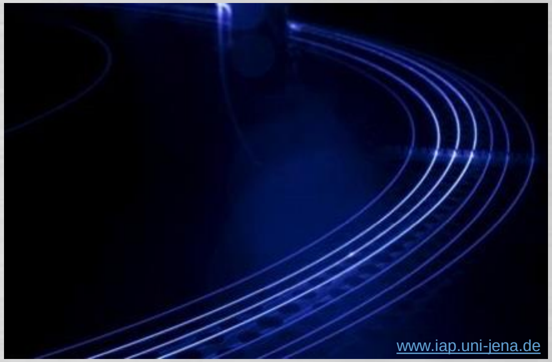
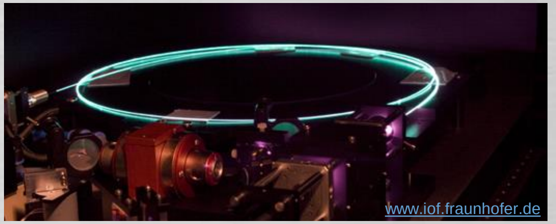
Requirements on delivery fibers in manufacturing processes

EWAG AG, 09.12.2015





Dr. Claus Dold, Head of process technology / PM Laser, Claus.Dold@ewag.com

Contents

The structure of the Körber group

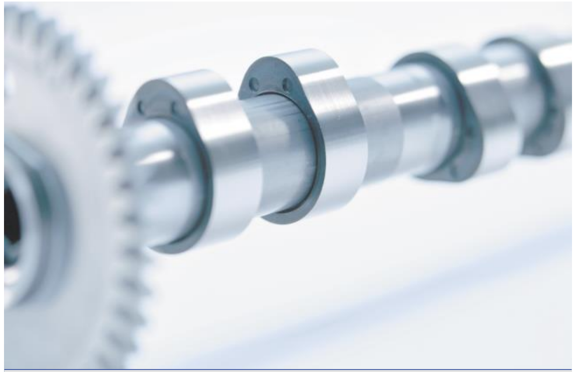
Our brands

Surface and Profile

MÄGERLE
KÖRBER SOLUTIONS

BLOHM
KÖRBER SOLUTIONS

JUNG
KÖRBER SOLUTIONS



Cylindrical

STUDER
KÖRBER SOLUTIONS

SCHAUDT
KÖRBER SOLUTIONS

MIKROSA
KÖRBER SOLUTIONS

Tools

WALTER
KÖRBER SOLUTIONS

EWAG
KÖRBER SOLUTIONS

Technology group tool

WALTER / EWAG – complete solution partner for tools

- GRINDING TECHNOLOGY
- EDM TECHNOLOGY
- LASER TECHNOLOGY
- MEASURING TECHNOLOGY
- SOFTWARE & PROCESS DEVELOPMENT
- CUSTOMER CARE

Contents

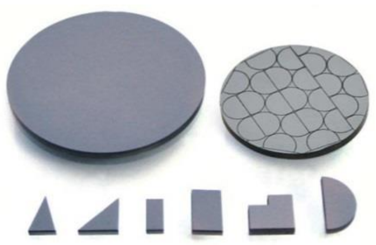
Materials & applications

Typical processing materials

- **Ultrahard materials**
  - Polycrystalline diamond (PCD)
  - Chemical vapor deposition diamond (CVD-D)
  - Cubic boron nitride (cBN)
  - Monocrystalline diamond (MCD)
- **Application**
  - Plate based(e.g. milling or drilling tools)
  - Grain based (e.g. dressing wheels)
  - Combinations (e.g. full PCD on carbide base)

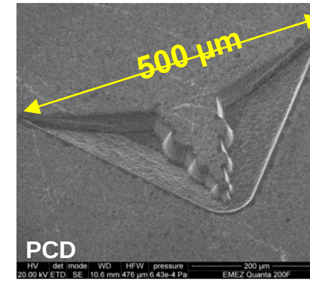
- **Metals**
  - Tungsten carbide
  - Iron / iron cast
  - Steel
- **Application**
  - Tool body
  - Substrate material for plating
  - General machining parts

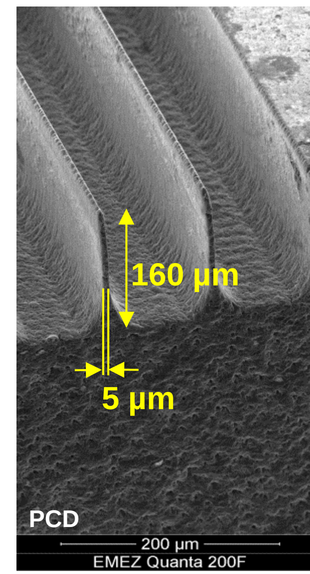
- **Ceramics / others**
  - Individual material mostly unkown
  - Parameter range needs to be found on every trial
- **Application**
  - Tooling industry
  - IT industry



