Chapter 2. Photopolymer based additive processes

October 28, 2024

2.1.1 Foreword: light - electromagnetic wave

Light and additive processes

- *For most additive processes, the consolidation principle is based on different type of interactions between light and matter (curing, heating etc...). For a better understanding of the technological aspects and of the limitations of AM, basic knowledge about light and light generation are therefore necessary.*

Electromagnetic wave (emw)

- *Light actually refers to a transport of information process in a medium. The physical support of the transported information is the **electric field**. The electric field distributes in the medium under the form of a wave called **emw**.*
- *A basic understanding of the simple **plane and linearly polarized emw** is enough to understand most of the principles associated to light. Other type of waves are for instance spherical or gaussian emw and, if they are not linearly polarized, they can be circularly or randomly polarized.*

Programm

- *Chapter 2 (SLA): plane emw, wavelength, angular frequency, photons*
- *Chapter 4 (SLS): intensity, gaussian emw, focalisation*
- *Chapter 6 (Energy): lasers*

2.1.2 Nature of a plane and linearly polarized emw

General theory of electromagnetic wave (emw)

- *The physical support of the information carried by a emw is an **electric field**.*
- *Maxwell equations reduce the possible distribution of the electric field to a sine function involving three generic parameters:*

$$\mathbf{E}(x, y, z, t) = \mathbf{E}_0 \sin(kz - \omega t)$$

- *In this equation, t is the time and z the propagation direction. If this direction changes, one has to rotate the axis and the above formula is still valid.*
- *The parameters $\mathbf{E}_0$, k and ω give a **quantitative characterization** of the emw:*

Symbol	Value	Name	Unit	Constraint (Maxwell)
$\mathbf{E}_0$	$\in \mathbb{R}^3$	***el. amplitude***	N/C	$\mathbf{E}_0 \cdot \mathbf{e}_z = 0$ ***(transversality)***
ω	$\in \mathbb{R}_+$	***ang. frequency***	$\frac{1}{s} = Hz$	
k	$\in \mathbb{R}$	***wave number***	$\frac{1}{m}$	$k = \frac{\omega}{c}$ ***(dispersion)***

→ *The ratio $c = \frac{\omega}{k}$ has the dimension of a velocity. It is called speed of light in vacuum and its value is $c = 2.99792 \times 10^8$ m/s.*

(see Append. 1)

2.1.3 Wavelength and period of the emw

The electric field $\mathbf{E}_0 \sin(kz - \omega t)$ is a **periodic** function:

- *After a time $T = \frac{2\pi}{\omega}$, the space distribution of the electric field is the same again.*
- *If one moves a distance $\lambda = \frac{2\pi}{k}$ along the $z-$axis, one observes the same time-evolution of the electric field.*

Symbol	Formula	Name	Unit
T	$\frac{2\pi}{\omega}$	***period***	*s*
λ	$\frac{2\pi}{k}$	***wavelength***	*m*

Remarks

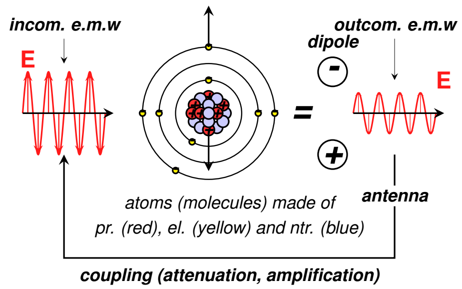
- *The period and the wavelength are physical interpretations of the angular frequency and of the wave number.*
- *The dispersion relationship $\omega = kc$ can be written $\lambda = cT$.*
- *The quantity $kz - \omega t$ is called **phase**.*
- *The phase isosurfaces (for fixed t) are called **wavefronts**. For a plane emw the wavefronts are **planes** perpendicular to the propagation direction.*

(see Append. 1, 2)

2.1.4 Interaction e.m.w - matter (general)

Interaction mechanism between matter and emw

- *The molecules in the matter are made of charged particles (protons, electrons)*
- *The electric field of the incoming emw applies a force on the charged elementary particles. It moves them.*
- *Oscillating particles then starts to generate an outcoming emw (by Maxwell equations).*

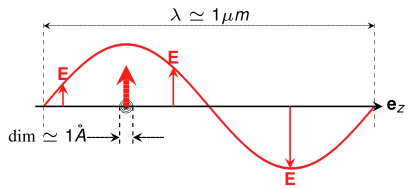


- *The outcoming and incoming emw superpose. The result is usually an attenuation of the ewm, but, in particular cases (lasers) the emw might be amplified.*
- *The outcoming emw is obtained after solving the motion equations of the elementary particles building the molecule. These equations correspond to a classical mechanical problem known as the **multi-bodies problem** ($N = N_{\mathrm{pr}} + N_{\mathrm{el}} + N_{\mathrm{ntr}}$ bodies).*

2.1.5 Interaction e.m.w - matter (simplification)

Atoms and emw in the visible range (UV to IR)

- *The wavelengths of the e.m.w used in additive processes (UV to IR) are $\gg$ than the atoms dimensions. The spatial distribution of the electric field is thus more or less uniform in the molecules.*



(1) *Every elementary particle sees the **same** value of **E** $\Longrightarrow$ all the protons (electrons) experience the same force and have a tendency to move together.*

(2) *The cohesion forces between the protons and the neutrons and between the protons and the electrons are extremely strong.*

- *As a consequence to (1)-(2), the nucleus and innermost electrons can be considered as a **rigid** body having a positive charge. It is called **the heart**.*
- *Only the outermost (peripheral) electron(s) have to be considered as individual bodies. If there is only one such electron (most cases), we are left with a **spring like** 2-bodies problem with a $\omega-$ periodic sollicitation (the period of the emw).*

N.B. *If $\lambda \ll 1$Å the protons and the electrons experience different forces leading to a nucleus shear mechanism. The multi-bodies problem cannot be simplified.*

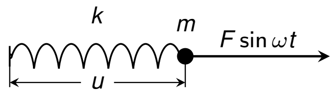
(see Append. 3, 4)

2.1.6 Interaction e.m.w - matter (cnt'd)

Multi-bodies problem and resonance

- *The two-bodies problem looks like the problem for the displacement u of a particle (mass m) connected to a spring (rigidity k) and subject to a periodic force*

$$m\ddot{u} + ku = F \sin \omega t$$

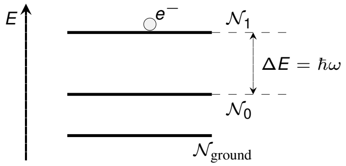


- *In this classical spring problem, there is no significative interaction between the force and the particle ($u \approx 0$ on average) unless the force varies at a frequency ω matching a reasonant value: $\omega = \sqrt{k/m}$.*
- *In the two bodies problem coming from the light-matter analysis, the particle is the peripheral electron of charge q. The spring is the connection of the peripheral electron to the heart and the force is the effect of the electric field associated to the interacting emw.*
- *In the case of light-matter interaction, quantum mechanics applied to the peripheral electron helps identifying the resonant frequencies at which a significant reaction is observed.*

2.1.7 Interaction e.m.w - matter (cnt'd)

Quantum aspects - band theory

- *In quantum mech., the resonance analysis of atoms reduces to the band theory:*
- *The possible energy values for the peripheral electron form a* ***countable and increasing*** *sequence of real numbers.Each energy value is called energy state and corresponds to a possible probability distribution for the electron location.*



- *The energy values are computed numerically (eigenvalue problem) and represented in a* ***band diagram****.*
- *The rule is that there will be resonance between the peripheral electron and an e.m.w of angular frequency ω, if and only if the peripheral electron*
  - (i) *has two energy states separated by a precise amount: $\Delta E = \hbar\omega$ where $\hbar = 1.05457148 \times 10^{-34} \mathrm{m}^2\,\mathrm{kg/s}$ is the Dirac constant,*
  - (ii) *is in one of those two states.*
- *The interaction of the e.m.w with the electron will be a transition between these two states and the absorption (or the emission) of the amount of energy ΔE.*
- *The energy ΔE is called* ***energy quantum****. It can be seen as the energy of a theoretical particle associated to the emw and called* ***photon*** *(Planck).*

Stereolithography

2.2.1 Stereolithography, basic

Basic principle

- *A 3D part is built layer by layer from a photoresist.*
- *The resin is* ***selectively*** *consolidated by a UV laser deflected by galvanometric mirrors. The principle of consolidation is the curing of the photoresist molecules under the effect of UV light (UV-curing) .*
- *A chemical substance (inhibitor) prevents the UV-curing to diffuse to all the photoresist.*
- *The intelligence of the process goes through the management of the galvanometric mirrors displacements.*

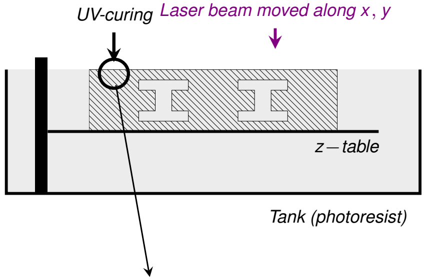
Etymology and acronym (3dPrinting before time!)

