Solutions for Throughput scaling of laser micro processing

Dr. Soeren Richter, TRUMPF Korea Technology Center

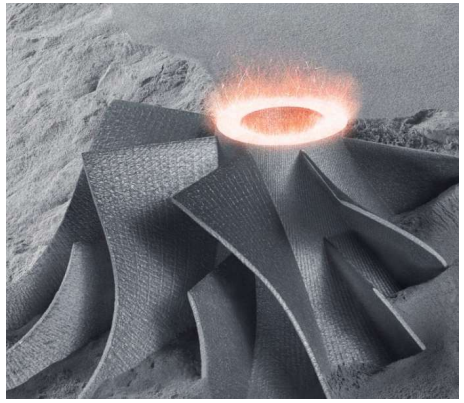
TRUMPF

TRUMPF is…

Family business since 1923

Technology leader in two business divisions

Close to its customers with 77 subsidiaries

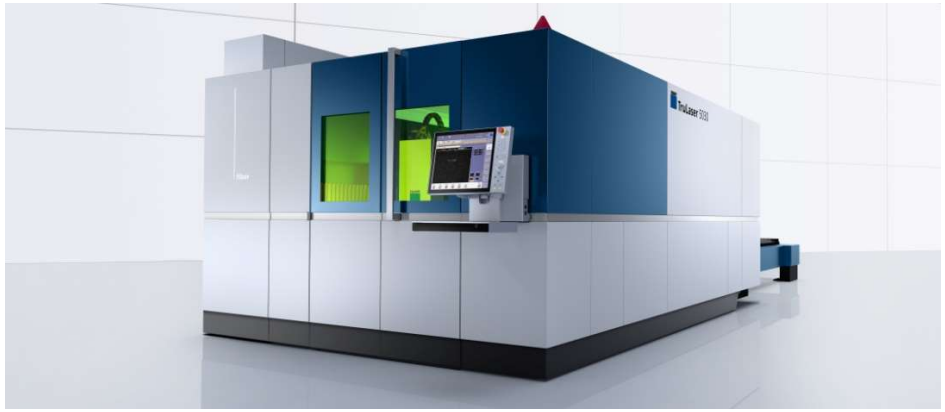


Innovation promise – holistically and constantly

Our business divisions

Share of sales in 2017/18

Machine tools for flexible sheet metal processing

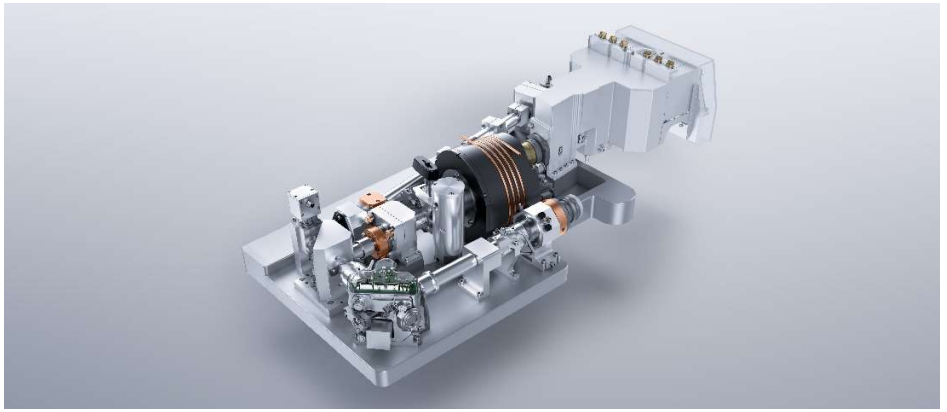


Sales 2017/18

3.02 bn. €

+11.3%

Laser technology



Sales 2017/2018

1.50 bn. €

+21.5%

TRUMPF

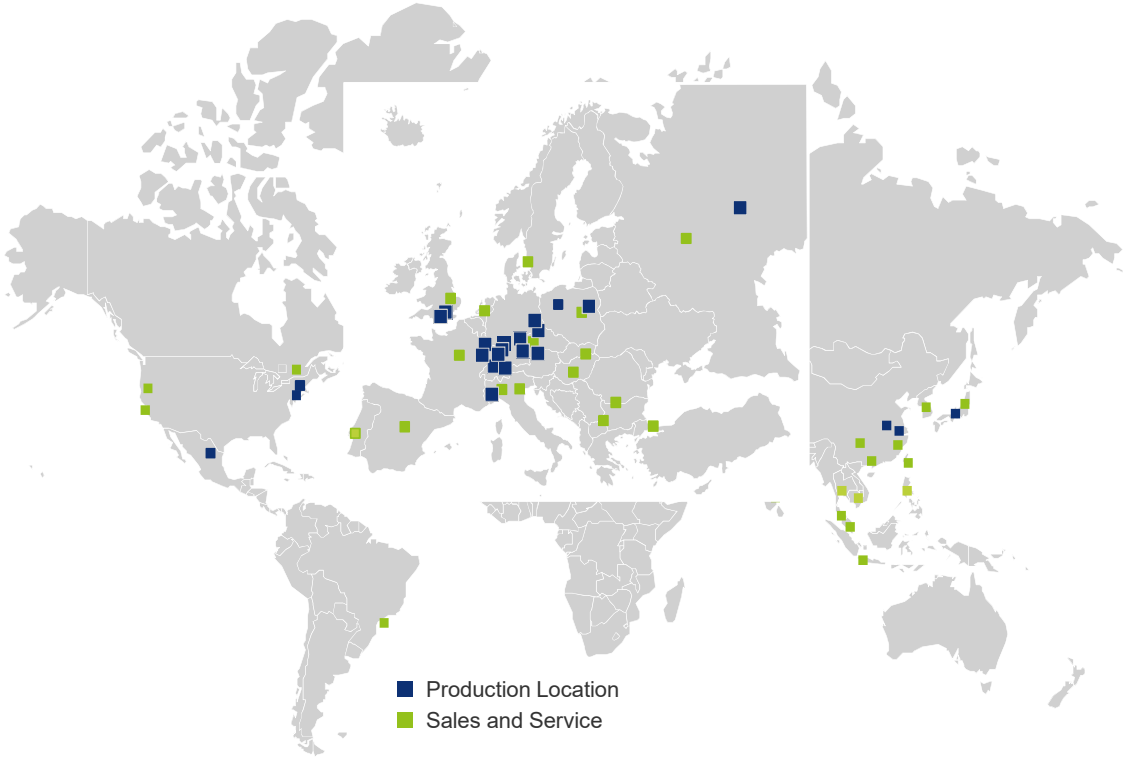
Worldwide presence

Our locations close to our customers

Locations worldwide

Germany	America
14	10

Europe (without GER)	Asia/Pazific/ Others
26	16



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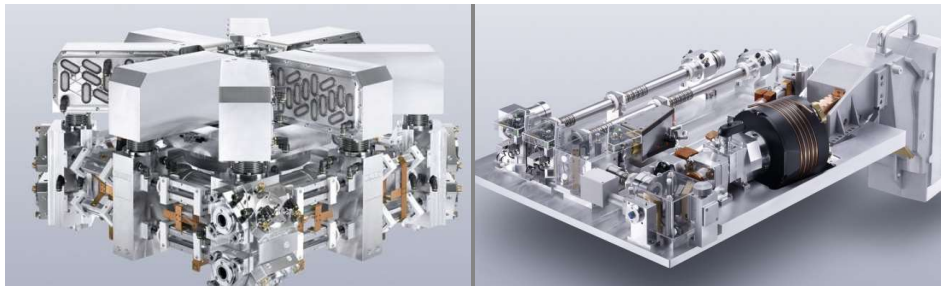
Laser Technology business division

