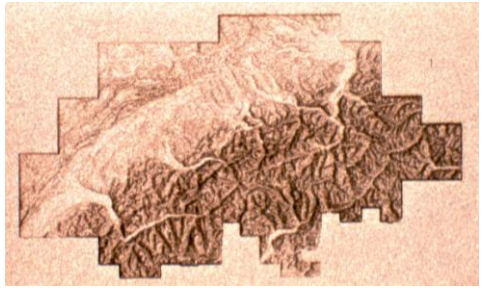
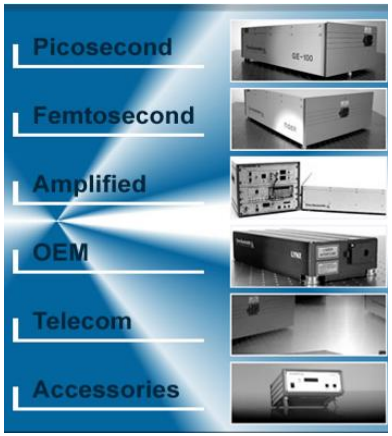
Precision Cold Ablation Material Processing using High-Power Picosecond Lasers



Dr. Kurt Weingarten
kw@time-bandwidth.com

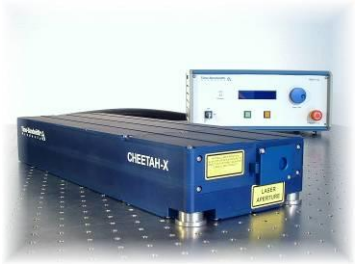
Background of Time-Bandwidth Products

- First product sales end of 1996, organically grown (no outside investors)
- Spin-off of ETH Zurich - “SESAM®” know-how
- Strong technical staff (Ph.D. & masters level) focused on laser production
- Headquartered at Technopark Zurich
- International network of sale representatives/distributors in all key markets
- Industrial customers in semiconductor, biotech, material processing, etc.
- Products established as reliable in “24-7” operation – for either R&D or industrial applications



TBP product range

OEM & Customized
Pico- & Femtosecond **Lasers**



Flexible, modular set of product platforms

Customizable for scientific or industrial applications

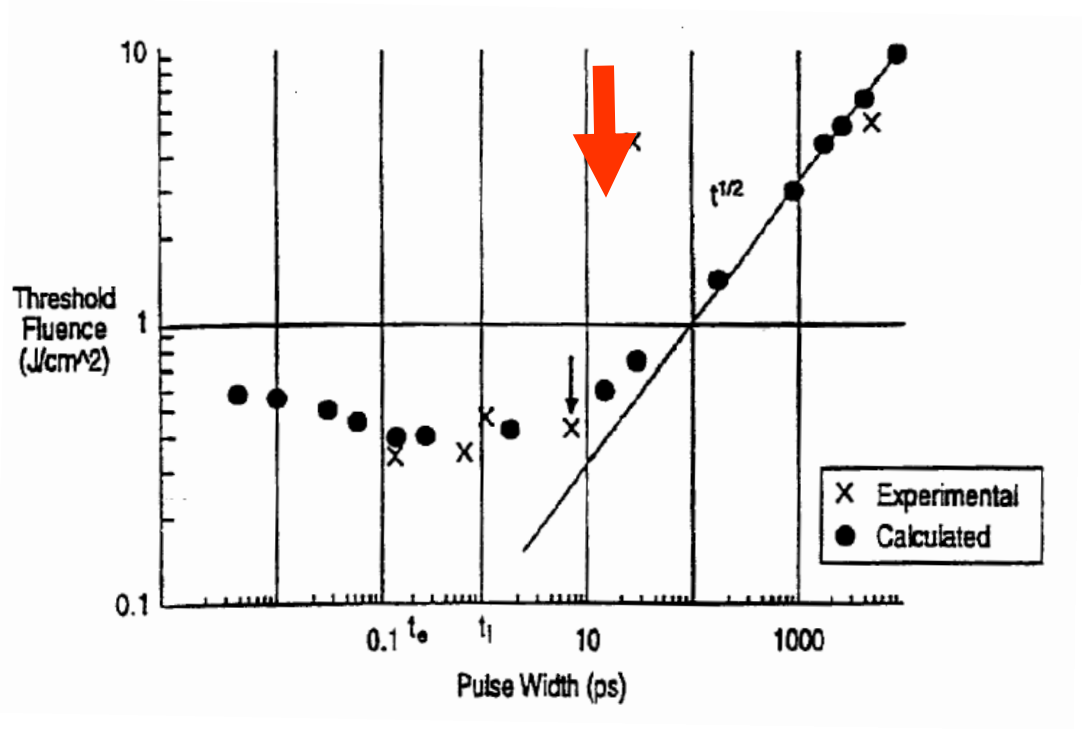
Broad set of performance parameters

Pulse durations	**<50 fs to >500 ps**
Wavelengths	**260 nm – 1550 nm**
Output power	**<1 W to >50 W**
Pulse energies	**up to 1 mJ**
Repetition rates	**single shot to >10 GHz**

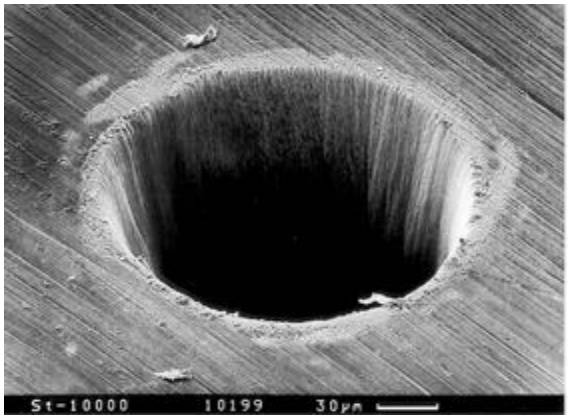
Material processing: "long" versus "short" pulses

Picosecond pulses can cut through "anything" with a very low amount of heating / residual damage

"Cold ablation" starts at around 10 ps pulsewidth



Why? Peak Power required to start ablation is reached at lower pulse energy with shorter pulses



Why picoseconds?

- **Substantial process advantages compared to nanosecond pulses for micromachining**
  - **smaller heat-affected zone (less than 1 micron typical)**
  - **less micro-cracking**
  - **less recast**
  - **with substantially faster speed / productivity (depending on process)**
  - **higher quality ↔ higher speed ↔ (lower cost)**

- **Substantial system advantages compared to femtosecond pulses**
  - **system much less complex and lower costs**
  - **dispersion of picosecond pulses not an issue**
  - **system components more proven in industrial environments**
  - **power scaling currently possible for increased process speeds**
  - **"Most of the advantages of femtosecond lasers but much simpler / scalable"**
  - **Femtosecond systems more applicable for "2-photon" processes**

DUETTO™ - Integrated Industrial MOPA

Master Oscillator Power Amplifier diode-pumped picosecond laser system

Seed oscillator

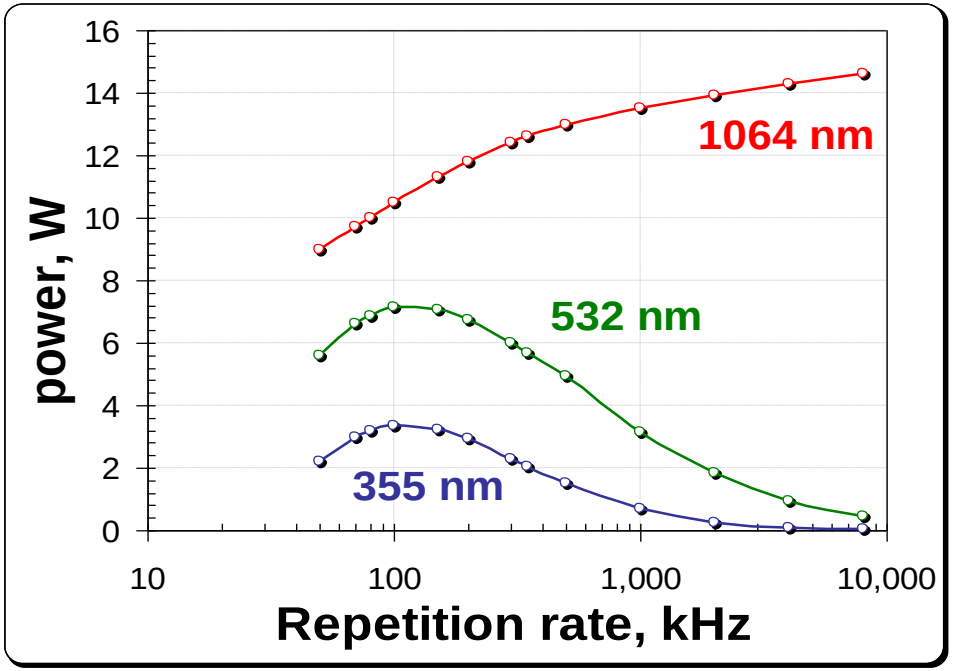
- based on proven LYNX
- 10 nJ, 10 ps, 1064 nm pulses
- **High-rep pulses seed amplifier stage with user-selectable pulse rate**

