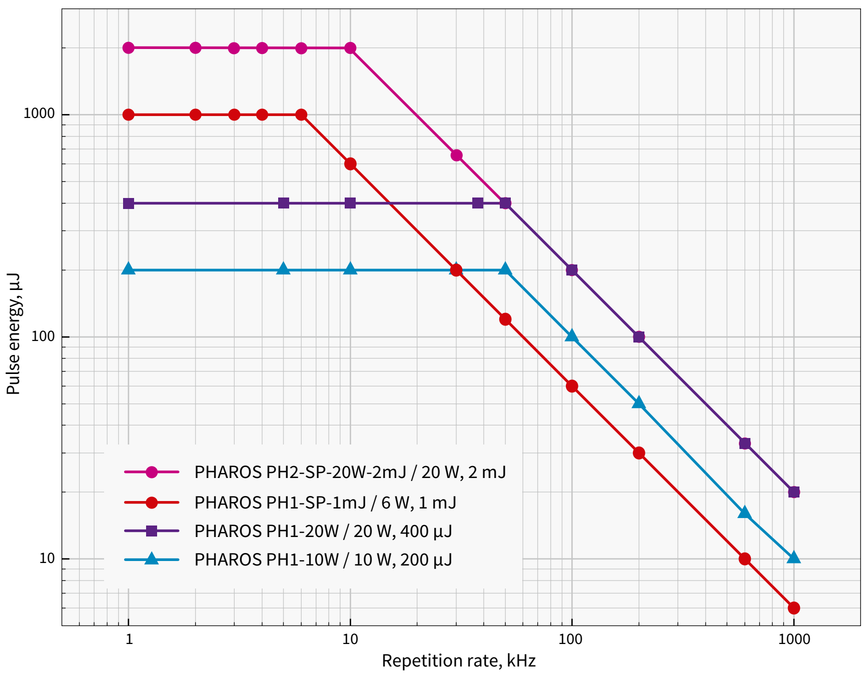
PHAROS

High Power and Energy Femtosecond Lasers

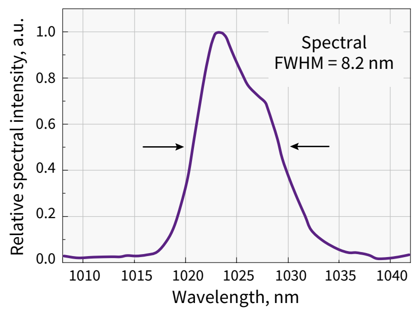
FEATURES

- 190 fs – 20 ps tunable pulse duration
- 2 mJ maximum pulse energy
- 20 W output power
- 1 kHz – 1 MHz tunable base repetition rate
- Pulse picker for pulse-on-demand operation
- Rugged industrial grade mechanical design
- Automated harmonics generators (515 nm, 343 nm, 257 nm, 206 nm)
- Optional CEP stabilization
- Possibility to lock oscillator to external clock

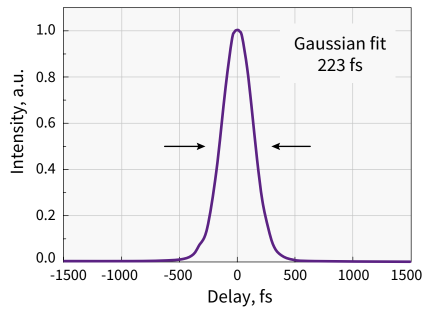
PHAROS is a femtosecond laser system combining millijoule pulse energies and high average powers. PHAROS features a mechanical and optical design optimized for industrial applications such as precise material processing. Compact size, an integrated thermal stabilization system, and sealed design allow PHAROS integration into machining workstations. Laser diodes pumping Yb medium significantly reduces maintenance costs and provides a long laser lifetime. Software tunability of PHAROS allows the system to cover applications normally requiring different classes of laser. Tunable parameters include pulse duration (190 fs – 20 ps), repetition rate (single pulse to 1 MHz), pulse energy (up to 2 mJ) and average power (up to 20 W). Its power level is sufficient for most material processing applications at high machining speeds. The built-in pulse picker allows convenient control of the laser output in pulse-on-demand mode. PHAROS compact and robust optomechanical design features stable laser operation across varying environments.



Pulse energy vs base repetition rate for PHAROS



Typical spectrum of PHAROS



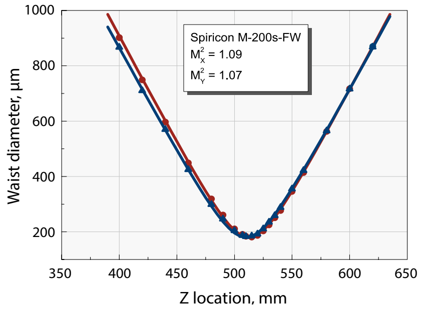
Typical pulse duration of PHAROS

SPECIFICATIONS

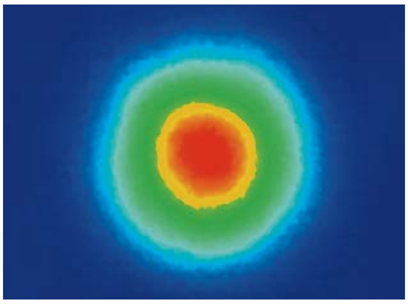
Model [1]	PH1-10W	PH1-15W	PH1-20W	PH1-SP-1mJ	PH2-SP-20W-2mJ (NEW)
OUTPUT CHARACTERISTIC					
Max. average power	10 W	15 W	20 W	6 W	20 W
Pulse duration (assuming Gaussian pulse shape)	< 290 fs			< 190 fs	
Pulse duration range	290 fs – 10 ps (20 ps on request)			190 fs – 10 ps (20 ps on request)	
Max. pulse energy	> 0.2 mJ or > 0.4 mJ			> 1 mJ	> 2 mJ
Beam quality	TEM_{00} ; $M^2 < 1.2$			TEM_{00} ; $M^2 < 1.3$	
Base repetition rate [2]	1 kHz – 1 MHz				
Pulse selection	Single-Shot, Pulse-on-Demand, any base repetition rate division				
Centre wavelength	1028 nm ± 5 nm			1033 nm ± 5 nm	
Output pulse-to-pulse stability [3]	< 0.5 % rms over 24 hours				
Power stability	< 0.5 % rms over 100 h				
Pre-pulse contrast	< 1 : 1000				
Post-pulse contrast	< 1 : 200				
Polarization	Linear, horizontal				
Beam pointing stability	< 20 µrad/°C				
OPTIONAL EXTENSIONS					
Oscillator output	Optional. Please contact *sales@lightcon.com* for more details or customized solutions				
Typical output	1 – 6 W, 50 – 250 fs, ~1035 nm, ~ 76 MHz, simultaneously available				
Harmonics generator	Integrated, optional *(see page 8)*				
Output wavelength	515 nm, 343 nm, 257 nm, 206 nm				
Optical parametric amplifier	Integrated, optional *(see page 15)*				
Tuning range	640 – 4500 nm				
BiBurst mode	Tunable GHz and MHz burst with burst-in-burst capability, optional *(see page 9)*				
GHz-mode (P)					
Intra burst pulse separation [4]	~ 200 ± 40 ps			~ 500 ± 40 ps	
Max no. of pulses [5]	1 . . 25			1 . . 10	
MHz-mode (N)					
Intra burst pulse separation	~ 16 ns				
Max no. of pulses	1 . . 9, (7 with FEC)				
PHYSICAL DIMENSIONS					
Laser head [6]	670 (L) × 360 (W) × 212 (H) mm				730 (L) × 419 (W) × 233 (H) mm
Rack for power supply & chiller	642 (L) × 553 (W) × 673 (H) mm				PS integrated in the laser head
UTILITY REQUIREMENTS					
Electric	110 V AC, 50 – 60 Hz, 20 A or 220 V AC, 50 – 60 Hz, 10 A				
Operating temperature	15 – 30 °C (air conditioning recommended)				
Relative humidity	< 80 % (non condensing)				