CO_2 and disk lasers



Laser systems

Laser marking systems

RF generators for industrial applications

TRUMPF

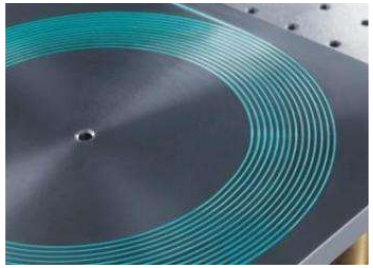
The TRUMPF Laser Portfolio

The Power of Choice: The right laser for every application

CO_2 lasers
TruFlow

Disk lasers
TruDisk

Diode lasers
TruDiode



Fiber lasers
TruFiber

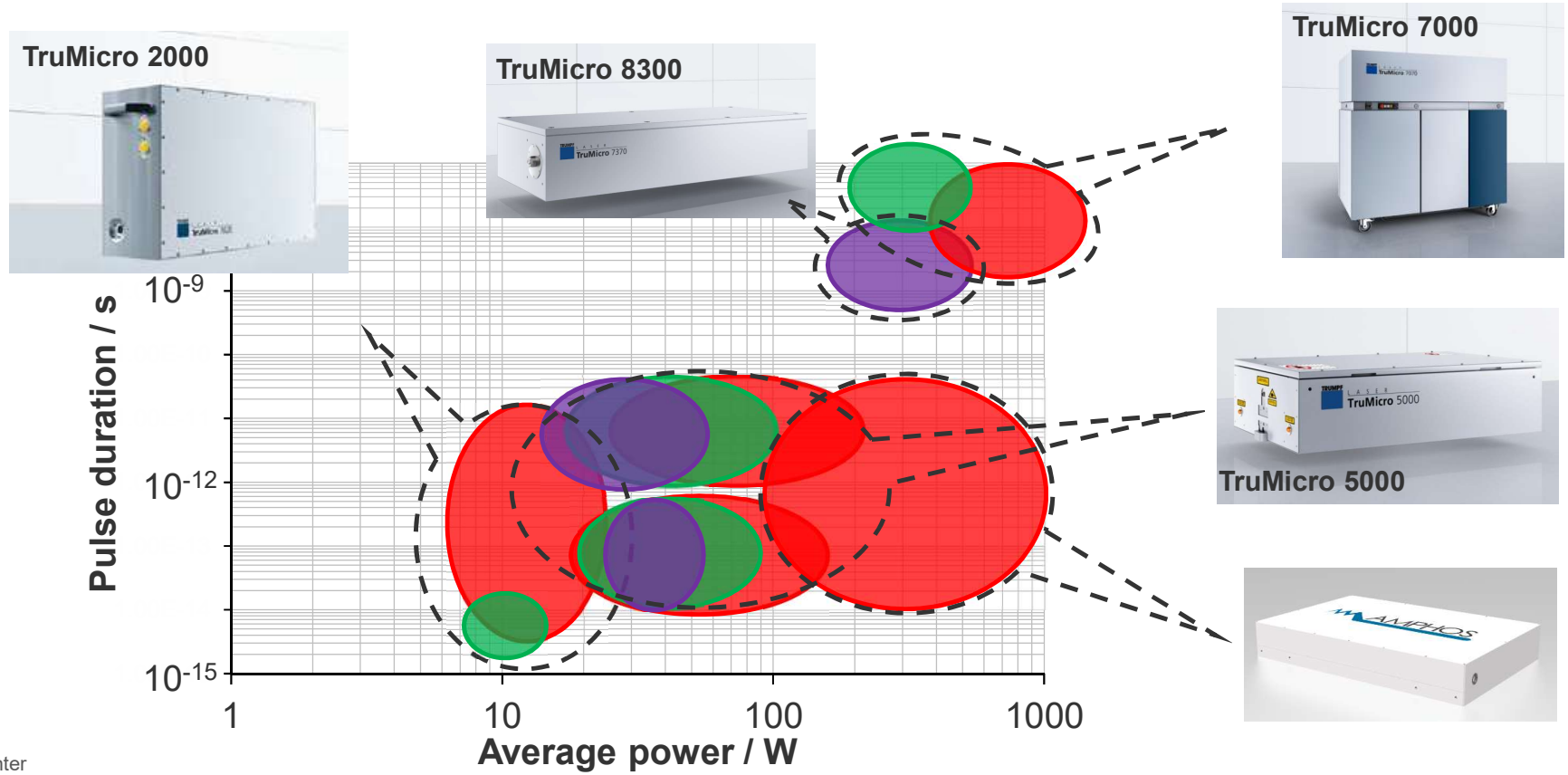
Pulsed SSL
TruPulse

Ultrafast lasers
TruMmicro

Marking lasers
TruMark

Microprocessing with ultrashort laser pulses

Full flexibility over the whole field of parameters

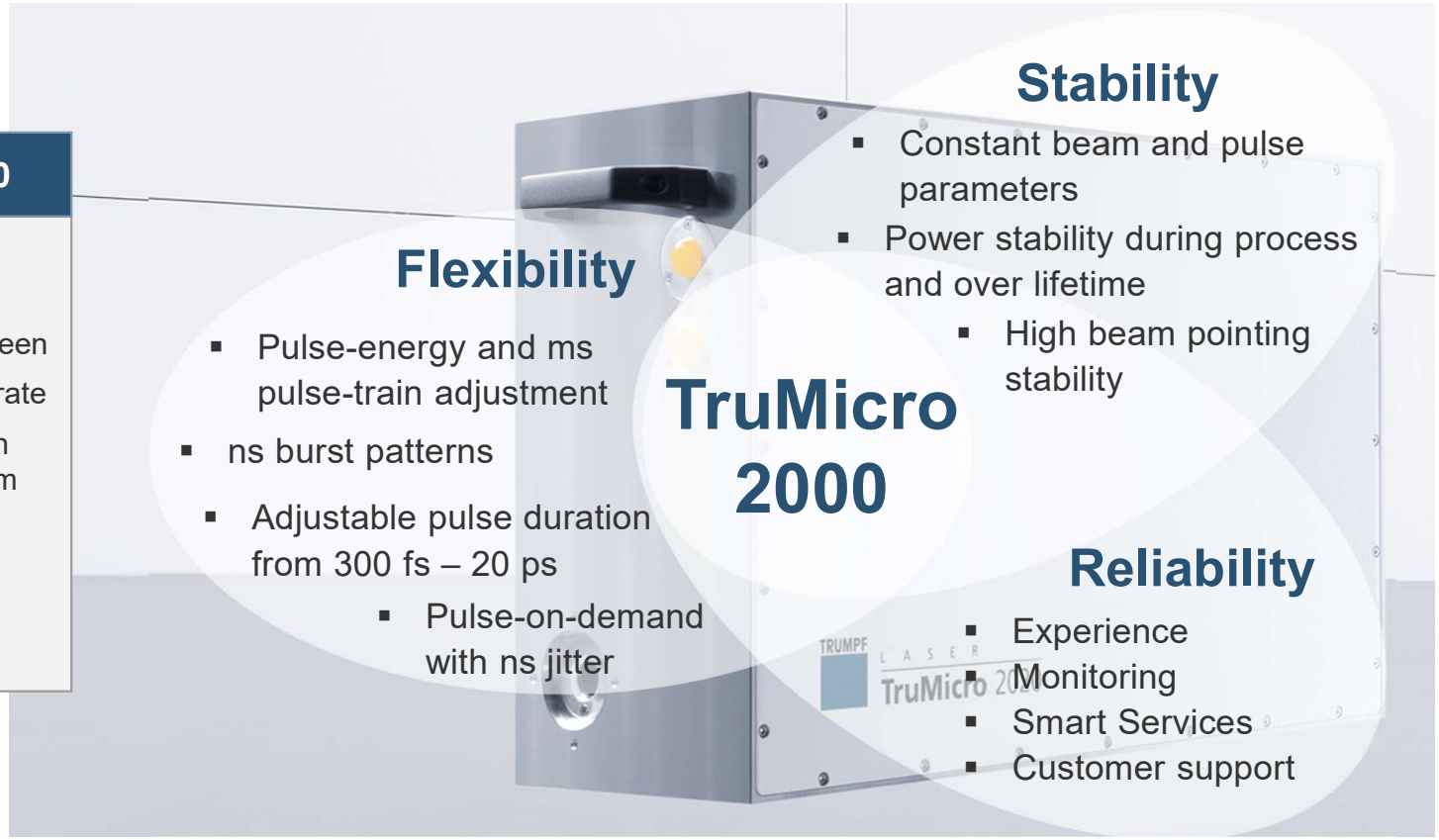


TruMicro 2000

Compact size but full flexibility

NEW TruMicro 2000

- 20 W IR, 10 W green
- up to 100 µJ IR/50 µJ green
- up to 50 MHz repetition rate
- adjustable pulse duration (no impact on other beam parameters)
- Burst mode
- Pulse on Demand



TruMicro 5000 – FU06

Third generation of industrial ultrashort-pulsed lasers

- **Acousto-optical modulator with internal power reserve**
- **Zero leakage power**
- **Improved serviceability**
- **Optional: improved beam quality M² <1.2**

	TruMicro 5080	TruMicro 5280	TruMicro 5380	TruMicro 5080 Femto Edition	TruMicro 5280 Femto Edition	TruMicro 5380 Femto Edition
