Ultrafast_RAZipol Deliverable Report

Ultrafast Laser with Radial and Azimuthal Polarizations for High-efficiency Micro-machining Applications

Context		
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Declaration	Any work or result described therein is genuinely a result of the Ultrafast_RAZipol project. Any other source will be properly referenced where and when relevant.	

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Machined sample, created with the RAZipol High Rep Rate system

The recently concluded Ultrafast_RAZipol project aimed to push the limits of laser micromachining capabilities. This ambitious project received EUR 3,240,000 of grant funding from the European Union's Seventh Framework Programme (FP7). Coordinated by Dr Marwan Abdou-Ahmed from the University of Stuttgart's IFSW this unique consortium brought together manufacturers and research organisations specialising in Single Crystal Fibre lasers, oscillators, scanners, the creators of the thin-disk-multipass amplifier, and machining specialists, along with end-users to create two revolutionary systems.

In the oscillator stage of the laser system, boundaries have been pushed to achieve as high as possible pulse energies in fs and ps pulses. The pre-amplifier stage is characterizing the new single crystal fiber technology for radial and azimuthal polarization amplification and pushing for highest power and pulse energy output.

The thin disk final amplifier has been designed for fs pulses with radial and azimuthal polarization and more than 500W of average power. In parallel, laser partners have developed beyond state-of-the-art modulation schemes to gate output pulses with high average power. Scanners have been developed with larger field of view and higher damage coatings to sustain high average and peak powers.

The laser market generated EUR 9.3 billion in sales for 2016. The end-user applications which the project has focused on include lab-on-chip and micro structuring of large dielectric surfaces for the High Rep Rate System and drilling of holes for the automotive industry for the Low Rep Rate System.

Through the Ultrafast_RAZipol project, the Consortium have delivered significant advances in the speed and performance of the micromachining systems. Excellent progress has been made during the project for each stage of the laser and scanner.

NST will be launching a new scanner to the market in 2017 based on developments made during the RAZipol project.

As the lead technical partner, University of Stuttgart have gone on to file four patents which were developed as part of the project. The Thin-Disk Amplifier is being further developed in other European Union funded projects, including HIPERDIAS and TresClean.

Main technical results:

- Oscillator:

Output Parameters	HRR System	LRR System
Pulse energy	137 nJ	94 nJ
Pulse duration	350 fs	7 ps
Central wavelength	1030 nm	1030.2 nm
Pulse repetition rate	20 MHz	500 MHz
Average power	2.9 W	47 mW

- Single Crystal Fiber:
  - The HRR integrated system contains three SCF amplification stages in a 740x550 mm footprint
    - The typical output power of the system is 60 W at 20 MHz, with pulses of 680 fs
    - The stability of the system output was measured to be as good as 0.2% RMS over 10 hours
  - The LRR integrated system contains two SCF amplifiers and an integrated version of the DPA setup, in a 710x460 mm footprint.
    - In nominal operation, the amplifier delivers an output power of 47 W at the repetition rate of 500 kHz, leading to a pulse energy of 94 µJ

- Thin-disk amplifier:

High Rep Rate System	Configuration 1 (20 MHz)		Configuration 2 (10 MHz, including AMOs)	
	Seed	TD-MPA	Seed	TD-MPA
Output Power (W)	75	580	40	416
Repetition rate (MHz)	20	20	10	10
Pulse duration (fs)	727	782	670	716
Pulse energy (µJ)	3,45	29	4	41,5
Beam qualitiy factor (M^2)	<1,3	<2,3	<1,3	2,3
Optical efficiency (%)	n.m.	48	n.m.	45
Polarization	Linear	radial/azimuthal	linear	radial/azimuthal
DOP (%)	n.m.	>95	n.m.	>95

Low Rep Rate System	Configuration 1 (500kHz, ps pulses)		Configuration 2 (200 kHz, ps pulses)		Configuration 3 (200 kHz, fs pulses)	
	Seed	TD-MPA	Seed	TD-MPA	Seed	TD-MPA
Output Power (W)	44	265	36	210	40	235
Repetition rate (kHz)	500	500	200	200	200	200
Pulse duration (ps)	5,3	5,3	8,2	7,8	805	888
Pulse energy (µJ)	3,45	530	180	1050	200	1175
Beam qualitiy factor (M^2)	<1,3	<2,3	<1,3	<2,3	<1,3	<2,3
Optical efficiency (%)	n.m.	29	n.m.	30	n.m.	27
Polarization	Linear	radial/azimuthal	linear	radial/azimuthal	linear	radial/azimuthal
DOP (%)	n.m.	>95	n.m.	>95	n.m.	>95

- Polygon scanner:
  - A polygon scanner with 170 mm scan line length, and focused spot size of 25 µm has been developed
  - Spot scan speeds can be set from 25 to 100 m/sec
  - Using a 20 MHZ rep-rate laser the scanner can be operated at highest moving speed (100 m/s) at a 5 µm spot pitch
- Applications testing:
  - Patterning large wafers with the HRR system using radial or azimuthal polarization enabled a 78 times faster processing time, compared to the benchmark application
  - A 50 % higher ablation rate was achieved using radial or azimuthal instead of linear polarization

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For more information about the Project and its results, please visit the website at: www.razipol.eu or contact razipol@kiteinnovation.com

Consortium Partners:

Universitaet Stuttgart - Germany
Lumentum - Switzerland
Centre National de la Recherche Scientifique - France
Fibercryst SAS - France
Next Scan Technology BVBA - Belgium
Next Scan Technology BV - Netherlands
GFH GMBH - Germany
Schweisstechnische Lehr und Versuchsanstal SLV Mecklenburg-Vorprommern - Germany
Class 4 Laser Professionals AG - Switzerland
Kite Innovation (Europe) Ltd. – United Kingdom

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