



Scalable High Power and Highly Homogeneous Line Lasers

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SPIE Photonics West 2013

6th February 2013

**L3 LIMO LINE
LASERS**

Overview

Motivation

Principle of Beam Shaping

LIMO Line Laser - Examples

Summary



Overview

Motivation

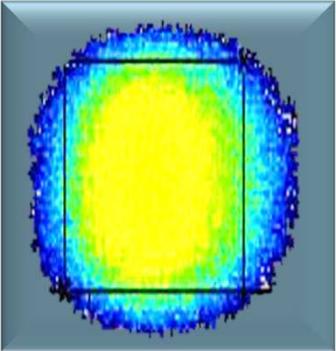
Principle of Beam Shaping

LIMO Line Laser - Examples

Summary



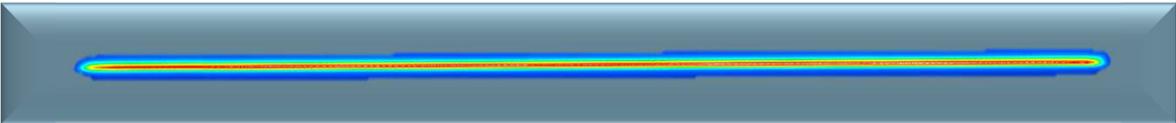
Motivation



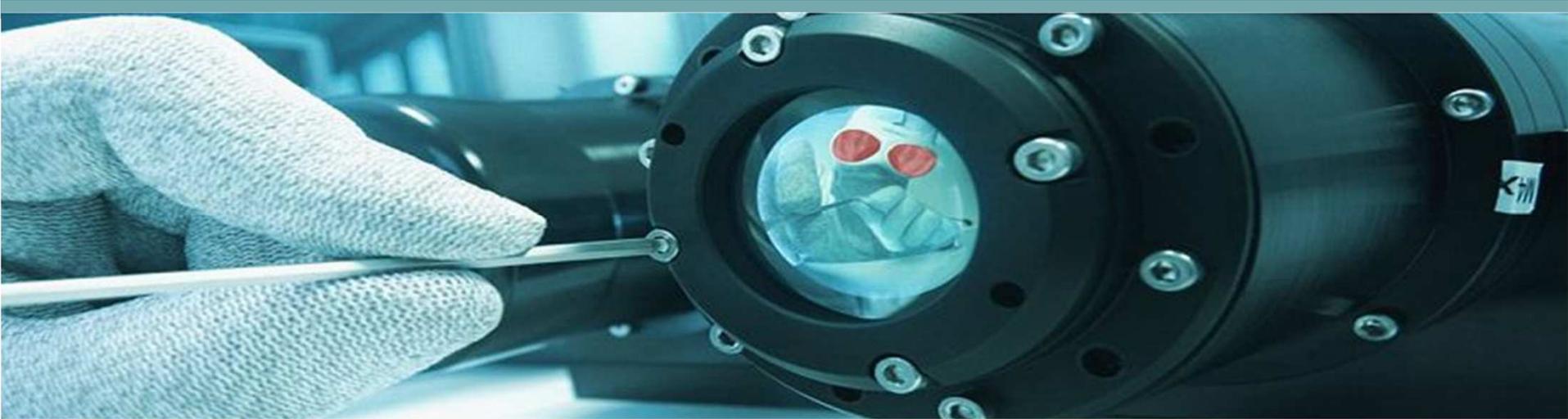
raw laser beam



beam
shaping
optics

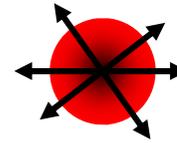


required light field



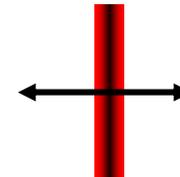
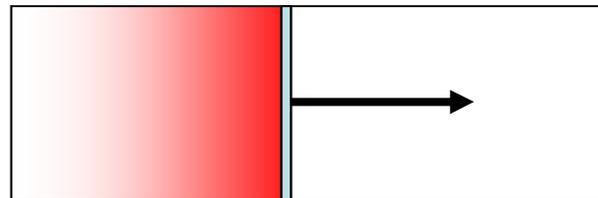
LIMO Line Laser

Punctiform laser source

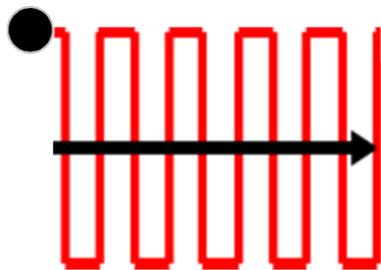


Discontinuous,
multidirectional heat
distribution

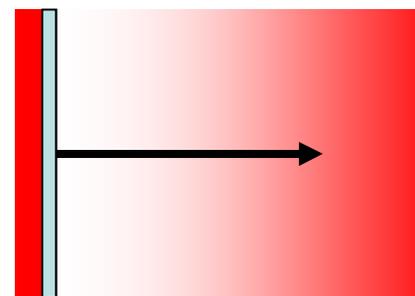
L³ - Limo Line Laser



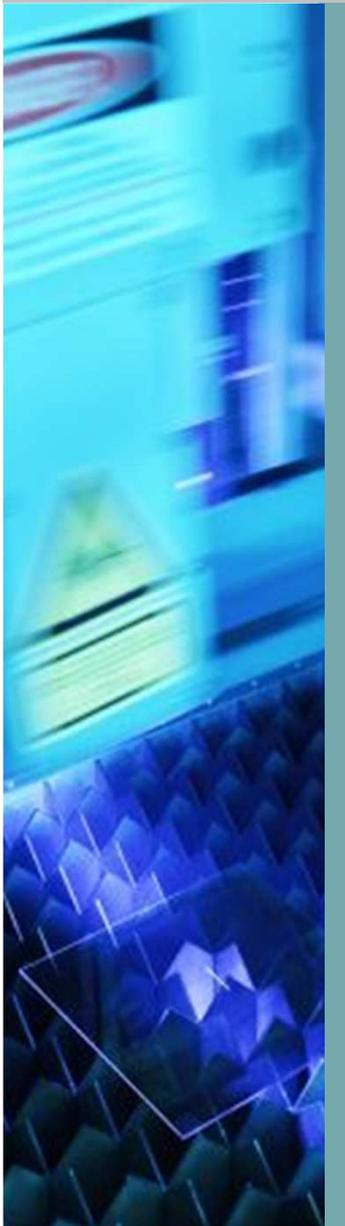
Continous linear
heat distribution



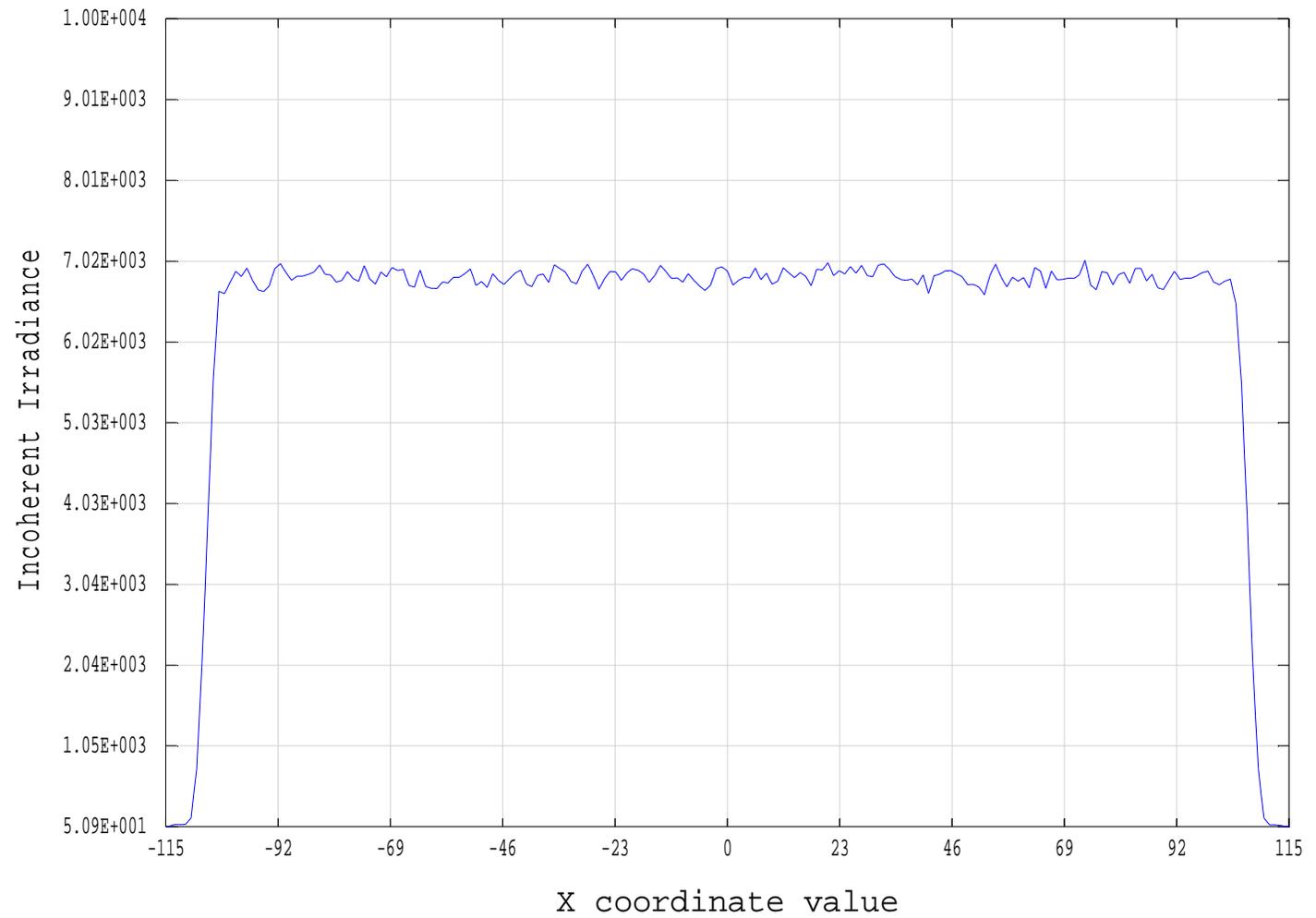
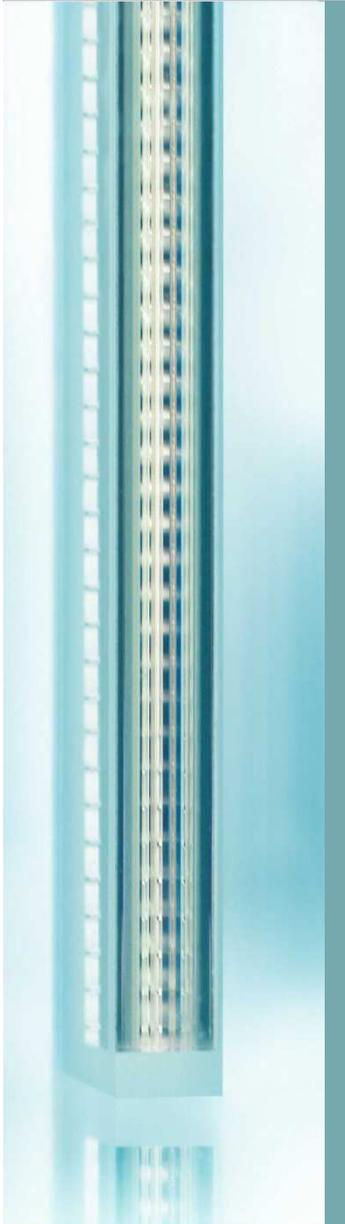
Punctiform laser source



