Extreme Laser Science Laboratory（2022）
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(0) Research fields

CPR Subcommittee**:** Physics

Keywords: attosecond science, coherent soft x-ray, nonlinear optics, ultrafast lasers, quantum electronics

(1) Long-term goal of laboratory and research background

Laser is highly controllable light, and by using various laser technologies, we can create optical pulses with arbitrary electric field shape, pulse duration, and beam shape. The main research goal of our laboratory is to extend the wavelength range of coherent light sources up to hard x-ray by using the extreme nature of laser light, such as ultra-short pulse duration, ultra-broadband wavelength, and ultra-high intensity. Recently, we have been advancing research aimed at achieving sub-10 fs pulse duration in the mid-infrared laser through the utilization of femtosecond laser technologies, and targeting the single- and sub-cycle of the laser electric field contained within its intensity envelope. This effort not only leads to the shortening the temporal duration of attosecond soft x-ray pulses generated by high-order harmonic generation but also serves as fundamental research for post-attosecond laser, namely zeptosecond laser sources.

(2) Current research activities (FY2022) and plan

(A-1) Development of a sub-2 cycle 100 mJ class laser system

In high-intensity laser science dealing with an interaction of light and matter, the "cycle number of electric field" within a pulse envelope becomes an extremely important parameter. Our laboratory has demonstrated a sub-two-cycle pulse with 100 mJ pulse energy via DC-OPA.

Our DC-OPA consists of three-stage BiBO ($BiB3O_6$) crystals (see Fig. 1). To achieve a CEP-stabilized sub-two-cycle pulse, SPM and self-DFG have been employed for generating a broadband seed pulse. Thanks to the DC-OPA scheme, we have succeeded in developing a laser system with a pulse duration of 10.4 fs, pulse energy of 102 mJ, and peak power of 10 TW. The center wavelength of the output pulse is around 1.7 um, which achieves sub-two cycles electric field within the FWHM of the intensity envelope.
From our previous experiments on water window harmonic generation, it is possible to generate 10-nJ class isolated attosecond pulses with photon energy region in the 500 - 300 eV using our developed IR source. This result is expected to realize soft x-ray attosecond pulses with sub-GW peak power.

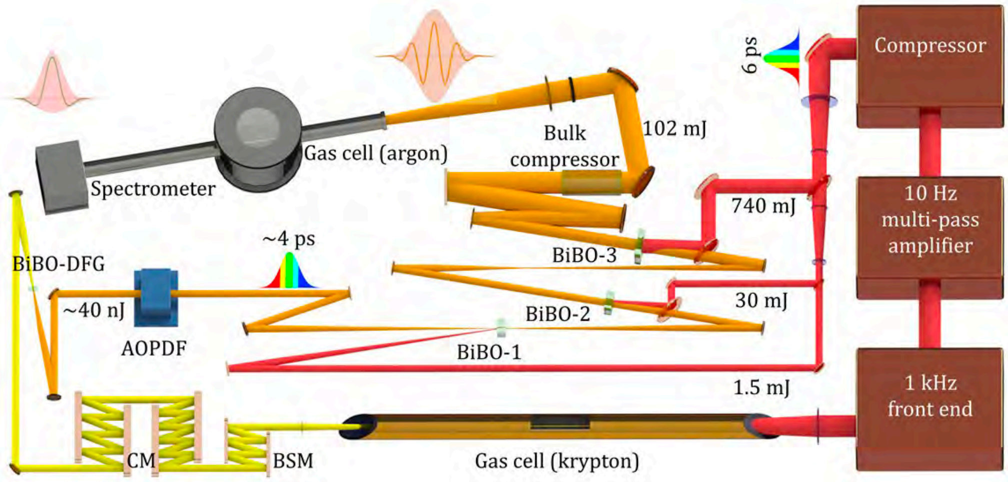


Fig 1. 10-TW sub-two-cycle IR source based on DC-OPA

Future plan, We will improve the DC-OPA method based on insights gained from the development of the sub-2 cycle laser system, and then proceed with the development of a single-cycle laser system as described below.

(B-1) Development of a high-intensity single-cycle laser

In high-intensity laser science dealing with the interaction of light and matter, the "number of electric field cycles" in the pulse envelope is a critical parameter determining the interaction time and frequency. Our lab has been developing TW (10^{12} W)-class a few-cycle laser system and has planned to develop a single-cycle TW laser to realize a more extreme light source consisting the long-term goal of the lab. To realize a single-cycle laser system, it is necessary to develop (1) seed light generation with one-octave bandwidth, (2) amplification with one-octave bandwidth, and (3) pulse compression with one-octave bandwidth. In particular, the laser amplification method covering one octave is the most important laser technology because there are no demonstrations so far.

