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High average power, high pulse energy picosecond lasers for material processing

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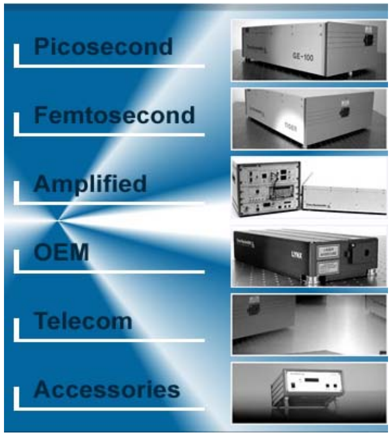
Time-Bandwidth® Products

Outline

- Introduction to Time-Bandwidth Products
- Why picosecond lasers might be the "next big thing" in micromachining: faster ⇔ better ⇔ (lower cost)
- Overview of the Duetto – flexible picosecond system for micromachining
- Application examples
- Future outlook

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

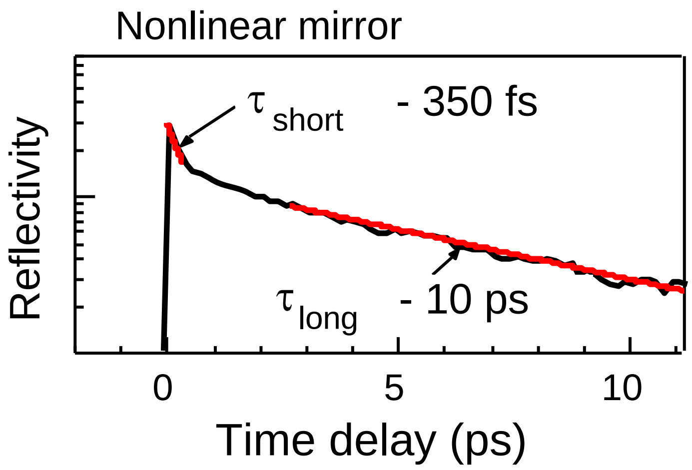


SESAM® – enabling technology

SESAM®: semiconductor saturable absorber mirror
“Nonlinear mirror” - pulsed light reflects more than continuous light

-“Simple” piece of semiconductor gives reliable ultrafast laser performance, allowing for a broad range of precision pulsed laser systems

- plus substantial system know-how: laser design, precision opto-mechanics, electronics, etc.



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

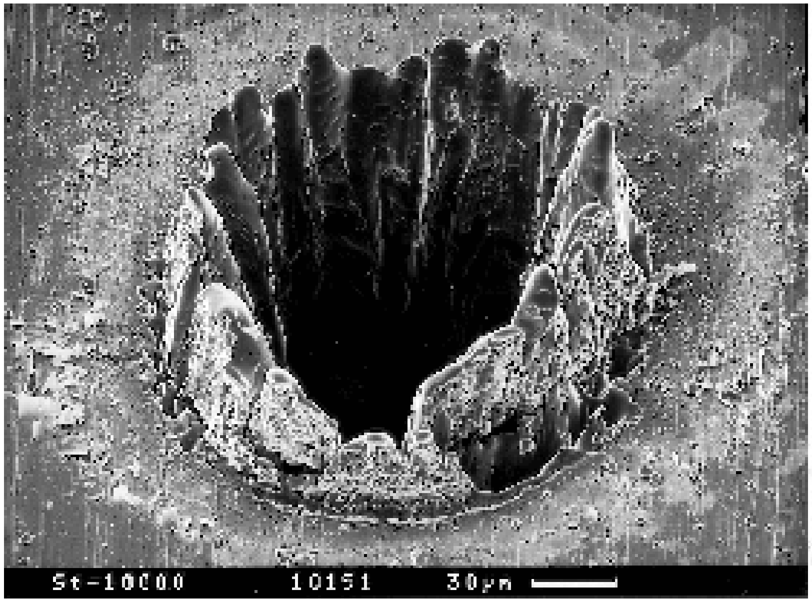
Pulse durations	**<50 fs to >500 ps**
Wavelengths	**260 nm – 1550 nm**
Output power	**<1 W to >50 W**
Pulse energies	**up to 1 mJ**
Repetition rates	**single shot to >10 GHz**

Material processing: "long" versus "short" pulses

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

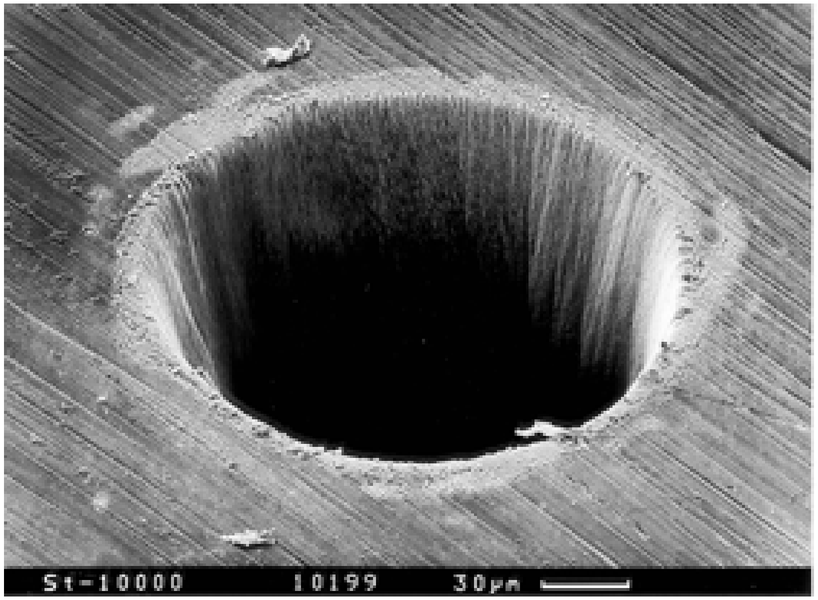
Long pulse:

nanoseconds



Short pulse:

