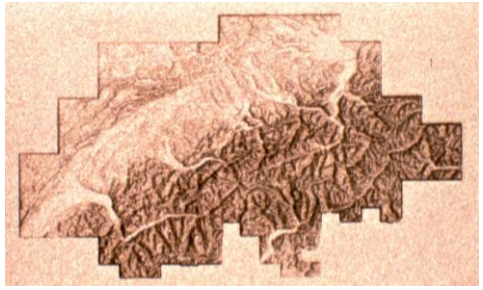
Powerful, flexible, and cost-effective picosecond lasers for industrial micromachining



Dr. Kurt Weingarten

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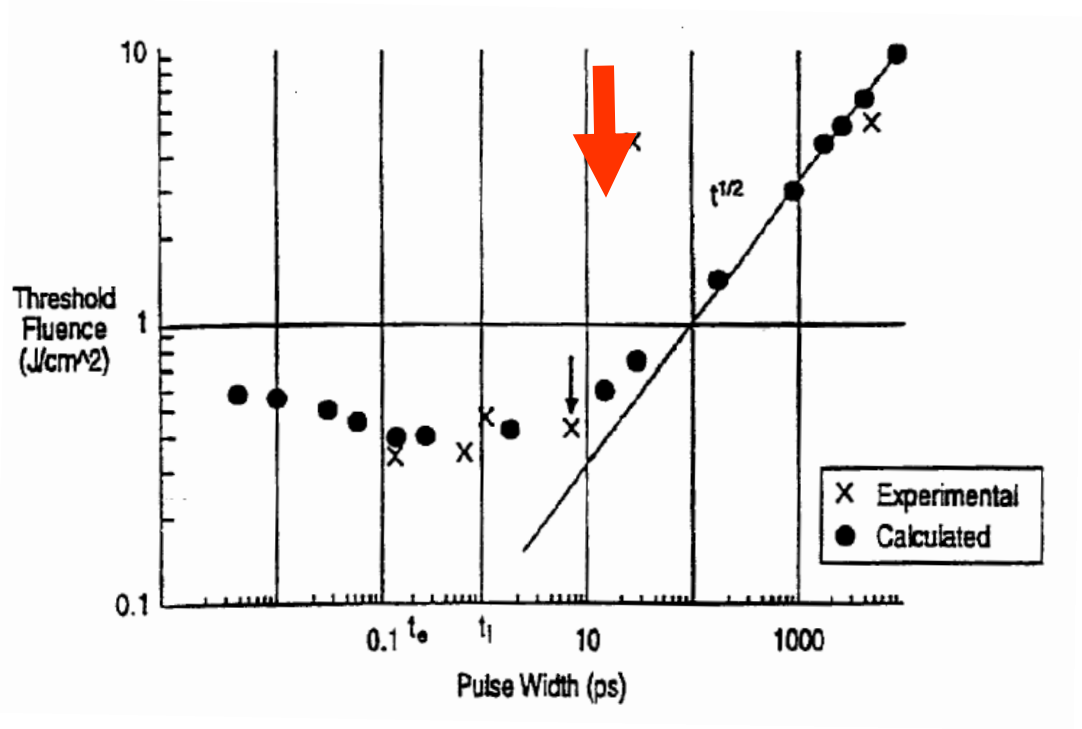
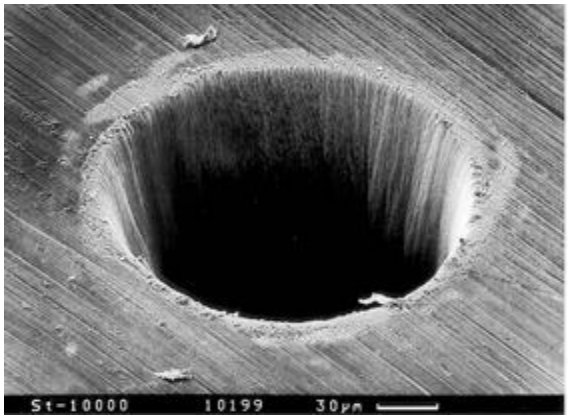
Material processing: "long" versus "short" pulses

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**
  - **bandwidth of femtosecond pulses can degrade scanner performance**
  - **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 product family

Master Oscillator Power Amplifier diode-pumped picosecond laser system - architecture

Seed oscillator

- based on Lynx industrial laser with >decade of proven field reliability
- 10 nJ, 10 ps, 1064 nm pulses
- **High-rep pulses seed amplifier stage with user-selectable pulse rate**

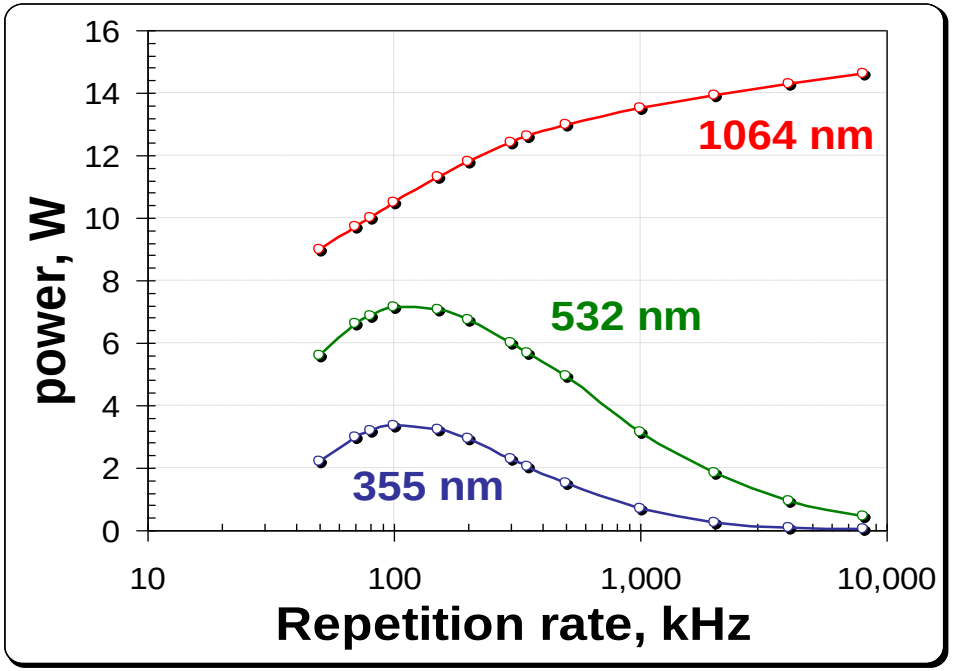
Pulse Picker

Amplifier stage(s)

