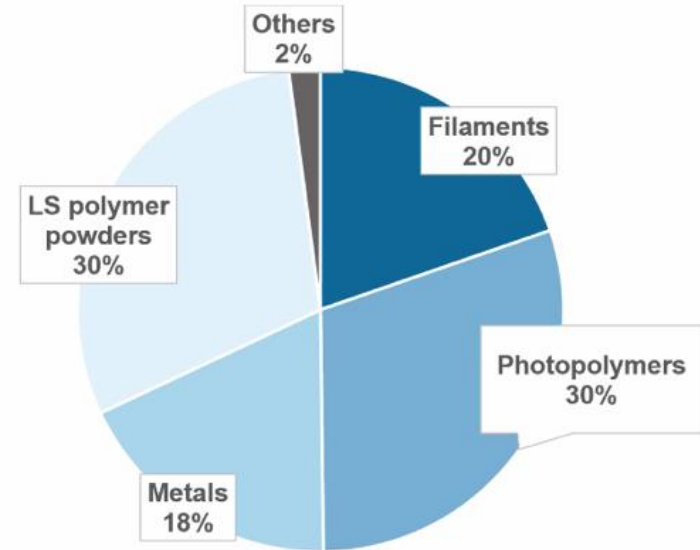
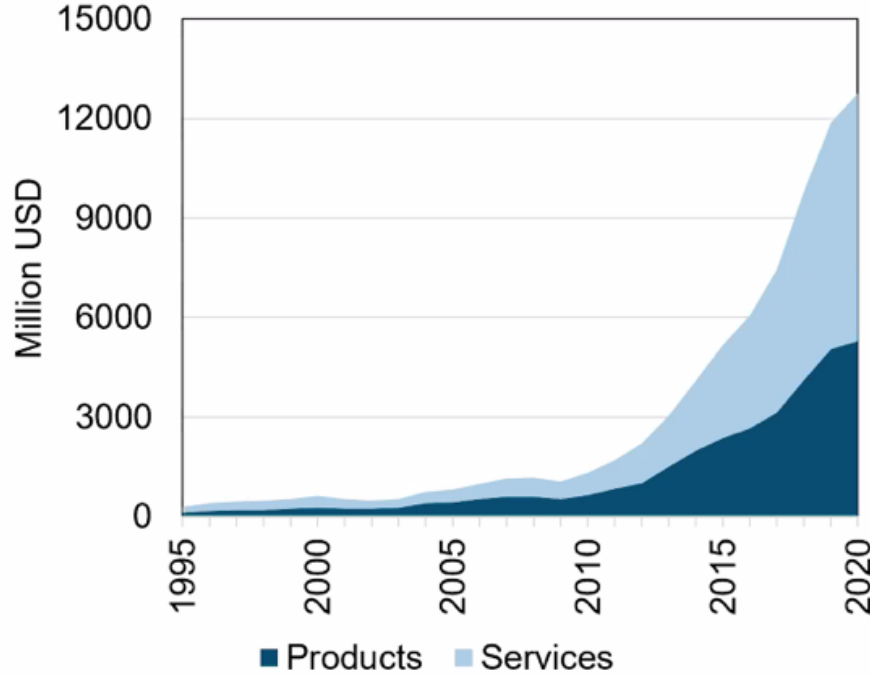
Topics covered	No	Lecture/Date
VAT Photo polymerization (history) – DLP printer – light engine – part I	5	20.03.2025
DLP printer – chemical components in a photoresin – role of oxygen – CLIP method– part II	6	27.03.2025
Tomographic Volumetric Additive Manufacturing (TVAM)	7	03.04.2025
Two photon Polymerization : 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



Are polymers important in AM ?

AM market revenues 2020

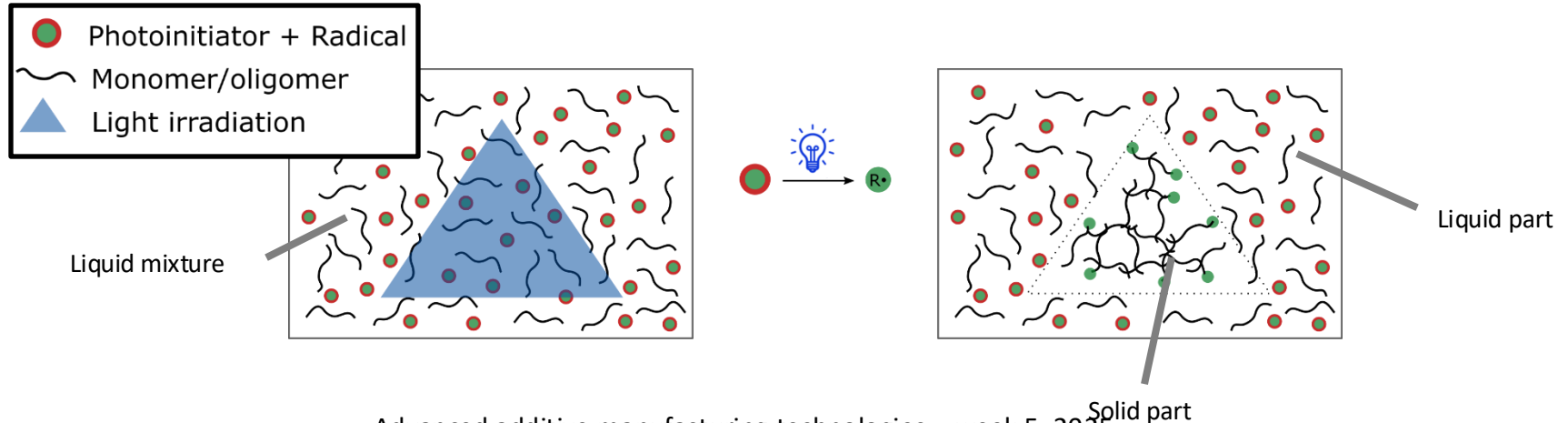


Source: Wohlers Report 2020

Photopolymerization



Light Irradiation



Historical perspective

First use of single photon polymerization in 3D printing

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

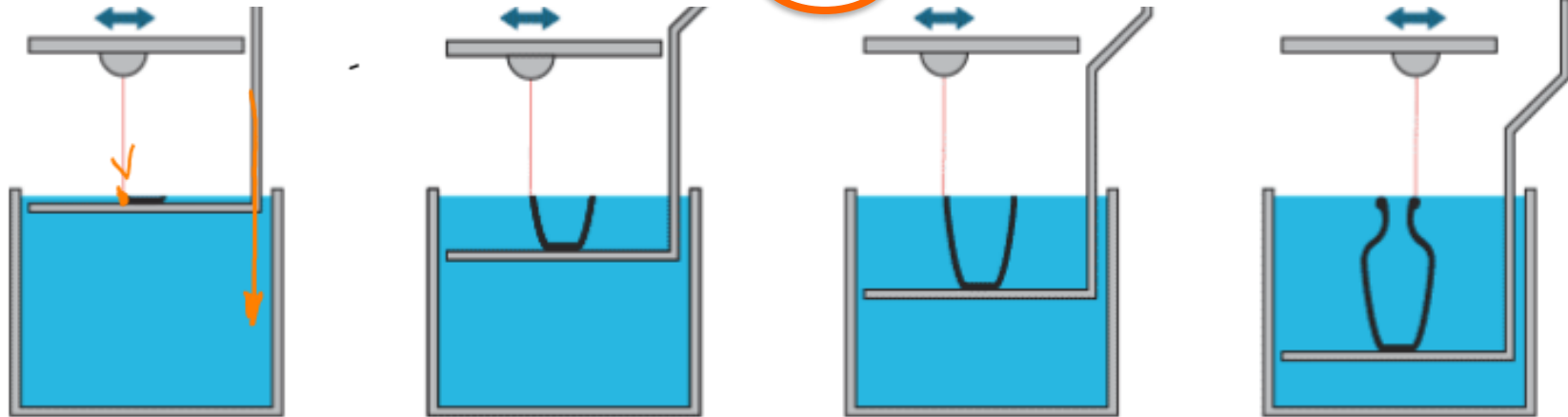
Hideo Kodama

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

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



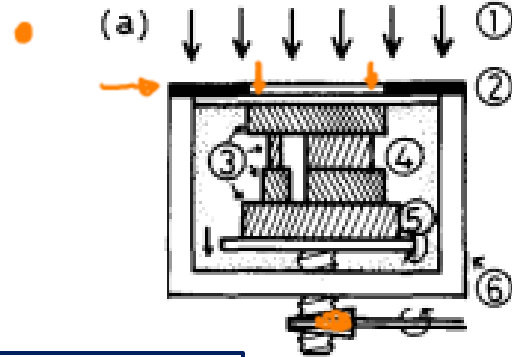
Review of Scientific Instruments,
Vol. 52, Issue 11, Nov. 1981



