LASER SCANNING WITH PRISMS

Author: Rik Starmans   **Date: 26-11-2019**
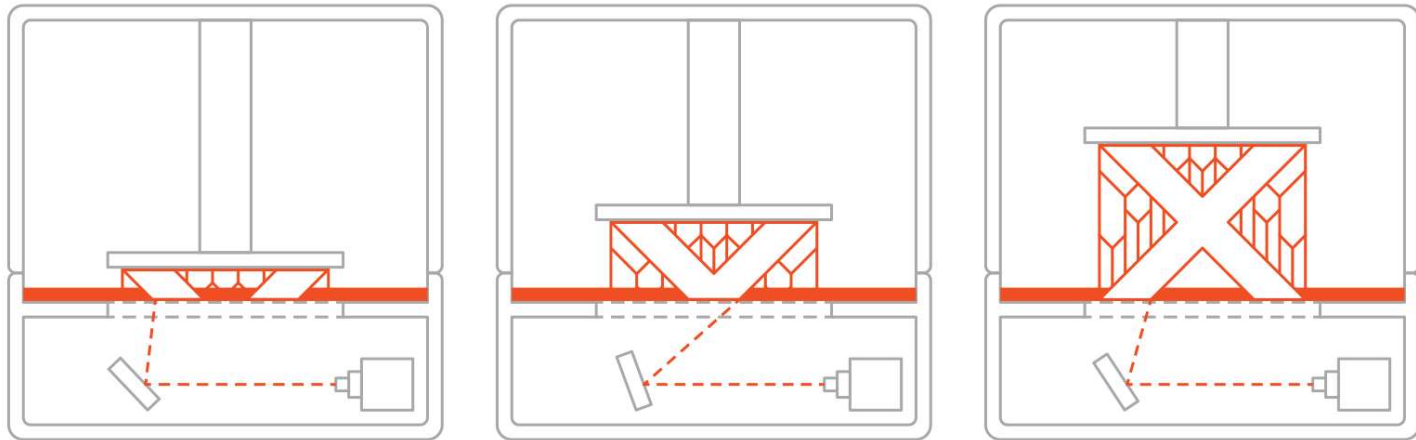
Global Outline

1. Introduction to laser scanning
2. Photopolymer 3D printing
3. Inkbit
4. Optical coherence tomography
5. Moving mirrors limitations
6. Prism scanning
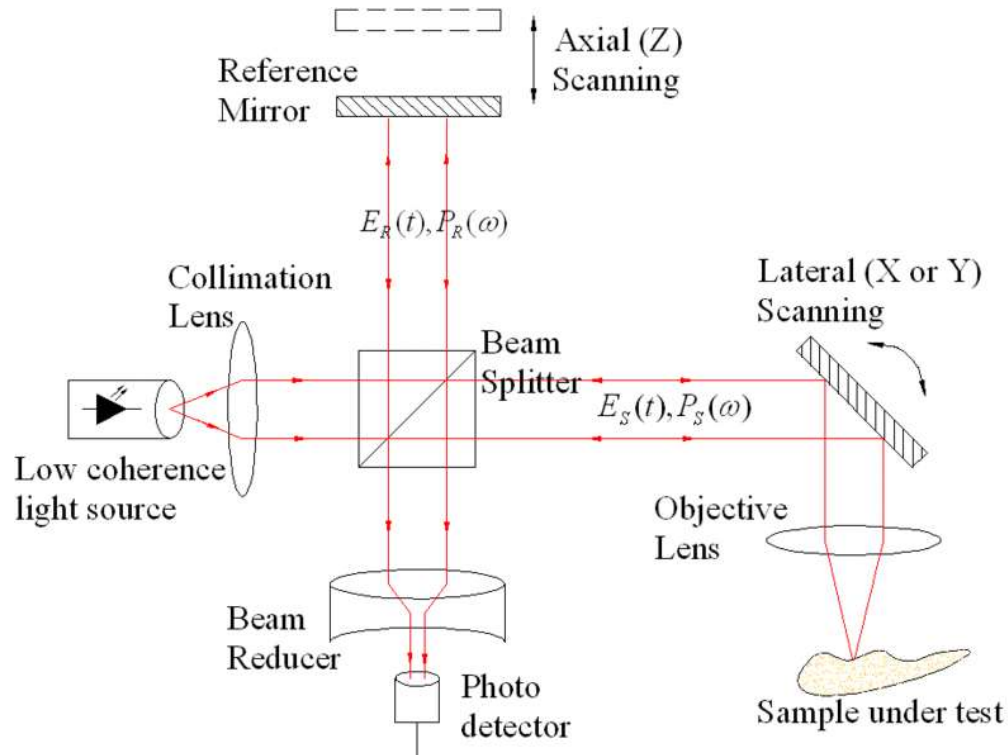7. Market overview

Photopolymer 3D printing

Movable mirrors are used to illuminate photo-polymers

Inkbit

- digital twin of printed part
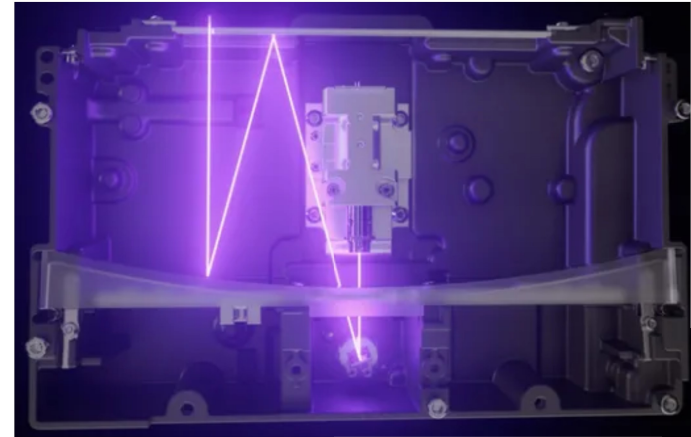**- improve process with machine learning**