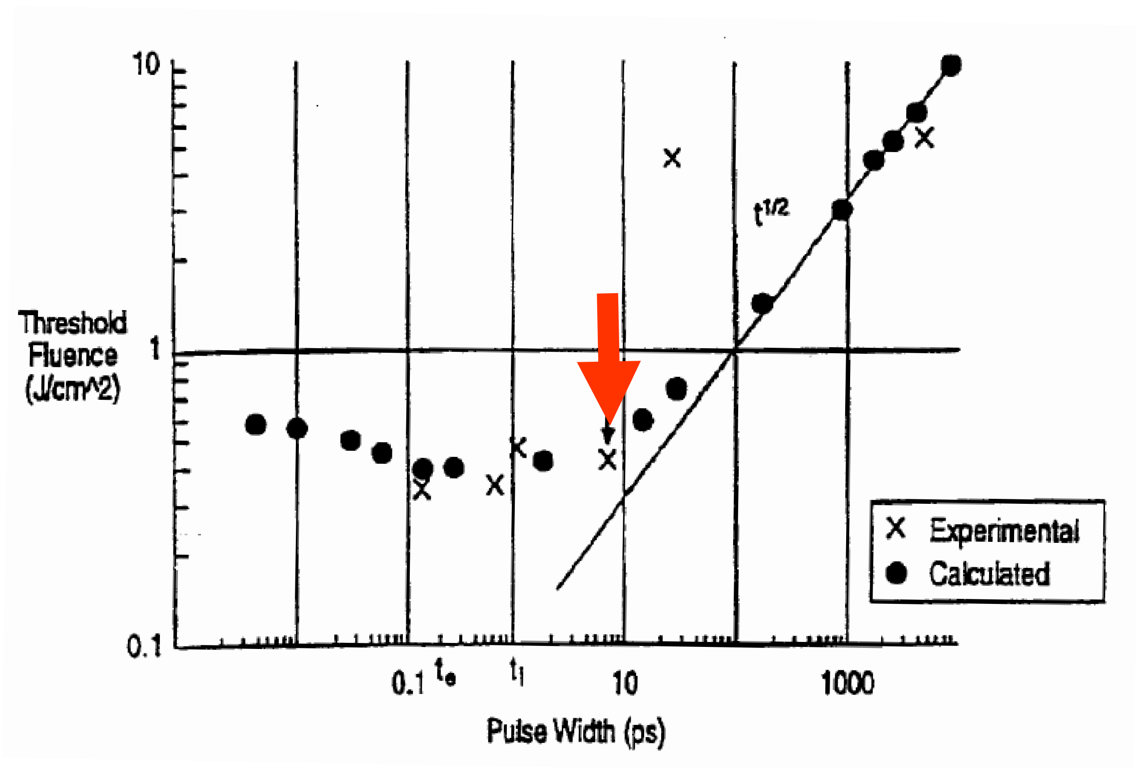
pico- or femtoseconds



Time-Bandwidth® Products

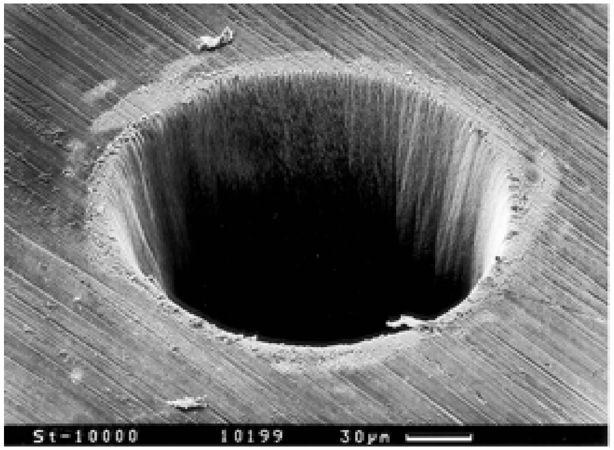
Material processing: "long" versus "short"

"Cold ablation" starts at around 10 ps pulsewidth



(Mourou et. al. 2002)

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



Why picoseconds?

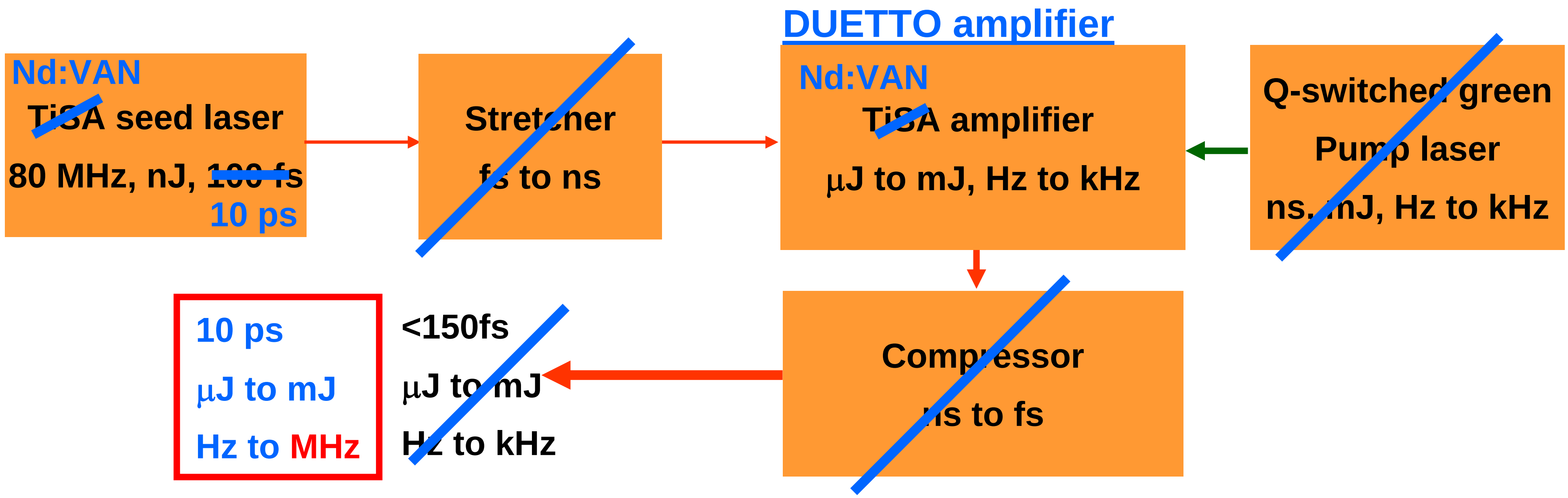
- **Substantial process advantages compared to nanosecond pulses for micromachining**
  - **smaller heat-affected zone**
  - **less micro-cracking**
  - **less recast**
  - **with substantially faster speed / productivity (depending on process)**
  - **higher quality ↔ higher speed ↔ (lower cost)**

- **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**
  - **“Most of the advantages of femtosecond lasers but much simpler / scalable”**

High power / high pulse energy picosecond amplifier

Why consider a picosecond amplifier and not a femtosecond amplifier?

- In the past – many positive research results in material processing with femtosecond Ti:sapphire amplifiers.
  <u>HOWEVER: too complex and too slow (low repetition rate)</u>



Picosecond amplifier system is much simpler, with increased reliability and ease of use

- ✓ Higher output power
- ✓ Higher repetition rate
- ✓ No stretcher and compressor, no Q-switched green pump laser

DUETTO™

Integrated master oscillator power amplifier (MOPA) diode-pumped picosecond laser

Seed oscillator

- 1 W average power
- 1064 nm wavelength
- High repetition rate (quasi-CW)
- based on proven LYNX design
- **Seeds amplifier stage with user selectable pulse repetition rate**

Pulse Picker

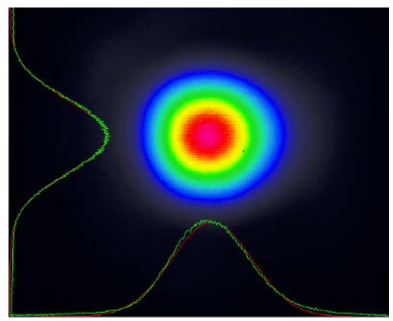
Amplifier stage

- > 10 W average power
- 1064 nm wavelength
- 50 kHz to 8 MHz repetition rate
- 10 ps pulsewidth
- M^2 <1.3 spatial mode quality
- based on proven CHEETAH design

DUETTO™ - integrated picosecond amplifier

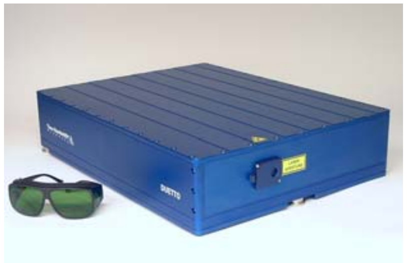
New class of robust industrial picosecond laser