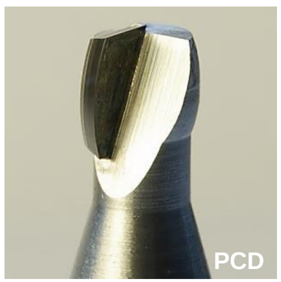
Typical applications & research partners

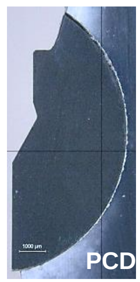
Research

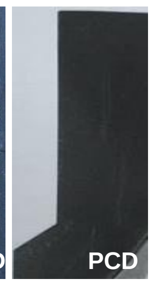


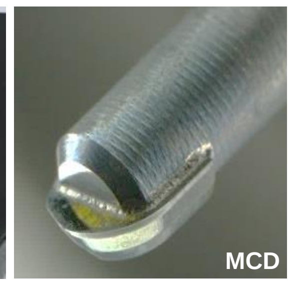


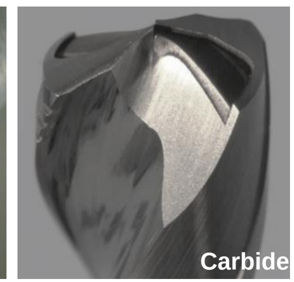
Standard

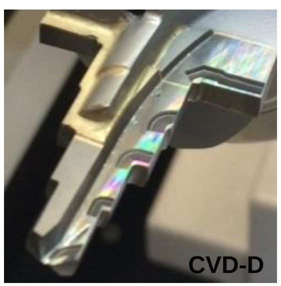


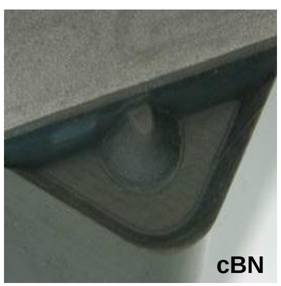


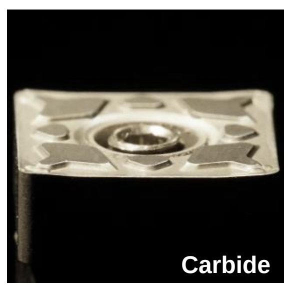


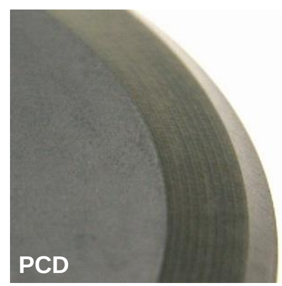


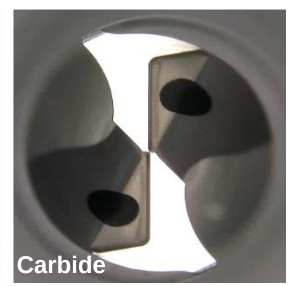












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ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