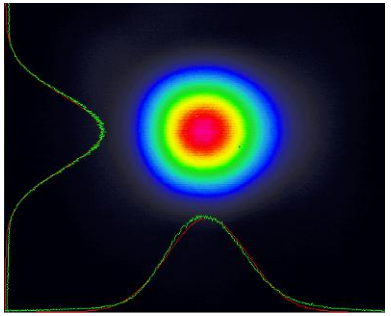
- based on field-proven 10W Cheetah system
- amplifies to >100 µJ (>40 dB gain)

Duetto Integrated MOPA

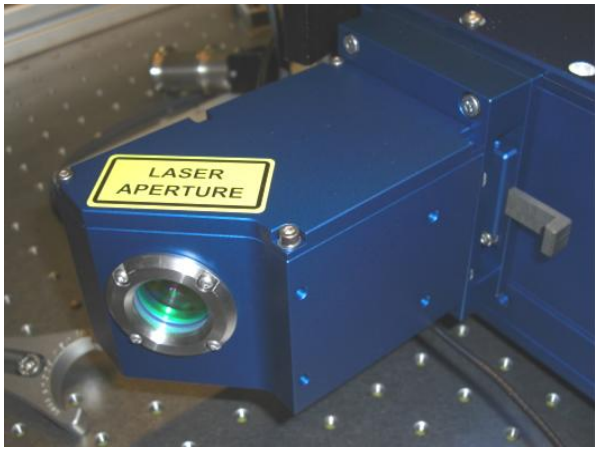
DUETTO - key performance parameters



output power	up to 15 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



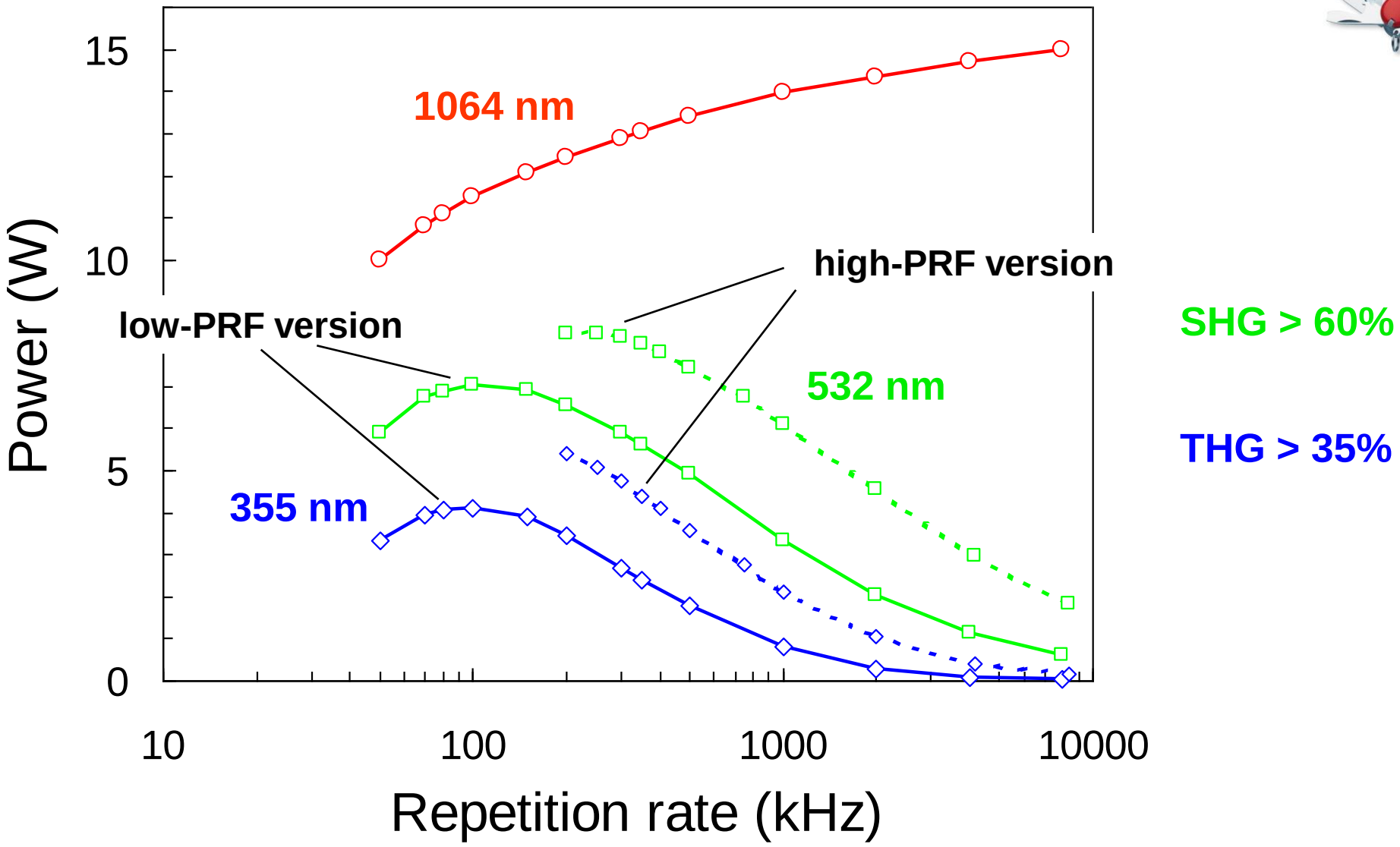
DUETTO family of modular customizable options