Optical coherence tomography

OCT provides phase and amplitude information via movable mirrors

Moving mirrors limitations

formlabs ✌

Galvo mirror

- **slow**
- **calibration needed**
- **requires lens**

Rotating Mirror

- **patented US9079355B2, expires 2035**
- **requires f-theta lens**

envisionTEC

Drum Mirror

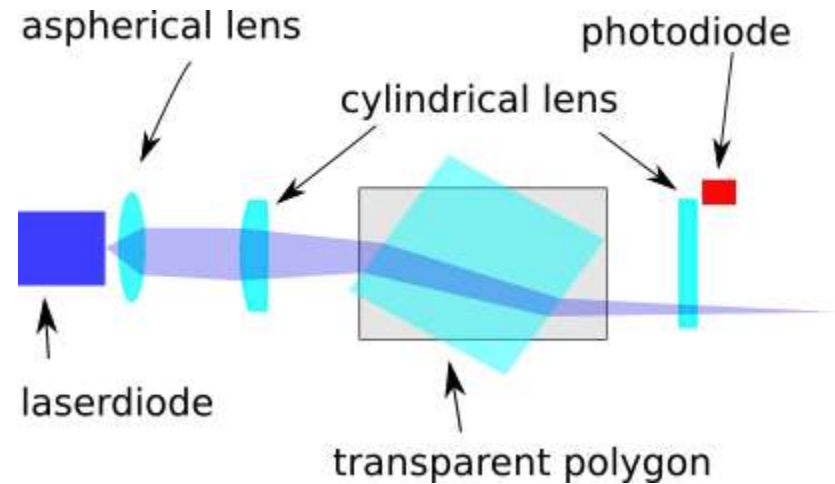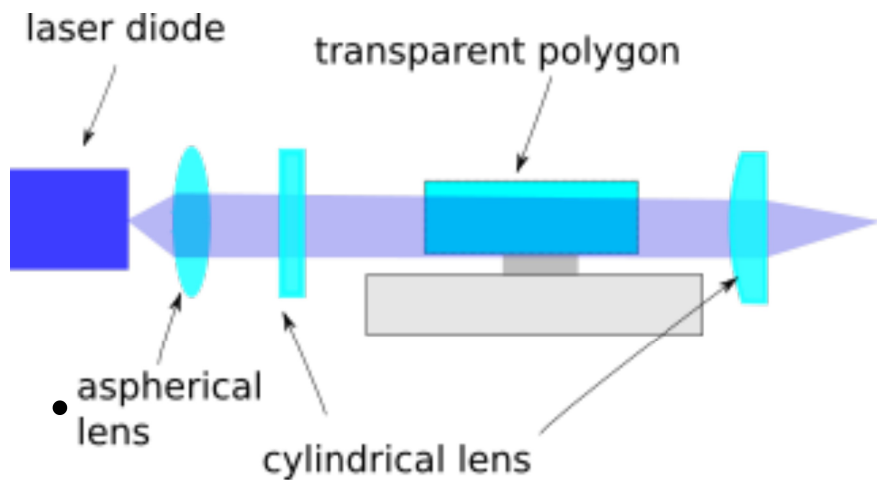UV Laser

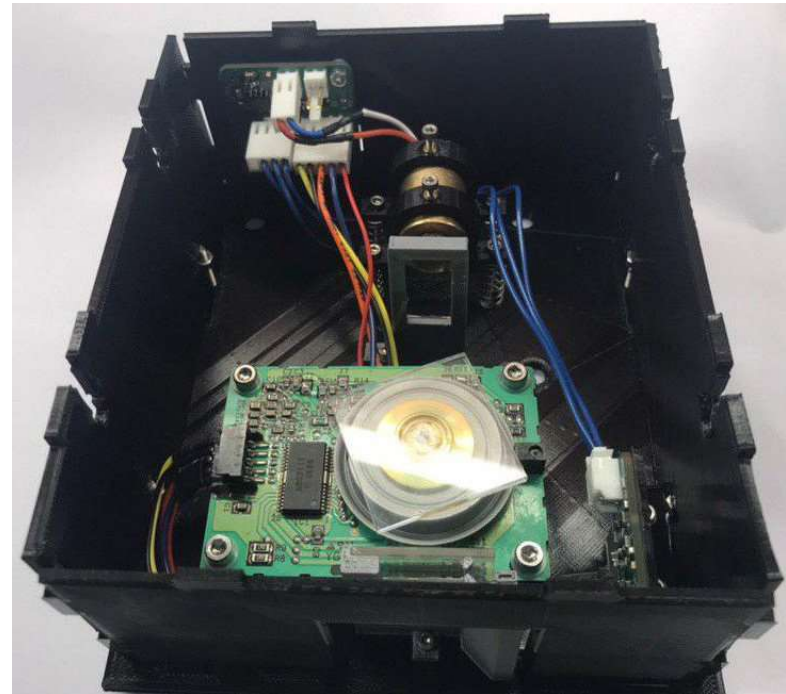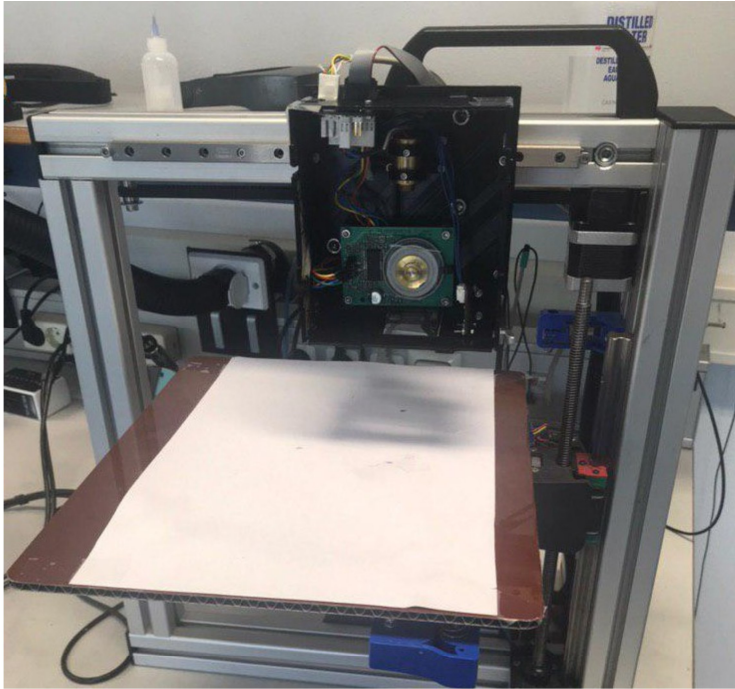F-Theta Lenses