LZN
LASER ZENTRUM NORD

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

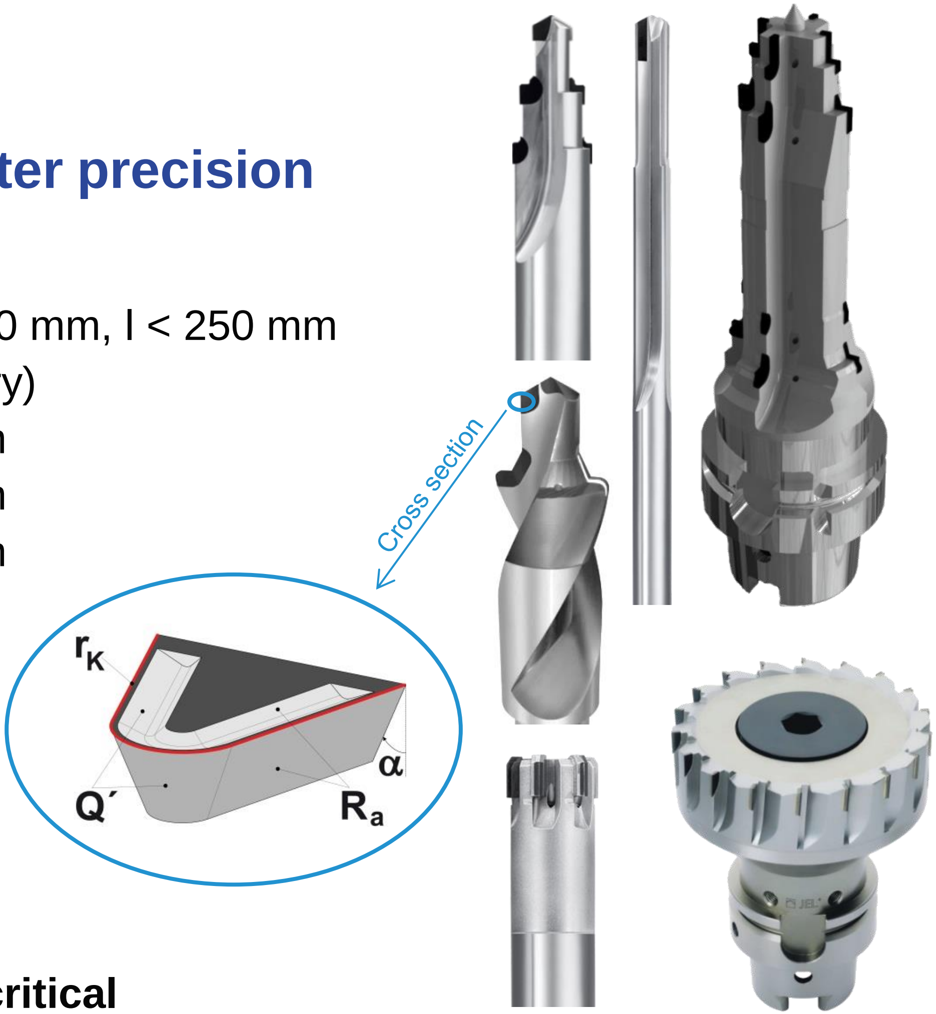
SEVENTH FRAMEWORK PROGRAMME

Sources: G. Eberle, C. Dold, K. Wegener (2015) Picosecond laser fabrication of micro cutting tool geometries on polycrystalline diamond composites usinng a high-numerical aperture micro scanning system. Lase – Spie Photonics West, USA, 935103/1-9.

EWAG LASER LINE series

Machine requirements for micrometer precision

- **Accuracy**
  - Tool dimensions: d < 200 mm, l < 250 mm
  - Typical tolerances (e.g. automotive industry)
    - Profile form (entire tool): < 3 µm
    - Diameter: < 2 µm
    - Runout: < 2 µm
- **Operating environment**
  - Climate control highly recommended
- **Machine base**
  - Massive vibration damping required



-> Machine design & environmental issues critical

-> Fiber lasers & fiber delivery systems help reduce complexity & enable high accuracy

EWAG LASER LINE series

Current machining centers

- 5 CNC- + 3 optical axes
- Free-space laser system & beam delivery
- t_P = 10 ps, P = 50/100 W, f_P < 2 MHz
- Water cooling (+- 0.1 K)
- On-site servicing challenging
- High laser system costs

- 5 CNC- + 2 optical axes
- Fiber laser system & fiber beam delivery
- t_P = 1.5 ns, P = 20 W, f_P < 0.6 MHz
- Air cooling
- Laser system easily exchangable
- Low laser system costs

Contents

- **Introduction**
  - EWAG AG as a member of the Körber- and the United Grinding group
- **EWAG LASER LINE series**
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  - Machine designs, laser & optical requirements
- **Beam path / delivery fibers**
  - Properties & requirements
  - Free-space vs. fiber delivery
  - Current market situation industrial lasers & fiber laser development
  - Ultrashort pulse fiber lasers – many beam guiding concepts
- **Conclusions**

Fiber laser systems & fiber based delivery

Properties & requirements

- **Free space systems**
  - Bulky
  - Complex
  - Expensive
- **Fiber based systems**
  - Compact
  - Reliable
  - Reduced maintenance

- **Transport challenging (e.g. free-space system)**
  - Laser mounted into machine bed /no vibration isolation possible
    - Laser system
    - Beam path
    - All optical components
  - Machine weight approx. 4.5 t
  - Machine transported via ship / airplane
    - Shock events up to 10g

