Generating sub-100 nJ soft x-ray super continuum at 120-eV region by a fully stabilized three-channel optical waveform synthesizer

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Previously, we reported a 50 mJ three-channel optical waveform synthesizer operating at 10 Hz and applied high order harmonic generation in argon gas. In this work, the synthesizer's performance is updated and applied to generate broadband (>30 eV) soft X-ray supercontinuum at 100 eV in neon gas. Briefly, The typical single shot CEP noise of the 10-Hz pump pulses has been stabilized to be 524 mrad.. By introducing Mach-Zehnder (MZ) interferometer and balanced optical cross-correlator (BOC), the delay jitters are successfully suppressed (MZ for both < 20 as, BOC for signal & pump < 245 as). Phase jitter between pump and signal pulse is also measured by monitoring the interference fringe variation between the pump and spectral broadened signal pulse spectrum through the spectrometer. The specific value is concluded to be 1 rad. during 5 minutes of acquiring time. The synthesized pulses are focused by using two separated long focal length lenses (4.5 m for pump pulse, 3.5 m for signal and idler pulses) into a 10 cm long neon gas filled cell. The focused intensity in the three-color case is measured to be 4.4×10^{14} W/cm^2 with 20 mJ, 4.3 mJ and 1.6 mJ input pulse energy for pump, signal and idler, respectively. The generated harmonic spectra are shown in the Fig. 1. A broadband (>30 eV) continuum harmonic spectrum appeared around the cut-off region (90 ~ 120 eV) when using synthesized pulse input (gas pressure: 8.8 torr). By increasing the pump pulse energy up to 25 mJ and using a 5 cm length cell, we further extend the supercontinuum to 100 ~ 130 eV and obtain higher intensity. Taking our previous experimental results [1] into account, the continuum soft-x-ray spectrum (100 ~ 130 eV) is evaluated to be approximately 42 nJ, which supports 100 as transform-limited pulses. Our supper continuum HH intensity is almost 1,000-fold higher than the energies previously reported [2].

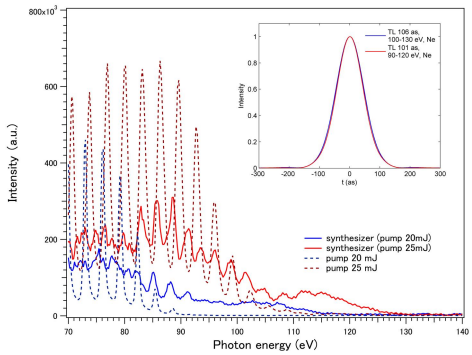

Fig.1 Generated high-order harmonic spectrum. With synthesizer input is shown in solid line; pump pulse input is shown in dash line. Inset figure: transform limited pulses for the super continuums.

[1] E. J. Takahashi, *et al*., Appl. Phys. Lett. 84, 4 (2004)

[2] E. Goulielmakis, *et al*., Single-cycle nonlinear optics. Science 320, 1614–1617 (2008)