1) *More models are available on request.*
2) *Some particular repetition rates are software denied due to system design.*
3) *Under stable environmental conditions.*
4) *Custom spacing on request.*
5) *Maximum number of pulses in a burst is dependent on the laser repetition rate. Custom number of pulses on request.*
6) *Dimensions might increase for non-standard laser specifications.*

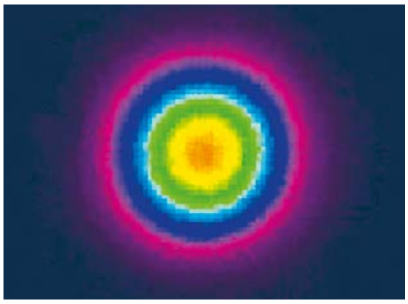
DANGER: VISIBLE AND/OR INVISIBLE LASER RADIATION AVOID EYE OR SKIN EXPOSURE TO DIRECT, REFLECTED OR SCATTERED RADIATION
CLASS 4 LASER PRODUCT



Typical M² measurement data of PHAROS

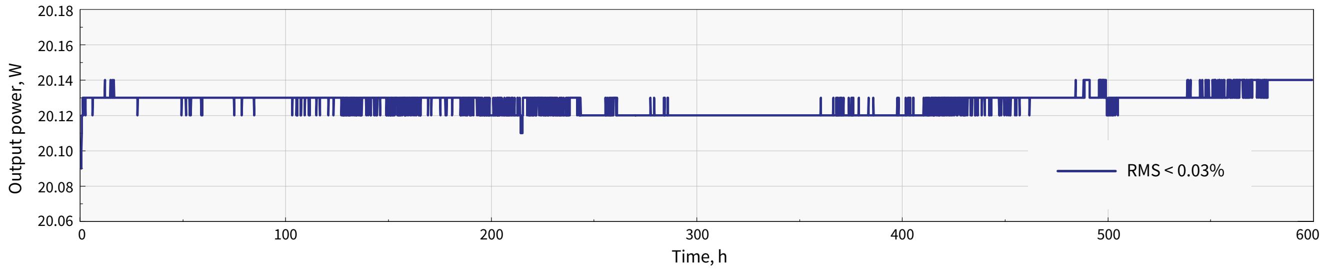


Typical near-field beam profile of PHAROS at 200 kHz

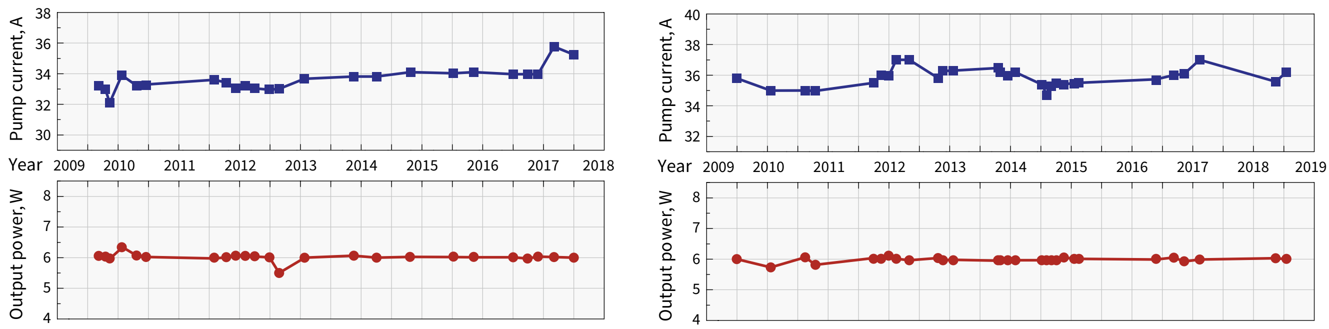


Typical far-field beam profile of PHAROS at 200 kHz

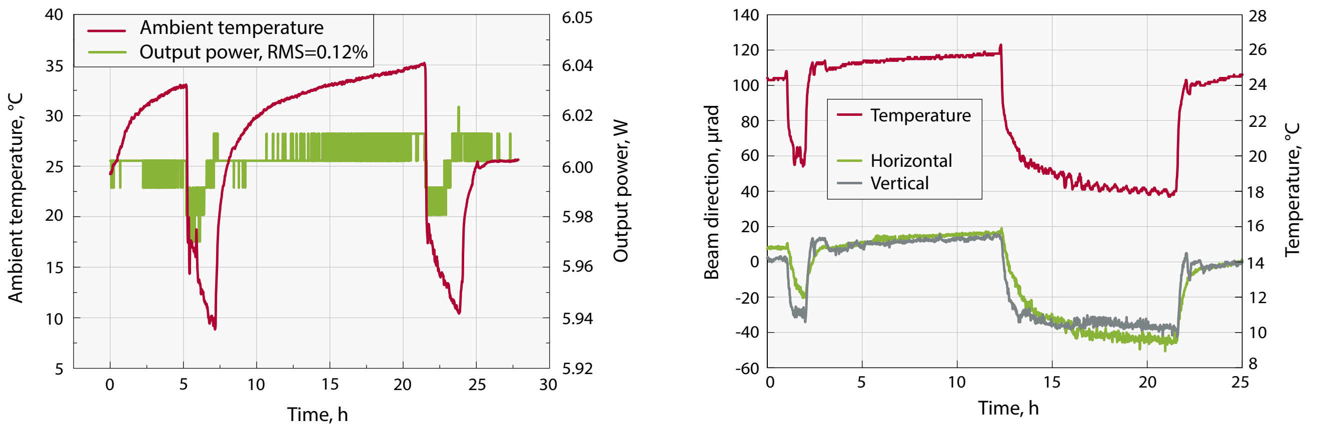
STABILITY MEASUREMENTS



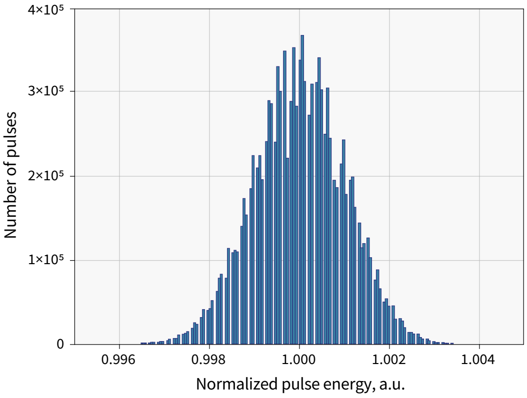
Long term stability graph of PHAROS



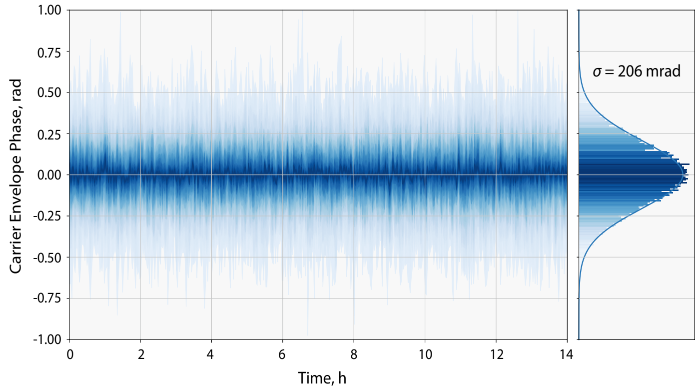
Output power of industrial PHAROS lasers operating 24/7 and current of pump diodes during the years