- *Lithography, a printing process?*
- ***stereo-*** *is a reference to tri-dimensionnal reconstruction (στερεος=solid)*
- *The common acronym for this process is SLA.*

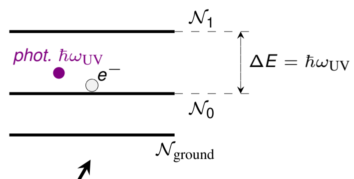
(see Append. 5)

2.2.2 Stereolithography, basic design

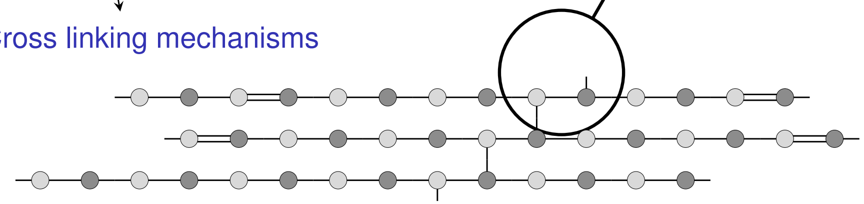
Diagram



Transition to excited level

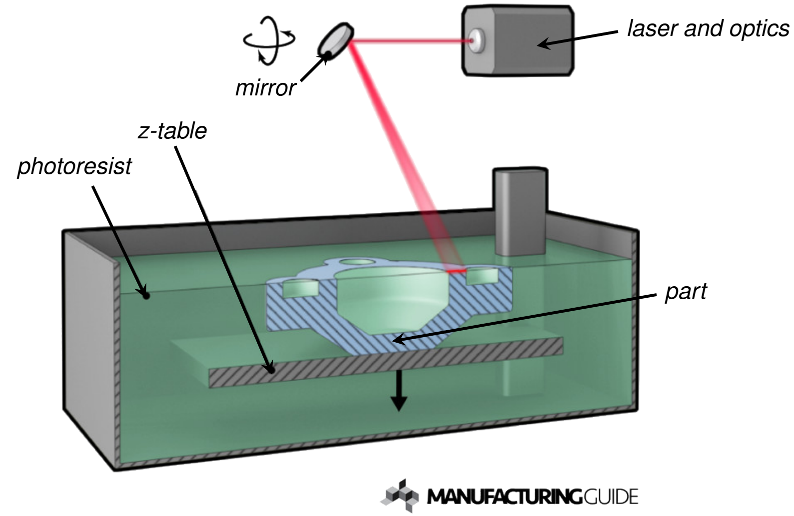


Cross linking mechanisms



2.2.3 Stereolithography, the machine

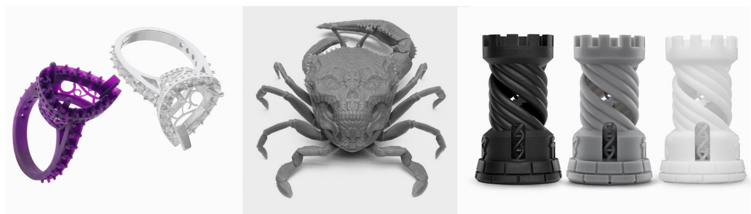
Details of the machine



2.2.4 Stereolithography, parts

Example of parts

lost patterns *prototypes/hobbies*



source: Formlabs™

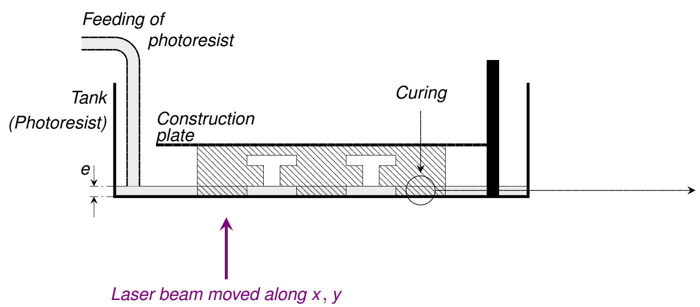
occlusal protection *dental models* *surgical guides*

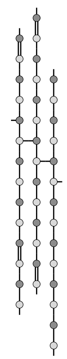
source: Formlabs™

2.2.5 Stereolithography, design top-down (new)

Diagram

Consolidation mechanism: cross-linking





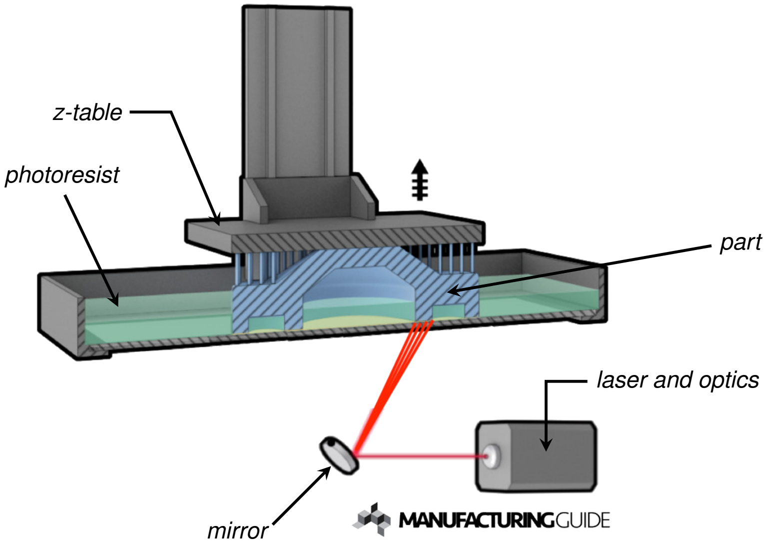
Advantages (compared to basic SLA (down-top))

- *Small volume of resin in the tank.*
- *Assured flatness of the treated resin surface (no recoater needed).*

(see Append. 6)

2.2.6 Stereolithography, new design (top-down)

Details of the machine



2.2.7 Stereolithography

Equipments: 3DSystems, Formlabs

sPro 60HD (down-top)	Form3 (top-down)
	

2.2.8 Stereolithography, technical data

Mechanical properties of part (order of magnitude)

Material	*E*, GPa	R_m, MPa	ε_{rup}, %
VisiJet Flex	*1.6*	*38*	*16*
VisiJet HiTemp	*3.4*	*66*	*6*

Equipment (type, dimensions)

Laser	λ, μm	*P*, W	*Build volume*, mm^3
Helium-Cadmium (HeCd)	*0.325*	*0.025*	$250 \times 250 \times 500$

Performances

x-y resol., μm	*layer thick.*, μm	*build speed*, mm^3/s	*layering time*, s
$25-50$	$50-100$	$MCR = 5-10$	$10-20/1-2$[1]

(see Append. 7, 8, 9)

[1] down-top or top-down

2.2.9 Stereolithography

Companies

- 3DSYSTEMS™ (*PROJET serie, IPRO serie, SPRO serie)*
- FORMLABS™.