- FUEGO power booster to >50W average power
- Frequency Conversion
  - to 532 nm (green): >60% conversion efficiency
  - to 355 nm (UV): >35% conversion efficiency
  - to 266 nm or other wavelengths also available
  - fixed, manual, or auto (software) switching
- Pulse on demand – POD - highest speed pulse control
  - Individually triggerable pulses single-shot to 4 MHz, digital or analog gating
  - or arbitrary groups of pulses
  - prevents typical pre-pulse or first-pulse overshoot often seen in other systems
  - FlexBurst™ technology
- Other options
  - timing synchronization to external clock with sub-picosecond accuracy
  - variable (switchable) pulsewidths
  - repetition rate at oscillator output (80 MHz typical)

⇨ **Optimized parameters for targeted process**

Flexibility: Wavelengths

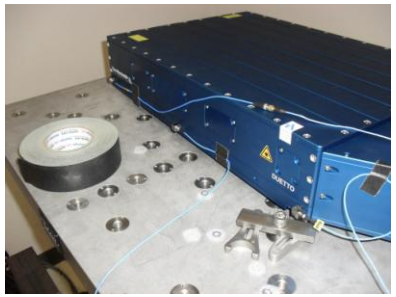


SHG > 60%

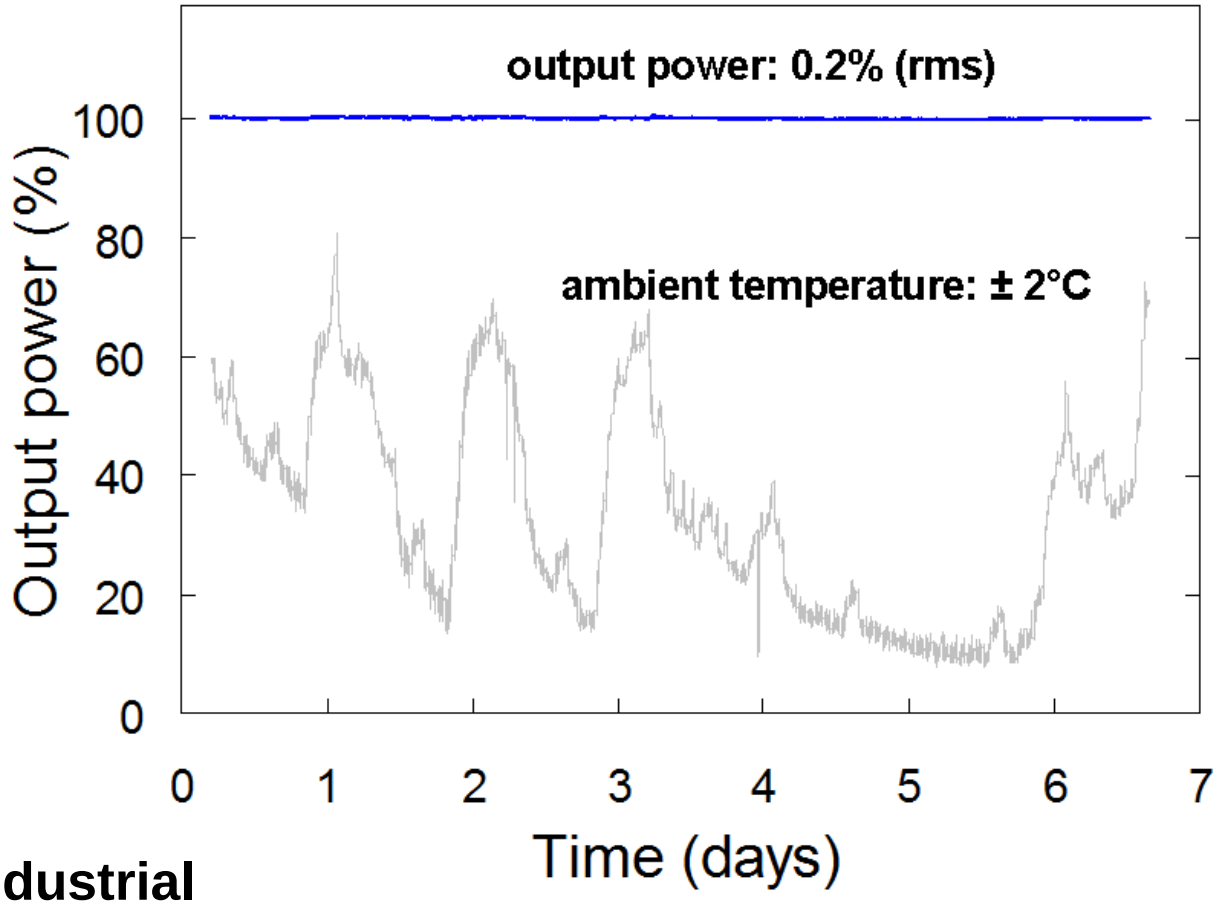
THG > 35%

Time-Bandwidth® Products

DUETTO – excellent long-term stability characteristics

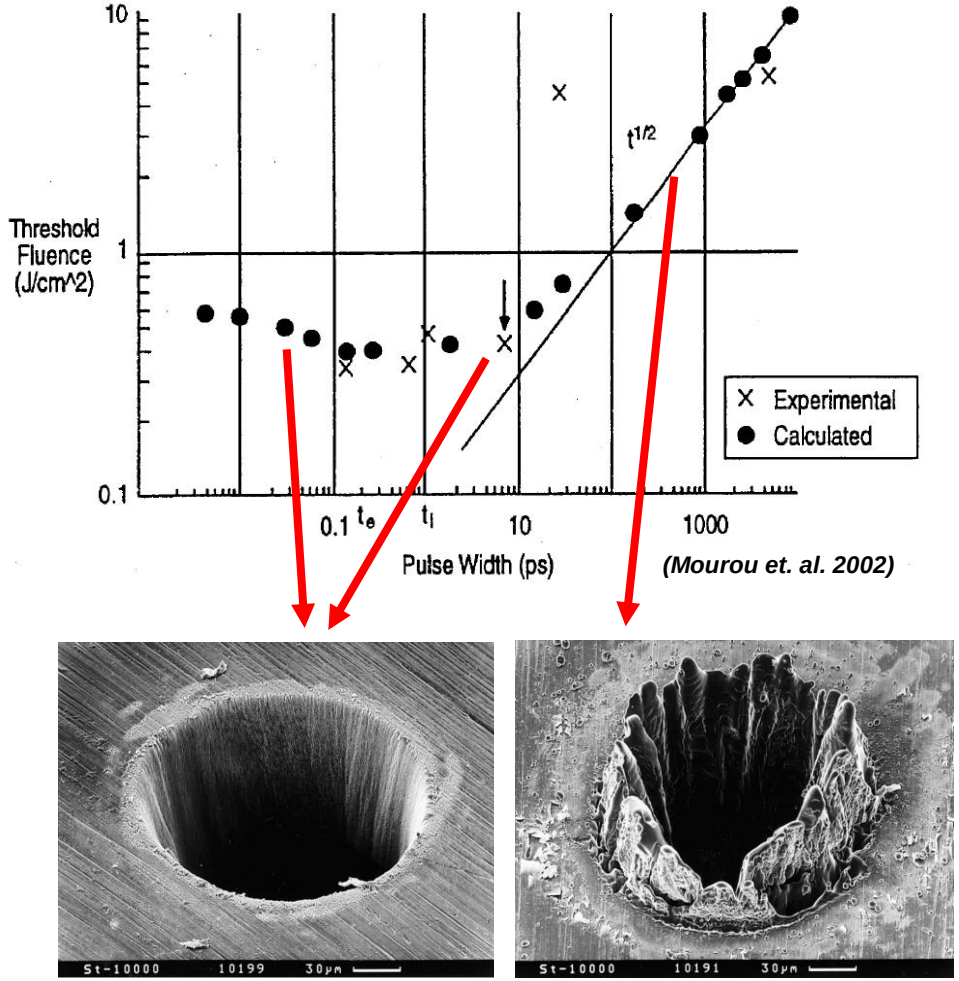


passes standardized industrial shock and vibration testing



Cold ablation – simple guidelines

Cold ablation ⇨ operate near threshold fluence ⇨ need moderate pulse energy