Average power	150 W	90 W	45 W	120 W	75 W	36 W
Wave length	1030 nm	515 nm	343 nm	1030 nm	515 nm	343 nm
Max. Pulse energy	250 µJ	150 µJ	75 µJ	200 µJ	125 µJ	75 µJ
Pulse duration	<10 ps	<10 ps	<10 ps	~ 900 fs	~ 800 fs	~800 fs
Guar. Beam quality	M ² < 1.3	M² < 1.3	M² < 1.3	M² < 1.3	M² < 1.3	M ² < 1.3

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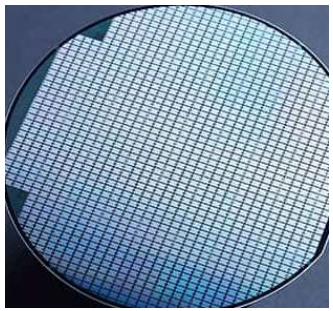
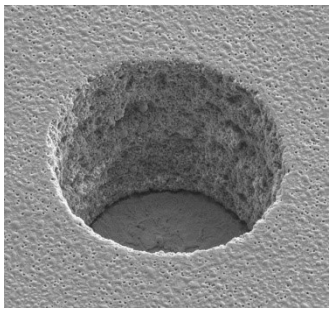
Laser Applications in Manufacturing for Electronics Devices

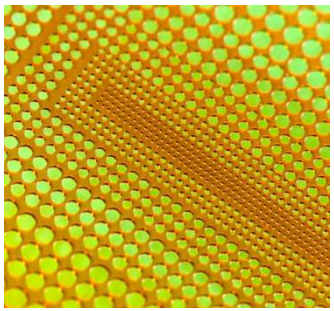


Wafer dicing

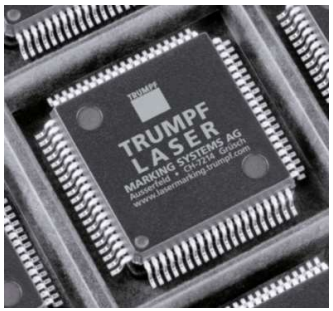
Surface
Structuring



PCB and
interposer drilling

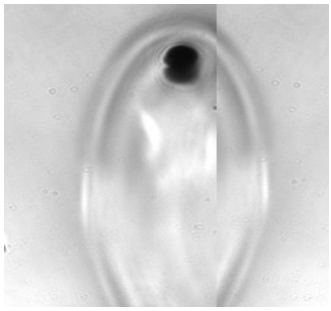


Foil cutting

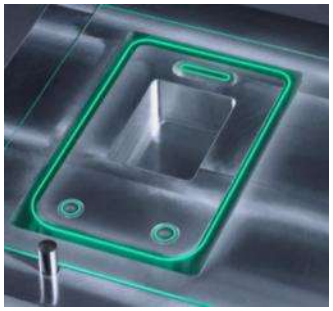


Marking

Laser
Lift-Off

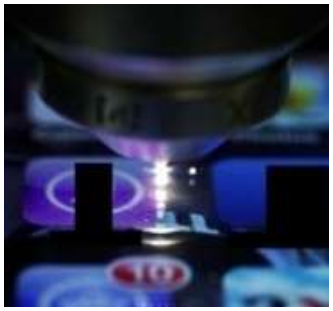


Glass
Welding



Glass
Cutting

Package and
Housing Cutting



Waveguide
Writing

Scaling ultrafast processing

Pulse parameters enable advanced processing concepts

- **Ultrafast processing is typically applied for high precision machining**
- **Industrial applications benefit from high throughput**