-> Beam path flexible -> shock protection possible
-> Fiber beam path is ideal

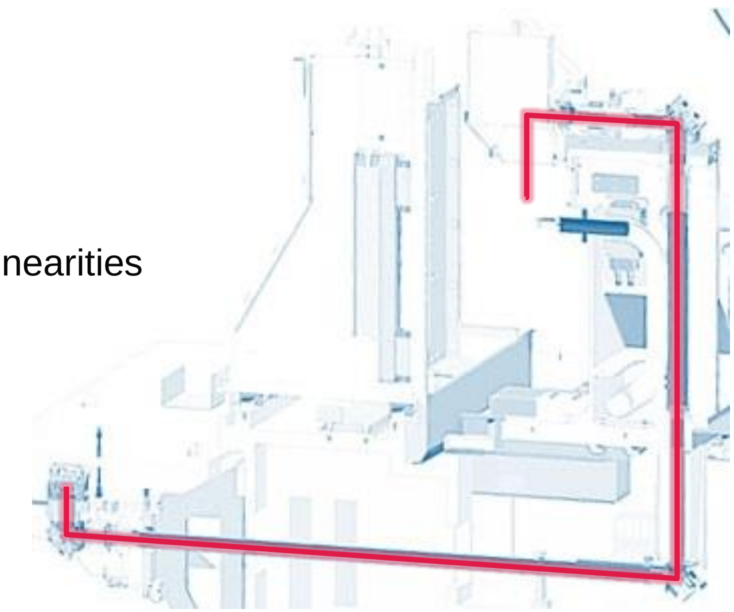
Example of an ultrashort pulse free-space system.

Delivery of a machine with installed ultrashort pulsed laser system. Shock events up to 10g when handling system.

Laser system integration (machine & application)

Beam path challenges & parameter ranges of interest

- **Beam delivery challenges**
  - Short & ultrashort pulses for efficient high quality ablation (ns -> fs)
  - Laser beam alignment through machine
    - Short, stiff beam paths
    - Vibration isolation, esp. optical elements
- **Fiber delivery systems**
  - Ideal deployment system
  - Higher pulse energies must be handled / reduction of nonlinearities
- **Processing parameter ranges & requirements**
  - Large pulse energy range (µJ-mJ)
  - Large repetition rate range (kHz – MHz)
  - Fast beam deflection systems (1 - 100 m/s)
  - Synchronized CNC- / optical axes motion

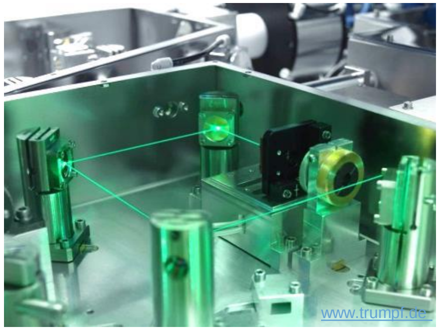


Machine design / beam path example.

Laser system & delivery system analysis

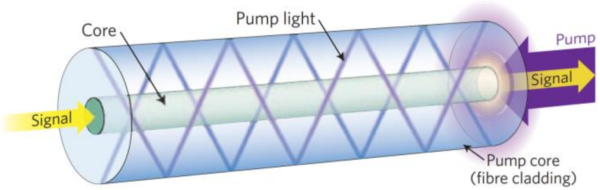
Fiber vs. free-space system comparison

- **Laser system design is not the primary objective**
  - Free-space or fiber laser not primarily important
  - Machine design for ideal laser operating conditions
  - Vibration damping (laser) & cooling (water / air / climate control,etc)



- **Beam delivery systems can provide flexibility**
  - **Free-space** beam delivery highly challenging
    - Micrometer precision of entire beam path
    - 8 axes kinematics -> tolerances / vibrations
  - **Fiber based** beam delivery
    - Fiber integration simple & accurate, lengths < 5 m ideal
    - Laser pulse shape / wave properties
      - Spatial — TEM_{00}
      - Temporal — ±10% acceptable but constant
      - Spectral — ± 10 nm linewidth acceptable but constant in time

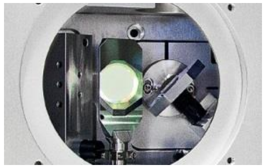
-> constant ablation behavior is key

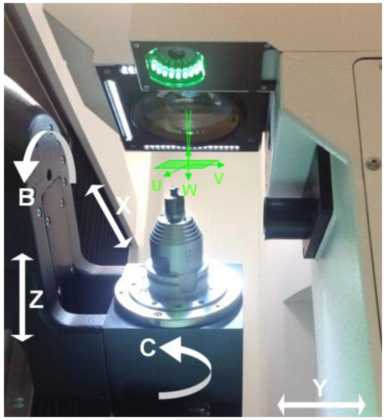


Source (2nd from bottom): C. Jauregui, J. Limpert, A. Tünnermann (2013) High-power fibre lasers. Nature Photonics, 7:861-867.