Advantages and applications

- *Relatively precise (even better then 25 μm)*
- *Transparent materials, assembly of several parts (bonding),*
- *Master model for investment casting, for PUR molding (vacuum casting),*
- *Rapid manufacturing of parts in small series, fabrication of custom items.*

Disadvantages and issues

- *Technique limited to photoresists,*
- *Standard materials are expensive, toxic and difficult to store,*
- *Significant change in properties of the parts with time (aging),*
- *Post-processing required as well as supporting structures.*

(see Append. 10, 11, 12, 13, 14, 15 16, 17)

Digital Light Processing (DLP)

2.3.1 Direct light processing

Basic principle

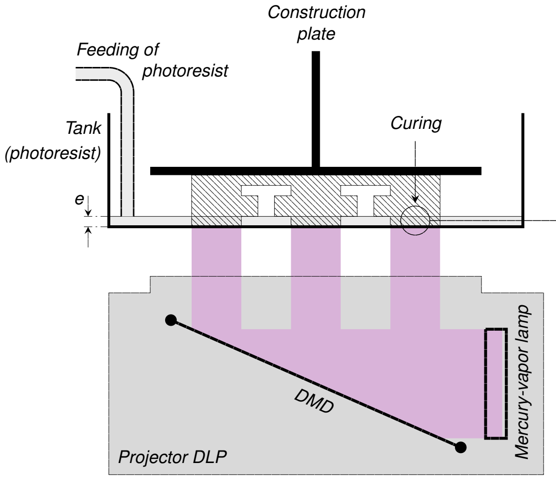
- *A 3D part is built layer by layer out of a **photoresist***
- *The resin is selectively consolidated by a UV flash deflected by a network of mirrors. The principle of consolidation is **photocuring**.*
- *The details of the part geometry are transferred into the process through the management of the deflecting mirrors.*
- *The acronym of this process is **DLP**.*

Direct light processing and stereolithography

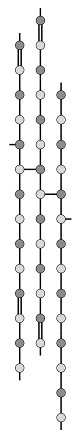
- *Direct light processing derives from the stereolithography by a modification of **the consolidation tool** and of **the intelligence transfer**.*

2.3.2 The DLP process

Diagram



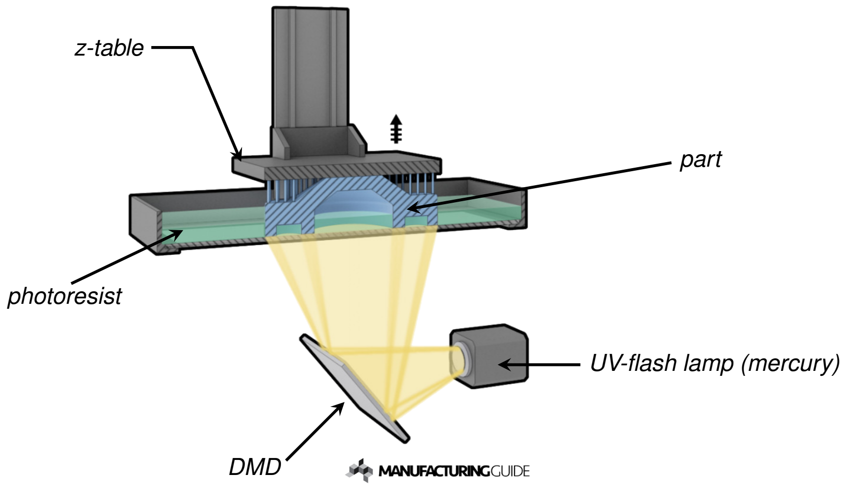
Consolidation mechanism: cross-linking



(see Append. 21)

2.3.3 Direct light processing, the machine

Details of the machine



2.3.4 Direct light processing

Typical equipments

Sisma EVE	Envisiontec™	B9 Creator™

source: Sisma™

source: Envisiontec™

source: B9 Creator ™

2.3.5 DLP (Envisiontec™), technical data

Use of material

Material	*Application*
Standard resin	*prototyping, master models (vacuum casting)*
Thermofusible resin	*lost patterns (investment casting)*
Charged resin	*mold cavity*

Equipment (type, dimensions)

Build volume, mm^3	*Low Precision (LP Mode)*	*High Precision (HP Mode)*
	$120 \times 90 \times 230$	$60 \times 45 \times 230$

Performances

DLP beamer with 1400 $\times$ 1050 pixels

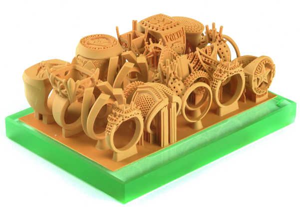
Mode	*x-y resol.*	*layer thick.*	*build speed*	*layering time*
LP	86 μm	50 μm	*n.a.* $(\infty)^2$	$< 10\,s$
HP	43 μm	25 μm	*n.a.* $(\infty)^2$	$< 10\,s$

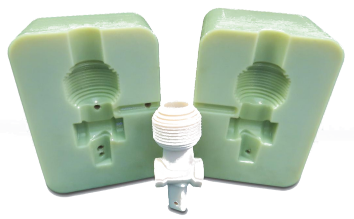
[2] *the build time is not sensitive to part volume but only to part height:* $fab.time = \frac{height}{e}\frac{\tau_{layer}}{N}$ *with* e *: layer thickness,* N *: batch size.*

2.3.6 Direct light processing

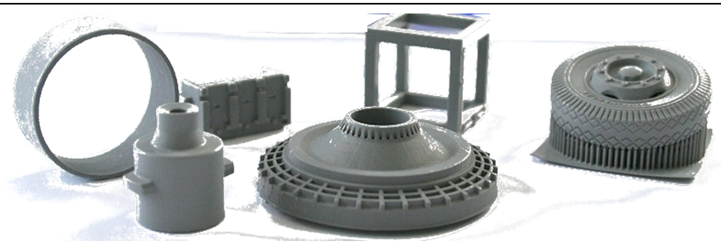
Examples of parts

Thermofusible resist (PIC100)	Resist with ceramic filler(RC25)





Standard resist (R11)



source: Envisiontec™

2.3.7 Direct light processing

DLP characteristics/ providers

- *No DLP system is based on a down-top construction which has only drawbacks (more material, recoating, ...) compared to the top-down strategy.*
- ***Providers**: Envisiontec™ , B9 Creator™ , Sisma™ , Carbon3d™ ...*

Advantages (compared to stereolithography) and applications

- *Price and simplicity of the machine, fabrication time possibly faster.*
- *Indirect production of ceramic parts (Lithoz™).*
- *Fabrication of expendable tooling for the GA process. In that case, the DMD is replaced by an engraved mask and the process chain is called UV-LiGa*
- *The DMD system can be replaced by Liquid Crystal Displays (LCD) to cut-off machine prices (at the expense of accuracy and productivity!)*

Disadvantages compared to stereolithography

- *Less precise ($\simeq$ 45 μm against $\simeq$ 20 μm), lower productivity.*
- *Smaller work surface ($\simeq 60 \times 45\,mm^2$ against $\simeq 250 \times 250\,mm^2$).*
- *Achieving the accuracy and productivity of SLA would require to increase the number of DMDs: we would need* $>$ 100 *DMDs (150MPx against 1.5MPx now).*

(see Append. 18, 19, , 22, 23, 24, 24, 26, 27, 28.)