Optical Sensor

Prism scanning

1. Prism scanner
2. Scan strategy
3. Optical properties
4. Facet imperfections
5. Resolution limits
6. Speed limits
7. Unique selling points of prisms
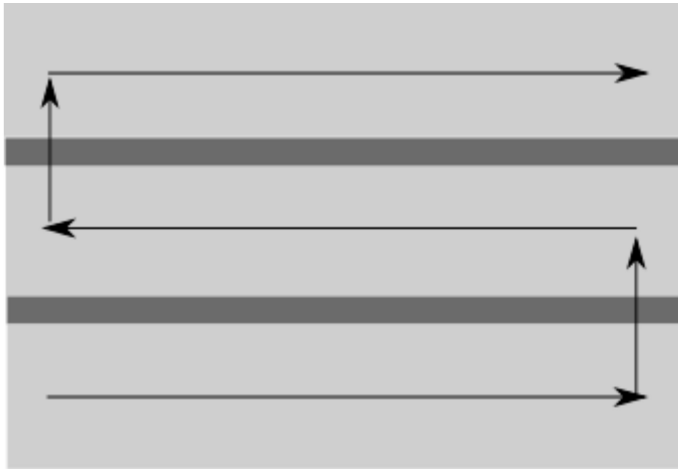
Prism scanner

cylinder lenses are optional!

Prism scanner

- **software in C++, Python and assembly**
- **designed circuit boards in Kicad**
- **computer animated design using Freecad**

Scan strategy

snakelike pattern
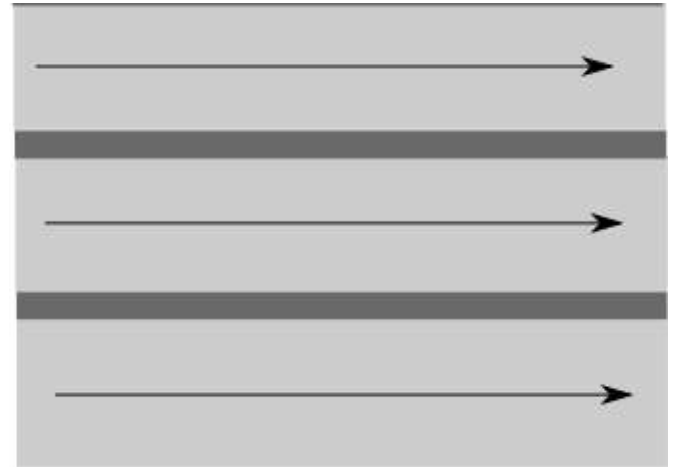
combining laser modules

Optical properties
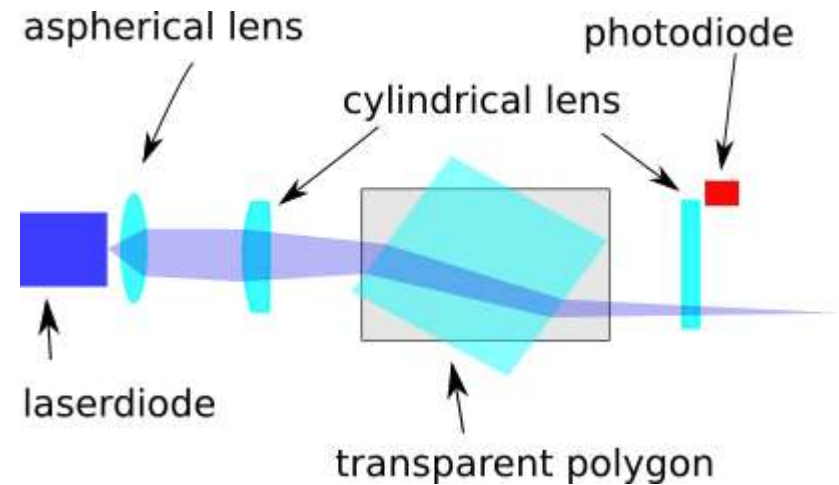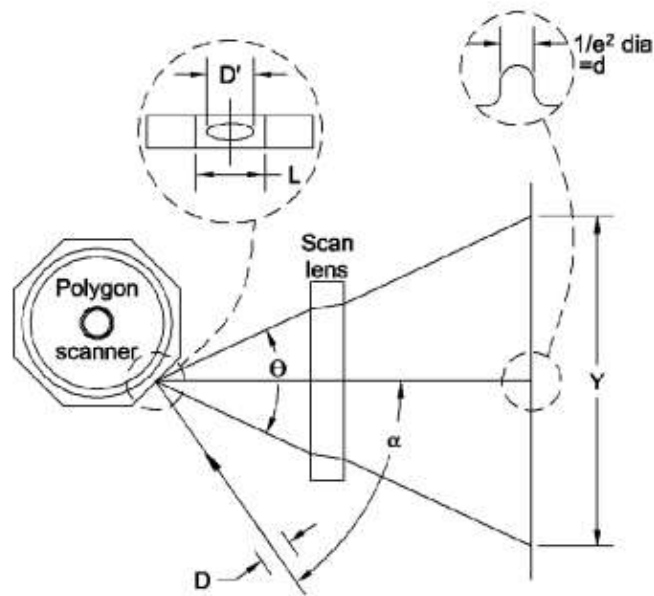
light is incident at 90 degrees angle

Optical properties

longitudinal displacement
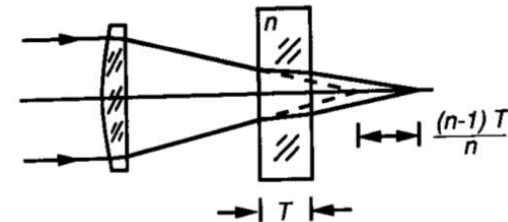
angle dependent scan speed

$$D = T \cos I(\tan I - \tan I')$$

$$= T \sin I \left(1 - \sqrt{\frac{1 - \sin^2 I}{n^2 - \sin^2 I}} \right).$$
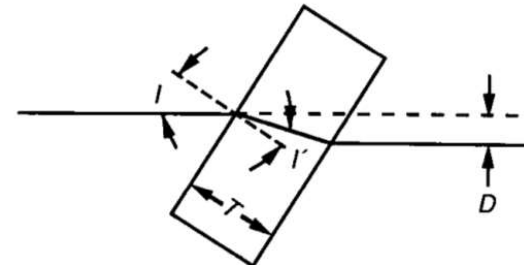
Facet imperfections