Pulse Picker

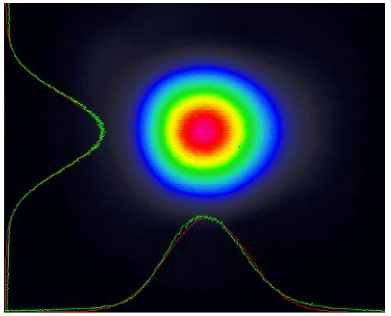
Amplifier stage

- based on proven 10W CHEETAH
- amplifies to >100 µJ (>40 dB gain)
- up to 8 MHz repetition rate

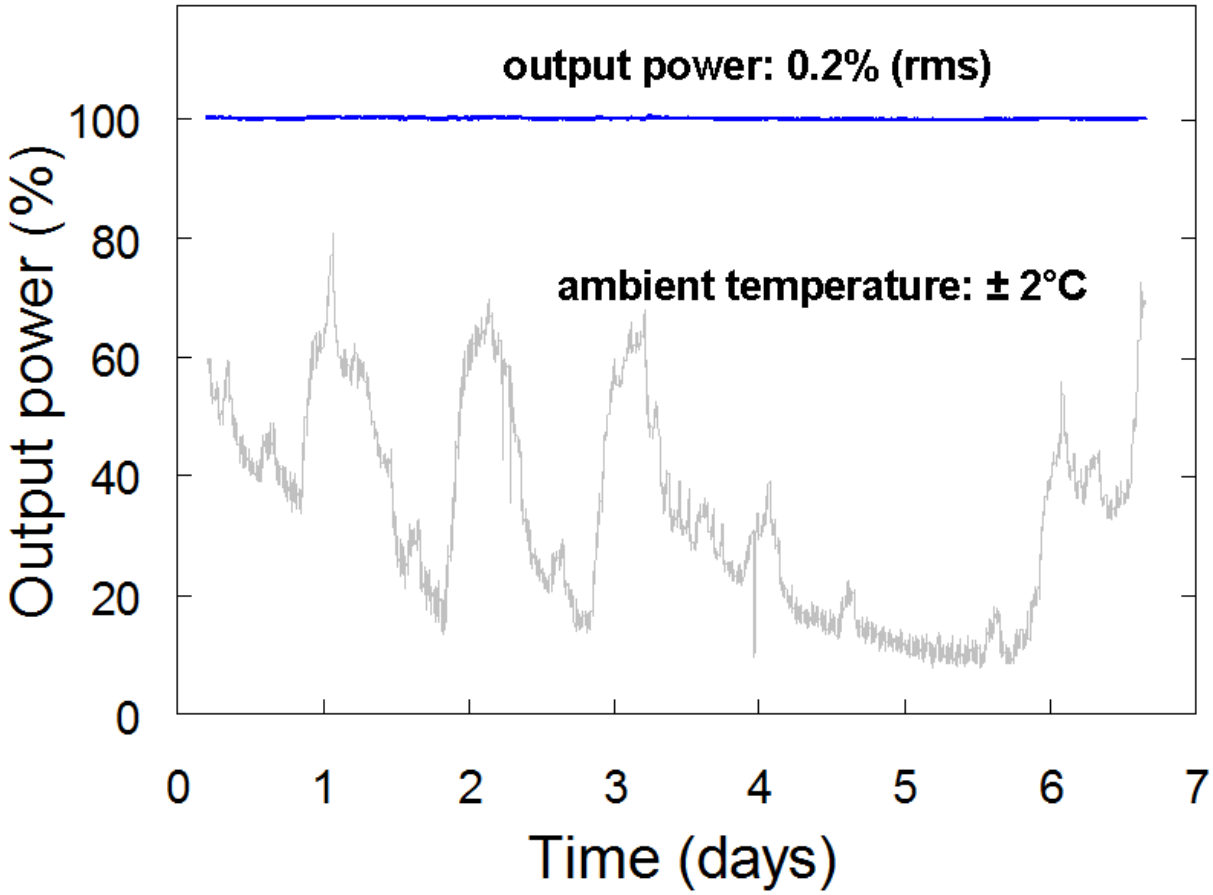
DUETTO - key performance parameters



output power	> 10 W
repetition rate	50 kHz – 8 MHz
pulse energy	up to 200 µJ
pulse width	10 ps
peak power	up to 20 MW
wavelength	1064 nm
M^2 (TEM_{00})	< 1.3

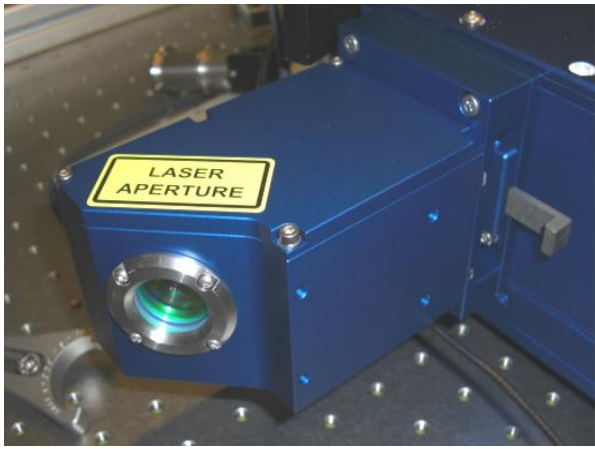


DUETTO – excellent long-term stability characteristics



DUETTO - modular customizable options

- **Power scalable with booster amplifier**
  - FUEGO optional power booster to >50W average power



- **Frequency Conversion**
  - to 532 nm (green): >60% conversion efficiency
  - to 355 nm (UV): >30% conversion efficiency
  - to 266 nm or other wavelengths also available

- **Pulse on demand - POD**
  - Individually triggerable pulses single-shot to MHz regime
  - or arbitrary groups of pulses
  - avoids typical pre-pulse or first-pulse overshoot often seen in other systems
  - FlexBurst™ technology (next slide)

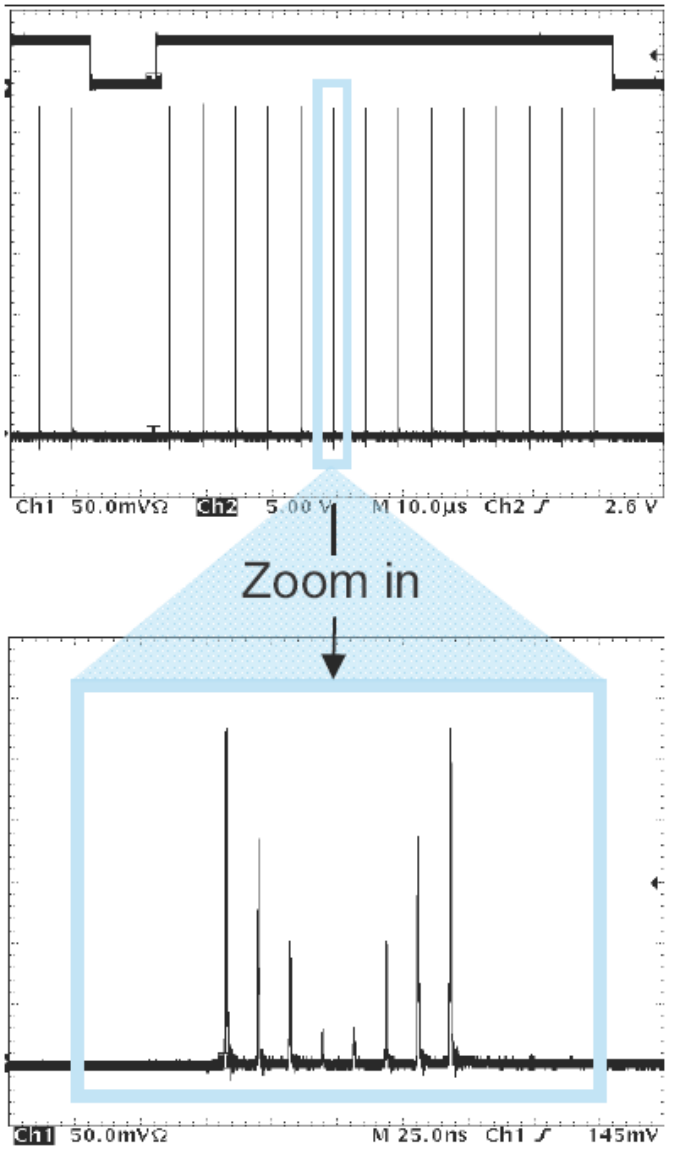
- **Other options**
  - timing synchronization to external clock with sub-picosecond accuracy
  - variable (switchable) pulsewidths
  - repetition rate at oscillator output (80 MHz typical)