L³ - Limo Line Laser



Typical Beam Profile



Overview

Motivation

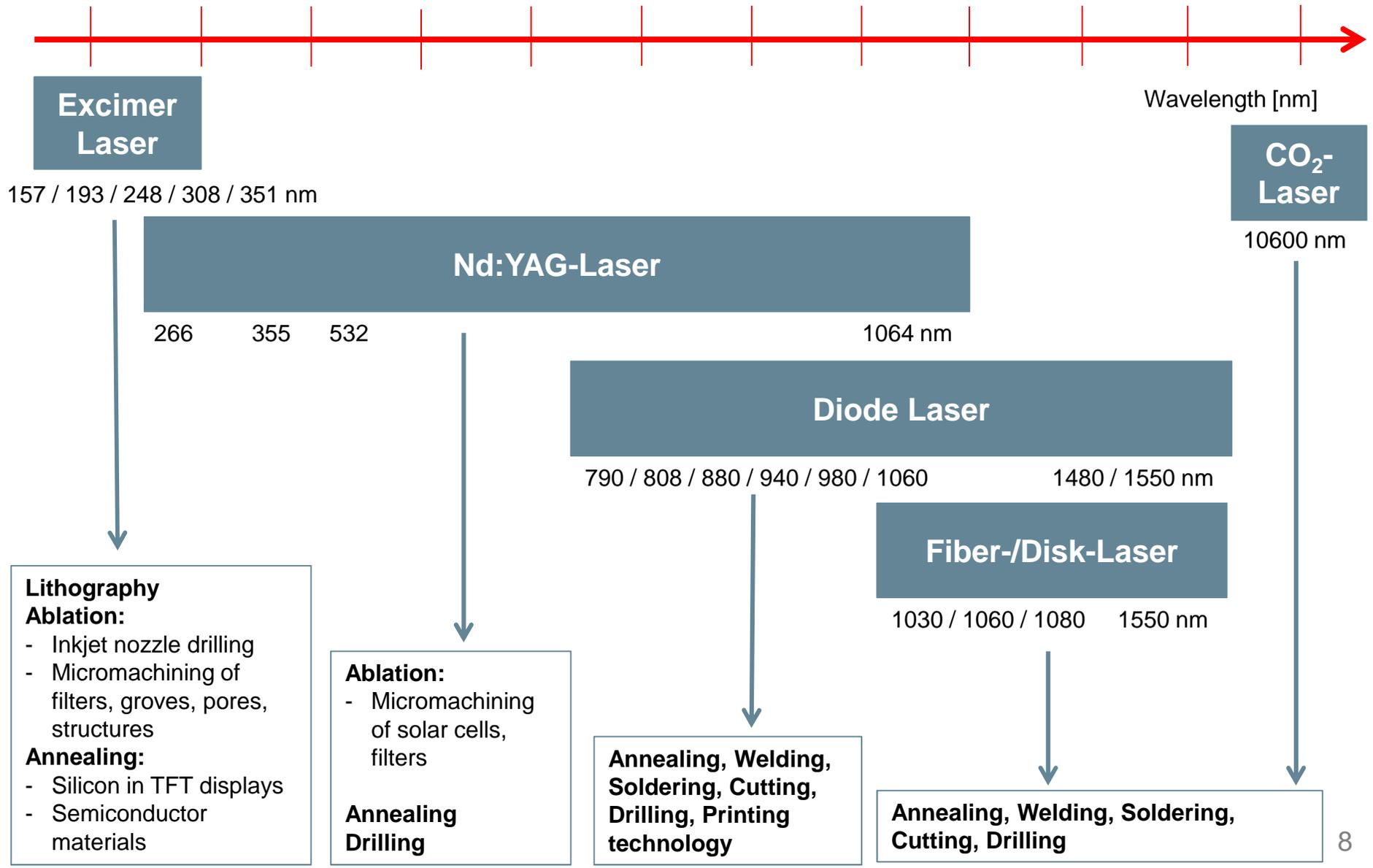
Principle of Beam Shaping

LIMO Line Laser - Examples

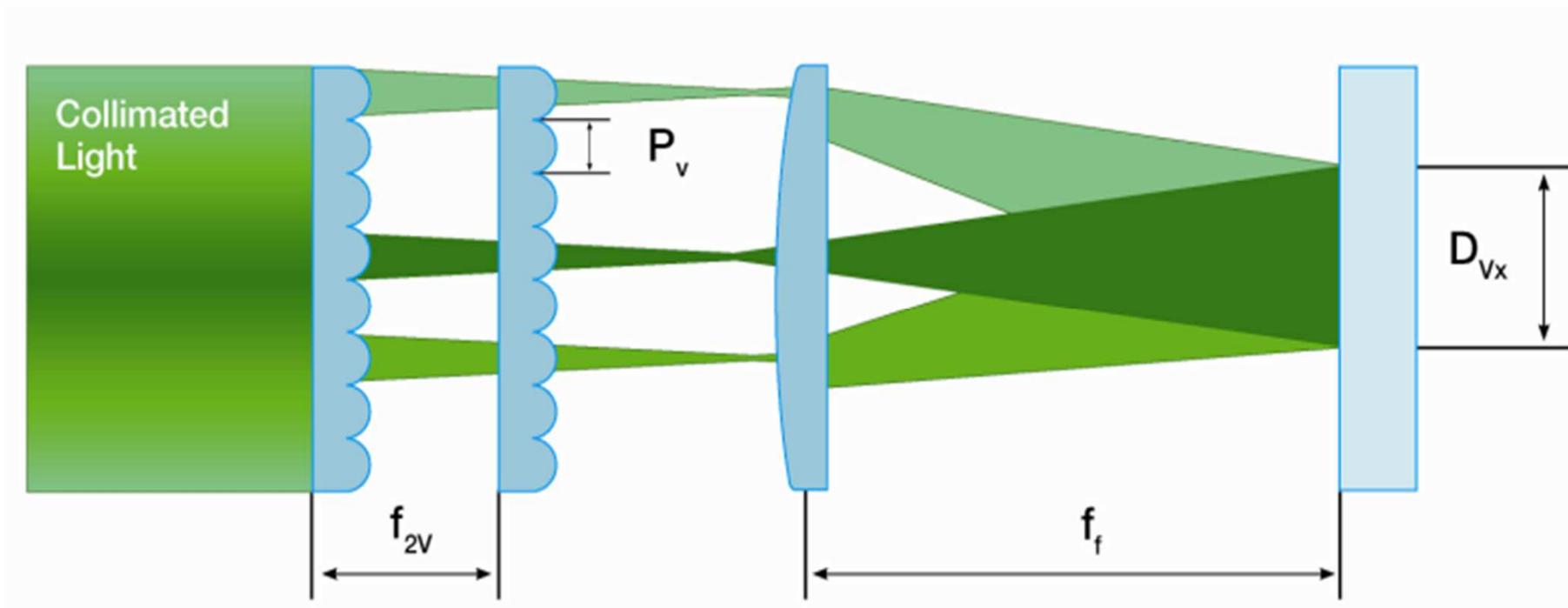
Summary



High Power Laser Sources & Applications in Materials Processing



Principle of Beam Shaping for Multi Mode Sources

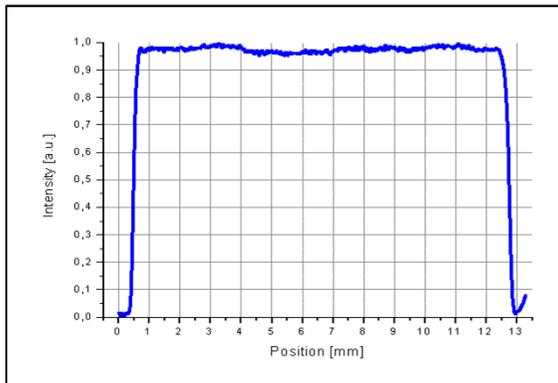
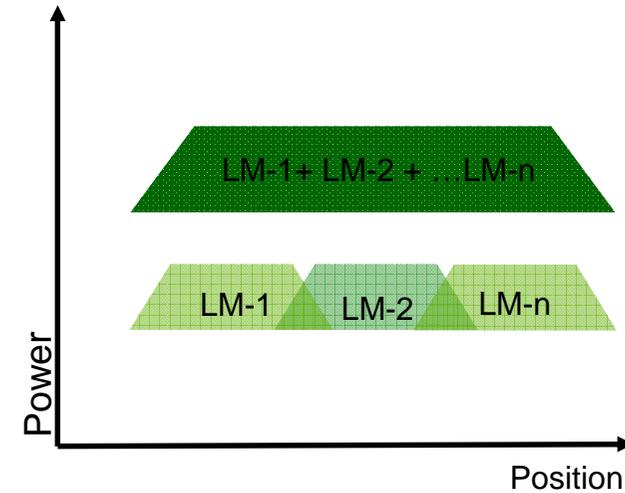
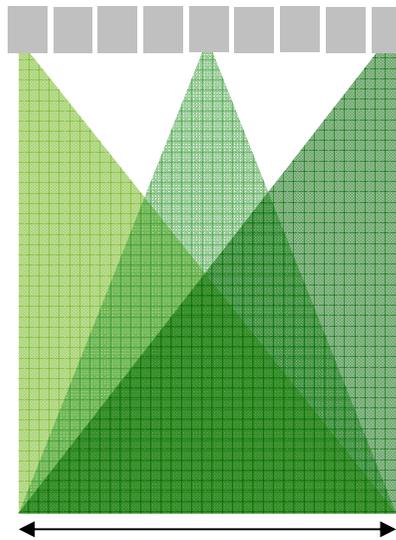
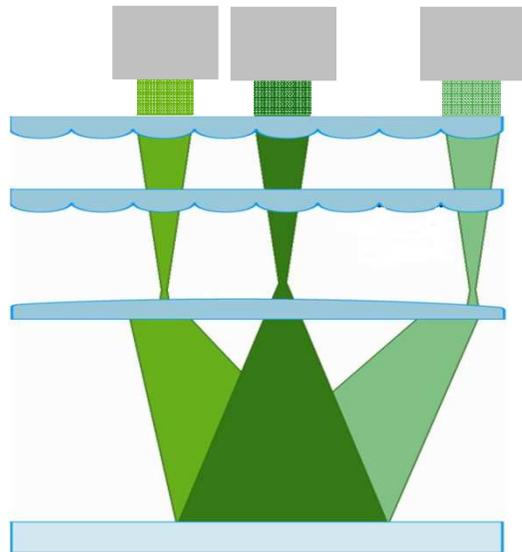