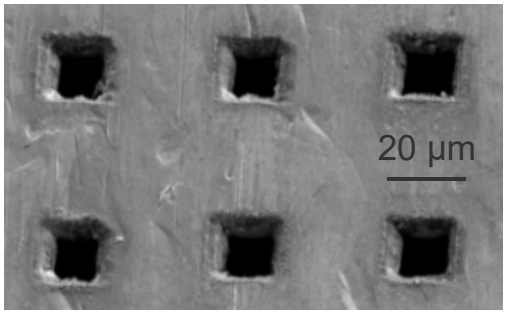
Goal: **develop concepts for high precision ultrafast processing**

- **Scaling normally via average power of ultrafast lasers** ✓
- **Precision usually by impact from tailored gradients in space and time** ✓

Major task: **Ensure tailored effective gradients even at elevated average power**

Available TRUMPF laser parameter:

- Pulse duration: 300 fs – 20 ps
- Wavelength: 1030 nm – 254 nm
- Repetition rate: < 2 MHz (+ bursts)
- Average power: < 150 W (IR)
- Beam quality: 1.2 (M^2)
- ….



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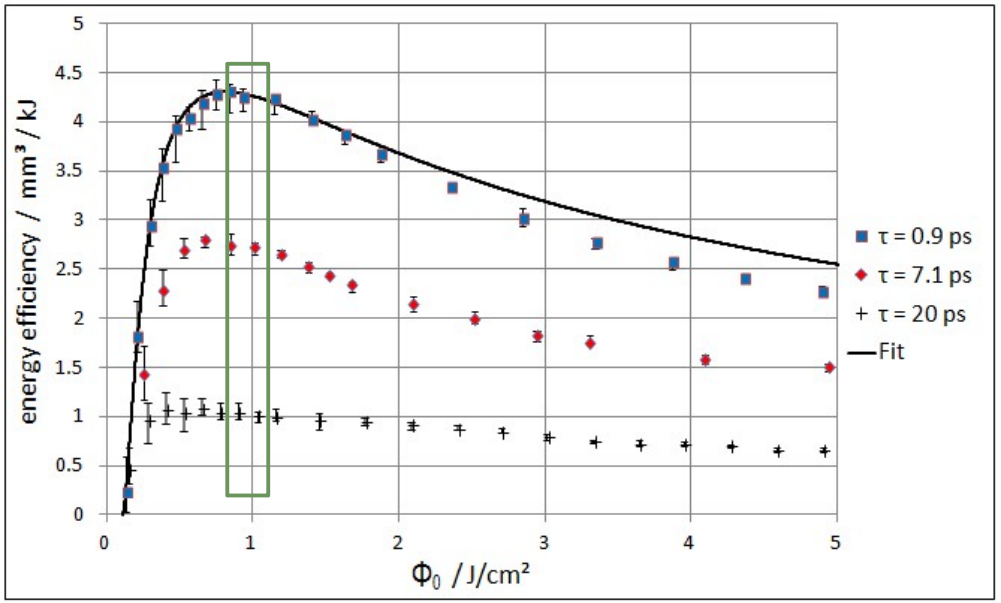
Energy distribution for efficent ablation

Efficient energy distribution

- **Single pulses: Optimized ablation efficiency at ~1 J/cm² and 900 fs**
- **Distribution of 80 W average power of TruMicro 5070 (Femto Edition) to enable parallel processing**
- **No detrimental effects due to heat accumulation at 80 W**

Energy efficiency over fluence



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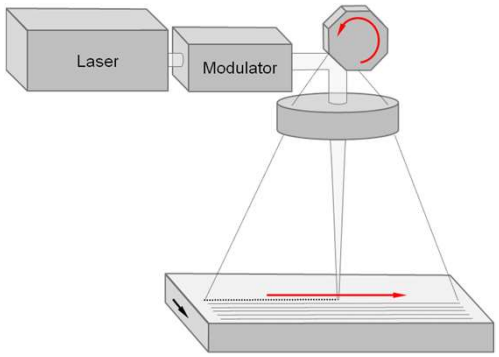
Efficient energy distribution for throuput scaling

Develop scaling for high precision ultrafast processing

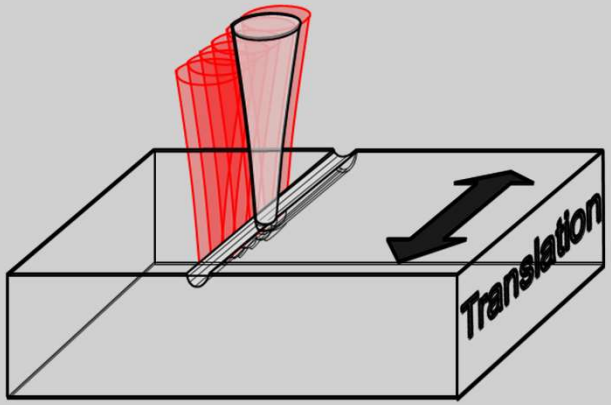
Option 1:

Temporal distribution of average power:
Need: High repetition rates
PSO
fast and precise scanner concepts
Drawback: heat accumulation



Option 2:

Spatial distribution of average power:
Need: spatial beam shaping
beam shaping concepts
DOE/SLM
drawback:



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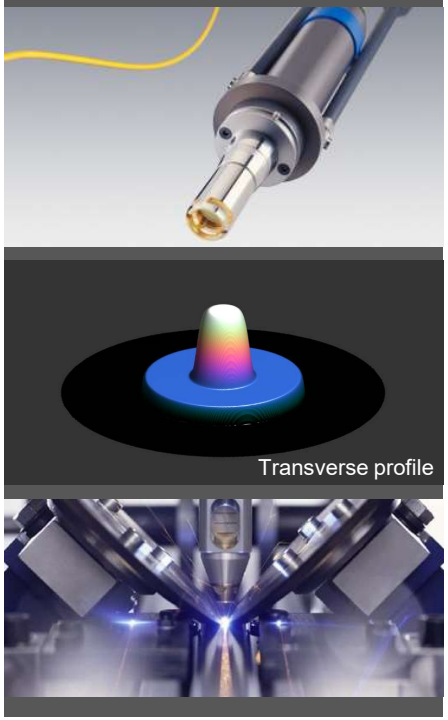
Beam Shaping at TRUMPF