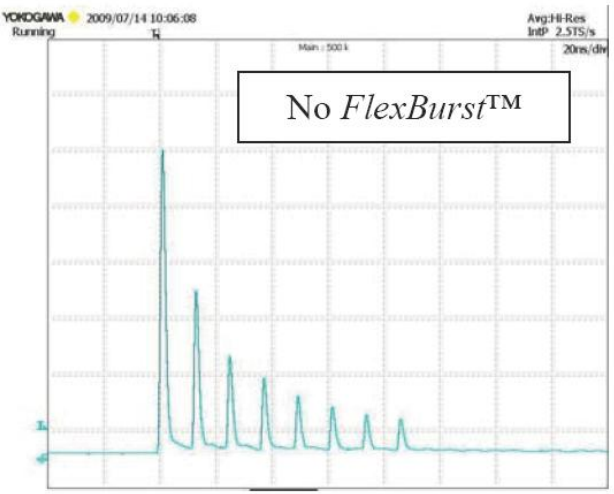
FlexBurst™ technology

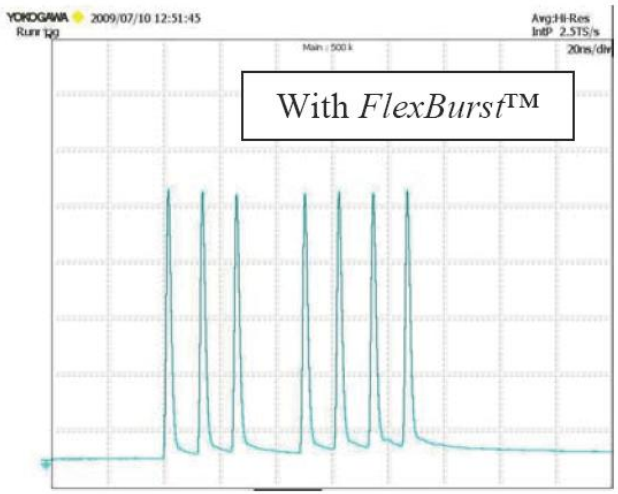
- Generation of arbitrary bursts of pulses
- Frequency of bursts adjustable
- Time between pulses within burst: ca 12 ns
- Number of pulses adjustable
- Amplitude of each individual pulse adjustable
- NO first pulse problem