$M^2 > 20$

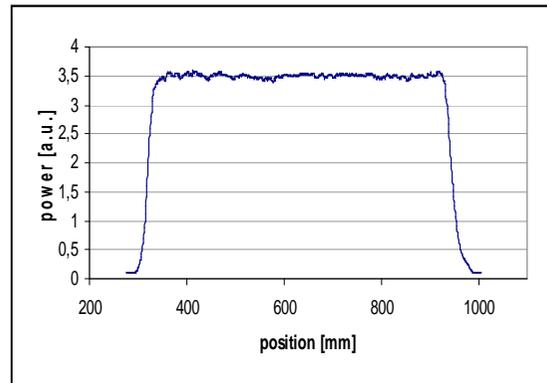
Field dimensions:

$$D_v = \frac{P_v}{f_{2v}} \cdot f_f$$

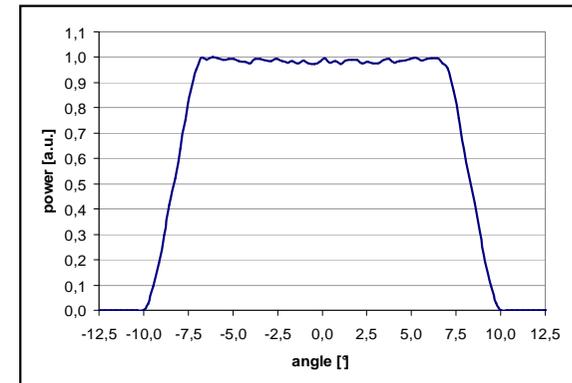
Different Concepts of Line Generation



Beam mixing of all laser source by using **symmetric** homogenizer



Beam mixing of all laser source by using **asymmetric** homogenizer



Beam stitching for the generation of long uniform lines

Overview

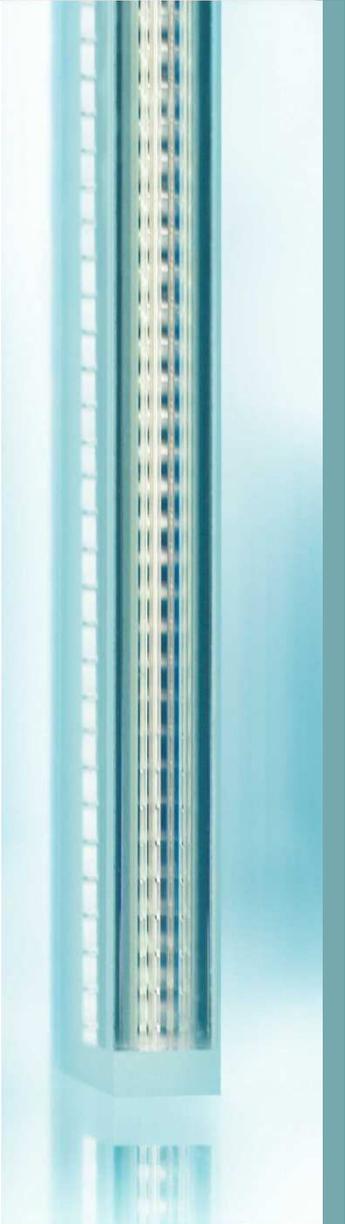
Motivation

Principle of Beam Shaping

LIMO Line Laser - Examples

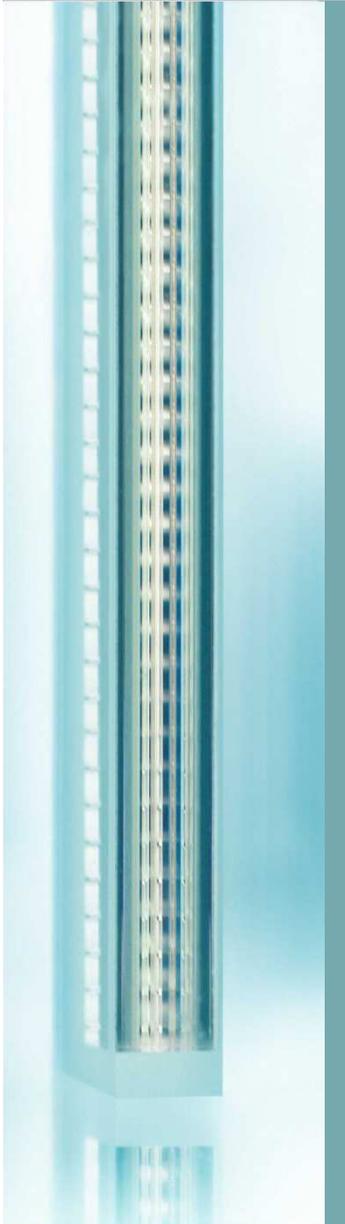
Summary





LIMO Line Laser

- Green Line
- Diode Line Laser



LIMO Line Laser

Green Line

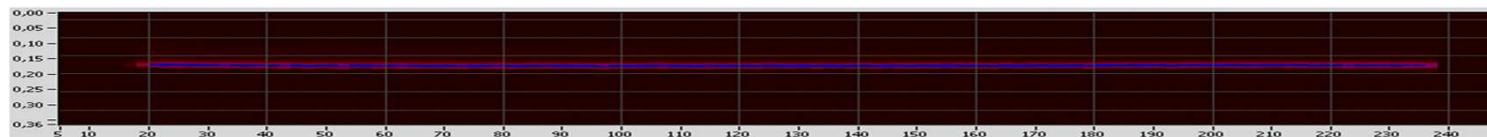
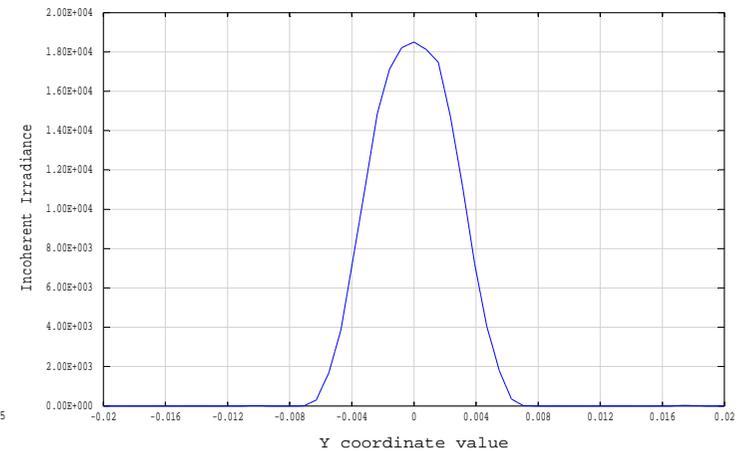
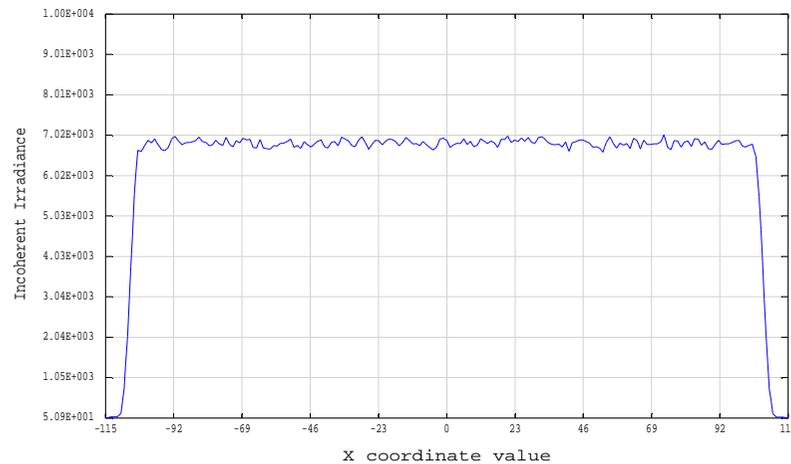
Diode Line Laser

Green Line (@ 532 nm) – Technical Specifications



Specifications	
Line length (FW 95%)	200 mm
Line width (FWHM)	$\leq 8.5 \mu\text{m}$
Inhomogeneity	$\leq 2.5 \%$
Energy density @ target plane	$\geq 1.3 \text{ J} / \text{cm}^2 @ 60 \text{ ns} / 10 \text{ kHz}$

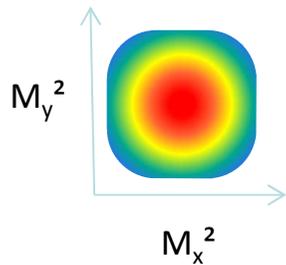
Simulation data:



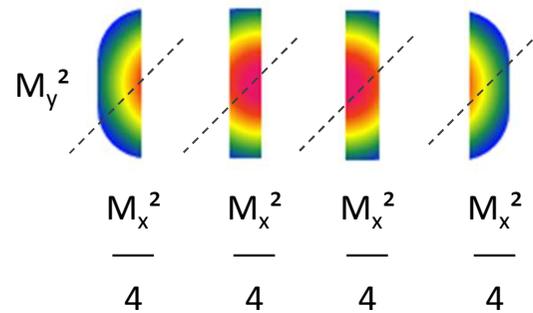
Anisotropic Laser Beam Quality Transformation

