High-order harmonic generation by 50 mJ three-channel optical waveform synthesizer

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In this work, a high-energy three-channel optical waveform synthesizer system is built up by using a CEP-stabilized Ti:sapphire laser [1] operating at 10 Hz. By focusing the laser pulse from the synthesizer into an argon gas cell, high-flux continuum harmonics are demonstrated.

High-energy three-channel synthesizer consist of a 800 nm Ti:sapphire laser (pump, 44 mJ), and a OPA laser, which including two channel output: 1380 nm (signal, 6 mJ) and 1900 nm (idler, 3 mJ). The pulse duration for each channel is measured to 28 fs, 33 fs and 40 fs, respectively. The output electric field (E_{3C}) of the synthesizer is described in the Equation 1. It contains three terms which corresponding to each channel. To shape light fields from the synthesizer, a stabilizing of the CEP (φ_{CEP}) and relative timing jitter (δt_1, δt_2) among each channel is needed. As the pump laser is provided by our CEP-stabilized laser system [1], the typical single shot CEP noise is controlled around 600 mrad rms. To measure the optical path variation over time in the delay line, the Mach-Zehnder interferometer is built by introducing a continuous wave (CW) laser into the experiment. By using a photodiode, the intensity fluctuation of spatial interference fringes on the superposed beam profiles of the CW laser is monitored and the delay jitter is feedbacked to the synthesizer system with the piezo stage. The optical path delay jitter is successfully suppressed under 30 as. Furthermore, a balanced optical cross-correlator (BOC) is introduced to suppress the induced delay jitter in the white-light generation, which is due to the Kerr effect by the energy fluctuation of pump pulse. Thus, the total delay jitter is precisely suppressed from 1.6 fs to 450 as rms.

$$E_{3C} = E_p \exp\left[-2\ln 2\left(\frac{t}{\tau_{p0}}\right)^2\right]\cos(\omega_p t + \varphi_{CEP}) + E_s \exp\left[-2\ln 2\left(\frac{t+\delta t_1}{\tau_{s0}}\right)^2\right]\cos(\omega_s(t+\delta t_1) + \varphi_{CEP}) + E_i \exp\left[-2\ln 2\left(\frac{t+\delta t_2}{\tau_{i0}}\right)^2\right]\cos(\omega_s(t+\delta t_2) + \varphi_{error} + C) \quad (1)$$

The harmonic spectra by this synthesizer are shown in the Fig. 1. The discrete harmonic components disappear at the three-channel case while the continuum harmonic spectrum around the cut-off region (> 45 eV). Taking our previous experimental results [2] into account, the continuum soft-x-ray spectrum (45 ~ 55 eV) is evaluated to > 100 nJ, which supports < 300 as transform limited pulses. It can be concluded that the multi-channel synthesizer is suitable for generating the high-flux broadband continuum harmonic.

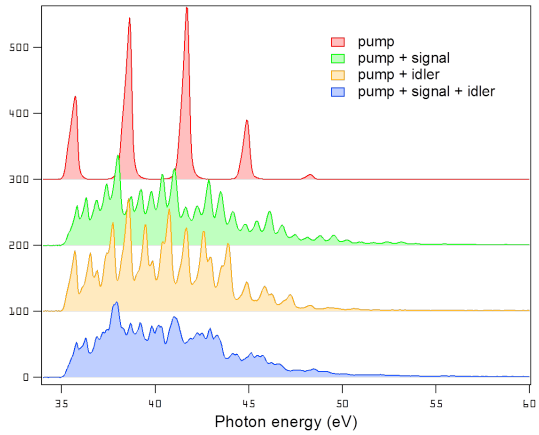

Fig. 1 Single-shot harmonic spectrum from 10-cm Ar cell.

Reference:

[1] E. J. Takahashi, *et al.*, Opt. Lett. 40, 4835 (2015). [2] E. J. Takahashi *et al.*, Phys. Rev. Lett. 104, 233901 (2010).