Chichkov, et al., *Appl. Phys. A* **63**, 109 (1996)

$$fluence = \frac{pulse\ energy}{beam\ area}$$

High quality ablation is a *gentle* process, it requires:

- ✓ short pulses
  typically < 10 ps
- ✓ high enough fluence
  typically > 1 J/cm^2

&

- ✓ not too high fluence
  typically < 2 x threshold

Typical cold ablation numbers

Example :

$F_{threshold}$ = 1 J/cm^2

$F_{operation}$ = 1.5 J/cm^2

Area = 500 μm^2

(~25 μm spot diameter)

} E = 10 μJ at focus

high quality processing

⇕

moderate pulse energy

"True" variable pulse rate is important

High power, fixed pulse rate laser (e.g. 40W, 400kHz, 100μJ) :

typical process requires 10μJ → MUST ATTENUATE 10X

High power, variable pulse rate laser (e.g. 40W, *200kHz – 8MHz, 200μJ – 5μJ*) :

typical process requires 10μJ

→ set pulse rate to 4MHz (and use full laser power)

Variable pulse rate gives more speed

Typical ablation rate (for most materials):

$r_A = 0.1\ mm^3/min$ per Watt

⇨ slow ⇨ speed is an important (cost) factor

process speed = laser power * r_A

determined by material & process

laser power = E * PRF = F * A * PRF

Pulse Repetition Frequency

beam area ← *process feature size*

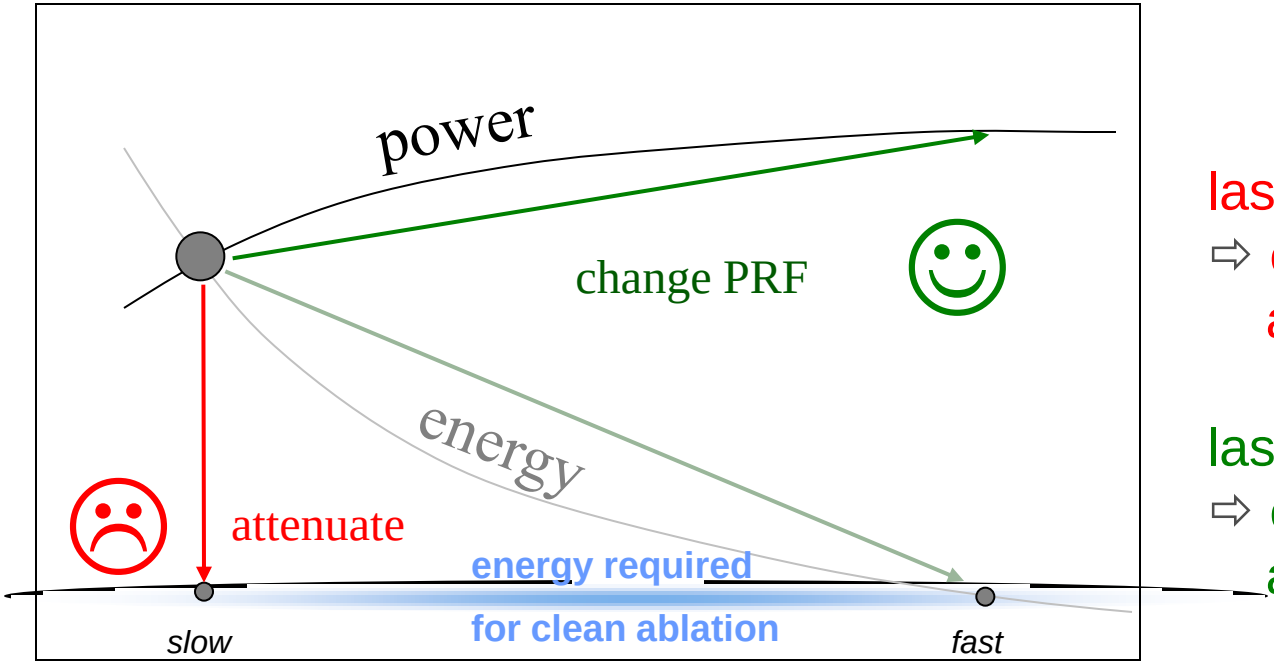
pulse fluence ← *just above ablation threshold*