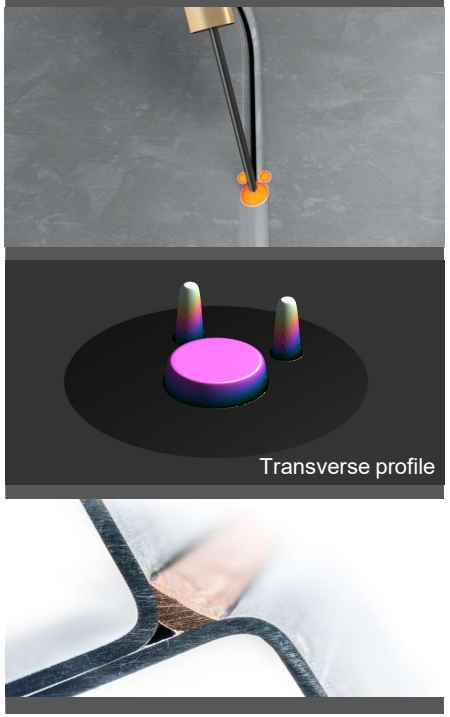
Tailored focus distributions for advanced materials processing

BrightLine Weld – High quality and efficient welding



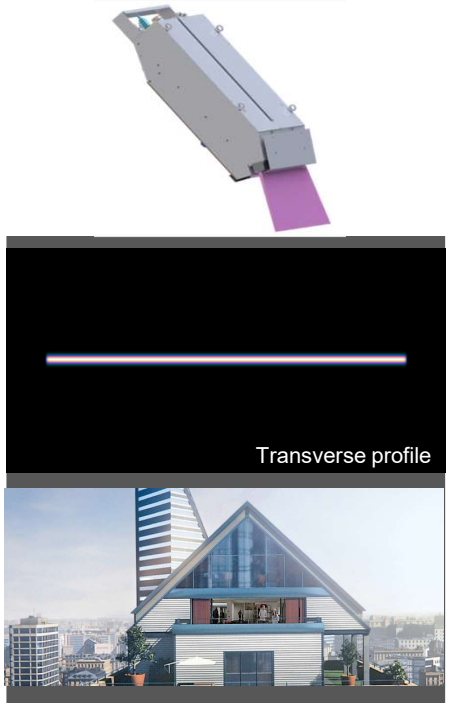
[N. Speker, P. Haug, S. Feuchtenbeiner, *et al.*, Proc. SPIE, 105250C, 2018]

TOP Braze –Brazing of hot-dip galvanized material



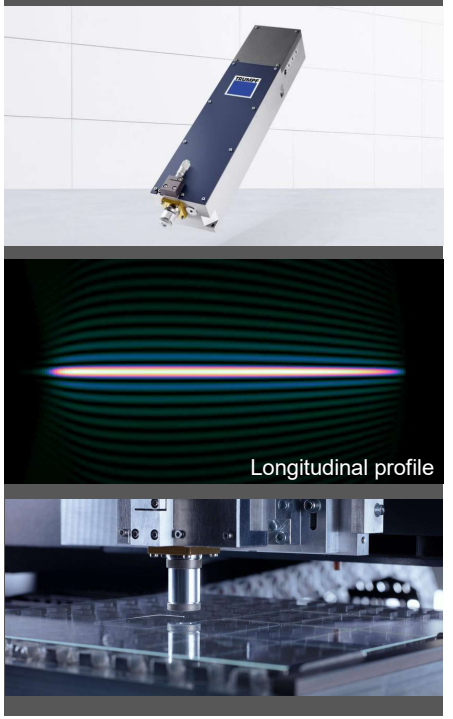
[Y. Guertler, M. Kahmann, D. Havrilla, Proc. SPIE, 10097, 2017]

Rapid thermal processing



[C. Tillkorn, A. Heimes, D. Flamm, *et al.*, Proc. SPIE, 10518, 2018]
[www.saint-gobain.com]

TOP Cleave – Processing of transparent materials



[D. Flamm, D. Grossmann, M. Kaiser, *et al.*, LIM 2015]

