Generation of the Second Harmonic of a XUV Pulse by a IR-Laser-Dressed Atom

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An intense infrared (IR) laser pulse induces in a gas medium a strongly nonlinear process of high-order harmonic generation (HHG), which can be well described in terms of an atomic polarization response (APR) determining the HHG amplitude at a given frequency. The properties of IR-field-induced APR can be changed drastically by adding a weak extreme ultraviolet (XUV) isolated attosecond pulse. Indeed, the synchronized with IR filed XUV pulse induces new channels for the high-energy photons generation [1-3]. For instance, it may contribute to the secondary generated radiation (SGR) spectra through the elastic XUV scattering channel (determined by the polarizability of an atomic system), which results in the increasing of SGR yield and manifests strong dependence on the internal collective electron dynamics of an atom [3].

In this work, in order to analyze the APR for an atom subjected to synchronized intense IR and weak XUV pulses, we develop the perturbation theory (PT) in the XUV field on the basis of the IR-dressed wave functions for an atomic electron obtained within adiabatic approximation [4]. We show that the second order of PT for APR describes the amplitude of the second harmonic generation of the XUV pulse (*i.e.*, the SGR at the doubled carrier frequency of the external XUV pulse). We note that the second harmonic generation of the XUV pulse is allowed only in the presence of the IR field. Within our recently developed approach [4], we show that in the adiabatic approximation the APR for the second harmonic generation channel is proportional to the instant value of the IR-field strength. Taking into account this linear dependence of the SGR yield on the IR-pulse intensity, we suggest the retrieving method for the IR pulse of arbitrary shape from the SGR yield at the doubled carrier frequency of the XUV pulse.

Analyzing the dependence of the SGR yield on the time-delay between IR and XUV pulses, we observe an oscillating structure resulted from an interference of two channels: i) second XUV-harmonic generation channel and ii) the XUV-assisted HHG channel [2]. The second channel corresponds to the first order of PT in the XUV field and can be described within three-step scenario of HHG, for which the recombination step is accompanied by the XUV photon emission. We confirm our findings both analytically, accurately treating the joint interaction of an atomic electron with IR and XUV pulses, and numerically by solving the time-dependent Kohn-Sham equations for the Ar atom.

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References

[1] A C Brown and H W van der Hart, Phys. Rev. Lett. **117**, 093201 (2016)

[2] T S Sarantseva, M V Frolov, N L Manakov, A A Silaev, N V Vvedenskii and A F Starace, Phys. Rev. A **98**, 063433 (2018)

[3] A A Romanov, A A Silaev, N V Vvedenskii, A V Flegel and M V Frolov, Opt. Lett. **47**, 3147 (2022)

[4] A V Flegel, N L Manakov, Ia V Breev and M V Frolov, Phys. Rev. A **104**, 033109 (2021)