Historical perspective

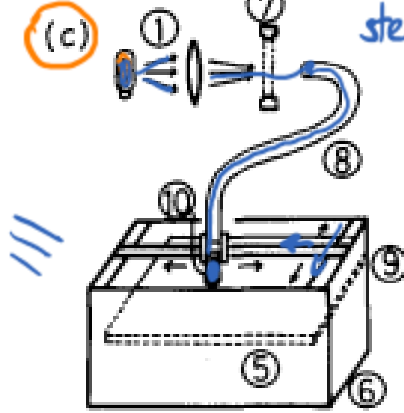
Top-bottom

DLP printing
UV



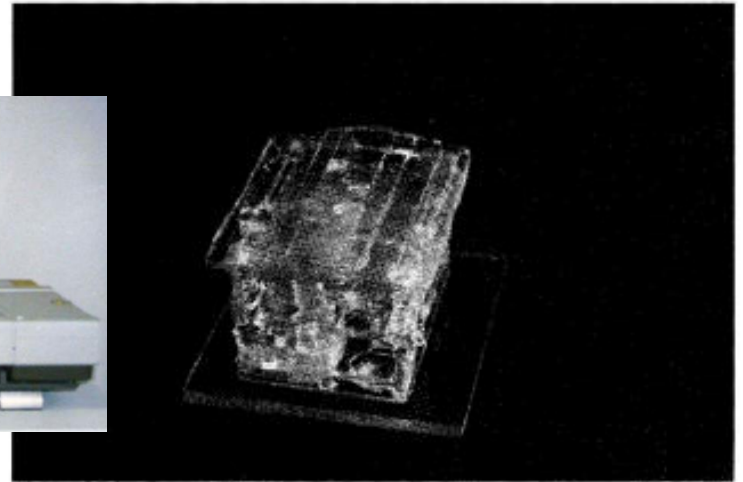
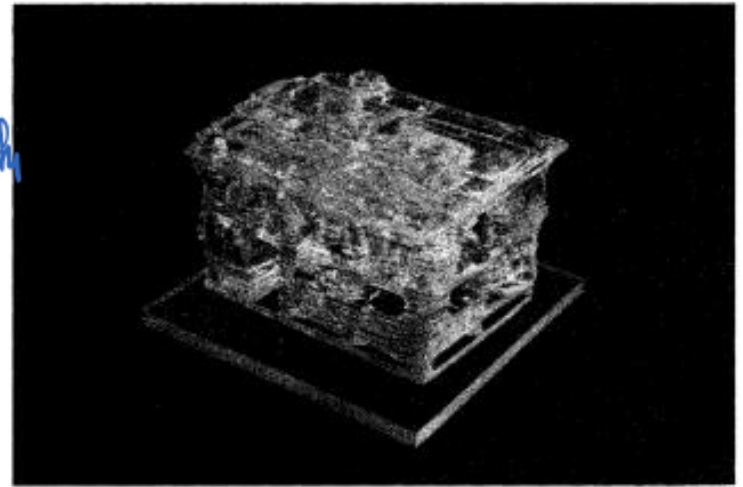
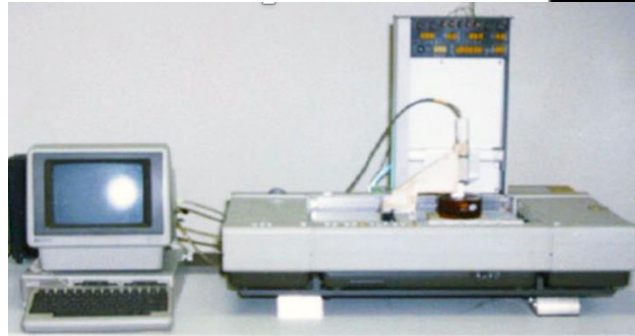
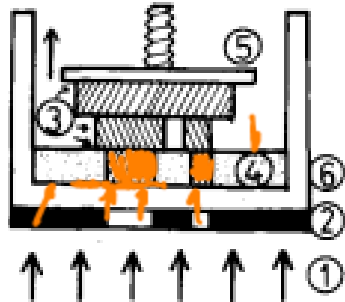
Point by Point

stereolithography



Bottom-up

(b)



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.

⑫ DEMANDE DE BREVET D'INVENTION

A1

②② Date de dépôt : 16 juillet 1984.

③③ Priorité :

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

⑥④ 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) :

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 STEREO LITHOGRAPHY**

[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.



3D SYSTEMS

\$ 600 Million/year

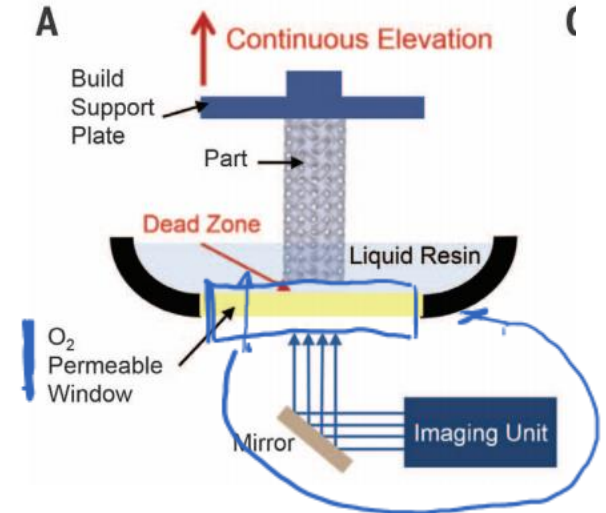
ADDITIVE MANUFACTURING

Continuous liquid interface production of 3D objects

2015

1200 citations

John R. Tumbleston,¹ David Shirvanyants,¹ Nikita Ermoshkin,¹ Rima Januszewicz,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

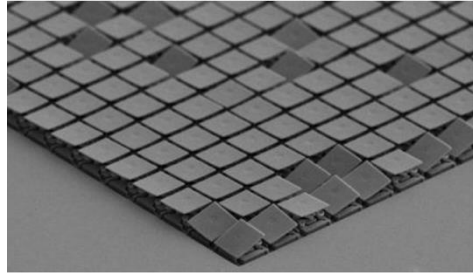
Founded 2013: Raised \$422 M.

Advanced additive manufacturing technologies – week 5, 2025

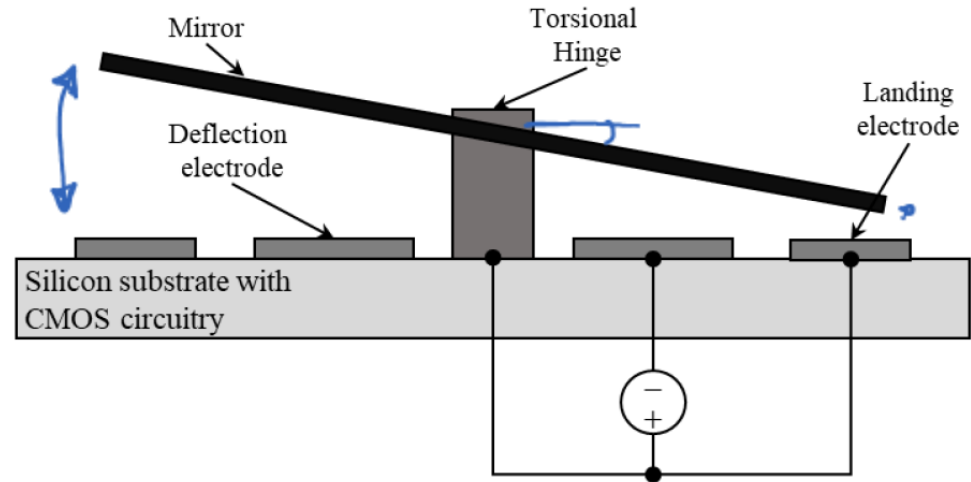
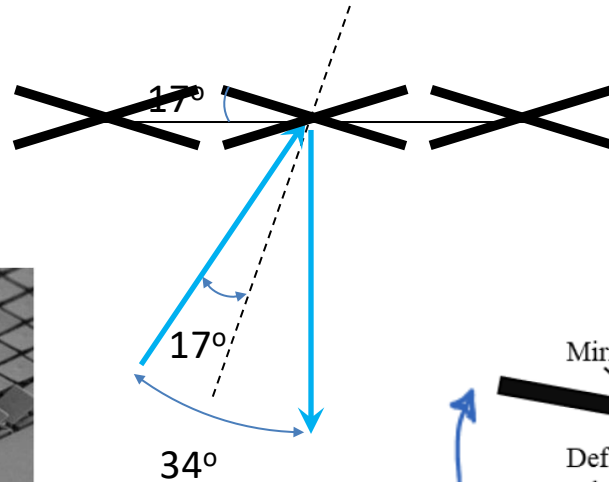
- light engine for DLP printing
- Experiments with DLP
- Resin chemistry

