TRUMPF Laser- und Systemtechnik GmbH

PICOSECOND, FEMTOSECOND AND BEYOND

Will the trend continue?

Christof Siebert
Head of Industry Management Microtechnology

Ditzingen, 16.09.2015

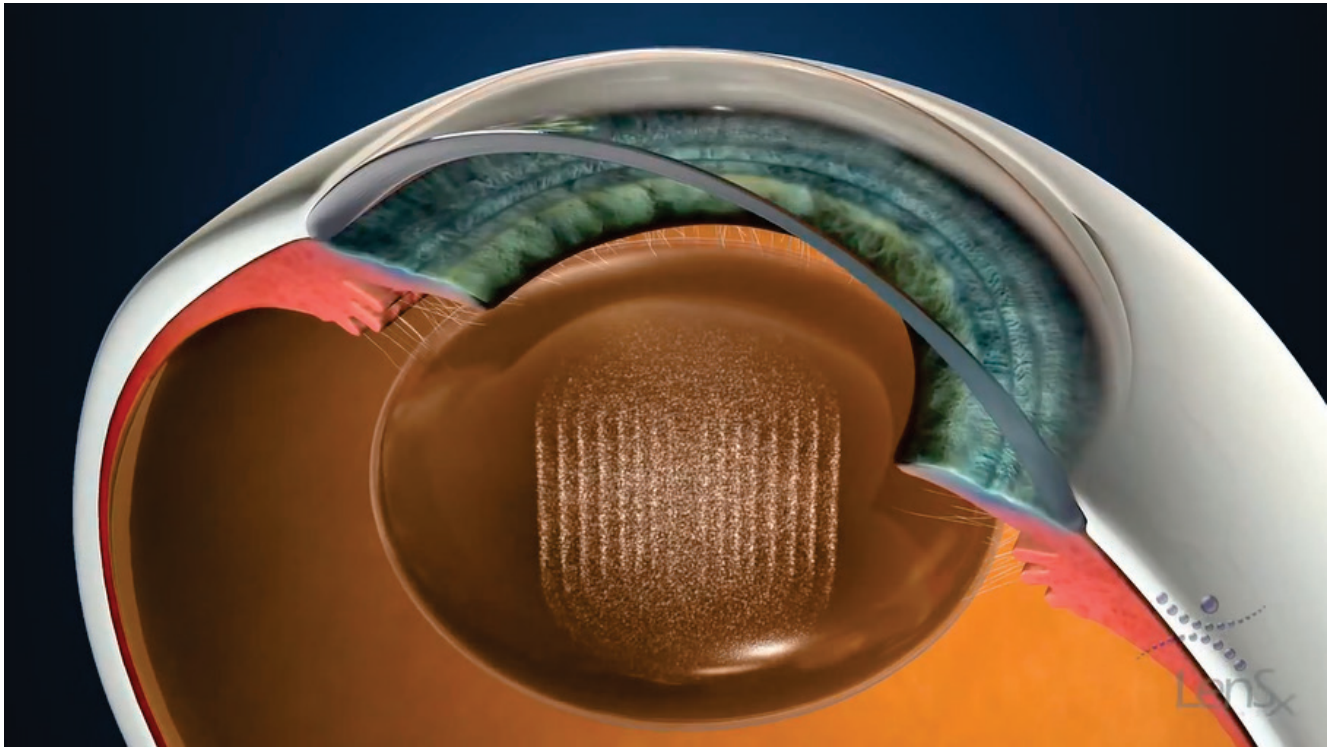
WHICH PULSE DURATION SHALL I USE?

A LITTLE BIT OF HISTORY

The Benefit of Cold Microprocessing

University of Michigan Patent (Gerard Mourou et al., 1994)

Prominent Example: Opthalmology



United States Patent [19] Mourou et al. [11] Patent Number: 5,656,186 [45] Date of Patent: Aug. 12, 1997

(12) EX PARTE REEXAMINATION CERTIFICATE (5685th)
United States Patent (10) Number: US RE37,585 F1
Mourou et al. (45) Certificate Issued: Mar. 6, 2007

(54) METHOD FOR CONTROLLING CONFIGURATION OF LASER INDUCED BREAKDOWN AND ABLATION

(75) Inventors: Gérard Mourou, Ann Arbor, MI (US); Detao Du, Dremond, CA (US); Subrata K. Dutta, Ann Arbor, MI (US); Victor Elner, Ann Arbor, MI (US); Roe Kurtz, Ann Arbor, MI (US); Paul R. Lichter, Ann Arbor, MI (US); Xinlong Liu, Acton, MA (US); Peter F. Fronke, Dexter, MI (US); Jeffrey A. Squier, San Diego, CA (US)

(73) Assignee: Silicon Valley Bank, Santa Clara, CA (US)

Reexamination Request: No. 90/007,102, Jun. 25, 2004

Reexamination Certificate for: Patent No.: Re. 37,585; Issued: May 15, 2002; Appl. No.: 09/366,685; Filed: Aug. 4, 1999

Related U.S. Patent Documents

Reissue of: (64) Patent No.: 5,656,186; Issued: Aug. 12, 1997; Appl. No.: 08/234,901; Filed: Apr. 8, 1994

(51) Int. Cl.: B23K 26/00 (2006.01); B23K 26/40 (2006.01)

(52) U.S. Cl. 219/121.69

(58) Field of Classification Search ..... None
See application file for complete search history.

(56) References Cited

U.S. PATENT DOCUMENTS

3,720,213 A 3/1973 Hebert et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE 41 19 004 12/1992
EP 0 461 328 A1 5/1991
JP 62-144393 6/1987
JP 63-033005 8/1987
JP 3-155105 5/1991
JP 402215277 A * 8/1990
JP 5-43222 2/1993
WO WO 93/08929 5/1993

OTHER PUBLICATIONS

Hamilton et al. "Ablation thresholds in ultrafast laser micromachining of common metals in air" (2003), p. 474.*

(Continued)

Primary Examiner—Kiley Stoner

(57) ABSTRACT

In one aspect the invention provides a method for laser induced breakdown of a material with a pulsed laser beam where the material is characterized by a relationship of fluence breakdown threshold (F_{th}) versus laser beam pulse width (τ) that exhibits an abrupt, rapid, and distinct change or at least a clearly detectable and distinct change in slope at a predetermined laser pulse width value. The method comprises generating a beam of laser pulses in which each pulse has a pulse width equal to or less than the predetermined laser pulse width value. The beam is focused to a point at or beyond the surface of a material where laser induced breakdown is desired.

The beam may be used in combination with a mask in the beam path. The beam or mask may be moved in the x, y, and Z directions to produce desired features. The technique can produce features smaller than the spot size and Rayleigh range due to enhanced damage threshold necessary in the short pulse regime.

Example of Ultrafast Industrial Machining

Ultrafast Laser Machining at **BOSCH** using the TruMicro Series 5000

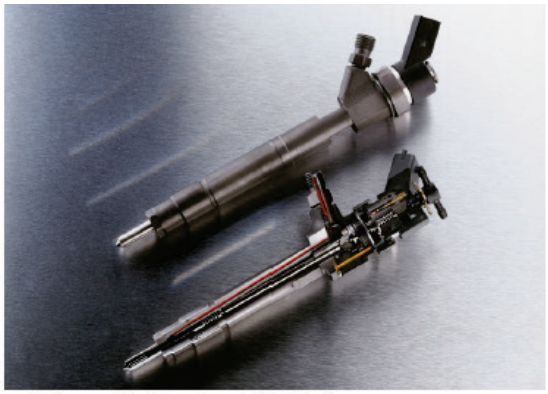
APPLICATIONS

Ultrafast Serial Production at Bosch

Examples: Automotive Applications

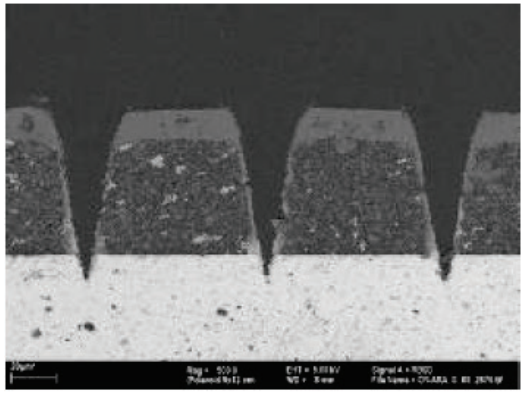
all images: BOSCH

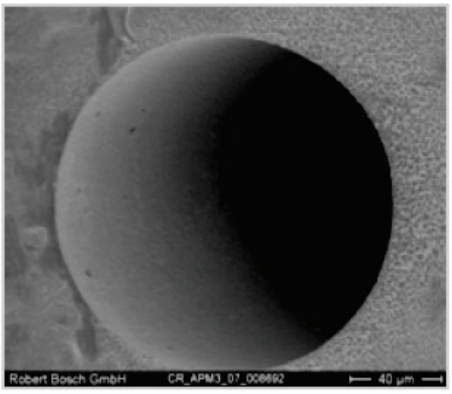
Broad band lambda Probe
Trimming structures



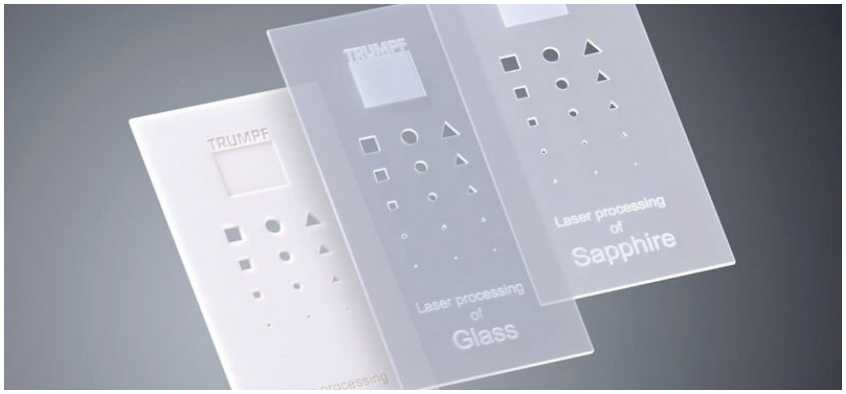
Diesel injector 1800 bar
Drainage groove