Typical machine & process layout

Requirements for industrial level machining





Laser system
- Pulse duration
- Pulse energy
- Repetition rate
- Wavelength
- Size & weight

Beam path
- Free-space
- Fiber-based
- Optical elements
- Flexibility

Processing head
- Deflection system
- Dynamic properties
- Overall stability

Machine kinematics
- CNC-axes
- Optical axes
- Motion control
- High precision

Beam control / calibration
- Focal plane
- Axes calibration
- Fiber failure detection
- Pulse duration?
- Pointing stability?

Workpiece
- Geometrical accuracy
- Surface roughness
- Efficiency

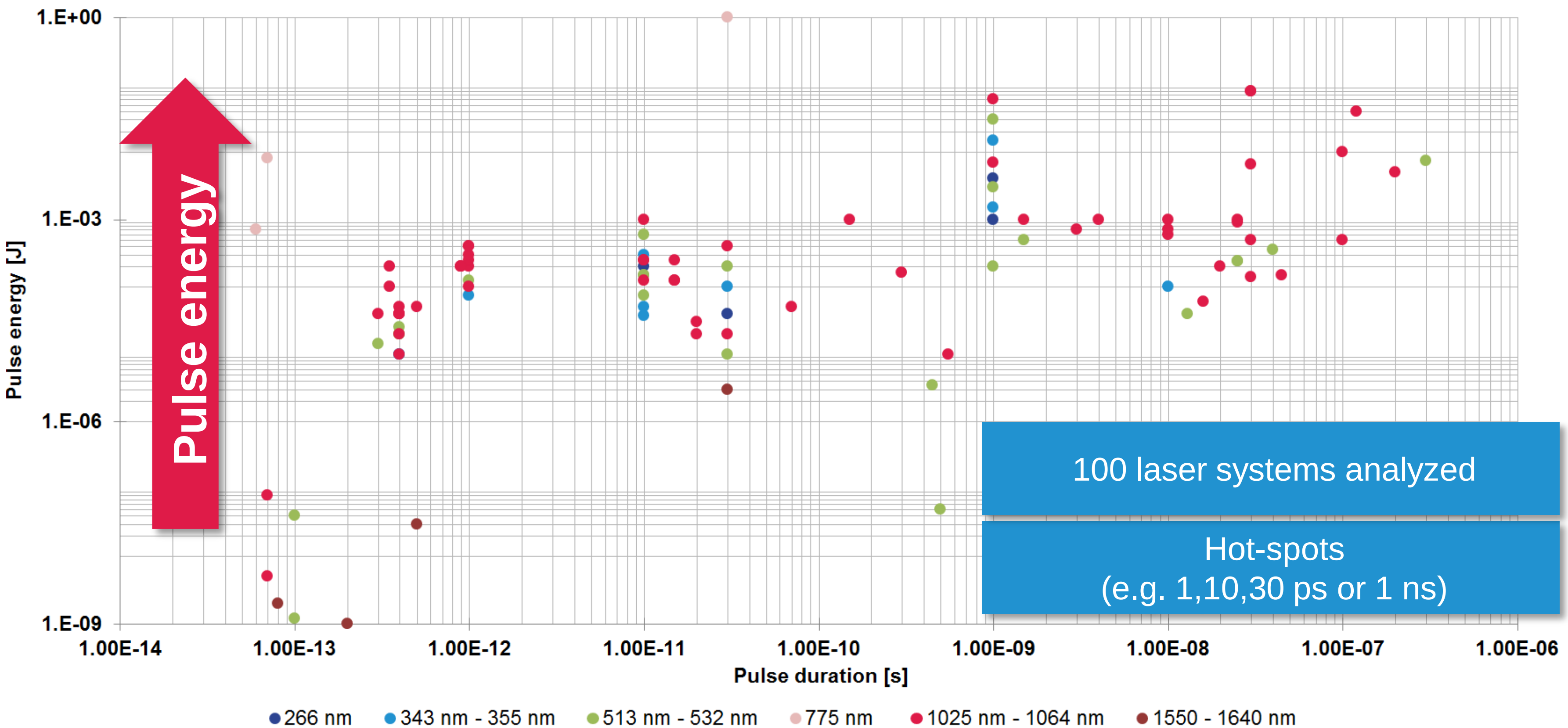
Vibration isolation
Climate control
Separate housing

Water cooling
Vibration damping by machine bed only
Stiff construction

Tool clamping
Automation

Industrial laser sources

Current market situation (short & ultrashort pulses)