Digital MicroMirror Array (DLP™)

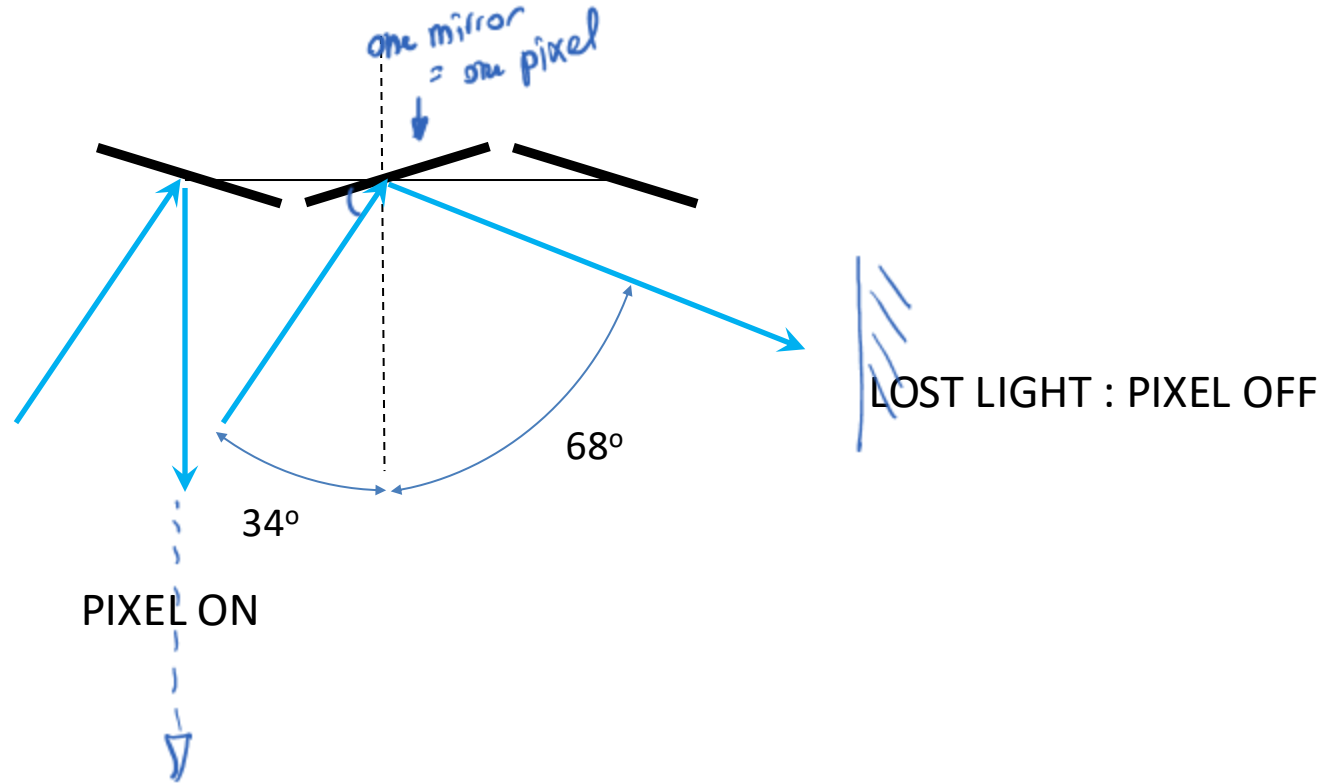
DMD



Pixel size.
5.4 x 5.4 μm
1920 x 1080 pixels



Digital MicroMirror Array (DLP™)