Direct gasoline injection valve
Spray holes

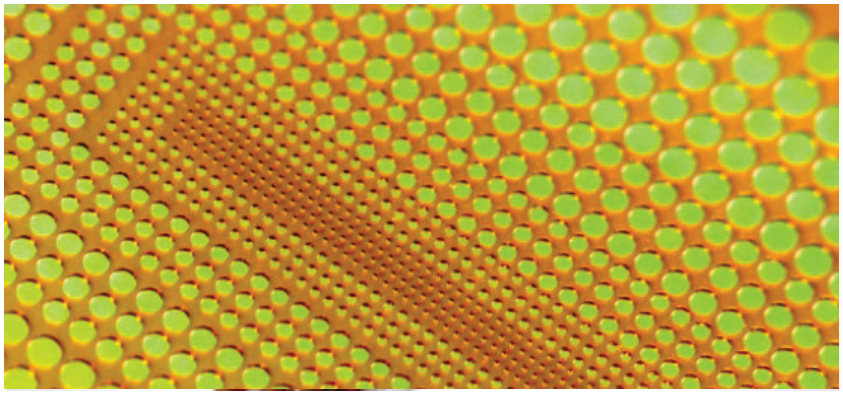




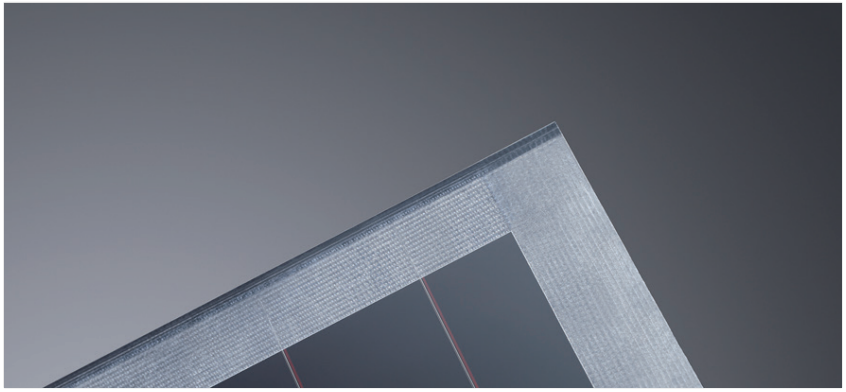
Ultrafast Laser Applications



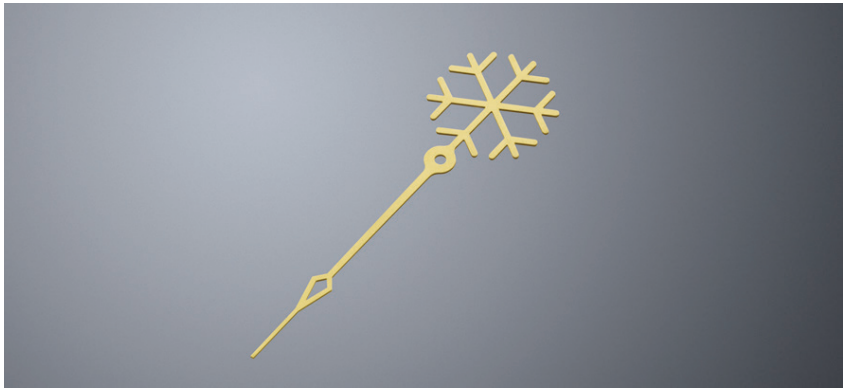
Brittle Materials



Plastics



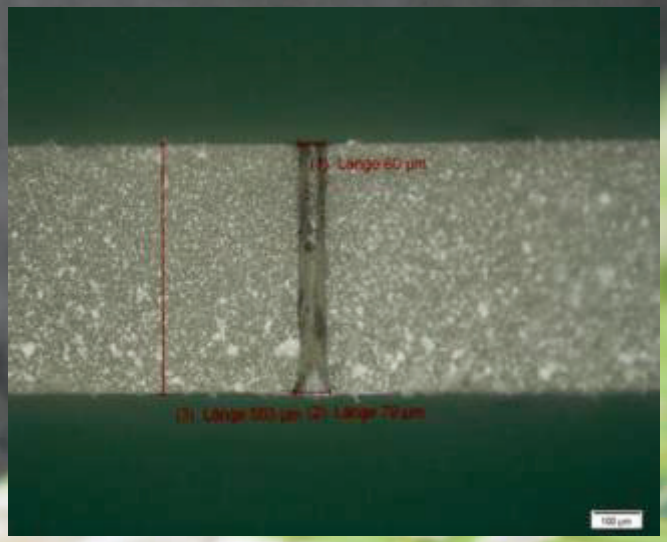
Thin Films



Metals

Percussion Drilling of AlN and Al2O3 Ceramics

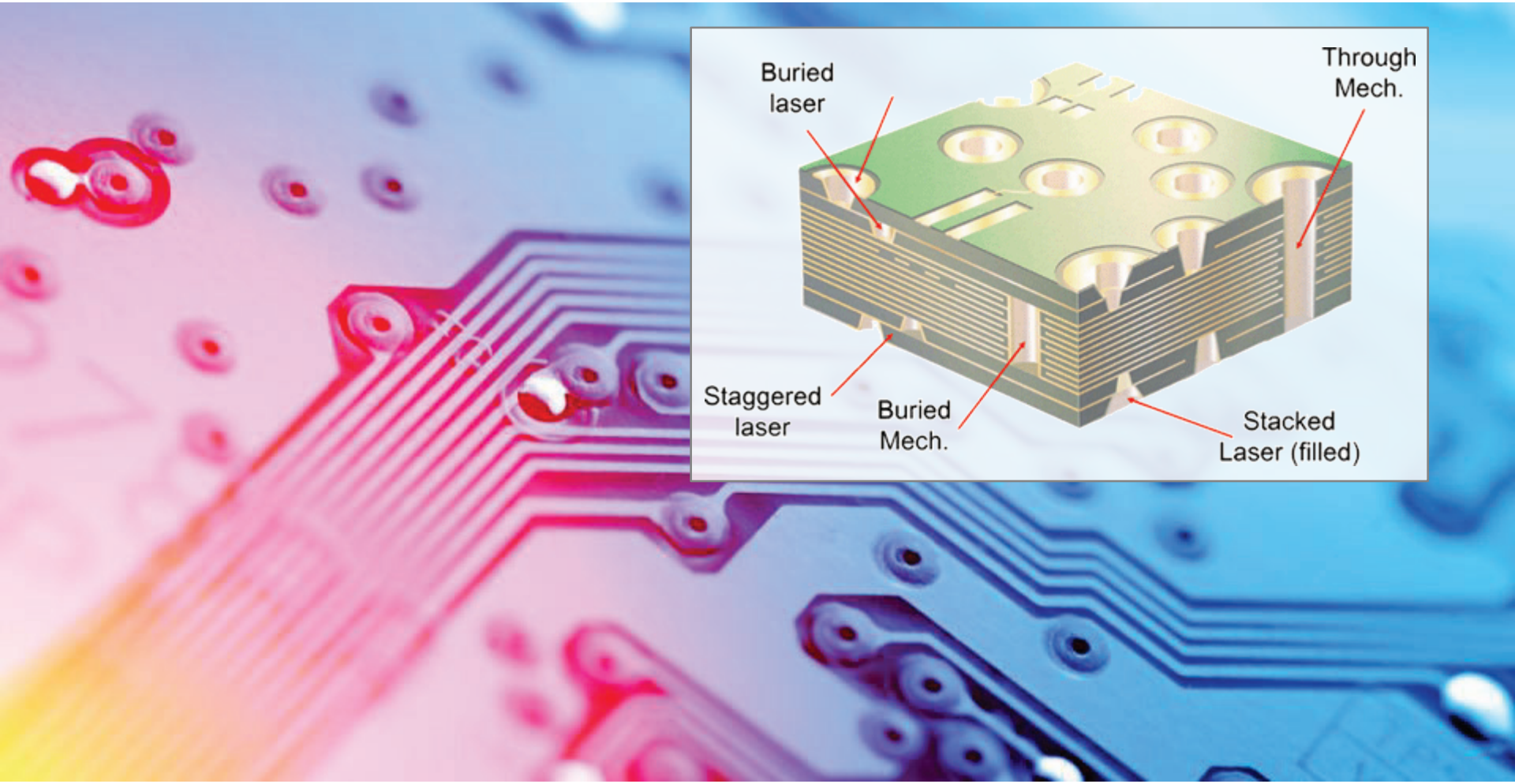
VIAs for ceramic PCBs



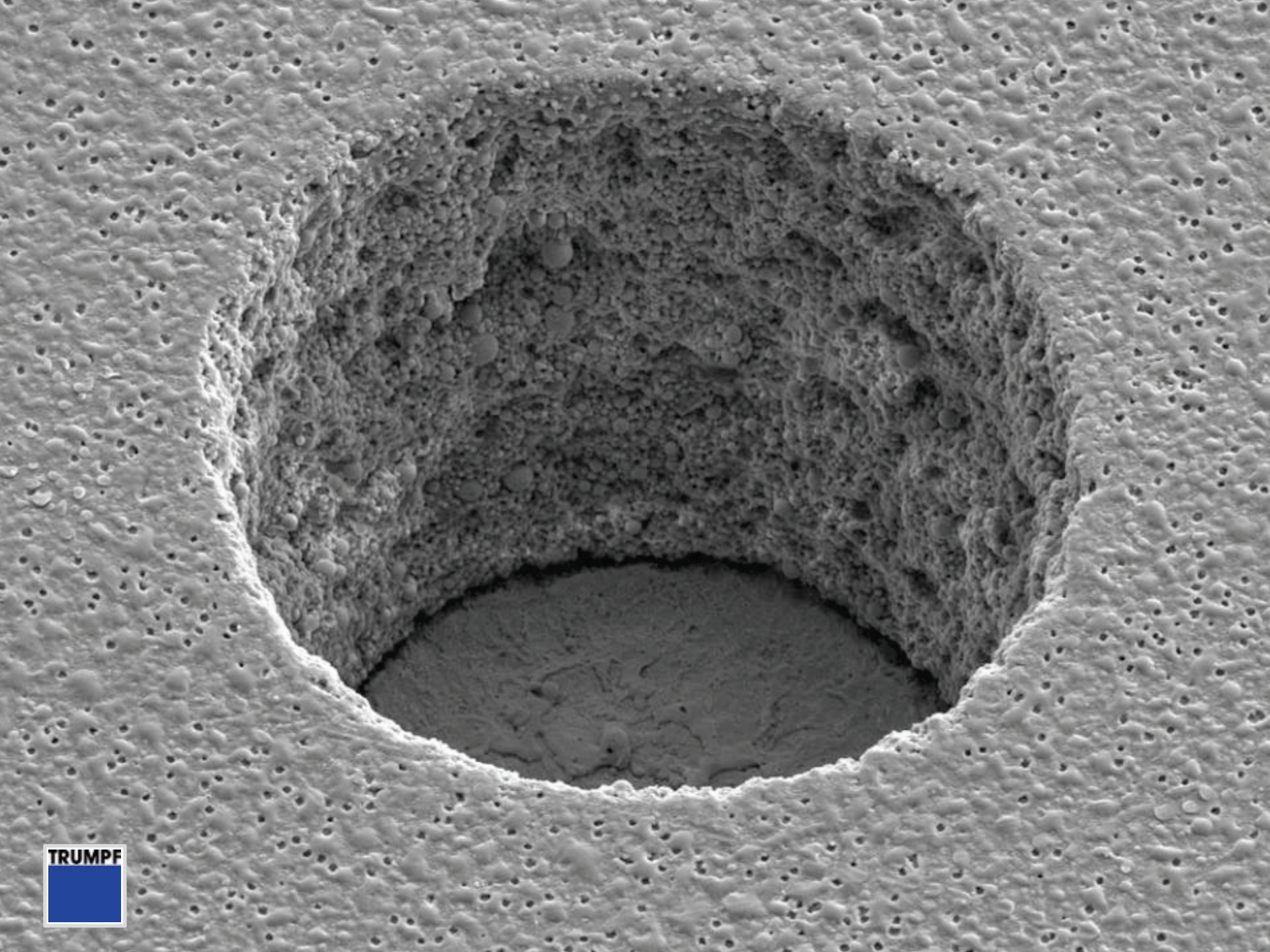
Source: bestpcbs.com

Via drilling on PCB

Interconnections between layers

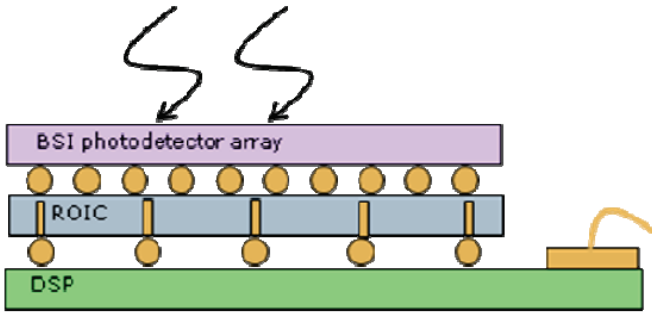


Source: matz.in, printline.dk


TRUMPF

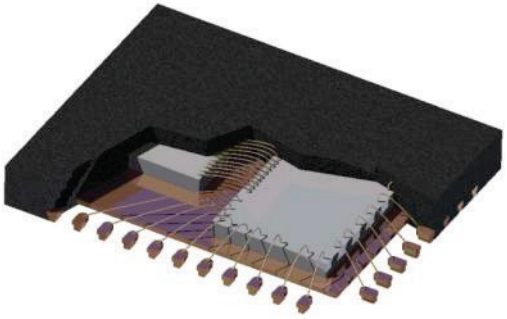
Semicon: More than Moore

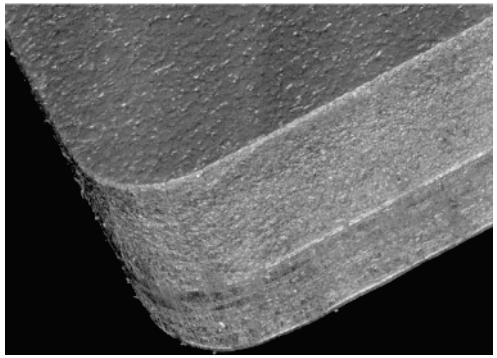
System in Package



- 3D packaging of chips: material mix
- Conventional wheel dicing is inflexible regarding varying geometries
- Ultra short pulse lasers can dice with high quality

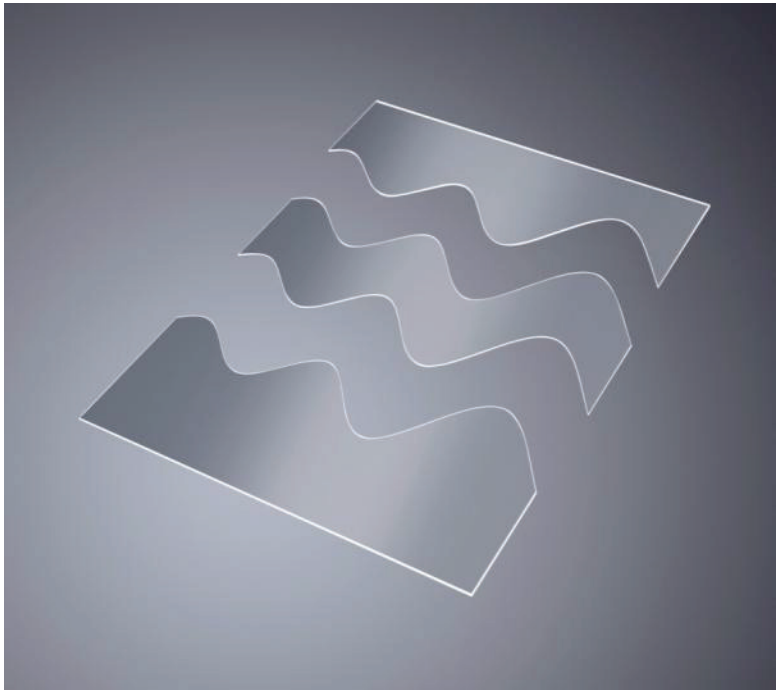
➔ **Femtosecond lasers**





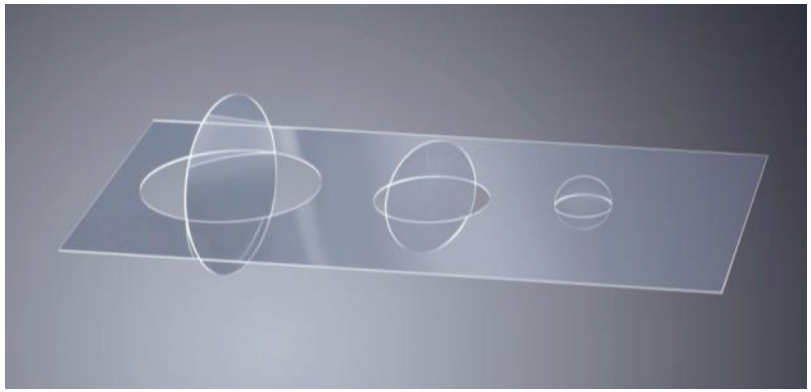
Flat Panel Displays: Cover glass and displays

Displays for mobile devices

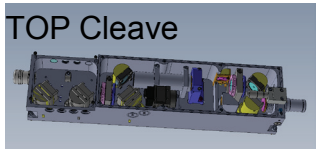


- Cutting of chemically strengthened cover glass and display glass
- Picosecond lasers with special optics enable high speed cutting up to 1 m/s

➔ Picosecond lasers

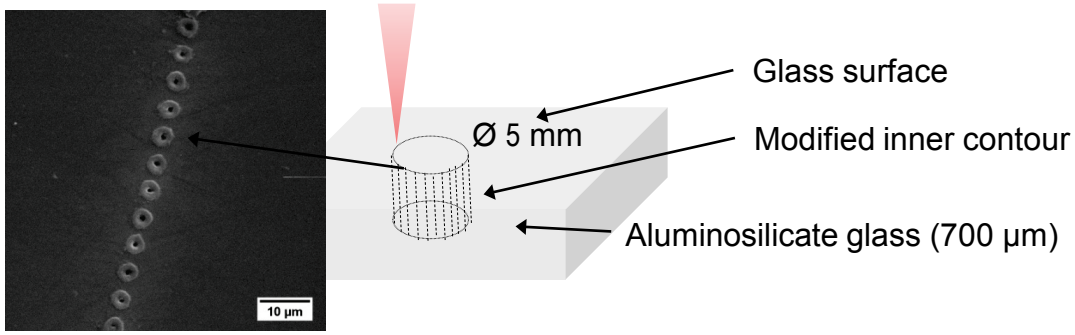


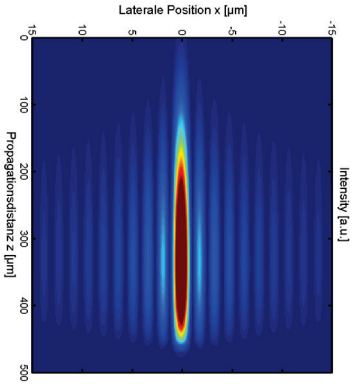
Selective Laser Etching for Separation of Modified Samples



