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Investigation of Generated attosecond EM by Recoiling of ionized and bounded electrons in atom with fs laser

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ABSTRACT

High intense Laser interaction with matter is described as new phenomena during the last twenty years. Femtosecond time duration is interested to transfer high power in interaction with matter and plasma. Recently, Attosecond technique is a new method that used in the fast atomic scales measurement. In normal condition, Electrons are confined by coulomb potential in atom. By using the high intense femtosecond laser field, a time-dependent force on the bound electron could be exerted. In the large produced force, the electron can tunnel from the atom. This splits the electron and the attraction of the negative electron to the positive ion rapidly decreases so electron escapes the ion. In fact, electrical field of the light pushes the wave packet away from the ion firstly, but by reversing the field direction, the force cause to come back the electron. The times of recollision could be synchronized by laser pulse and it can be of attosecond precision. In this work we have described the energy difference of recoiled electron before and after collision. The EM Attosecond generated pulse has investigated in frequency domain. It is demonstrated major effective parameters for control of shape and intensity in attosecond phenomena.

INTRODUCTION

Recently, by ultrashort laser pulse generation, the very short time intervals measuring are possible directly. It may done by using a pair of very short laser pulses, first one for exciting the dynamics to be observed and second one use to probe its evolution as a function of the time delay [1-4]. Ultrafast measurement by using the attosecond technology could be a new extreme in fast measurement [5-9]. Most important features of atoms, molecules and solids could be probed by attosecond because the attosecond time scale is the natural time scale for electron motion. One of the important attosecond characteristics is to be accompained always by attosecond electron pulses, so it can use in spatial resolution determined by electron wavelength. The second important characteristics of attusecond is to be accompanied by a synchronized visible pulse of controlled waveform8.Then conventional ultrafast spectroscopy and strong-field coherent control are possible as atoms or molecules while the strong field is present could be probed. For final important attosecond characteristics case, Core-level and multi-electron dynamics or even nuclear dynamics can be time-resolved by attosecond photon or electron pulses that have energies of 10 eV to 1 keV or beyond.

THEORY OF ATTOSECND EM GENERATION

Tunnelling ionization and ion-electron recoiling

The process of attosecond EM generation is included of four main steps as shown in figure 1. In first step, the strong laser field causes to ionize. In fact it causes the tunneling of electron through the potential barrier of ion charged. In second step, during the first femtosecond of laser freedom, the electron will gain a kinetic energy and move in direction of field.

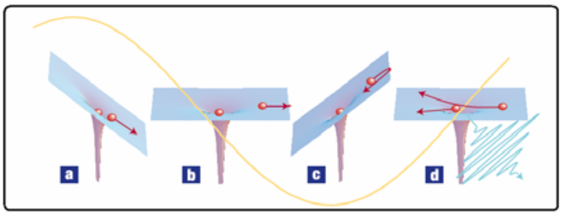

Figure 1: attosecond EM generation steps: a - Ionization and tunneling of electron. b – Electron will gain and move in direction of field. c –electron is driven back by reversed laser field d- recollision of the back driven electron causes to the emission of an attosecond photon burst [1].

For third step, after the laser field reverses, the electron is driven back and in last step, recollision of the back driven electron causes to the emission of an attosecond photon burst.

The free and bound components of wave function in recollision could be produced an oscillating dipole that emits light. It is important controlling the waveform of light, because it will imply in attosecond timescale photon emission. Minimum duration of attosecond pulses is related to most energetic recollision. For 5-fs, 750-nm laser pulse, photon energy about 100 eV, with 10 eV band is reported that allows a 250 attosecond duration pulse [1]. Also for above properties laser pulse, photon energy about 1 KeV, with 100 eV band will result a 24 attosecond duration pulse [6]. It is reported that the relative bandwidth of single pulse emission could be broadened by the polarization state of the laser pulse. In fact it will switch off recollision before and after the main event [10-15].

Our calculation on recoiling and EM Energy transmitted

In our model we consider two wave packets, bound and continuum wave packets. A continuum wave packet could be demonstrated by:

$$\left|\psi_{vlm}\right\rangle = \psi_{vlm}(r)\; e^{\frac{i}{\hbar}E_v t}$$

That

$$\psi_{vlm}(r,\theta,\varphi) = R_{vl}(r) Y_{lm}(\theta,\varphi)$$

and $\psi_{vlm}(r) = R_{vl}(r)$. Laser separates electron from the atom structure, and causes to excite it. We have considered excited atom state as $R_{21}(r)$. It could be defined as:

$$R_{21}(r) = \frac{1}{\sqrt{3}}\left(\frac{Z}{a_0}\right)^{\frac{3}{2}} \frac{Zr}{a_0} e^{\frac{-zr}{a_0}} e^{\frac{-i}{\hbar}E_v t}$$

and

$$\left|\psi_{vlm}\right\rangle = \frac{1}{\sqrt{3}}\left(\frac{Z}{a_0}\right)^{\frac{3}{2}} \frac{Z_r}{a_0} e^{\frac{-Zr}{a_0}} e^{\frac{i}{\hbar}E_v t}$$

That a_0 is bohr radius and $a_0 = \hbar / \mu c a$.