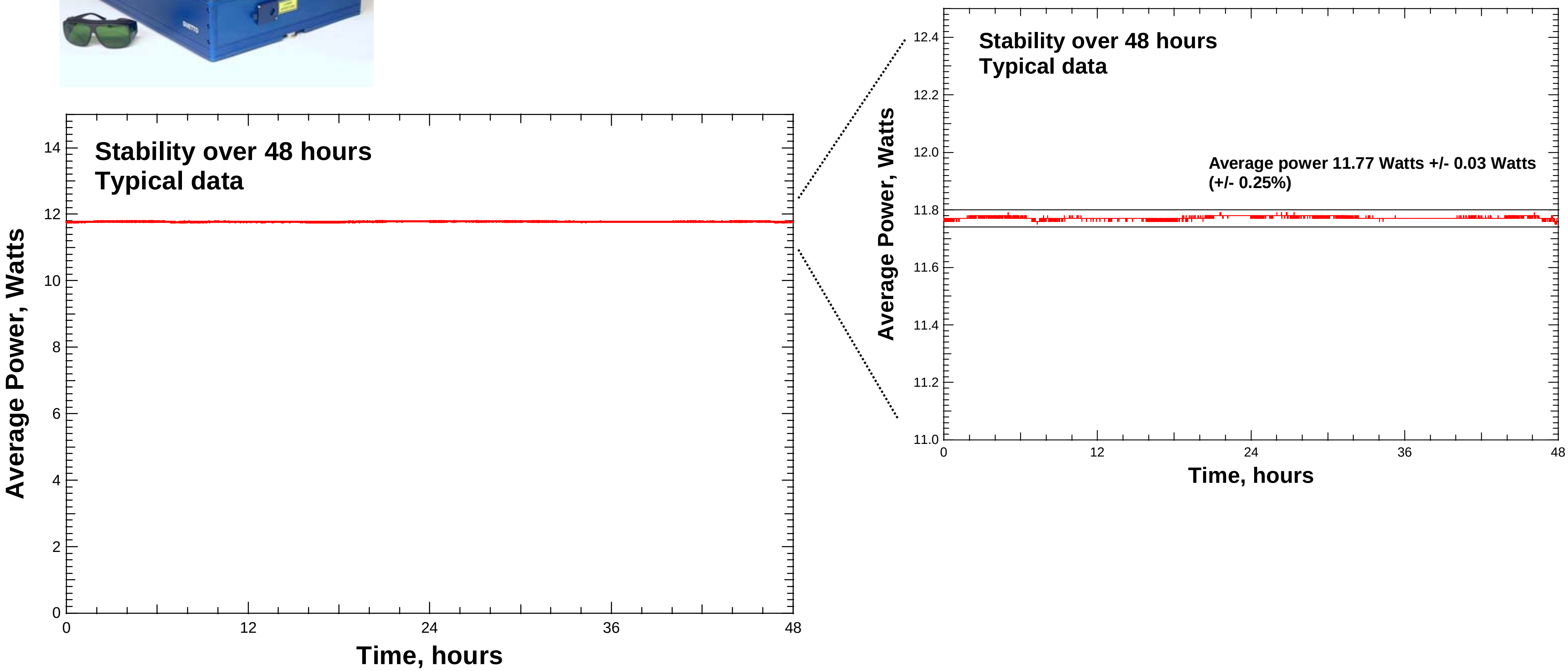
output power	> 10 W
repetition rate	50 kHz – 8 MHz
pulse energy	up to 200 µJ
pulse width	10 ps
peak power	up to 20 MW
wavelength	1064 nm
M^2 (TEM_{00})	< 1.3



DUETTO™ - integrated picosecond amplifier

Long-term stability required for industrial applications





Duetto: modular customizable approach

- 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 ablative processes
  - to 266 nm or other wavelengths also available

- Pulse on demand
  - Optional pulse-on-demand (POD) allows for individually triggerable pulses
  - or arbitrary groups of pulses
  - “perfect” pulse selector avoids pre-pulse or first-pulse overshoots typically of other systems

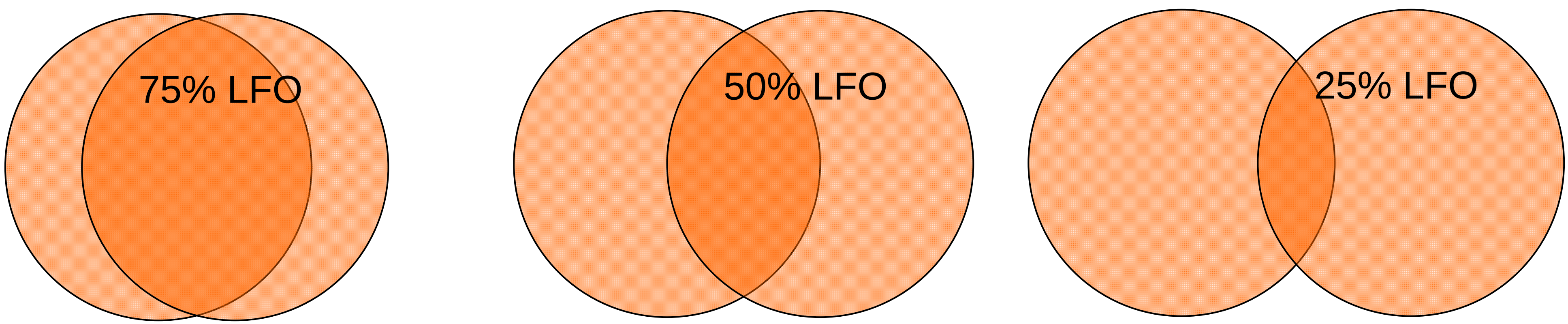
- Other options
  - timing synchronization to external clock with sub-picosecond accuracy
  - variable (switchable) pulsewidths
  - repetition rate at oscillator output (80 MHz typical)

Picosecond Micromachining Guidelines

- Energy density required for ablation typically 1 Joule / cm^2
- 10-100 nm layer removed per pulse: "gentle ablation"
- High repetition rates increase speed ➔ limited by scanner speeds and "LFO" = Laser Focus Overlap: "speed limit" due to spot size overlap
- ~10W average power: ~1 mm^3 / minute
- up to ~10 mm^3 / minute at 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 virtually no change in pulse and beam parameters
  - as opposed to Q-switched lasers where pulse quality and stability degrades as repetition rate increases
- Single-pulse processes 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 1 m/s at 200 kHz
  - maximum scan speed of 10 m/s at 2 MHz



Time-Bandwidth® Products

Applications

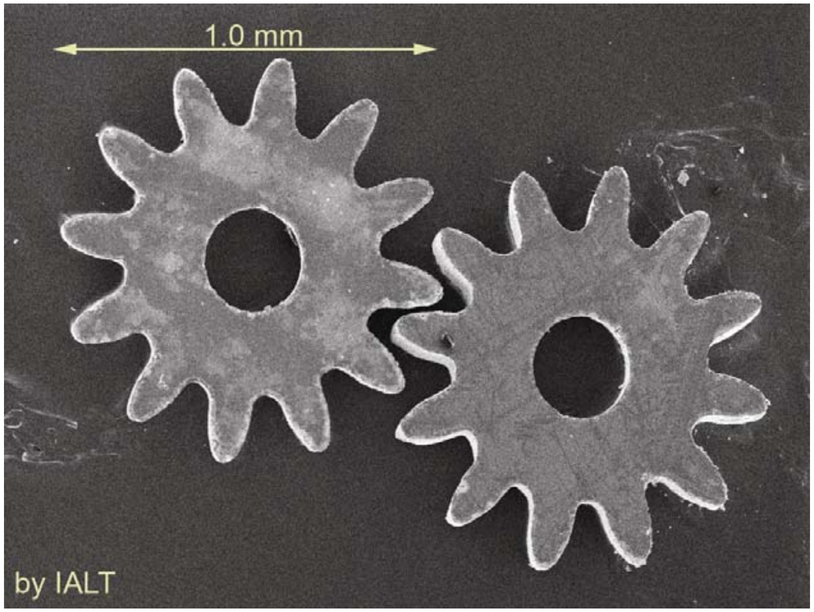
- **Metals**
  - very thin (thin-film)
  - precision holes (sub-100 μm)
  - surface features / tribology