- TruMicro 5000

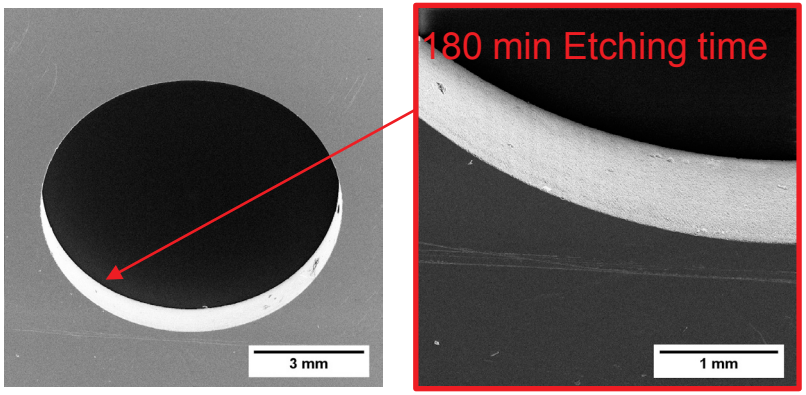
➔ **Picosecond lasers**

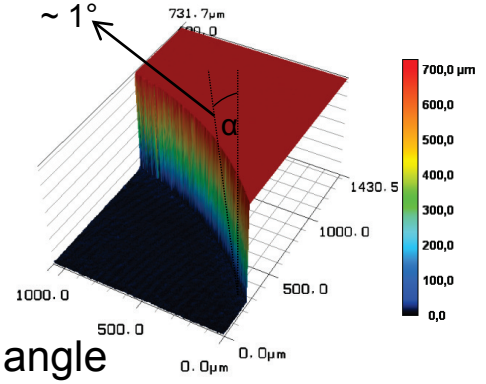




Intensity distribution

- Etching in 28 wt.-% KOH, Etching rate: 3 µm/min, ~ 1:100

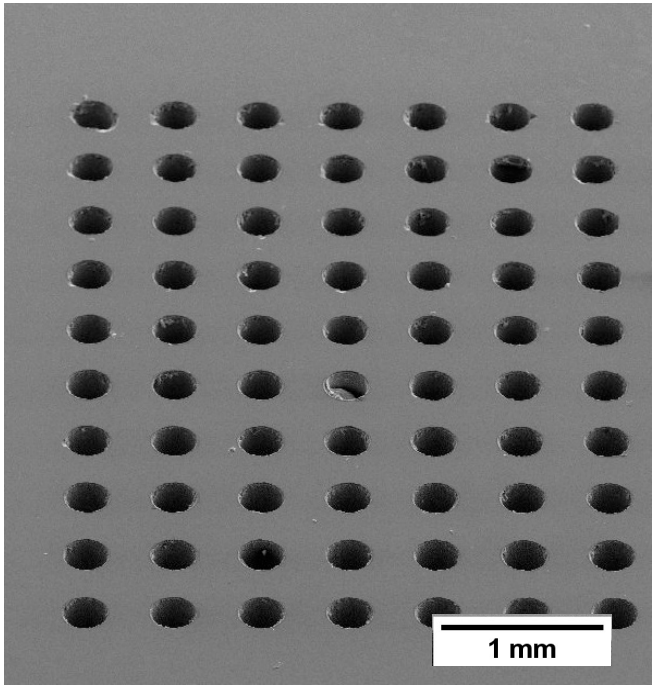




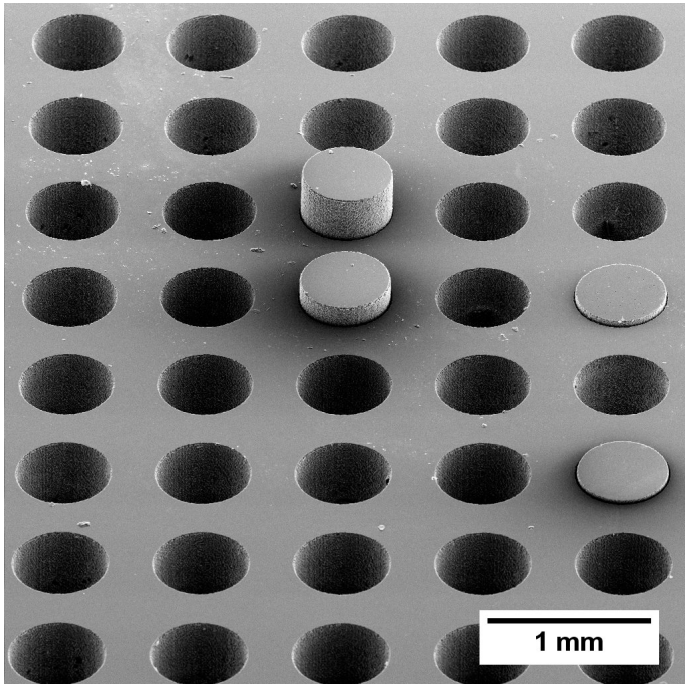
➔ No taper lead angle

➔ Internal contours/complex shapes

Selective Laser Etching of Microholes in Glass

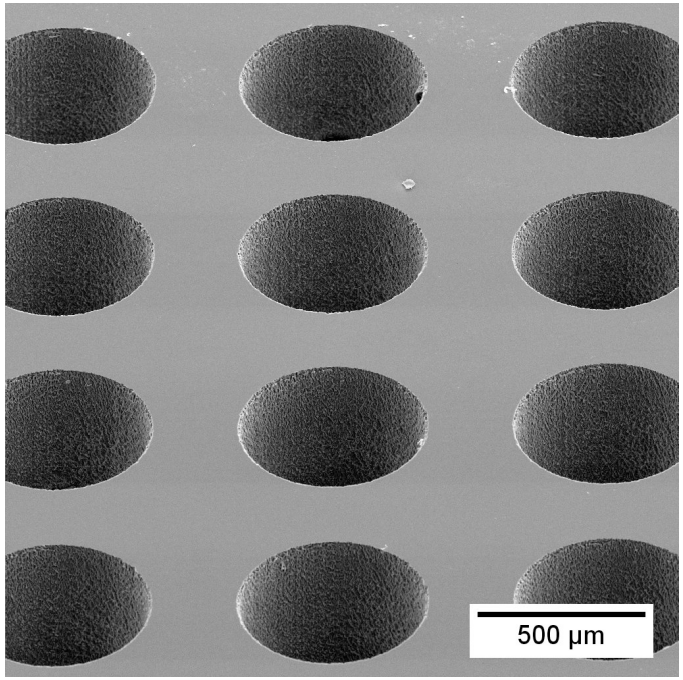


Ø 200 µm microholes

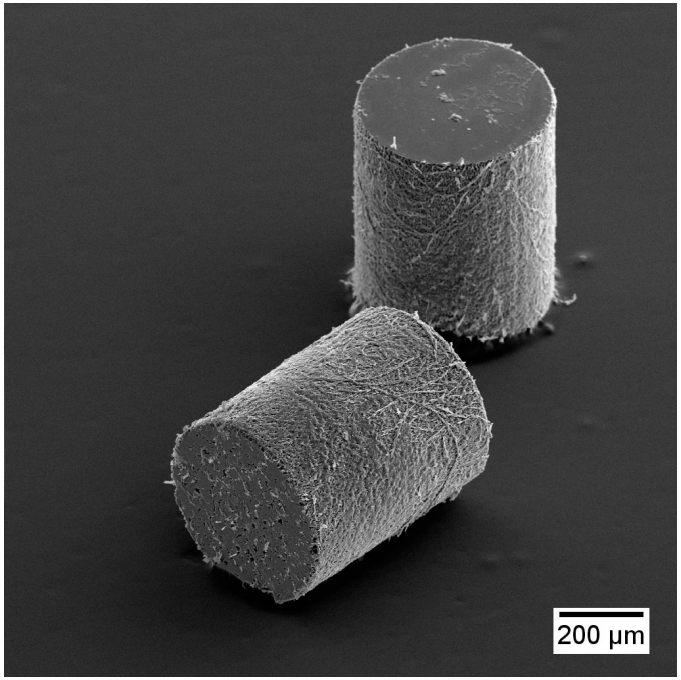


Ø 500 µm microholes

Selective Laser Etching of Microholes in Glass

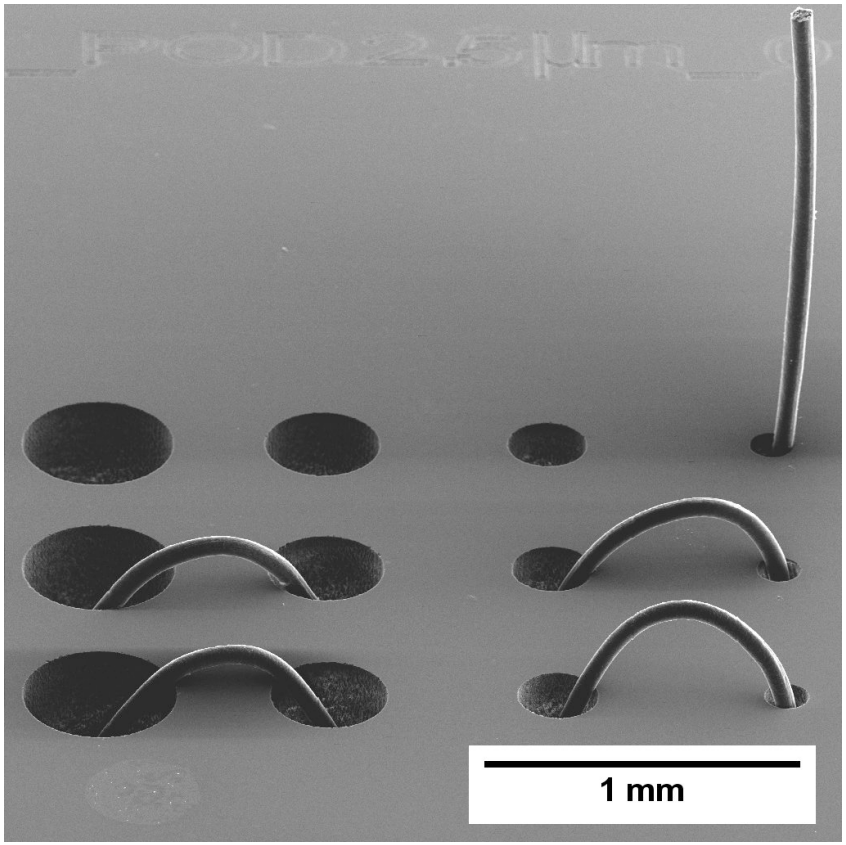


