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Femtosecond OPCPAs from UV to MIR for ultrafast dynamics experiments - a brief overview

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Ultrafast dynamics experiments in physics, chemistry and biology, in condensed matter or gas phase require different types of ultrafast laser sources. Class 5 Photonics builds high-power optical parametric chirped pulse amplifiers (OPCPA) which are a powerful toolbox to deliver femtosecond pulses from the UV to MIR spectral range.

2D Infrared spectroscopy (2DIR) / PEEMS / tr-ARPES / Multi-color pump-probe, Mid-IR and THz spectroscopy / Magneto-optical Kerr-effect (MOKE) microscopy / Raman spectroscopy / HHG, x-ray and electron spectroscopy

Generally, research laboratories focused on ultrafast phenomena require robust and flexible laser systems in order to drive a variety of experiments. Previously, laser sources were driven from Ti:Sapphire lasers at 800 nm with limited spectral bandwidth (Fourier limited pulse of ca. 20 fs), and more importantly limited power levels and repetition rates. Commonly available systems were achieving a few microjoules at 100 kHz repetition rate, or a few millijoules at 1 kHz repetition rate.

However, for many applications high repetition rates in the MHz range are needed to increase the signal-to-noise ratio. At the same time, driving nonlinear interactions requires sufficient pulse energies up to the millijoule range. The recent advances in Yb-based lasers brought a new generation of high-power scientific lasers to the community, however, also at limited spectral bandwidth (Fourierlimited pulses of 200-2000 fs).

Optical parametric chirped-pulse amplication (OPCPA) together with bulk crystal white-light-generation (WLG) opens up the possibility for ultrashort (< 10 fs), high-power lasers with average power up to 100 W, repetition rates of 100 kHz in the millijoule-range or up

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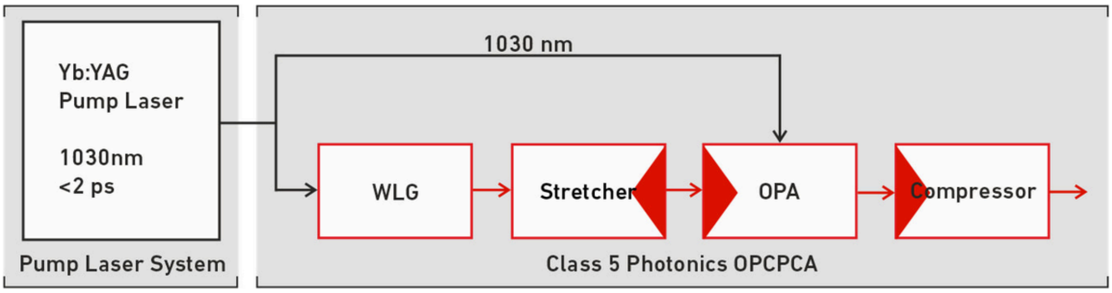
to 10 MHz in the microjoule-range. Further, a wide wavelength range is accessible from ultraviolet (UV) to mid-infrared (MIR), making OPCPA an ideal technology for realizing complex pump-probe architectures, including secondary sources, such as terahertz and extreme ultraviolet high-harmonic generation (HHG).



Basic schematic set-up comprising: Yb-based pump laser, White Light Generation (WLG) to generate a broad-band signal pulse, stretcher to optimize bandwidth and temporal overlap between signal and pump pulse, optical parametric amplifier (OPA) to amplify signal pulse, compressor to compress amplified signal pulse to its Fourier transform limit.

Example: PEEMS

The White Dwarf for ultrafast material science is a compact OPCPA system developed by Class 5 Photonics to provide two synchronized outputs that can be individually spectrally tuned at a repetition rate of 4 MHz. The complete system is realized in a single housing on a footprint of 800 mm x 1200 mm, including the pump laser (Coherent Monaco-1035-80-60). A first output is tunable between 650 and 1300 nm, with corresponding SHG output between 325 and 650 nm in order to achieve gap-less excitation from 325 to 1300 nm. A second output for probing is tunable between 650 and 950 nm (fundamental wavelength), with a second-harmonic generation stage (SHG) providing wavelengths between 325 and 475 nm, and a third-harmonic generation stage (THG) providing UV wavelengths between 250 and 316 nm.