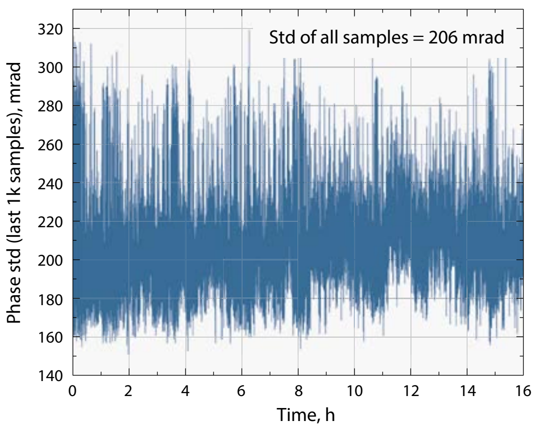
PHAROS output power with power lock enabled under unstable environment



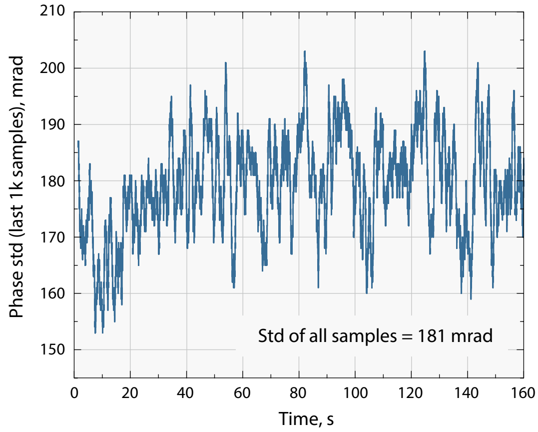
Short term pulse-to-pulse energy stability of PHAROS lasers. 1.2×10^7 pulses (1 min at 200 kHz), STD < 0.11%, peak-to-peak < 1%



Carrier-envelope phase (CEP) over the long period with active phase stabilization system



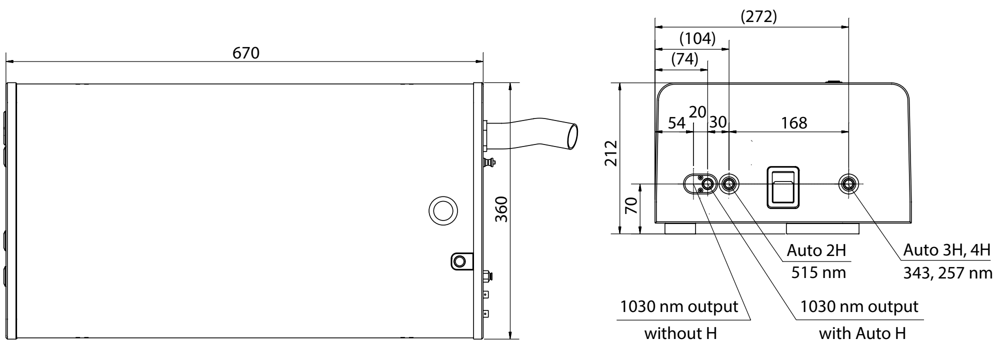
CEP stability over a long time scale



CEP stability over a short time scale

PHAROS CEP stability when laser is isolated from all noticeable noise sources – vibrations, acoustics, air circulation and electrical noise. System can achieve < 300 mrad std of CEP stability over a long time scale (> 8 hours) and < 200 mrad over a short time scale (< 5 min)

OUTLINE DRAWINGS



PHAROS PH1 laser outline drawing

HG | PHAROS

Automated Harmonics Generators

FEATURES

- 515 nm, 343 nm, 257 nm and 206 nm
- Output selection by software
- Mounts directly on a laser head and integrated into the system
- Rugged industrial grade mechanical design

Harmonics generator module attached to PHAROS

PHAROS laser can be equipped with automated harmonics modules. A selection of fundamental (1030 nm), second (515 nm), third (343 nm), fourth (257 nm) or fifth (206 nm) harmonic outputs are available through software control.

Harmonics generators are designed to be used in industrial applications where a single output wavelength is desired. Modules are mounted directly on the output of the laser and integrated into the system.

SPECIFICATIONS

Model	2H	2H-3H	2H-4H	4H-5H
Output wavelength [1] **(automated selection)**	1030 nm 515 nm	1030 nm 515 nm 343 nm	1030 nm 515 nm 257 nm	1030 nm 257 nm 206 nm
Input pulse energy	20 – 2000 µJ	50 – 2000 µJ [2]	20 – 2000 µJ [2]	200 – 1000 µJ
Pump pulse duration	190 – 300 fs			
Conversion efficiency	> 50 % (2H)	> 50 % (2H) > 25 % (3H)	> 50 % (2H) > 10 % (4H) [3]	> 10 % (4H) [3] > 5 % (5H) [4]
Beam quality (M^2) ≤ 400 µJ pump	< 1.3 (2H), typical < 1.15	< 1.3 (2H), typical < 1.15 < 1.4 (3H), typical < 1.2	< 1.3 (2H), typical < 1.15 n/a (4H)	n/a
Beam quality (M^2) > 400 µJ pump	< 1.4 (2H)	< 1.4 (2H) < 1.5 (3H)	< 1.4 (2H) n/a (4H)	

[1] Depends on pump laser model.
[2] High energy versions are available, please contact Light Conversion for specifications.
[3] Max 1 W output.
[4] Max 0.15 W output.

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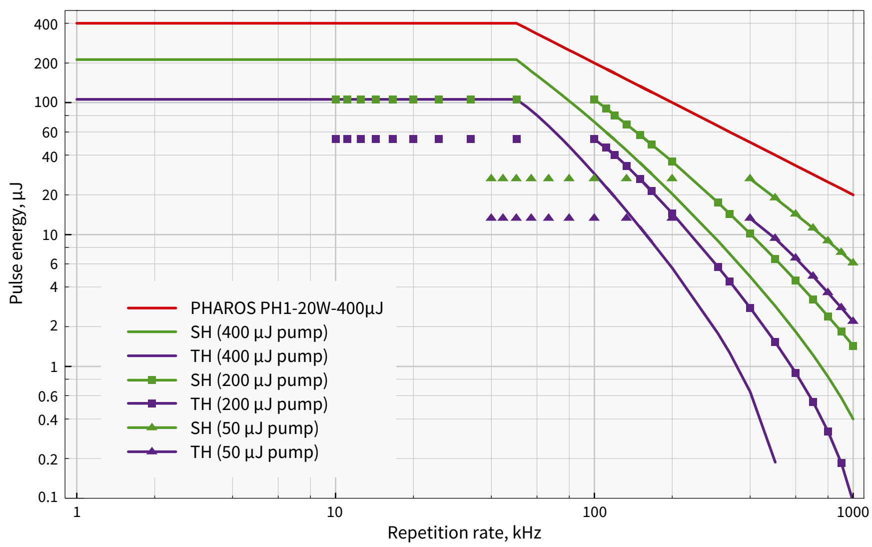
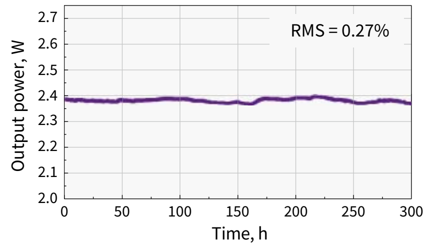
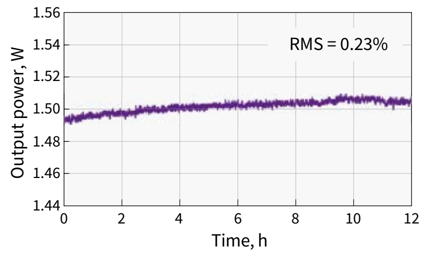


