

# Additive manufacturing of passive and active optical components

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*Center for Optical Technologies*  
*Aalen University, Germany*



# Agenda

- **3D printing @ Center for Optical Technologies**
- **printing of passive optical components**
- **printing of active optical components**
- **Printer development**
- **Summary**

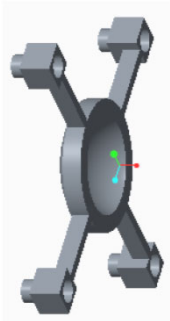
# Agenda

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# 3D printing @ Center for opt. Technologies

## ➤ a brief introduction into AM

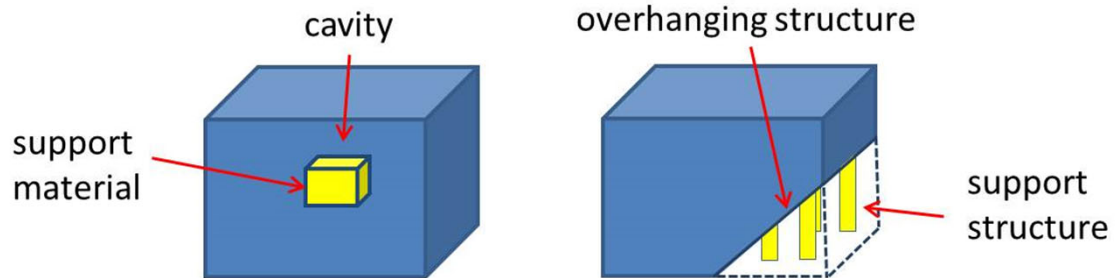
CAD model



3D printing



finished part



# 3D printing @ Center for opt. Technologies



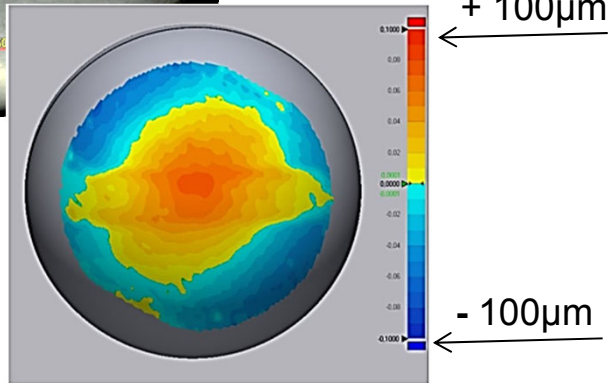
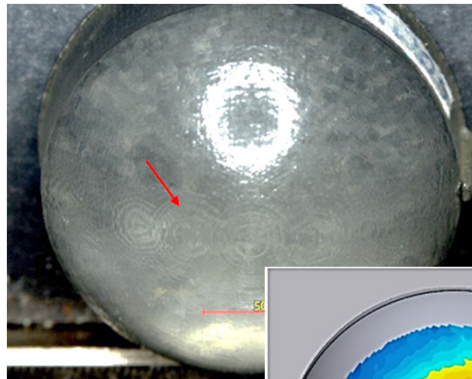
- printing technologies

**Each system has its individual advantage / disadvantage wrt. optics**

# 3D printing @ Center for opt. Technologies

## ➤ Characteristics of 3D printed optics / shape deviation & surface

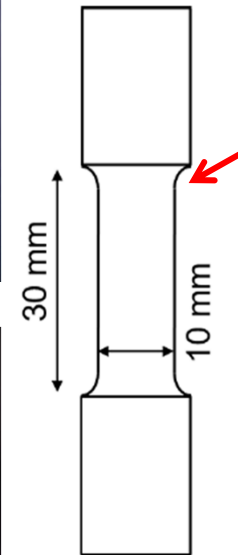
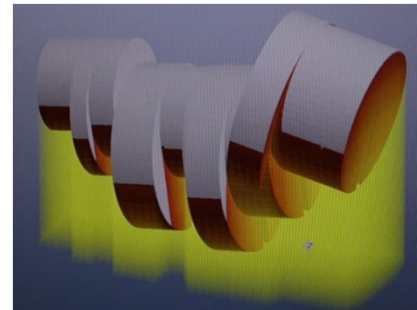
MJM printed lens



comparison:  
best-fit sphere

**need to be reflected in design**

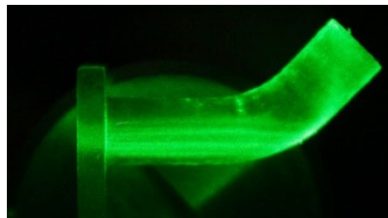
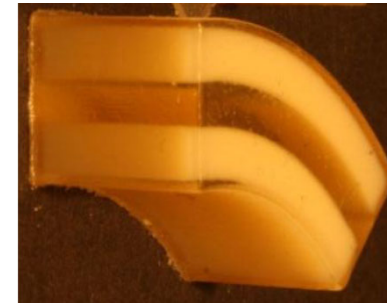
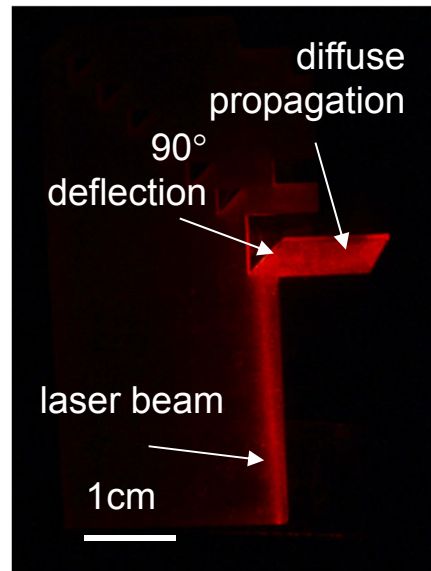
support structure



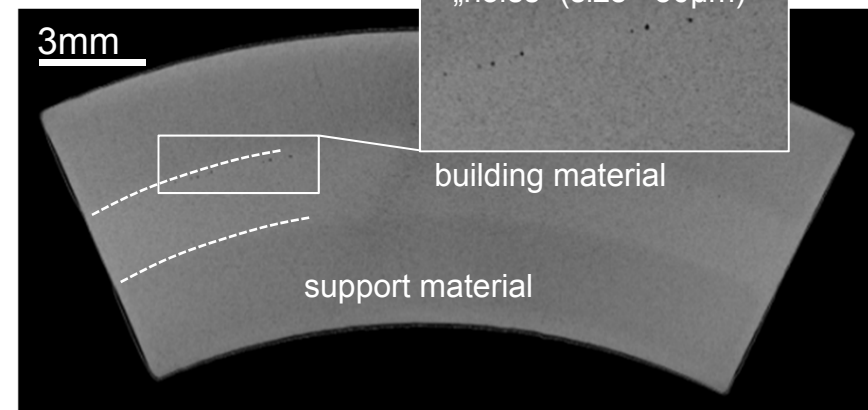
**surface need to be reworked**

# 3D printing @ Center for opt. Technologies

## ➤ Characteristics of 3D printed optics / volume scattering

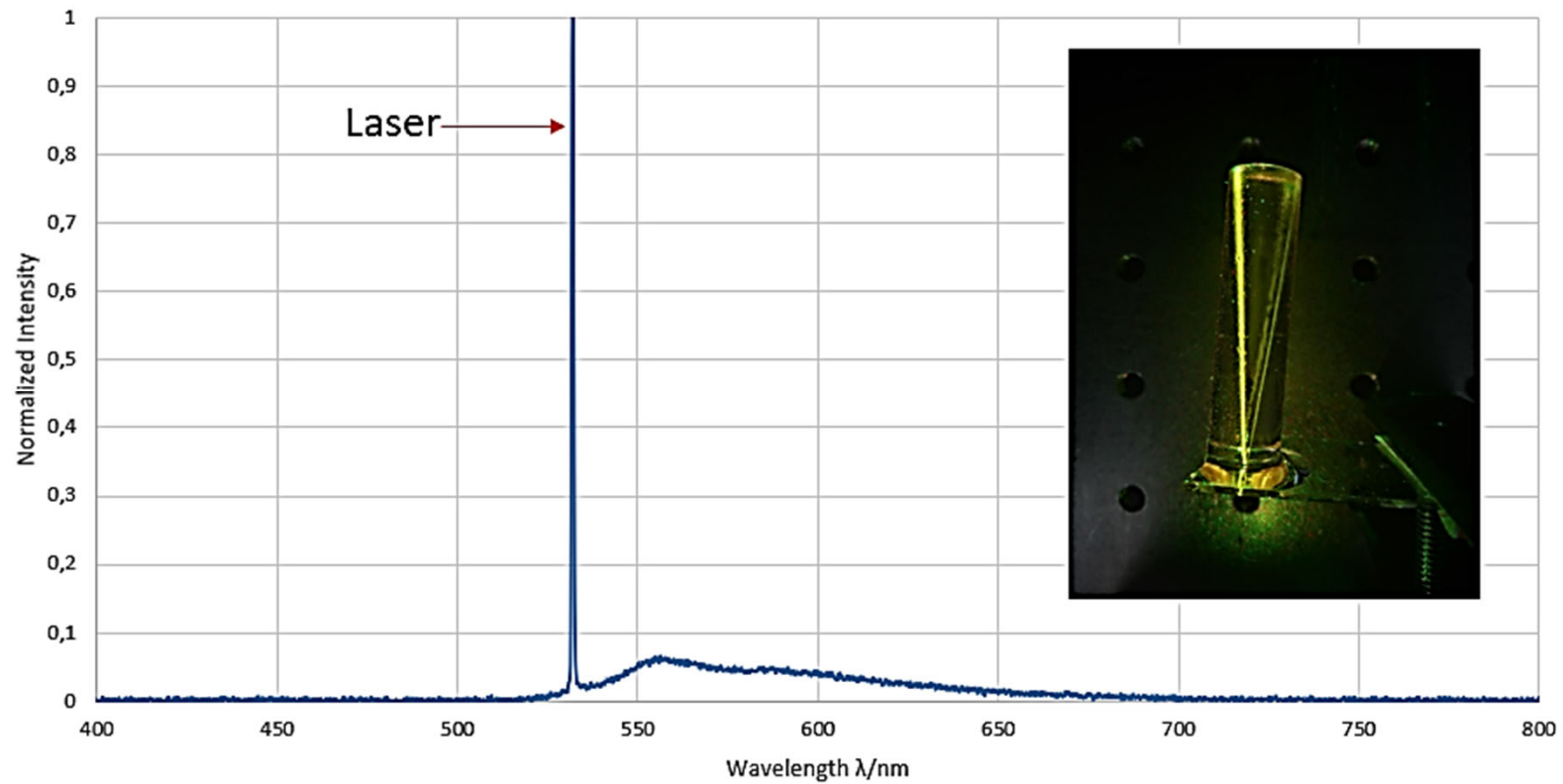


CT measurement



# 3D printing @ Center for opt. Technologies

## ➤ Characteristics of 3D printed optics / fluorescence

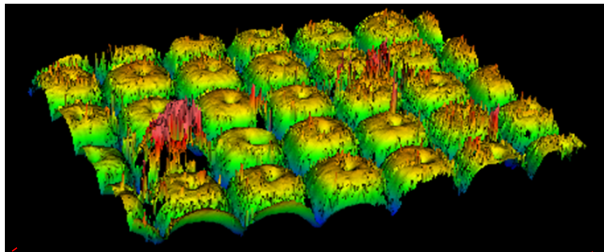




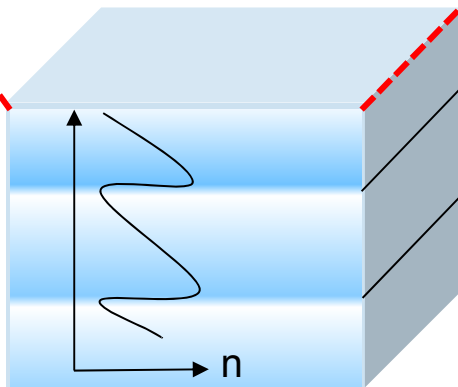
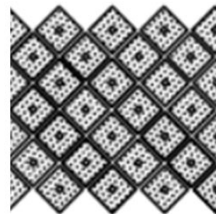
# 3D printing @ Center for opt. Technologies

## ➤ Characteristics of 3D printed optics / refractive index

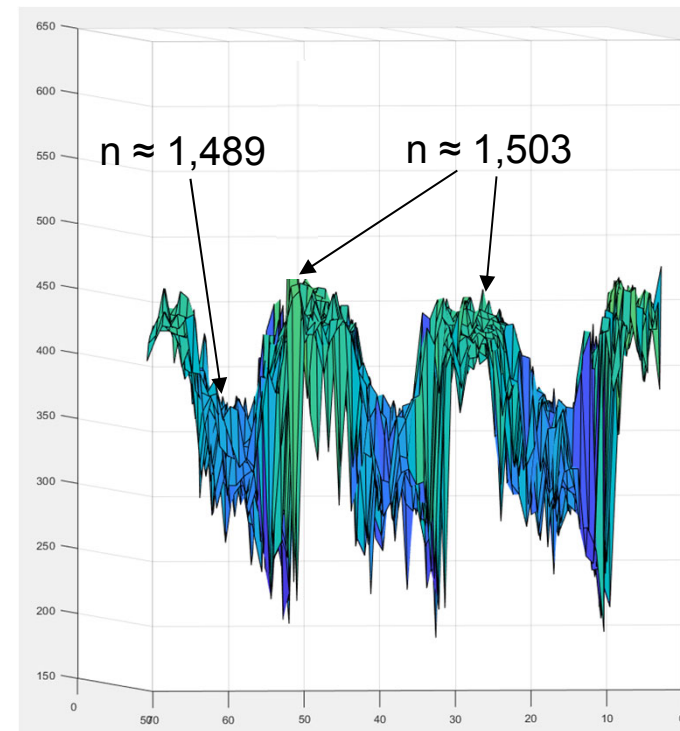
top surface (white light interferom.)