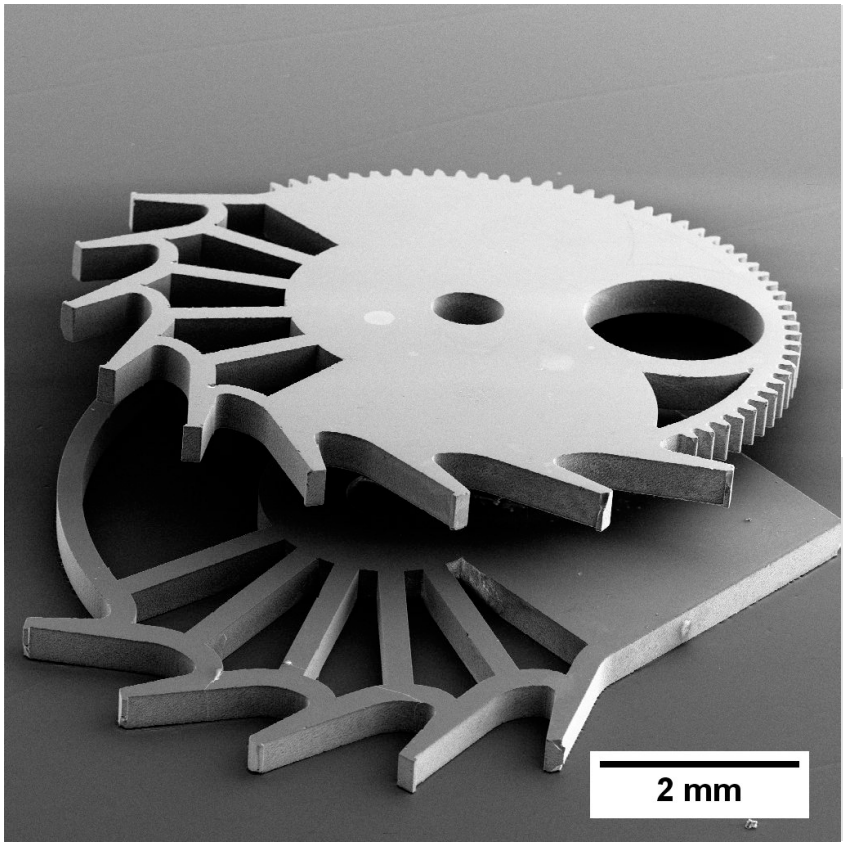
Ø 500 µm microholes



Ø 500 µm glass cylinders

Selective Laser Etching on Fused Silica, Sapphire

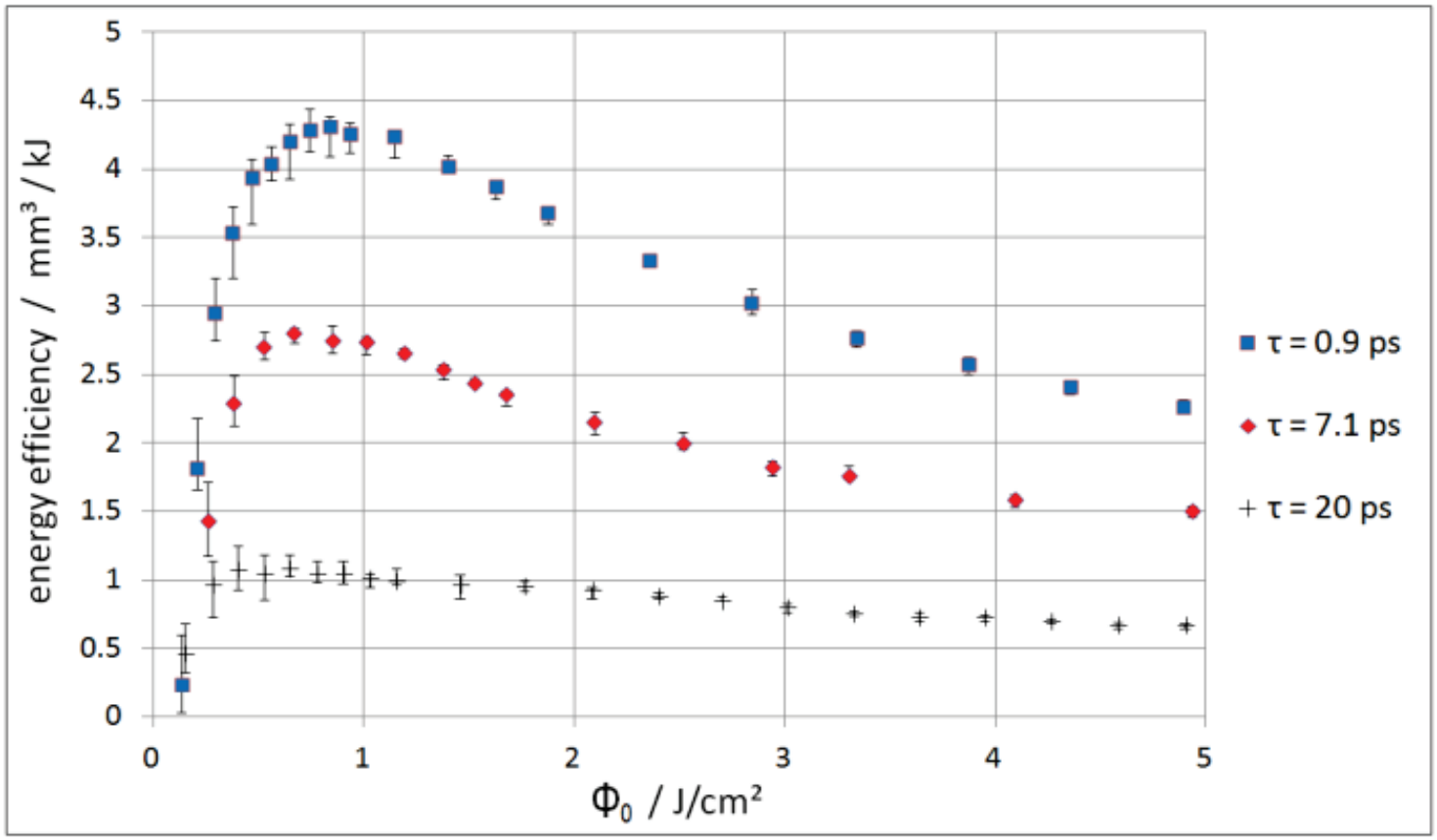




STAINLESS STEEL – PS VS. FS

Energy efficiency increases with lower pulse durations

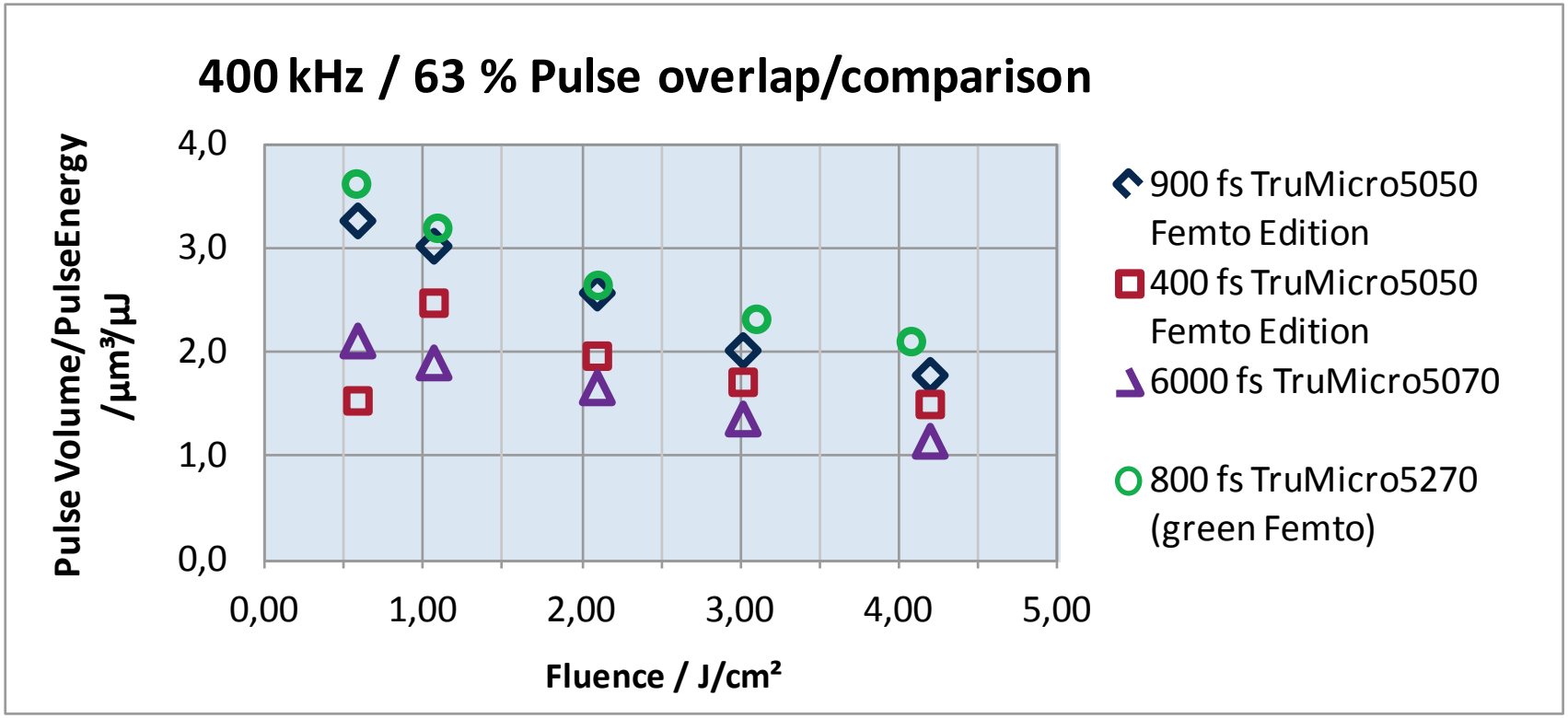
Stainless steel, infrared



M. Sailer et al.

Energy efficiency optimum for 800 fs green

Stainless Steel

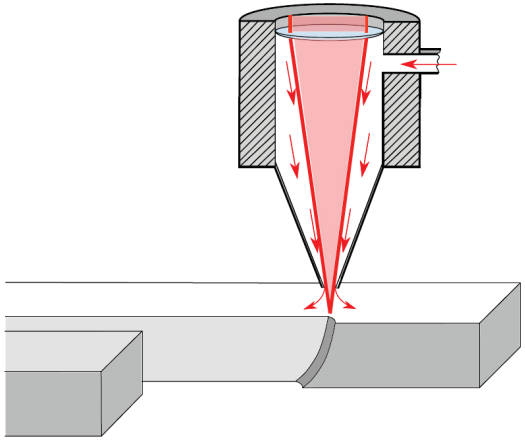


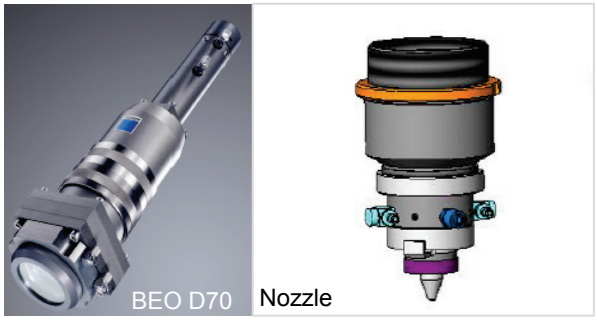
S. Russ et al.

SINGLE PASS CUTTING OF DURNICO

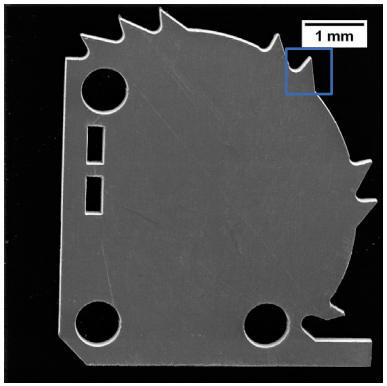
Single Pass Cutting with Ultra-short Laser Pulses