PHAROS harmonics energy vs pulse repetition rate



3H output stability



4H output stability

LIGHT CONVERSION

BiBurst

Tunable GHz and MHz burst with burst-in-burst capability

PHAROS and CARBIDE 40W (CB3) have an option for tunable GHz and MHz burst with burst-in-burst capability – called BiBurst. The distance between burst packet groups is called nanosecond burst, N (MHz-Burst). The distance between sub-pulses in the group is called picosecond burst, P (GHz-Burst).

In single pulse mode, one pulse is emitted at a time at some fixed frequency. In burst mode, the output consists of several picosecond burst packets each separated by an equal time period between each packet. Each packet can contain a number of sub-pulses which are also separated by an equal time period between each pulse.

High pulse energy femtosecond laser with flexible BiBurst functionality brings new production capabilities to high-tech manufacturing industries such as consumer electronics, integrated photonic chip manufacturing, stent cutting, surface functionalization, future displays manufacturing and quantum computing.

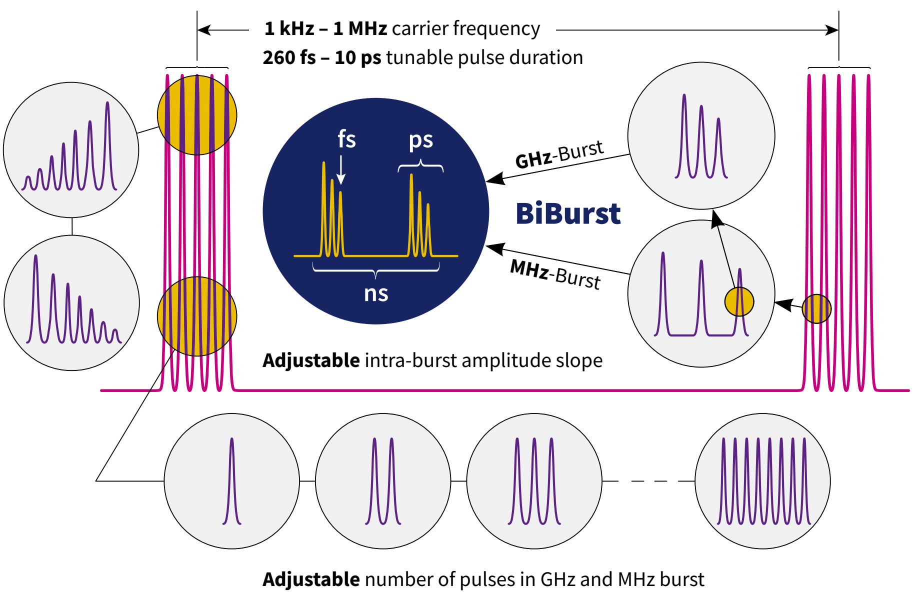
BiBurst material fabrication areas cover:

- brittle material drilling and cutting
- deep engraving
- selective ablation
- transparent materials volume modification
- hidden marking
- surface functional structuring.

SPECIFICATIONS

Model		CARBIDE-CB3 (40 W)	PHAROS	PHAROS-SP
P, GHz-mode	Intra burst pulse separation [1]	~ 440 ± 40 ps	~ 200 ± 40 ps	~ 500 ± 40 ps
	Max no. of pulses [2]	1 . . 10	1 . . 25	1 . . 10
N, MHz-mode	Intra burst pulse separation	~16 ns		
	Max no. of pulses	1 . . 10	1 . . 9, (7 with FEC)	1 . . 9, (7 with FEC)

[1] Custom spacing on request.
[2] Maximum number of pulses in a burst is dependent on the laser repetition rate. Custom number of pulses on request.



I-OPA

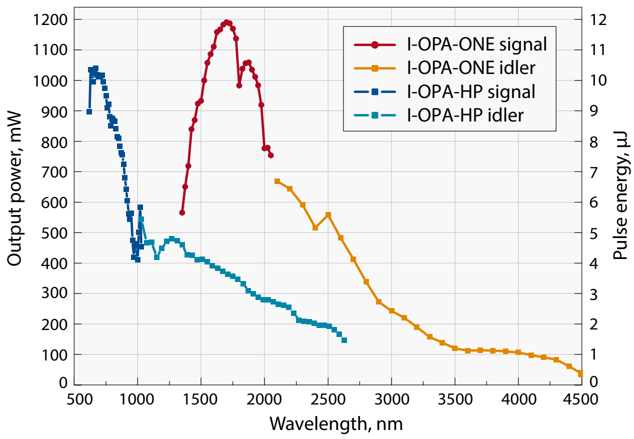
Industrial-grade Optical Parametric Amplifier

FEATURES

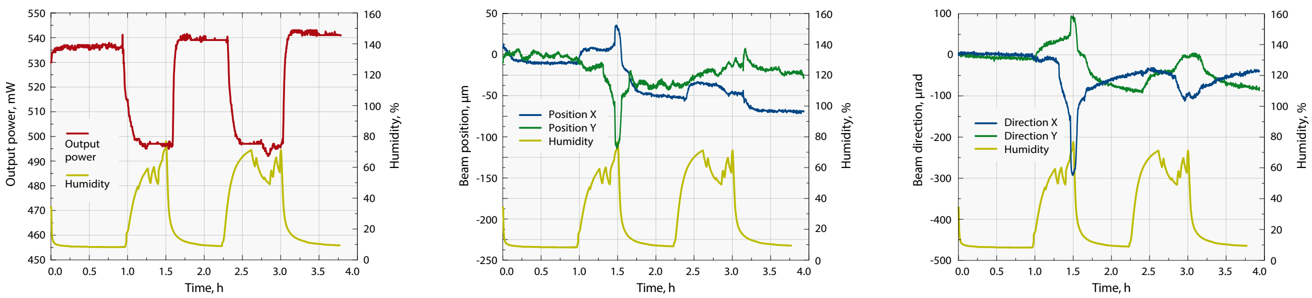
- Automatically tunable or fixed wavelength options
- Robust, integrated mechanical design
- Simple, user-friendly operation
- Up to 2 MHz repetition rate, down to single shot operation
- Up to 40 W pump power
- Integrated beam splitter for pump laser beam

Tunable I-OPA-TW module attached to air-cooled CARBIDE-CB5

I-OPA series of optical parametric amplifiers marks a new era of simplicity in the world of tunable wavelength femtosecond light sources. Based on 10 years of experience producing the ORPHEUS series of optical parametric amplifiers, this solution brings together the flexibility of tunable wavelength with robust industrial-grade design. The original I-OPA is a rugged module attached to our PHAROS laser, providing long term stability comparable to that of the industrial harmonics modules. The new and improved tunable version is designed to be coupled with our PHAROS and CARBIDE series femtosecond lasers and primarily intended to be used with spectroscopy or microscopy applications that demand high stability. The -HP model is targeted to be coupled with our HARPIA series as a pump beam source for ultrafast pump-probe spectroscopy. The -F model is primarily designed to be used as a light source in multiphoton microscopy devices. The -ONE model will be useful in the field of mid-IR spectroscopy, as well as other applications where higher pulse energy is required in the infrared part of the spectrum. All of these models can be used for micromachining and other industrial applications; the tunable version suited to be the ideal R&D system, while the fixed wavelength I-OPA would be the cost-effective solution for large scale production.