Wintech Pro 4500



refractive index distribution @ surface

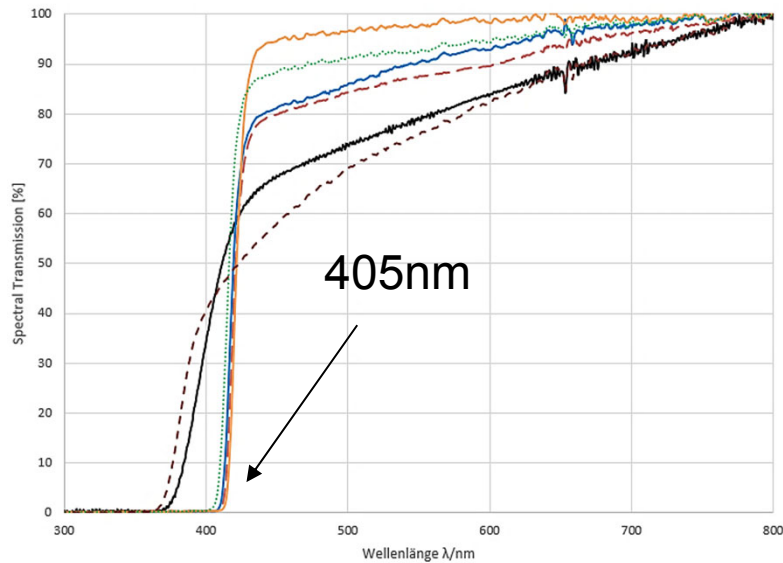


# 3D printing @ Center for opt. Technologies

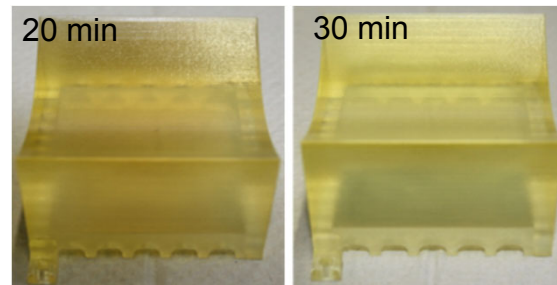
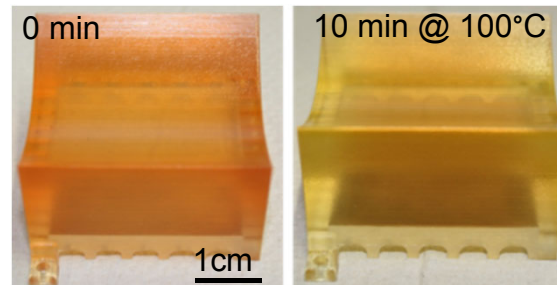
## ➤ Post processing / transmission

- thermal treatment
- UV treatment

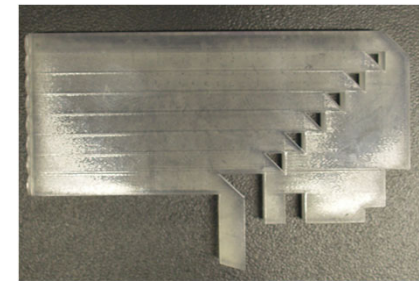
## ➤ material



Keyence (MJM):

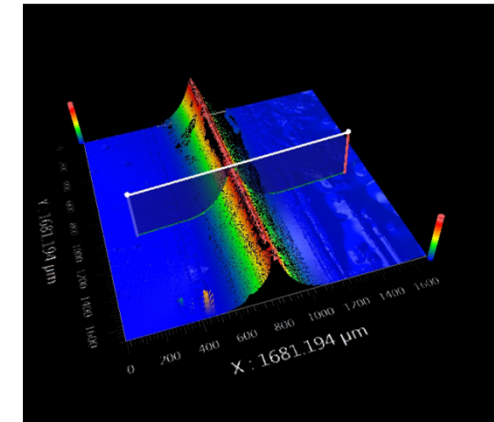
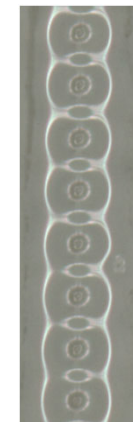
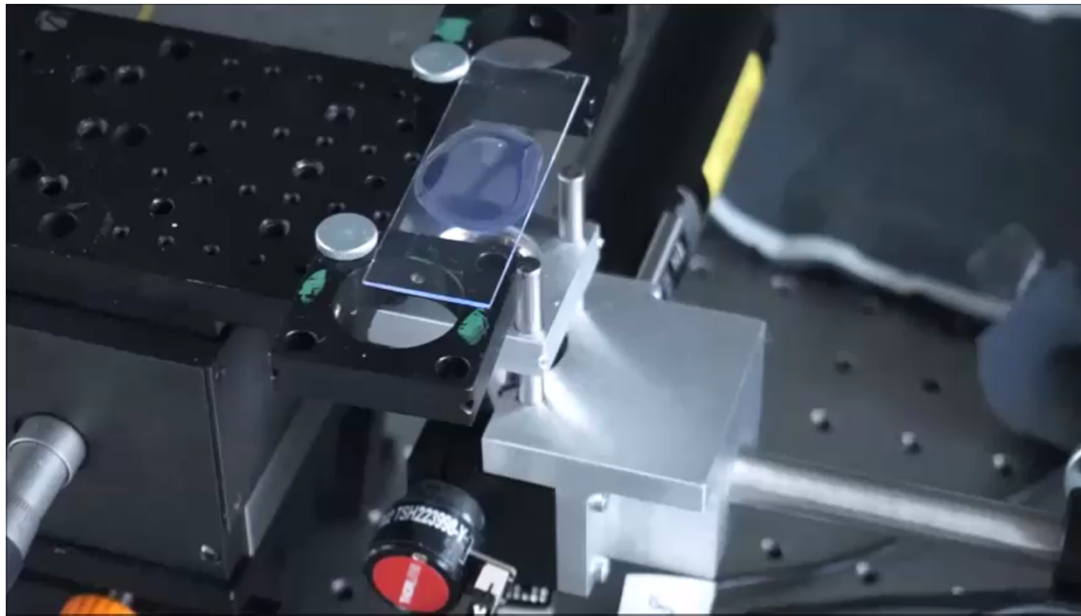


Accura 60 / Viper (SLA):



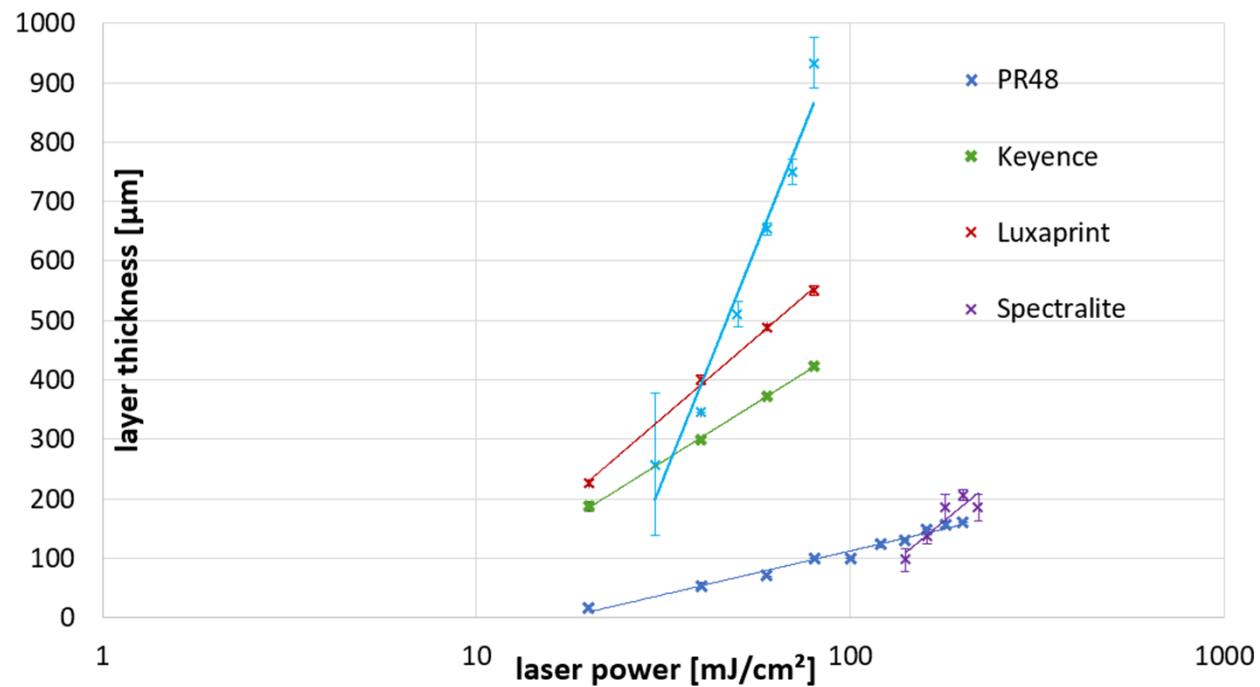
# 3D printing @ Center for opt. Technologies

- Post processing / transmission / material



# 3D printing @ Center for opt. Technologies

## ➤ Post processing / transmission / material

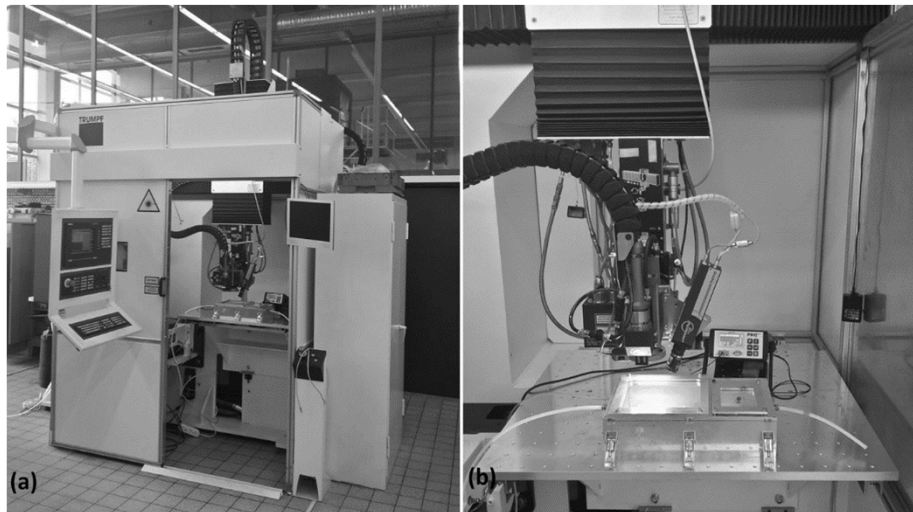


### Parameters:

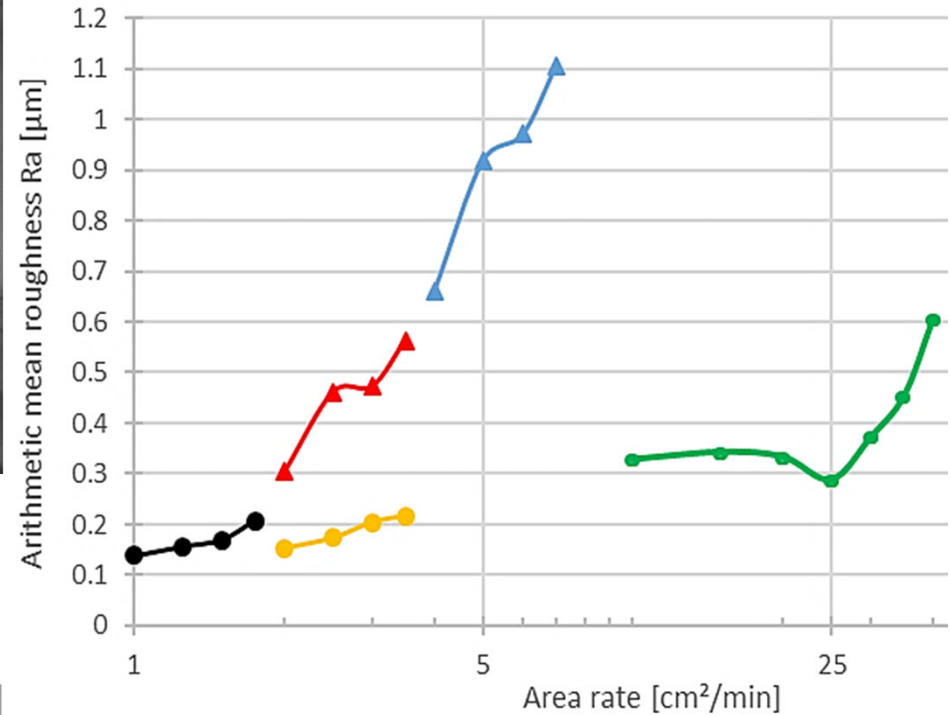
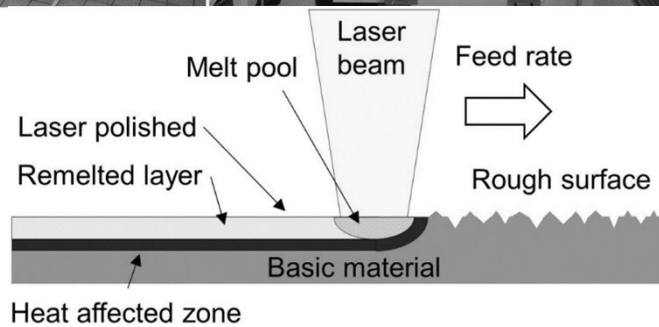
- optical penetration depth
- critical energy
- cure depth
- transmission
- refractive index
- Abbe number
- ...