ideal
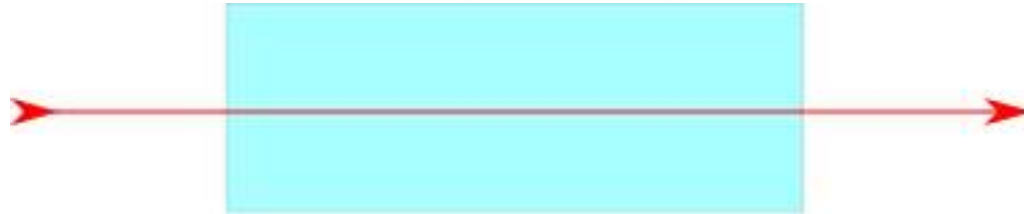
reality
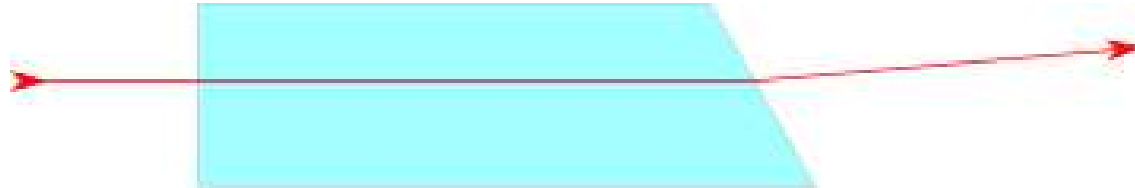
facet imperfections cause cross scan error

Facet imperfections

$$\delta = 2\alpha$$

$$\delta \approx (n-1)\alpha = 0.5\alpha$$
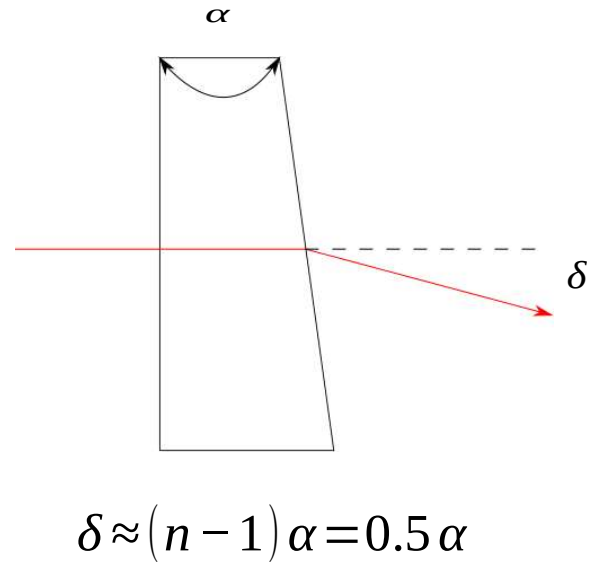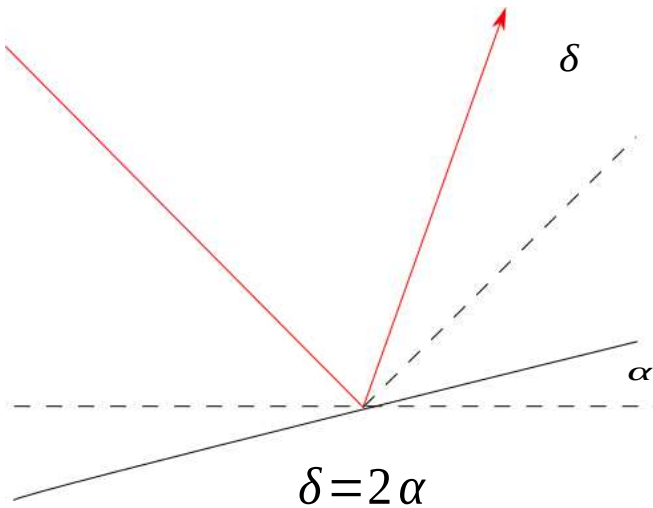
prism is four times more accurate than mirrors

Resolution limits
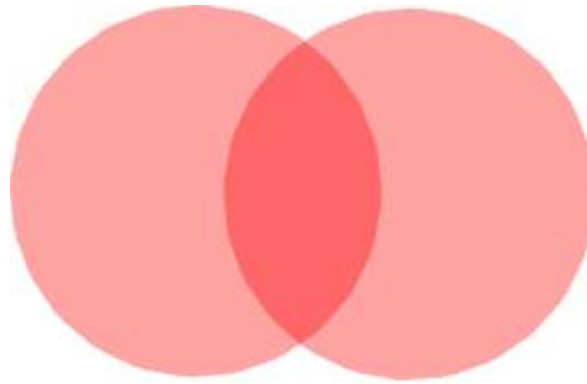
Multi-patterning

Resoluton limits
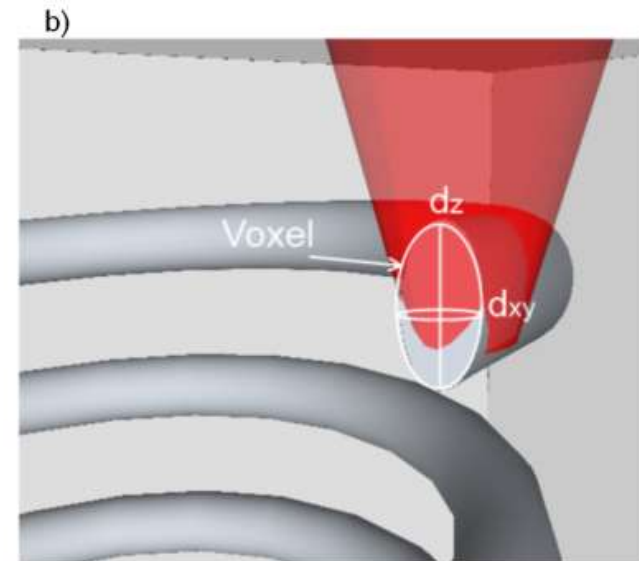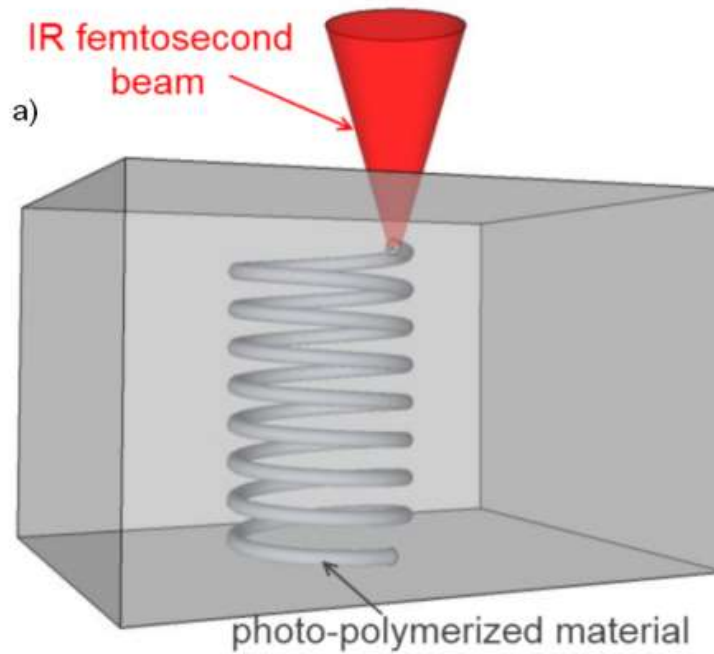
Dual-photon lithography