⇒**Current research activities show that burst mode can**

- **significantly increase the ablation rate**
- **improve surface quality**

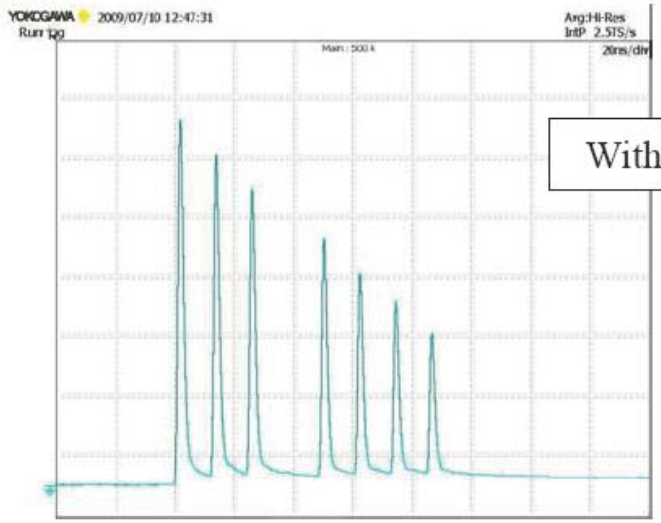




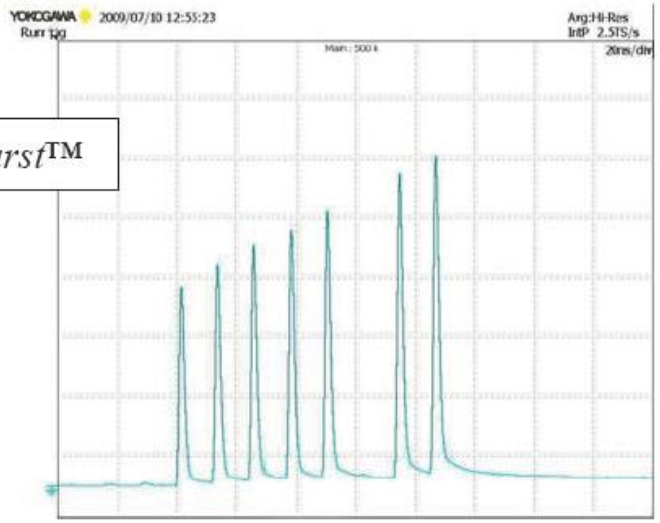


Time-Bandwidth® Products

FlexBurst technology: example patterns

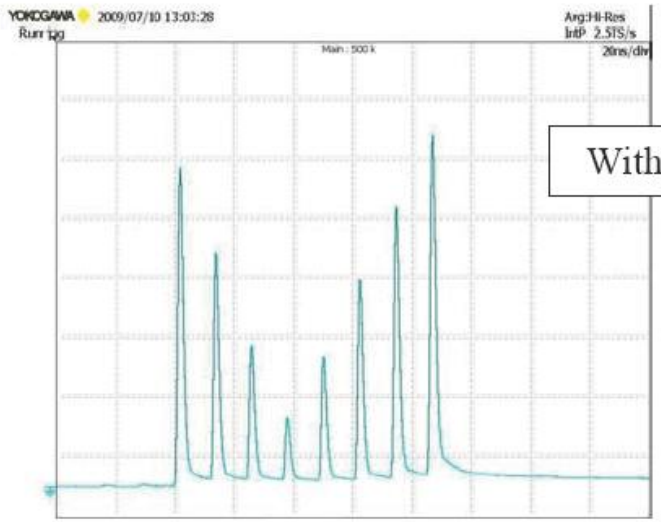


With *FlexBurst*™

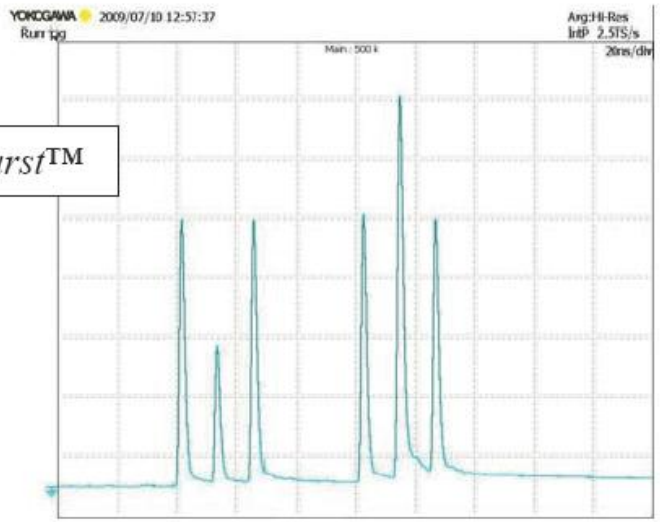


Decreasing pulse energy, 4th pulse blanked

Increasing pulse energy, 6th pulse blanked



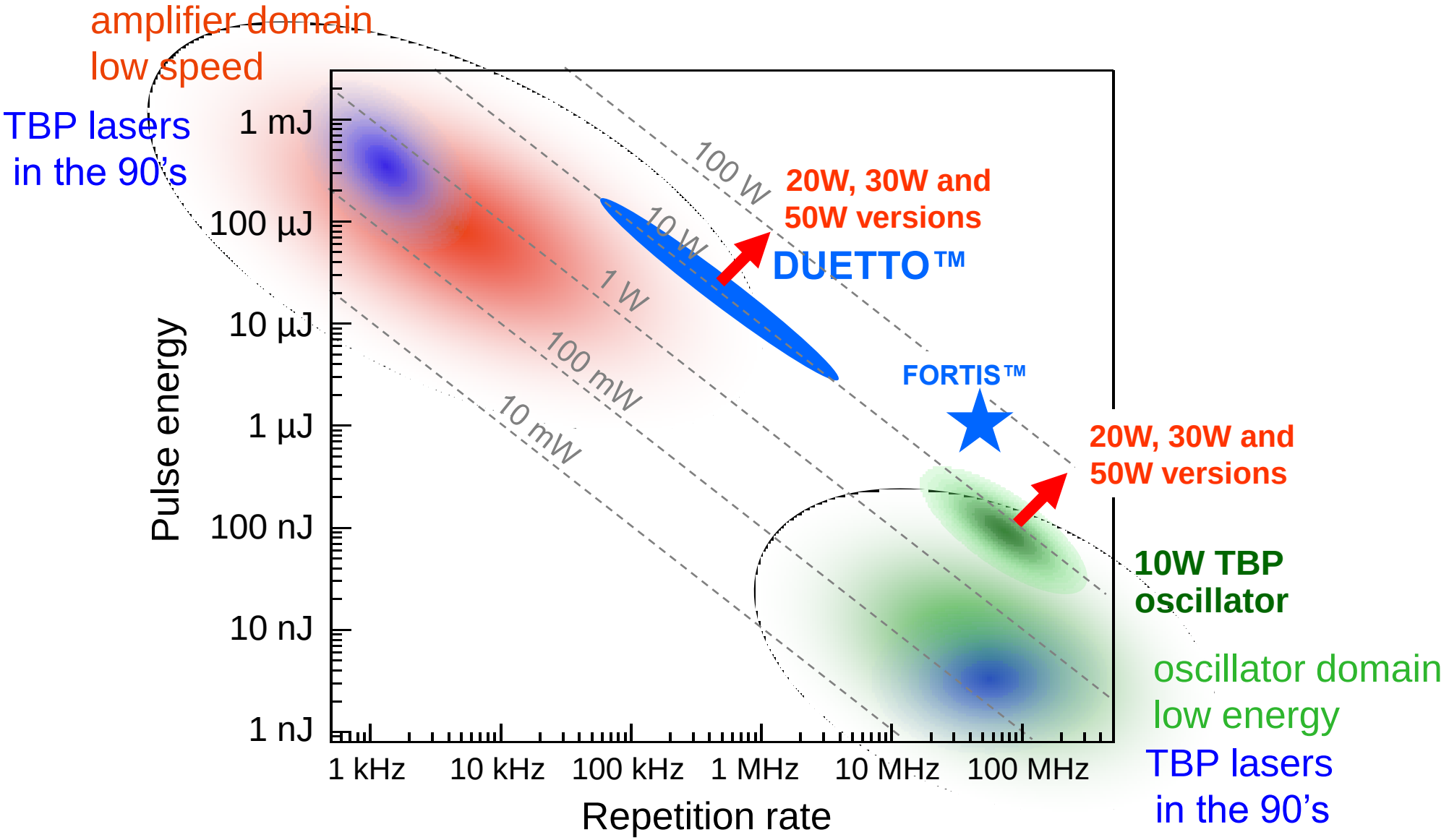
With *FlexBurst*™



Arbitrary energy distribution #1

Arbitrary energy distribution #2

Power scaling with both high power and pulse energy

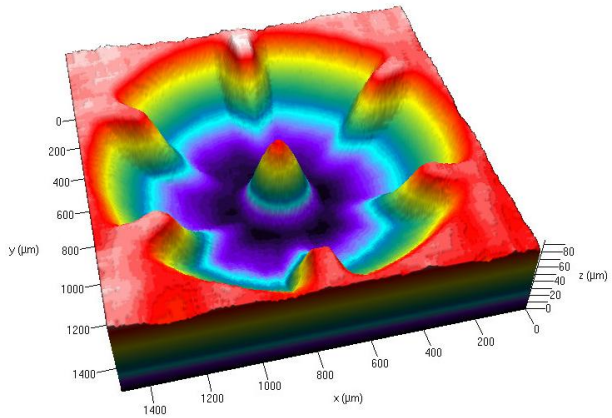


Power amp - high average power & high pulse energy

High Pulse Energy Laser Products

Duetto (amp) *or* **Cheetah (oscillator)** → **power amplifier** → **Fuego** *or* **Argos**

	DUETTO™ laser model	FUEGO™ laser model	ARGOS™ laser model
Type:	MOPA	MOPA	oscillator
Repetition rate:	50 kHz – 8 MHz	200 kHz – 8 MHz	50 MHz to 200 MHz
Fundamental wavelength:	1064 nm	1064 nm	1064 nm
Pulse width:	12 ps or longer	12 ps or longer	12 ps or longer
Output power:	≥ 10W	20W, 30W or ≥45W	20W, 30W or ≥45W

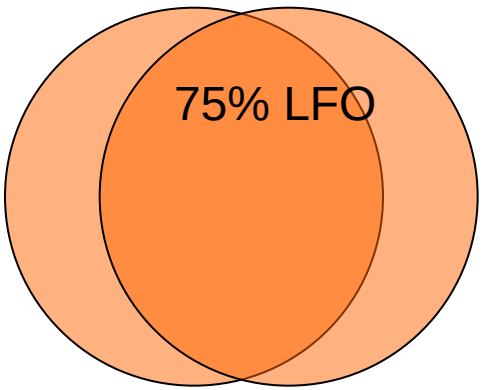


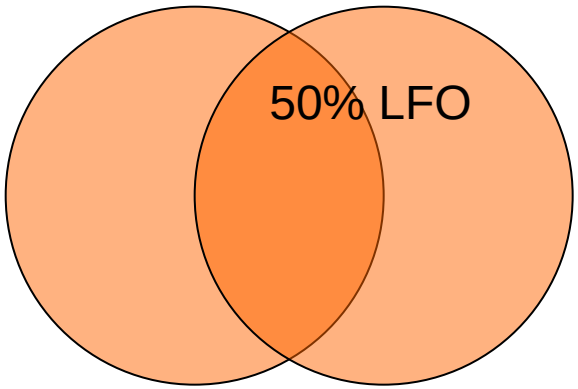
Picosecond Micromachining Guidelines

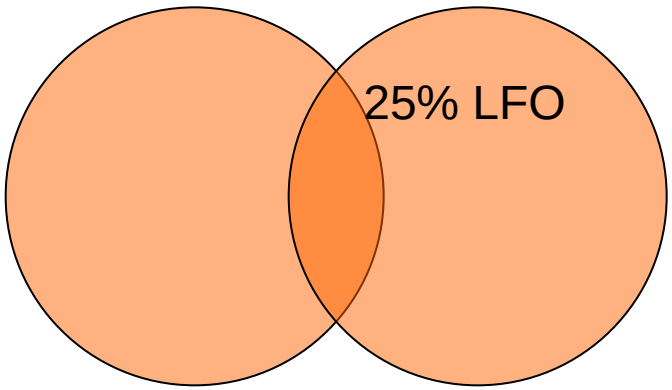
- Energy density required for ablation typically 1 Joule / cm^2
- 10-100 nm layer removed per pulse: "gentle ablation"
- Top Hat beam profile can give ~35% more efficiency than Gaussian
- High repetition rates increase speed ➔ limited by scanner speeds and "LFO" = Laser Focus Overlap: "speed limit" due to spot size overlap
- Thin films can benefit from high scan speeds (>>10 m/s) due to the high repetition rates possible (>1 MHz), but require precise scanner systems
- ~1 mm^3 / minute for un-optimized process with 10W average power
- up to 10-50 mm^3 / minute for optimized process with 50W average power
- Final speed limit depends critically on material, process parameters, and beam delivery limitations

Processing speed and pulse repetition rate

- **Pulse repetition rate of the Duetto scales from 100 kHz to 8 MHz with <u>virtually no change in pulse and beam parameters</u>**
  - **as opposed to other approaches where pulse quality and stability degrades as repetition rate increases**
- **Single-pulse processes can benefit from higher pulse rate**
- **"Laser Focus Overlap" (LFO) sets upper speed limit on ablative (line) processes**
- **Small features require high pulse repetition rate to achieve high scan speed**
- **Example: spot size 10 μm, LFO 50%**
  - **maximum scan speed of <u>1 m/s at 200 kHz</u>**
  - **maximum scan speed of <u>10 m/s at 2 MHz</u>**