- **Semiconductor**
  - hole / via drilling
  - ablative processes / structures
  - singulation

- **Dielectric**
  - structuring
  - selective ablation

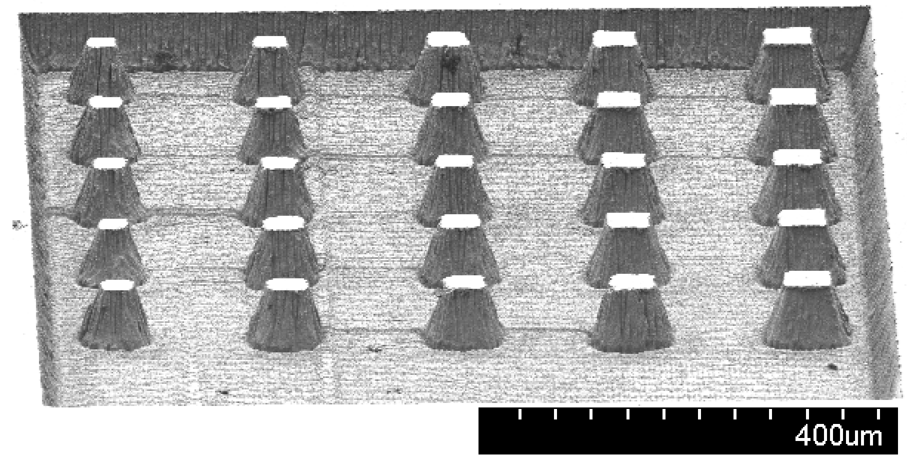
- **“Mixed” materials**
  - picosecond (IR or UV) can cleanly cut / ablate through combinations of the above materials
  - semiconductor: low-k coated chips
  - solar: thin-film technologies (CIGS, CdTe, etc)
  - medical: coated stents

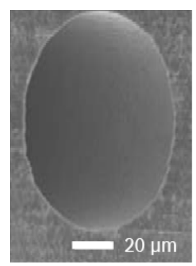
Application Examples of Duetto: Metals



Miniature gears in 50 μm stainless steel foil

Columns ablated in copper





Sub-100 μm holes (e.g. diesel injectors)

Application Examples of Duetto: Surfaces

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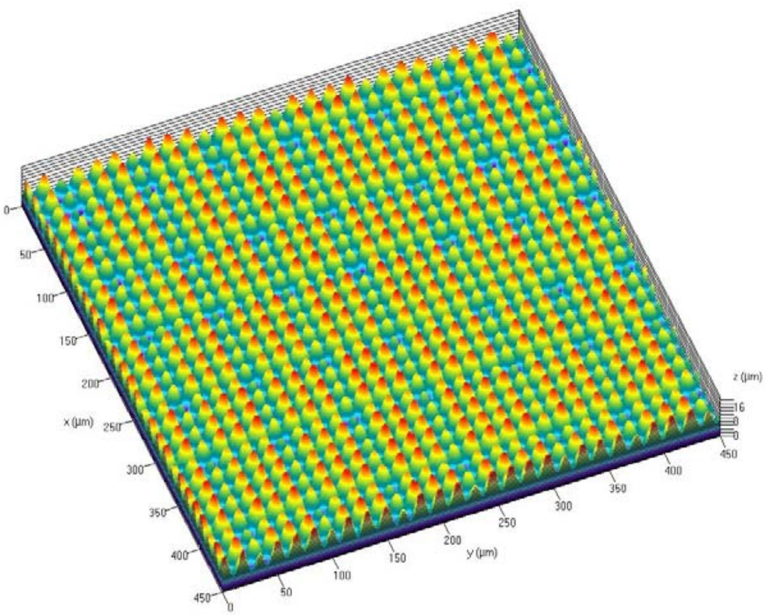
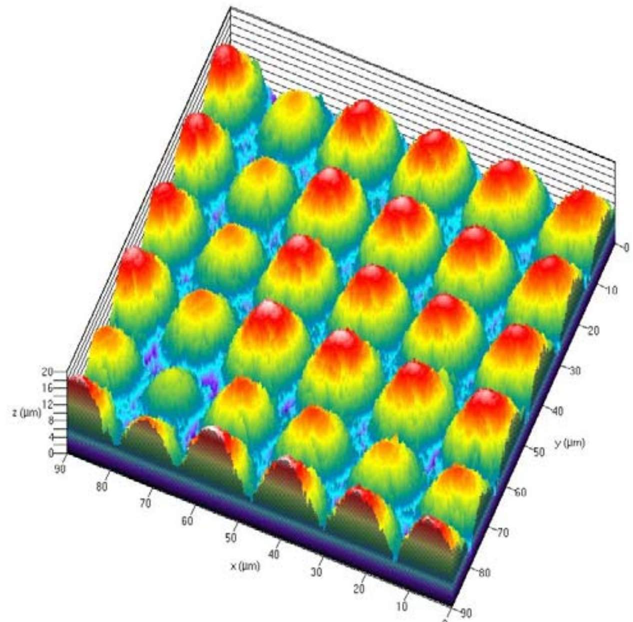
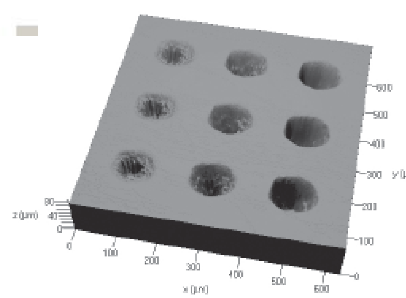
Tribology: microstructuring of surface features