pulse energy E determined by material and process requirements

process speed = F * A * r_A * PRF

set by material and process

“True” variable pulse rate gives speed



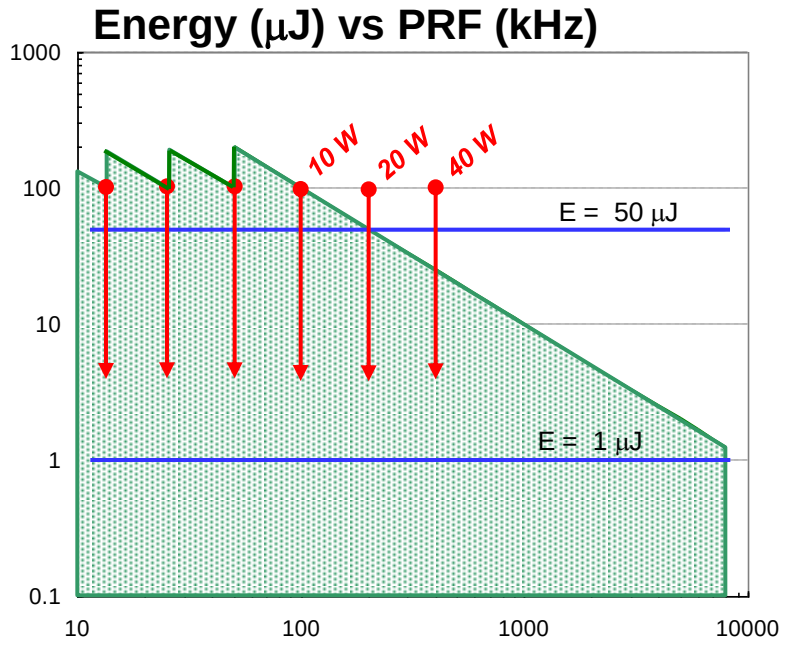
laser # 1: fixed PRF
⇨ energy must be adjusted via attenuation

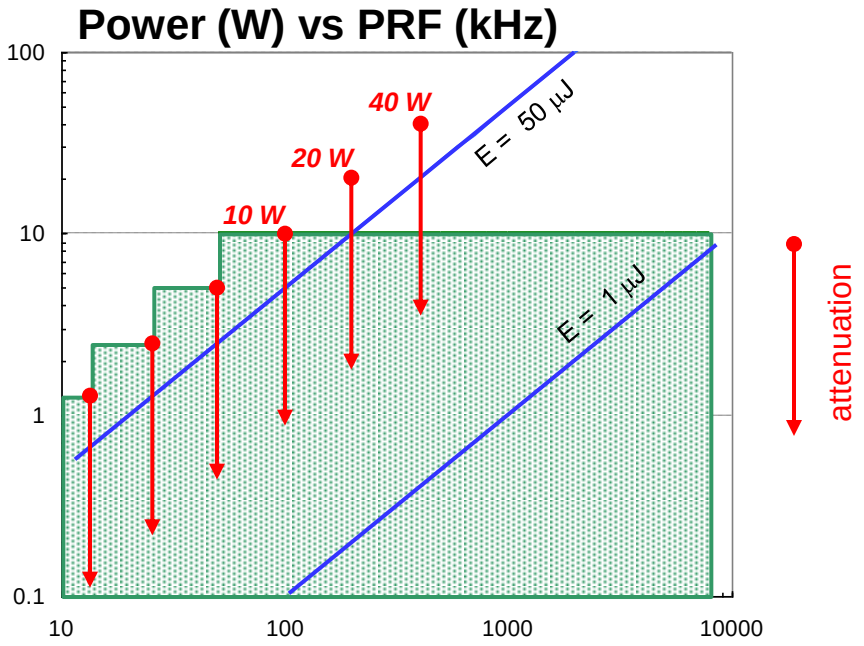
laser # 2: variable PRF
⇨ energy can be adjusted via PRF

PRF [= process speed]

variable PRF ⇔ higher process speed

Variable PRF - better process optimization





blue curves: areas between E=1 μJ and E=50 μJ denote parameter space for typical applications
laser # 1: fixed PRF (40W @ 400kHz), equipped with "pulse on demand" system
⇨ covers red arrows in parameter space
laser # 2: variable PRF (10W @ 50kHz-8MHz), equipped with "pulse on demand" system
⇨ covers green area in parameter space

Although laser # 1 is more powerful (40W), laser #2 (10W) covers a much broader area in the application parameter space due to the flexibility of its PRF. This is a clear advantage because the parameter window for many applications is small and thus requires fine adjustments of the pulse energy as well as the PRF.

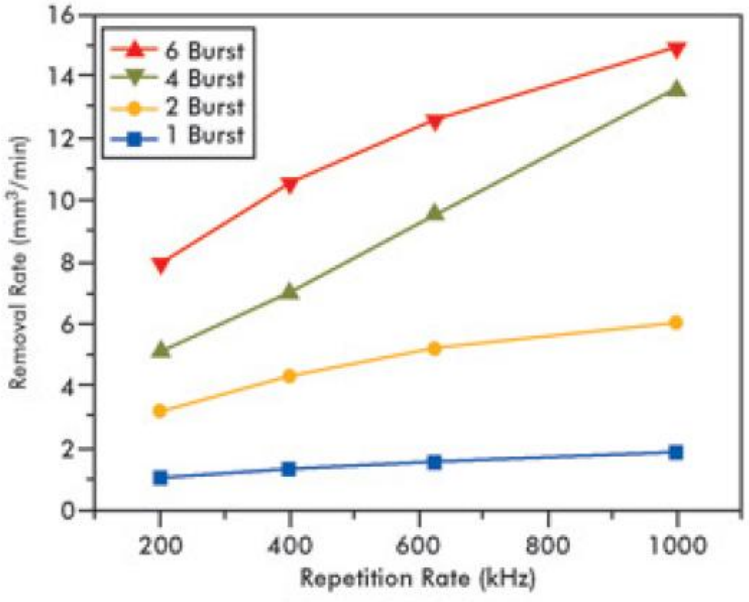
!

