December 15-17, 2021

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International Conference on Advances in Engineering, Architecture, Science and Technology

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MUHAMMED SAYRAÇ

has participated in the **'' 1st International Conference on Advances in Engineering, Architecture, Science and Technology ''** with the paper entitled

Effect of Ultrashort Laser Pulse Shape on the Dipole Spectrum of a Single Electron
Muhammed SAYRAÇ

which has been held in Erzurum, Turkey on December 15-17, 2021.

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06.12.2021

Dear **Muhammed Sayrac,**

We are pleased to inform you that your paper titled **“Effect of Ultrashort Laser Pulse Shape on the Dipole Spectrum of a Single Electron”** (Paper ID:**48** submitted to **International Conference on Advances in Engineering, Architecture, Science and Technology (ICA-EAST 2021)**) has been evaluated utilizing a two-person referee process and upon their recommendation your paper has been accepted for **Online** presentation and publication.

Please visit our web site for presentation guidelines and detailed information. We thank you for your contribution to ICA-EAST 2021 and expect meeting you in Erzurum Technical University Erzurum/Turkey during 15-17 December 2021.

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Effect of Ultrashort Laser Pulse Shape on the Dipole Spectrum of a Single Electron

Muhammed Sayrac [1*][0000-0003-4373-6897]

[1]muhammedsayrac@cumhuriyet.edu.tr, Department of Nanotechnology Engineering, Sivas Cumhuriyet University, Sivas, Turkey

Abstract

In this study, the effects of ultrashort laser pulse shape for the laser-matter interaction have been considered. Three different pulse shapes, Gaussian, Super-Gaussian, and Cosine-Squared, are used to calculate the dipole spectrum of the single atom by considering the Lewenstein model. The ultrashort laser pulse shapes are presented, and it has been found that the super-Gaussian laser pulse, which has a spiky and strong tail, has been more effective in transferring energy to the electron. The electron is excited and gains kinetic energy under the ultrashort laser pulse. The laser pulse-electron interaction affects the ground state wave function and the returning electron wave packet. The optimum dipole spectrum, which is extended to higher photon energies, has been obtained under the Super-Gaussian pulse shape.

Keywords. Ultrashort Pulse shapes, Intense Laser Field, Electron Dipole Spectrum, Gaussian, Electron Propagation

1. Introduction

Laser-matter interaction brings out the nonlinear phenomena. Electron propagation under the intense and short laser pulse has been the subject of great interest for experimental and theoretical research. Attempts have been made to achieve ultrahigh technological devices using high-intensity ultrashort laser pulses [1]. The ionized electron wave packet is controlled by the driving laser field. The dipole spectrum of a single atom is evaluated by the electric field of the driving pulse.

The spectral distribution of an electron depends on several parameters, namely the ionization potential of the target atom, driving laser wavelength, the intensity of the laser field, and the pulse shape. These parameters steer the electron during the propagation. The electron accelerated under the laser field, and gain kinetic energy. Then, the electron recombines with the parent atom, and the emission of its gained energy is released.

In this paper, the dipole spectrum of a single electron is obtained for different pulse shapes by using the Lewenstein model. An ultrashort laser pulse excites the electron to gain energy that directly affects the interference of the ground state wave function and the returning electron wave packet. The paper is organized as follows. Section 2 gives the expression of the pulse shapes and the dipole moment. Section 3 is devoted to the simulation results where the effects of laser pulse shapes and dipole spectrum are examined. Finally, the summary of the whole analysis is presented in the last section.

2. Theory

In this study, we consider different pulse shapes to obtain the dipole spectrum of a single atom. The pulse shapes are assumed to be an ultrashort pulse, and the spectrum is broad. Gaussian pulse shape, Super-Gaussian pulse shape, and Cosine-squared pulse shape are used as a driving field to compute the dipole spectrum of a single electron. The pulse envelope for the pulse shape is given below [2].

$$E \approx e^{-(t/\tau)^2} \rightarrow Gaussian$$
$$E \approx e^{-(t/\tau)^4} \rightarrow Super-Gaussian$$
$$E \approx Cos(t/\tau)^2 \rightarrow Cosine-Squared$$

here t is the time axis in atomic units, and τ is the full width at half-maximum (FWHM) pulse duration. In the case of the driving field being an ultrashort pulse, the driving field has many frequency components, i.e. the spectrum is broad.

The Gaussian pulse shape is described with a Gaussian function. On the other hand, the Super-Gaussian pulse shape has a spiky appearance with heavy tails. The Cosine-Squared pulse is the square of the cosine function. The pulse shapes simulated by using Eq. 1 are presented in Fig. 1.