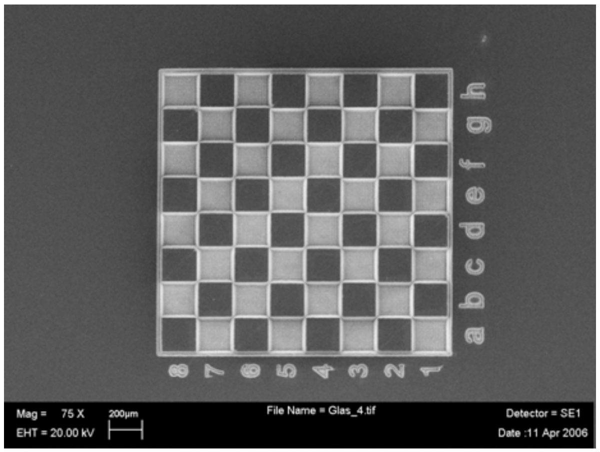


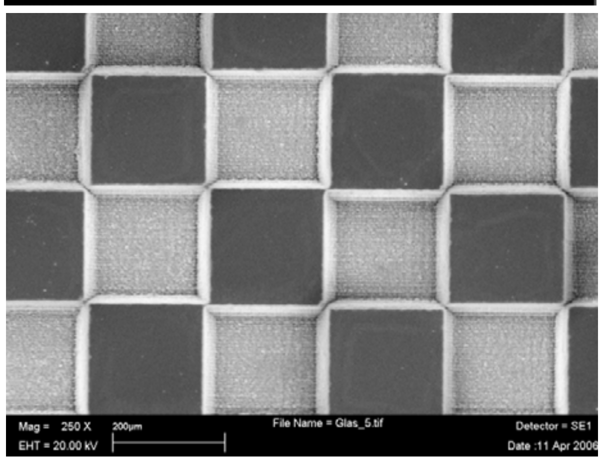
"Spikes" and "Dimples" on surfaces



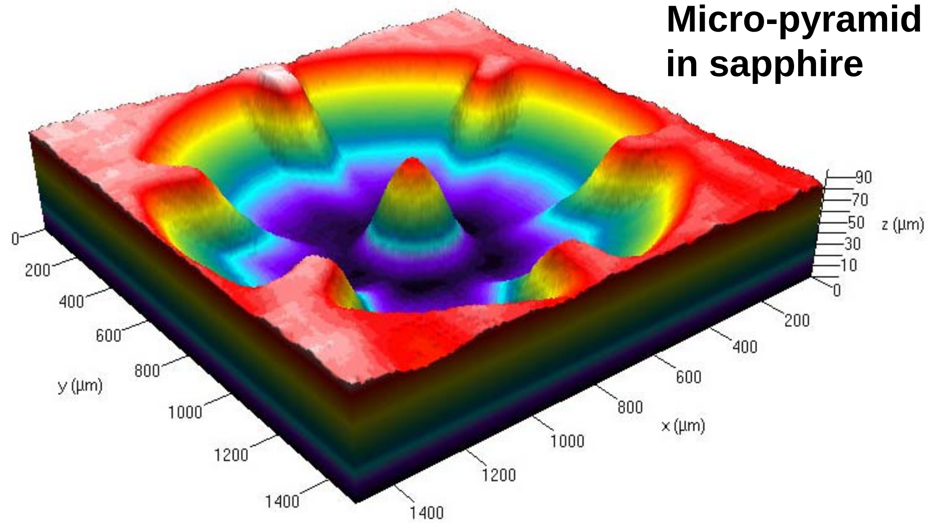
Application Examples of Duetto: Transparent Materials

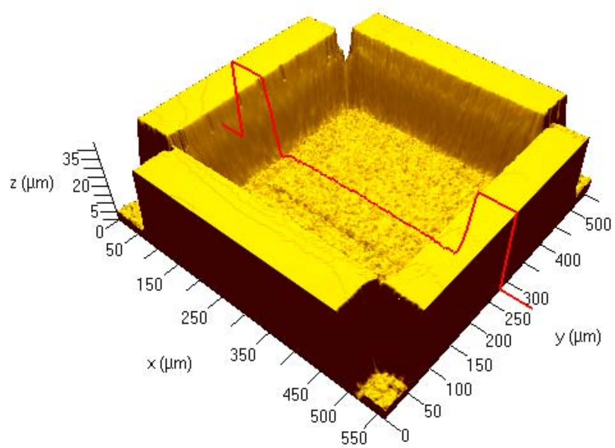
Checkerboard patterns on glass



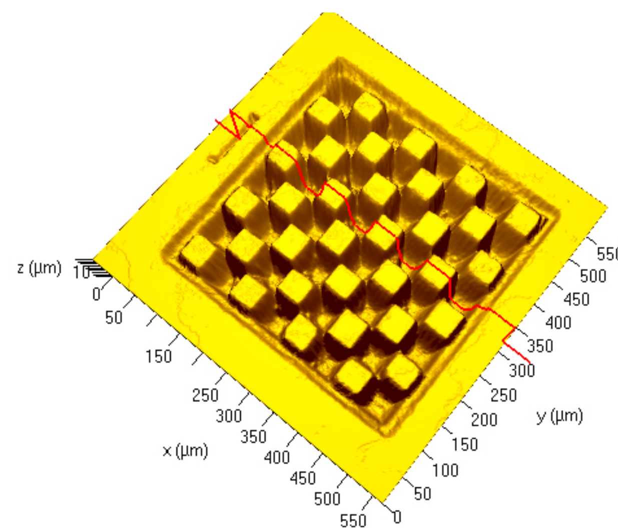


Micro-pyramid structure in sapphire





area: ~400 µm; depth: ~35 µm

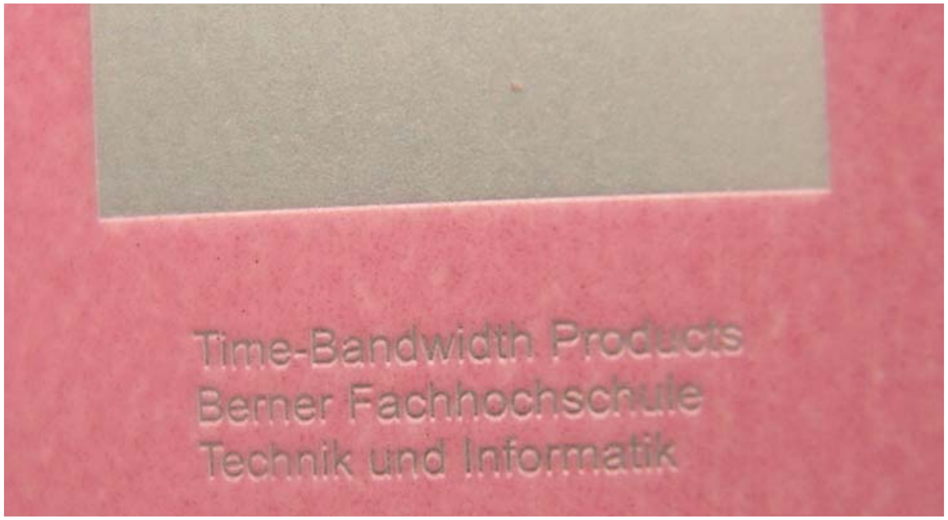


area: ~50 µm; depth: ~35 µm

Time-Bandwidth® Products

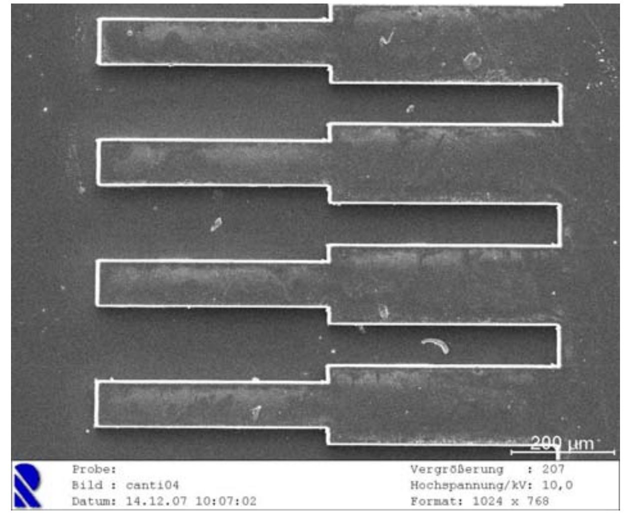
Pictures courtesy of IALT

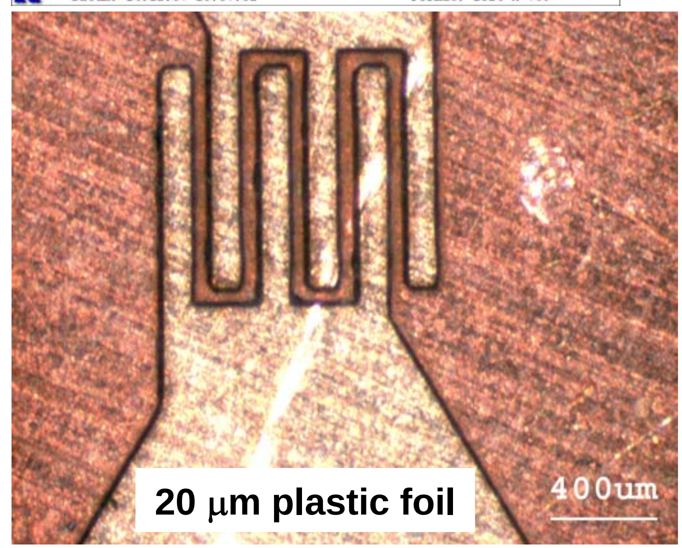
Application Examples of Duetto: Plastics, Polymers