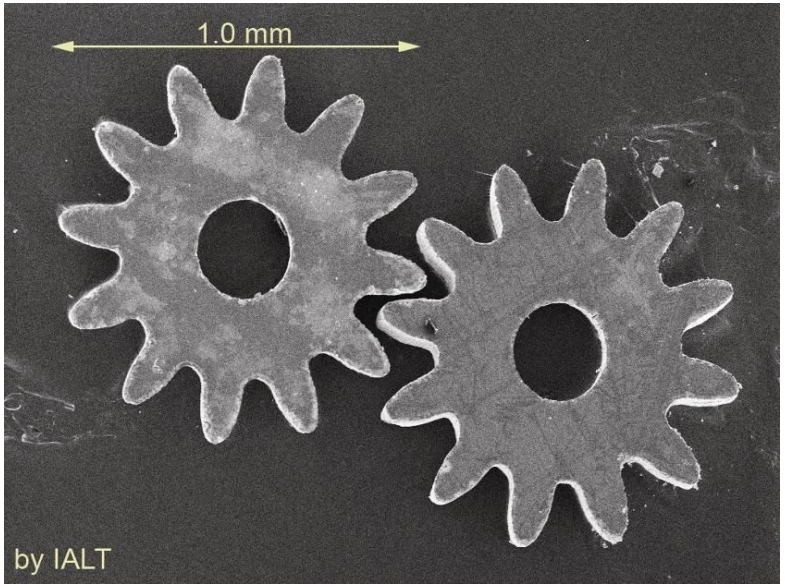




Applications

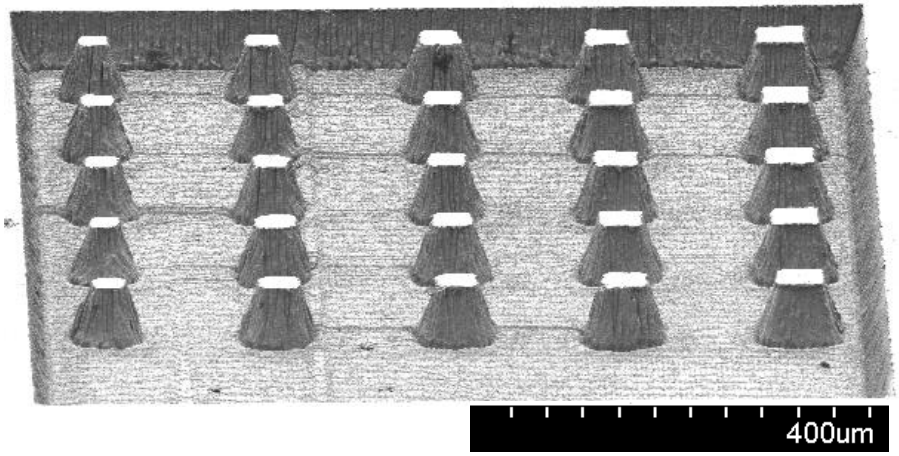
- **Metals**
  - very thin (thin-film)
  - precision holes (sub-100 μm)
  - surface feature structuring / tribology
- **Ceramics**
  - precision cutting / structuring without cracking (resulting in low-yields)
- **Semiconductor / Photovoltaic**
  - hole / via drilling
  - ablative processes / structures
  - singulation
- **Dielectric**
  - structuring
  - selective ablation
  - hard dielectrics like sapphire and diamond
  - glass welding
- **“Mixed” materials**
  - picosecond (IR or UV) can cleanly cut / ablate through combinations of the above materials
  - semiconductor: low-k coated chips
  - solar: thin-film technologies (CIGS, CdTe, etc)
  - medical: coated stents
  - etc, etc.

Application Examples of Duetto: Metals, Ceramic



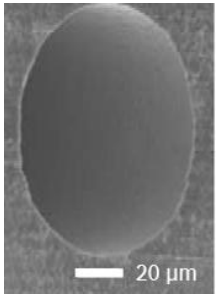
Miniature gears in 50 μm stainless steel foil

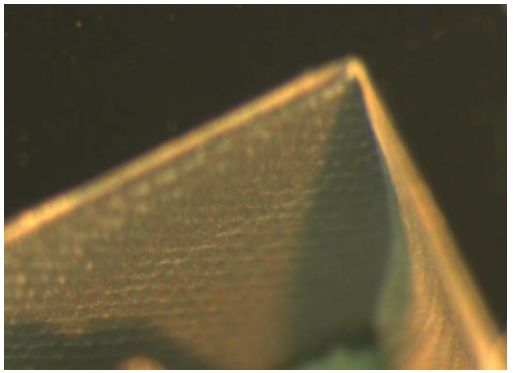
Columns ablated in copper



Sub-100 μm holes

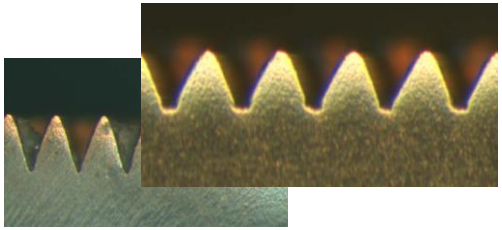
(e.g. diesel injectors)

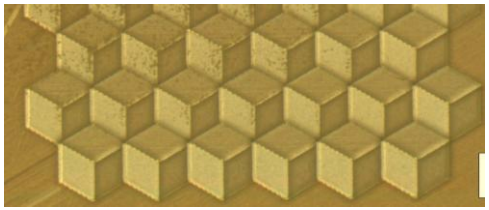




Ceramic micro-machining without cracking

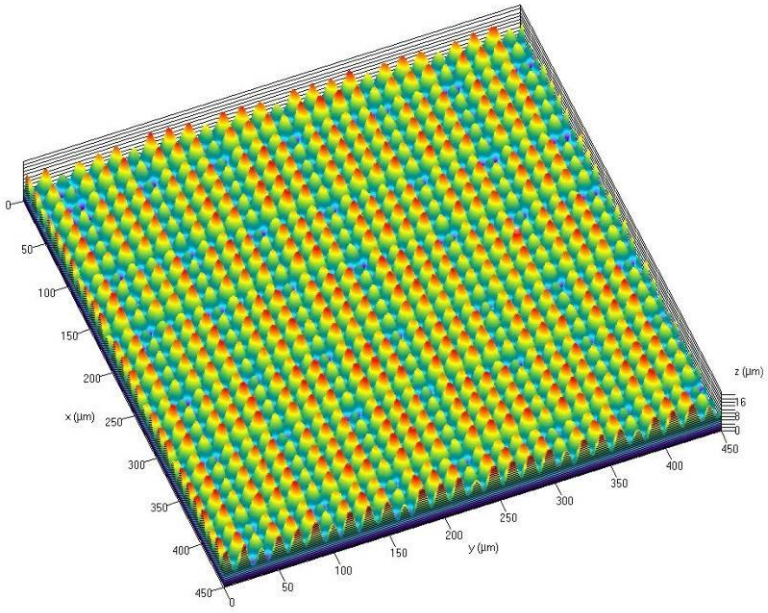
Gears, teeth structures, patterns in metal

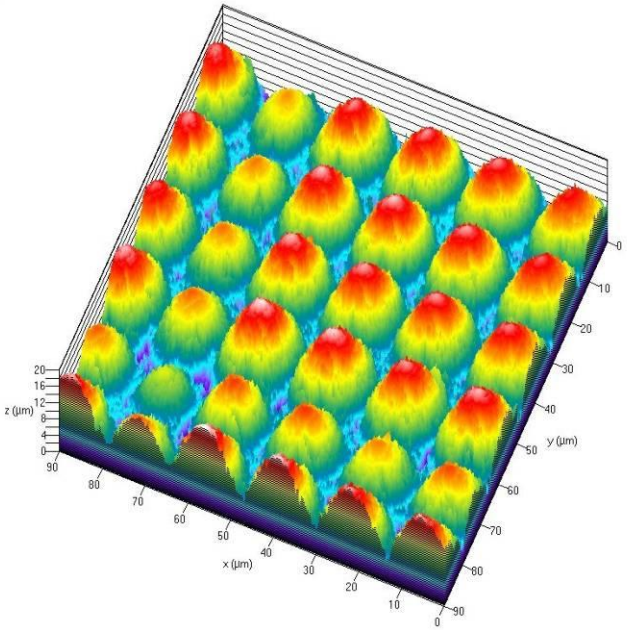




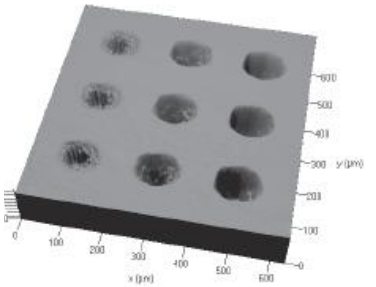
Application Examples of Duetto: Surfaces