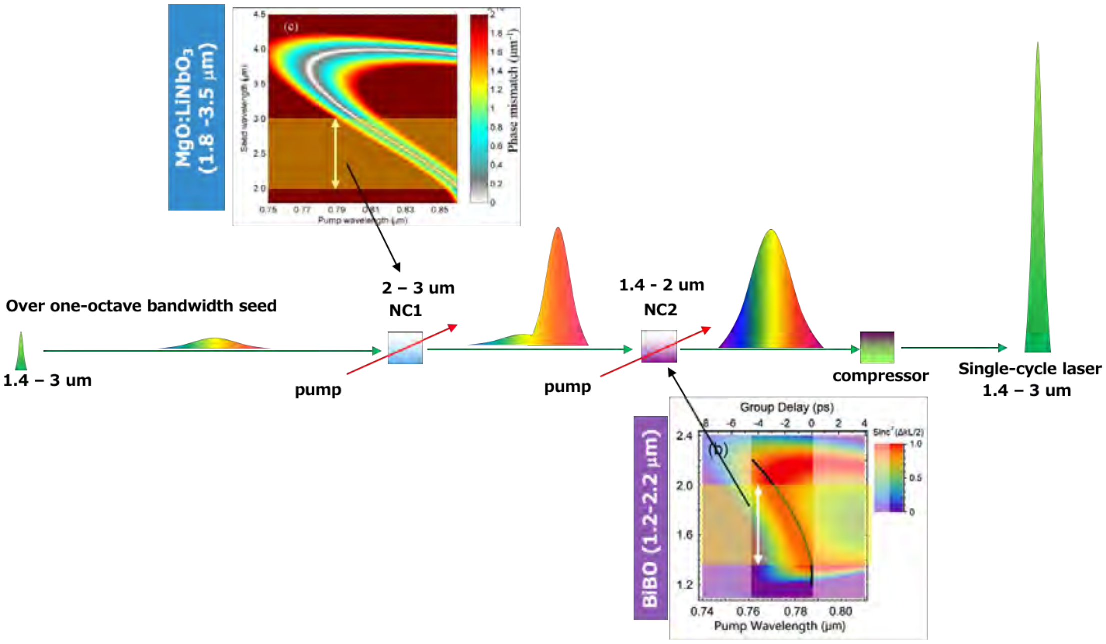


Fig 2. Concept to amplify a single-cycle pulse (called aDC-OPA).

In this research, we propose a new laser amplification method (called the advanced DC-OPA) based on the dual-chirped OPA (DC-OPA) that was developed in our lab. Figure 1 shows a conceptual diagram of the advanced DC-OPA. Conventional DC-OPA uses a single nonlinear crystal as the wavelength conversion medium in OPA, but this new method combines two types of nonlinear crystals to achieve broadband OPA amplification beyond a one-octave bandwidth. The basic idea is to efficiently amplify the short wavelength component (1.4 - 2 μm) and the long wavelength component (2 - 3 μm) of a seed pulse (1.4 - 3 μm) over one octave independently by using different nonlinear crystals.

Future plan, Based on the newly proposed laser amplification method (aDC-OPA), we will design and construct a laser system. To achieve an amplification bandwidth of one octave or more, we plan to test a DC-OPA combining $MgO:LiNbO_3$ and BiBO Type-I.

(3) Members

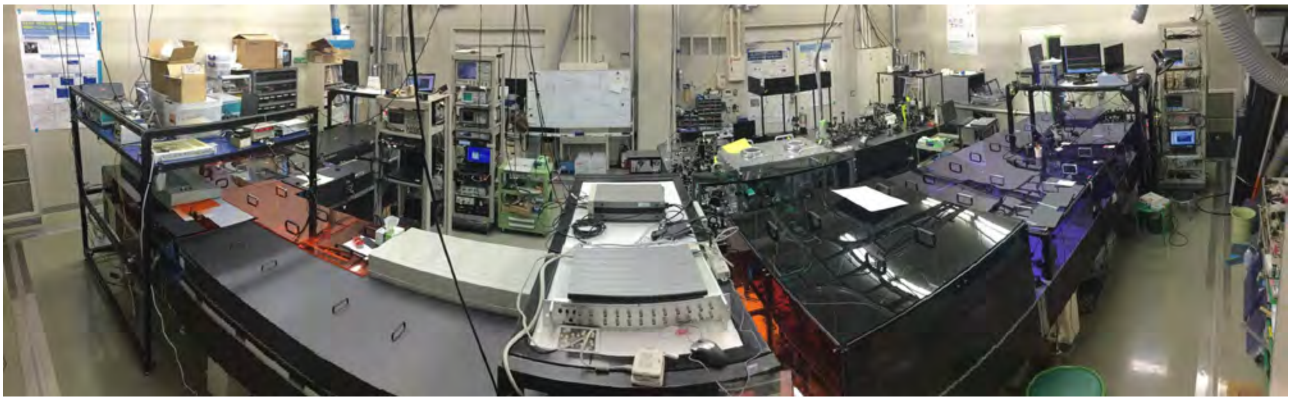
(Chief Scientist)
Eiji J. Takahashi

(4) Representative research achievements up to 5 FY2022

1. B. Xue, K. Midorikawa, and E. J. Takahashi, "Gigawatt-class, tabletop, isolated-attosecond-pulse light source", Optica 9, 360-363 (2022).
2. L. Xu, B. Xue, N. Ishii, J. Itatani, K. Midorikawa, and E. J. Takahashi, "100-mJ class, sub-two-cycle, carrier-envelope phase-stable dual-chirped optical parametric amplification", Opt. Lett. 47, 3371-3374 (2022).
3. E. J. Takahashi, “Novel ultrafast laser technologies for generating GW-scale isolated attosecond pulses,” The 1st International Conference on UltrafastX, Xi'an, China, Apr. 2022
4. E. J. Takahashi, “Intense single-cycle pulses via serial waveform synthesis,” International Symposium on Ultrafast Intense Laser Science 2022, Hawaii, USA, Dec. 2022

5. E. J. Takahashi, “Novel laser sources for driving an intense attosecond pulse”, The 13th International Conference on Information Optics and Photonics (CIOP 2022), Online, Aug. 2022

Supplementary



Panoramic view of our laser systems

Laboratory Homepage

https://www.riken.jp/en/research/labs/chief/els/index.html