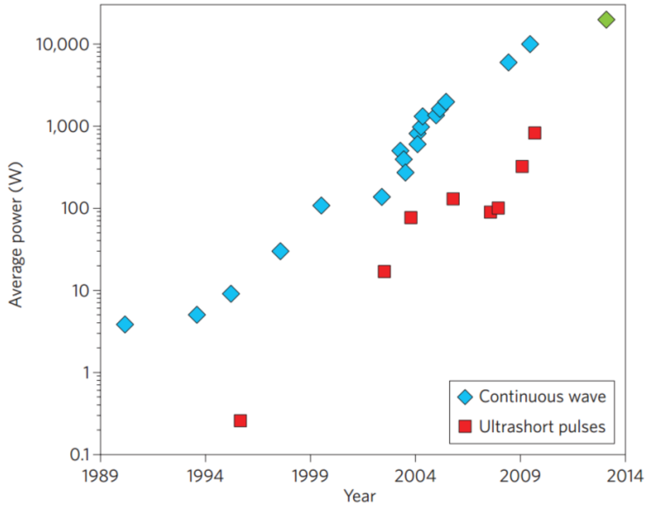


Recent developments

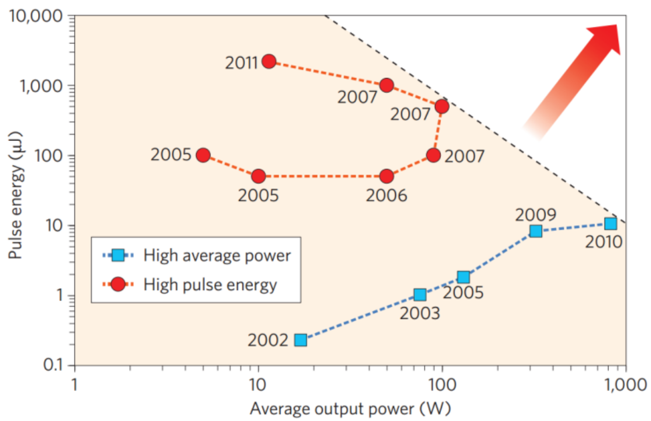
Average power & pulse energy scaling

- **Fiber laser research**
  - Average output power of fiber laser systems strongly developed in the past 25 years
  - Ultrashort pulsed lasers have been developed in terms of high average power or high pulse energies
  - Further increases towards high average power and high pulse energies are yet under development due to mode instability problems
  - New fiber design layouts are under heavy development from research groups worldwide

⇒ **Even higher average power and pulse energies soon to be expected.**



Average output power of nearly diffraction limited fibre lasers.



Evolution of pulse energy vs. average output power of single-emitter fs fiber lasers.

Source: C. Jauregui, J. Limpert, A. Tünnermann (2013) High-power fibre lasers. Nature Photonics, 7:861-867.

Fiber delivery concepts for fiber lasers

Laser system & delivery fiber architecture

- **Many system ideas are on the market**
  - Laser & beam delivery as modular system in order to
    - Reduce nonlinearities / achieve higher pulse energies / average powers
    - Placing some components at unusual locations
      - Use amplifier fiber as delivery fiber?
      - Add pulse compression at end of fiber?

-> What is the ideal system design for which task?

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- **Conclusions**

Conclusions

- **Beam delivery challenges**
  - Short & ultrashort pulses essential for highest ablation quality & process efficiency
  - Increased repetition rates & increased pulse energies beneficial for thick materials
  - Laser beam alignment must be accurate on micrometer level in harsh environments (temperature, humidity, vibration/shock events)
  - Fiber delivery for short & ultrashort pulses currently not sufficient on an industrial scale for high pulse energies and high average powers -> laser system design incl. Beam transport to workpiece location

- **Laser system challenges**
  - Industrial use involves transport (up to 10g), easy installation and 24/7 operation in rough conditions in terms of vibrations / shocks, temperature, humidity
  - Good servicability of all system components

⇒ **Modular concept of laser, delivery fiber, frequency conversion and pulse compressor could prove to be highly beneficial for future system designs**

Thank you.