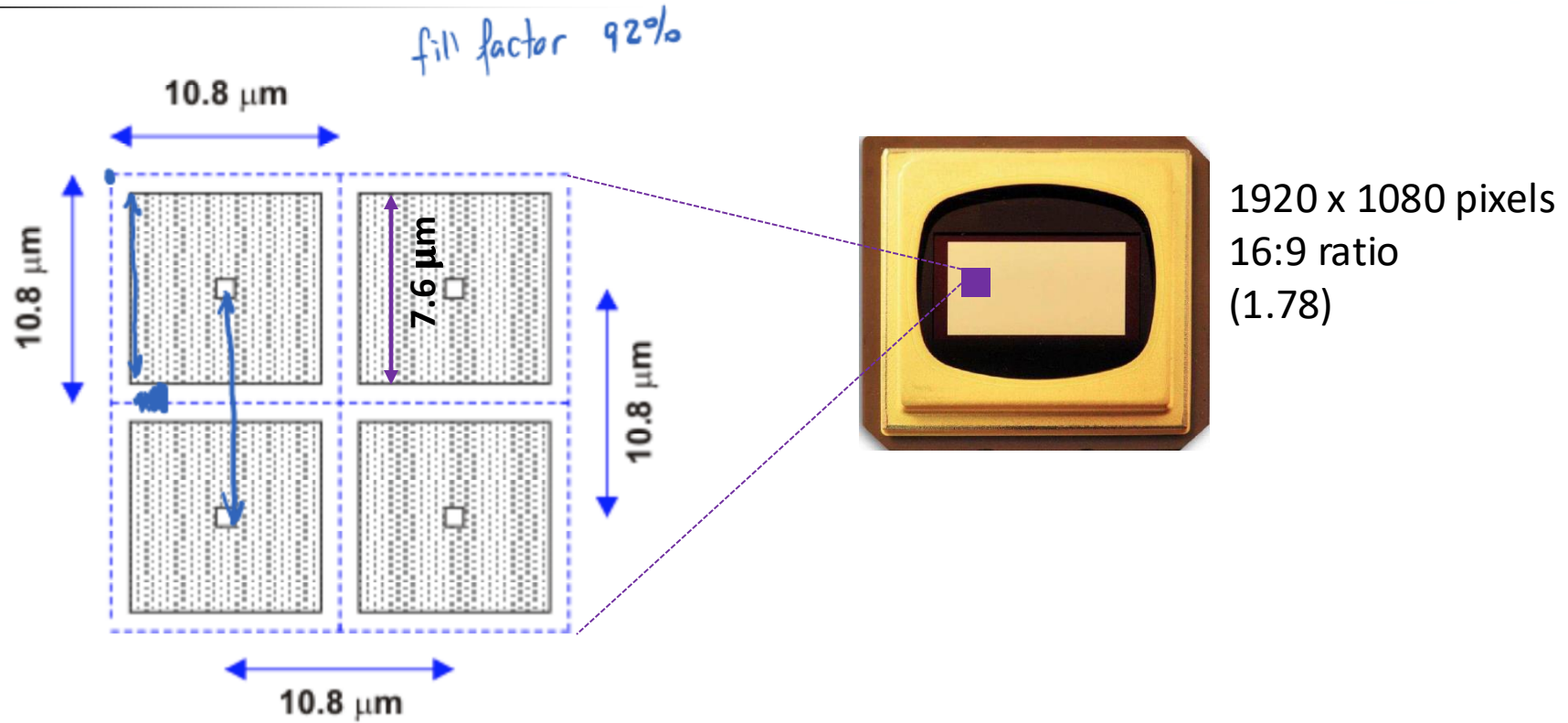
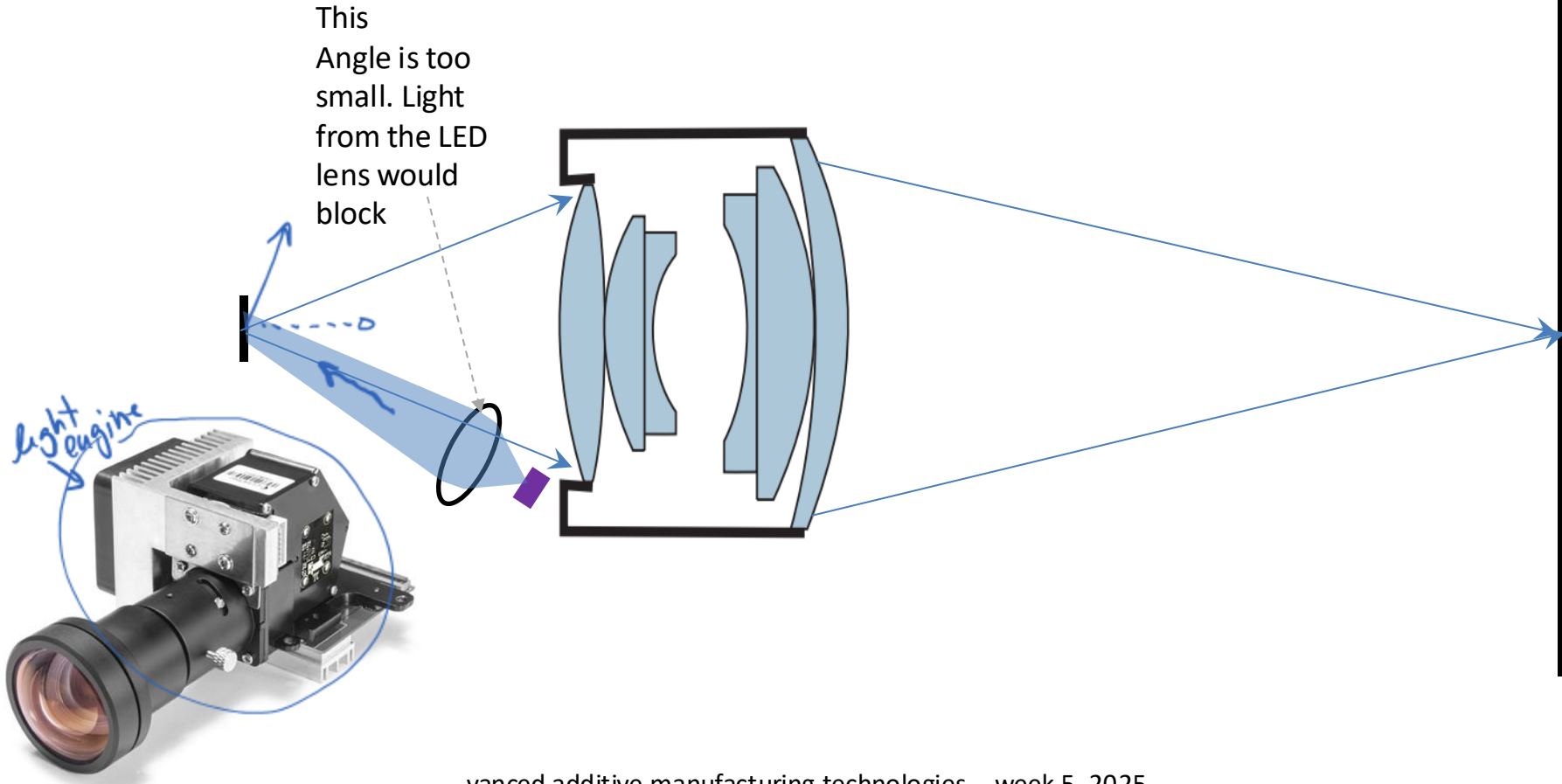
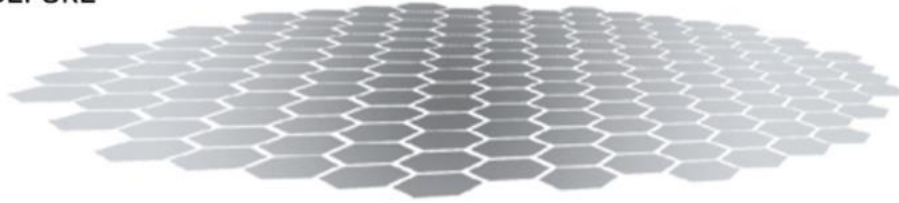


Figure 4. DLP5500 Micromirror Pitch



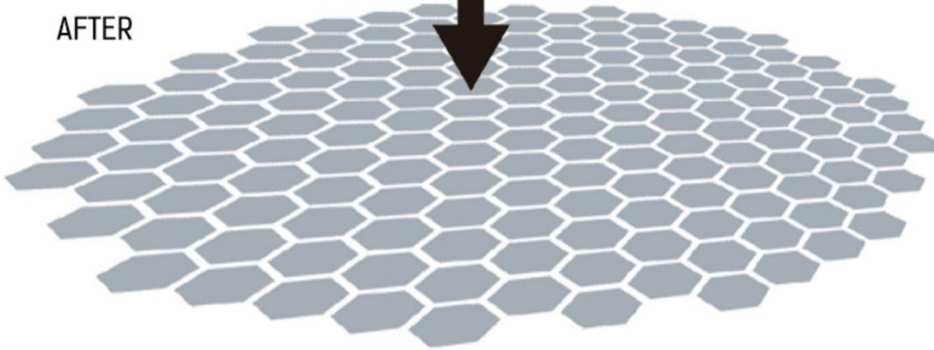
BEFORE



Light intensity uniformity
(pixel by pixel attenuation)



AFTER



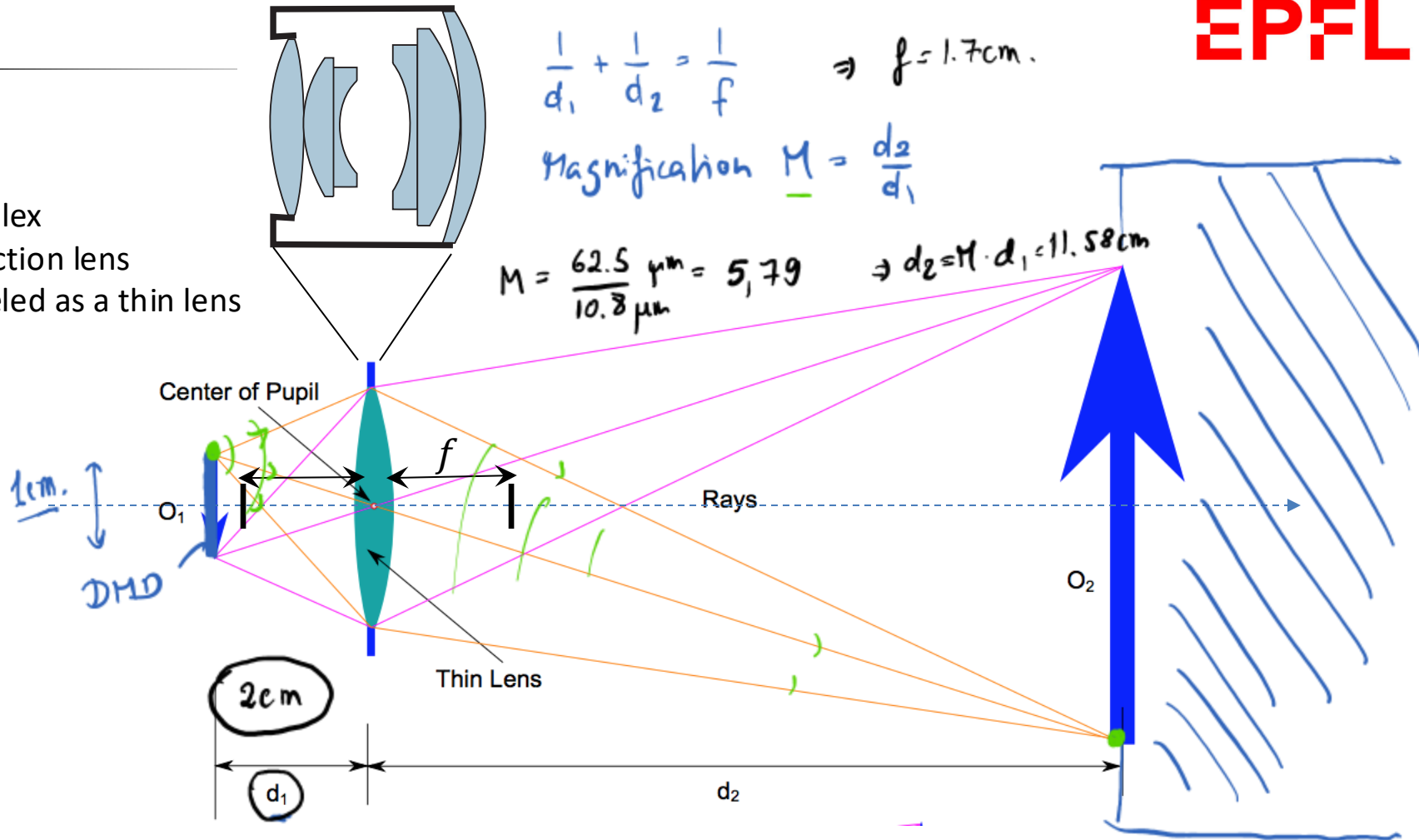
Build Volume: 4.72" x 2.66" x 5.91"