Photopolymer jetting

2.4.1 Photopolymer jetting

Basic principle

- *A 3D part is built layer by layer out of a photoresist **selectively** deposited by an array of nozzles.*
- *The resin is consolidated by a UV flash and the principle of consolidation is UV-curing.*
- *The part geometry in transferred into the process through the management of the nozzles (displacement and feed rates).*

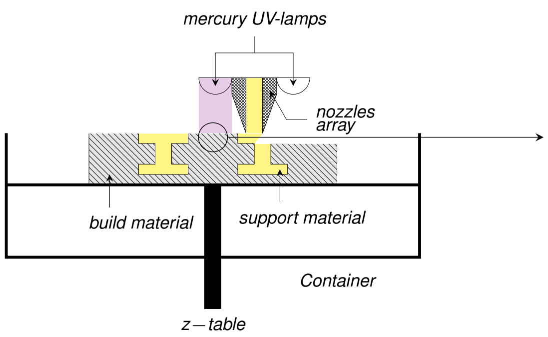
Remarks

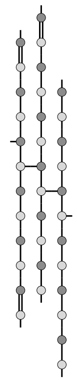
- *Photopolymer jetting derives from stereolithography by a change in **the consolidation tool** and in **the way to transfer the part geometry**.*
- *Its recent development is due to the new nozzle technology for handling fluid with high viscosity.*
- *The nozzles deliver at least two different materials (construction/support).*

2.4.2 Photopolymer jetting

Diagram

Consolidation mechanism: cross linking



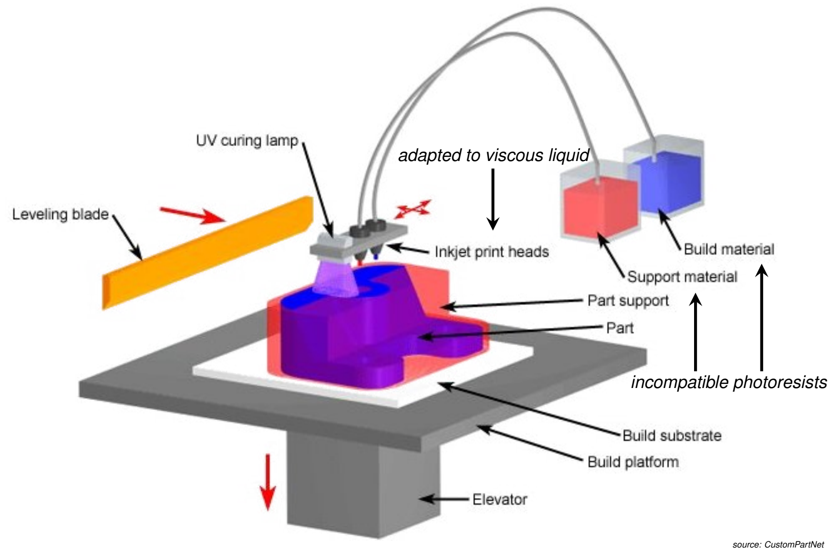


Remarks

- *The nozzles array translates along the x axis*
- *The build and support materials are two different photoresists. These materials are simultaneously cured by UV lamps.*

2.4.3 Photopolymer jetting

Block diagram of the equipment



2.4.4 Photopolymer jetting

Equipments: Eden and Connec Serie (Objet™)

Eden 260	***Connec 500***

source: Objet™

source: Objet™

2.4.5 Photopolymer jetting

Example of parts 1

source: Objet™

source: Objet™

2.4.6 Photopolymer jetting

Example of parts 2

source: Objet™

source: Objet™

source: Objet™

source: Objet™

2.4.7 Photopolymer jetting

Example of parts 3

source: Objet™

source: Objet™

2.4.8 Photopolymer jetting, technical data

Mechanical properties of part (order of magnitude)

Material	*E, GPa*	R_m*, MPa*	ε_{rup}*, %*
RGD 515	*2.6-3.0*	*55-60*	*25-40*
RGD 525	*3.2-3.5*	*70-80*	*10-15*

Equipment (type, dimensions)

Build volume, mm^3
from $260 \times 260 \times 200$ *to* $1000 \times 800 \times 500$

Performances

x-y resol., μm	**layer thickness**, μm	**build speed**, mm^3/s	**layering time**, *s*
$40 - 50$	$15 - 80$	$MCR = n.a.(\infty)$[1]	$\simeq 20 - 15$ s

[1] *the build time is not sensitive to part volume but only to part height:* $fab.time = \frac{height}{e} \frac{T_{layer}}{N}$ *with* e *: layer thickness,* N *: batch size.*

2.4.9 Photopolymer jetting

Characteristics of the jetted photopolymer process, providers

- *The construction material and the support material are solid photoresists. They are incompatible (i.e not connected after UV-flashing).*
- *The photopolymer jetting process is a consequence of a recent development of nozzles able to deliver high viscosity fluid without being blocked. Traditional printhead are designed for jetting only low viscosity fluid like ink.*

Compagnies

- *This process, developped by an Israeli company (Objet™) 15 years ago, is now commercialized by Stratasys™(USA).*

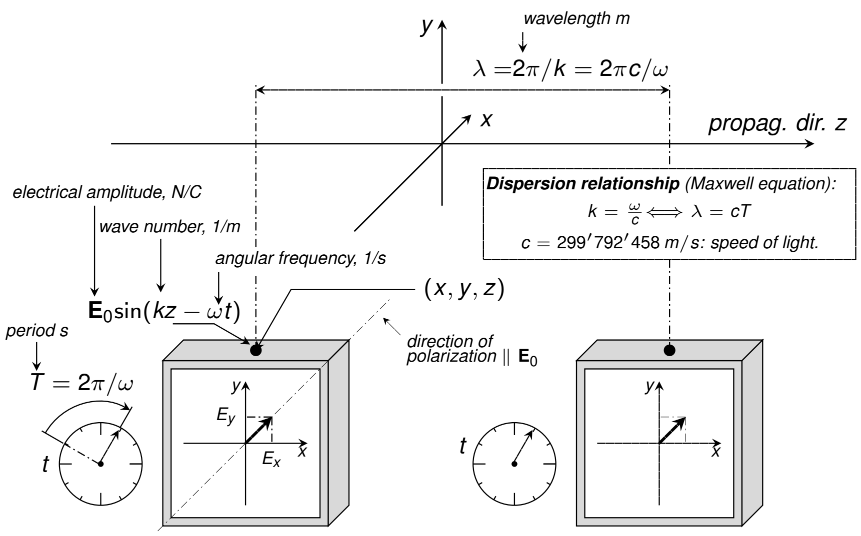
Advantages

- *Price and simplicity of the machine (from 50 kFrs to 250 kFrs).*
- *Precision (comparable to SLA).*
- *Simple management of the supports,*
- *Possibility of combining materials.*

APPENDICES

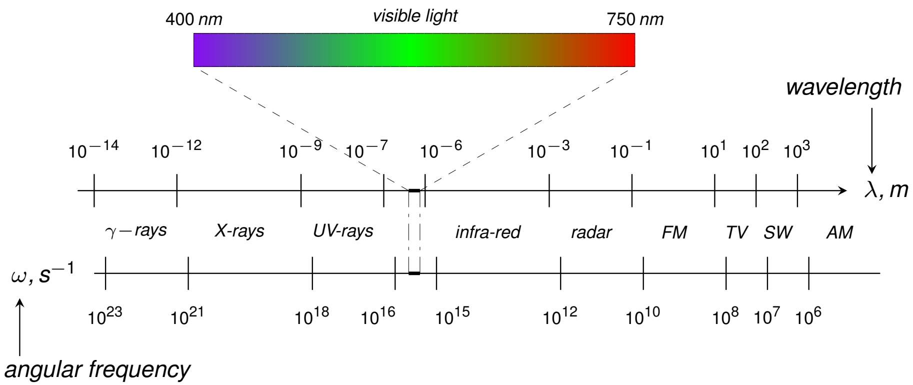
A 1: A plane linearly polarized emw in the void