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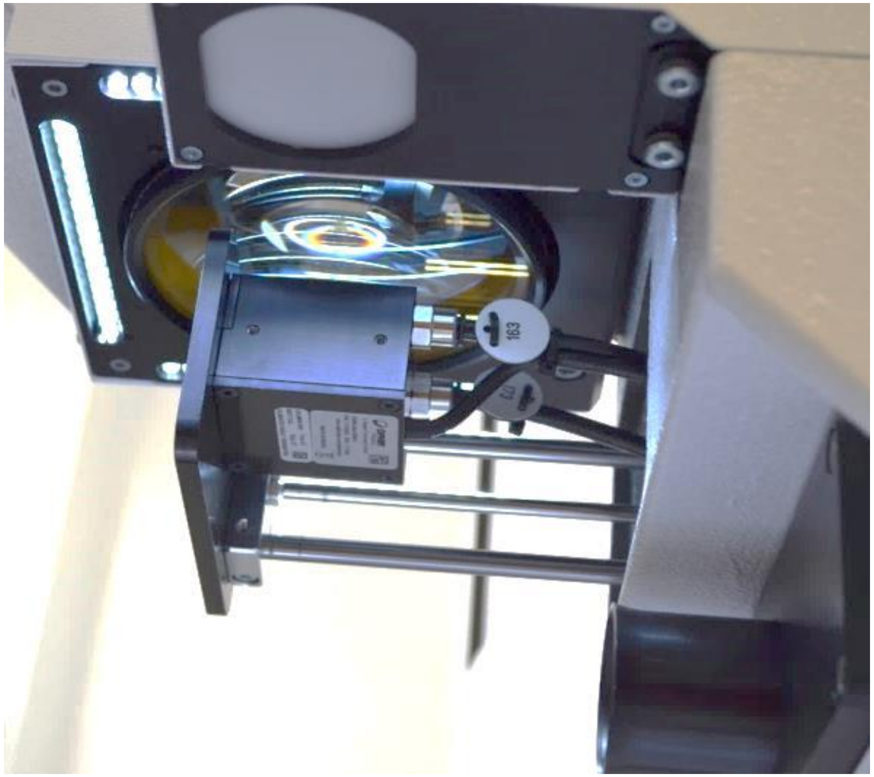
EWAG LASER LINE series

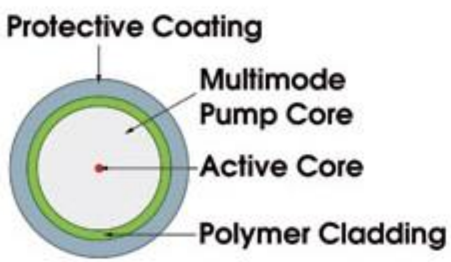
Beam path

- **Current automatic calibration routines**
  - Power monitoring at the workpiece
  - Focal plane location adjustment
  - Kinematic CNC-/optical beam path alignment
- **Delivery fiber monitoring**
  - Fiber damage
- **Future fiber monitoring aspects?**
  - Pulse dispersion / distortion?
  - Fiber temperature?

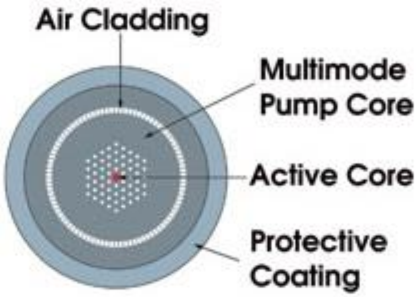


Fiber designs

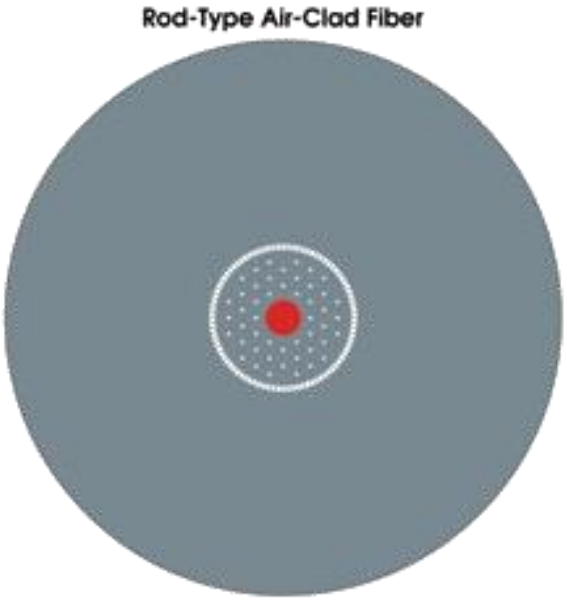
Examples



few 100 um
Low NA (pump core)



few 100 um
Large NA (pump core)
-> highly efficient



1-2 mm
No bending, no coating (thermal effects)

Source: K. P. Hansen, J. Broeng (2006) High-power fibre lasers. Photoncis Spectra.