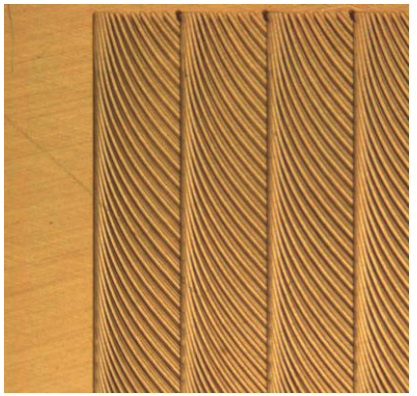
Tribology: microstructuring of surface features





“Spikes” and “Dimples” on surfaces

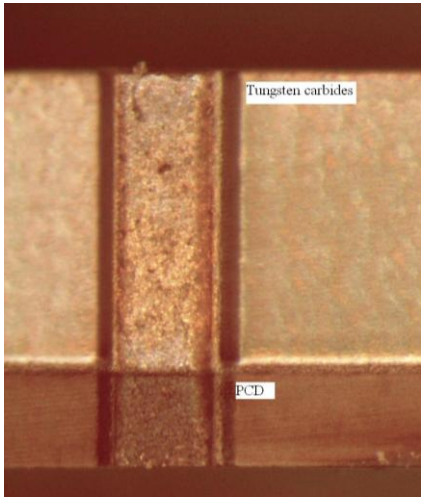




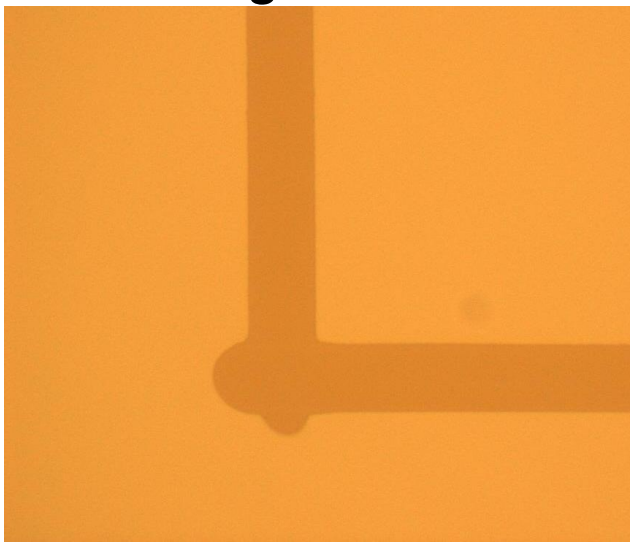
surface patterning

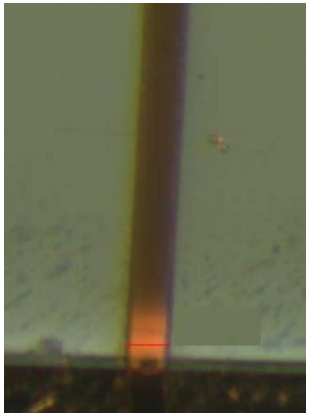
Application Examples of Duetto: Thin Films

TCO on glass



TCO on organic substrate

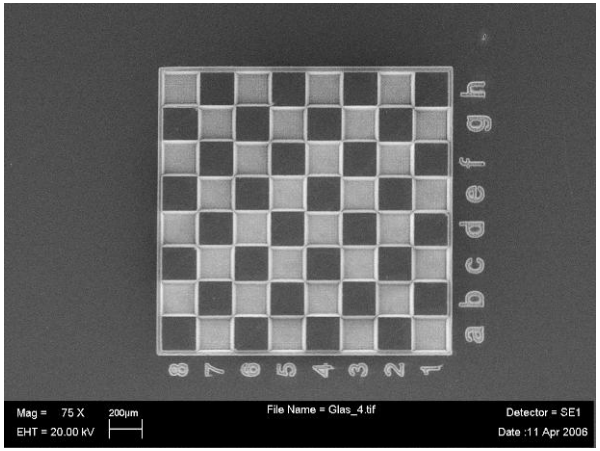


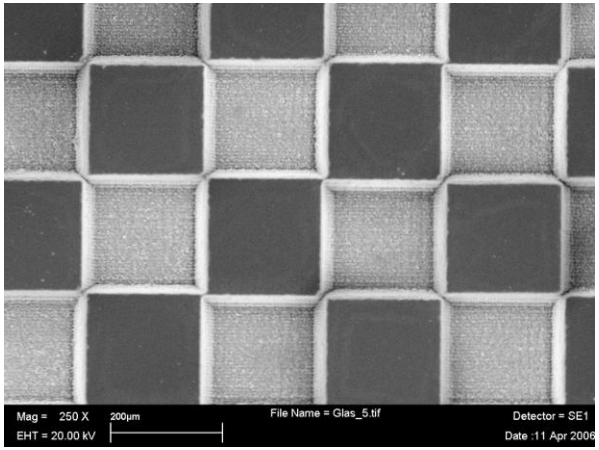


Metal layer on organic substrate

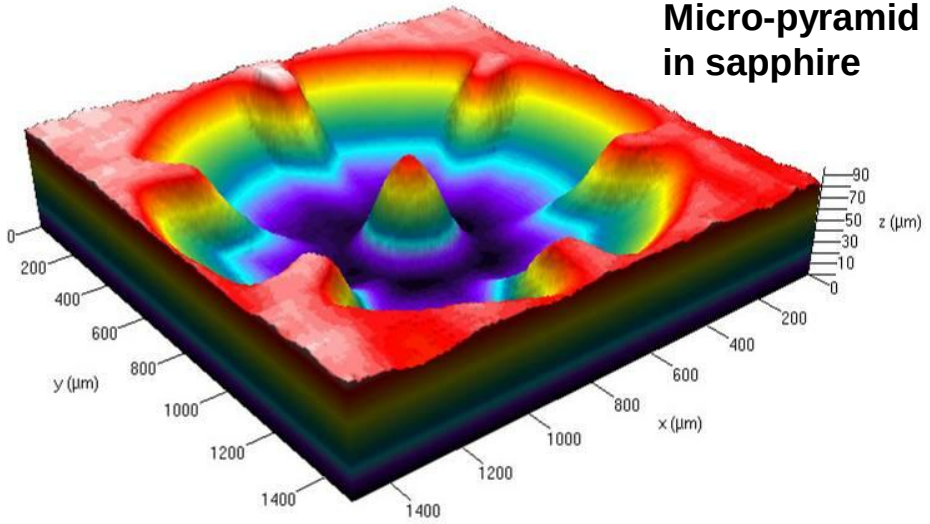
Application Examples: Transparent Materials