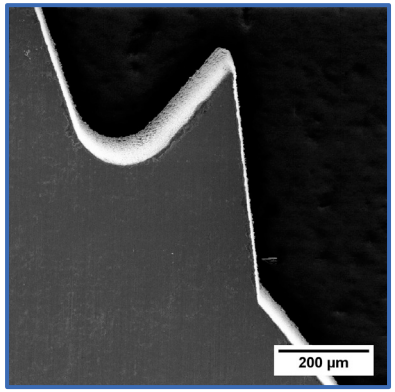
Cutting process



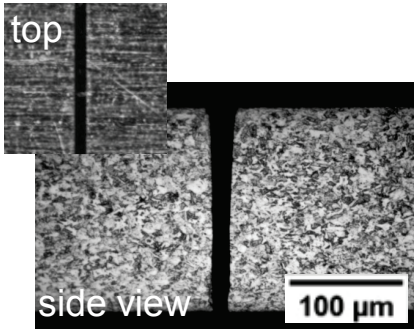


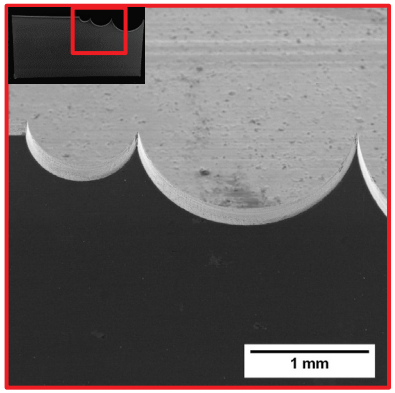
Cutting results using 400 fs pulses





Analysis of HAZ

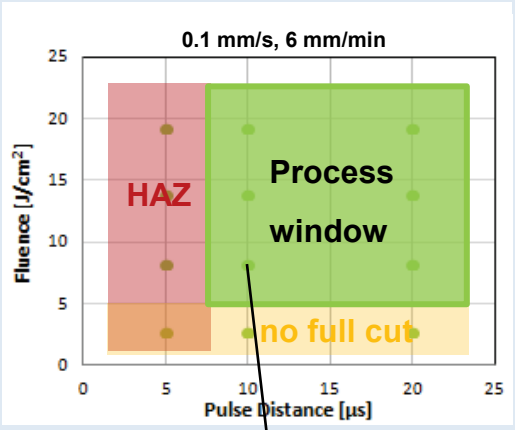


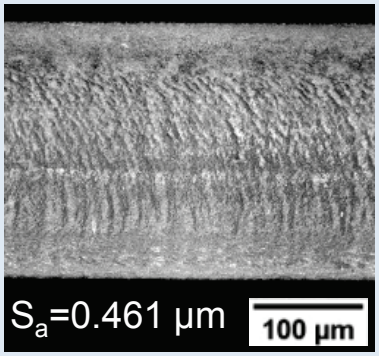


Single Pass Cutting with Ultra-short Laser Pulses

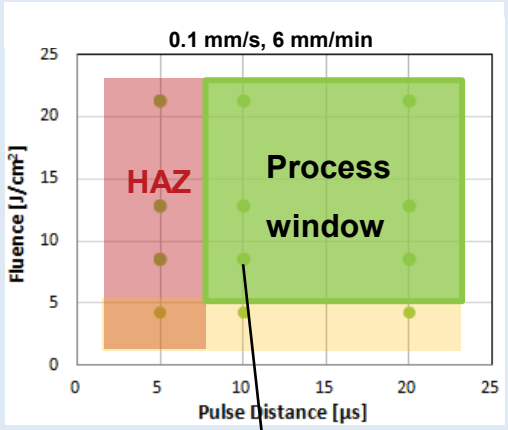
200 µm Durnico

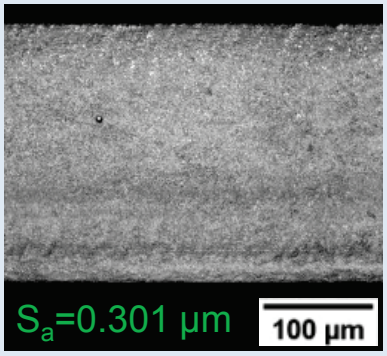
400 fs



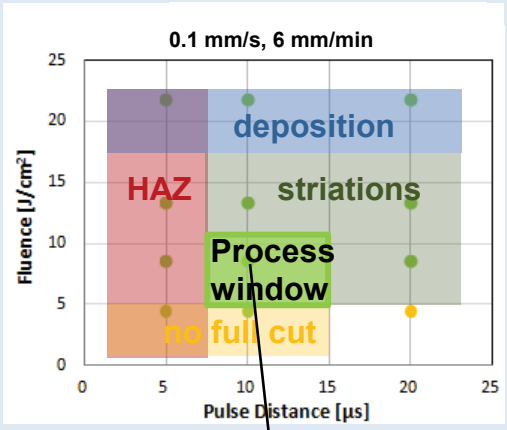


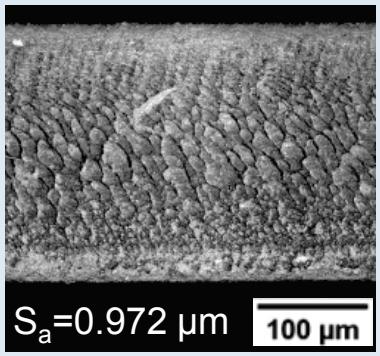
800 fs





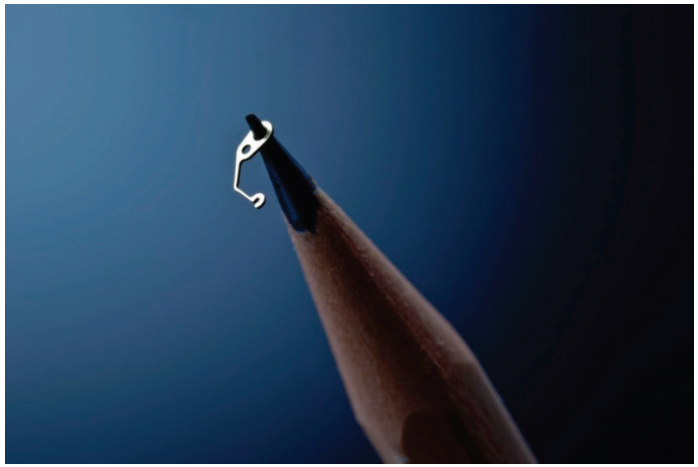
6 ps

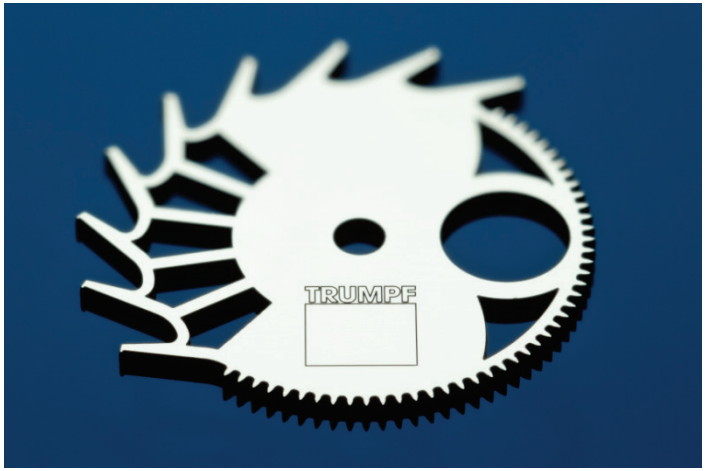




Benchmark parts (EPHJ Genève)