Resolution limits
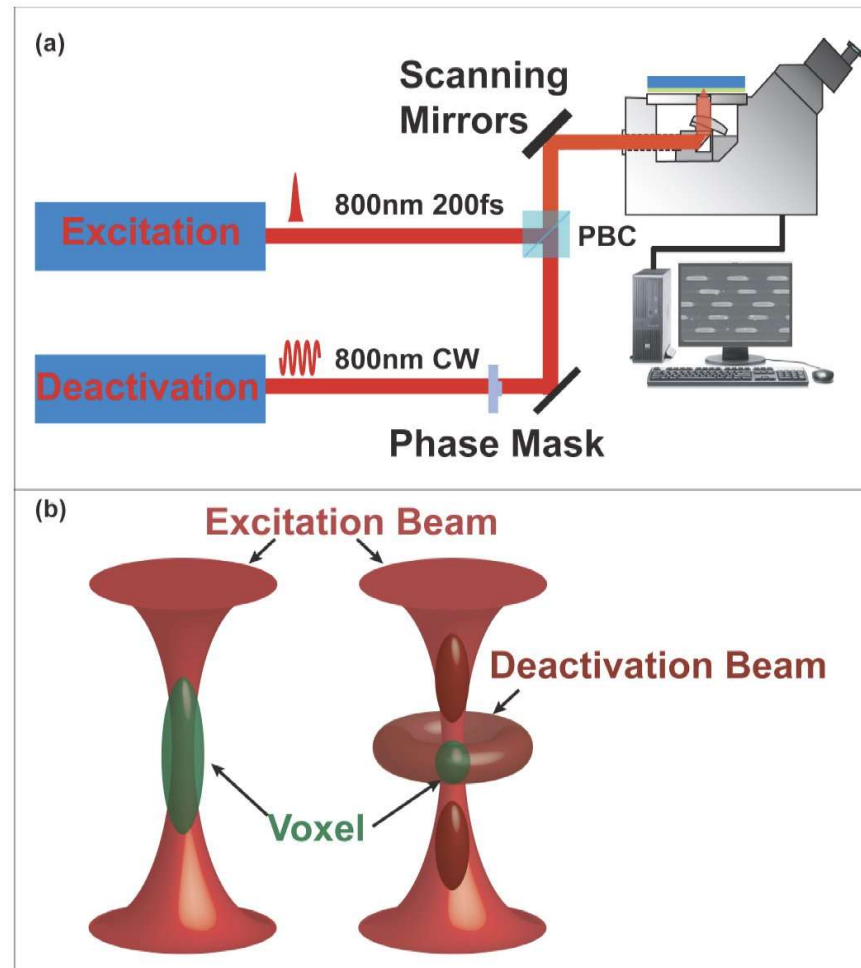
**stimulated emission depletion lithography:
with the appropriate materials 10 nm might be feasible**

Speed limits
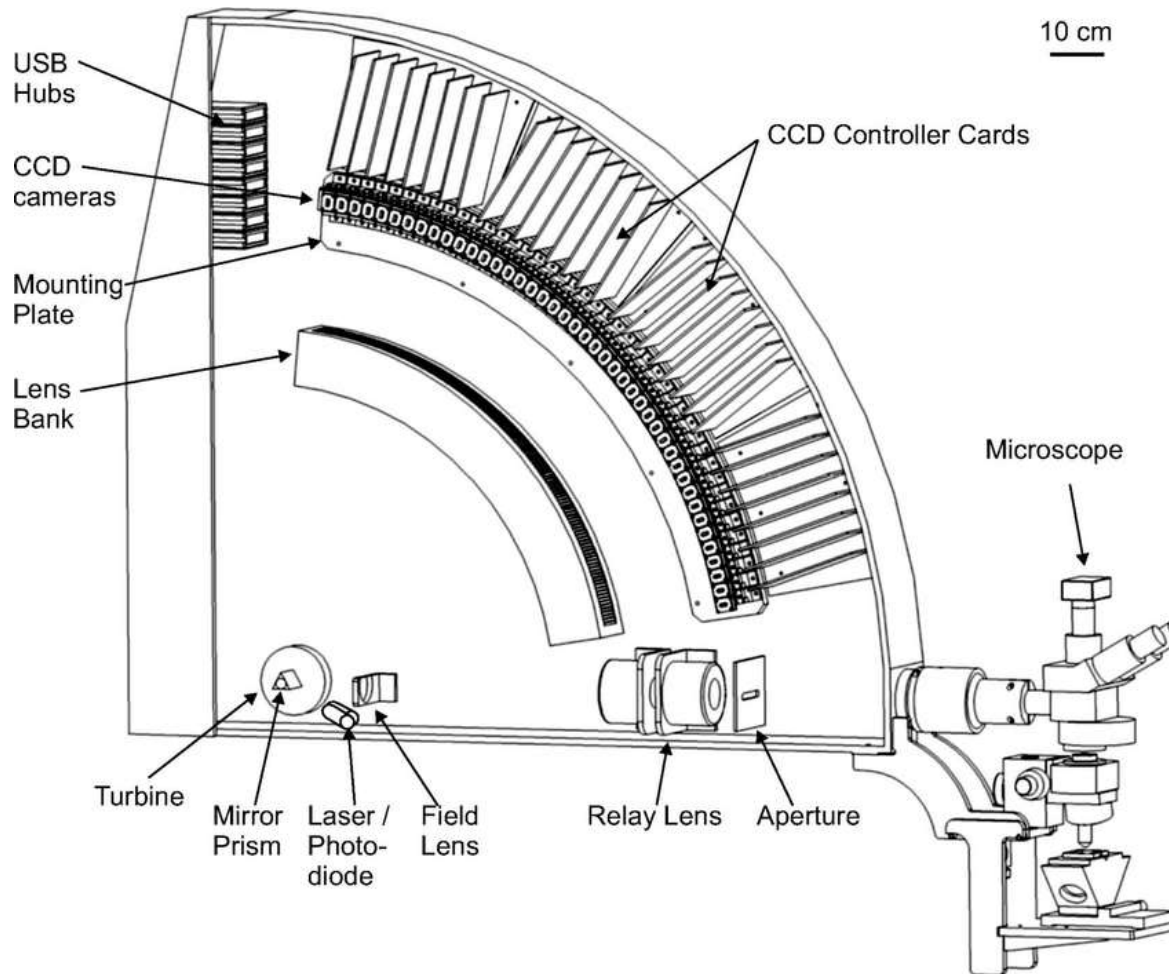
prisms can spin up to 1 million revolutions per minute