Typical I-OPA module energy conversion curves.
Pump: PHAROS-10W, 100 µJ, 100 kHz



FIxed wavelength I-OPA-FW beam pointing and output power measurements under harsh environment conditions (humidity and temperature cycling)

SPECIFICATIONS OF TUNABLE I-OPA

Model	I-OPA-TW-HP	I-OPA-TW-F	I-OPA-TW-ONE
Based on ORPHEUS model	ORPHEUS	ORPHEUS-F	ORPHEUS-ONE
Pump power	Up to 40 W		
Pump pulse energy	10 – 400 µJ		20 – 400 µJ
Pulse repetition rate	Up to 2 MHz		
Tuning range, signal	640 – 1010 nm	650 – 900 nm	1350 – 2060 nm
Tuning range, idler	1050 – 2600 nm	1200 – 2500 nm	2060 – 4500 nm
Conversion efficiency at peak, signal wavelength	> 7 % @ 700 nm		> 9 % @ 1550 nm
Additional options	n/a	SCMP: Signal pulse compressor ICMP: Idler pulse compressor PCMP: pre-chirp dispersion compensator	n/a
Pulse bandwidth [1]	80 – 220 cm^{-1} @ 700 – 960 nm	200 – 750 cm^{-1} @ 650 – 900 nm 150 – 500 cm^{-1} @ 1200 – 2000 nm	60 – 150 cm^{-1} @ 1450 – 2000 nm
Pulse duration [2]	120 – 250 fs	< 55 fs @ 800 – 900 nm < 70 fs @ 650 – 800 nm < 100 fs @ 1200 – 2000 nm	150 – 300 fs
Wavelength extension options	SHS: 320 – 505 nm SHI: 525 – 640 nm Conversion efficiency 1.2% at peak	Contact sales@lightcon.com	DFG: 4500 – 10000 nm [3]
Applications	Micro-machining Microscopy Spectroscopy	Nonlinear microscopy Ultrafast spectroscopy	Mid-IR spectroscopy AFM microscopy

[1] I-OPA-F outputs broad bandwidth pulses which are compressed externally.
[2] Output pulse duration depends on wavelength and pump laser pulse duration.
I-OPA-F requires pulse compressors to achieve short pulse duration.
[3] Up to 16 µm tuning range is accessible with external Difference Frequency Generator.

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Fixed wavelength I-OPA in comparison to tunable version or standard ORPHEUS line devices lacks only computer-controlled wavelength selection. On the other hand, in-laser mounted design provides mechanical stability and eliminates the effects of air-turbulence ensuring stable long-term performance and minimizing energy fluctuations.

Fixed wavelength I-OPA-FW module attached to PHAROS

SPECIFICATIONS OF FIXED WAVELENGTH I-OPA

Model	I-OPA-FW-HP	I-OPA-FW-F	I-OPA-FW-ONE
Pump power		Up to 40 W	
Pump pulse energy	10 – 500 µJ	10 – 500 µJ	20 – 1000 µJ
Pulse repetition rate		Up to 2 MHz	
Wavelength range, signal	640 – 1010 nm	650 – 900 nm	1350 – 2060 nm
Wavelength range, idler	1050 – 2600 nm	1200 – 2500 nm	2060 – 4500 nm
Conversion efficiency at peak, signal wavelength	>7 % @ 700 nm	>7 % @ 700 nm	> 9 % @ 1550 nm
Pulse bandwidth [1]	80 – 220 cm^{-1} @ 700 – 960 nm	200 – 750 cm^{-1} @ 650 – 900 nm 150 – 500 cm^{-1} @ 1200 – 2000 nm	60 – 150 cm^{-1} @ 1450 – 2000 nm
Pulse duration [2]	120 – 250 fs	< 55 fs @ 800 – 900 nm < 70 fs @ 650 – 800 nm < 100 fs @ 1200 – 2000 nm	150 – 300 fs
Applications	Micro-machining Microscopy Spectroscopy	Nonlinear microscopy Ultrafast spectroscopy	Micro-machining Mid-IR generation

[1] *I-OPA-F outputs broad bandwidth pulses which are compressed externally.*
[2] *Output pulse duration depends on wavelength and pump laser pulse duration. I-OPA-F requires external pulse compressors to achieve short pulse duration.*

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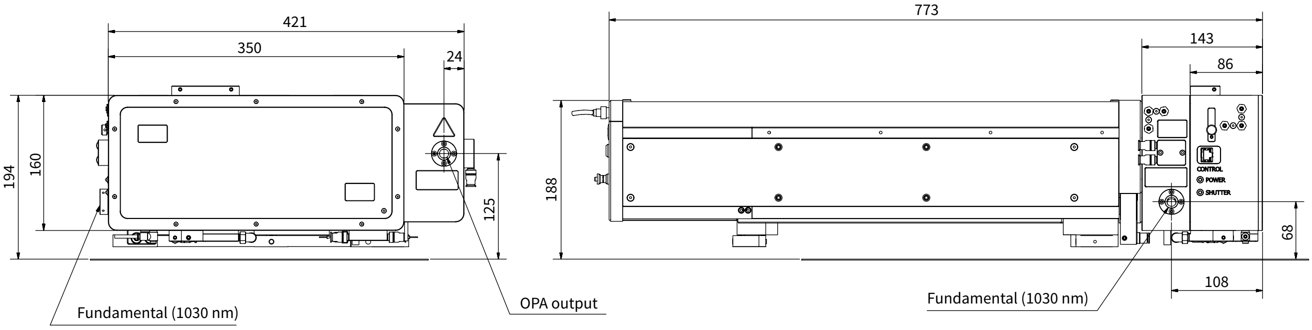
COMPARISON WITH OTHER FEMTOSECOND AND PICOSECOND LASERS