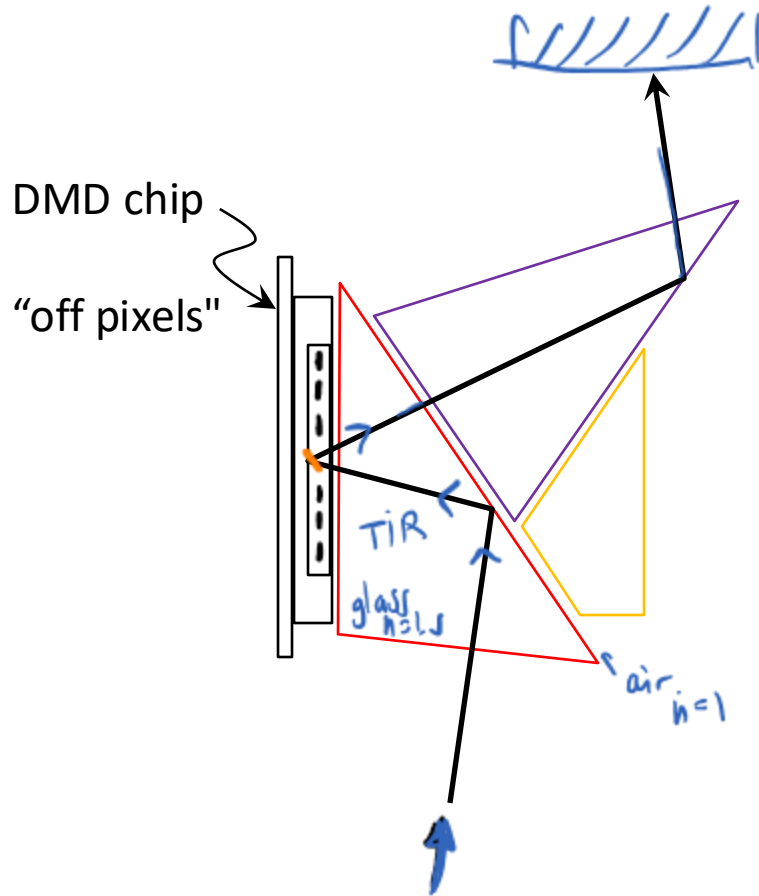
(120 x 67.5 x 150mm)
L x W x H

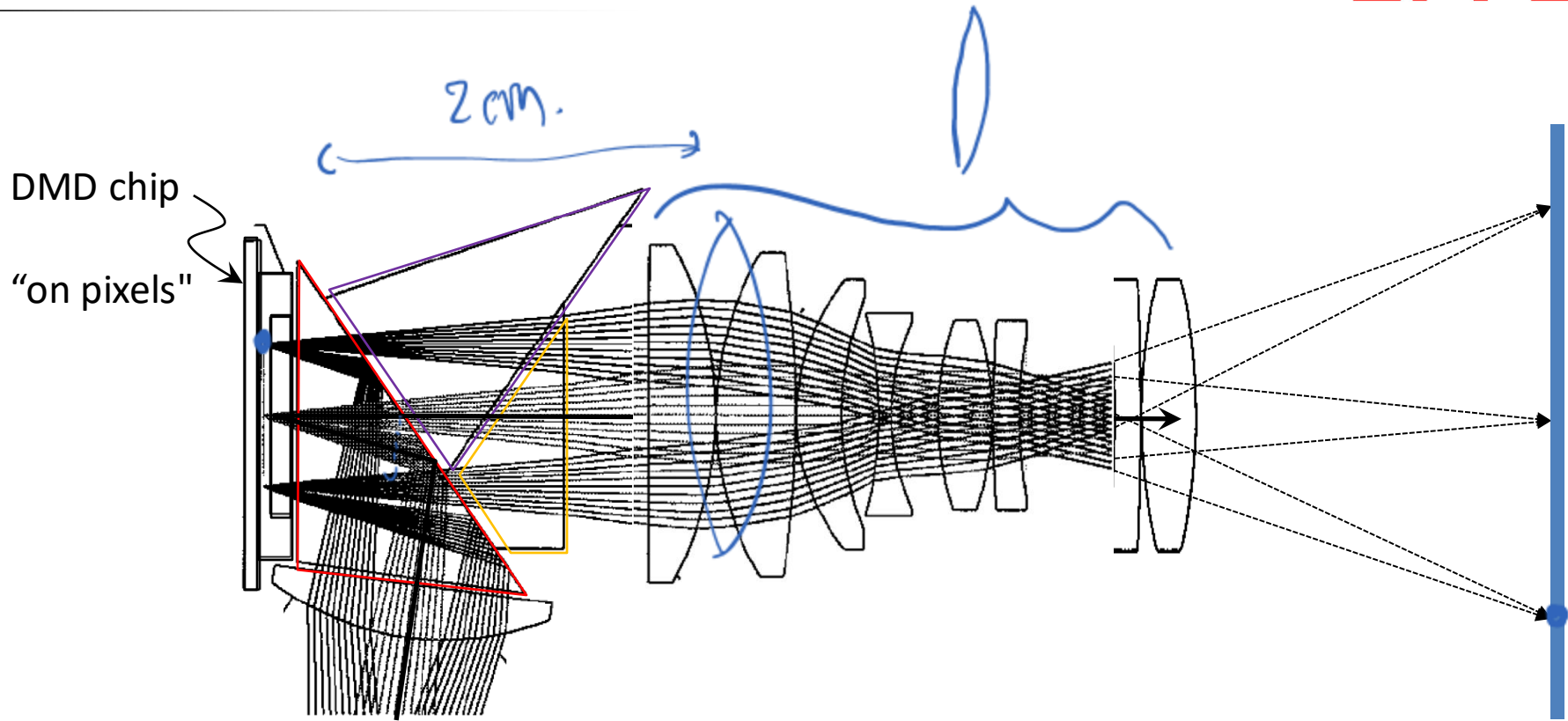
Pixel Size X, Y: 0.0025" (62.5µm)



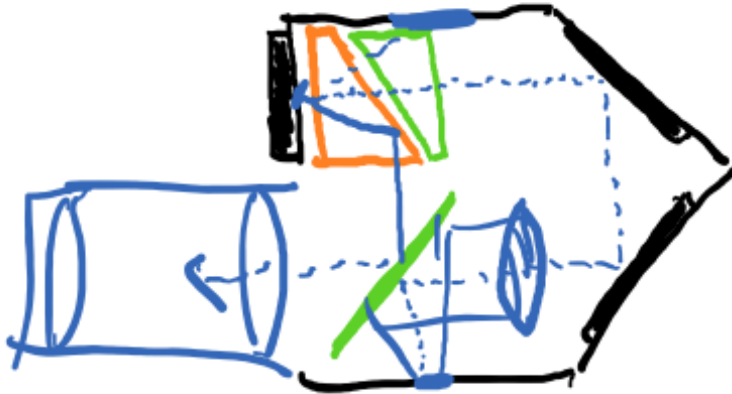
Complex
Projection lens
Modeled as a thin lens