# 3D printing @ Center for opt. Technologies

## ➤ Post processing / polishing / laser polishing

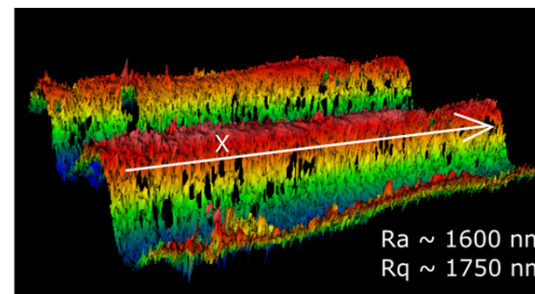
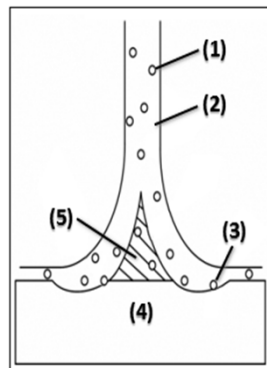
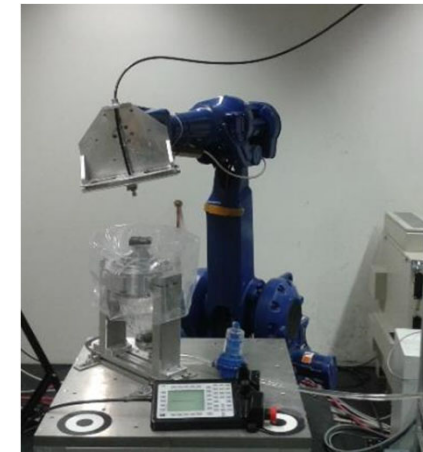
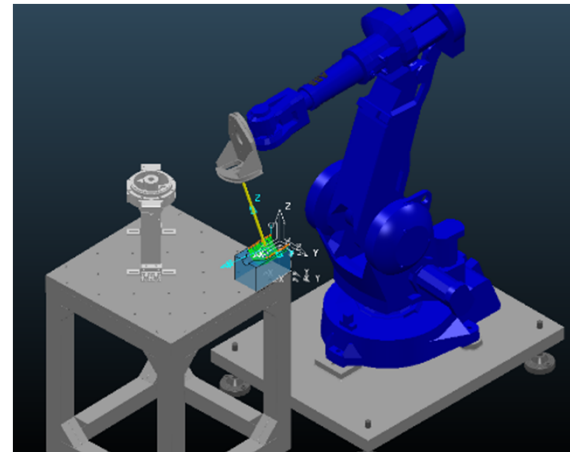
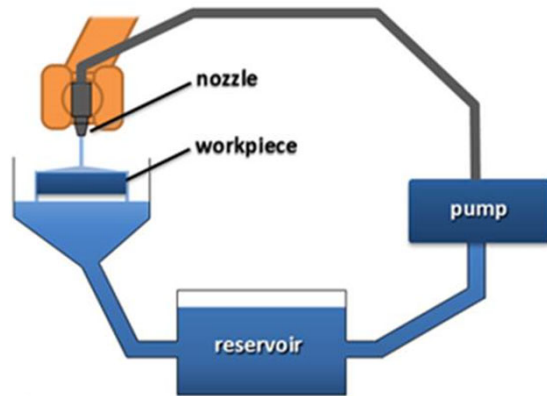


Trumpf  
TruDisk 4002  
(4kW, 1kHz,  
1030nm  
Ar-atmosph.)

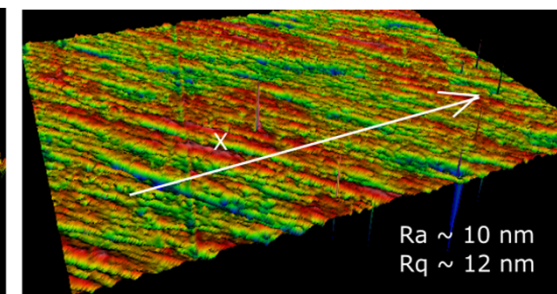


# 3D printing @ Center for opt. Technologies

## ➤ Post processing / polishing / fluid jet polishing



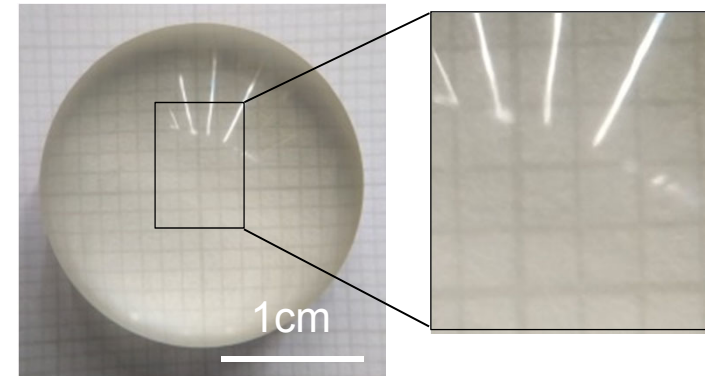
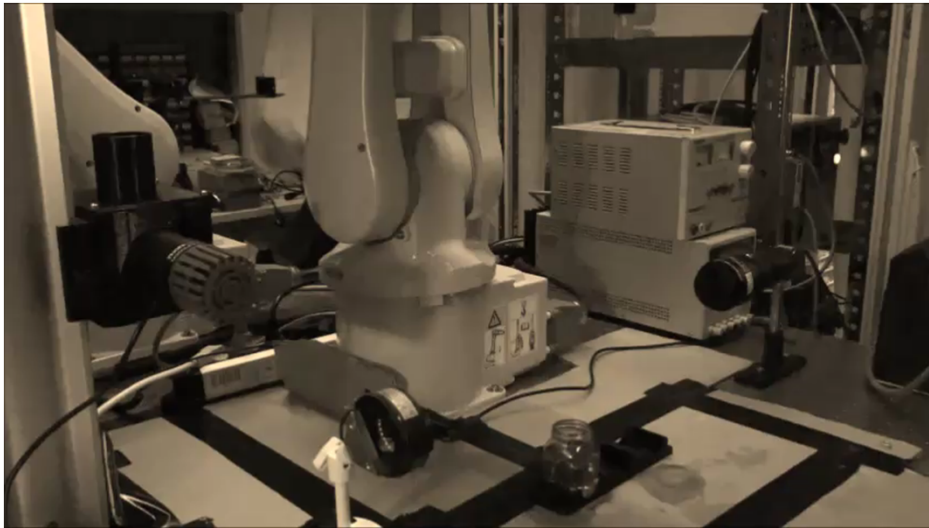
after 3D print:  $R_a > 10 \mu\text{m}$



after polishing:  $R_a < 10 \text{ nm}$

## 3D printing @ Center for opt. Technologies

- Post processing / polishing / dip coating



- variations: cleaning process  
vaccum (1 mbar)  
temperature

$R_a \sim 10\text{nm}$   
(but: surface deviation)

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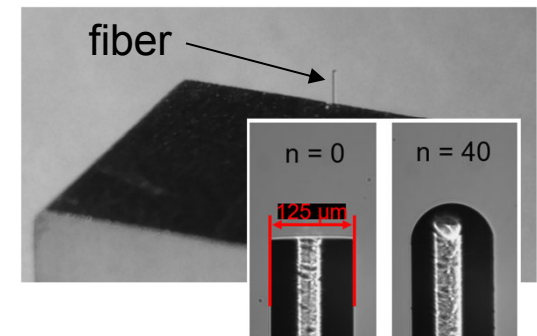
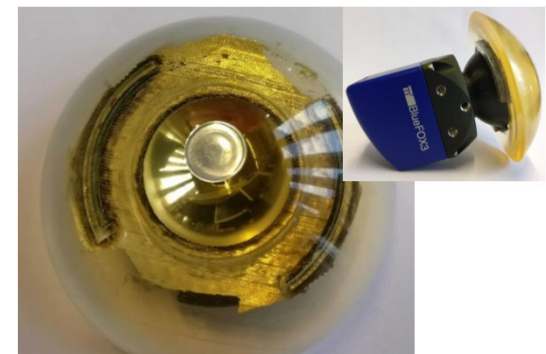
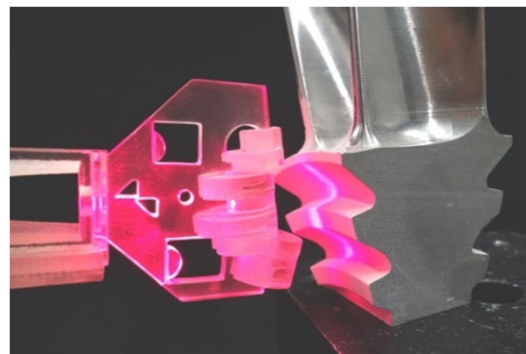


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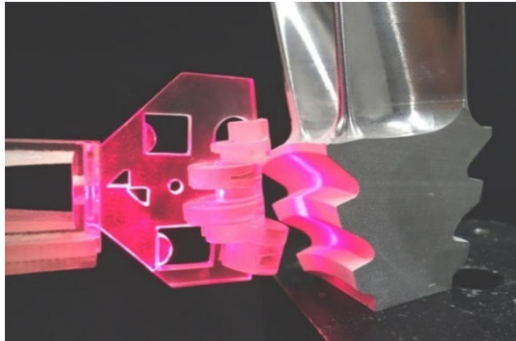
# 3D printing of passive optics

## ➤ examples



# 3D printing of passive optics

## ➤ process chain



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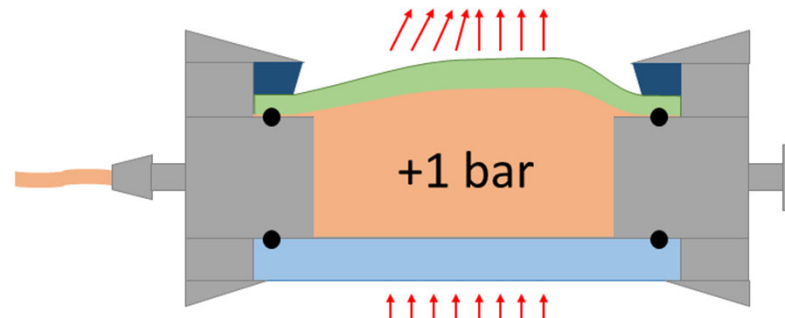
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# Printing of active optical components

## ➤ adaptive optical components



- Realization of adaptive optics, customized for each application
- Example Liquid lens: 3D printed membrane (spatially resolved thickness)



# Printing of active optical components

## ➤ adaptive optical components



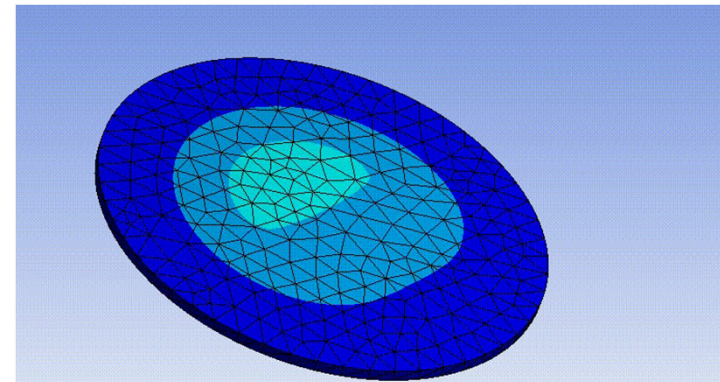
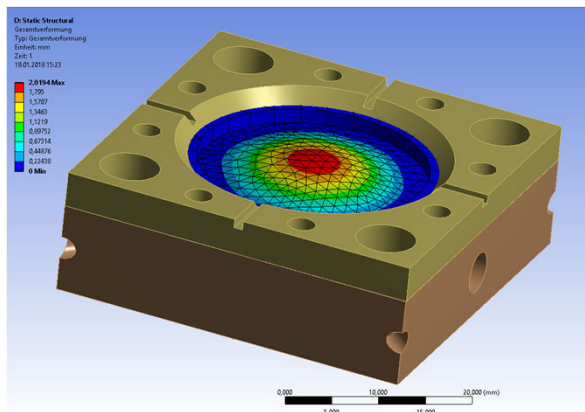
- Application based optic design
- Check performance
- Considering optical properties of 3D printed materials
- Loop with mechanical simulation