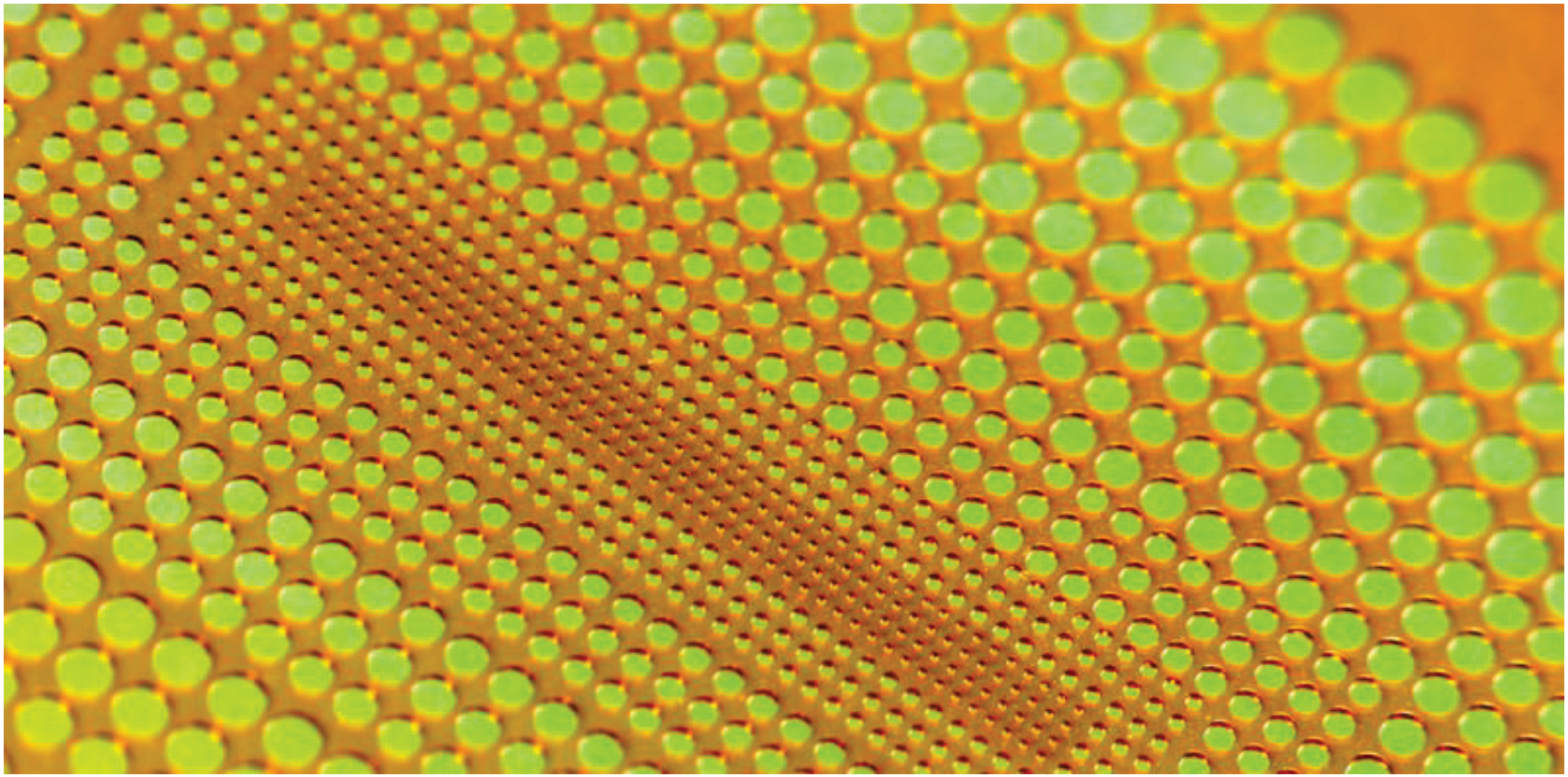
Watch component designs





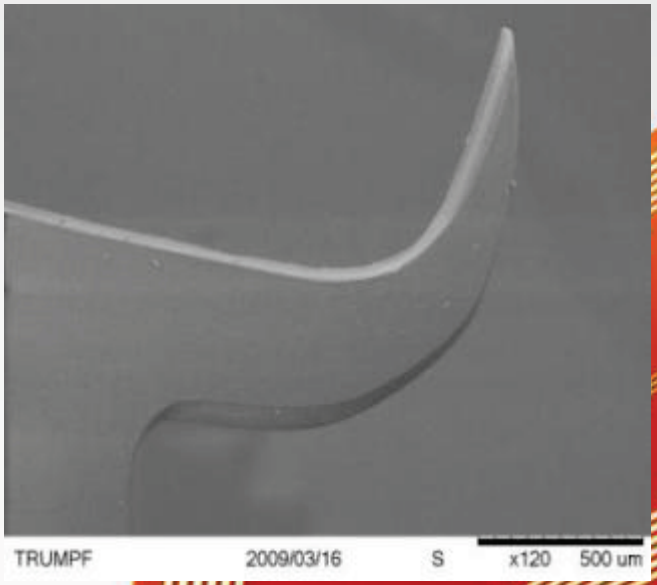
PI CUTTING WITH FEMTOSECOND LASER

Polyimide



Flexible PCBs

Drilling and cutting with TruMicro lasers

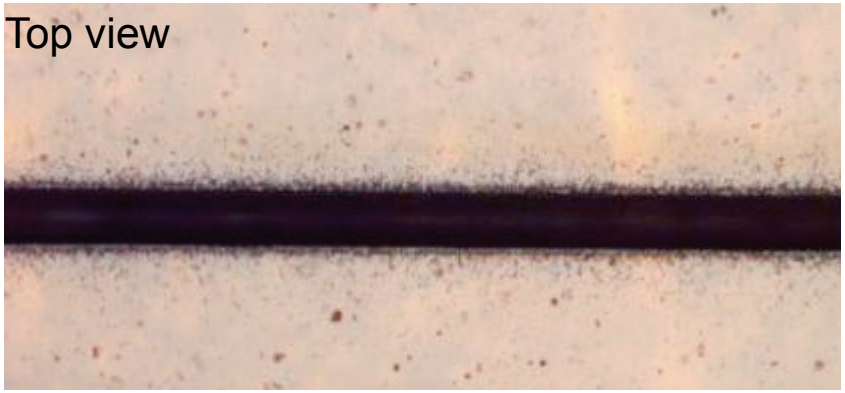


Source: st.com

Cutting of PI with 400 fs IR

PI foil thickness 0.1 mm

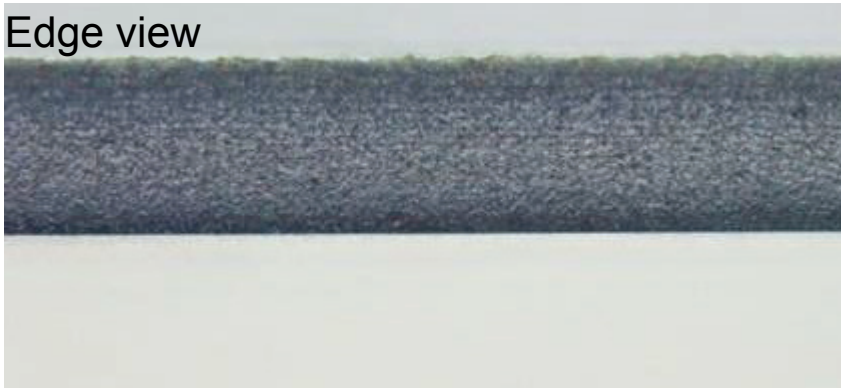
Top view



400 fs
1030 nm
166 mm/s

- Small HAZ visible
- Carbonization is ok

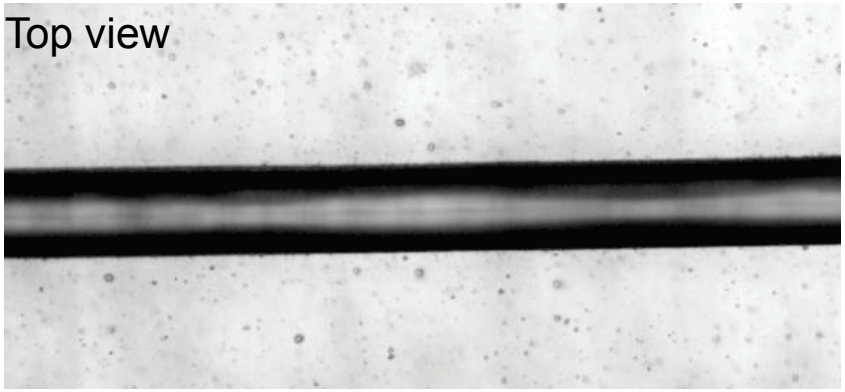
Edge view



Cutting of PI with 800 fs green

PI foil thickness 0.1 mm

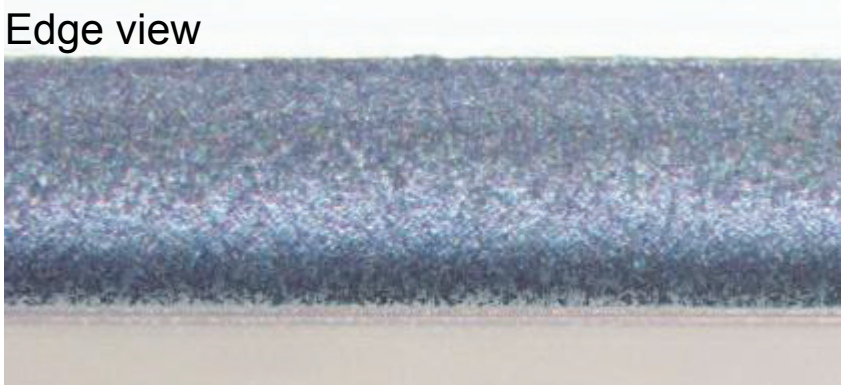
Top view



800 fs
515 nm
166 mm/s

- HAZ smaller
- No carbonization

Edge view



LASERS

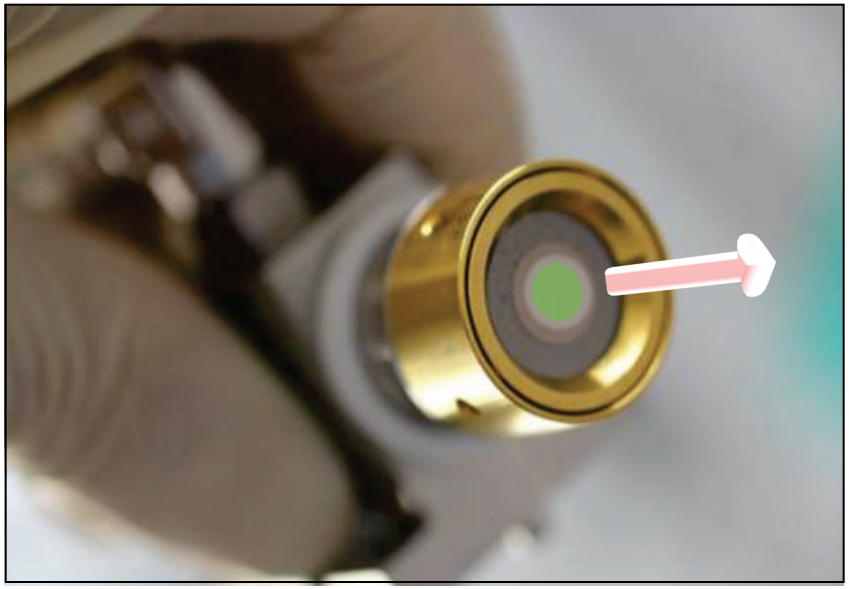
TruMicro Series 2000

TruMicro Series 2000

	TruMicro 2020	TruMicro 2020 FE
Wavelength	1030 nm	1030 nm
Pulse Energy	10 µJ (20 µJ)	10 µJ
Repetition rate	0 - 1 MHz (2 MHz)	0 - 1 MHz (2 Mhz)
Pulse duration	20 ps	500 fs
Average power	10 W (20 W)	10 W (20 W)