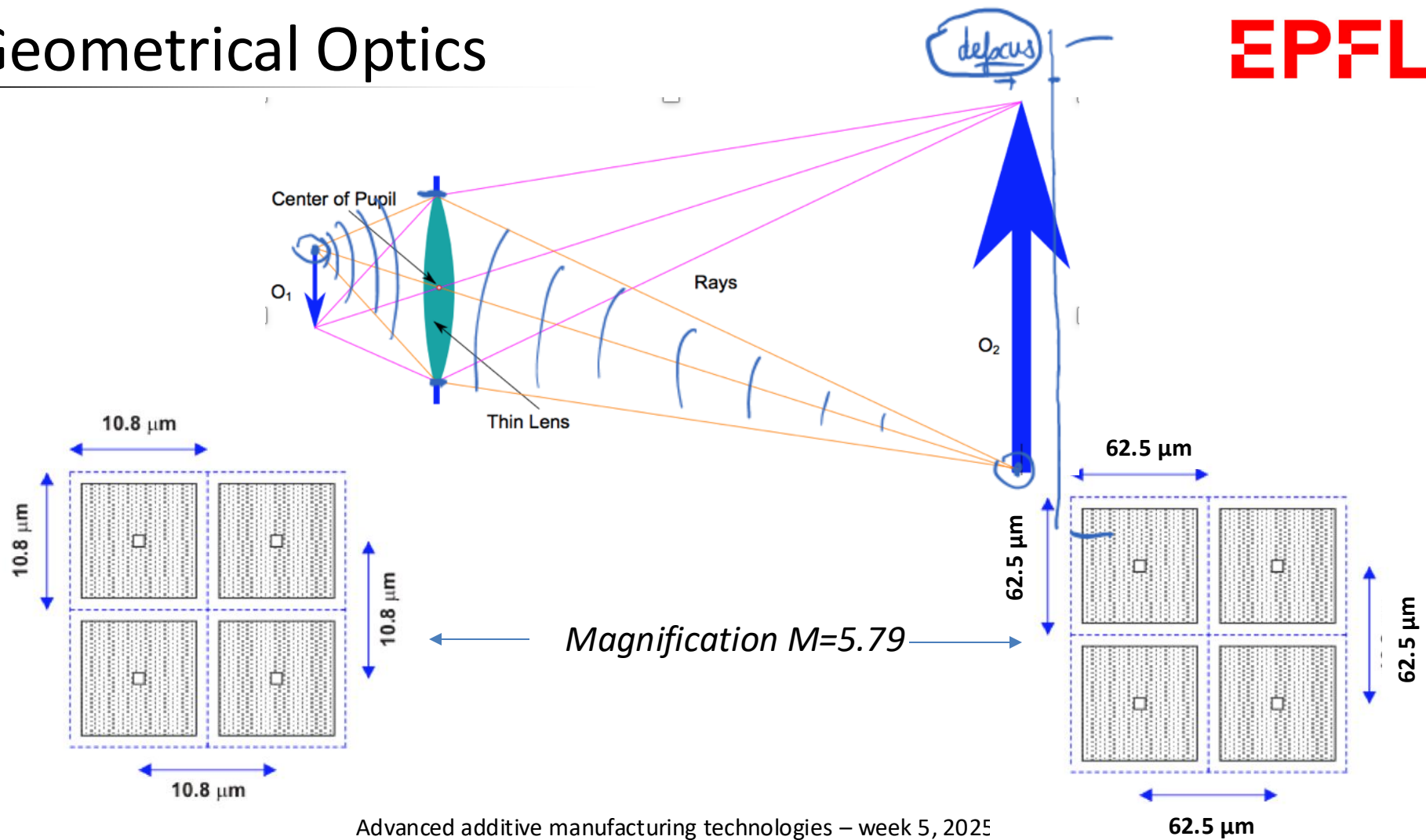




Draw a sketch of how the components are positioned (light source & board, DMD, lens) based on the system below



Geometrical Optics



Wave Optics

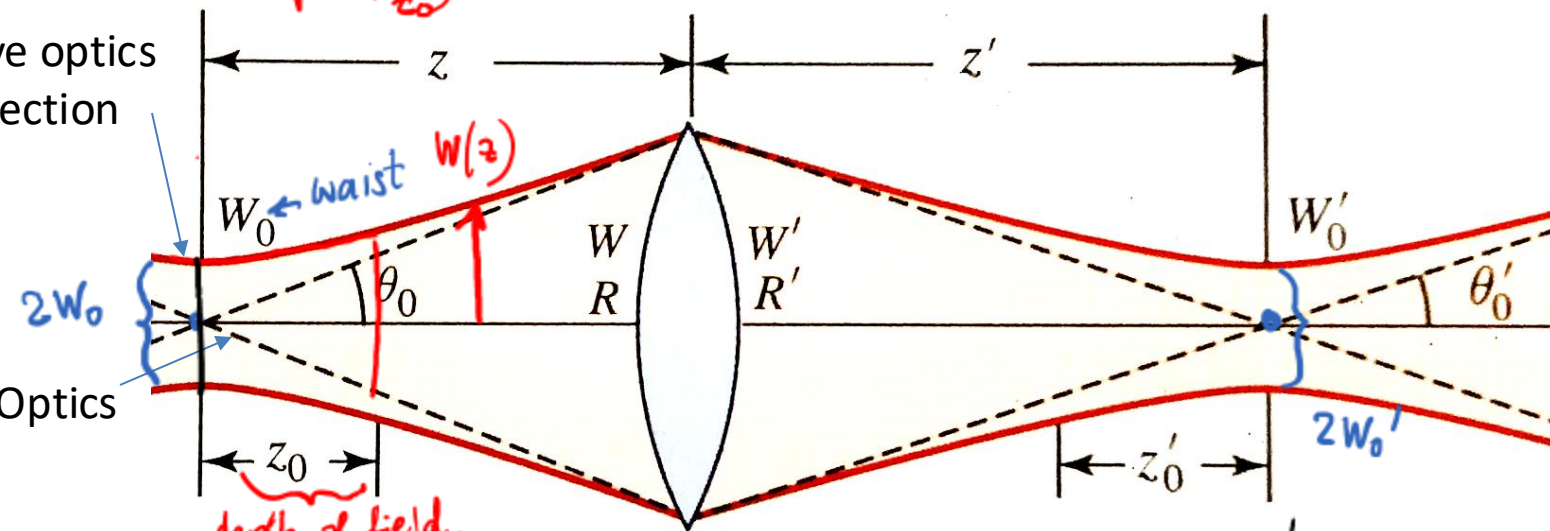
NOT TO SCALE

$$\lambda = 400 \text{ nm.}$$

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

Wave optics
correction

Ray Optics



$$z_0 = \frac{\pi W_0^2}{\lambda}$$

$$\Rightarrow z_0 = 183 \mu\text{m.}$$

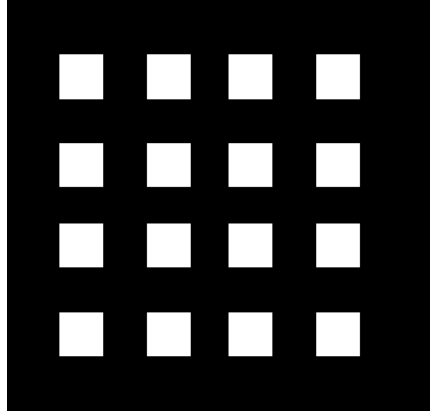
$$\text{pixel size: } 5.4 \mu\text{m} = W_0$$

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

$$z_0' = M^2 z_0 \Rightarrow z_0' = 6.13 \text{ mm.}$$

Simulation

Input



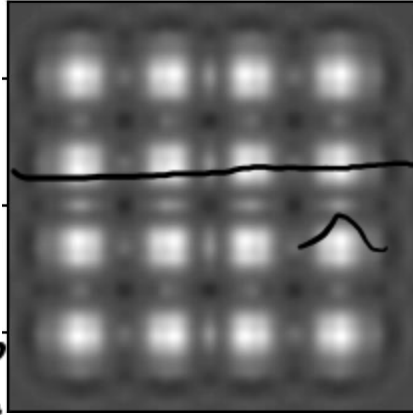
↑ input

(exercise)

propagation
to the image
⇒

Image plane

Output



1
0

Real surface measurement

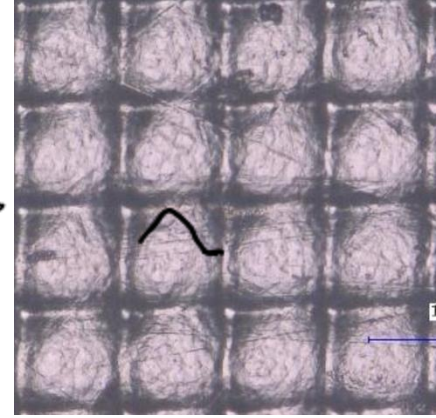
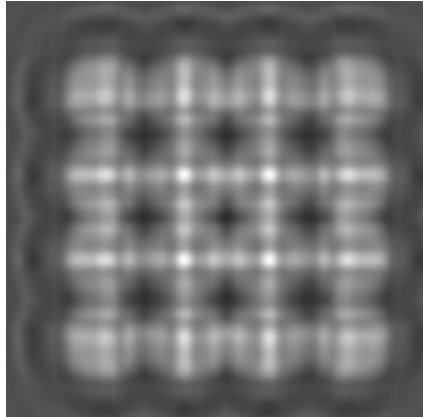


Image plane + 2mm



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 μm spatial resolution with a build volume of 15 x 15 x 15 mm.