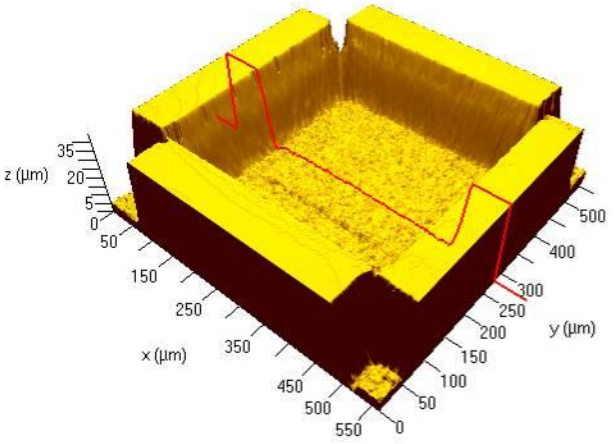
Checkerboard patterns on glass



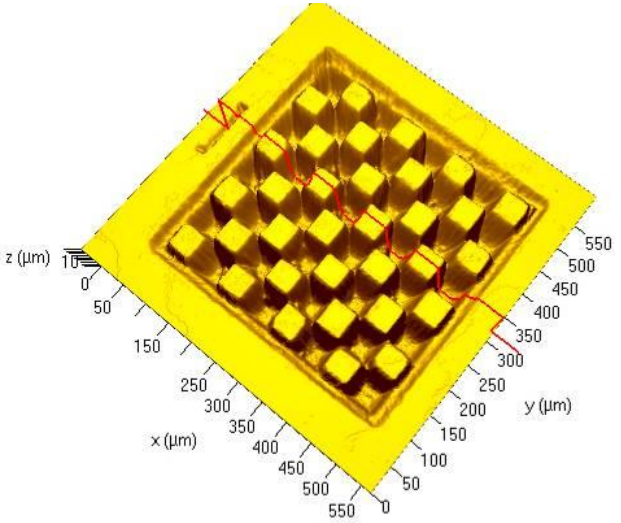


Micro-pyramid structure in sapphire





area: ~400 µm; depth: ~35 µm

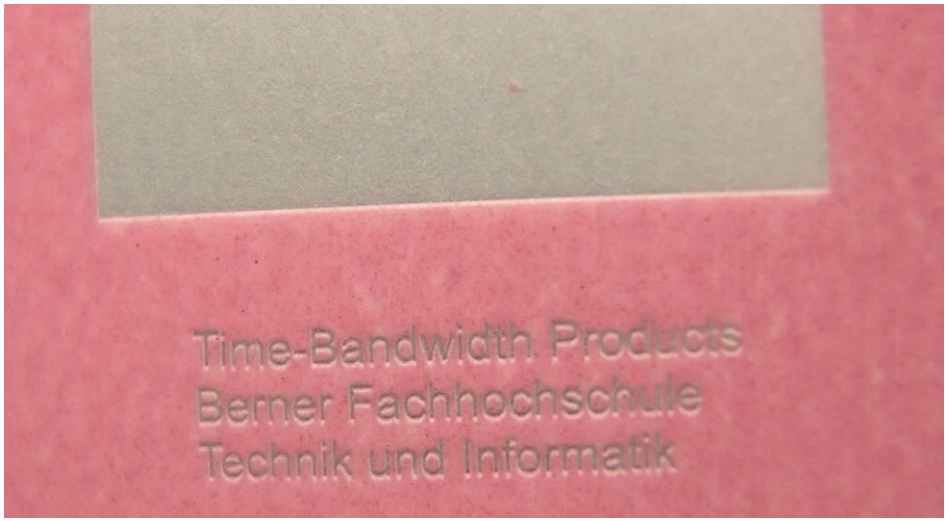


area: ~50 µm; depth: ~35 µm

Time-Bandwidth® Products

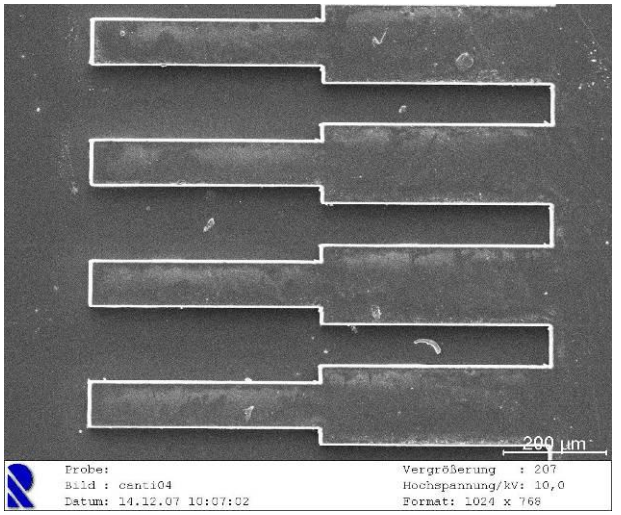
Pictures courtesy of IALT

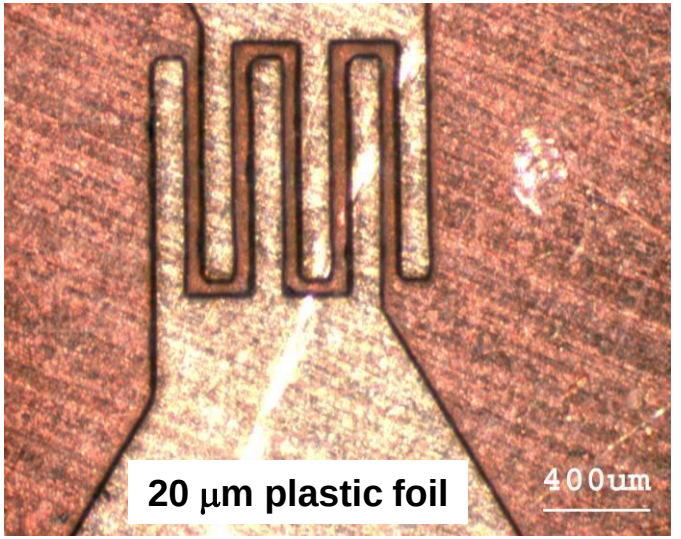
Application Examples of Duetto: Plastics, Polymers



Precise selective ablation of layers on polymer substrate

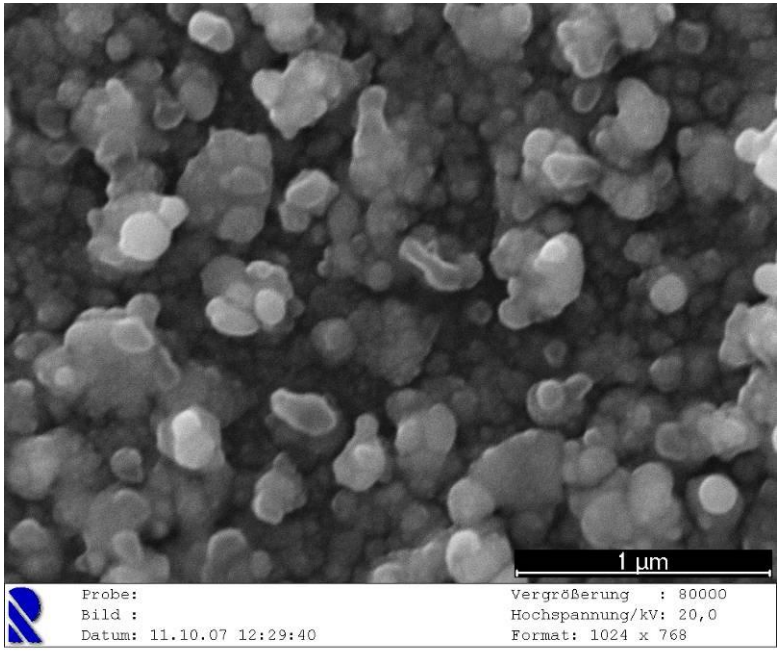
Plastic cantilevers 20 µm thickness



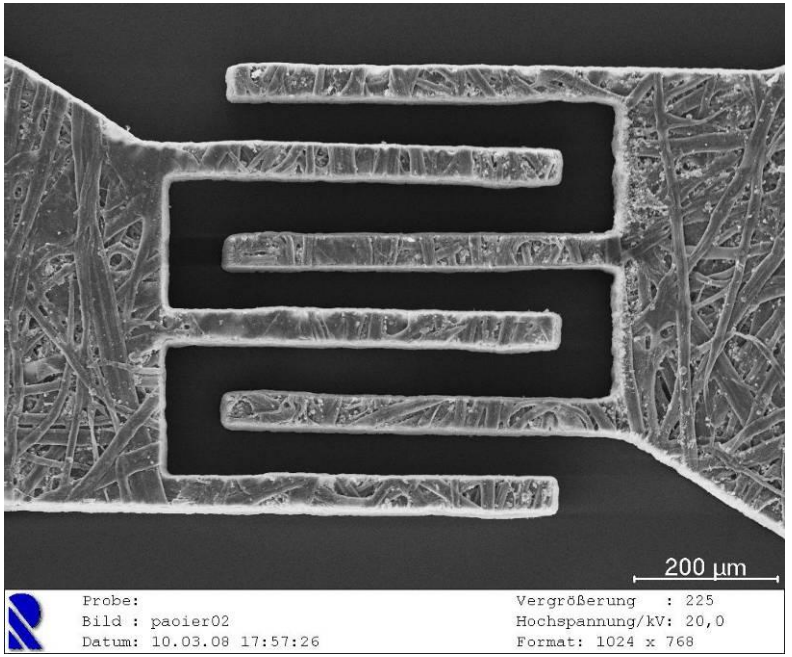


20 µm plastic foil

Application Examples of Duetto: Others



Deposition of Nanoparticles
(Laser Induced Plasma Assisted Ablation LIPAA)