Example with dividing of laser beam in $N = 4$ parts

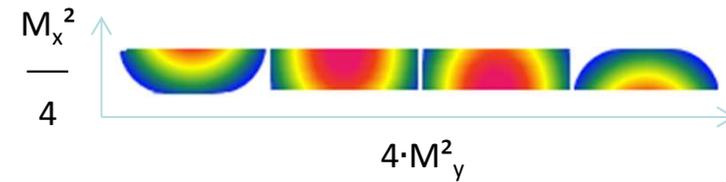
$$M_x^2 \cdot M_y^2 = \text{constant}$$



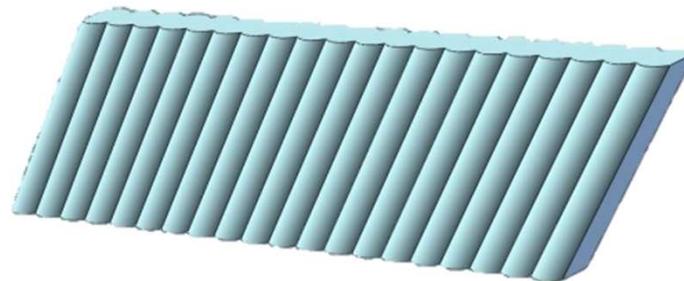
a



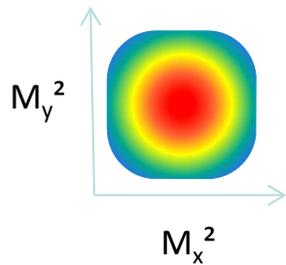
b



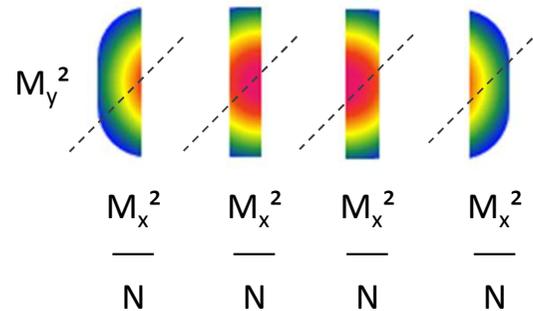
c



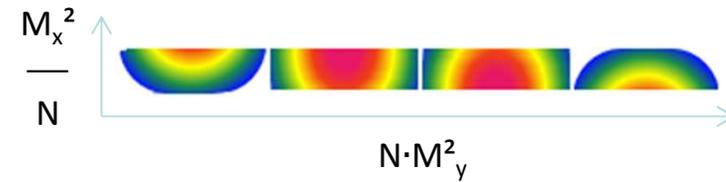
Anisotropic Laser Beam Quality Transformation



a



b



c

Example for DPSS laser $M_{x0}^2 = M_{y0}^2 = 45$, and $N = 15$:

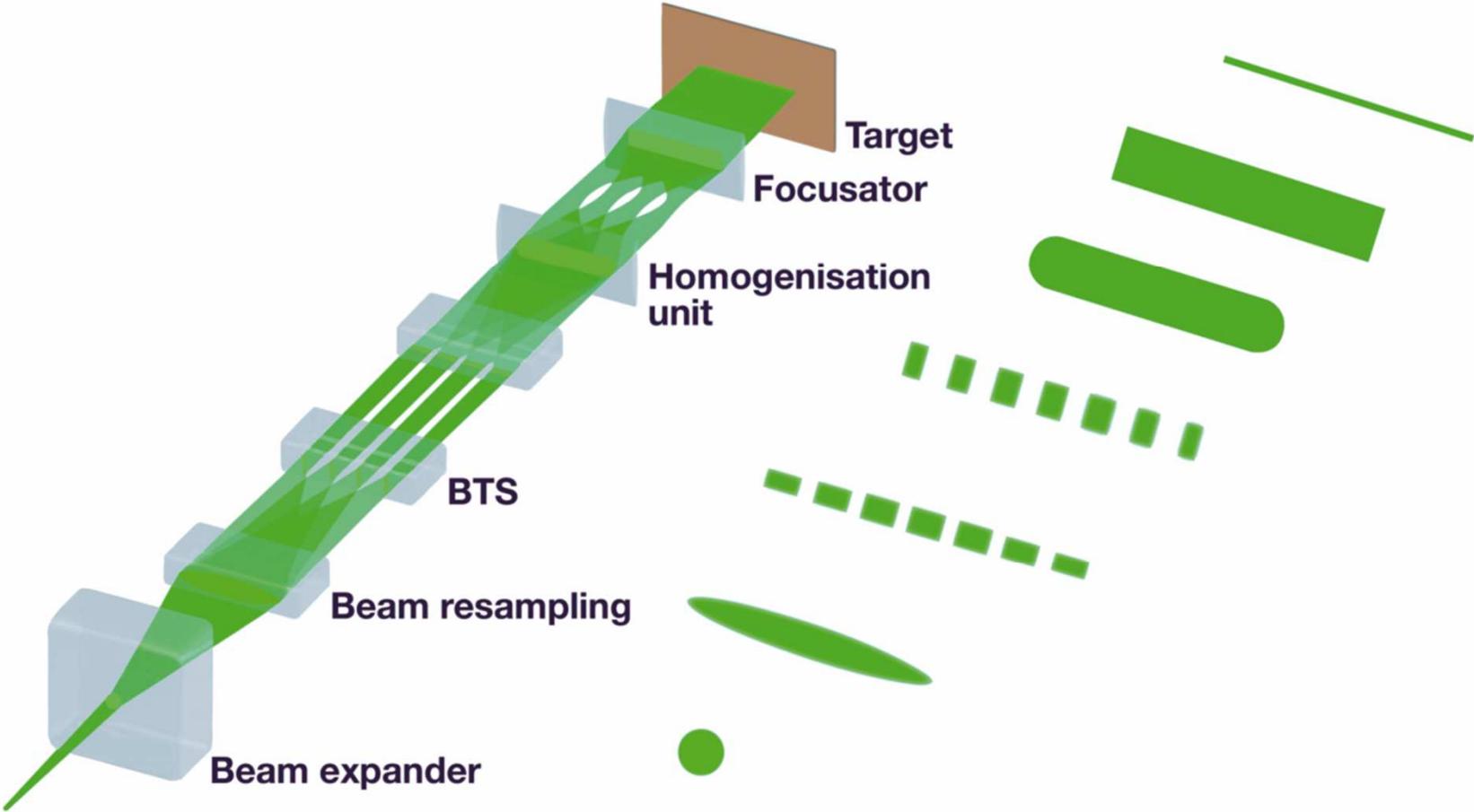
$$M_x^2 \approx 45/15 = 3$$

$$M_y^2 \approx 45 \cdot 15 = 675$$

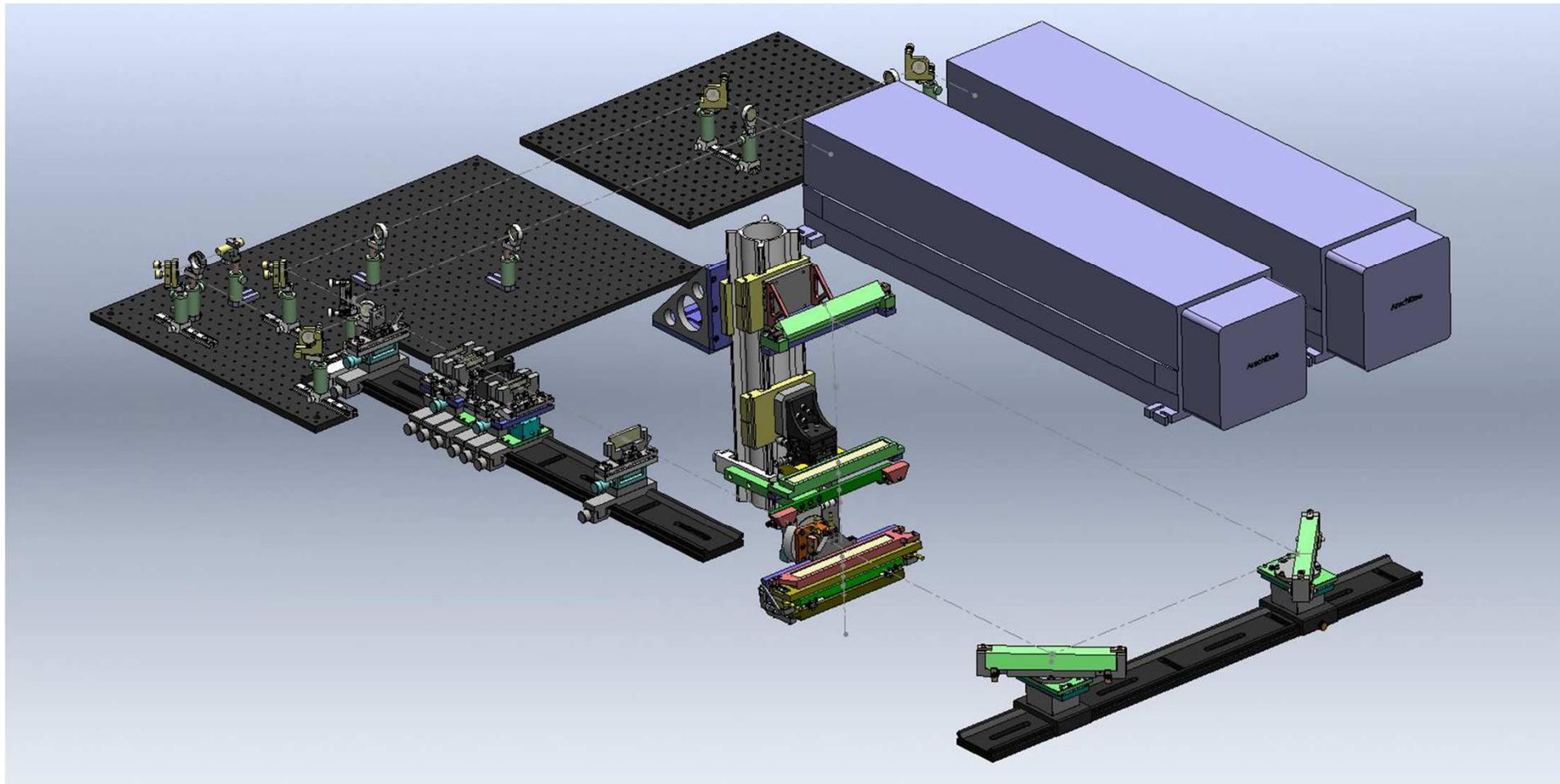
Enables to form the short axis X
with tight focus, long depth of
focus and long working distance

