Generation of high-order harmonics radiations around 13.5 nm by using a T-shaped He gas tube

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When an ultrashort high intensity laser pulse is focused onto rare gases, various order harmonics with frequencies with odd multiples in terms of the fundamental laser wavelength are generated. It was in 1987 such HH generation was discovered [1]. Since then, various attempts have been made to increase the photon energy that already reaches the keV region [2].

Material processing by lasers is indispensable as one of the recent processing methods. The shorter the wavelength of the laser light used for processing, the more precise processing can be performed, so that extreme ultraviolet light is more suitable for finer processing than ones by visible/UV lights. HHs generated in this study are in extreme ultraviolet wavelengths. The current issues are: (1) higher order HH generation by using longer wavelength pump laser, (2) single attosecond pulse, which provides powerful tools to understand the X-ray and matter interaction, (3) increase of the HH photon number. Among these, we have focused on the issue (3), especially, 13.5 nm (~59th order at 800 nm drive laser), where the HH can contribute to fundamental technology of efficient extreme ultraviolet (EUV) lithography.

The experiment was carried out at QST Kansai. We used a Ti:S laser (wavelength: 800 nm, pulse duration: 65 fs, beam diameter: 22 mm, maximum pulse energy: 50 mJ). The laser was focused onto He gas target with a lens (focal length: 4 m, Rayleigh length: 40 mm). The He gas target was fed by using a fast solenoid valve into T-shaped Mo tube of 40, and 80 mm in length and their inner diameter was 2.9 mm, in which the laser interacted with the He gas to generate HH emission. Figure 1 shows a photograph of the T-shaped He gas tube. The HH spectra were measured with a grazing incident spectrometer equipped with a spherical mirror, flatfield grating of 1200 grvs/mm, X-ray CCD. Fundamental laser light was blocked by a 0.5 μm thin Zr filter.

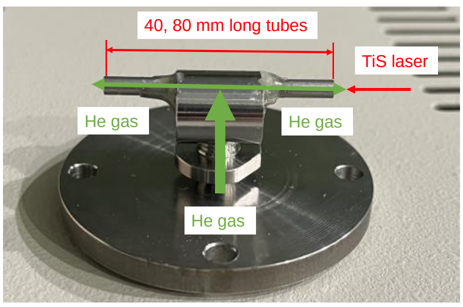

FIG.1 T-shaped gas tube for HH generation.

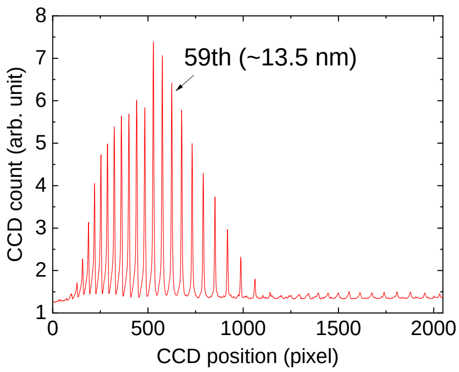

FIG.2 HH signal observed with 80 mm gas tube.

Figure 2 shows the highest HH signal observed by using 80 mm gas tube at 0.45 bar, 40-mJ pulse energy. With increasing the gas pressure, the HH intensities drops. Similarly, with increasing laser energy, the signal is decreased.

The parameter dependences of HH intensity and its distribution on laser energy, gas pressure, nozzle length will be reported in details.

References

[1] A. McPherson *et al.*, J. Opt. Soc. Am. B**4**, 595 (1987).
[2] T. Popmimtchev *et al*, Science **336**, pp.1287-1291 (2012).