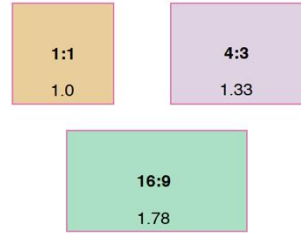


Figure 1. Aspect Ratios

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)

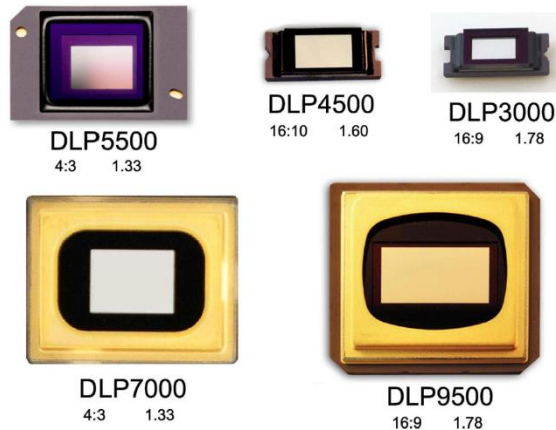


Figure 2. DLP DMDs With Their Aspect Ratios

Design

PFL

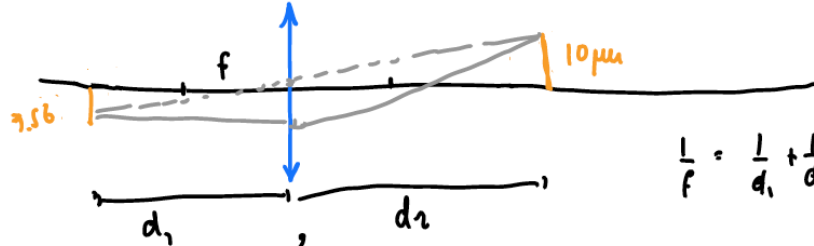
15 mm, 10 μm $\Rightarrow$ need $\frac{15 \text{ mm}}{10 \mu\text{m}} = 1500$ pixels in both x & y



2560 $\times$ 1600

$$M = \frac{10}{7.56} = 1.32 = \frac{d_2}{d_1}$$

$$d_1 = 2 \text{ cm} \Rightarrow d_2 = 2.64 \text{ cm.}$$

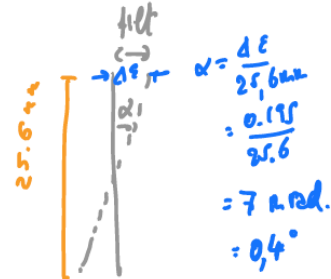


$$\frac{1}{f} = \frac{1}{d_1} + \frac{1}{d_2} \Rightarrow f = 1.13 \text{ cm}$$

$$z_0 = \frac{\pi \omega_0^2}{\lambda} = \frac{3.14 \cdot \left(\frac{7.56}{\mu}\right)^2}{0.4 \mu} = 112.2 \mu\text{m} \dots \dots \dots z_0' = M^2 \cdot z_0 = 195 \mu\text{m}$$

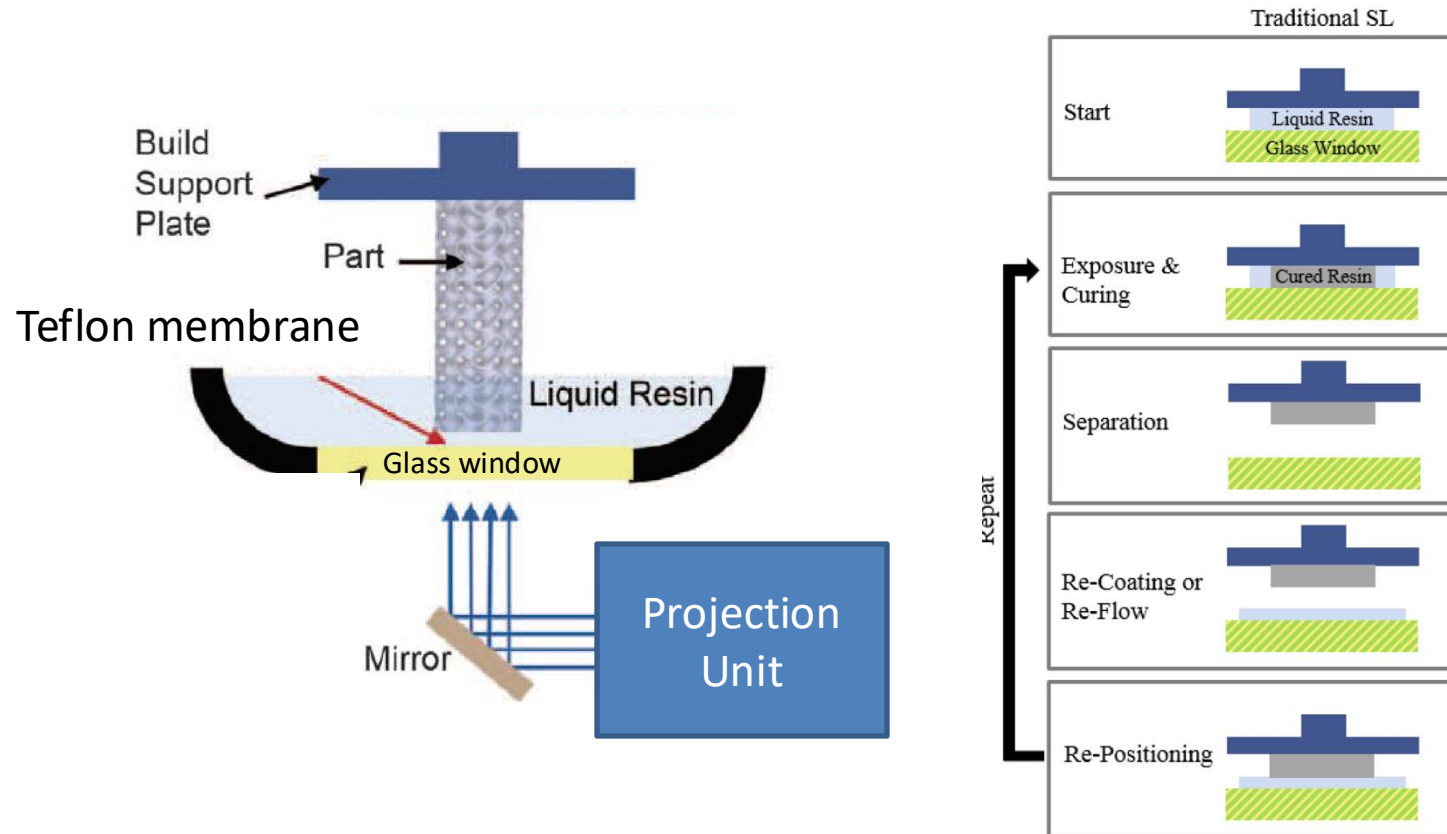
size of image

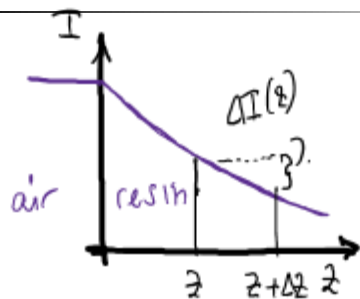
25,6 $\times$ 16 mm



$$\alpha = \frac{d \varepsilon}{25.6 \text{ mm}} = \frac{0.195}{25.6} = 7 \text{ mrad.} = 0.4^\circ$$