Detection of the electric field



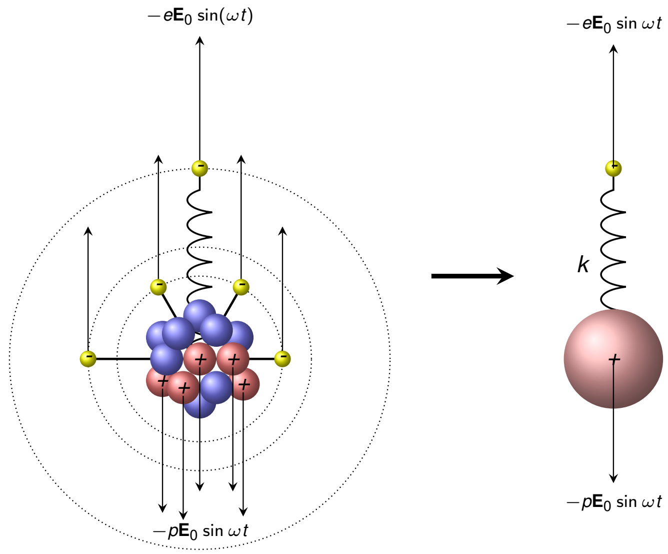
A 2: Electromagnetic spectrum

Different types of electromagnetic waves (void)



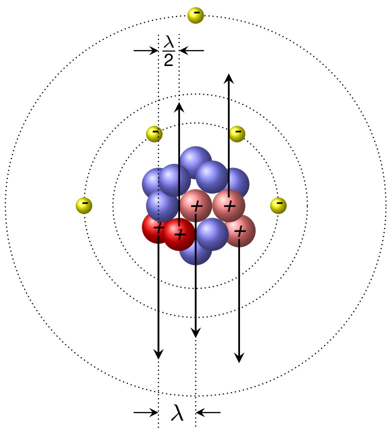
- *Beside its wavelength λ, the emw. is also characterized by its ang. frequency ω.*
- *In the void: $\omega = kc = \frac{2\pi c}{\lambda}$. **(dispersion)***

A 3: Model for laser matter interactions



- *We are left with a spring-like problem with $\omega-$periodic external sollicitation.*

A 4: Interaction with an emw with $\lambda \simeq \AA$



- *Adjacent protons (at half wavelength) are subject to opposite forces. This shear mechanism inside the kernel can overcome the atomic cohesive forces and break the atom!*

Assume this is the wavelength

Then the forces distribution will be like this. same force at wavelength

A 5: Lithography

Originally a printing process (Aloïs Senefelder, 1796, Bavaria)

(1) ***Drawing:*** *Fat wax on a smooth limestone.*

(2) ***Etching:*** *The stone is washed by a mixture of water and arabic gum:*
$\Longrightarrow$ *The gum is repelled by the fat parts and absorbed by others.*

(3) ***Inking:*** *The stone is inked:*
$\Longrightarrow$ *The ink is retained by the fat parts but slips on the gum.*

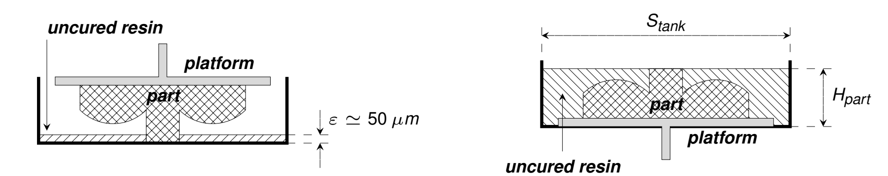
(4) ***Reproduction:*** *By pressing a paper sheet on the stone.*

- ***by extension,*** *one calls lithography any process where a part is partly protected (by fat, resine, ...) and then chemically etched (e.g fabrication of printed circuit board).*

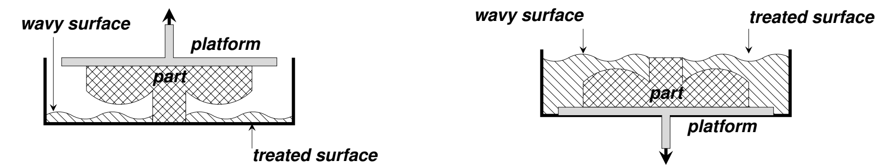
A 6: Some advantages to hang the part

Economy of resin and no need of recoating

SLA top-down (new) | *SLA down-top (basic)*



$V_{\text{resin}} \simeq V_{\text{part}}$ | $V_{\text{resin}} \simeq S_{\text{tank}} \times H_{\text{part}}$



wavy surface $\neq$ treated surface | *wavy surface $=$ treated surface*

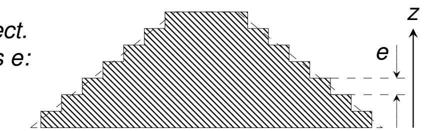
A 7: Resolution of an additive process

Resolution in different directions

- *Most of the additive processes build the part layerwise.*
- *Their resolution has to be considered differently in the build direction and in the layer plane.*

In the build direction (z)

- *The resolution is limited by a stair effect. It is proportional to the layer thickness e:*

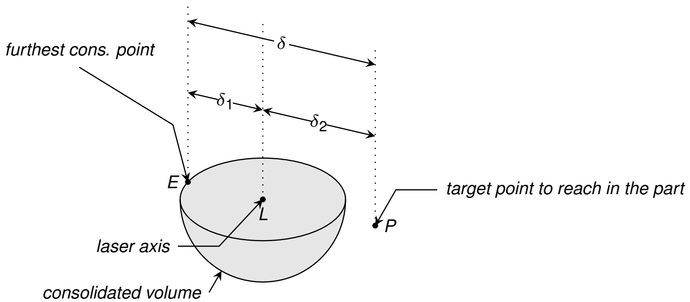


In the layer plane (x, y)

- *the resolution is limited by two independant factors:*
  - (1) *the dimensions of the smallest matter element to be added:*
    - *UV-cured or molten volume, deposited liquid droplet,...*
  - (2) *the positionning accuracy of the system depositing or inducing the consolidation of that element:*
    - *nozzle, laser beam, binder jet.*

A 8: Resolution of an additive process

Resolution issues in $x - y$



- *Laser positioning accuracy:* δ_2
- *Dimension of the smallest consolidated volume:* δ_1
- *Worst case resolution:* $\delta = \delta_1 + \delta_2$

A 9: Build speed of an additive process

Build speed (material consolidation rate MCR)

- *In AM, the fabrication time is essentially **proportional** to the volume of the part and **does not depend** on its geometrical complexity .*
- *The ratio between the fabrication time of a part and its volume is called build speed (MCR) is (unit: mm^3/s):*

$$\text{fab. time} \simeq \frac{\text{volume}}{MCR}.$$

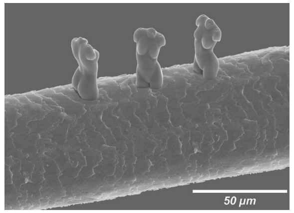
- *For a particular process, the build speed MCR varies between limits as a function of the used material.*
- *For most processes, the above formula only **underestimates** the fab. time. An accurate computation of the fabrication time of a part by an additive process also involves a term proportional to the construction height of the part :*

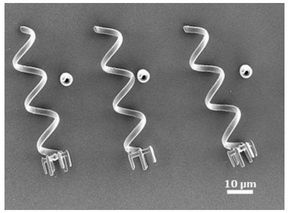
$$\text{fab. time} \simeq \frac{\text{volume}}{MCR} + \frac{\text{height}}{e} \times \frac{\tau_{layer}}{N}. \tag{1}$$

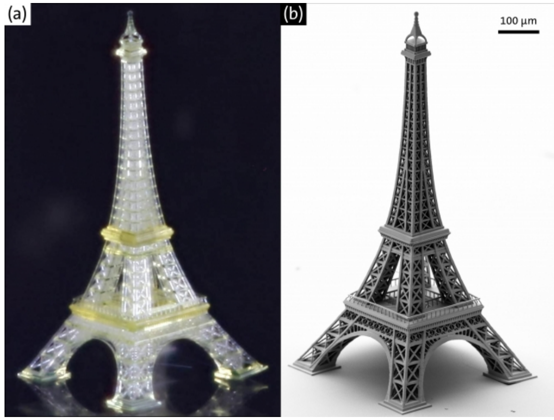
*where e is the layer thickness and τ_{layer} the **time to prepare a layer**: the ratio height/e represents the total number of layers. Note that the layering time can be **mutualized** between the N parts built in the same batch.*