# Printing of active optical components

## ➤ adaptive optical components



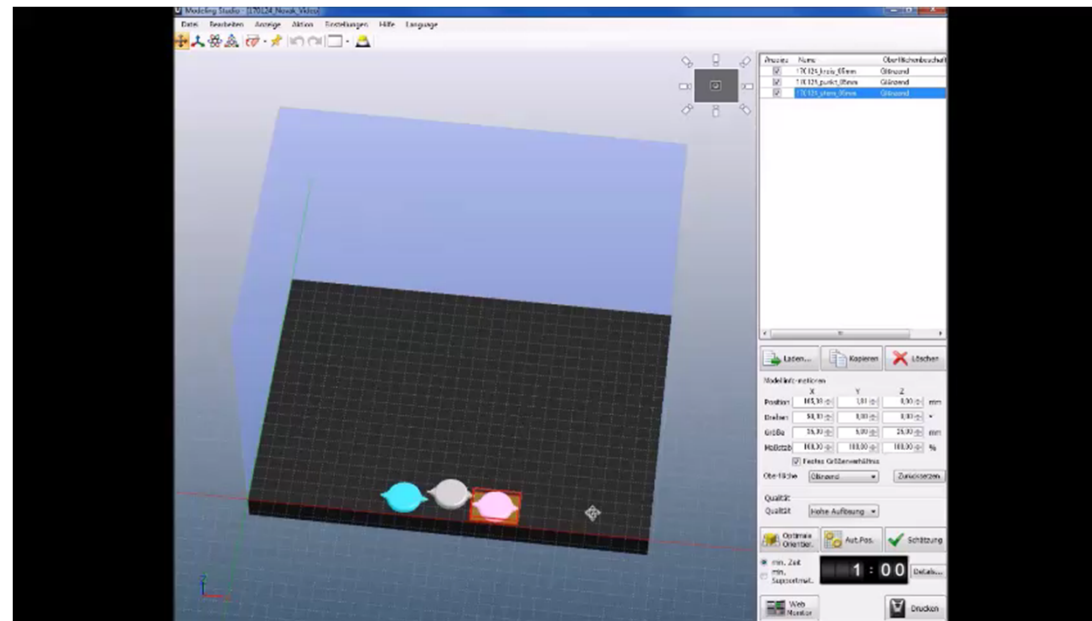
- comprehension of functionality by simulating mechanical behavior
- Combination of functional and mounting components → reducing part count
- Feedback loops with optic simulation for optimization





# Printing of active optical components

## ➤ adaptive optical components



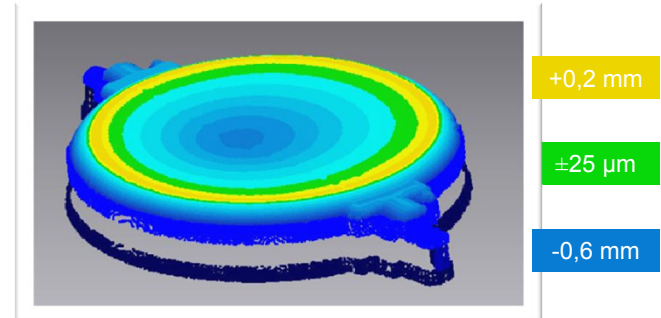
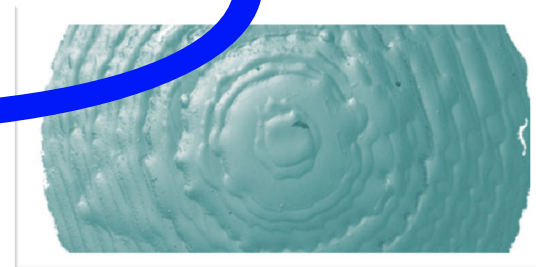
# Printing of active optical components

## ➤ adaptive optical components



### digital process chain

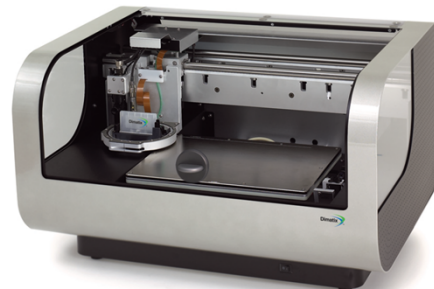
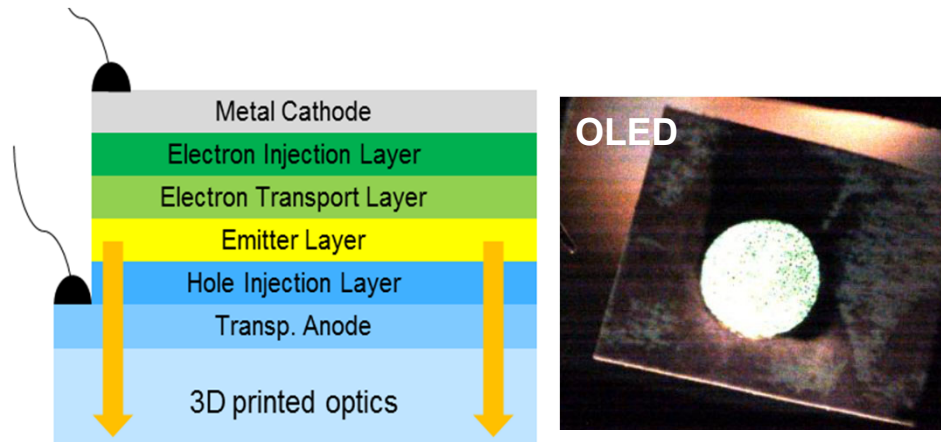
- mechanical properties
- surface (roughness) → rework
- shape (compare measurement / CAD)
- optical functionality
- etc.



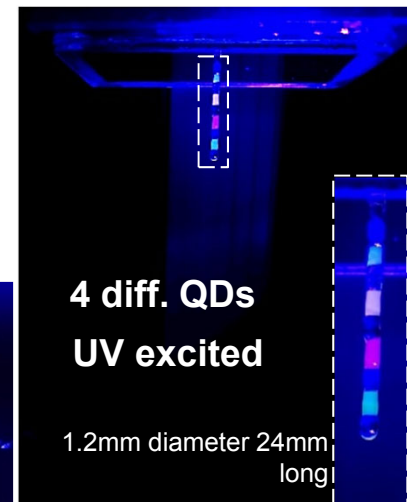
# Printing of active optical components

## ➤ Luminescent optical components

### Printing Organic Light Emitting Diodes



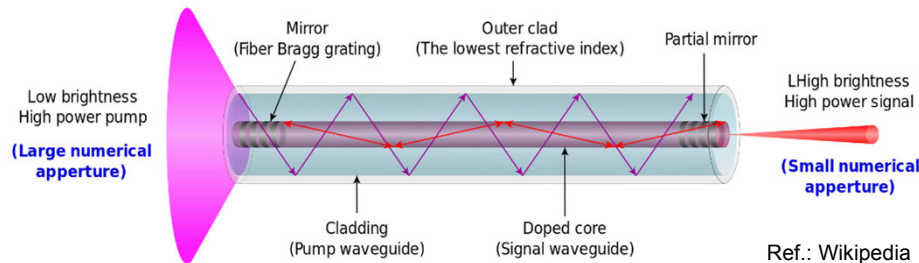
### Multimaterial Quantumdot printing



# Printing of active optical components

## ➤ amplifier / converter

### • Basic principle:

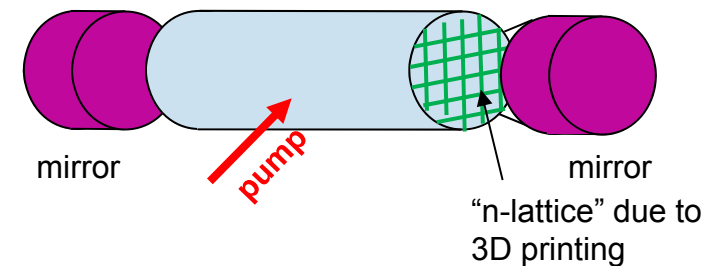


### • Design parameters

- cladding pumped or core pumped
- Bragg grating to realize resonator
- Gradient in refractive index
- Doping: Yb, Tm, Er, ...

### • Concept idea:

- macroscopic “POF fiber laser”



- Doping: Nd-YAG nanoparticles (40nm) (low concentration:  $\ll 10^{26}$  Ions/m<sup>3</sup>)
- Pump source 4x 2W LD (808nm)
- Resonator: 1<sup>st</sup>: hemispherical; 2<sup>nd</sup>: mirror or Bragg grating (inkjet printed)

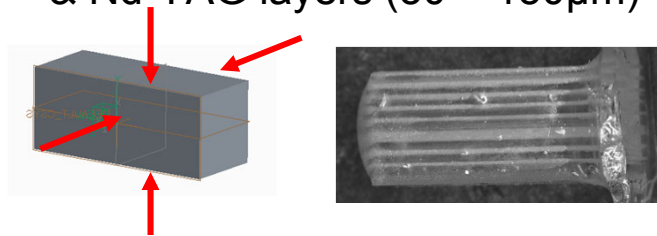
**homogeneous Nd-YAG distribution & scattering will be a task!**

# Printing of active optical components

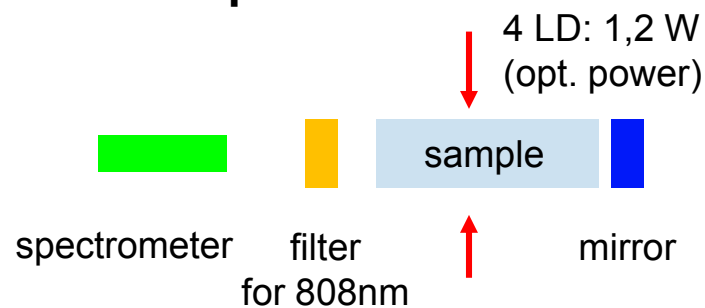
## ➤ amplifier / converter

- **printing the cavity**

- cuboid (5x5x12mm<sup>3</sup>) standard material & Nd-YAG layers (50 – 150µm)

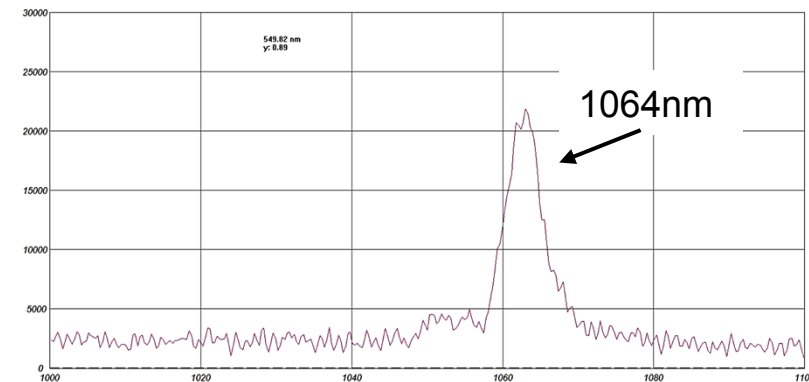


- **Test set-up**



- **result:**

- 1,2W; integration time: 5sec
- clear 1064nm signal (spont. emission)



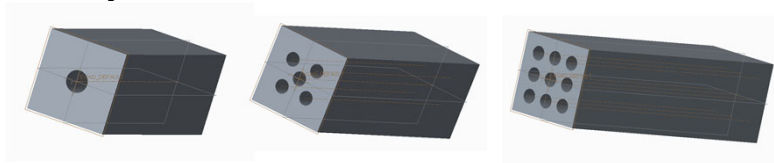
- other configurations possible?