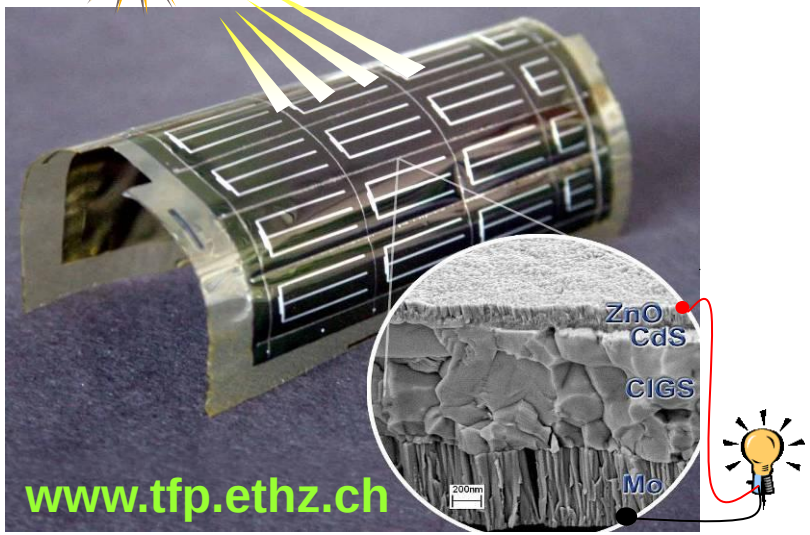
Micro-cutting of paper

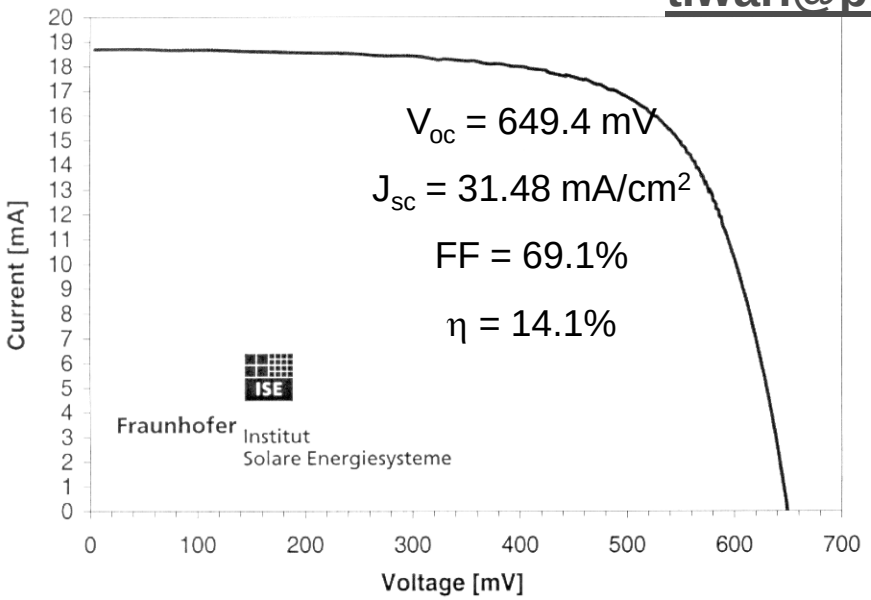
(no residual burning / damage)

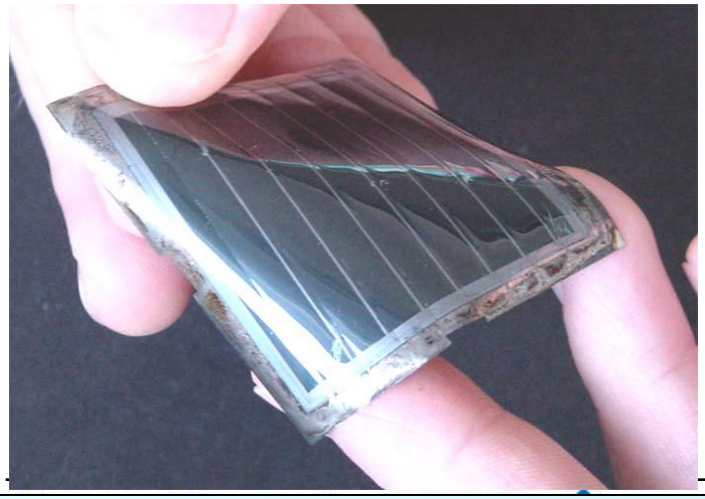
Lightweight and flexible solar cell on polyimide World record efficiency of 14.1%

Thin film Cu(In,Ga)Se_2 solar cell

tiwari@phys.ethz.ch







- Multifunctional layers and heterostructures
- Large area coatings with vacuum and chemical processes
- Laser scribing and patterning of structures
- Monolithically interconnected solar module

Monolithic interconnection in CIGS solar modules

Mo back contact deposition by sputtering

Scribing of Mo by laser beam

CIGS absorber deposition by vacuum evaporation

CdS or ZnS buffer deposition by chemical method

Patterning of buffer/CIGS by laser scribing

ZnO:Al Front contact deposition by sputtering

Patterning of front contact & wiring

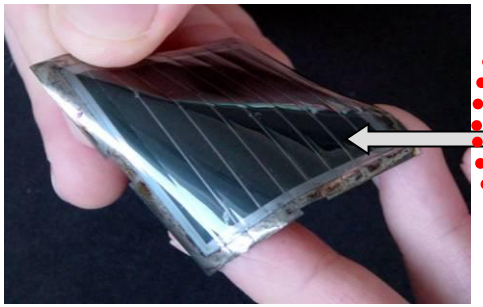
ZnO:Al (1 μm)

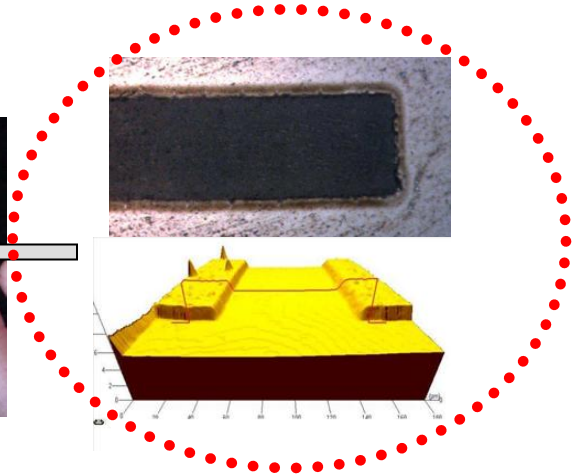
CdS or Zns (0.03 μm)

CIGS (2 μm)

Mo (1 μm)

Substrate





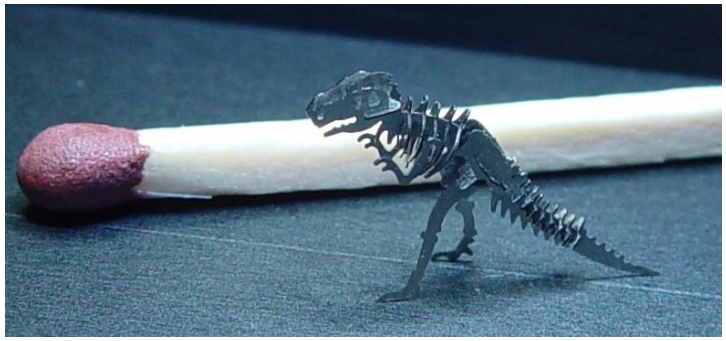
Summary

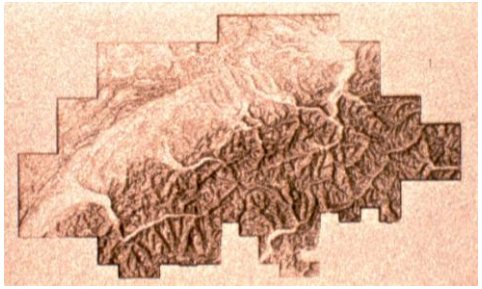
- Picosecond lasers offer improved quality, faster processing speed for “fine” ablation processes
- Duetto – flexible, modular industrial picosecond system for micromachining
  - Broad repetition rate changing for process optimization
  - Wavelength flexibility (IR, green, UV)
  - High-power add-on modules
  - FlexBurst pulse control
- Thin-film, surface, microstructuring applications
  - Semiconductor, biotech, solar cell, security, ….

Many Thanks

- **Thanks for your attention!**
- **Man thanks to Professor Beat Neuenschwander and team from Laser Surface Engineering group at Applied Laser, Photonics and Surface Technologies, Bern University of Applied Sciences for all the application support!**

ALPS@BFH
Applied Laser, Photonics and Surface technologies
Bern University of Applied Sciences
Engineering and Information Technology





Time-Bandwidth® Products

Other applications

- Analysis
  - Wafer inspection, Multi-photon microscopy, CARS, FLIM
- Medical applications
  - Ophthalmology, Laser dissection
- Metrology
  - Optical clocking, Optical sampling, Laser ranging
- Optical communication
  - Special high-performance data transmission
- Wavelength conversion
  - Visible / UV wavelengths, optical parametric oscillators, THz generation
- High-Energy Physics
  - Photocathode illumination, EUV & X-ray generation