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Agenda

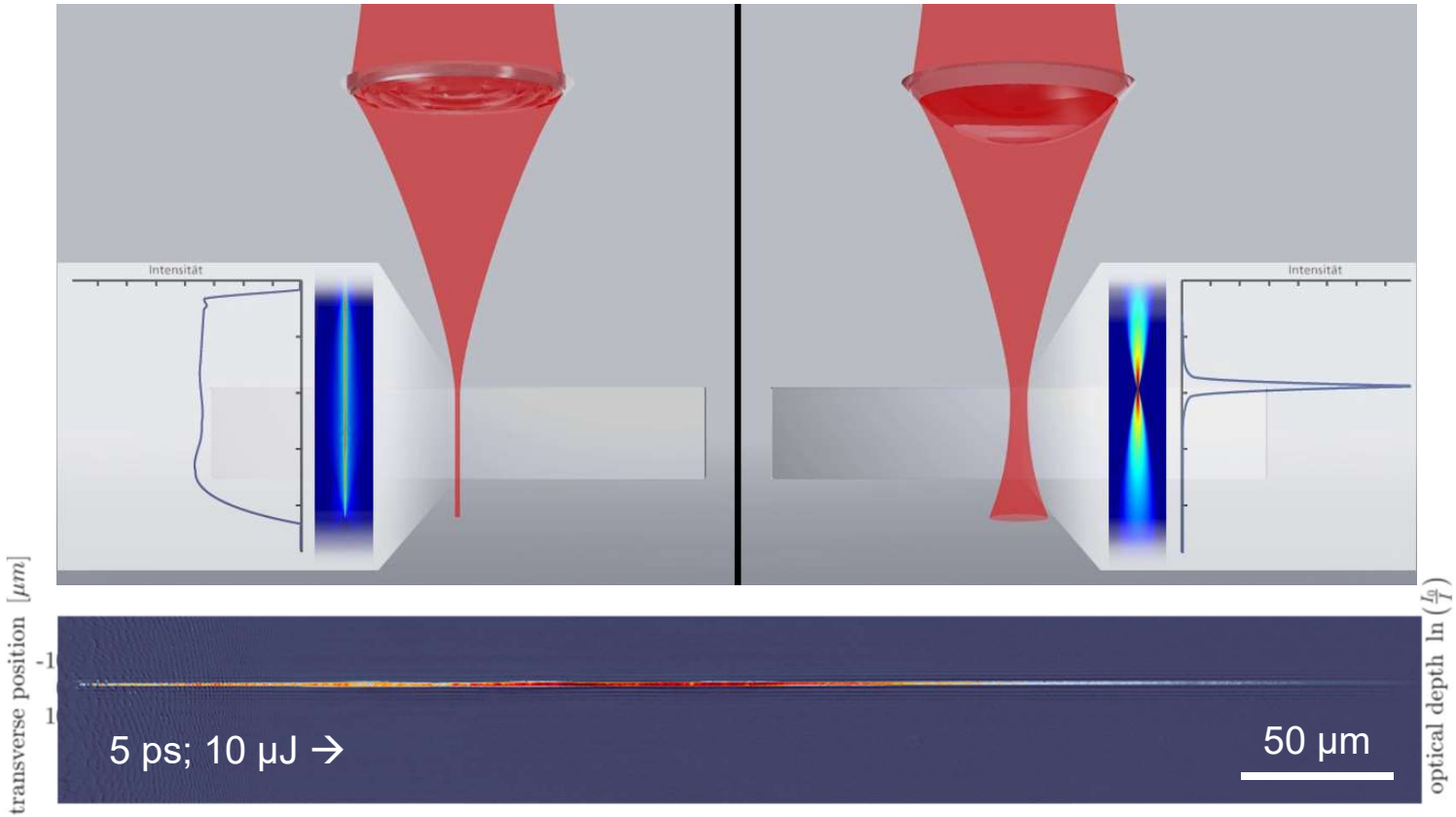
Ultrafast Bessel-like Beams

Ultrafast 3D-focus Distributions

Ultrafast Digital-holographic Drilling and Structuring

Bessel-Gaussian beam generation

Bessel beams supply elongated focal regions for glass modification



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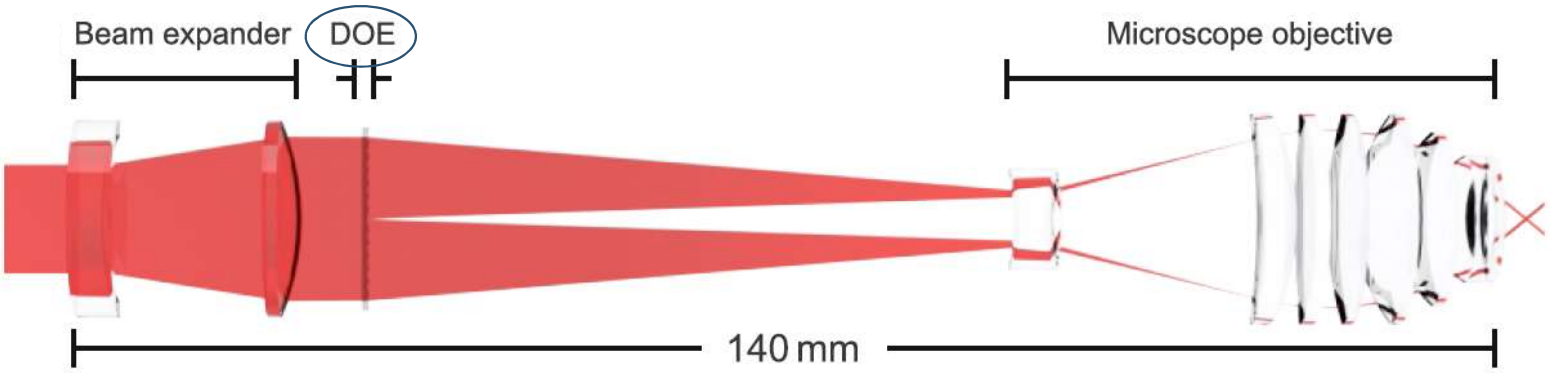
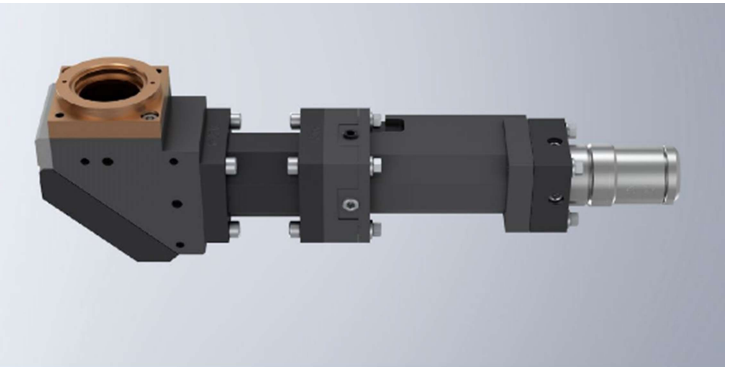
Ultrafast Bessel-like Beams at TRUMPF

TOP Cleave cutting optics (2nd gen)



[M. Kumkar, D. Grossmann, and D. Flamm, US Patent 15/599, 623]



Usage of DOE instead of an Axicon

- Glass thicknesses to be modified (0.3 … 8) mm
- All common transparent materials (Glasses, ceramics, glass ceramics)
- W x H x D: 40mm x 140mm x 40mm
- Mass: 300g
- Different focussing configurations, working distances up to 20 mm

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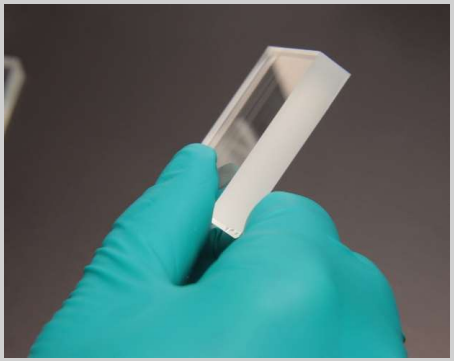
Optimized Cutting of Transparent Materials

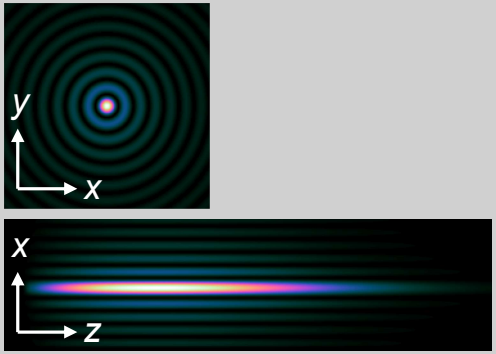
Current Status – TOP Cleave cutting optics

Cleaving result



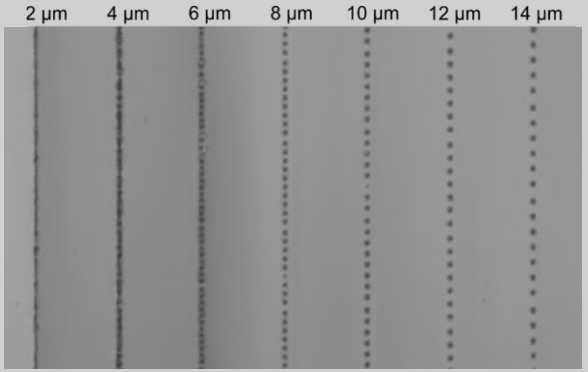
- 12mm soda lime glass
- Single pass, 1.5mJ

Beam profile



- Bessel-like beam
- Zero order → radial symmetry

Modifications



- Radial symmetric voids (surface)
- Crack orientation: statistic
- Spatial pulse distance (2…4) µm

[Jenne, M., Flamm, D., Grossmann, D., *et al.* „Pump-probe microscopy of tailored ultrashort pulses for glass separation processes." Laser-based Micro-and Nanoprocessing XIII. Vol. 10906. International Society for Optics and Photonics, 2019]