# Printing of active optical components

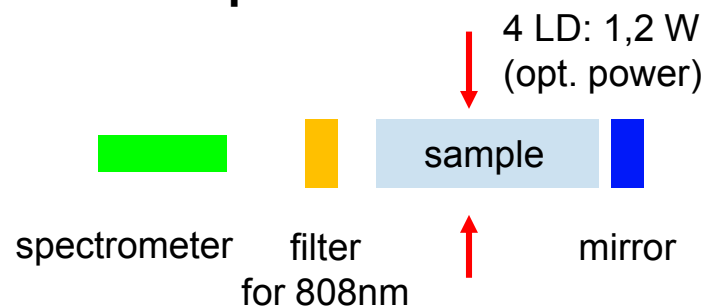
## ➤ amplifier / converter

- **printing the cavity / design #4**

- cuboid (5x5x12mm<sup>3</sup>) & Nd-YAG cylinders

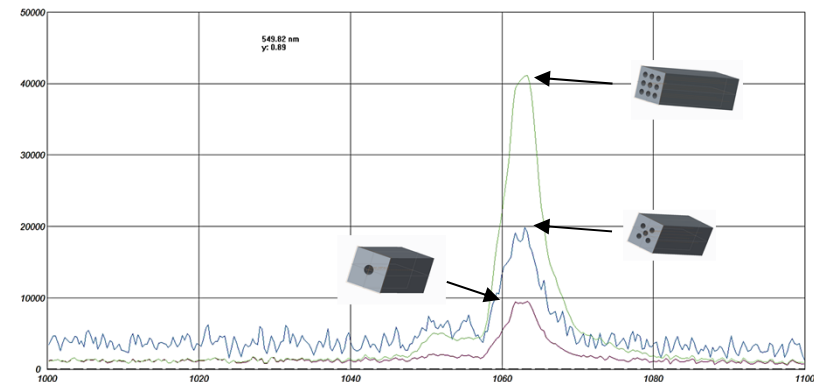


- **Test set-up**



- **result:**

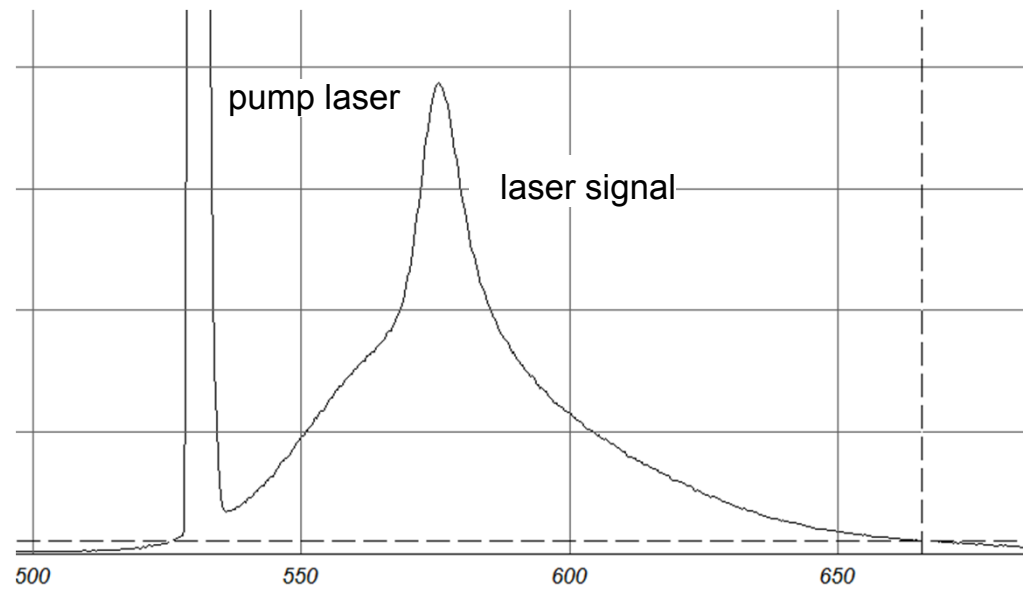
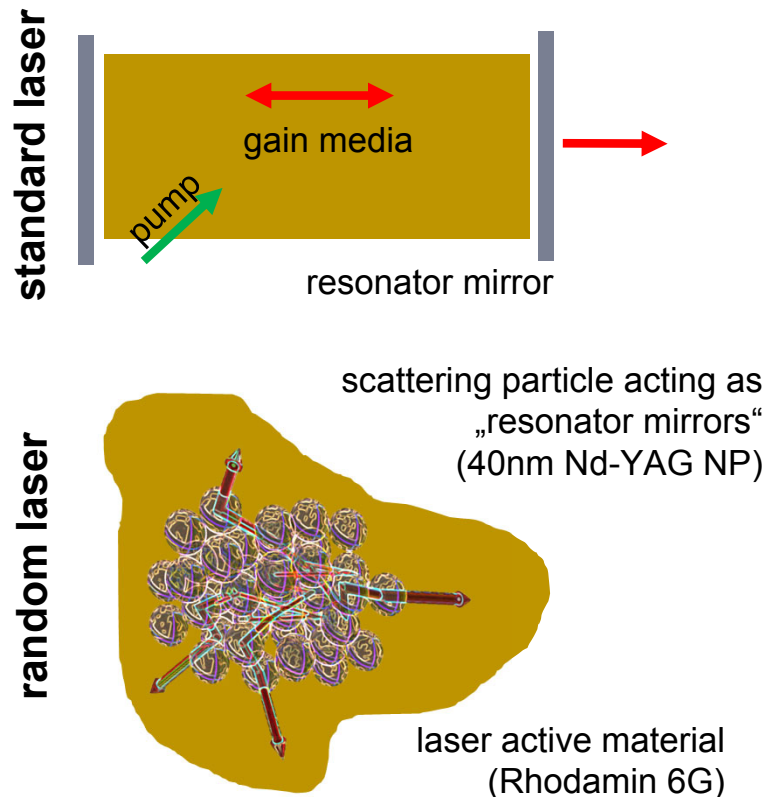
- 1,2W; integration time: 5sec
- clear 1064nm signal



- works as a converter 808nm → 1064nm
- building a resonator will be demanding!

# Printing of active optical components

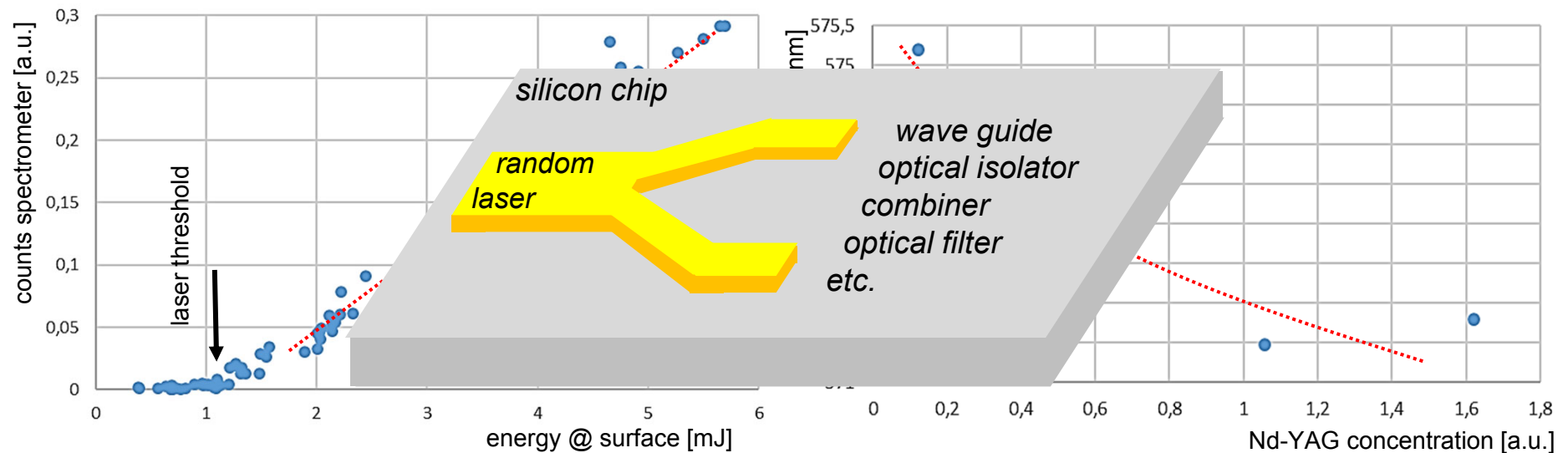
## ➤ Random lasers for 3D printed integrated photonics



# Printing of active optical components

## ➤ Random lasers for 3D printed integrated photonics

- Intensity vs. pump energy
- Influence of Nd-YAG concentration





# Agenda

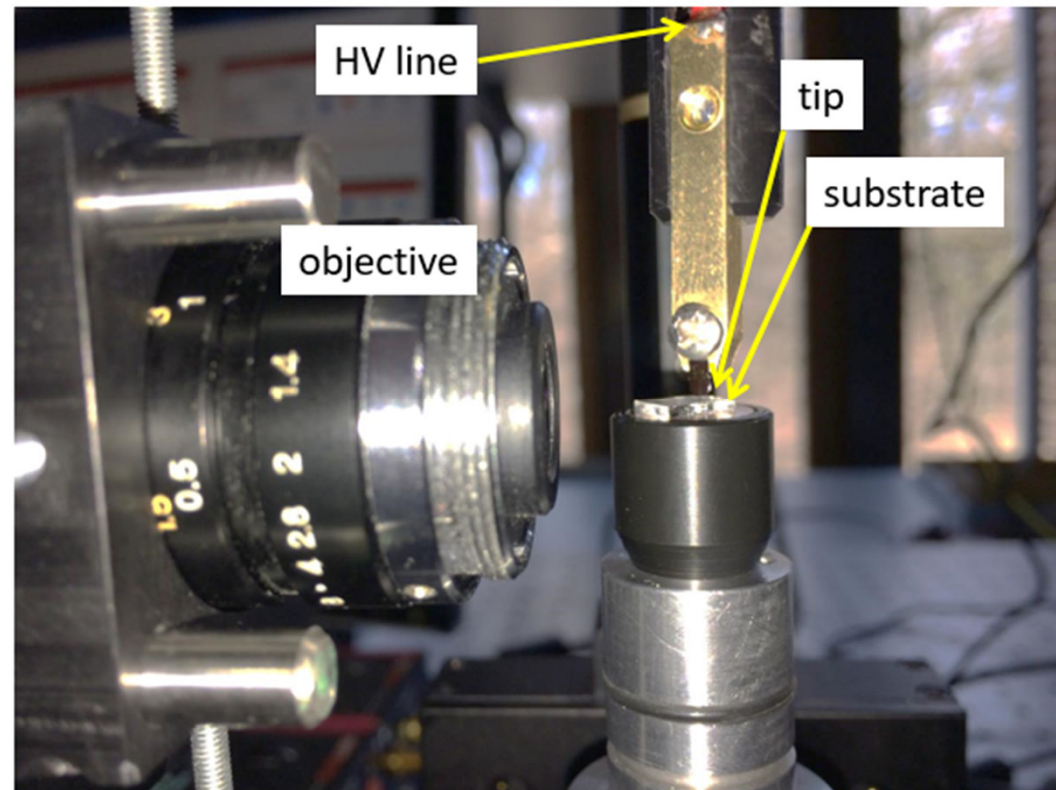
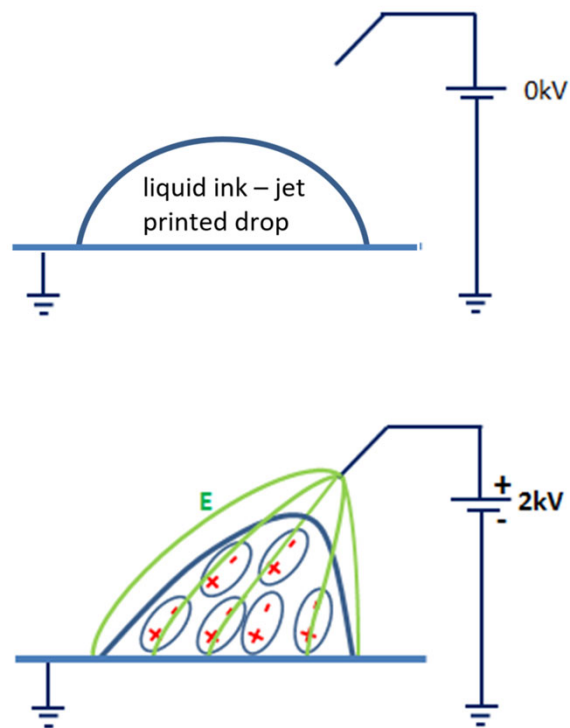
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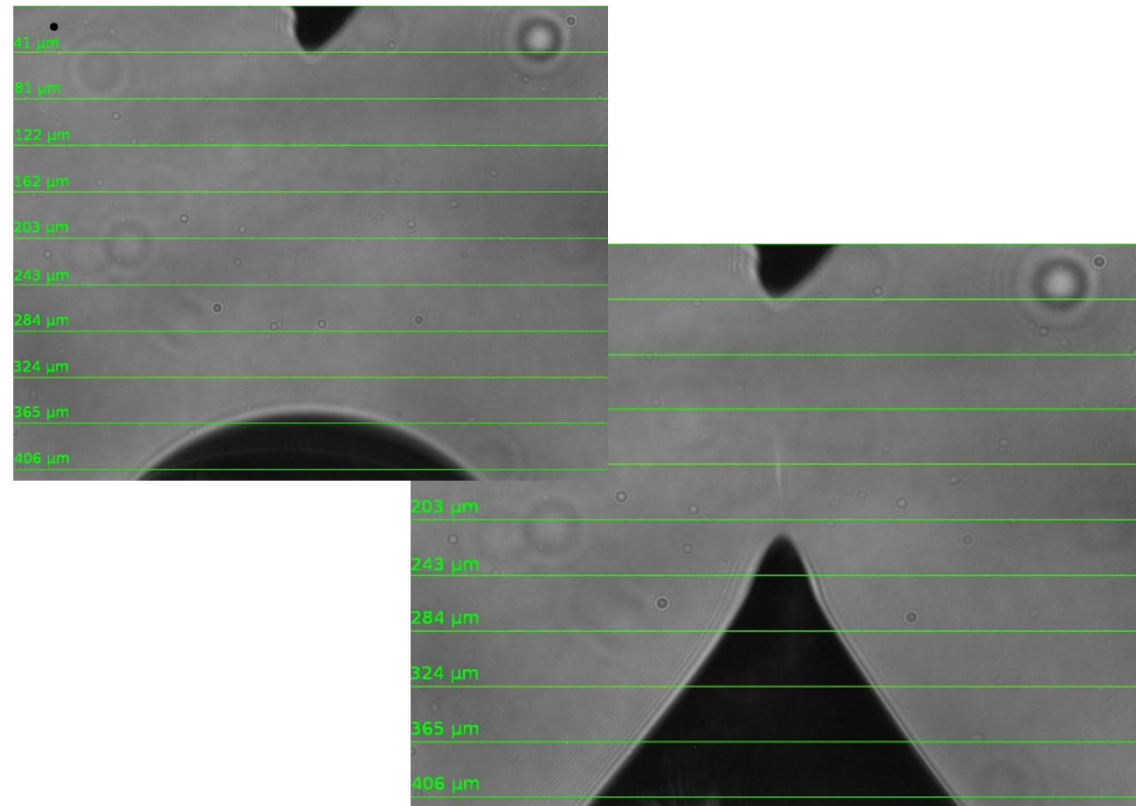
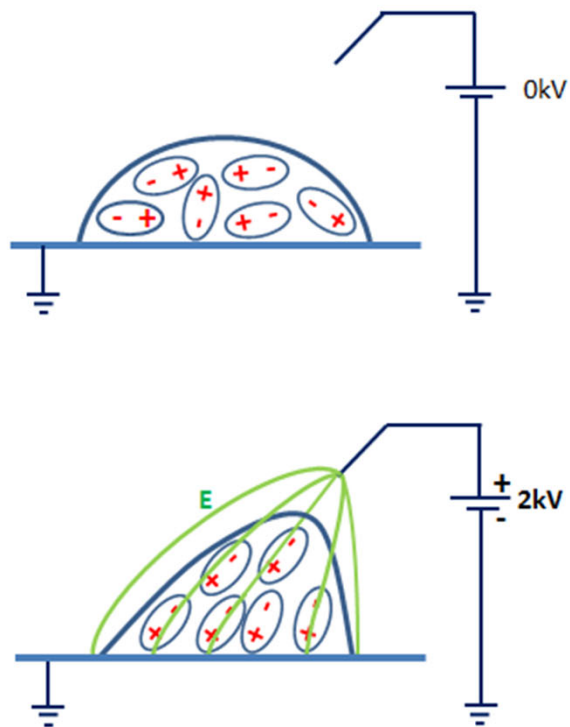
# Printer development: Electro3DOptics

