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Theoretical study of isolated attoseond pulse generation with two methods

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Abstract. We theoretically investigated high-order harmonic generation and isolated attosecond pulse generation from a model of helium atom by two methods: numerically solve time dependent Schrödinger equation (TDSE) by splitting-operator method and Lewenstein's strong field approximation theory. A left circularly polarized pulse (800 nm) is combined to a right circular polarized pulse (1200 nm) with a timedelay of 4 fs. A supercontinuum spectrum plateau with a broad bandwidth of 215 eV (from 230 to 445 eV) is obtained for the case of $I_0 = 7\times 10^{14} W/cm^2$. By superposing a bandwidth of 70 eV in the plateau region, an linear polarized isolated attosecond pulse with the duration of about 56 as can be obtained. Moreover, we illustrate the quantum path control in terms of the time-frequency analysis by Morlet wavelet transform method.

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Key words: isolated attosecond pulse, high-order harmonic generation, quantum path control

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1 Introduction

Isolated attosecond pulse (IAP) generation has been a hot topic due to its potential application in ultrafast science [1–3]. Recently, IAPs are mainly generated by superposing high-order harmonic spectra which obtained from intense laser field interacting with atoms or molecules [4, 5]. The spectrum of high-order harmonic generation (HHG) has a general structure: the intensity decreases rapidly in low order region, and then comes a plateau area, a cutoff with the maximum energy $I_p + 3.17U_p$ appears at the end, where I_p is the ionization potential and $U_p = E^2/4\omega^2$ denotes the ponderomotive energy.The feature can't be explained by perturbation theory but can be well explained by the semi-classical three-step model [6]. First, the electron is ionized by tunneling the potential barrier, this is a quantum process. Second, the ionized electron which is regard as free

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*Corresponding author. *Email address:* `xiachl2008@163.com` (C.-L. Xia) classical electron propagates in the laser field. Finally, as the intense laser field reverse, the electron may go back to the nuclei and emits an energetic photon. In addition, the isolated attosecond pulse would be more useful in pump-probe ultrafast physical process. So control the quantum path that contributing to HHG process is an essential issue.

Different schemes have been proposed to control the quantum path and obtain IAPs, such as few-cycle scheme [4, 7], two-color scheme [8–10], three-color scheme, polarization gating (PG) scheme [11] and so on. The PG scheme can be obtained by combing two counterrotating circularly polarized laser pulses with a proper delay, the frequencies of the two pulses are the same. In addition, an IAP with the duration of 67 as was obtained by the double optical gating (DOG) in experiment [12]. The DOG scheme can be obtained by adding another pulse to a PG scheme, this means that the frequency of the two circularly polarized laser pulse is equal . In our previous work [13], we investigated the IAP generation by two circularly polarized pulses with different frequencies, and found that the quantum paths can be controlled. In this paper, we theoretically study the IAP by combining a left circularly polarized pulse with a right circular polarized pulse, and the frequencies are different for the two pulses. To ensure our calculation, we investigate the HHG with two methods: splitting-operator (SO) method [14] and strong field approximation (SFA) model [15].

2 Theoretical methods

The laser-matter interaction can be described by Schrödinger equation. Our calculation is based on the single-active electron approximation, and the time dependent Schrödinger equation (TDSE) can be written as (in atomic units)

$$i\frac{\partial}{\partial t}\Psi(\vec{r},t)=\left[-\frac{1}{2}\nabla^2+U(\vec{r},t)\right]\Psi(\vec{r},t), \tag{1}$$

where, $U(\vec{r},t)=V(\vec{r})+\vec{r}\cdot\vec{E}(t)$ is the total potential of the Coulomb potential and the laser-matter interaction potential. In this paper, we investigate the HHG by two-color circular polarized laser pulses in two methods.

A. Numerically solve TDSE by SO method

Because the laser pulse is circular polarized, and it has two dimensions. We numerically solve two-dimensional TDSE:

$$i\frac{\partial}{\partial t}\Psi(x,y,t)=\left[\frac{p_x^2+p_y^2}{2}+U(x,y,t)\right]\Psi(x,y,t), \tag{2}$$

where, (p_x^2,p_y^2) is the electronic momentum, $U(x,y,t)=V(x,y)+xE_x(t)+yE_y(t)$ is the total