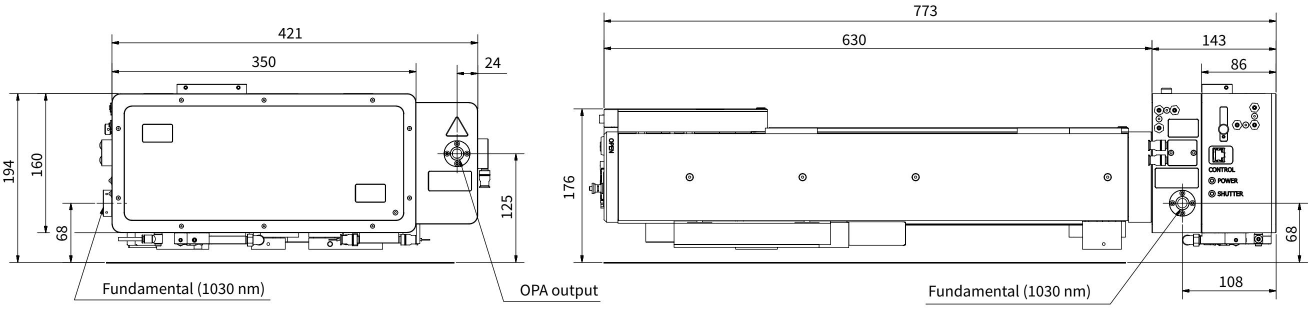
Laser technology	Our solution	HG or HIRO	I-OPA-FW-F	I-OPA-FW-ONE
		Pulse energy at 100 kHz, using PHAROS-10W laser		
Excimer laser (193 nm, 213 nm)	5H of PHAROS (205 nm)	5 µJ		
TH of Ti:Sa (266 nm)	4H of PHAROS (257 nm)	10 µJ	n/a	
TH of Nd:YAG (355 nm)	3H of PHAROS (343 nm)	25 µJ		n/a
SH of Nd:YAG (532 nm)	2H of PHAROS (515 nm)	50 µJ	35 µJ	
Ti:Sapphire (800 nm)	OPA output (750 – 850 nm)	n/a	10 µJ	
Nd:YAG (1064 nm)	PHAROS output (1030 nm)		100 µJ	
Cr:Forsterite (1240 nm)	OPA output (1200 – 1300 nm)		5 µJ	n/a
Erbium (1560 nm)	OPA output (1500 – 1600 nm)	n/a	3 µJ	15 µJ
Thulium / Holmium (1.95 – 2.15 µm)	OPA output (1900 – 2200 nm)		2 µJ	10 µJ
Other sources (2.5 – 4.0 µm)	OPA output			1 – 5 µJ

Note that the pulse energy scales linearly in a broad range of pump parameters. For example, a PHAROS PH1-20 laser at 50 kHz (400 µJ energy) will increase the output power twice, and the pulse energy 4 times compared to the reference table above. The pulse duration at the output is <300 fs in all cases. The OPA output is not limited to these particular ranges of operation, it is continuously tunable as shown in energy conversion curves.

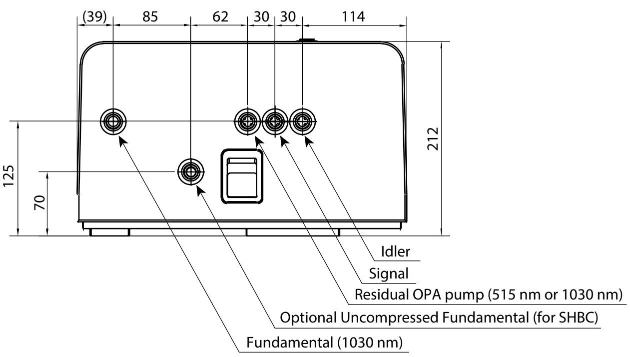
OUTLINE DRAWINGS



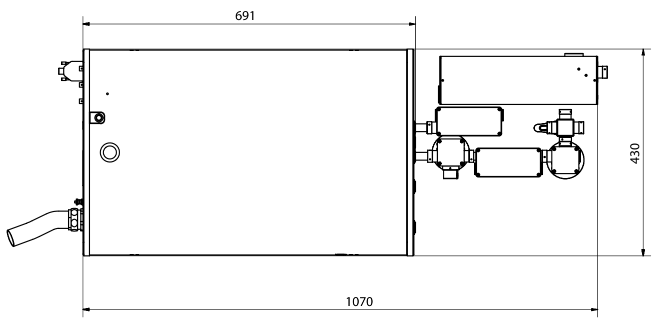
Outline drawing and output ports of CARBIDE-CB3 with tunable I-OPA-TW-HP



Outline drawing and output ports of CARBIDE-CB5 with tunable I-OPA-TW-HP



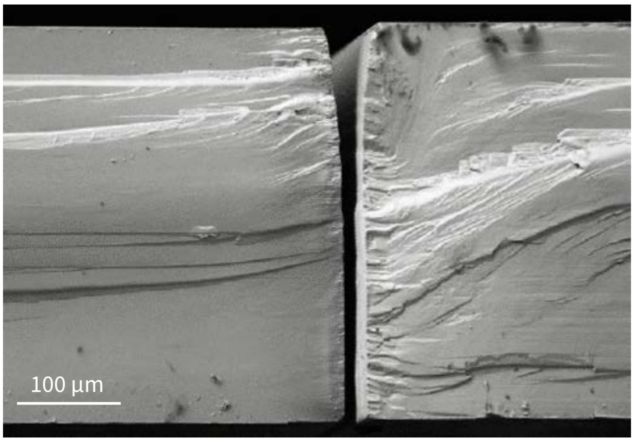
Output ports of Pharos with fixed wavelength I-OPA-FW



PHAROS with fixed wavelength I-OPA-FW-F and compressors for signal and idler

EXAMPLES OF INDUSTRIAL APPLICATIONS

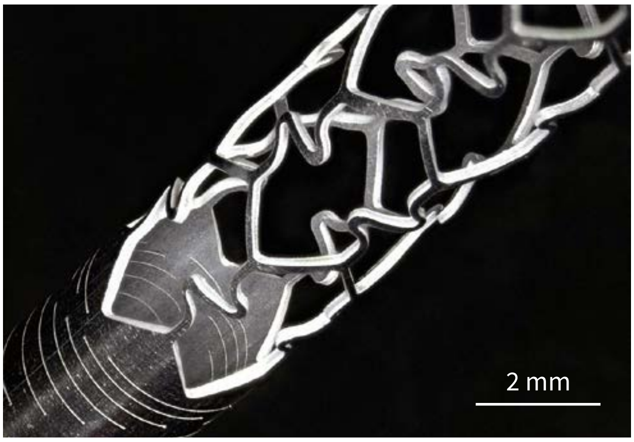
Brittle & highly thermal sensitive material cutting



Multi-pass, cadmium tungstate cutting.
No cracks. All thermal trace effects eliminated.

Source: Micronanics Laser Solutions Centre.

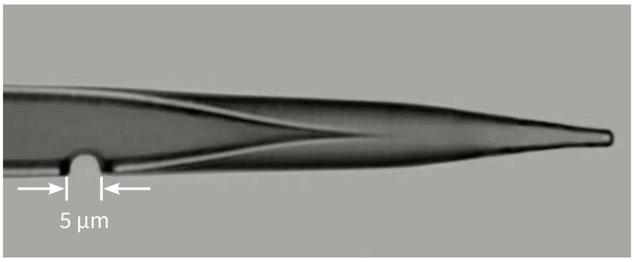
Stainless steel stent cutting



Stent cut using CARBIDE laser.

Source: Amada Miyachi America.

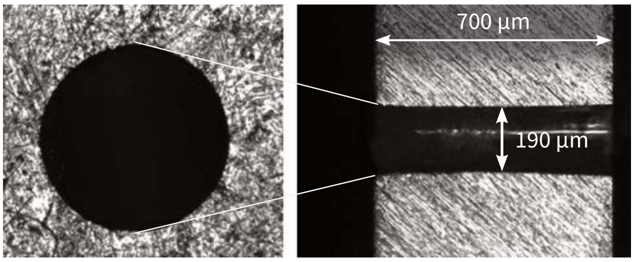
Glass needle microdrilling



Glass needle microdrilling.