- modify shape by electrical fields



# Printer development: Electro3DOptics

- modify shape by electrical fields

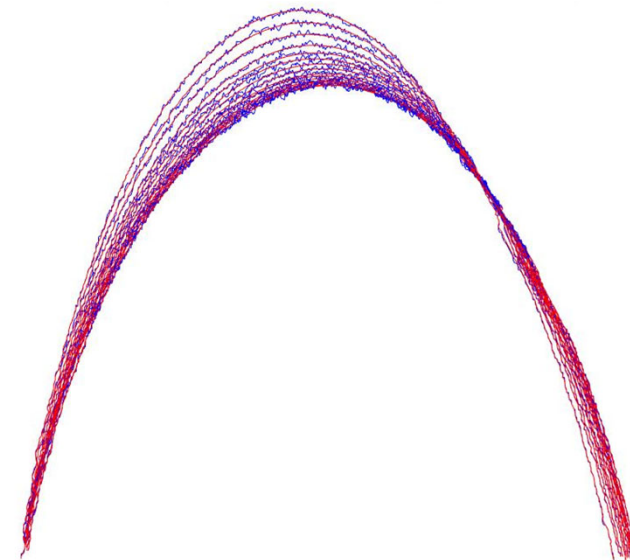
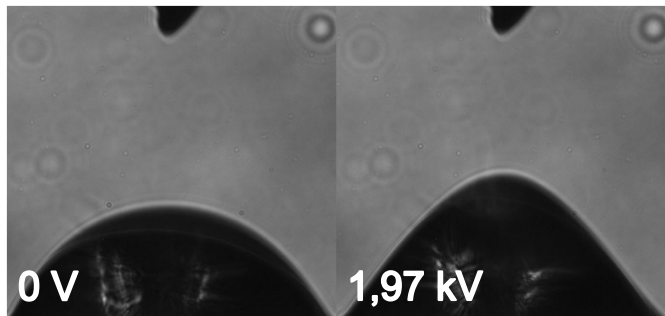


## Printer development: Electro3DOptics

### ➤ modify shape by electrical fields / modelling

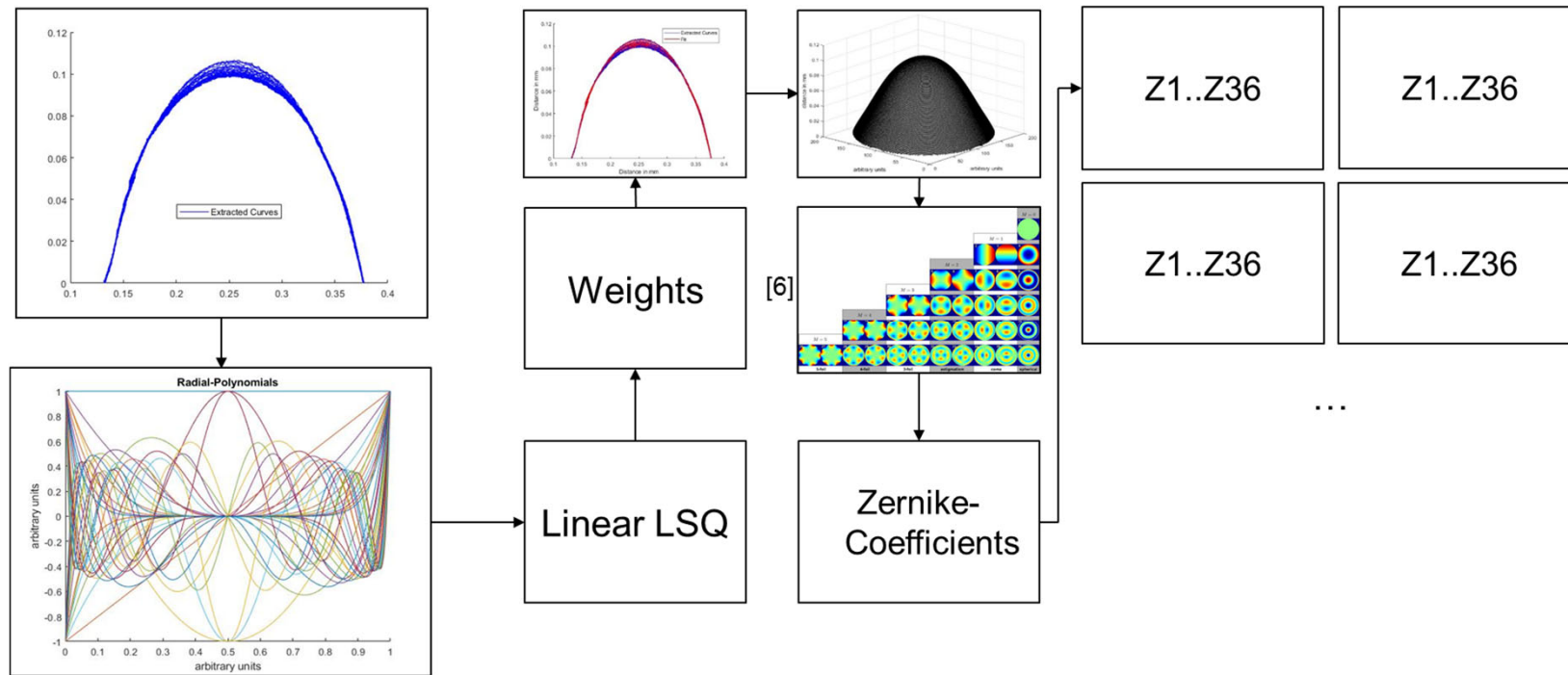
- Target: correlate electrical field with deformation, thus optic. perform.
- Variable Parameters
  - Droplets/volumina
  - Distance between electrode and droplet
  - Voltage & tip position

Measure shape (2D) → Fit using first 36 Jacobi polynomials & Tikhonov-Regularization



# Printer development: Electro3DOptics

➤ modify shape by electrical fields / modelling



# Printer development: 6 DOF printing platform

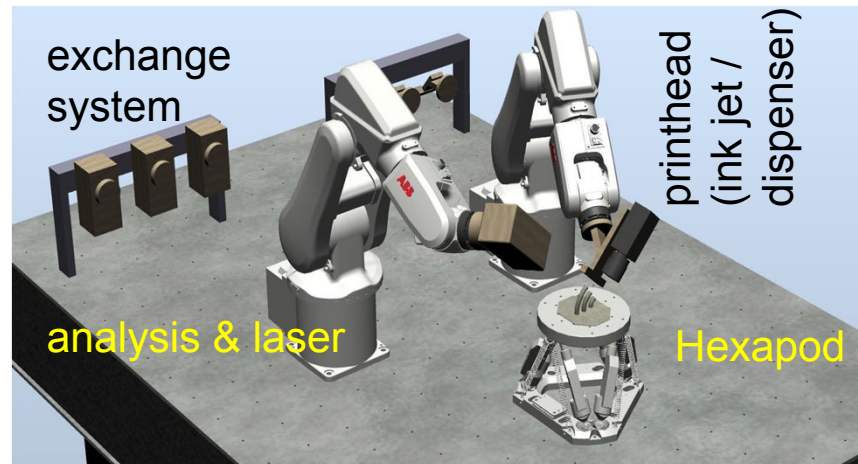
## ➤ overview

Feature Size  
~ 1  $\mu\text{m}$

Build Volume  
> 100  $\text{cm}^3$

Multimaterial

Flexibility due to  
Exchange Modules



No support

Laserstructuring  
/ Coating

In-Situ Analysis

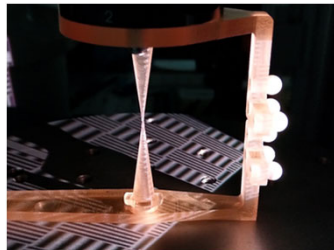
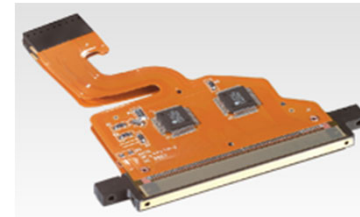
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

**Curing Unit**



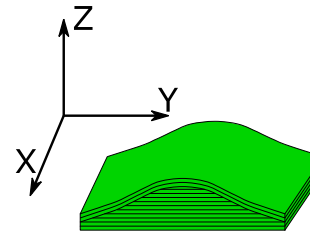
**Printing Unit**



**Metrology Frame**



**Trajectories**



**Dropwatcher**



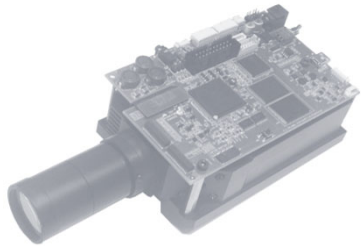
**Kinematic Unit**



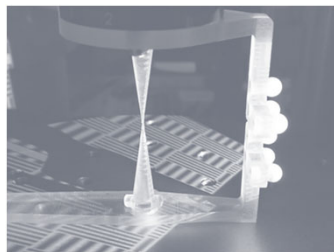
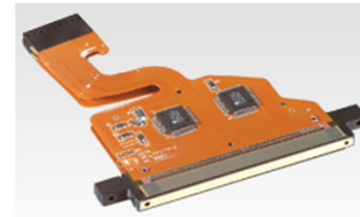
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

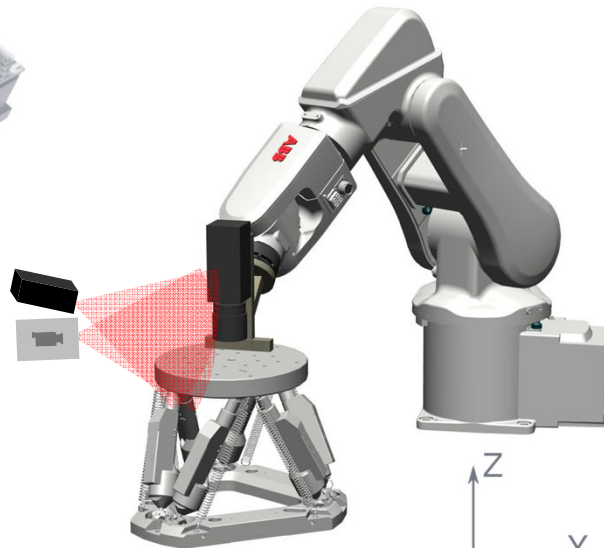
Curing Unit



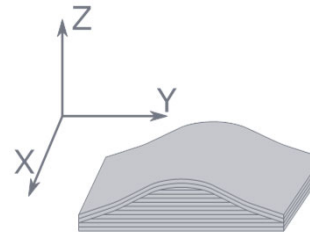
Printing Unit



Metrology Frame



Trajectories



Dropwatcher

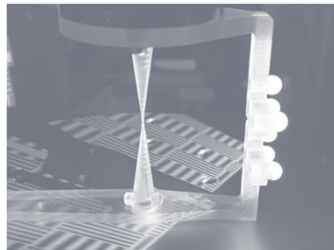
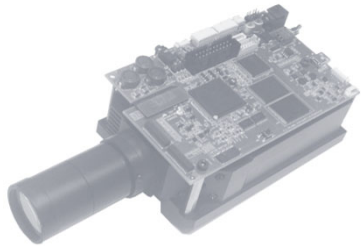


Kinematic Unit

# Printer development: 6 DOF printing platform

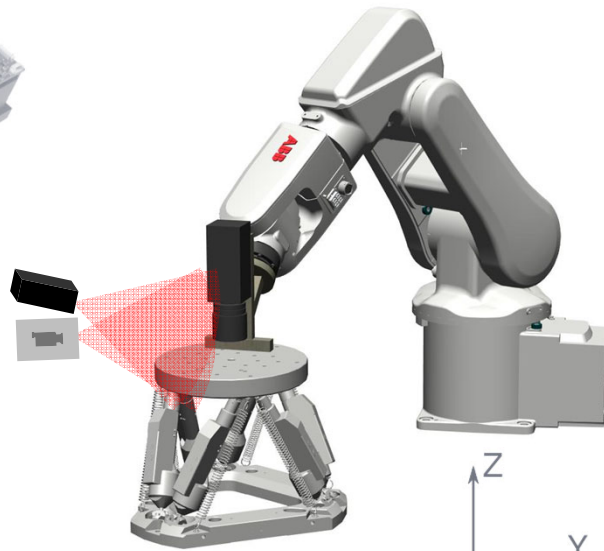
## ➤ system overview

Curing Unit

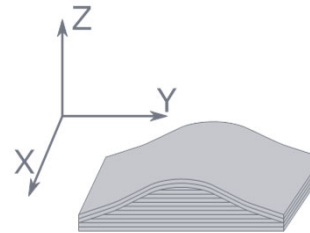


Metrology Frame

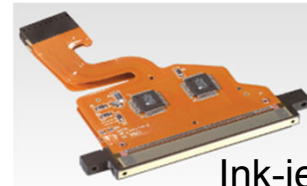
Printing Unit



Trajectories



FDM



Ink-jet

dispenser



Dropwatcher

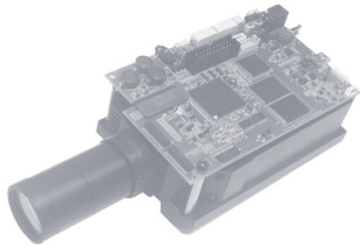


Kinematic Unit

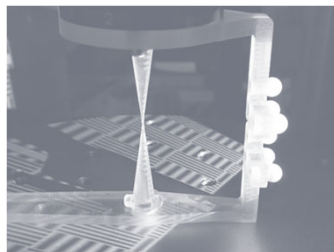
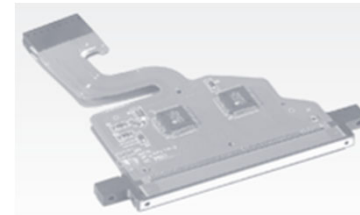
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

