160 W 800 fs Laser System without CPA for High Speed Surface Texturing

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Introduction

- **Ultrashort laser pulses** are a proven tool for high quality laser micromachining
- Demand for **high throughput** is a key factor for large scale industrial applications
**Introduction**

- **Ultrashort laser pulses** are a proven tool for high quality laser micromachining.
- Demand for **high throughput** is a key factor for large scale industrial applications:
  - **High repetition rate** lasers operating at > 1 MHz deliver > 1 million pulses per second.
  - Minimum surface roughness is achieved with a spatial overlap of two consecutive pulses of 50-75% \([1]\) → **high marking speeds** (several 100 m/s) are needed
    - Provided by novel **polygon line scanners**
  - For a given material, there is an **optimum fluence** (**pulse energy**) at which maximum specific removal rate (removal rate per average power) is achieved \([2,3]\)
  - \(P_{\text{average}} = E_{\text{pulse}} \times f_{\text{rep}}\) → **to work at high rep rates high average power is needed**
  - **Demand for laser systems with high average power and high repetition rate**

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2. Raciukaitis, G. et al. JLMN 4, 186, 2009
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- \[P_{average} = E_{pulse} \cdot f_{rep}\] → to work at high rep rates high average power is needed.
- Demand for laser systems with high average power and high repetition rate.


- Collaboration between the end-users, research labs and laser manufacturers (21 partners, 8 countries).
- Laser system for high speed surface texturing
  - high rep rate > 3 MHz,
  - high average power ~ 100 W,
  - ultrashort pulses ≤ 500 fs,
  - compact foot print,
  - low cost,
  - robust system,
  -...

**APPOLO** - Validation of Process Feasibility and Adaptation of Innovative Laser Technology and Equipment

Gediminas Raciukaitis, today, 11:20 h
Forum A2 - Optical Metrology and Imaging

2. Raciukaitis, G. et al. JLMN 4, 186, 2009
Laser System Design: Oscillator

- **MOPA**: YBIX oscillator + 2-stage SCF amplifier
Laser System Design: Oscillator

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- **Why YBIX?**
  - Robust SESAM® mode-locking
  - High peak power
  - Ultrashort pulses, 200 fs
Laser System Design: Oscillator

- **MOPA**: YBIX oscillator + 2-stage SCF amplifier

- **Why YBIX?**
  - Robust SESAM® mode-locking
  - High peak power
  - Ultrashort pulses, 200 fs

- **Customized YBIX oscillator parameters:**
  - 2.8 W, 83.4 MHz, 1030.3 nm, FWHM = 2.4 nm, < 400 fs, M2<1.1

Autocorrelation trace of 380 fs at 2.8 W.

Beam profile measured at 200 mm distance from the housing at 2.8 W.
Laser System Design: Amplifier

- **Why single crystal fiber (SCF)?**
  - A short rod fiber or a thin and long crystal
  - Direct amplification of femtosecond pulses avoiding the standard CPA technique
  - Designed for a pump light guidance and a free-space propagation of a laser signal

- **SCF**: 1 mm diameter Yb:YAG rod

*picture credits: property of Fibercryx SAS*
- YBIX is directly seeded into SCF-amplifier, **no CPA**
Laser System Design

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- **1st stage amplifier:**
  - Double-pass signal configuration using the retro-reflective mirror and Faraday rotator
  - **High brightness 105-µm fiber-coupled pump diode, 140 W, 940 nm**
**Laser System Design**

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- **1\(^{st}\) stage amplifier:**
  - Double-pass signal configuration using the retro-reflective mirror and Faraday rotator
  - **High brightness 105-µm fiber-coupled pump diode, 140 W, 940 nm**

- **2\(^{nd}\) stage amplifier:**
  - Single-pass signal configuration
  - **Bidirectional pumping:** 105-µm fiber-coupled diode, 140 W, 940 nm and 200-µm fiber-coupled diode, 200 W, 940 nm
Gain Curves

- **1st stage amplifier:**
  - Small signal gain: >32 dB
  - Highest small signal gain with SCF so far
  - Maximum output power: 42 W
  - Extraction efficiency: 28 %
**Gain Curves**

- **1st stage amplifier:**
  - Small signal gain: \(>32\, \text{dB}\)
  - Highest small signal gain with SCF so far
  - Maximum output power: 42 W
  - Extraction efficiency: 28 %

- **2nd stage amplifier:**
  - Maximum output power: 162 W
  - Highest average power of femtosecond pulses achieved with SCF so far
  - Extraction efficiency: 42 %
  - Highest value achieved with SCF so far
# Beam quality

## Beam quality factor, $M^2$

<table>
<thead>
<tr>
<th>Oscillator</th>
<th>@ 102 W output</th>
<th>@ 124 W output</th>
<th>@ 162 W output</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1.1, 1.1</td>
<td>1.3, 1.3</td>
<td>1.4, 1.5</td>
<td>1.9, 1.9</td>
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P = 102 W

$M^2_x = 1.3$, $M^2_y = 1.3$
### Beam quality

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![Beam quality factor, M^2](image)

\[
P = 124 \text{ W} \\
M^2_{x} = 1.4, \quad M^2_{y} = 1.5
\]
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\[
P = 162 \text{ W} \\
M^2_x = 1.9, \ M^2_y = 1.9
\]
Spectrum and Pulse Duration

Optical spectrum centered at 1030.5 nm with 1.7 nm full width half-maximum at maximum output power of 160 W.

Autocorrelation trace of 800 fs at maximum output power of 160 W.
Summary and Outlook

- Compact laser system that delivers >100 W femtosecond pulses with only 2 amplifier stages

- High brightness pumping results in the highest small signal gain (close to 33 dB) achieved so far

- We implemented bidirectional pumping scheme of SCF amplifier for the first time, and this allowed us to reach 160 W with 2 amplifier stages

- Highest average power of femtosecond pulses achieved with SCF
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- Working on **beam quality improvement of 160 W beam**
Acknowledgment

This work was partially financially supported by EU FP7 project Appolo, grant agreement number 609355.
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