As we know $E_v = \frac{1}{2} m v^2$ and $E_v > 0$. In schordinger equation we have:

$$i\hbar \frac{\partial \psi(r,\theta,\varphi)}{\partial t} = (k+v)\psi(r,\theta,\varphi)$$, that $v = e / 4\pi\varepsilon_0 r$. So

$$i\hbar \frac{\partial}{\partial t}\psi(r) - \frac{e}{4\pi\varepsilon_0 r}\psi(r) = k\psi(r)$$

that k could be obtained as below:

$$i\hbar \frac{\partial}{\partial t}\left[\frac{1}{\sqrt{3}}\left(\frac{Z}{a_0}\right)^{\frac{3}{2}} \frac{Zr}{a_0} e^{\frac{-zr}{a_0}} e^{\frac{-i}{\hbar}E_v t}\right] - \frac{e}{4\pi\varepsilon_0 r}\left[\frac{1}{\sqrt{3}}\left(\frac{Z}{a_0}\right)^{\frac{3}{2}} \frac{Zr}{a_0} e^{\frac{-zr}{a_0}} e^{\frac{-i}{\hbar}E_v t}\right] = k\left[\frac{1}{\sqrt{3}}\left(\frac{Z}{a_0}\right)^{\frac{3}{2}} \frac{Zr}{a_0} e^{\frac{-zr}{a_0}} e^{\frac{-i}{\hbar}E_v t}\right]$$

For continuum wave packet, $k = E_v e / 4\pi\varepsilon_0 r$. We have calculated the total wave function by summation of both continuum and bound wave functions:

$$\left|\psi_{nvlm}\right\rangle + \left|\psi_{vlm}\right\rangle = \psi_{nlm}(r)\; e^{\frac{-i}{\hbar}E_n t} + \psi_{vlm}(r)\; e^{\frac{-i}{\hbar}E_v t}$$

For the bound state we know $E_n < 0$, and its wave function could be determined by:

$$\psi_{nlm}(r)\; e^{\frac{-i}{\hbar}E_n t} = R_{nl}(r) e^{\frac{-i}{\hbar}E_n t} = R_{10}(r) e^{\frac{-i}{\hbar}E_n t} = 2\left(\frac{z}{a_0}\right)^{\frac{3}{2}} e^{\frac{-zr}{a_0}} e^{\frac{-i}{\hbar}E_n t}$$

and for continuum wave function it could be determined by:

$$\psi_{vlm}(r)\; e^{\frac{-i}{\hbar}E_v t} = R_{vl}(r) e^{\frac{-i}{\hbar}E_v t} = R_{21}(r) e^{\frac{-i}{\hbar}E_v t} = \frac{1}{\sqrt{3}}\left(\frac{z}{2a_0}\right)^{\frac{3}{2}} \frac{zr}{a_0} e^{\frac{-zr}{a_0}} e^{\frac{-i}{\hbar}E_v t}$$

We have obtained difference of the total energy before and after electrons recoiling as below:

$$\Delta E = E' - E = \frac{E_n - E_V}{1 + \frac{1}{2\sqrt{24}}\left(\frac{zr}{a_0}\right) e^{-\frac{i}{\hbar}(E_n - E_v)t}}$$

and therefore frequency band of EM transmitted could be calculated as $\nu = \Delta E / h$.

We have developed our calculations for H, He, Ar, and Ne.

The results are demonstrated in figure 1.

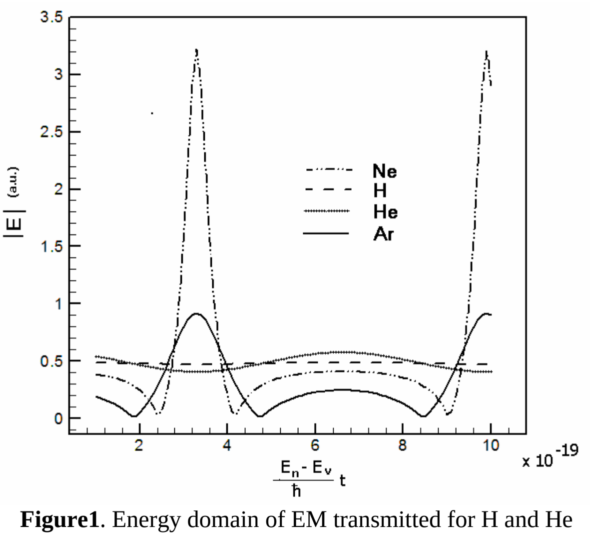

Figure1. Energy domain of EM transmitted for H and He

Conclusion

Attosecond has made a revolution in optical and collision science. Attosecond emission could be accured when a femtosecond laser interacts with matte. In this work we presented a new method for quantum model of interaction laser with matter. Our results shown it may be expected ultra short attosecond for Ne and Ar in comparison of H and He.

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