Enables to form the long
axis Y with high
homogeneity

Set Up – Green Line Laser System



Set Up – Green Line Laser System



Application Example

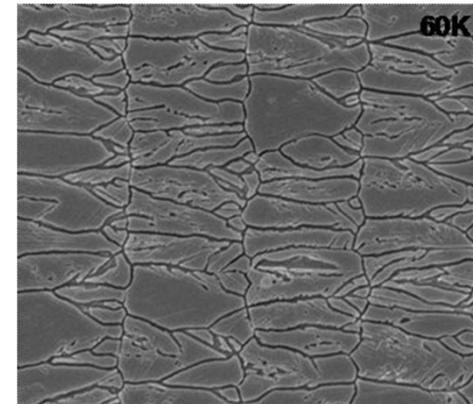
Process:

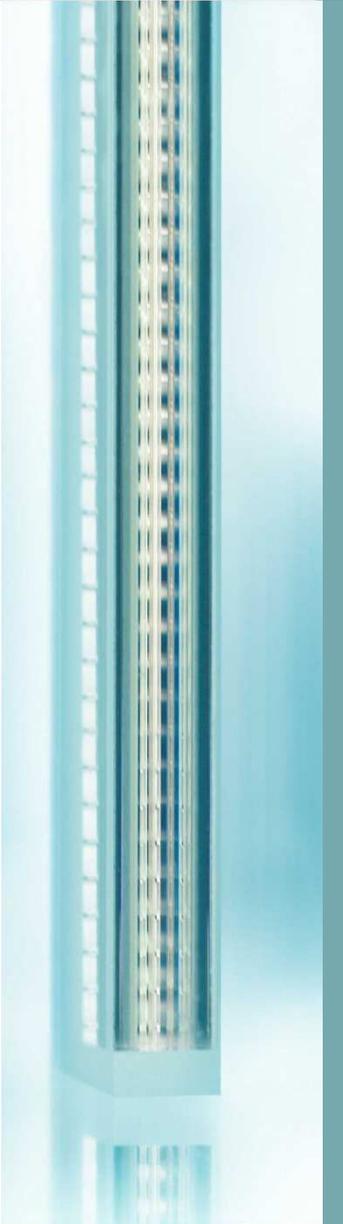
- Crystallization prozess

Result
(R&D):

- Increased charge carrier mobility
- Reduced surface resistance (R_{sq})

Crystallization of Si
for thin film solar cells

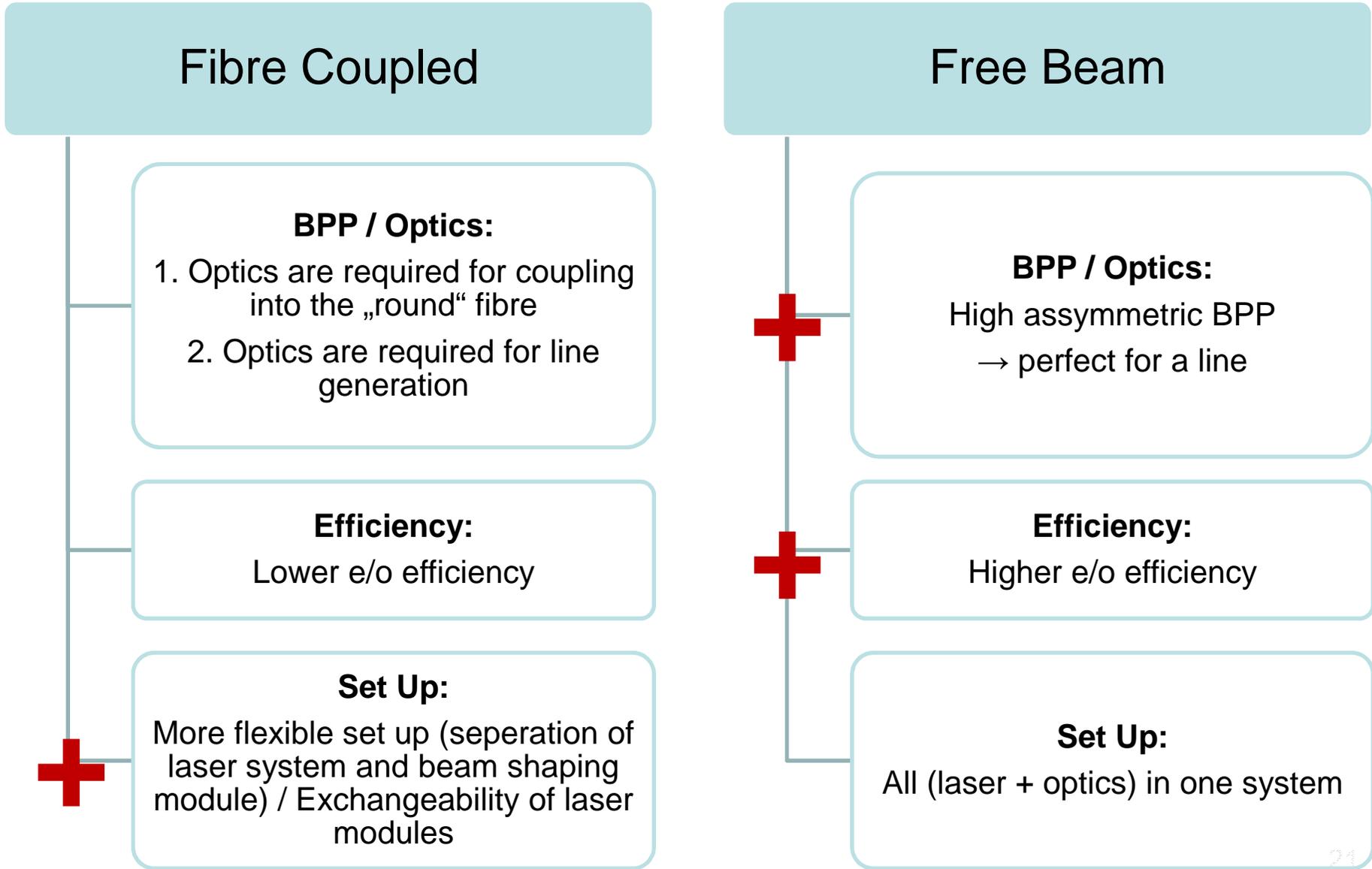




LIMO Line Laser

- Green Line
- Diode Line Laser

Fibre Coupled vs. Free Beam Line Laser



LIMO Line Laser

Typical Technical Data	
Line length	principally unlimited
Line width	from 0.05 mm up to 30 mm
Power density	up to 600 kW/cm ²
Inhomogeneity	down to 1%
Output power	up to Multikilowatts
Wavelength	from 790 nm up to 1470 nm



Diode Line Laser Applications

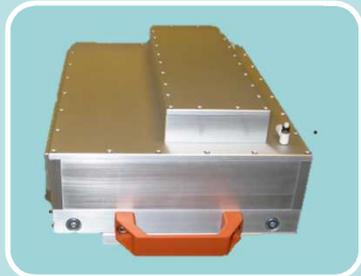
Application	Power Density	Power Range	Line Length	Line Width
Vision Application	~ 0.25 W/cm ²	10W...40W	up to 10m	<1mm...10mm
Plastic Processing Printing, Drying	~ 225 W/cm ²	10W...2kW	3mm...600mm	<1mm...5mm
Thin Film Processing	up to 250 kW/cm ²	300W...30kW	5mm...600mm	~ 0.05mm