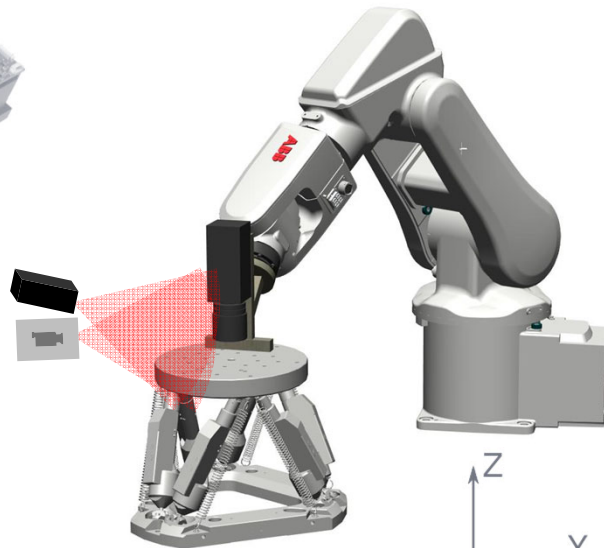
Curing Unit



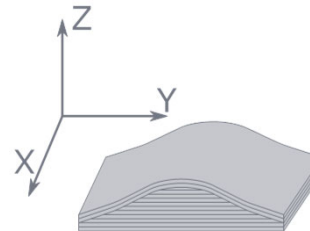
Printing Unit



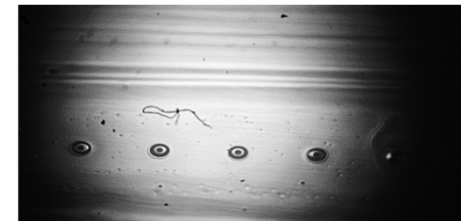
Metrology Frame



Trajectories



Dropwatcher

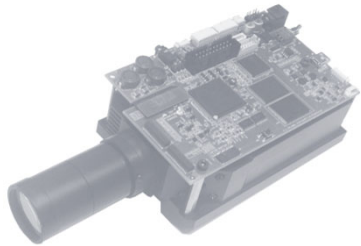


Kinematic Unit

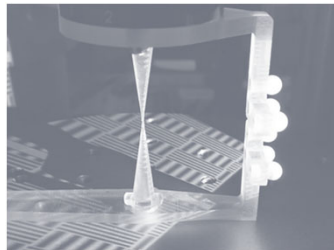
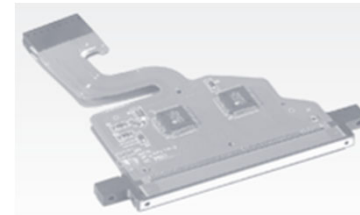
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

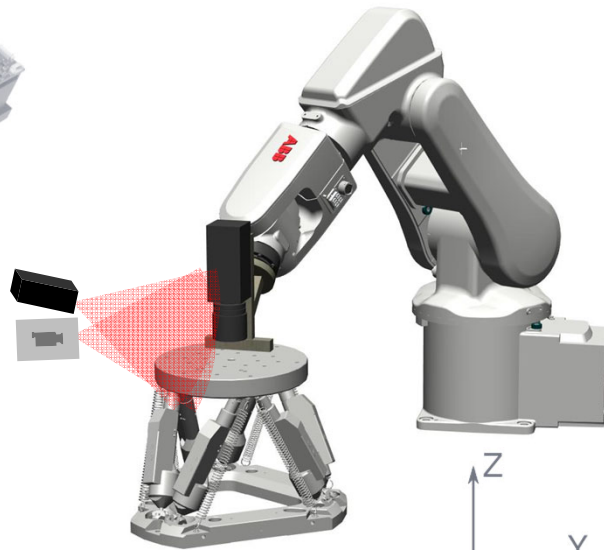
Curing Unit



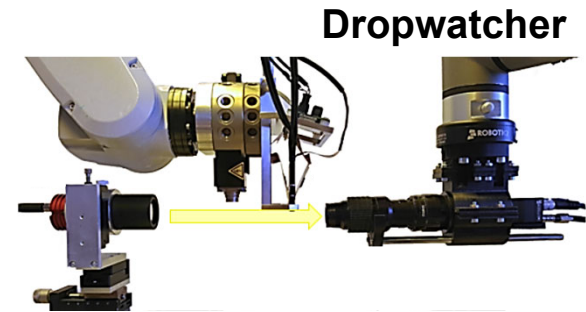
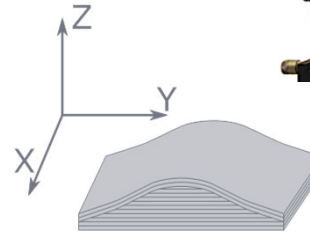
Printing Unit



Metrology Frame



Trajectories



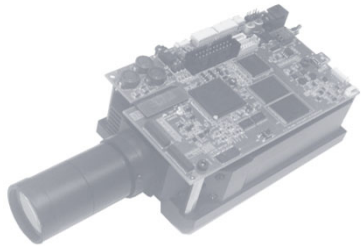
Dropwatcher

Kinematic Unit

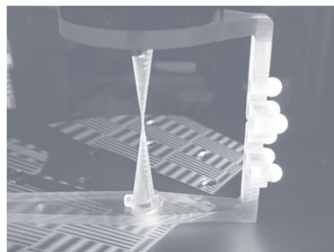
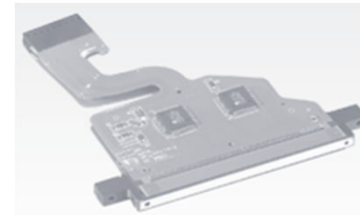
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

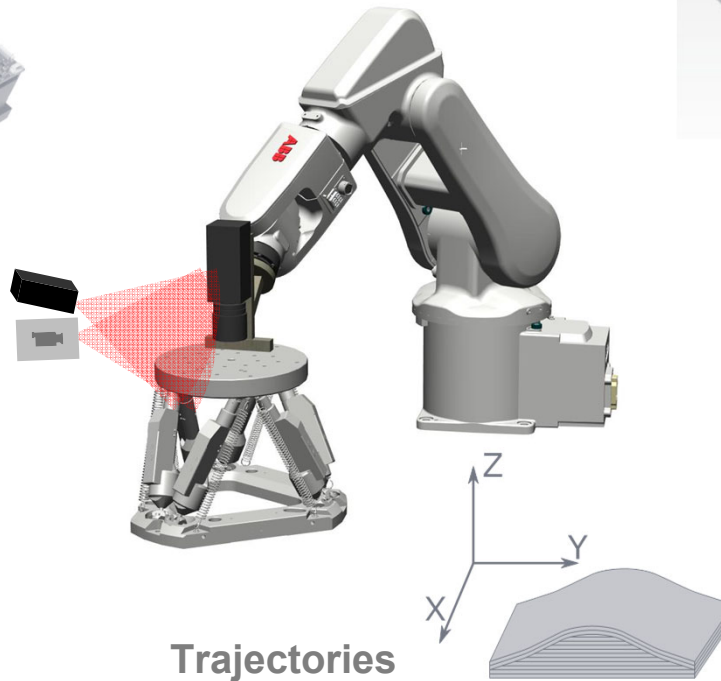
Curing Unit



Printing Unit

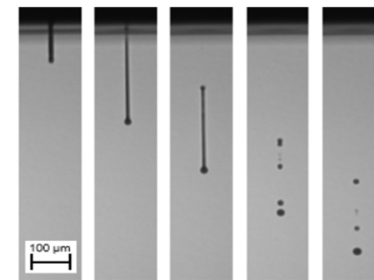


Metrology Frame



Trajectories

Dropwatcher

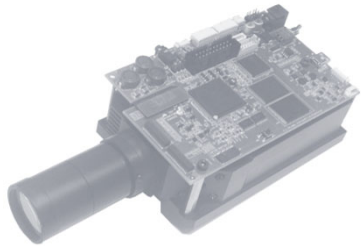


Kinematic Unit

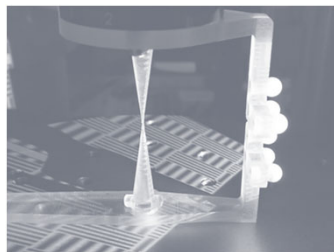
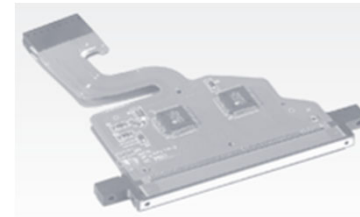
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

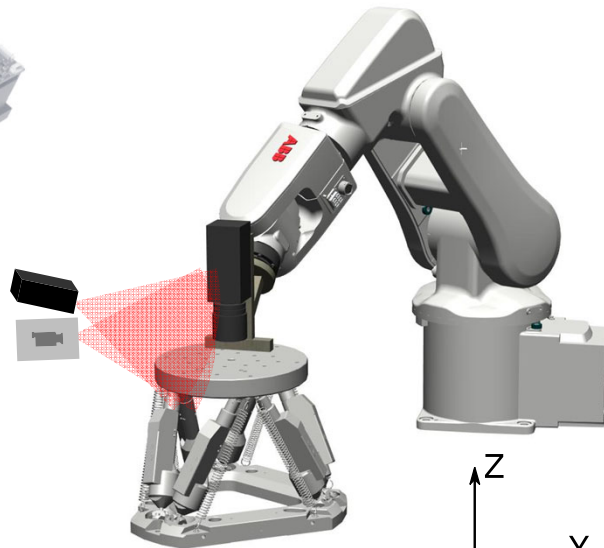
Curing Unit



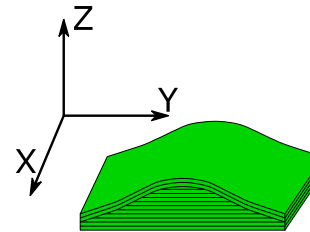
Printing Unit



Metrology Frame



Trajectories



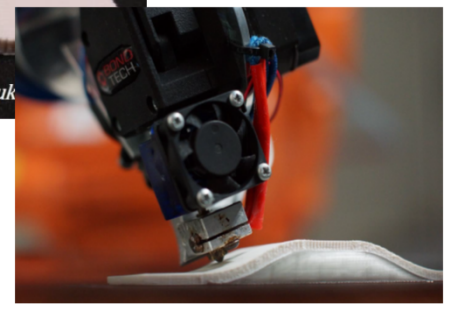
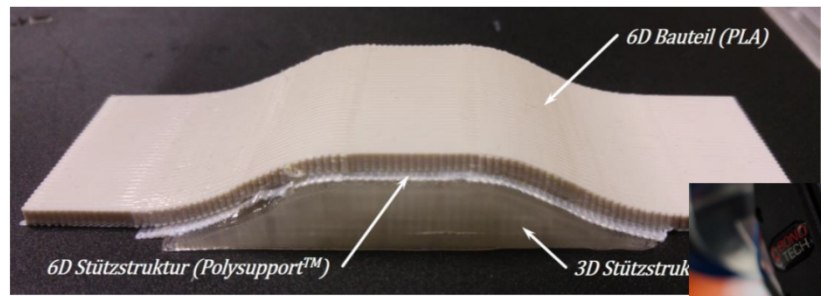
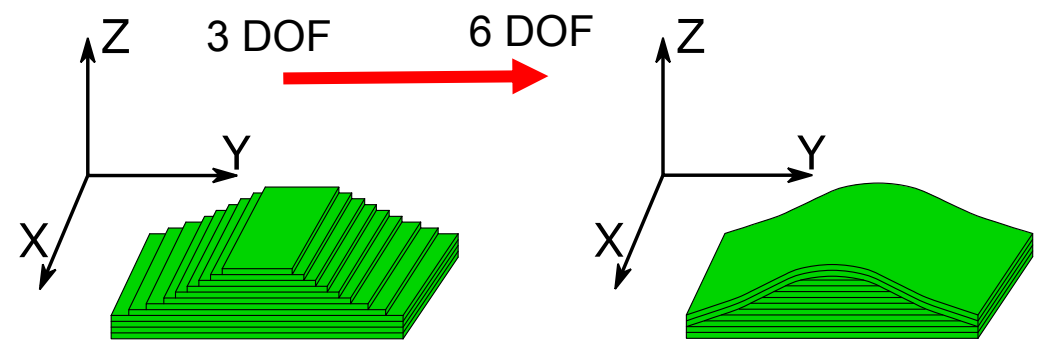
Dropwatcher