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Agenda

Ultrafast Bessel-like Beams

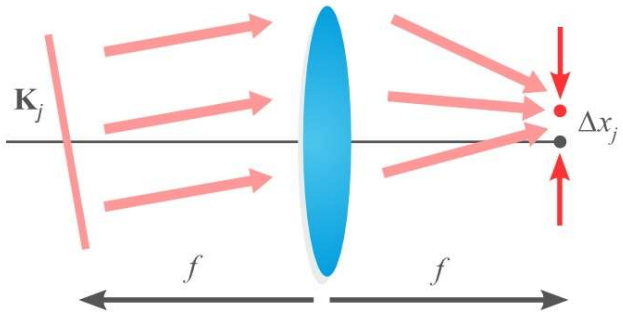
Ultrafast 3D-focus Distributions

Ultrafast Digital-holographic Drilling and Structuring

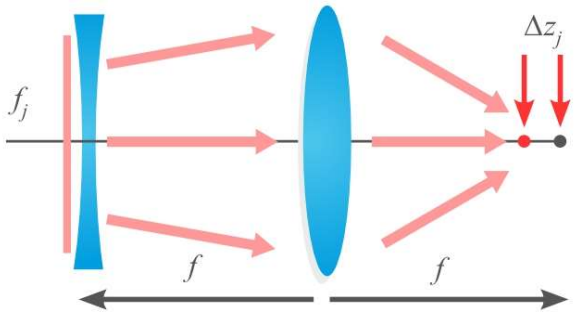
Ultrafast 3D-Focus distributions

Diffractive 3D-beam splitting concepts based on 2f-setups

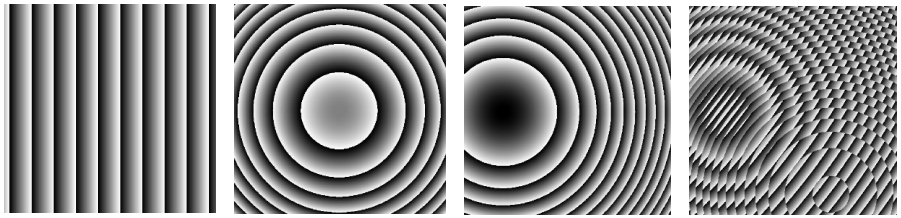
Transverse beam displacement



Longitudinal beam displacement



Displacement can be realized by designed DOE (or SLM):



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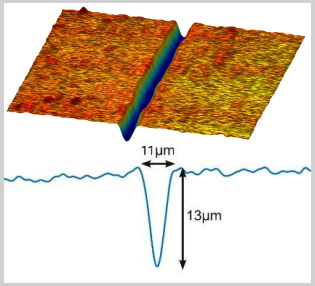
Multi-spot Line Engraving

81:1 beam splitter DOE

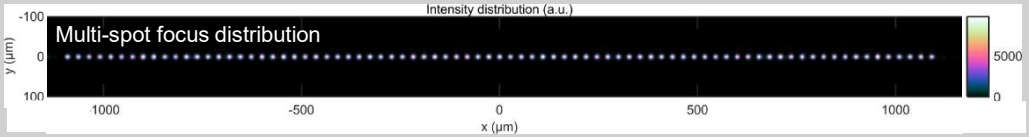
Application: Engraving

- Engraving of burr-free grooves in sheet steel in a roll-to-roll environment
- Scanner-based feed rates >2 m/s required
- Utilization of complete power performance of TruMicro 5070 (Femto Edition, 80 W, 900 fs, 800 kHz)



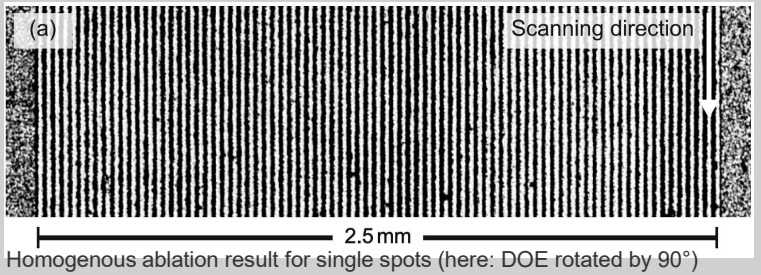
Solution: 81:1 beam splitter DOE

- Single pulses: Optimized ablation efficiency at ~1 J/cm² and 900 fs
- Utilization of complete power performance of TruMicro 5070 (Femto Edition, 80W, 900fs, 800kHz)
- implementation into scanning system; 2.4 mm focus line, feed rate of 2.2 m/s at 800 kHz



Efficiency 82%

Uniformity error 5%



Homogenous ablation result for single spots (here: DOE rotated by 90°)

[Flamm, D., Grossmann, D., Jenne, M., *et al.* "Beam shaping for ultrafast materials processing." Laser Resonators, Microresonators, and Beam Control XXI. Vol. 10904. International Society for Optics and Photonics, 2019]

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Agenda

Ultrafast Bessel-like Beams

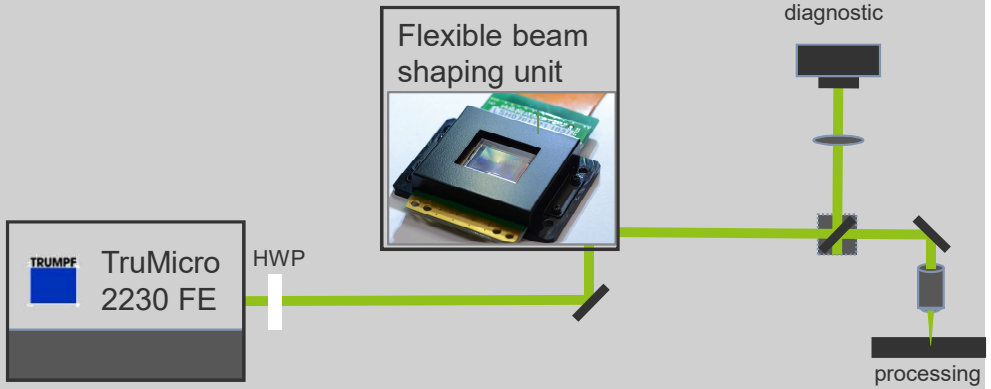
Ultrafast 3D-focus Distributions

Ultrafast Digital-holographic Drilling and Structuring

Ultrafast Digital holographic Drilling and Structuring

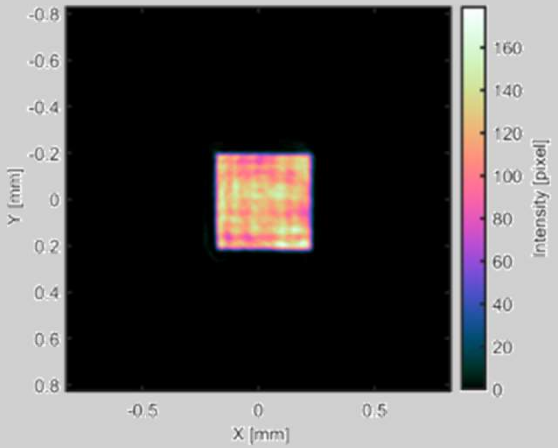
Flexible Spatial Light Modulation for Flat Top Generation