By considering the different pulse shapes, the Single Atom Dipole Response of an electron is simulated by using the Lewenstein method [3]. The dipole moment is given in Ref. [4].

$$d(t) = -ie_x \int_0^\infty d\tau \left(\frac{\pi}{\varepsilon + i\tau/2}\right)^{3/2} . E\cos(t-\tau) . \mathrm{D}_x(\mathrm{p}_s(\mathrm{t},\tau) - \mathrm{A}_x(t-\tau))$$
$$\times \exp(-i\mathrm{S}_s(\mathrm{t},\tau)) . \mathrm{D}_x^*(\mathrm{p}_s(\mathrm{t},\tau) - \mathrm{A}_x(t)) + c.c.$$

where the probability amplitude for the driving field is $\mathrm{D}_x^*(\mathrm{p}_s(\mathrm{t},\tau) - \mathrm{A}_x(t))$. A coupling the ground state to the vacuum continuum state is $\mathrm{D}_x(\mathrm{p}_s(\mathrm{t},\tau) - \mathrm{A}_x(t-\tau))$. The phase of the electron acquired during propagation is $\exp(-i\mathrm{S}_s(\mathrm{t},\tau))$. S_s is the quasiclassical action corresponding to the electron trajectory [5].

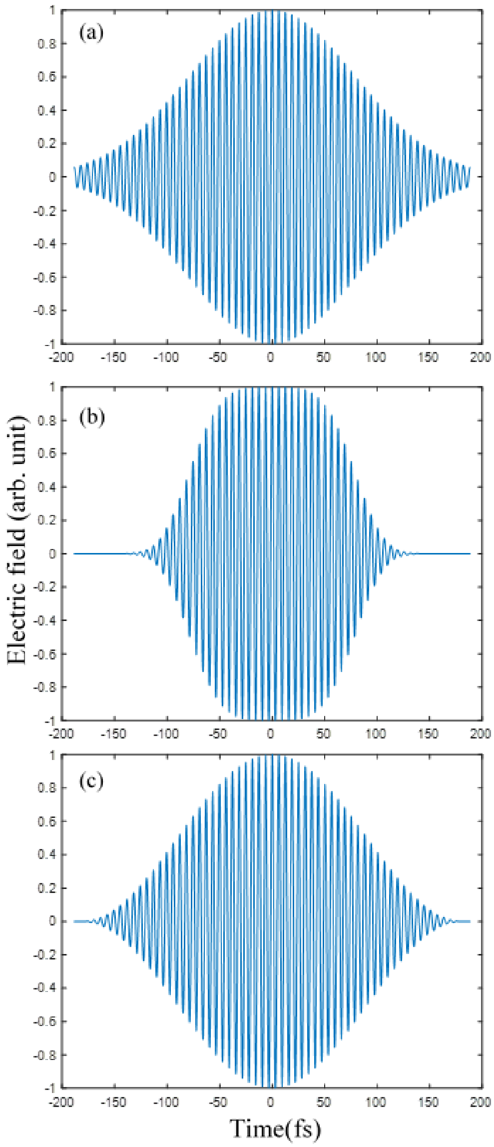

Figure 1: The simulated driving pulse shapes of (a) Gaussian, (b) Super-Gaussian, and (c) Cosine-Squared.

3. Results

The dipole response of a single atom is simulated by considering different driving pulse shapes with 70fs FWHM pulse duration, the central wavelength of 1000nm, and the intensity of 10^{14}W/cm^2. The simulated driving pulse shapes are presented in Fig. 1.

For the different driving pulse shape described in Eq. 1, the dipole spectrum of a single atom is calculated by considering the contribution of short and long electron trajectories. Most of the laser field is considered to have Gaussian distribution. The dipole spectrum is simulated for each described pulse shape presented in Fig.1. The frequency conversion of the initial driving radiation of 1000nm (corresponding photon energy of 1.24eV) is achieved up to about 80eV photon energy (corresponding wavelength of about 15nm). Figure 2 is for the simulation results taking into account the Gaussian pulse shape, where the extension of the radiation up to 75eV is obtained.

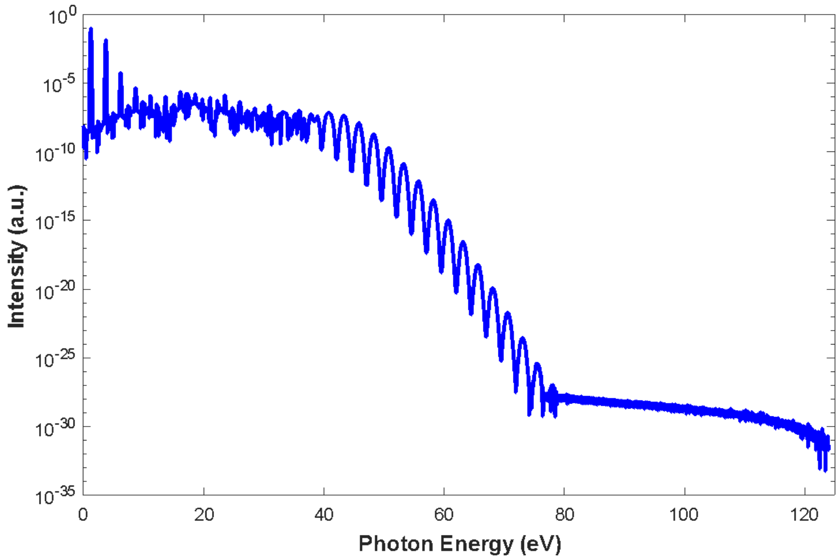

Figure 2: The electron dipole spectrum by using Gaussian pulse shape.