A 10: Micro-stereolithography

Very small parts can be obtained by scaling down the process



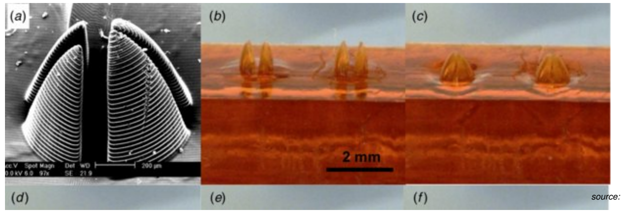




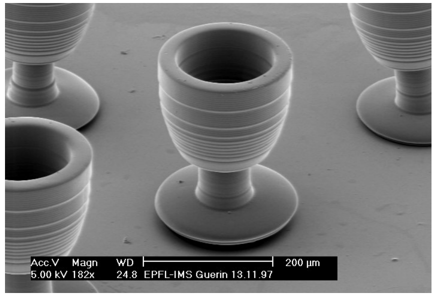
source: Fraunhofer-Institut für Lasertechnik Aachen

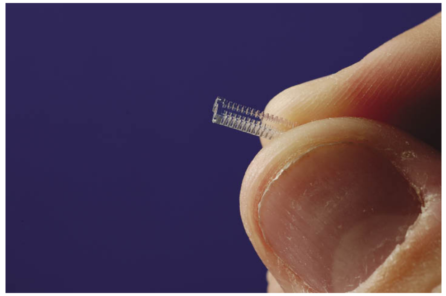
A 11: Micro-stereolithography

Very small parts can be obtained by scaling down the process



source: UniversityofWarwick



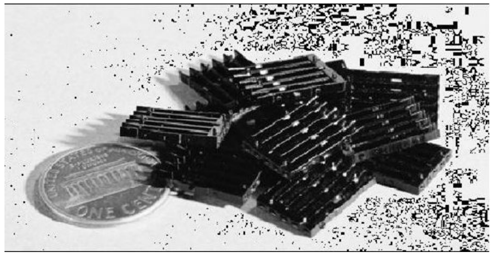


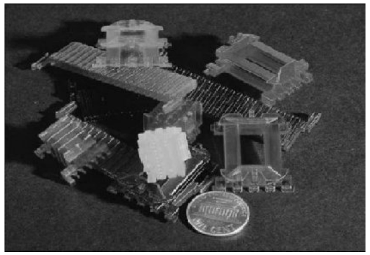
source: LMSi4

source: FineLinePrototyping

A 12: Manufacture of small series

Electrical components





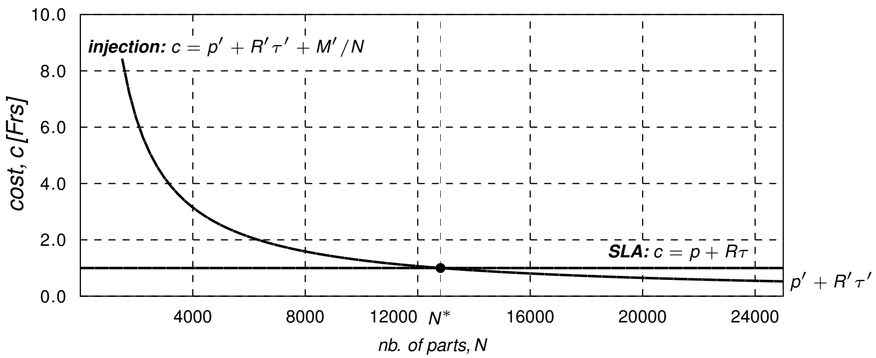
source: Fraunhofer-Institut für Lasertechnik Aachen

- *16'000 parts to produce*
  - *The **injection** and **SLA** processes are considered*
  - *SLA proves to be slightly more expensive*
  - *SLA is finally **chosen** due to shorter lead time (2 weeks against 2 month)*

A 13: Cost comparison SLA-injection

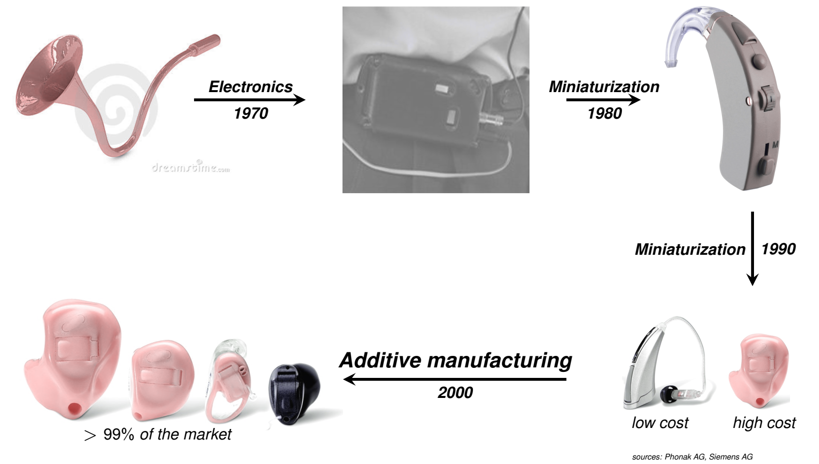
Determining parameters and cost comparison

	material cost, Frs	hourly rate (men+mach.), Frs/h	fab. time, h time, h	tool cost, Frs
SLA	p	R	τ	–
injection	p'	R'	τ'	M'



A 14: Custom items by SLA

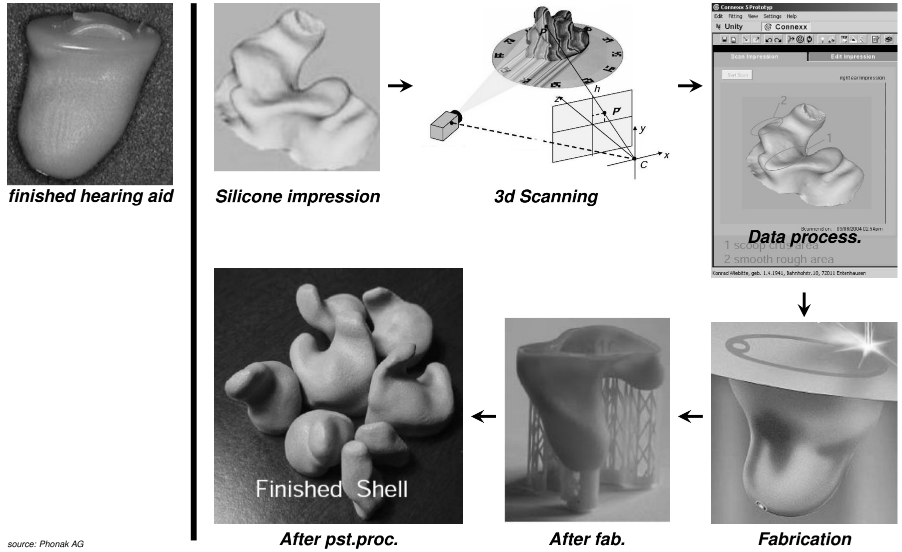
Transformation of an economical model



First:	***Nylon powders (by SLS), biocompatible but porous***
Today	***Biocompatible photosensitive resins (by SLA, PolyJet,...)***

A 15: Custom items by SLA

Hearing aids (Recent state of art)



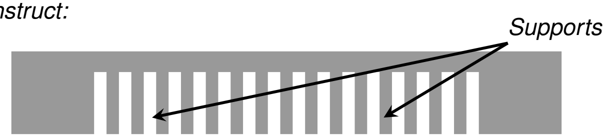
A 16: Supports

Request of support structures

- *The polymerization decreases the specific volume of the resine and increases its density*
- *Large overhangs have a tendency to sink inside the uncured resine*

To fabricate a part with a large overhang:

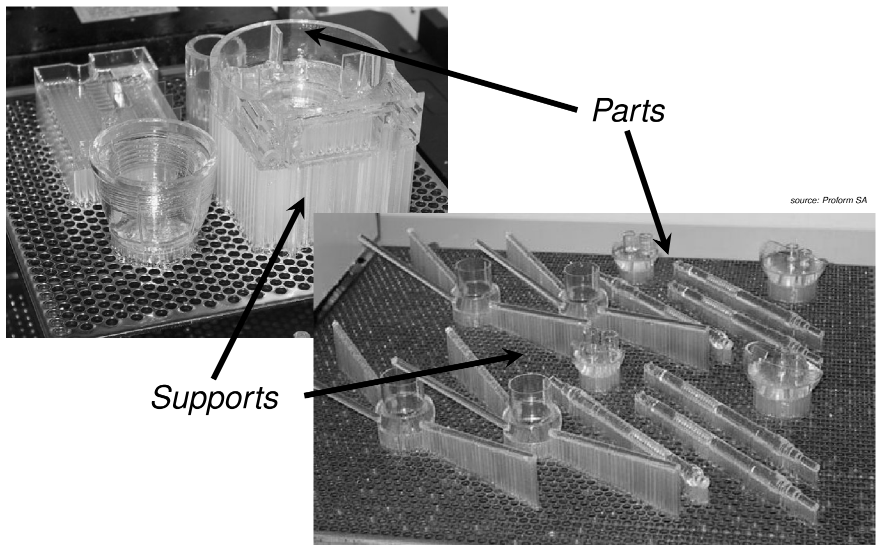
One has to construct:



and to remove the supports afterwards

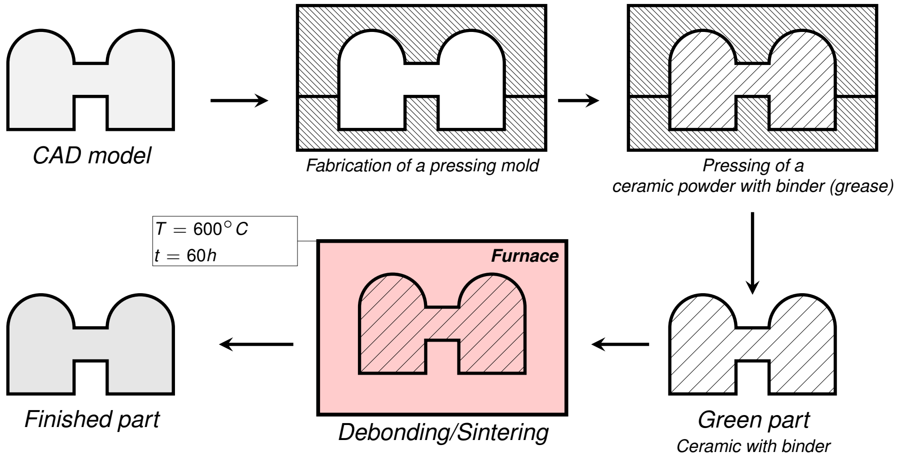
A 17: Supports

Example of support structures



A 18: Ceramic parts by the Lithoz™ process

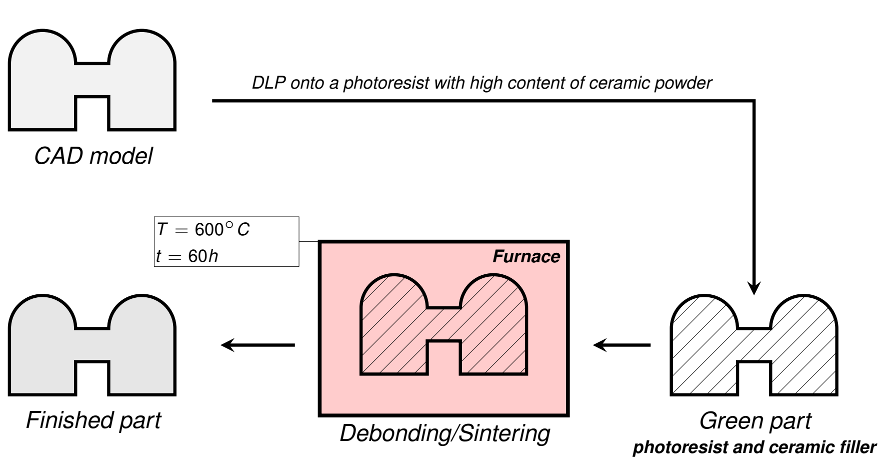
Traditional powder metallurgy for ceramic parts



(see Append. 20)

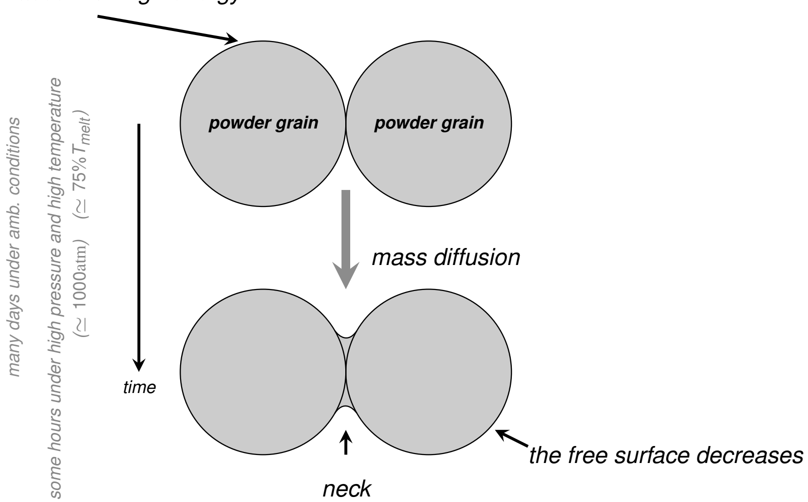
A 19: Ceramic parts by the Lithoz™ process (ctn'd)

Lithoz™: directly from CAD file to green part by DLP



A 20: Prod. processes: classical sintering

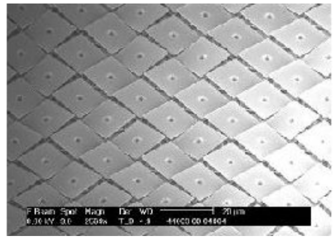
Physical principle of consolidation in classical sintering



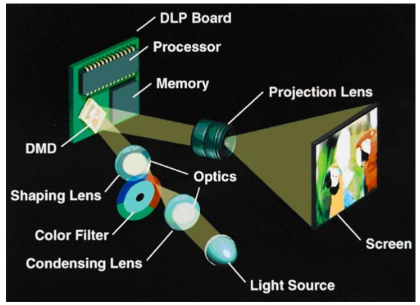
A 21: Digital micromirror devices (DMD)

A DMD acts as an optical switch of 1400 × 1050 pixels

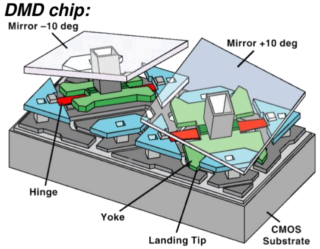
Mirrors network



Detailed operation of a DMD cell

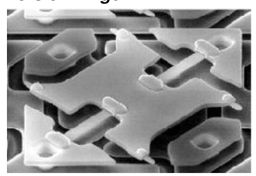


DMD chip:



Dim. mirror: $\simeq 16\mu\text{m} \times 16\mu\text{m}$

Torsion hinge



$t_{carac} \simeq 15\mu\text{s}$

DLP videoprojector in visible light

source: Envisiontec™

A 22: The UV-LIGA process chain

Basic principle

- *UV-LIGA denotes a **process chain** which ends with galvanic moulding (GA: Galvanisierung und Abformung) and where the sacrificial shape tool for the GA process is produced by UV lithography:*
  - *In the original process, the shape tool is made out of photoresist consolidated by a UV flash through a mask (no DMD nor lasers) .*
- *The main application of UV-LIGA is to manufacture thin metallic parts (cylindrical geometry) for the watch making industry .*
- *The mask is made by laser engraving (resolution: $> 10\,\mu m$) .*
- *To ensure accuracy the mask is engraved at a much higher scale (up to factor 50) .*
- *The down-scaling of the flash is achieved by converging optics achieveing a resolution of*