DLP 3D printing





- $I(z) = I_0 e^{-\alpha z}$: intensity of light ($\frac{\text{Power}}{\text{unit area}}$) at depth z in resin
- $\Delta I(z) = I(z) - I(z + \Delta z)$ absorbed light intensity between z and $z + \Delta z$

$$= \left| \frac{dI}{dz} \right| \cdot \Delta z$$

$$= \alpha I_0 e^{-\alpha z} \cdot \Delta z$$

$$\alpha = \alpha_{PI} + \alpha_{dye}$$

- $\frac{\Delta I(z)}{\Delta z} = \alpha \cdot I_0 e^{-\alpha z}$ absorbed light intensity per unit depth

$$D = \frac{\Delta I(z)}{\Delta z} \cdot t = \alpha \cdot t \cdot I_0 e^{-\alpha z} \quad \text{absorbed light dose (exposure) per unit depth}$$

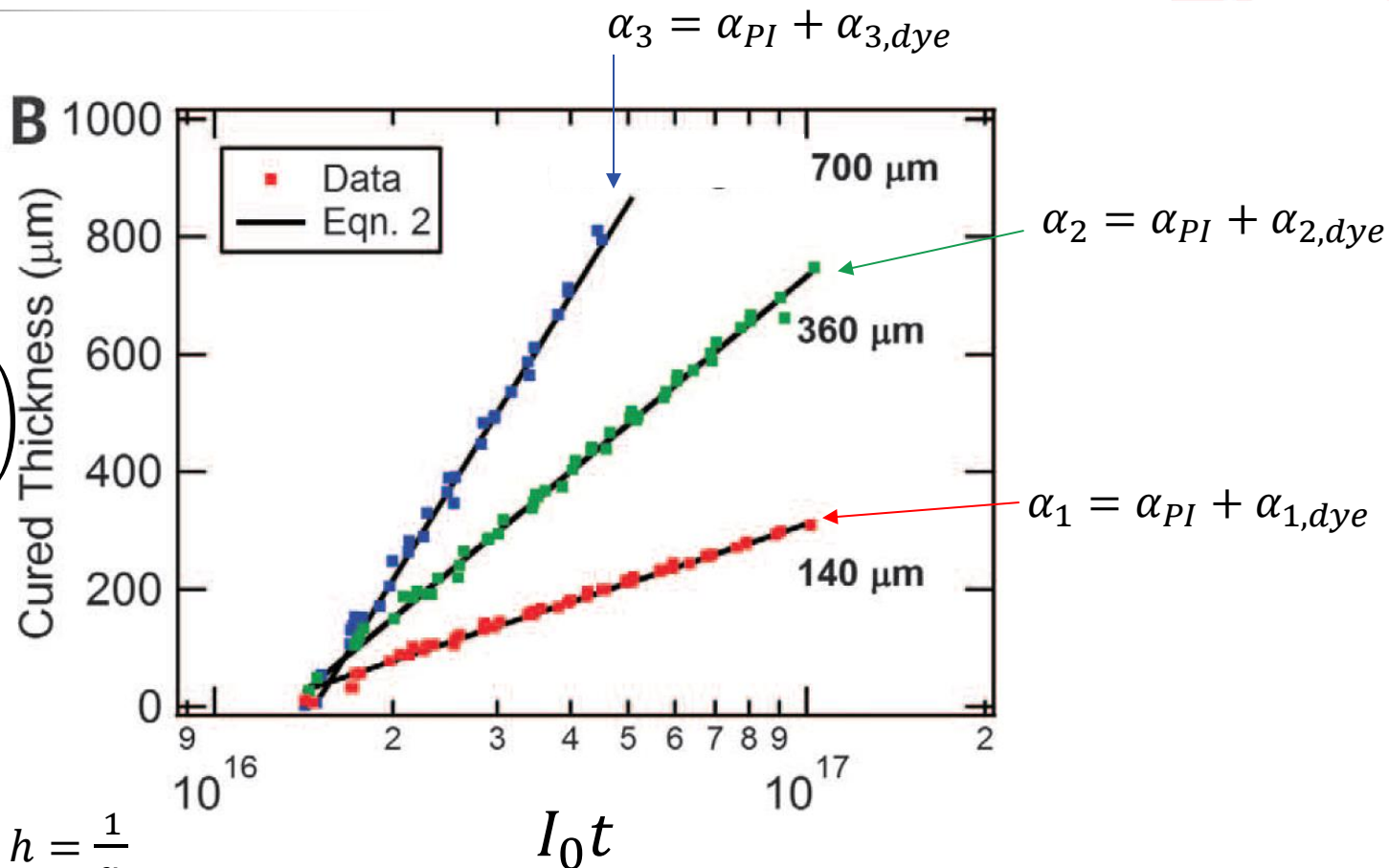
I want to cure (i.e. solidify) a thickness of depth z_{ct} (cure thickness)

$$D_c = \alpha t_c \cdot I_0 e^{-\alpha z_{ct}} \Rightarrow \frac{D_c}{\alpha t_c \cdot I_0} = e^{-\alpha z_{ct}} \Rightarrow \ln \left(\frac{D_c}{\alpha t_c \cdot I_0} \right) = -\alpha z_{ct}$$

$$\Rightarrow z_{ct} = -\frac{1}{\alpha} \ln \left(\frac{D_c}{\alpha t_c \cdot I_0} \right) = \frac{1}{\alpha} \cdot \ln \left(\frac{\alpha \cdot t_c \cdot I_0}{D_c} \right)$$

(the usual critical dose in $\text{mJ/cm}^2 = E_c$)

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



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

RESIN PARAMETERS

FH1100 STANDARD RESIN

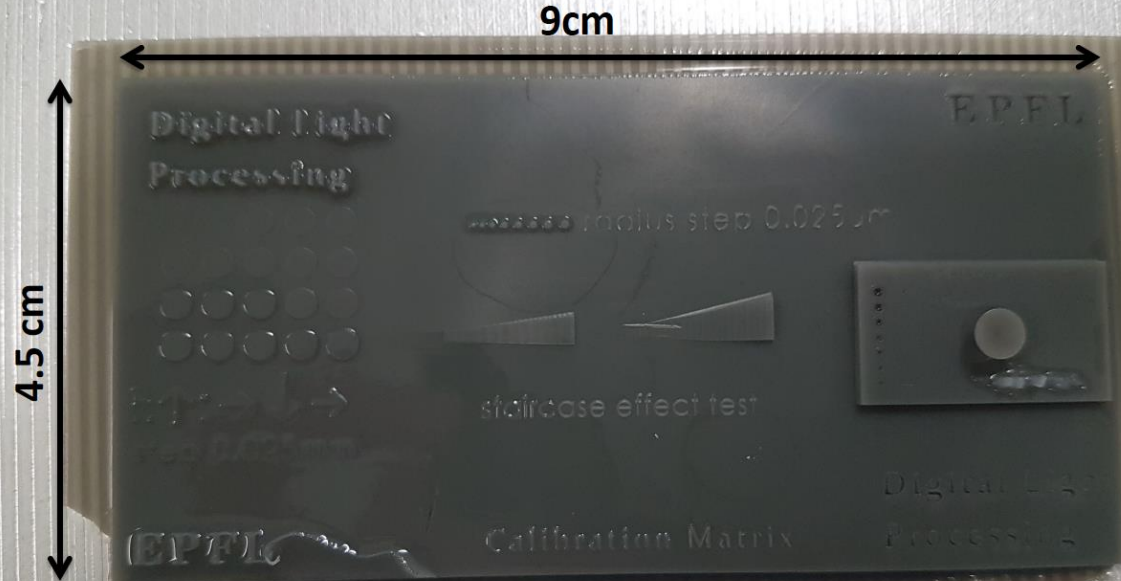
Appearance	Gray
Density (g/cm³)	1.14
Viscosity (cps)	350 cps (25°C)
Critical Exposure E_c (mJ/cm²)	12 mJ/cm²
Penetration Depth (dp)	0.2 mm

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





Printed structure on the build plate



Chosen layer resolution: 50um

Structure Thickness : 2.5mm

Total thickness (+base): 3mm