Moreover, the Super-Gaussian pulse shape has stronger wings compared to the Gaussian pulse, Fig. 1. The electron dipole spectrum under the super-Gaussian pulse shape is simulated, and the generated photon energy up to >80eV is well resolved. The reason for the high photon energy is because of the strong spiky peak and strong wing of the Super Gaussian pulse shape.

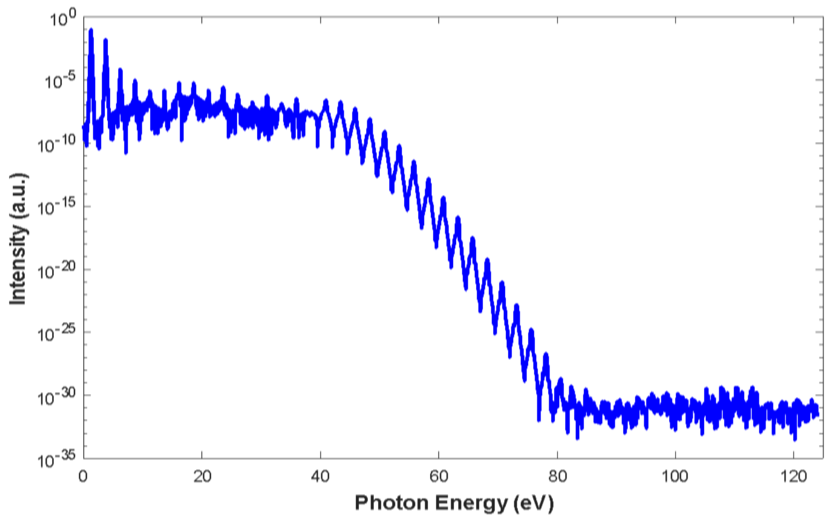

Figure 3: The electron dipole spectrum by using a Super-Gaussian pulse shape.

Finally, the Cosine-Squared pulse shape distribution is used for the simulation input parameter. The square term brings a slightly strong tail on the Cosine-Squared pulse shape. The calculated dipole spectrum up to 80eV photon energy is achieved in Fig. 4.

Overall, the photon energy of the generated radiation due to electron-laser interaction is obtained in an energy range from 75eV to >80eV, which is comparable to the photon energy of the fundamental field. The frequency conversion is significant for producing optical pulses with high photon energy for practical applications, which require high spatial and temporal resolution.

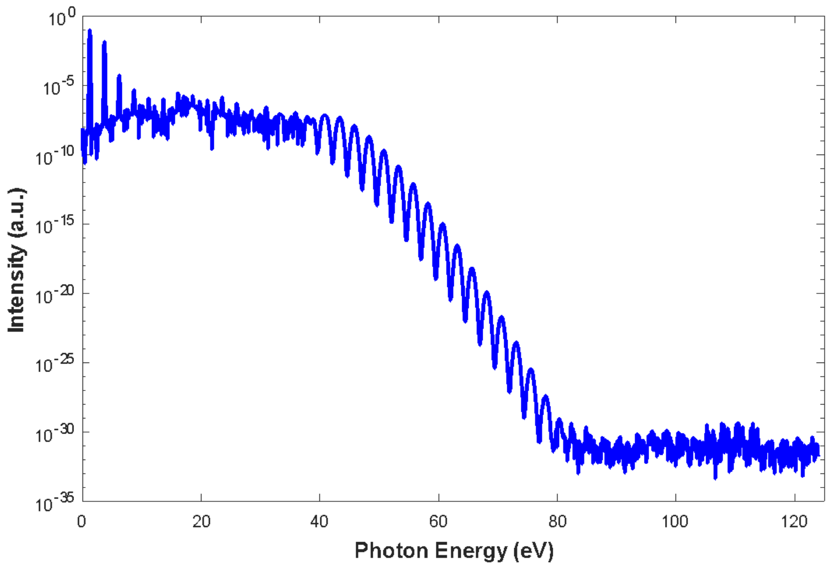

Figure 4: The electron dipole spectrum by using Cosine-Squared pulse shape.

4. Conclusion

In this work, the different pulse shape is considered for obtaining dipole spectrum, which gives the emitted radiation after the laser-matter interaction. The laser-matter interaction results in electron ionization and propagation under the effect of the laser field. The shape of the laser field directly affects the propagation of the free electron in the continuum.

Overall, the electron trajectories after the ionization are mainly affected by the driving laser field. The shape of the pulse controls the electron excursion time and results in different spectral distributions. The sharpness and strong wings of the pulse shape accelerate the electron, and the electron gains more kinetic energy. This results in the strong recombination, i.e. overlapping ground state wave function with the returning electron wave packet.

The simulation study can be useful for pre-experimental studies to determine how ultrashort pulse shape affects the electron behavior under the intense laser field, i.e. propagation, ionization, and recombination of an electron, or interference of electron wave packet with the ground-state electron wave packet.

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