Fiber delivery concepts for fiber lasers

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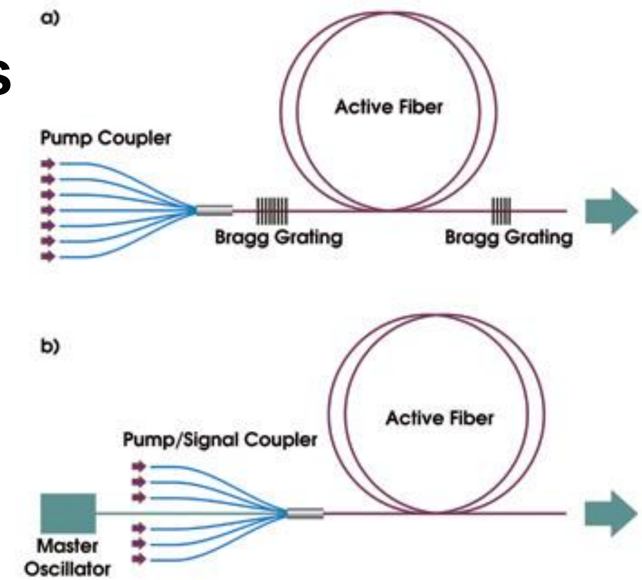


Fig. 1: Typical fiber laser designs (a) simple oscillator with Bragg reflectors. (b) Master oscillator power amplifier (MOPA) design.

Single mode laser
Fiber
Rod
Disk
Slab
etc.

Pulse stretcher

Amplifier

Delivery fiber
Step-index
Photonic crystal
etc.

Frequency conversion

Pulse compressor

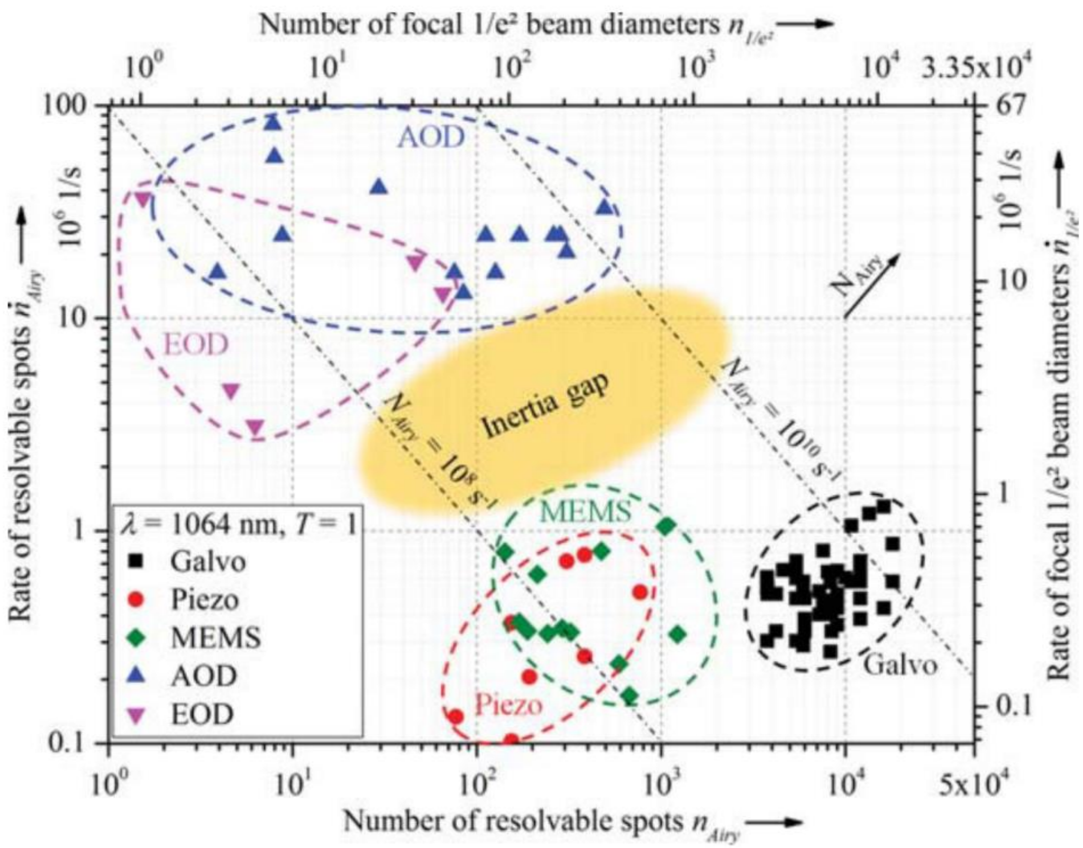
Amplifier

Output

Source: K. P. Hansen, J. Broeng (2006) High-power fibre lasers. Photoncis Spectra.

Deflection unit comparison

Different system designs



Source (top): P. Bechtold, R. Hohenstein, R. Schmidt (2014) Evaluation of disparate laser beam deflection technologies by means of number and rate of resolvable spots. Optics Letters, 38:2934-2937.