Effects of autoionizing states in HHG and attosecond pulse production

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High harmonic generation (HHG) via interaction of intense laser radiation with matter provides a unique source of coherent collimated XUV femto- and attosecond pulses. Recently much attention has been paid to the role of resonances in HHG in gases and plasma plumes [1,2,4-9]. It was shown that when the high-harmonic frequency is close to the transition to an excited quasi-stable state of the generating particle (in particular, to an autoionizing state (AIS)) the harmonic can be much more intense than the nonresonant ones.

We suggested a HHG theory [1] which generalizes the strong-field approximation to the resonant case. The interference of the nonresonant and the resonant terms leads to the Fano-like factor in the high harmonic spectrum. Our theory confirms the four-step resonant HHG model [2], where the first two steps are the same as in the three-step re-collision model [3], but instead of the last step (radiative recombination from continuum to the ground state) the free electron is trapped by the parent ion, so that the system (parent ion + electron) lands in the quasi-stable state, and then it relaxes to the ground state emitting XUV.

Our simulations predict phase-locking of the resonantly-enhanced high harmonics and strong influence of the resonance at the harmonic phases. This conclusion was confirmed by experiments using RABBIT technique [4]. The phase properties of the dipole matrix element for the AIS – ground state transition can be directly studied using resonant harmonic phase measurements.

The phase-locking of the resonant harmonics and relatively high conversion efficiency make them interesting for the attosecond pulse generation. The attosecond duration of the XUV pulse assumes broadband resonant enhancement; such enhancement due to a giant resonance was observed in Ref. [5,6]. We study theoretically [7] the effect of giant resonance on the phase difference between consecutive resonantly enhanced harmonics. We show that this effect leads to attosecond-pulse shortening in conjunction with the resonance-induced intensity increase of more than an order of magnitude.

Moreover, studies of the HHG using finely-tuned laser wavelength [8] show not only the resonant harmonic generation via AIS, but also a generation involving dressed-AIS that appears as two coherent satellite harmonics at frequencies $\pm 2\omega_{las}$ from the resonant one. Thus, the resonant HHG allows not just enhancement of the generation efficiency but also observation of the new phenomena like dressed-AIS.

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