Kinematic Unit

# Printer development: 6 DOF printing platform

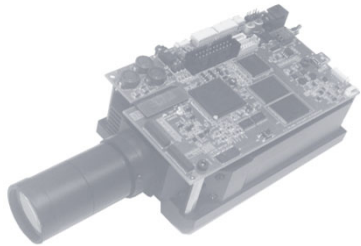
## kinematic unit



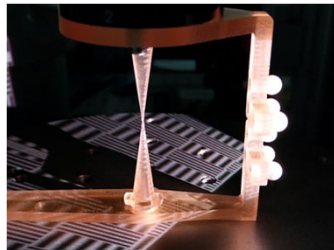
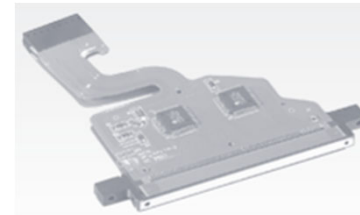
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ system overview

Curing Unit



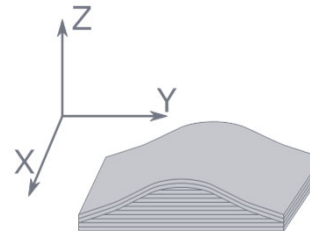
Printing Unit



Metrology Frame



Trajectories



Dropwatcher



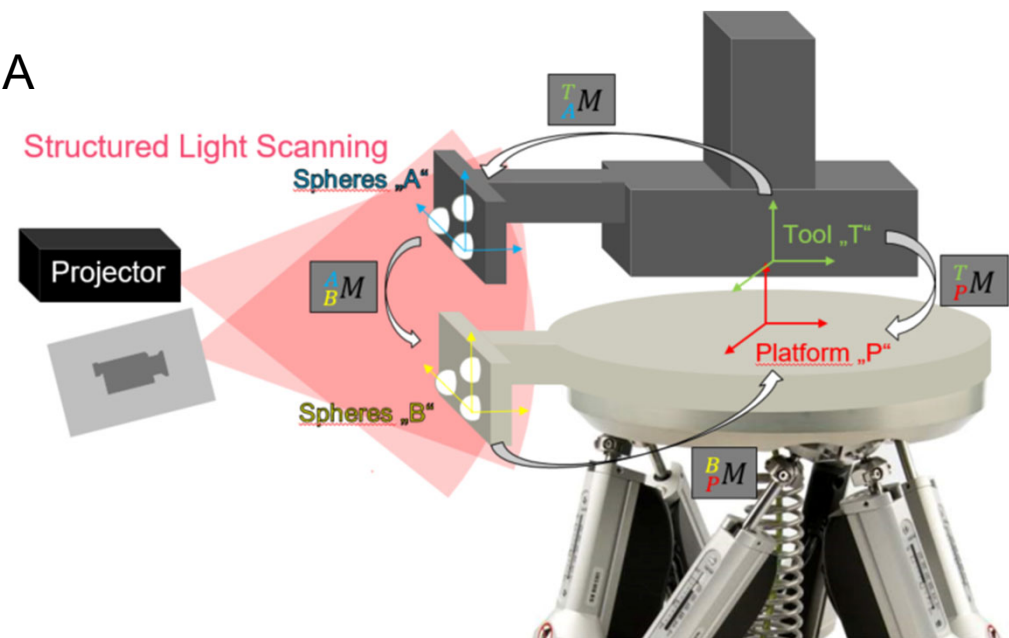
Kinematic Unit



# Printer development: 6 DOF printing platform

## ➤ metrology unit

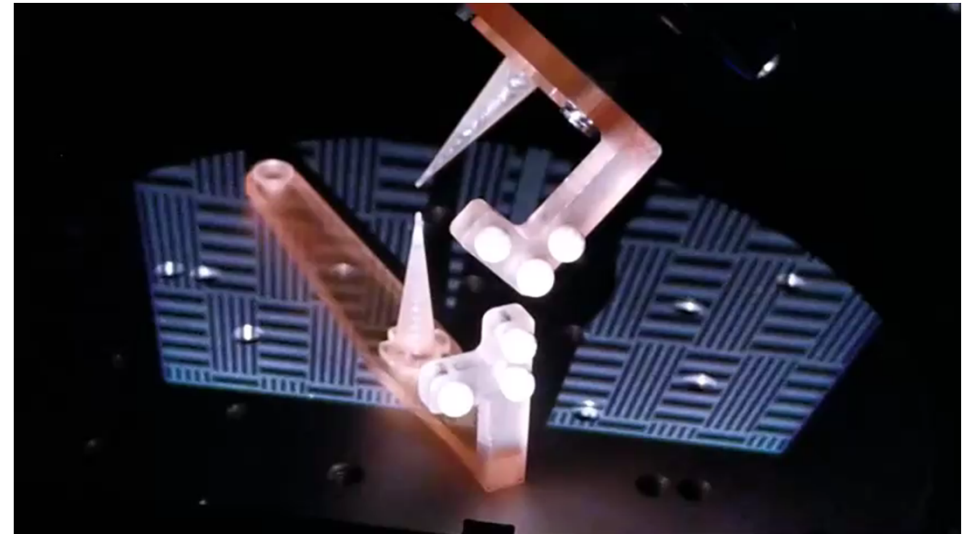
- Hexapod is global coordinate system A
- Robot is local coordinate system B
- Transform system B into A
- Registration of different spheres
- Spheres are different wrt. radius



# Printer development: 6 DOF printing platform

## ➤ metrology unit

- Measurement through structured light
- Point cloud:
  - calculated by Matlab script
- Result: Translation in
  - x,y - direction and y – direction
  - the angles alpha, beta and gamma
- Two modes:
  - Coarse mode: Robot movement (10 $\mu$ m accuracy)
  - fine mode: Hexapod movement (100nm accuracy)



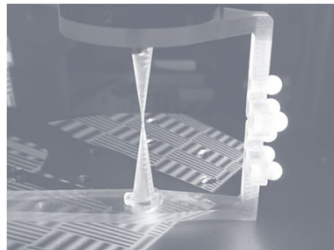
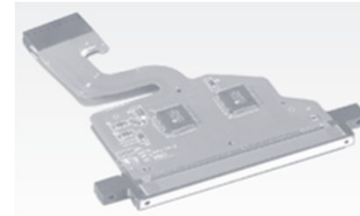
# Printer development: 6 DOF printing platform Hochschule Aalen

## ➤ curing unit

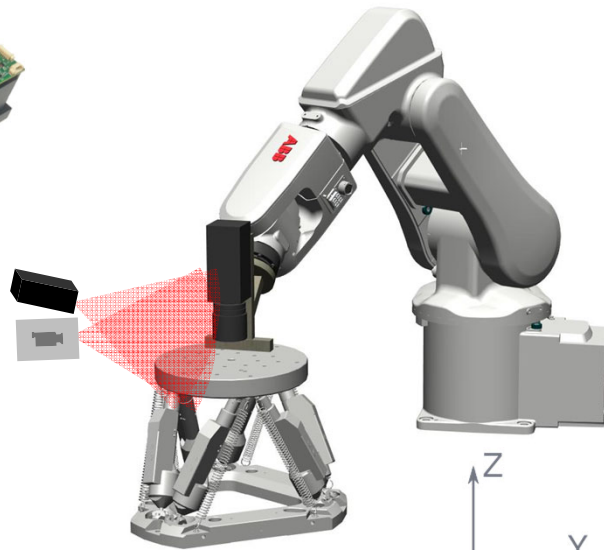
**Curing Unit**



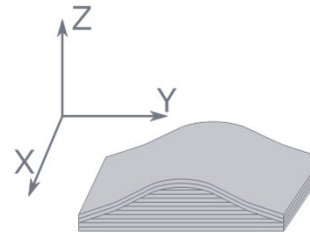
**Printing Unit**



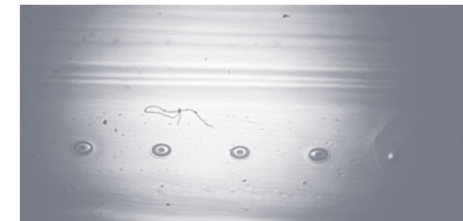
**Metrology Frame**



**Trajectories**



**Dropwatcher**

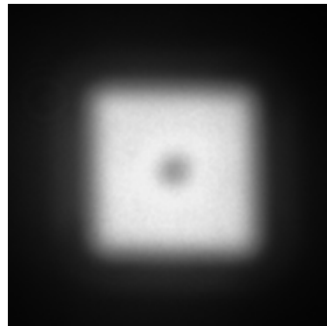


**Kinematic Unit**

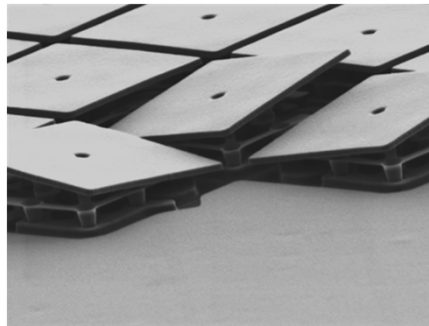
# Printer development: 6 DOF printing platform

➤ curing unit – how to achieve  $<10\mu\text{m}$ ?

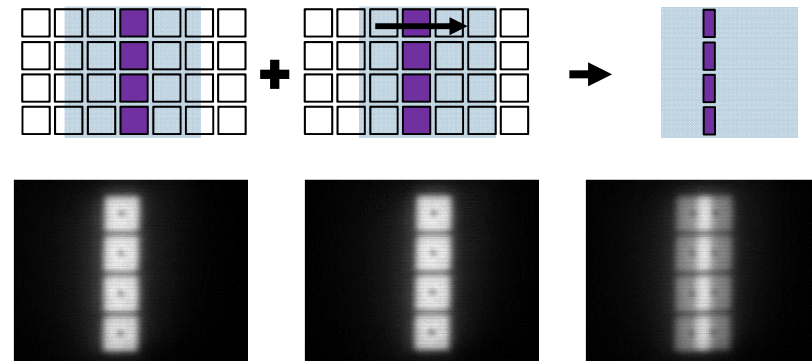
Intensity of one pixel



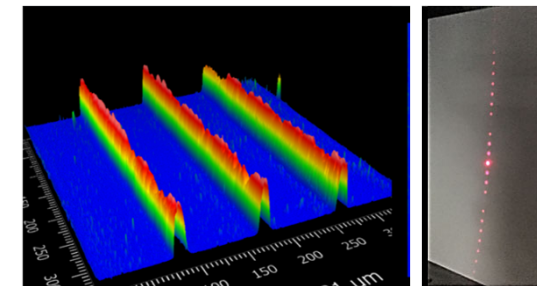
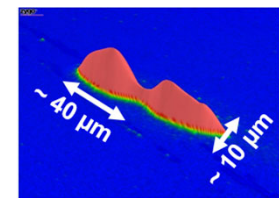
<http://e2e.ti.com/>



concept of double patterning



- Intensity well at Pixel center must be regarded  $\rightarrow$  about 30 % drop
- Reflections at mirror edges causes background radiation in “mirror off” state



# Agenda

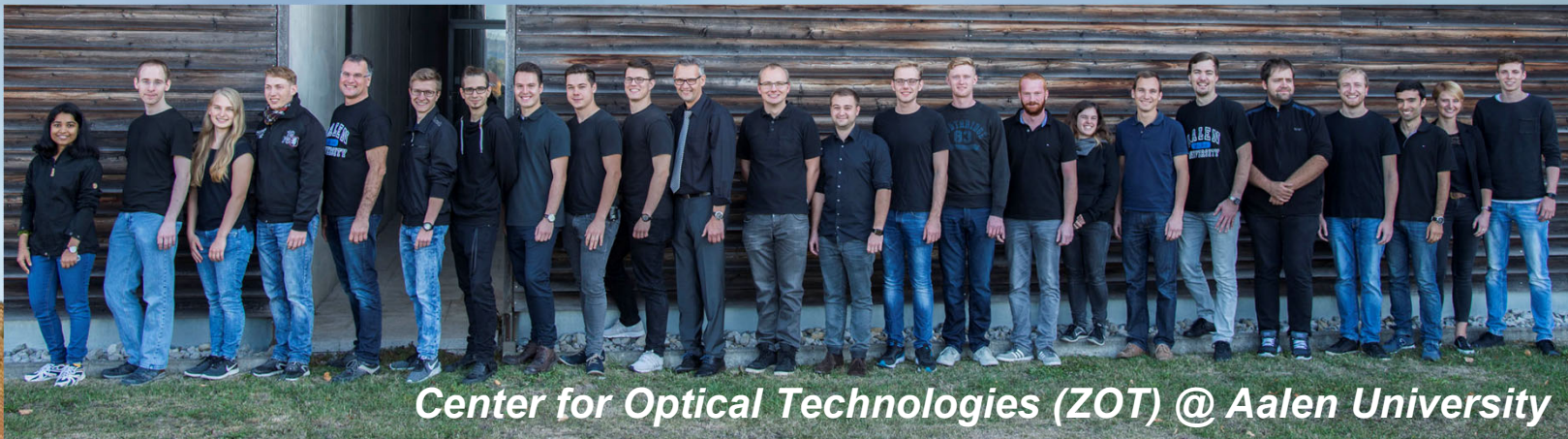
- 3D printing @ Center for Optical Technologies
- printing of passive optical components
- printing of active optical components
- **Printer development**
- Summary

## Summary

- **3D printing @ Center for Optical Technologies**
- **printing of passive optical components**
- **printing of active optical components**
- **Printer development**

# Thank you for your attention! – Any Questions?

*Many thanks to the group and to the sponsors!*



Center for Optical Technologies (ZOT) @ Aalen University



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