Source: Workshop of Photonics.

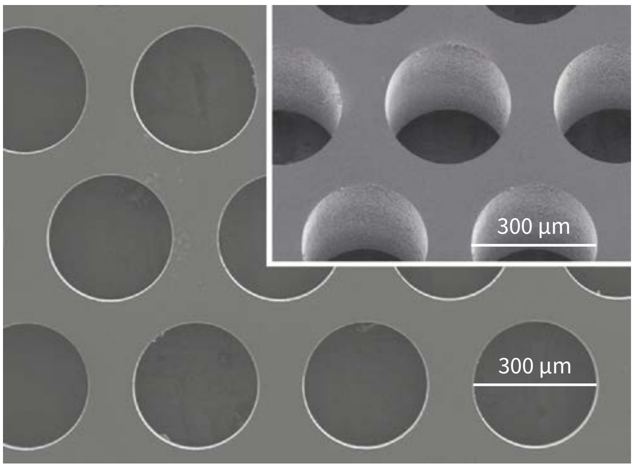
Steel drilling



Taperless hole microdrilling in stainless steel alloys.

Source: Workshop of Photonics.

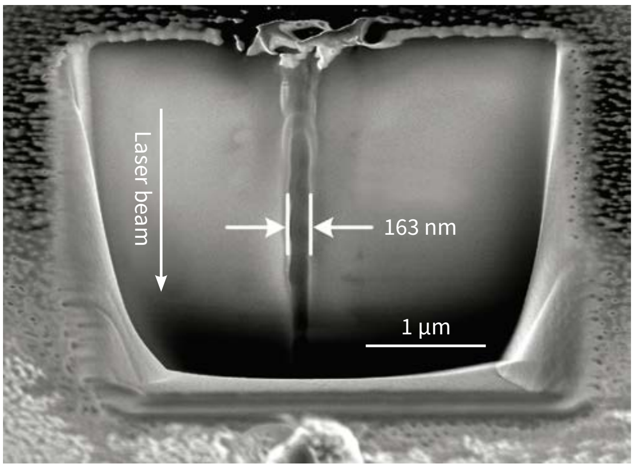
Various type glass drilling



Various glass drilling.

Source: Workshop of Photonics.

Nanodrilling in fused silica



Longitudinal section of the single void.

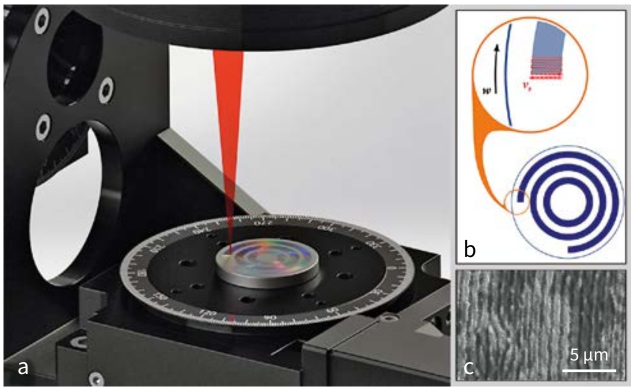
Source: "Ultrashort Bessel beam photoinscription of Bragg grating waveguides and their application as temperature sensors", G. Zhang, G. Cheng, M. Bhuyan, C. D'Amico, Y. Wang, R. Stoian. Photon. Res. (2019).

Milling of complex 3D surfaces

3D milled sample in copper. Zoom in SEM image.

Source: "Highly-efficient laser ablation of copper by bursts of ultrashort tuneable (fs-ps) pulses", A.Žemaitis, P.Gečys, M.Barkauskas, G.Račiukaitis, M.Gedvilas. Scientific Reports (2019).

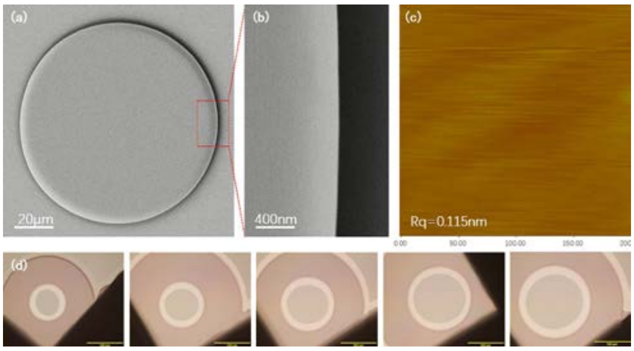
Friction and wear reduction



(a) Schematic of the laser treatment, (b) laser patterning strategy, (c) SEM image of induced LIPSS.

Source: "Tribological Properties of High-Speed Uniform Femtosecond Laser Patterning on Stainless Steel", I.Gnilitskyi, A.Rota, E.Gualtieri, S.Valeri, L.Orazi. Lubricants (2019).

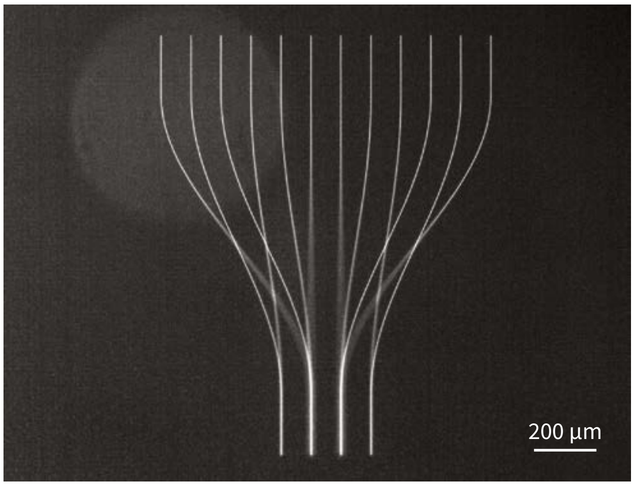
Selective Cr thin film ablation



(a) SEM image of a fabricated $LiNbO_3$ micro-disk resonator, (b) close up view, (c) atomic force microscope (AFM) image of micro-disk wedge, (d) optical microscope image of micro-disk resonator with different diameters.

Source: "Fabrication of Crystalline Microresonators of High Quality Factors with a Controllable Wedge Angle on Lithium Niobate on Insulator", J.Zhang, Z.Fang, J.Lin, J.Zhou, M.Wang, R.Wu, R.Gao, Y.Cheng. Nanomaterials (2019).

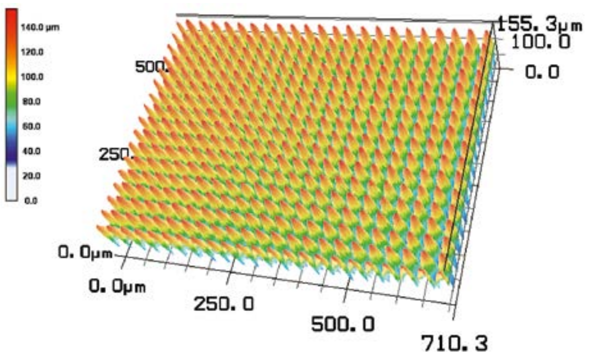
3D waveguides



3D waveguide fabricated in fused silica glass.

Source: Workshop of Photonics.