Beam quality	$M^2 < 1.3$	$M^2 < 1.3$

Disk Lasers

Large Aspect Ratio ⇒ High Average Power / High Peak Power



Thickness approx. 1/10 mm
Proprietary Mounting on Diamond

Excellent Cooling – compare a cup of tea…

Negligble Thermal Lensing ⇒ Excellent Beam Quality
Large Surface / Short Material Path ⇒ Tolerable Intensity & Low Nonlinearities

TruMicro Series 5000

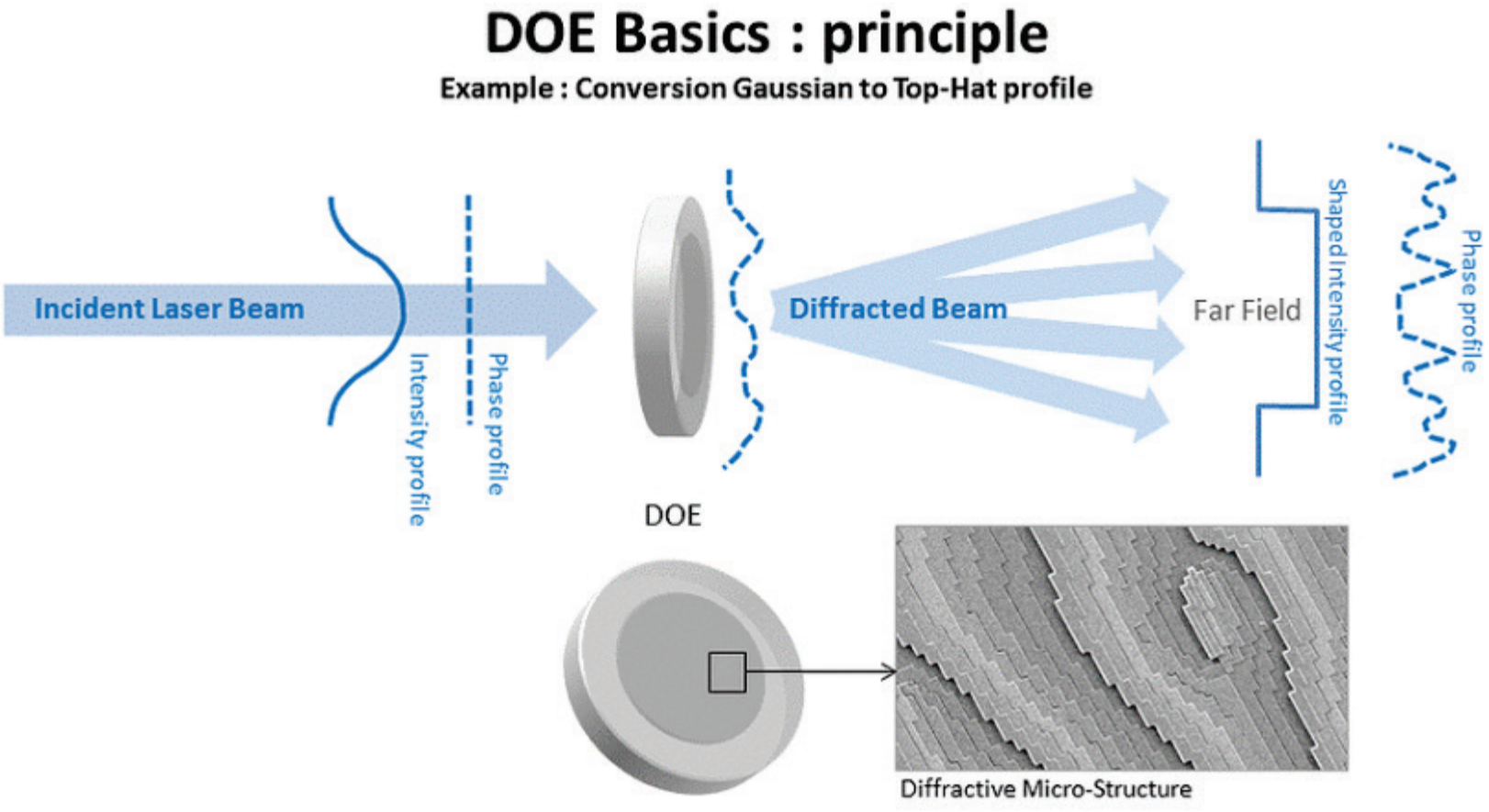
High Power Femto- and Picosecond Lasers

TruMicro Series	5080	5080 Femto Edition	5280	5280 Femto Edition	5380
Max. average power	150 W	120 W	90 W	75 W	45 W
Wavelength	1030 nm	1030 nm	515 nm	515 nm	343 nm
Pulse duration	< 10 ps	900 fs	< 10 ps	700 fs	< 10 ps
Max. pulse energy	500 µJ	200 µJ	225 µJ	125 µJ	75 µJ
Repetition rate	300 – 1000 kHz	600-1000 kHz	600 – 1000 kHz	600 – 1000 kHz	600 – 1000 kHz
Beam quality	$M^2 < 1.3$	$M^2 < 1.3$	$M^2 < 1.3$	$M^2 < 1.3$	$M^2 < 1.3$

SCALING

Beam Splitting and Beam Shaping

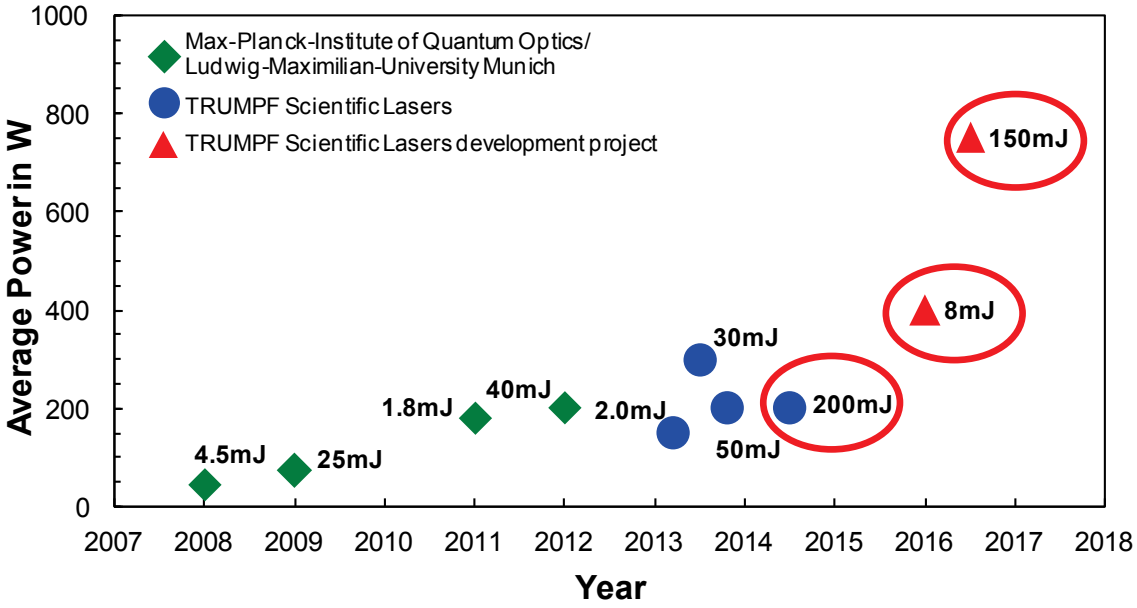
Diffractive Optical Elements (DOE)