Overview - Diode Line Laser



40 W Line Laser – 165 x 3 mm²
→ Quality control of solar cells



4.2 kW Line Laser – 200 x 2 mm²
→ Drying of ink

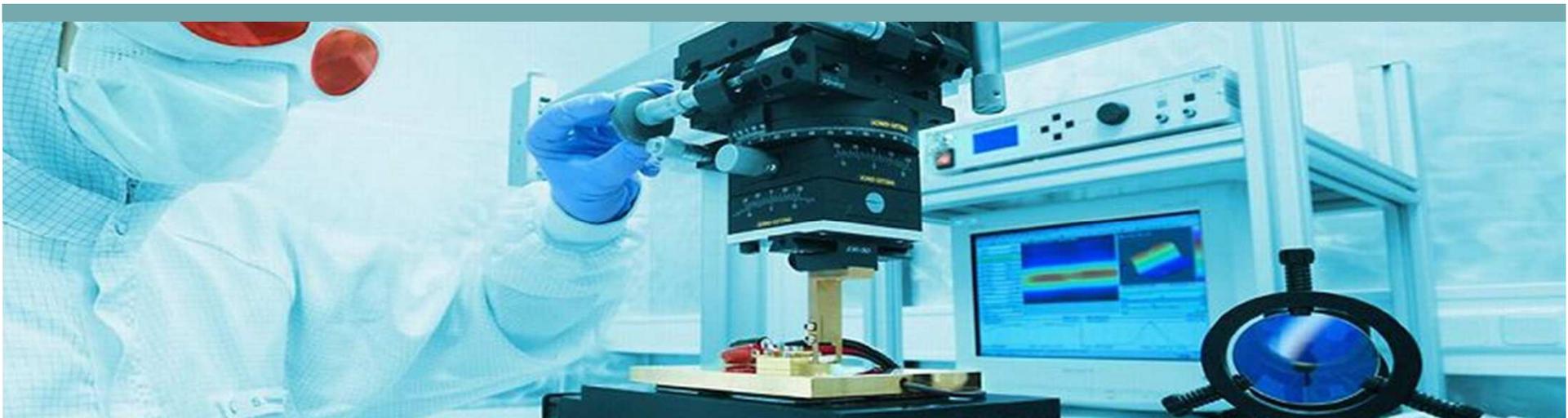


450 W Line Laser – 12 x 0.1 mm²
→ Thermal processing of thin films

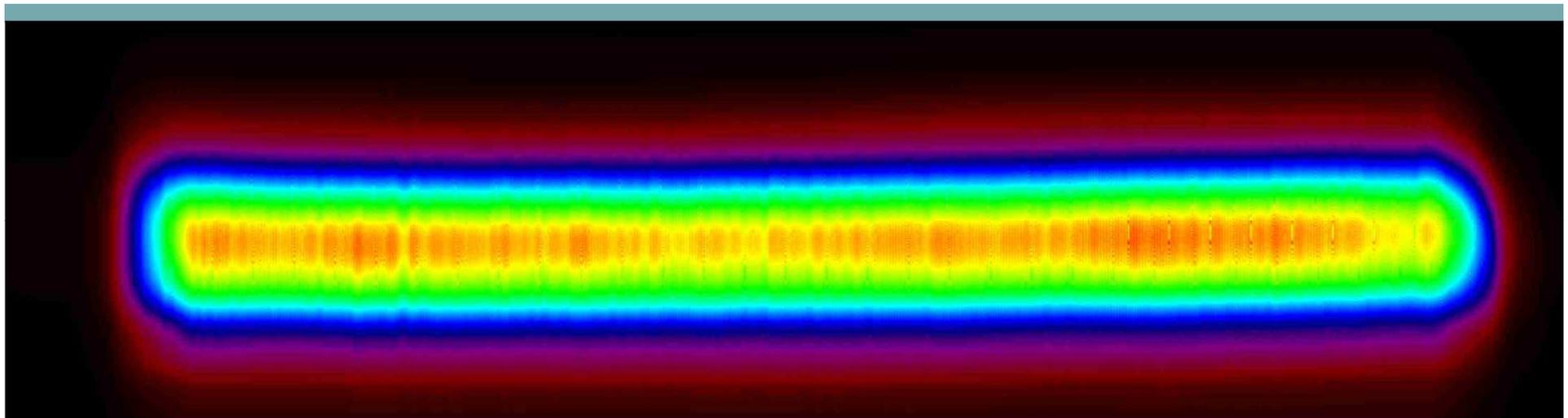
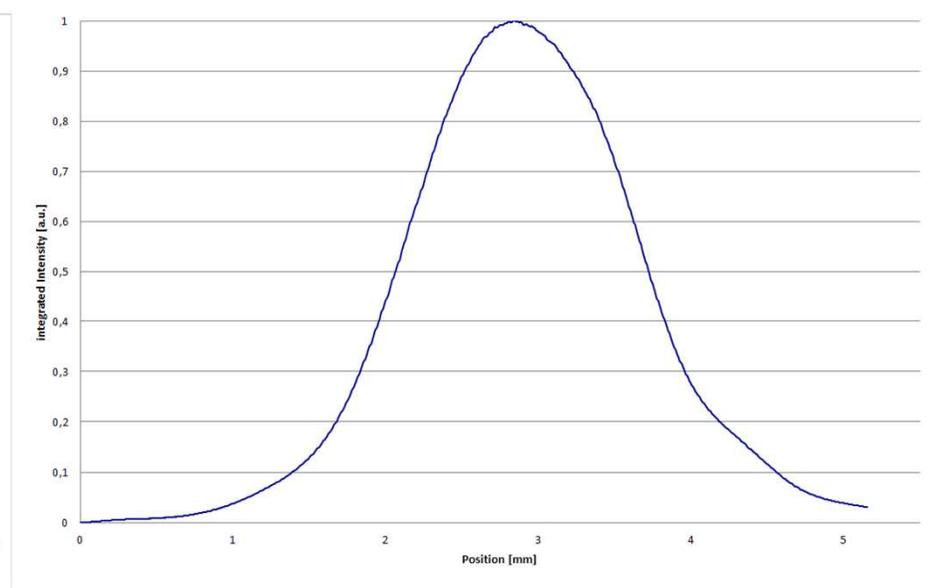
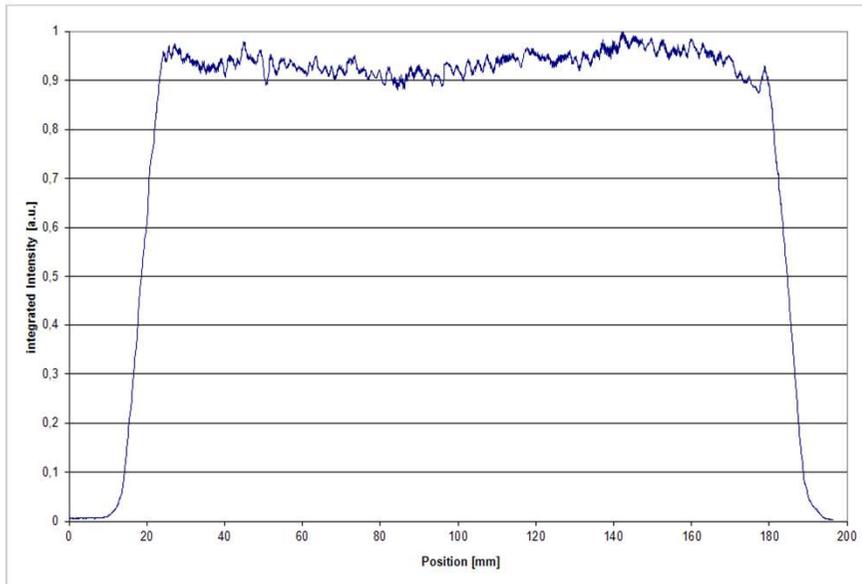
Line Laser for Scanning of the Solar Cell

Technical specifications for laser line generator:

- Compactness
- Line dimensions: 165 mm x 3 mm
- Power: 40 W
- Wavelength: 790 / 808 nm
- Inhomogeneity: $(I_{\max} - I_{\min}) / (I_{\max} + I_{\min}) < 7.5 \%$

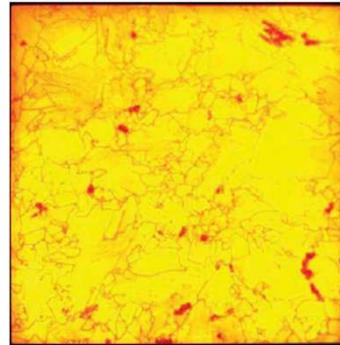
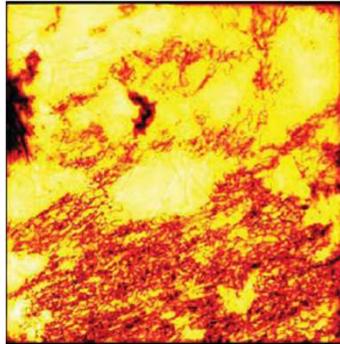


Measurement Results

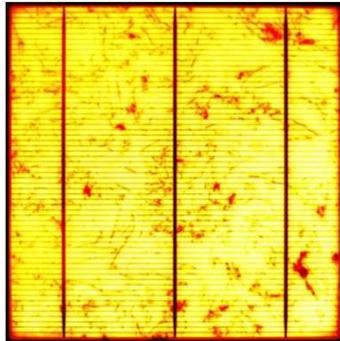
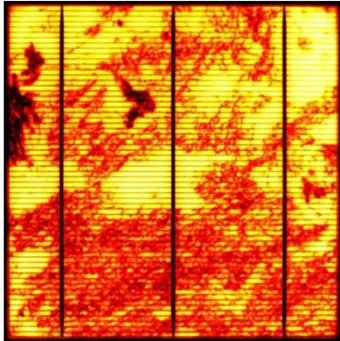


Photoluminescence Results

As cut wafers



Solar cell



(Courtesy of J. Haunschild,
Fraunhofer ISE)

Good correlation between PL of as-cut wafers and solar cells

Effective and cost-efficient inline analysis in solar cell production

Overview - Diode Line Laser



40 W Line Laser – 165 x 3 mm²
→ Quality control of solar cells



4.2 kW Line Laser – 200 x 2 mm²
→ Drying of ink



450 W Line Laser – 12 x 0.1 mm²
→ Thermal processing of thin films

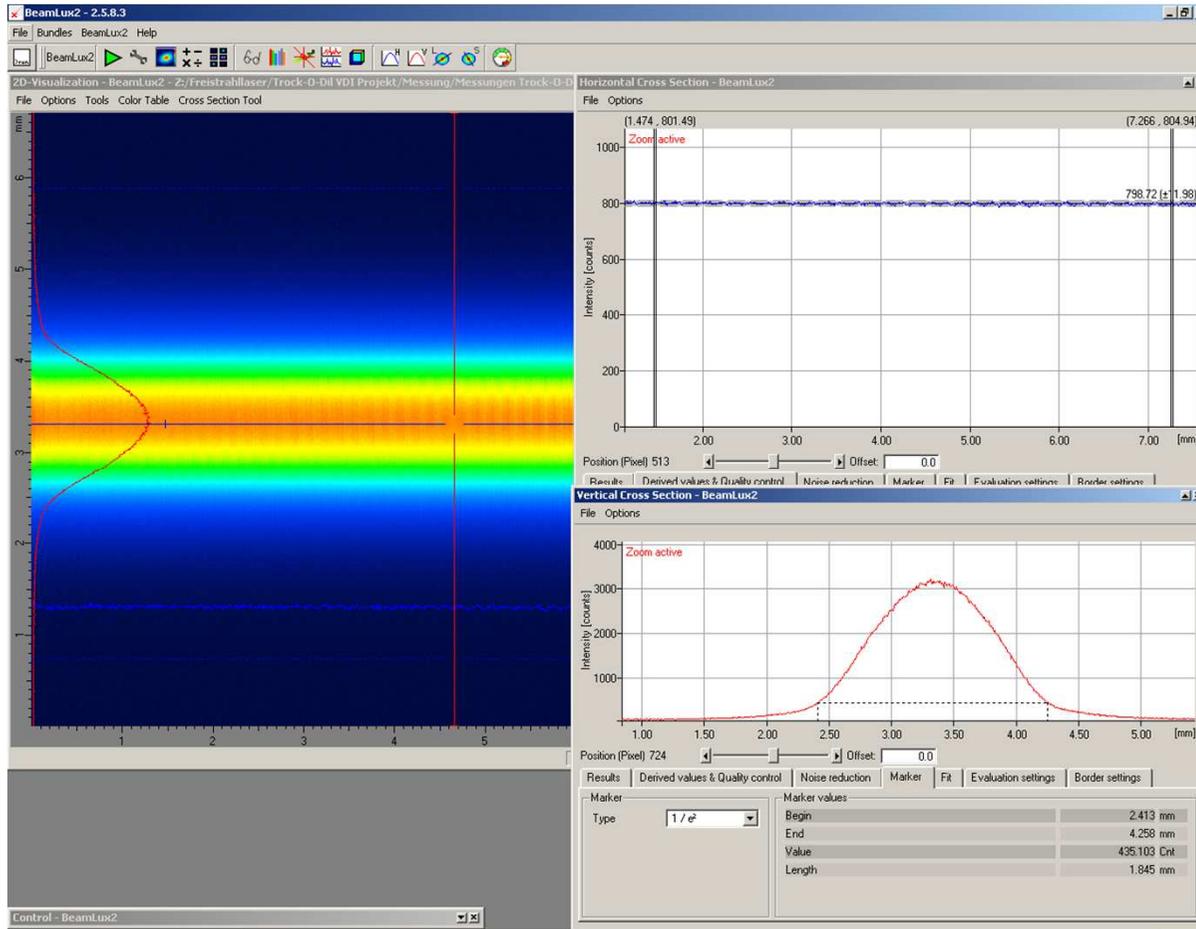
Line Laser for Drying of Ink

Technical specifications for laser line generator:

- Line dimensions: 200 mm x 2 mm
- Power: 4.2 kW
- Wavelength: 980 nm
- Inhomogeneity: (p-v) < 3 %
- 10 fiber coupled high power diode laser modules:
Power: 450 W, Fibre: 400 μm , NA: 0,22
- „Easy“ extendable source array - scalable line length
- Independent power regulation of each channel
- Segmented and stitched illumination of the line



Measurement Results

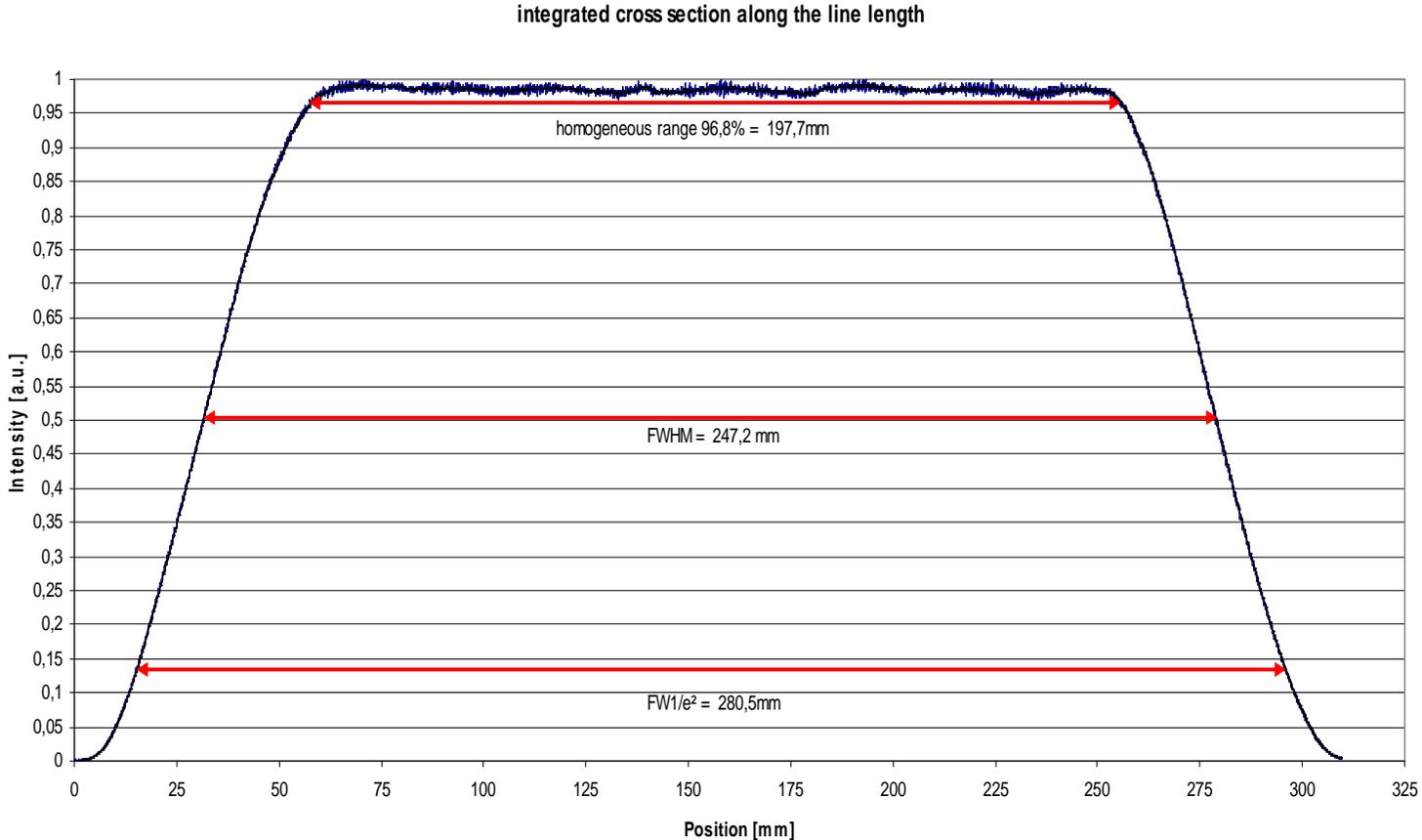


no visible overlap of the sources
depth of focus > 5 mm

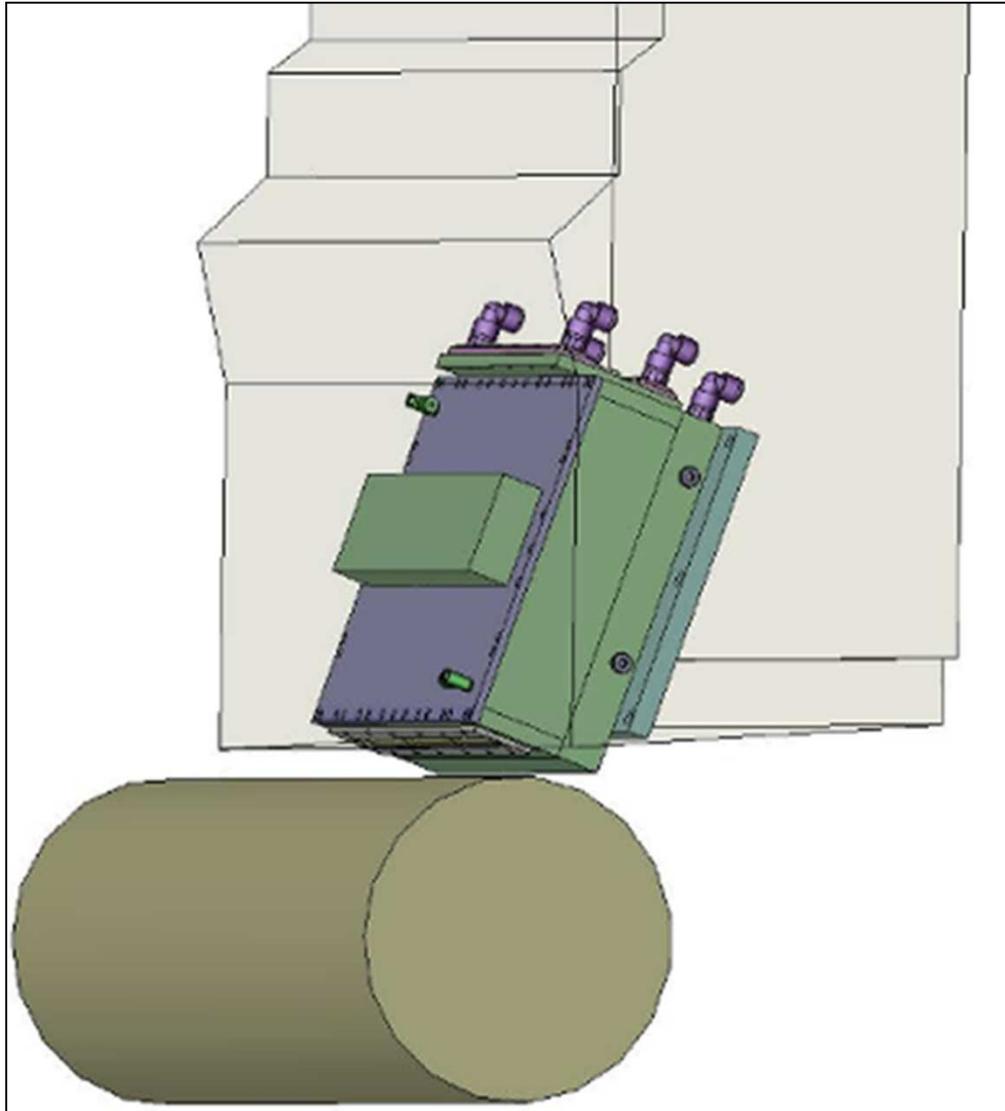
< 3% p-v inhomogeneity

beam width 1.7 – 1.9 mm
(FW1/e²)

Measurement Results



Integration of LIMO Line Laser to Printing Machine

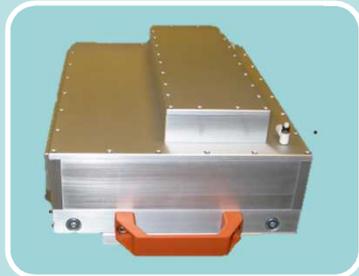


CAD-Modell with integrated
beam shaping unit

Overview - Diode Line Laser



40 W Line Laser – 165 x 3 mm²
→ Quality control of solar cells



4.2 kW Line Laser – 200 x 2 mm²
→ Drying of ink



450 W Line Laser – 12 x 0.1 mm²
→ Thermal processing of thin films

Crystallization of a-Si Thin Films on Glass Using a Diode Laser

Laser source

- 450W, 808 nm direct diode line beam 12 mm x 100 μm
- Inhomogeneity: $(I_{\text{max}} - I_{\text{min}}) / (I_{\text{max}} + I_{\text{min}}) < \pm 5 \%$