Flexibility: Pulse on Demand option

Pulse on Demand (PoD) – full user control over DUETTO pulse timing

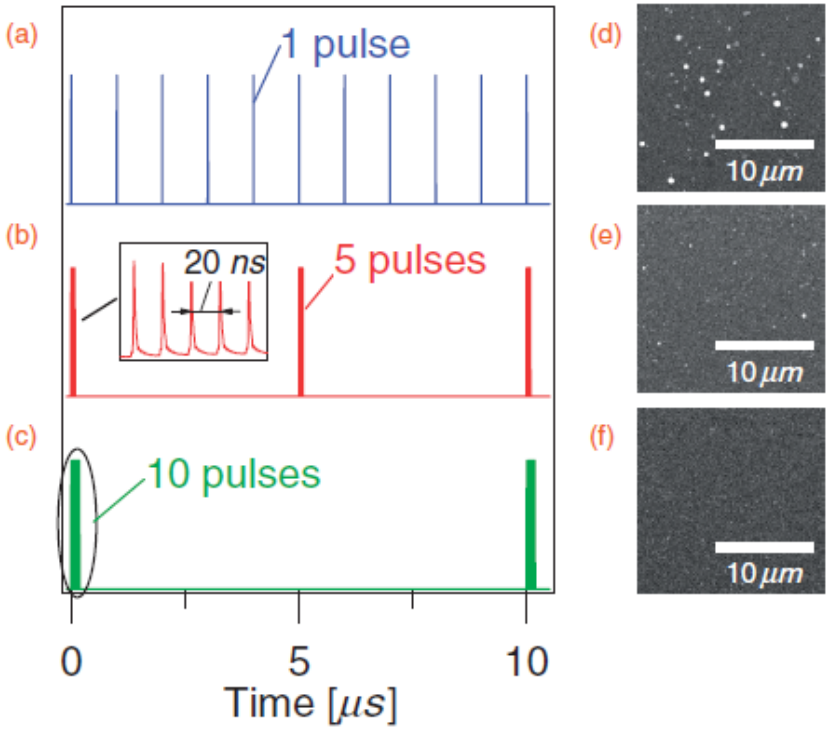
- Fast digital switching (pulse / no pulse) with single-pulse precision up to > 4 MHz with **no first-pulse problem**
  - via TTL user input or software-controlled
- Fast analog modulation (e.g. attenuation)
  - via analog user input or software-controlled

Flexibility: Why burst mode?



Burst mode increases ablation rate

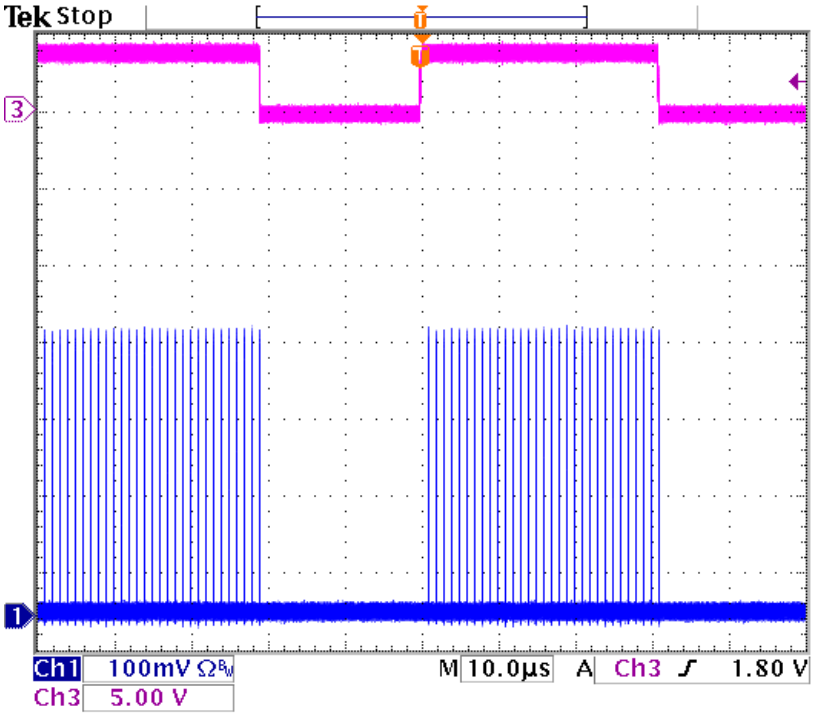
Phot. Spectra, issue 11, 2009.
(Ablation of Si)



Burst mode improves deposition rate and surface smoothness

Applied Physics Express 2 (2009) 042501
(Deposition of TiO_2 thin film)

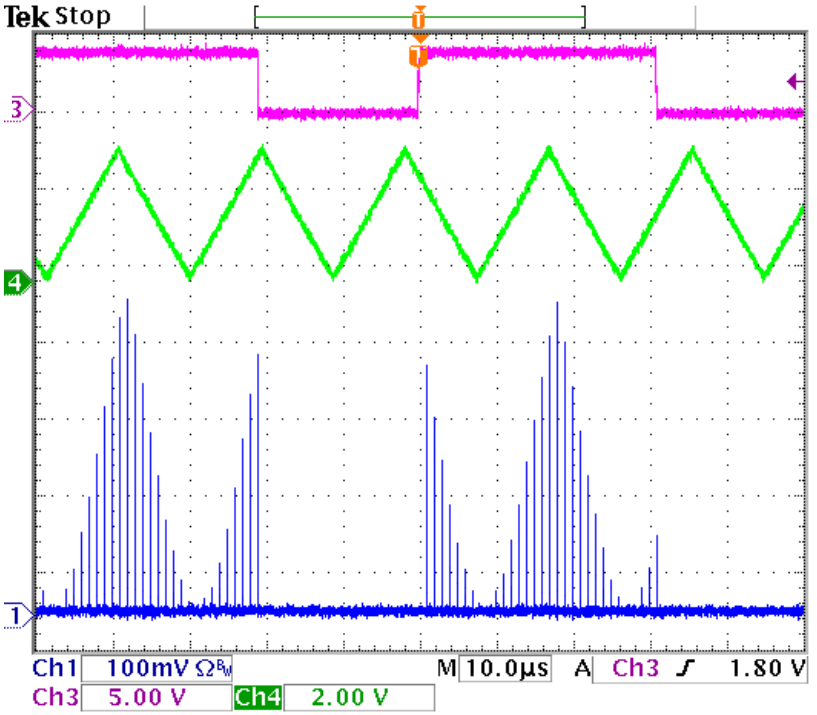
Flexibility: PoD digital & analog modulation