The outputs achieve up to 3 W of average power in each of the fundamental outputs, 0.9 W in the SHG, and 0.3 W in the THG with pulse durations between 30 and 50 fs.

The system includes full monitoring and diagnostics to ensure reliability, long-term robustness and user friendliness.

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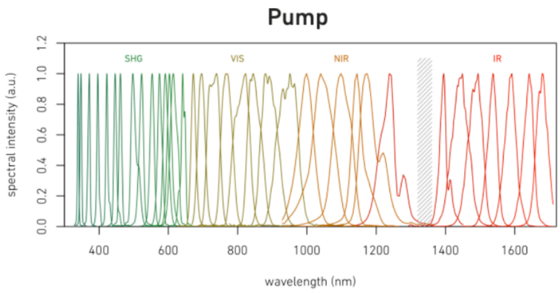
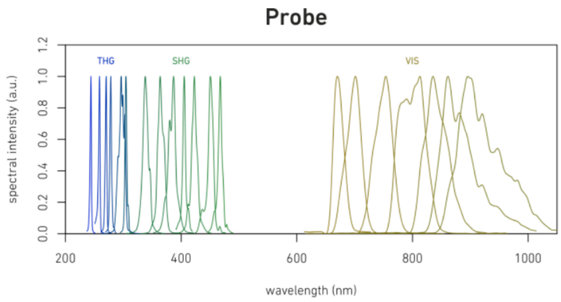
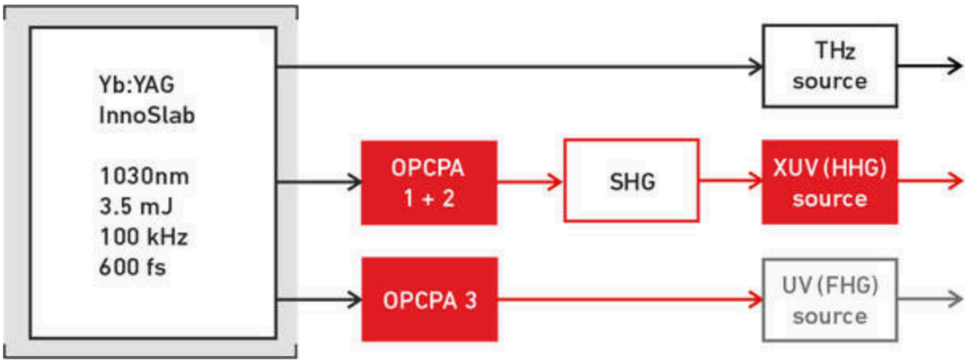




Example: Pump-Probe System from THz to XUV

The White Dwarf HE is a high-power, femtosecond laser system customizable to span an ultra wide frequency range from Terahertz (THz) to extreme-ultraviolet (XUV). The system can be used for long-wavelength excitation of carrier dynamics and short-wavelength (XUV) probing of excited photoelectrons, with suficient probing photon energy of 21.6 eV to cover the full Brillouin-zone of a solid-state material. The White Dwarf HE OPCPA is based on a 350 W Yb-based picosecond laser, which pumps three synchronized outputs: a high-field THz generation source, two individually tunable optical parametric chirped-pulse ampliers (OPCPA 1+2, 3), a second- and fourth-harmonic generation (SHG and FHG) source, and a high-harmonic generation source (HHG).



Example: THz-generation in organic crystals

The excitation of low energy modes in matter plays a key role in advanced material studies. A commonly used generation process for high-field THz-pulses is optical rectification, which is a second-order nonlinear process. Recently developed organic nonlinear crystals, such as DAST and DSTMS feature a high transparency and a large nonlinear coefficient. Using driver laser pulses centered at 1.55 μm allows for an easier collinear phase-matching scheme.

