Amplification of Attosecond High-Harmonic X-Ray Pulses by Plasma-Based X-Ray Lasers

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Coherent intense sub-femtosecond (sub-fs) X-ray pulses would provide unique combination of the record high spatial and temporal resolution (ultimately determined by carrier wavelength and pulse duration accordingly). The high-harmonic generation (HHG) technique allows to produce attosecond pulses extending to X-ray range, but of rather limited nJ energy. Modern table top plasma-based X-ray lasers produce high energy pulses (up to several mJ) but of rather long picosecond (ps) duration.

Combining the advantages of short pulse duration of HHG with high gain of plasma-based X-ray lasers one could produce an intense attosecond X-ray source.

However, a straightforward amplification of attosecond HH pulses in an active medium of X-ray lasers is impossible due to rather narrow spectral width of the corresponding lasing transitions. Only single harmonic amplification has been demonstrated so far resulting in improved temporal and spatial coherent properties of X-ray laser radiation [1]. Very recently we have shown that driving of the active medium of a plasma-based X-ray laser with a moderately strong infrared (IR) laser field during the process of X-ray seeding pulse amplification may result in production of amplified attosecond pulses via generation of the phase-matched sidebands of the seeding X-ray field, separated by doubled frequency of the driving IR field [2]. A similar scheme of attosecond pulse formation from quasi-monochromatic extreme ultraviolet (XUV) or X-ray radiation in passive (absorbing) medium was studied in detail in our recent paper [3]. In current work we show that under certain conditions not just a single high-order harmonic (HH) but the whole set of HHs may be efficiently amplified in the active medium of a plasma-based X-ray laser when it is modulated by a replica of the same IR field as used to produce an incident HH signal.

The possibility to amplify a train of attosecond pulses produced via HHG with a carrier wavelength 3.38 nm (in a “water window” range) in inverted plasma of the resonant hydrogen-like C VI (C\(^{5+}\)) ions driven by z-polarized IR field with a wavelength \(\lambda_{IR} = 2102.85\) nm and intensity \(I_{IR} = 2.7 \times 10^{15}\) W/cm\(^2\) is illustrated in Fig. 1. The C VI (C\(^{5+}\)) ion concentration and electron density \(N_{\text{ion}} = 10^{19}\) cm\(^{-3}\) and \(N_{\text{el}} = 15N\) are chosen to maximize the gain in a recombination X-ray laser generating at the 3.37 nm transition \(n=2-n=1\) of C VI ions (according to [4]), the pulse intensity of an incident z-polarized HH signal is chosen to be \(I_0 = 10^{12}\) W/cm\(^2\).

References