Digital input (TTL)

Analog user input

Optical output

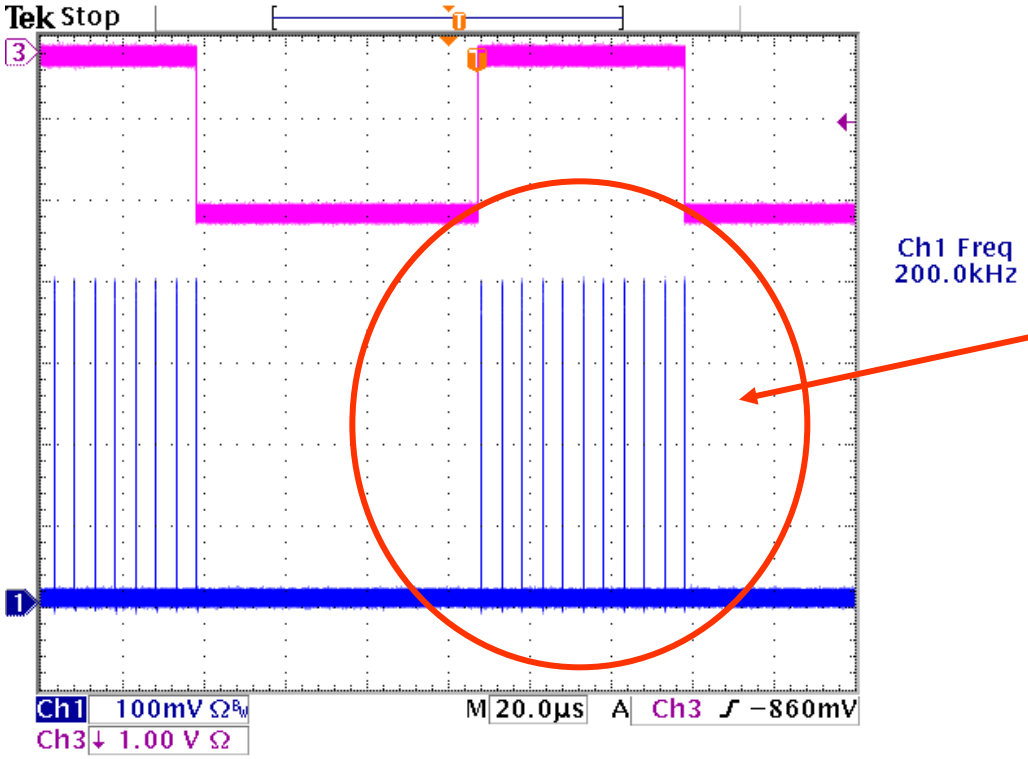


⇒ **Fast and simple analog modulation (e.g., attenuation of laser output)**

Flexibility: FlexBurst™ feature

First, some terminology:

Burst: a group of pulses with a spacing in the order of 10 nanoseconds.
The burst is repeated with the PRF.



We do <u>NOT</u> call this burst...
Spacing of pulses is
5 microsec (= 1/200 kHz)