Unique selling points of prisms

- • - short scan line
  - f-theta lens not needed
  - 90 degrees of incidence
  - less sensitive to facet imperfections

Market overview

photo-polymer printing
   small medium enterprise
   enterprise
   special
printed circuit board manufacturing
   prototyping
   enterprise
selective laser sintering
other applications

Small medium enterprise photopolymer printing

	Formlabs	Prusa Research
Machine Name	Form 3	Prusa SL1
Speed [m/s]	2	layer
Resolution [μm]	90 (spot)	47 (pixel)
Layer Thickness [μm]	25 - 150	25 - 100
Wavelength [nm]	405	405
Power at surface per source [Watt]	0.25	
Exposure Technology	**galvo mirror** + parabolic lens	LCD
Light source	Laser diode	LED
Platform size [mm]	145 x 145 x 175	120x68x150
Coating	Bottom-Up	Bottom-Up
Price [$]	3500	1700

Prism are 10x faster and 4x more accurate than Formlabs

Enterprise photopolymer printing

	Prodways	3D Systems	Envisiontec
Machine name:	ProMakerL7000D	ProX 950	XEDE 3SP
Exposure Technology	Moving beamer + mirror	Galvo mirrors + f-theta	+ f-theta
Light source	LED	SSL	laser diode
Resolution [µm]	40	130	100
Coating	Applicator	Applicator	Applicator
Layer thickness [µm]	25-150	25-150	50-100
Wavelength [nm]	365/405	355	405
source [Watt]	<4	1	0.5
Platform size [mm]	800 x 330 x 200	1500 x 750 x 550	457 x 457 x 457
Price [$]	350000	500000	100000-250000

Prism easier to combine due to short scan line

Special photopolymer printing

	Carbon 3D	Admatec	Nanoscribe
Machine Name:	L1 Printer	AdmaFlex 130	GT2
Exposure Technology	DMD	DMD	Polygon mirror + f-theta
Light source	LED @ 405 nm	LED @ 405 nm	nm
Resolution [µm]	40	50	0.2
Coating	Bottom Up	Foil	In fluid
Specialty	production speed flexible parts no stair stepping	metal ceramics	high resolution dual photon
Customer need Price [$]	100000 per year*	100000	450000
Customer need	**US7892474B2 circumvention**	**needs lasers for precise cure**	**prism**

* source [Fabbaloo](#)

All these companies have a need which prisms can provide.

PCB prototyping

- **Market size:** 30K printing systems (EU and USA)*
- **USP:**
-
-     **curved substrates**
-     **small feature size**

-
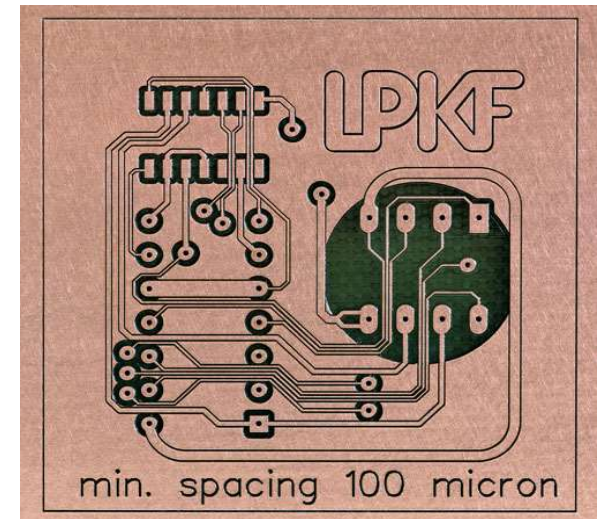
PCB prototyping

	Number of layers	Minimum Line Width	Cost
Nano Dimension DragonFly 2020	<17 layer PCB	90 micron	$150K
BotFactory Squink	2* layer PCB	254 micron	$4k
Optomec Aerosol Jet	3D object with embedded wiring	254 micron	$400k
Xerox	3D object with embedded wiring	N/A	unknown
LPKF mechanical milling	<8 layer PCB	100 micron	$6-17K
LPKF laser milling	<8 layer PCB	50 micron	$100K
LPKF laser transfer printing	Individual layers	unknown	unknown
Volterra V-One	2* layer PCB	200 micron	$4.2K
Bungard	2* layer PCB	50 micron	unknown
Prism scanner	2* layer PCB	**25 micron**	**700$ per module**

Prism scanner offers smallest feature size
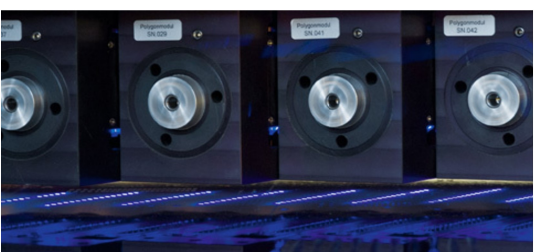
Enterprise PCB

	Orbotech	Kleo	Screen	Ucamco	Next scan technologies
Machine name	Nuvogo Fine10	Speedlight 2D	DT-3000	Ledia 3WL	LSE170A
Light source	DPSS Paladin	Laser diode	YAG laser i-line	LED	various
Wavelength	355	405	355	405/385/365	various
Exposure technology	**Rotating mirror** + refractive F-theta	9 Thick **rotating mirrors**	Grating light valve	Multiple beamers	**Rotating Mirror** + reflective F-theta
Track [µm]	10	15	3	15	5
Gap [µm]	15	15	3	15	5
Throughput [sides/hour]	240	360	65	405	
Depth of focus [µm]	300	300		?	
Light sources	1	288	1	? but >1	1