Setup



- SLM-based flat-top generation
- 25x reduced image for processing

Result

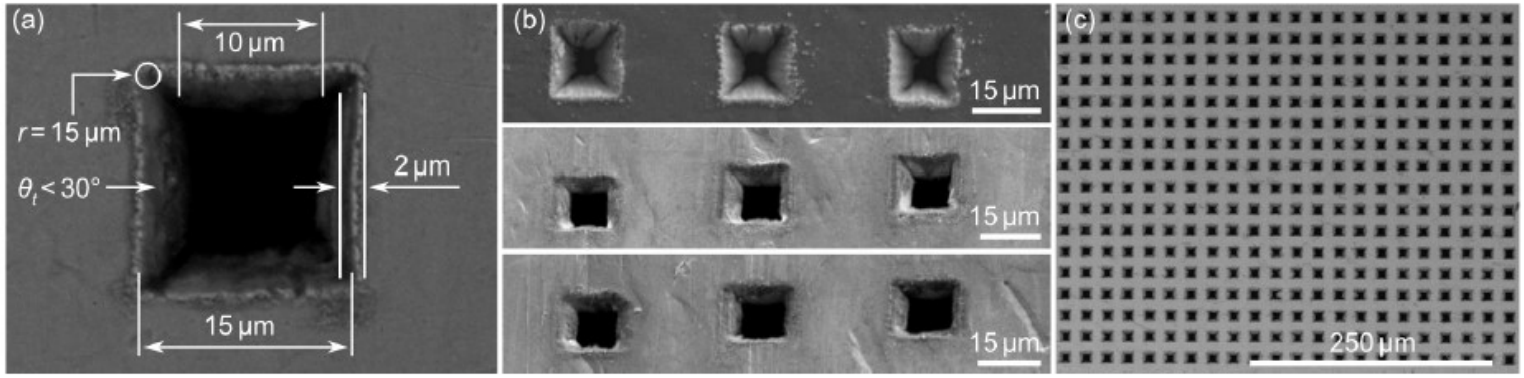


- Flexible SLM concept → control loop for compensation of wavefront distortions (e.g. aberrations)
- Edge steepness close to diffration limit
- Efficiency around 60%

Ultrafast Digital-holographic Drilling and Structuring

Direct drilling of quadratic shaped holes in thin metal sheets

- **Dimensions: ~10µm (telescopic demagnification)**
- **Density: >1000ppi**
- **TruMicro 2230 at 515nm**



- **Control of taper geometry and taper angle by multi-plane approach**
- **Parallel processing by combinig diffractive beam splitting concept**

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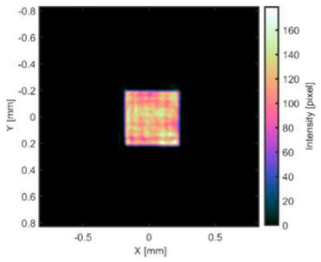
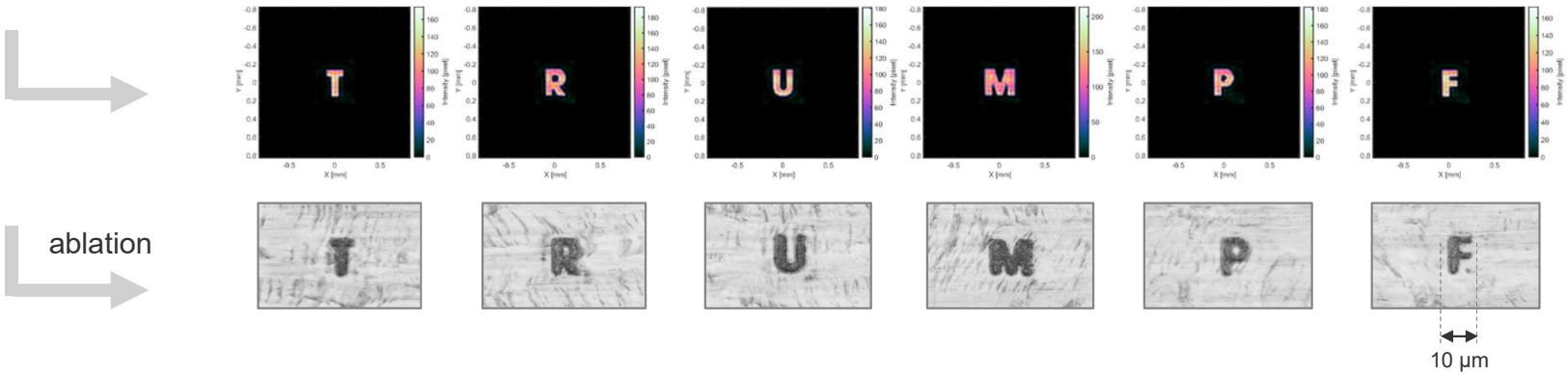
Further Potential of Ultrafast Digital-holographic Structuring

Flexible SLM concept



- **SLM-based arbitrary shape generation (from single-mode source)**
- **Switching of beam profile with ~10Hz**
- **Efficiency ~60% (depends on actual beam profile)**
- **Edge steepness close to diffraction limit**



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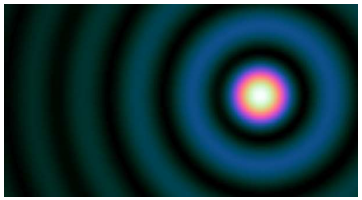
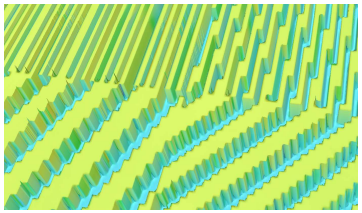
Conclusion

Structured light concepts applied to ultrafast micromachining

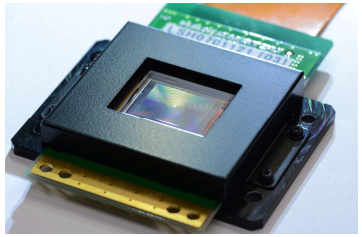
- Holographically generated Bessel-like beams with arbitrary
- Single-pass full thickness modifications of 12mm glass
- Implementation into an industrial cutting optics



- 3D-beam splitting concept demonstrated for parallel processing throughput generation (surface and volume)
- Exploitation of complete power performance of the laser source



- Tailored flat-top generation with steepness at diffraction limit
- Control of taper geometry and angle by multi-plane approach
- High spatial frequency masks >1000ppi



TRUMPF