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Isolated attosecond pulse generation in a 800 nm laser field by adding a terahertz (THz) pulse

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Abstract. We theoretically study the high-order harmonic and the isolated attosecond pulse generation in the near-infrared (IR) (3-fs, 800 nm) laser pulse by adding a terahertz (THz) controlling field with proper phases. It is found that the high-order harmonic spectrum in the IR pulse by adding a terahertz field is broader and smoother than that in the single IR pulse. The underlying physical mechanism is illustrated by means of the time-frequency analysis and the three-step model. We calculate the ionization rate by ADK model to further demonstrate the process of high-order harmonic generation. By superposing a proper range of harmonic spectrum, an isolated attosecond pulse with the duration of 71 as is obtained.

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Key words: High-order harmonic generation, isolated attosecond pulse, terahertz pulse

1 Introduction

High-order harmonic generation (HHG) has attracted a lot of attention for its excellent characteristics about spectrum for generating attosecond pulses [1-5] and coherent soft x-rays source [6]. The generation of attosecond pulse leads the study of ultrafast nonlinear optics into a new territory for observing the relaxation processes and the motion of electrons inside the atom or molecule [7]. Therefore, a lot of researches have been taken for characteristic of the high-order harmonic emission, and many efficient methods have been suggested [8-12].

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HHG is a nonlinear phenomenon when an atom or molecule are exposed to intense laser fields which can be well explained by the semi-classical three-step model [13]: the electron tunnels through the barrier of the atomic potential which is suppressed by the incident laser pulse, then it moves along with the vibrated electric field without the Coulomb interaction and captures energy, finally it may turn back to the parent ion, emitting high energy photon and the maximum energy of which reaches $I_p+3.17U_p$, where I_p is the atomic and U_p is the ponderomotive energy. Nowadays, a lot of advanced techniques have been proposed to enhance the HHG and generate an isolated attosecond pulse in experiment and theory, such as few-cycle laser driving [14], double optical gating (DOG) [15], the few-cycle pulses [16], polarization gating [17], two-color fields [18-20]. The rapid progress in the terahertz technology makes the extremely strong and long-wavelength THz field become experimentally available [21,22], which leads to a new area to study the effects of THz fields for controlling harmonic emission and generating attosecond pulses [23-25]. Scheme of a terahertz field superposing a mid-infrared driving laser can efficiently extend the cut-off of the spectrum for capturing much more energy during the acceleration and a double-plateau-structured spectrum has been observed [26].

In this paper, we theoretically study the generation of high-order harmonic and isolated attosecond pulses in an 3-fs, 800 nm laser pulse by adding a terahertz (THz) field with proper phases. The spectrum of the second plateau in the IR laser pulse by adding a THz field is broader and smoother than that in the single IR pulse. By superposing a proper range of harmonic spectrum, an isolated attosecond pulse with the duration of 71 as is obtained.

2 Theoretical method

In our calculations, the Lewenstein model [27] is applied to investigate the HHG of He atom in the intense laser field, in which the ground depletion is taken into account. The time-dependent dipole moment of an atom in the intense laser field can be described as

$$\begin{aligned} d(t)=i\int_0^\infty d\tau\left(\frac{\pi}{\varepsilon+i\tau/2}\right)^{\frac{3}{2}} d^*(p_{st}(t,\tau)-A(t))a^*(t)d(p_{st}(t,\tau)-A(t-\tau)) \\ \times a(t-\tau)E(t-\tau)e^{-iS_{st}(t,\tau)}+c.c., \end{aligned} \tag{1}$$

where ε is a positive regularization constant, τ is the traveling time of free electron between ionization and recombination. $E(t)$ is the electric field of the laser pulse and $A(t)$ is its associated vector potential. $p_{st}(t,\tau)$ is the stationary momentum obtained by the stationary points integral algorithm, which can be defined as

$$p_{st}(t,\tau)=\frac{1}{\tau}\int_{t'}^{t} A(t')dt'', \tag{2}$$