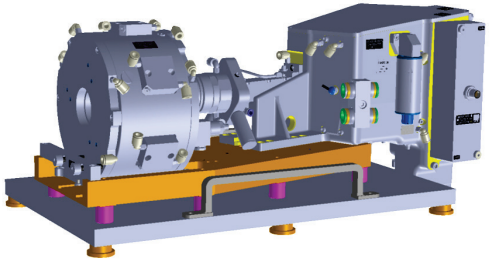
http://static.wixstatic.com/media/153fe5_1374ba37b69fdecbbeb09c95d47242f1.gif_srz_955_485_85_22_0.50_1.20_0.00_gif_srz

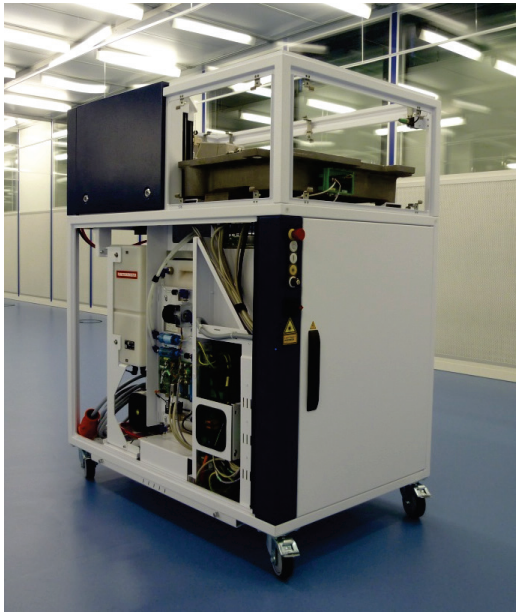
Current Ultra-Short Pulse Thin-Disk Laser Development

Increase of pump power

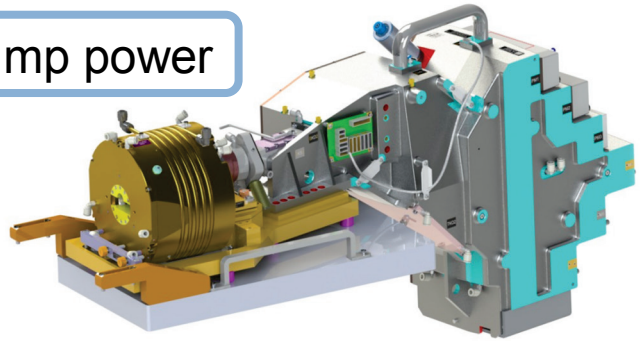


~ 4 kW pump power





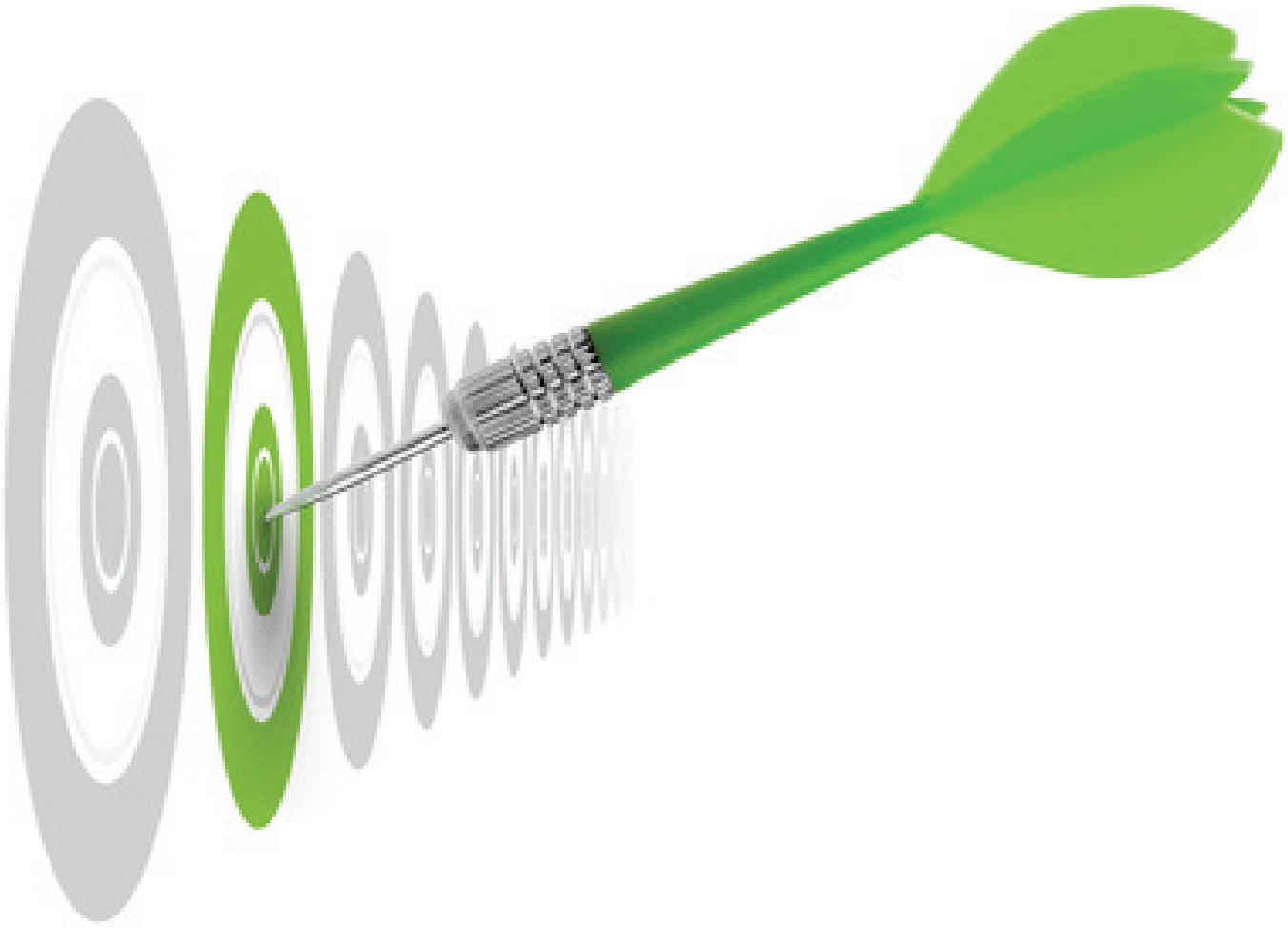
~ 12 kW pump power



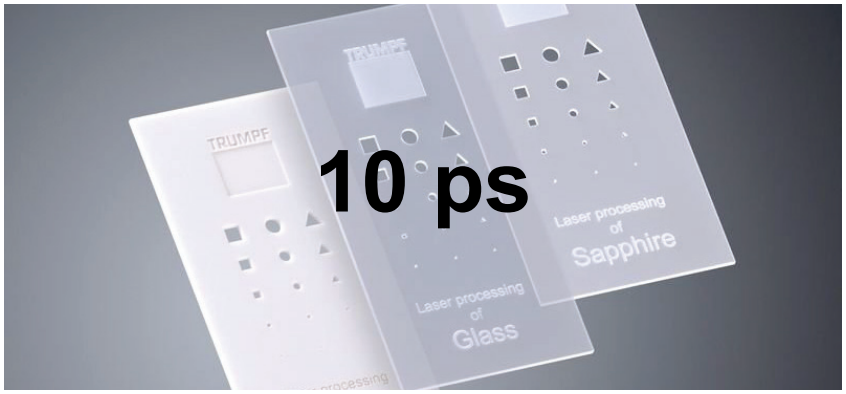
WILL THE TREND TO SHORTER PULSES CONTINUE?

DIFFICULT TO SAY BUT…

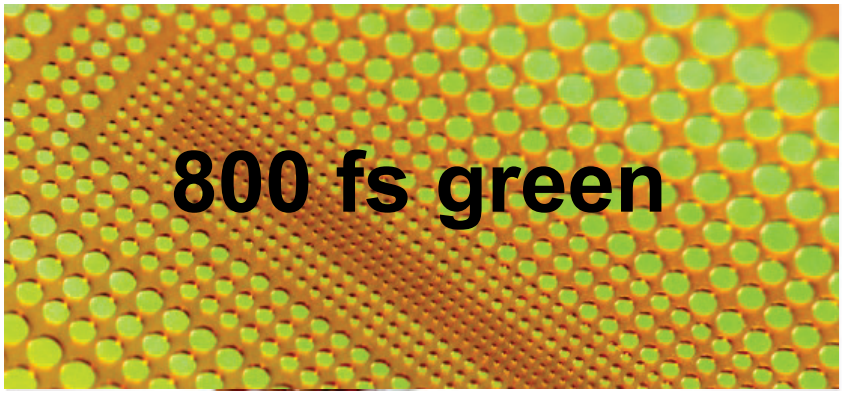
… use that pulse duration that hits the optimum for your material…



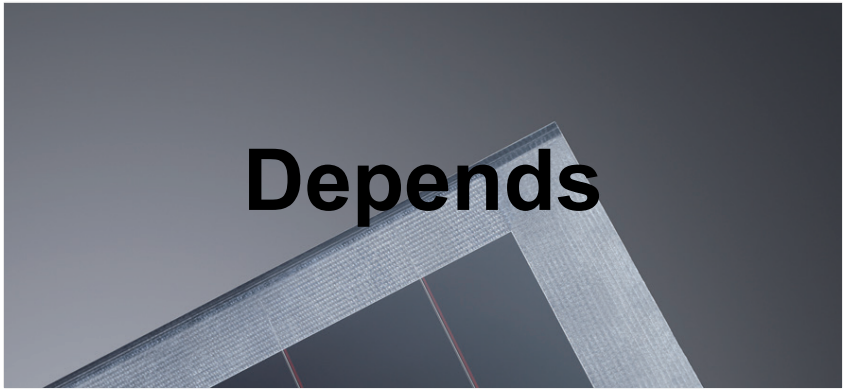
…and that is (as far as we know today)



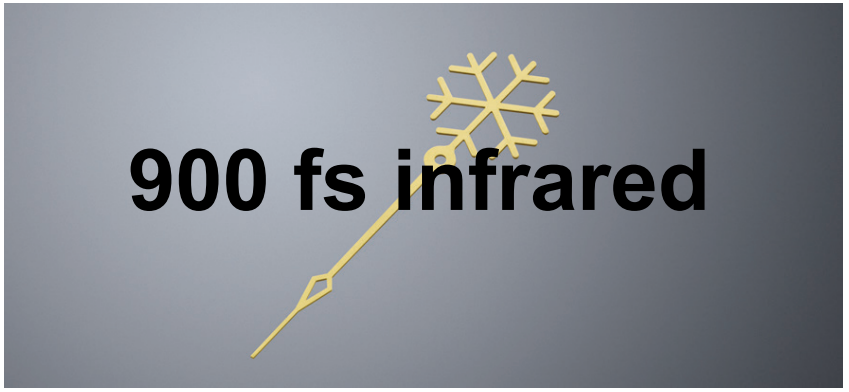
Brittle Materials



Plastics



Thin Films



Metals

IN THE FUTURE? LET‘S SEE…