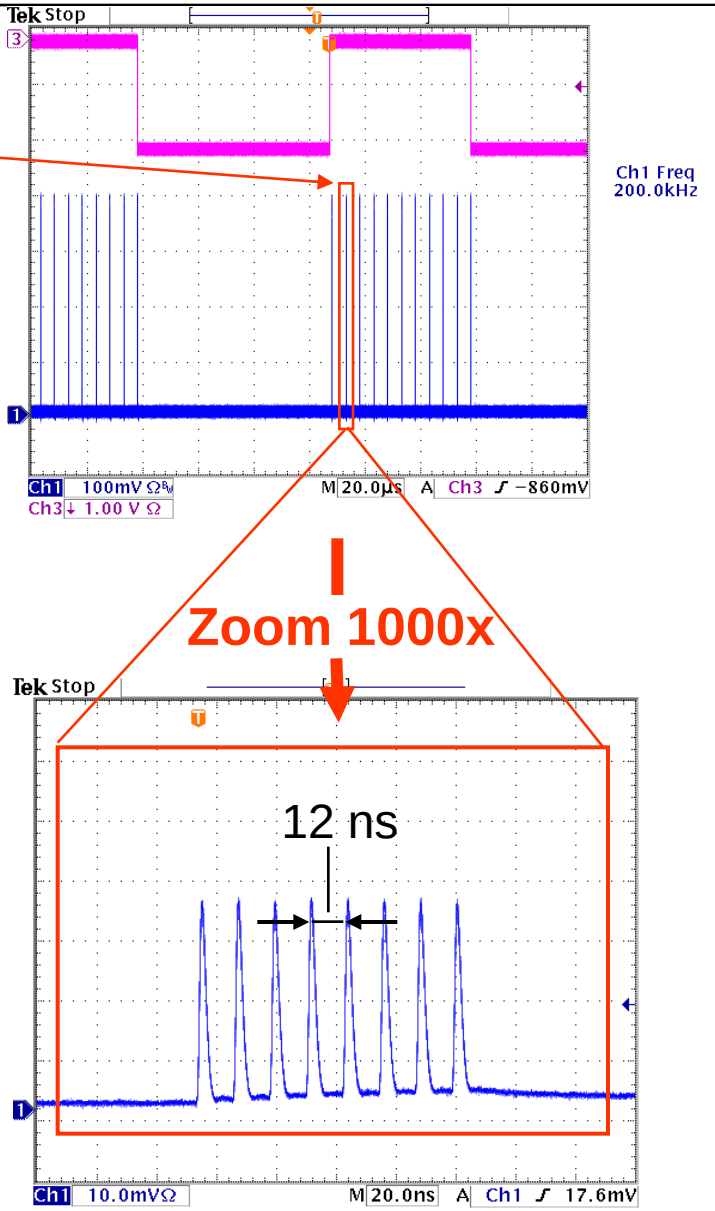
Flexibility: FlexBurst™ feature

... but each of these "lines" can consist of a <u>burst</u>

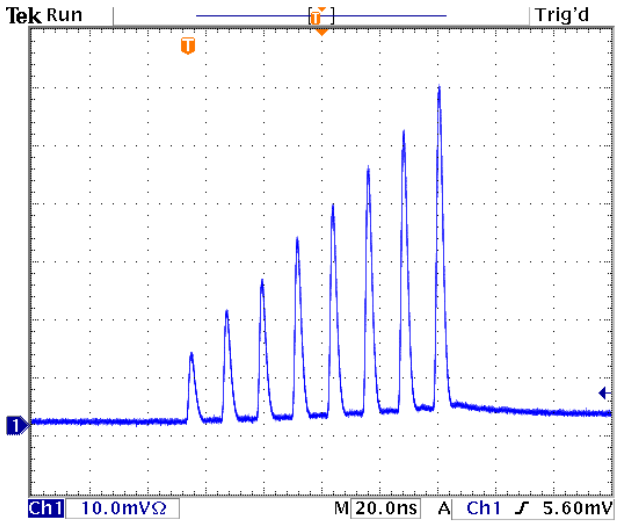
A regenerative amplifier can offer you this...
(with single pulses)

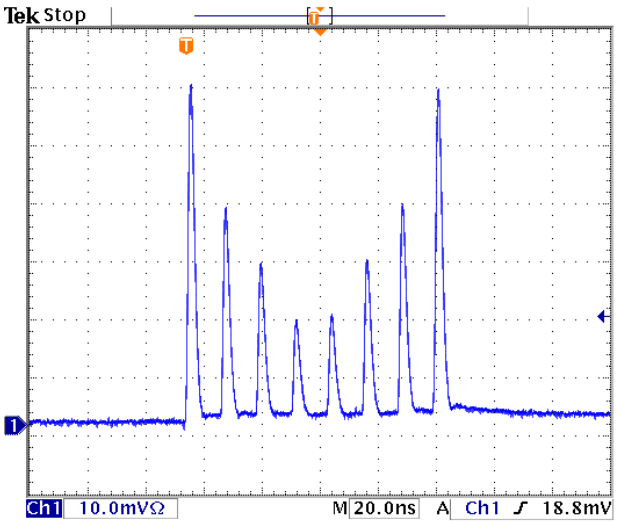
...but not this!

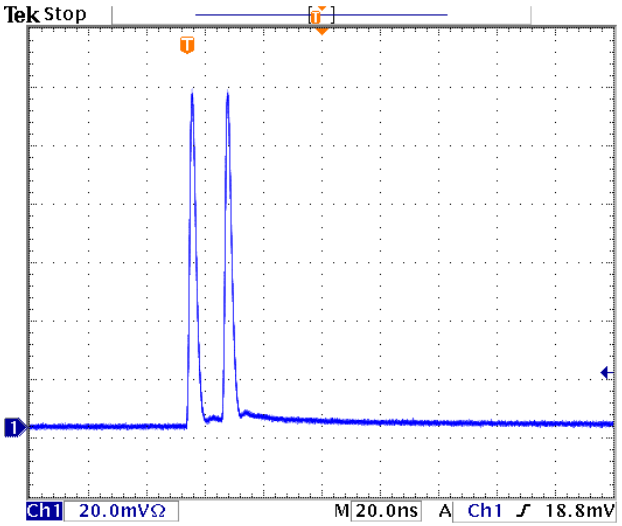
FlexBurst™!

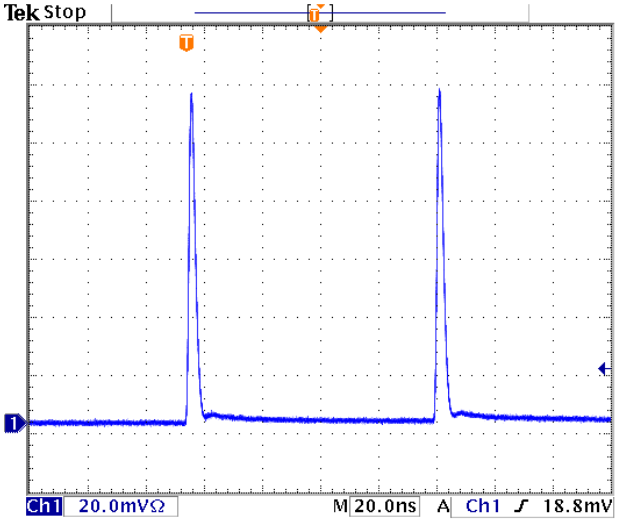


Flexibility: *FlexBurst*™ – a few examples





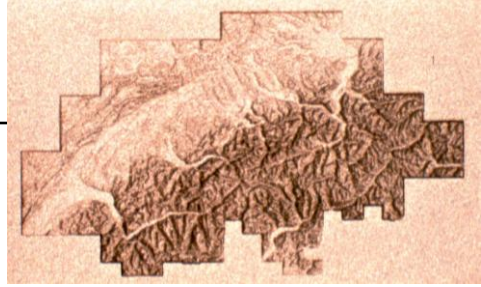




Summary

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

Thanks for your attention!



DUETTO™ product family offers

- Modular options
- Flexibility
- Industrial Reliability
- Optimized process
- Cost-efficiency