Precise selective ablation of layers on polymer substrate

Plastic cantilevers 20 μm thickness





20 μm plastic foil

Application Examples of Duetto: Others

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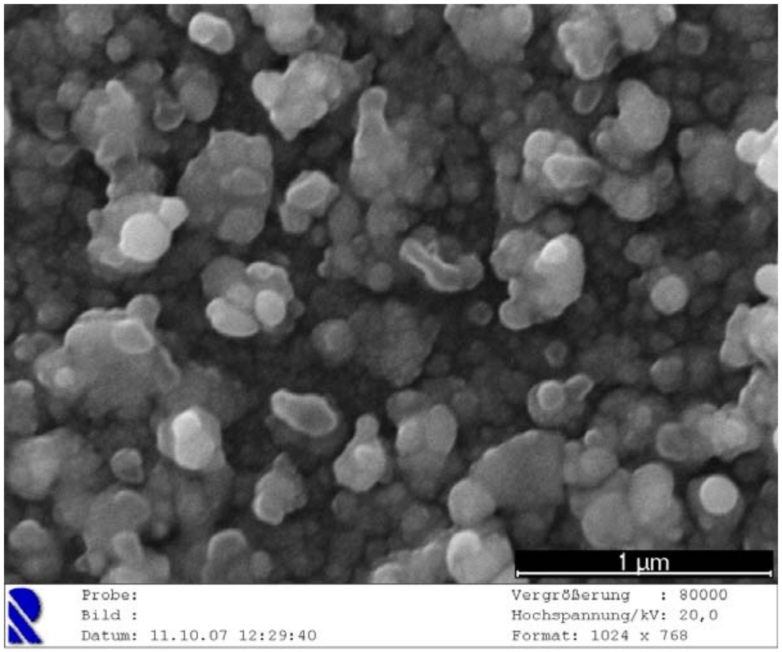
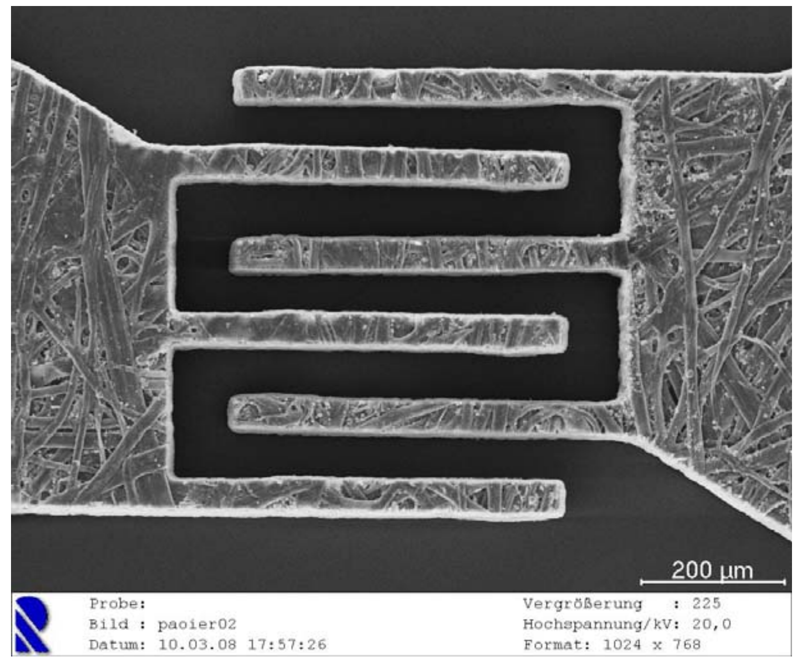


Deposition of Nanoparticles
(Laser Induced Plasma Assisted Ablation LIPAA)



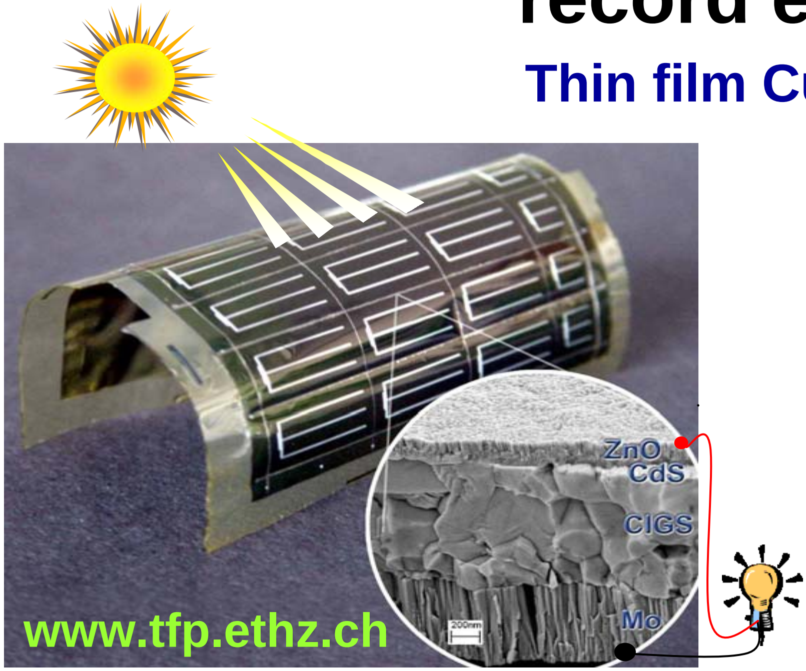
Micro-cutting of paper

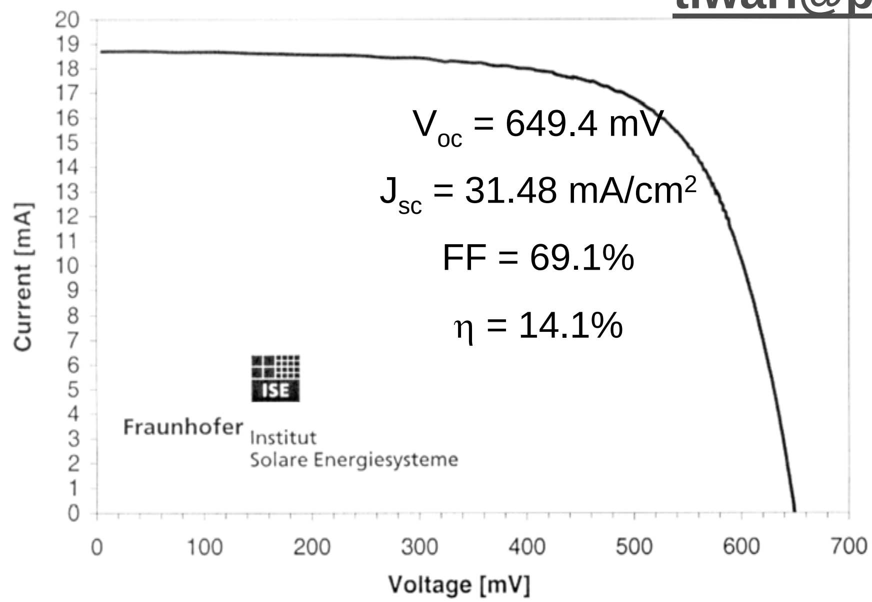
(no residual burning / damage)