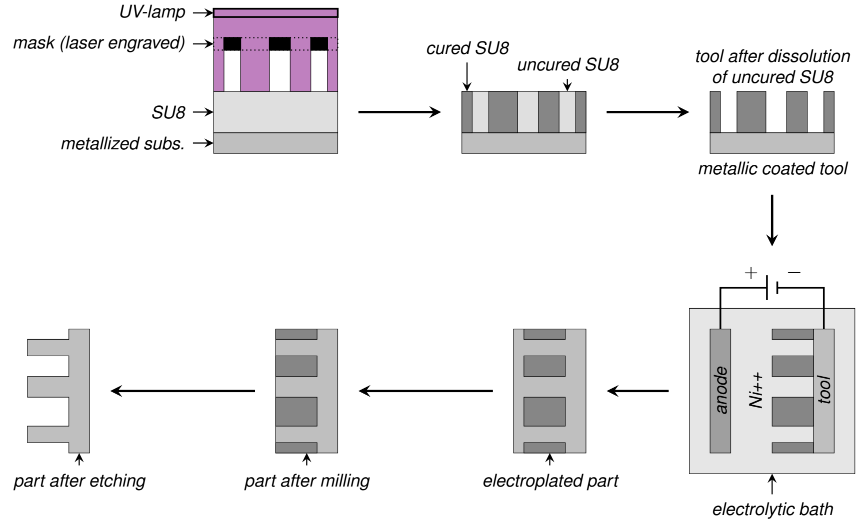
$$\frac{1}{50} \times 10 \simeq 0.2\,\mu m.$$

Acronym

*UV-LiGA stands for **U**ltra-**V**iolet-**Li**thographie **G**alvanisierung und **A**bformung.*

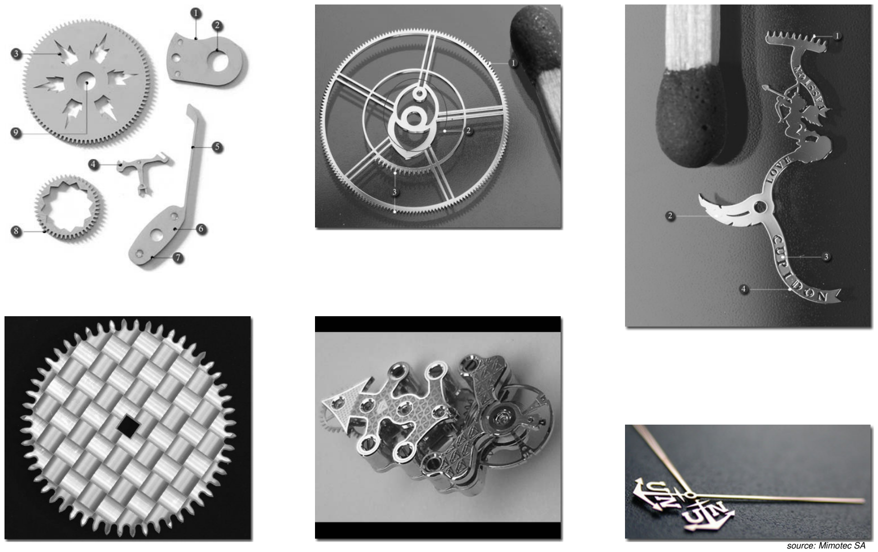
A 23: The UV-LIGA process chain

Principle



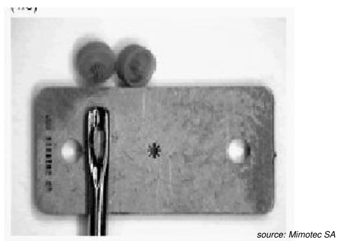
A 24: Examples of parts obtained by UV-LIGA

Example of parts

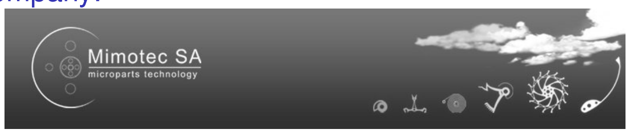


A 25: Examples of parts obtained by UV-LIGA

Example of parts: Micro-moulds for the watch industry



Company:



Mimotec SA
Blancherie 61
1950 Sion

A 26: Advantages and disadvantages of UV-LIGA

Advantages

- *Good accuracy $\simeq 1\mu m$ (small parts, accurate mask),*
- *Advantageous process for small to medium series:*
  1 mask → N expendable tools → N metal parts.
- *Direct competition for wire electro discharge machining and stamping.*

Disadvantages

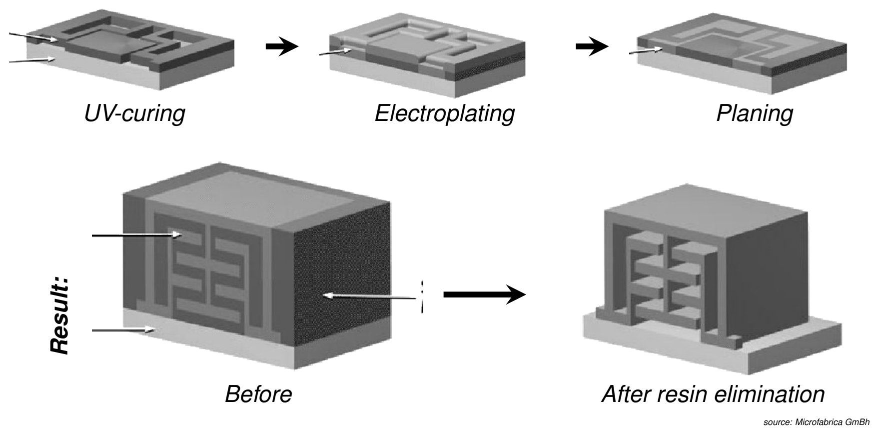
- *The electroplating process limits the choice of possible materials:*
  - *essentially pure metals (Ni, Cu, Au),*
  - *alloys are in principle excluded.*

Miscellaneous

- *This process has been developed at EPFL. It is derived from X-Liga.*
- *The X-Liga works on the same principle but uses X-rays instead of UV radiation.*
- *The X-Liga is even more accurate than the UV-Liga, but it is more expensive.*

A 27: The MICROFABRICA process

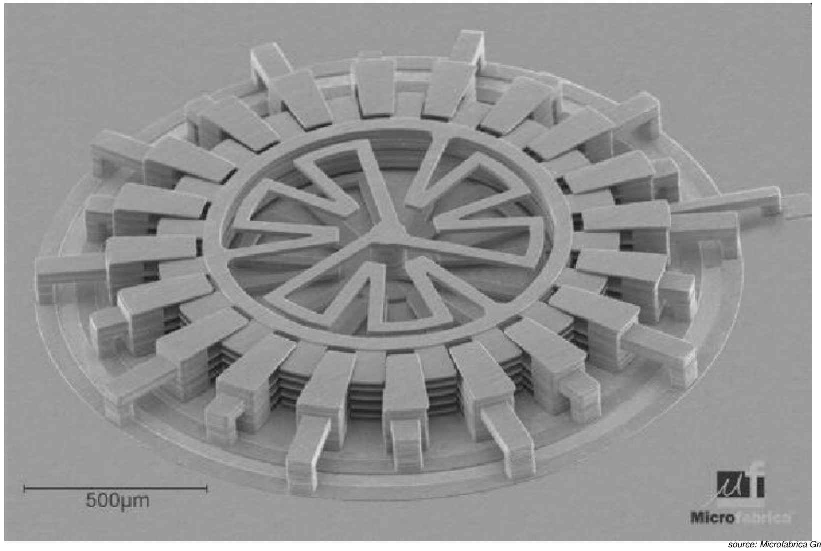
Non-cylindrical structures can also be fabricated by iterating the cycle:



N.B. *This process is known as* MICROFABRICA *process*

A 28: The MICROFABRICA process: parts

Example of parts



source: Microfabrica GmBh