Market can be disrupted by introducing rotating prism

Small medium enterprise selective laser sintering

	Formlabs	Sintratec
Machine name	Fuse 1	S2
Speed [m/s]	2	2
Resolution [µm]	90 (spot)	90 (spot)
Layer thickness [µm]	25 - 150	25 - 150
Wavelength [nm]	950	950
[Watt]	7-8	7-8
Light source	Laser diode	Laser diode
Exposure technology	**Galvo mirror**	**Galvo mirror**
Platform size [mm]	165 x 165 x 320	160 x 160 x 400
Coating	Counter rotating roller	Counter rotating roller
Price [$]	9999	30000 (includes peripherals)

**Prism is more accurate and easier to scale**

Other applications

| Company Name	Technology	Application
HP Cylite	Galvo mirror	Ophthalmology
Carl Zeiss Meditech	Galvo mirror	Ophthalmology & Optometry
TTP labtech	Galvo mirror	Laser scanning cytometry
Horiba	Galvo mirror	Laser Scattering Particle Size Distribution Analyzer
Bea Sensors	Rotating mirror	Security, Movement sensor industrial doors
Video Jet	Galvo mirror	Marking of medicine
Mirada	Rotating mirror	LiDAR for self-driving cars
Discover Aether	XY laser	Cure liquids during printing
Poeitis	Galvo mirror	Laser induced forward transfer in bioprinting
Keyence	Galvo mirror	Confocal Laser microscope
LAP Laser	Rotating mirror	Tube diameter inspection
Olympus	Galvo mirror	Photo-acoustic imaging

There are many more applications still!

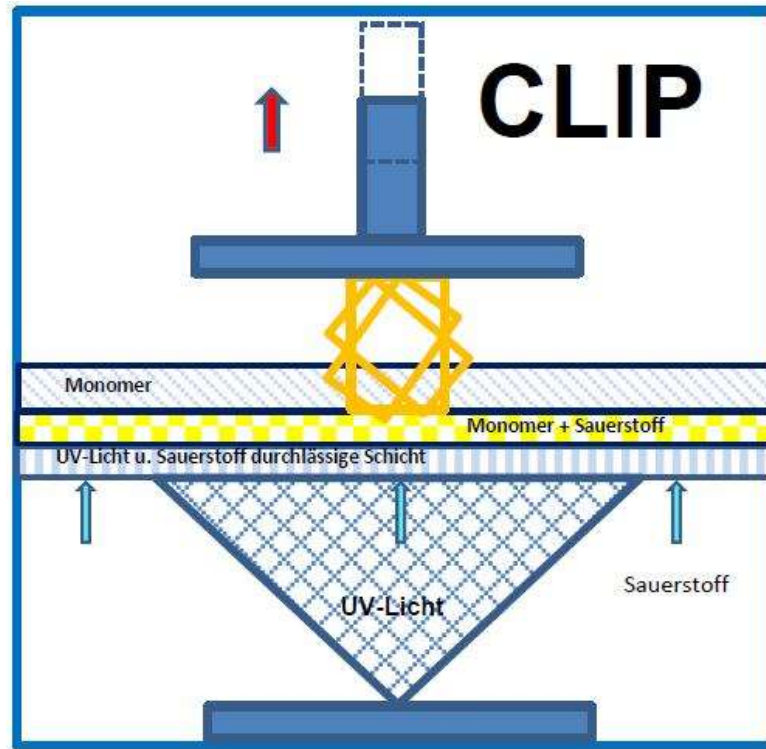# Questions ?

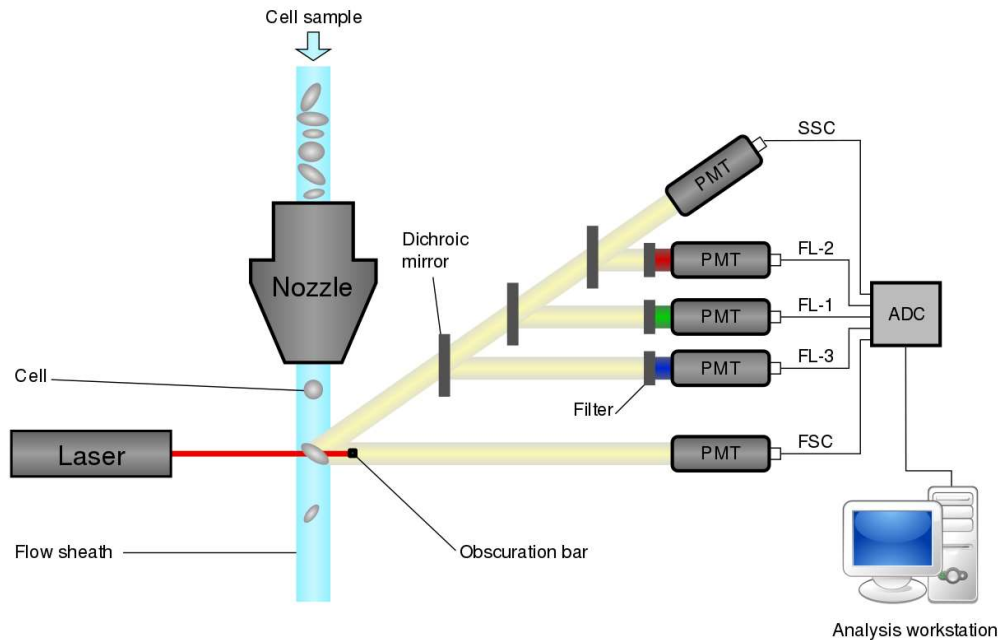# Mask Exposure
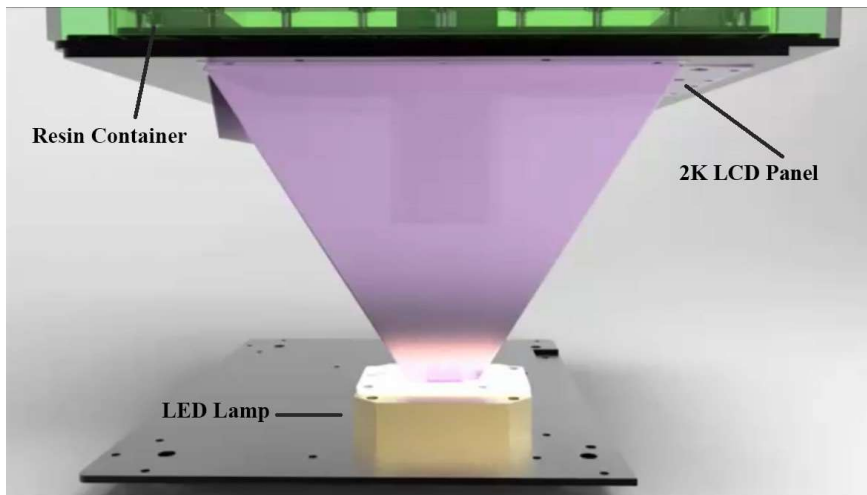
inaccurate
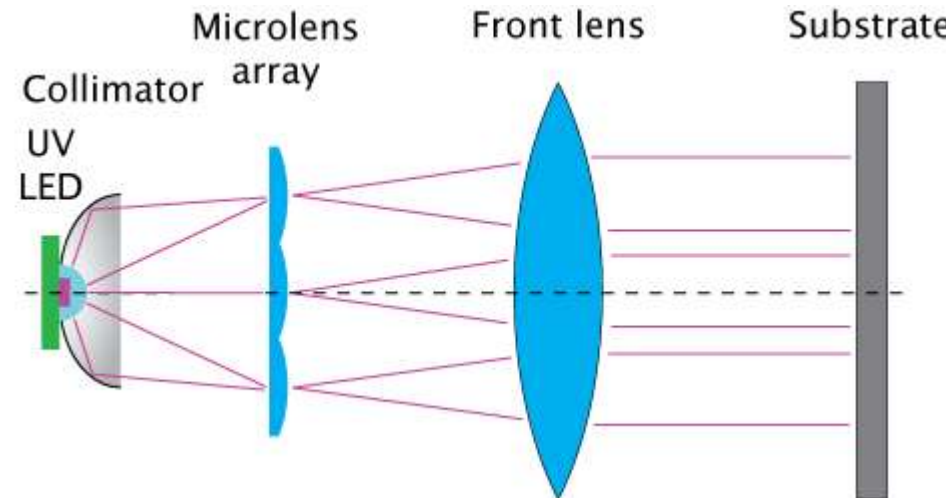
accurate