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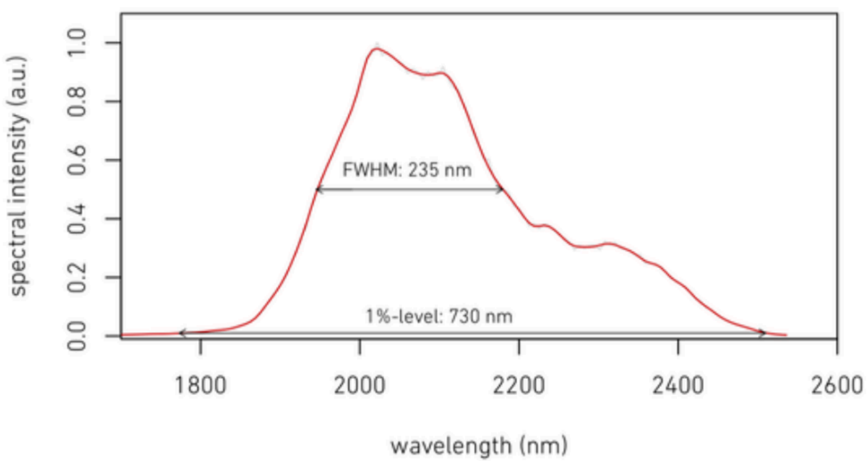
The White Dwarf HE OPCPA concept was extended to a tunable, high power laser system centered at a wavelength of 1.55 µm providing e.g. 30 µJ, sub 36 fs at 350 kHz. In addition, an optically synchronized compressed probe pulse with pulse duration of < 15 fs at 850 nm, was made available as a second output. This probe-pulse can be used, e.g. for electro-optical sampling in a THz set-up. The White Dwarf HE OPCPA can be pumped by a standard industrial Yb-based laser system with up to 300 W.

Example: Ultrafast dynamics in the water window (200-550 eV)

High-harmonic generation (HHG) spectroscopy and associated photoionization spectroscopy in the soft-x-ray regime have been successfully proven as a technique to resolve fundamental strong-field phenomena and electron dynamics on the attosecond scale. To scale the generated photon energy cut off, mid-infrared laser drivers are beneficial. Additionally, the majority of the measurements are subject to long integration times due to the weak light-matter interaction cross-sections in the experimental target and the detection technologies. Hence, higher repetition rates are required.

Class 5 Photonics further develops the high-power Supernova OPCPA system to provide a CEP-stable HHG laser driver at a wavelength of 2 µm at a repetition rate of 50 kHz, and a pulse duration of < 30 fs. Currently, the system is under commissioning achieving more than 47 W (940 µJ at 50 kHz).



Class 5 Photonics sponsored the "Ultrafast Phenomena and Nanophotonics" session at Photonics West 2020. Parts of the results described above have been presented at the corresponding conference.

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Please, find more information in the manuscripts:

- J. H. Buß, M. Schulz, I. Grguraš, T. Golz, M. J. Prandolini, R. Riedel, "Femtosecond OPCPAs from UV to short-wave IR wavelengths for ultrafast dynamics experiments from condensed matter to atoms, molecules, and clusters," Proc. SPIE 11278, Ultrafast Phenomena and Nanophotonics XXIV, 112781A (27 February 2020); doi: 10.1117/12.2551488
- M. Schulz, R. Riedel, I. Grguraš, T. Golz, J. H. Buß, M. J. Prandolini, "Dual channel laser system with gap-less tuning from 250-1300 nm at megahertz repetition rates for time-resolved photoelectron-emission microscopy and spectroscopy," Proc. SPIE 11264, Nonlinear Frequency Generation and Conversion: Materials and Devices XIX, 1126415 (2 March 2020); doi: 10.1117/12.2546247
- Robert Riedel, M. Schulz, I. Grguraš, T. Golz, J. H. Buß, M. J. Prandolini, "Femtosecond 100 W-level OPCPAs from near-IR to short-wave-IR wavelengths," Proc. SPIE 11259, Solid State Lasers XXIX: Technology and Devices, 112591F (21 February 2020); doi: 10.1117/12.2543731
- T. Golz, J. H. Buß, M. Schulz, I. Grguras, M. J. Prandolini, R. Riedel, "High power CEP-stable OPCPA at 800nm," Proc. SPIE 11259, Solid State Lasers XXIX: Technology and Devices, 112591L (21 February 2020); doi:10.1117/12.2546254