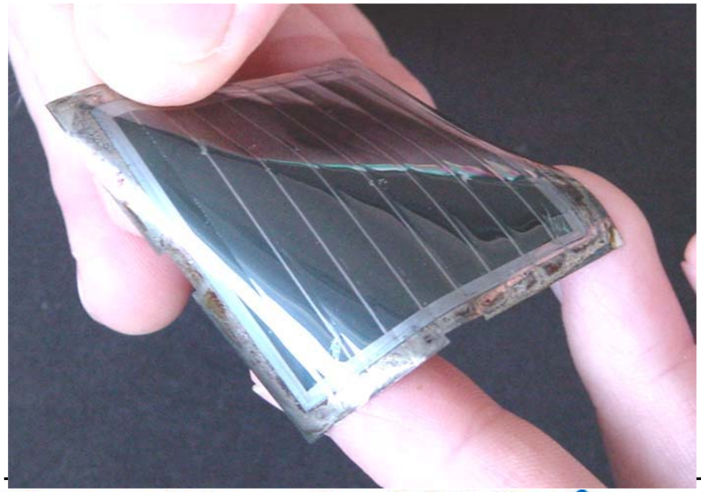
Lightweight and flexible solar cell on polyimide World record efficiency of 14.1%

Thin film $Cu(In,Ga)Se_2$ solar cell

tiwari@phys.ethz.ch

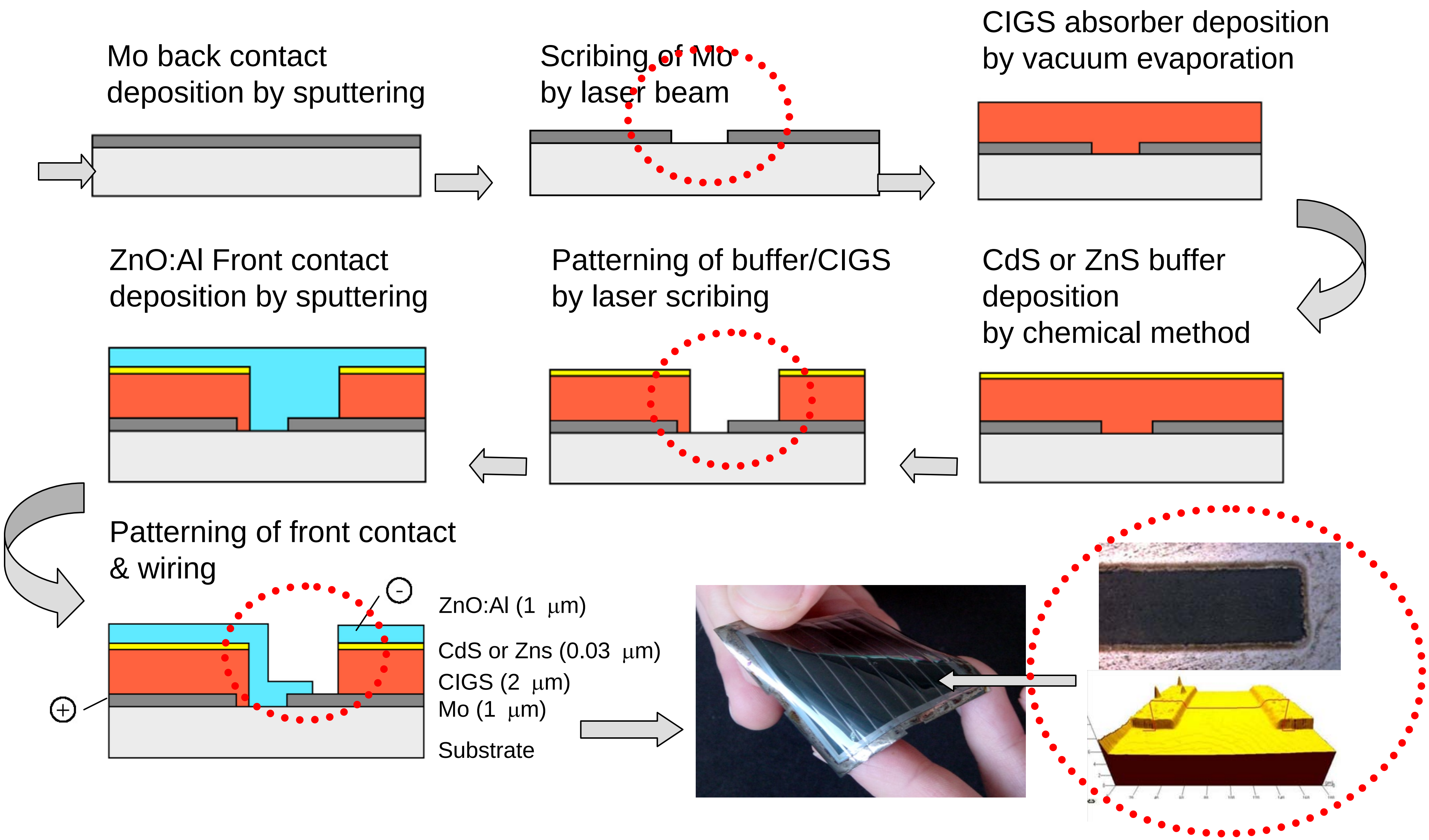




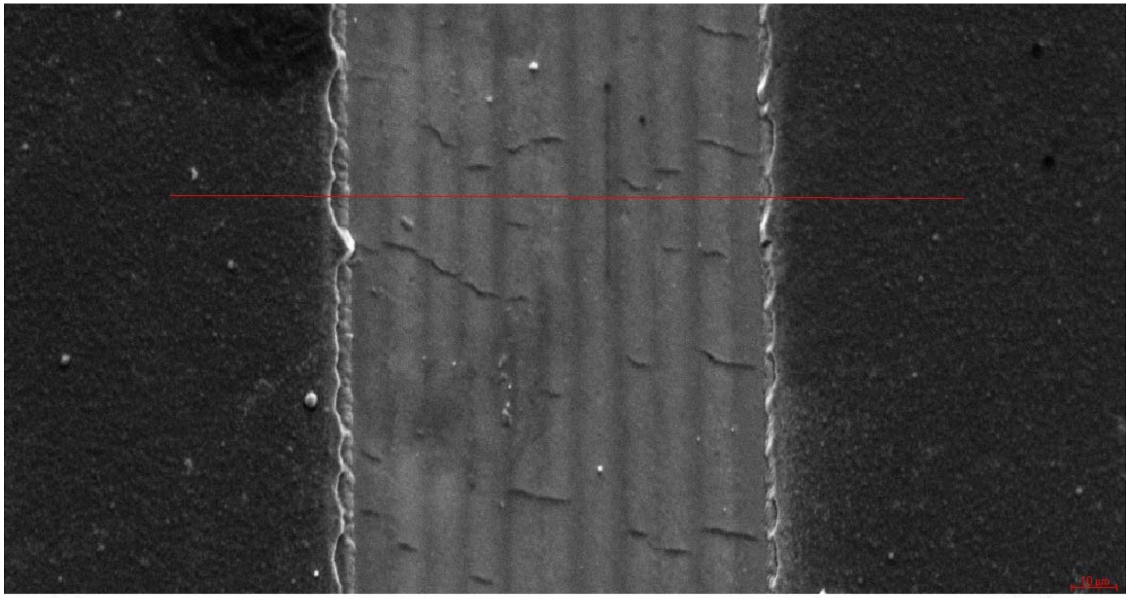


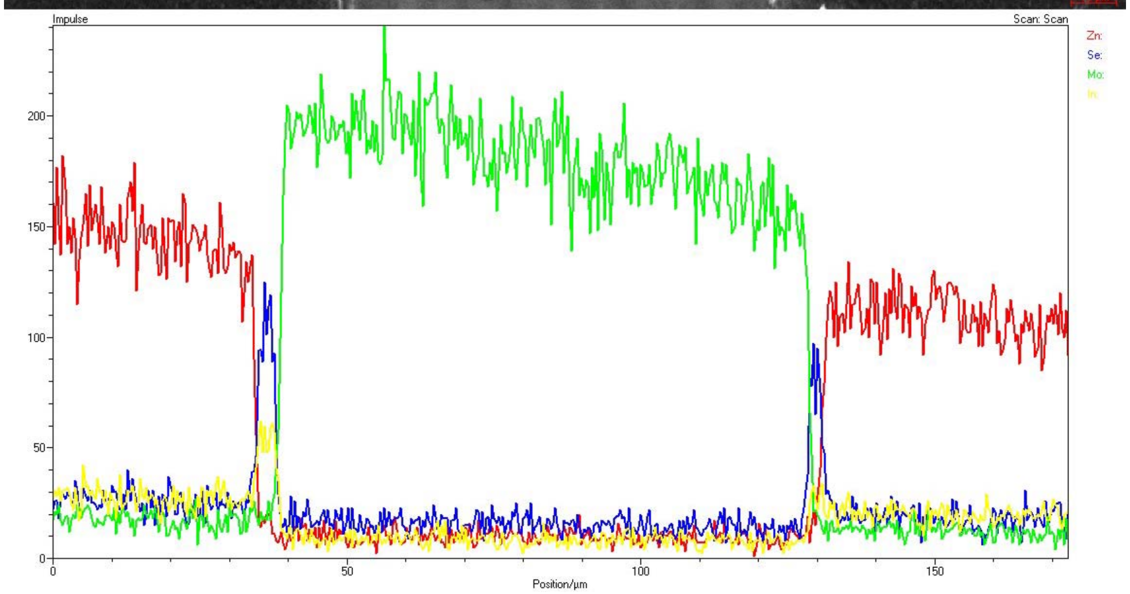
- Multifunctional layers and heterostructures
- Large area coatings with vacuum and chemical processes
- Laser scribing and patterning of structures
- Monolithically interconnected solar module

Monolithic interconnection in CIGS solar modules



Application Examples of Duetto: Thin-film solar





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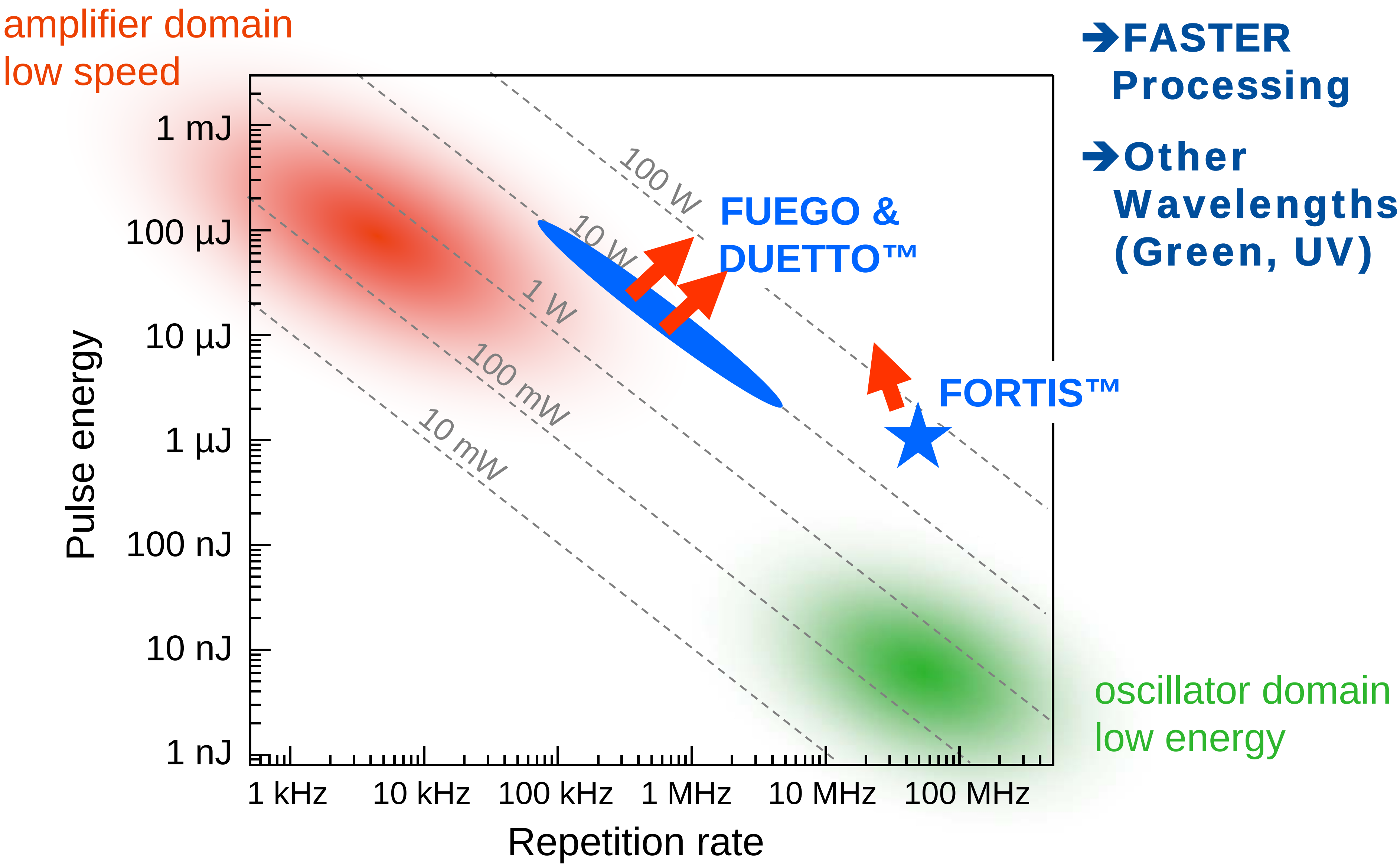
- **Effective selective ablation**
  - **different wavelengths for different material combinations P1 / P2 / P3**
- **High-quality**
  - **no substantial heat affected zone or damage to neighboring material**
  - **no damage of underlying layers**
- **Fast**
  - **Material remove rate is small**
  - **LFO sets speed limit**
  - **Ultimate challenge is scanner speed and accuracy combined with roll technology**

The future: MORE POWER



➔ **FASTER Processing**

➔ **Other Wavelengths (Green, UV)**

Summary

- **Picosecond lasers offer improved quality and faster processing speed for “fine” ablation processes**
- **Duetto – flexible picosecond system for micromachining**
  - **Flexible and broad repetition rate changing for process optimization**
  - **Wavelength flexibility (IR, green, UV)**
- **Thin-film applications**
  - **Semiconductor, biotech, solar cell, security**
- **Future outlook: Higher power ⇔ higher pulse rates ⇔ faster processing speed (ultimately limited by scanner / beam delivery technology)**

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

Many Thanks

- **To Professor Beat Neuenschwander and team at IALT in Burgdorf for all the application support!**