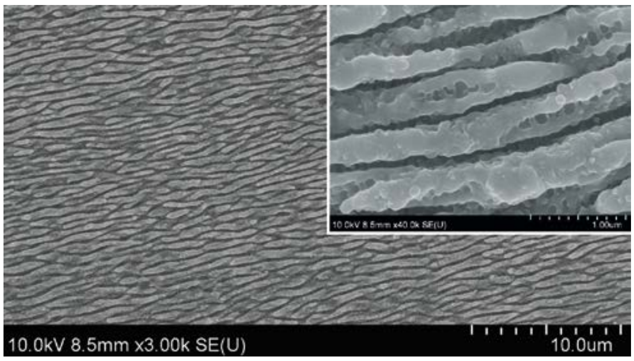
Terahertz broadband anti-reflection structures



Fabricated moth-eye 3-D profile image, taken by laser scanning microscope.

Source: "Terahertz broadband anti-reflection moth-eye structures fabricated by femtosecond laser processing", H.Sakurai, N.Nemoto, K.Konishi, R.Takaku, Y.Sakurai, N.Katayama, T.Matsumura, J.Yumoto, M.Kuwata-Gonokami. OSA Continuum (2019).

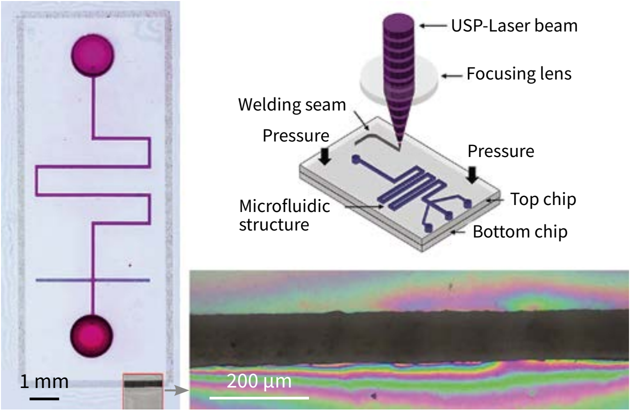
Surface-enhanced Raman scattering (SERS) sensors fabrication



SEM image of the Ti-6Al-4V (TC4) surface after irradiation with progressively laser scan.

Source: "Large-Scale Fabrication of Nanostructure on Bio-Metallic Substrate for Surface Enhanced Raman and Fluorescence Scattering", L.Lu, J.Zhang, L.Jiao, Y.Guan. Nanomaterials (2019).

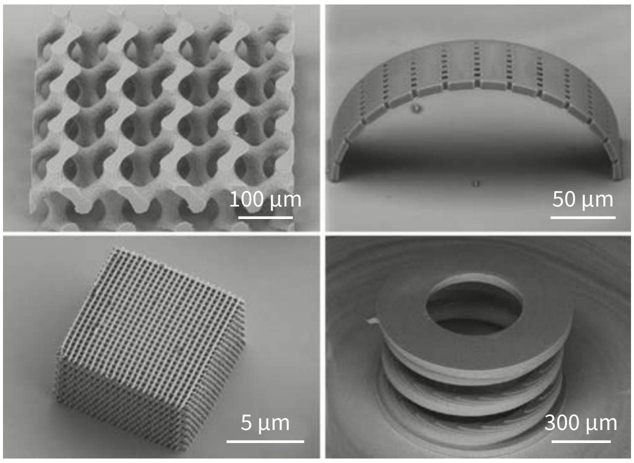
Lab-on-chip channel ablation and welding



(a) Welding of transparent polymers for sealing of microfluidic devices, (b) COC welding seam (c) top view on a sealed microfluidic device.

Source: “A New Approach to Seal Polymer Microfluidic Devices Using Ultrashort Laser Pulses”, G. Roth, C. Esen and R. Hellmann. JLMN-Journal of Laser Micro/Nanoengineering (2019).

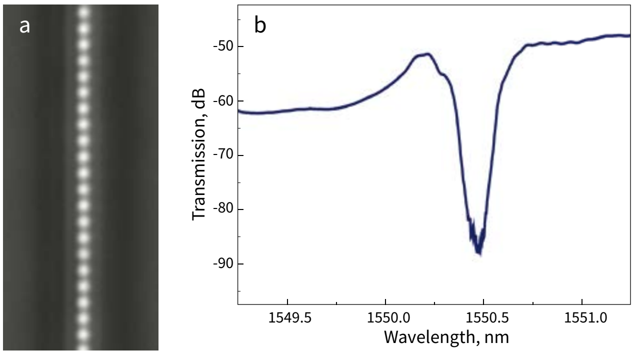
3D micro printing using multi-photon polymerization



Various 3D structures fabricated in SZ2080 polymer using multi-photon polymerization – nanophotonic devices, microoptics, micromechanics.

Source: Femtika.

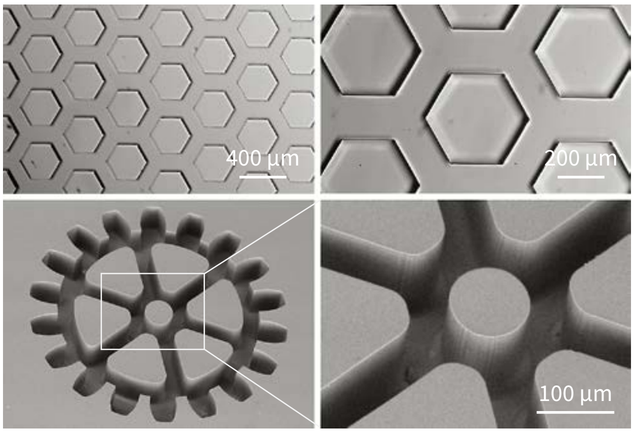
Bragg grating waveguide (BGW) writing



(a) first-order Bragg gratings inscribed in written waveguide, (b) Resonant spectral transmission of inscribed BGW.

Source: “Ultrashort Bessel beam photoinscription of Bragg grating waveguides and their application as temperature sensors”, G.Zhang, G. heng, M.Bhuyan, C.D’Amico, Y.Wang, R.Stoian. Photon. Res. (2019).

3D glass etching



Various structures fabricated in fused silica glass.

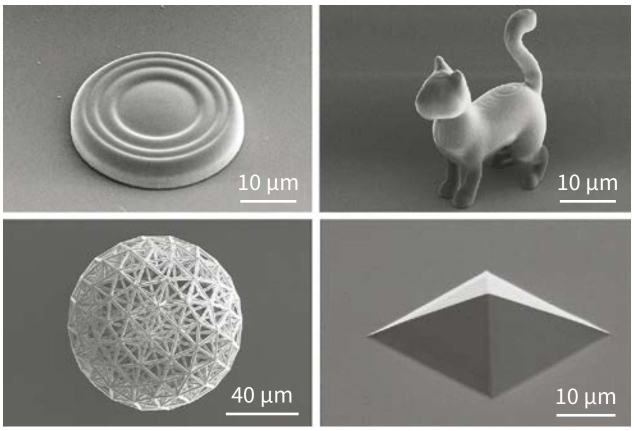
Source: Femtika.

Birefringent glass volume modifications

Form induced birefringence-retardance variation results in different colors in parallel polarized light.

Source: Workshop of Photonics.

3D free shape multi-photon polymerization



Various 3D structures fabricated in SZ2080 polymer using multi-photon polymerization.

Source: Workshop of Photonics.