Prusa SL1 does not use lenses;
illumination is not uniform
light exits under angle
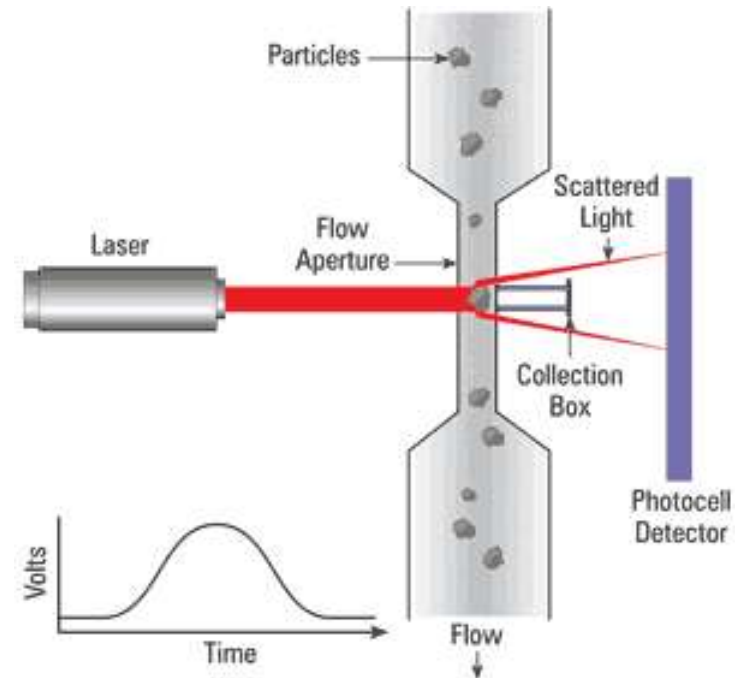
Carbon 3D

Carbon did not define top projection probably due to US7892474B2

Medical Analysis

flow cytometry

particle analyzer

Prisms can be used in flow cytometry and particle analyzers

Resolution prism scanner

wavelength	405 nm
rotation frequency	2400 rpm*
spot size FWHM	25 micrometers
cross scan error	40 micrometers
jitter	35 micrometers**
optical power	500 mW
duty cycle	47 % @ 4 facets
scan line length	8 mm

Microfluidics

	Kloe	4PICO
Machine name	Dilase 3D	PicoMaster200
Speed [mm/s]	50	405
Technology	XY gantry	XY gantry
Resolution [μm]	5 (spot)	0.300
Wavelength [nm]	375/405	375
Power at surface per source [Watt]	0.3	0.3
Light source	laser diode	laser diode
Platform size [mm]	100 x 100 x50	
Coating	Top-down	Top-down

Prism can be used to move laser.
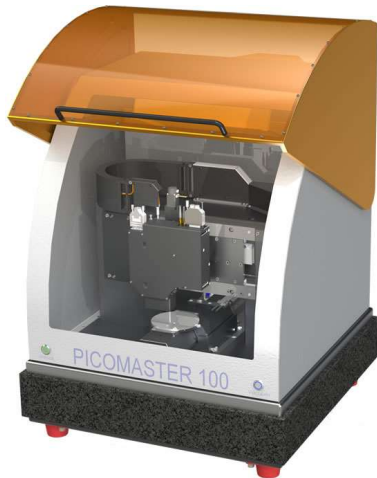
Virtual Reality Displays
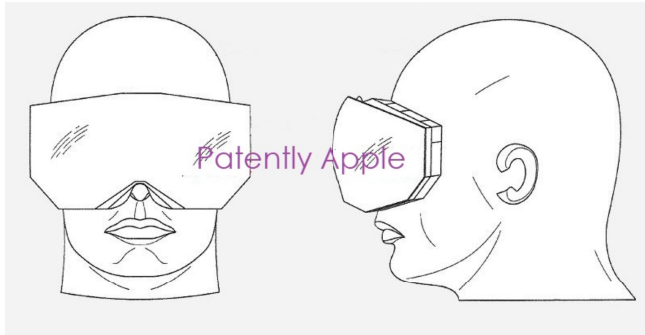
	Apple	**Magic Leap**
Exposure Technology	**Scanning mirror**	Fiber Scanning display* / Liquid Crystal on Silicon
Light source	Laser diode	Laser diode / LED
Pattern	square	circle / square
Patents	201902654 86	US20150178939A1 US20180052277A1

*Fiber scanning display is also used in endoscopes

**Apple believes scanning mirrors can be used in augmented reality.
I claim it should be prisms...**