Material

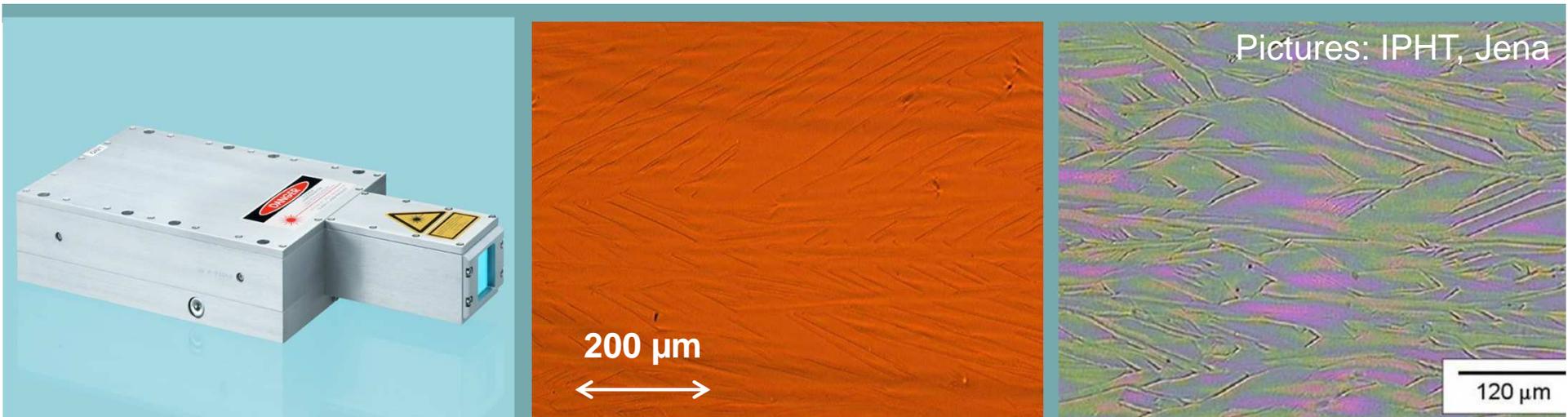
- 200 nm a-Si on glass

Process

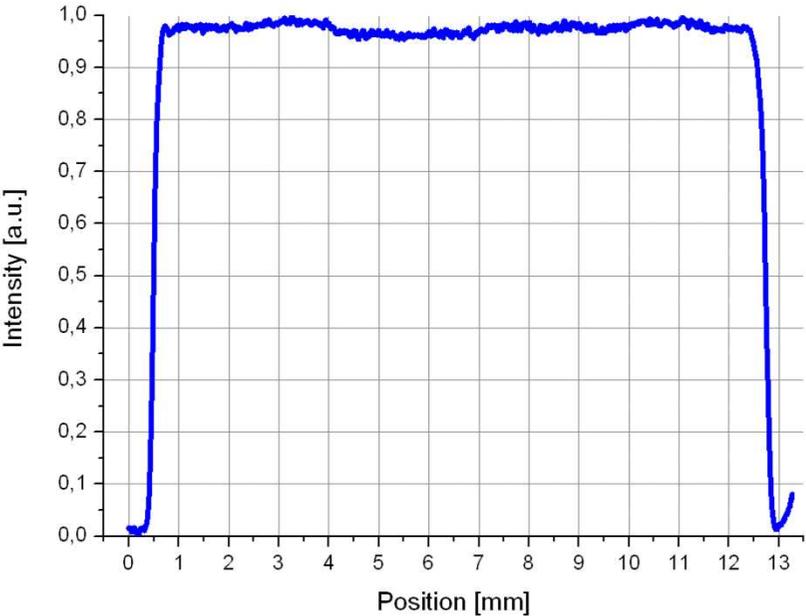
- single scan at a scanning speed of 33 mm/s
- crystal grain size $> 100 \mu\text{m}$

First results (R&D)

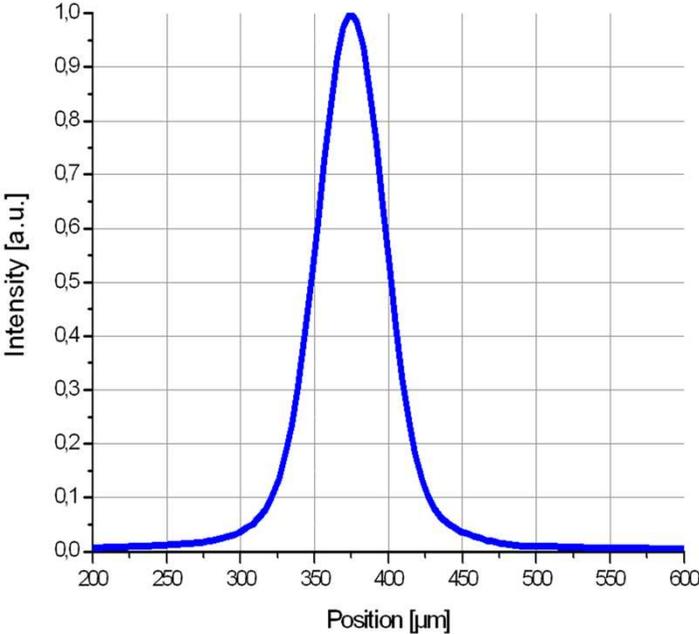
- increased charge carrier mobility in the absorber layer
- reduced surface resistance (R_{sq})



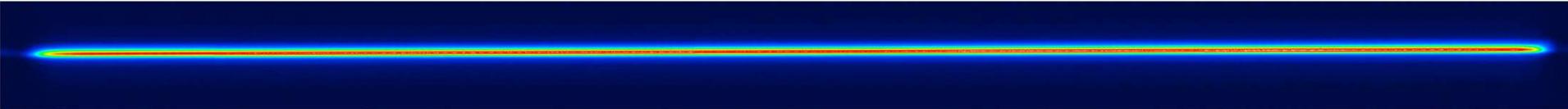
Measurement Results



integrated slow axis intensity profile

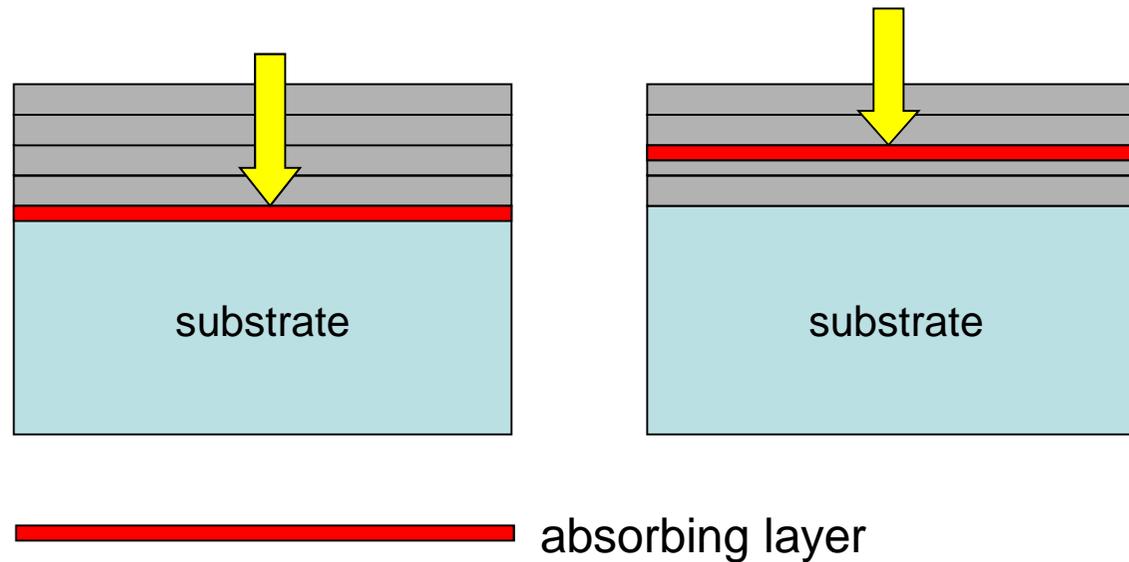


fast axis intensity profile



measured 2D profile

Selective Heating of Absorbing Thin-Film Layers



- generating of heat at different positions in a layer-stack possible
- well defined thermal processing in a millisecond range

vRTP – very Rapid Thermal Processing – Process Examples

- **crystallization** of TCO or semiconductor layer on glass - new solar cells, electronics
- **sintering / compaction** of nano-particle coatings on glass, metal, ceramic and polymer layers – reduced surface resistance R_{sq} , improved mechanical, optical and thermal performance and long-term stability – new solar cells, printed electronics
- **activation** of charge carriers for higher mobility and density – electronics, displays, energy storage



Overview

Motivation

Principle of Beam Shaping

LIMO Line Laser - Examples

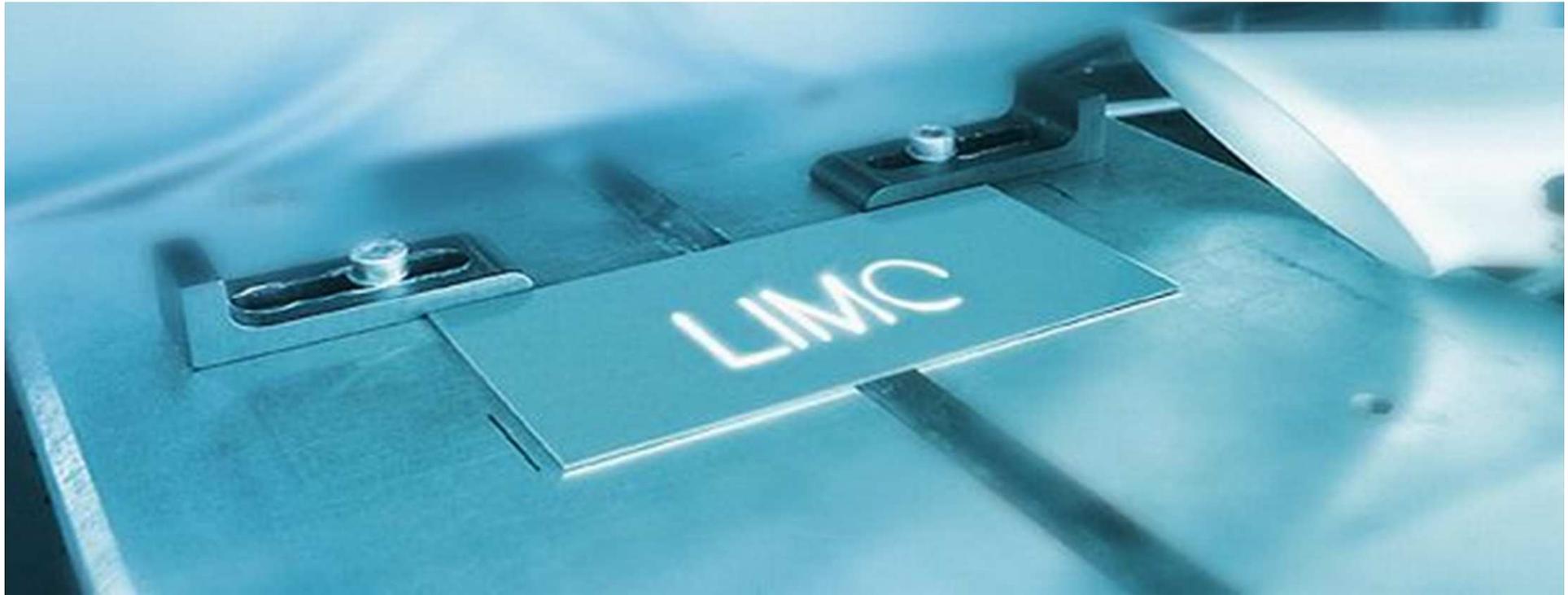
Summary



USP - LIMO Line Laser

- Higher throughput thanks to fast scanning speed of large areas
- Lower electrical power consumption due to high efficient laser systems
- Reproducible processing conditions due to high intensity and maximum homogeneity along the line





Thanks for your attention!

Please visit us at booth 816!