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Plasmonic Nanostructures Assisted Generation of x-ray Sources

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Abstract: A promising way to generate the isolated attosecond x-ray sources has been theoretically investigated emerging from the concept of nanostructures plasmonic field enhancement. It is found that by properly modulating the inhomogeneity of the input two-color weak field, not only the harmonic cutoff has been extended to the x-ray region, but also the single short quantum path has been selected to contribute to the harmonic. As a consequence, a series of sub-50as attosecond x-ray pulses have been obtained.

AMS subject classifications: 35Q41, 78A10, 81V55

Key words: High-order harmonic generation, x-ray source, plasmonic field enhancement

Ultrashort x-ray pulses are a key tool for probing the ultrafast electronic dynamics in atoms [1,2], attosecond time-resolved spectroscopy [3], and tomographic imaging of molecular orbitals [4,5], etc. High-order harmonic generation (HHG) as the most promising way to produce the isolated attosecond x-ray pulses by direct frequency upconversion of femtosecond near-infrared pulses has been widely investigated in the past two decades [6-8]. Currently, the HHG process can be well depicted in terms of the semiclassical three-step model [9]: ionization, acceleration, and recombination of the electrons in the intense laser field. During the recombination, a maximum harmonic cutoff with $E_{max}=I_p+3.17U_p$ can be obtained, where I_p is the ionization potential and $U_P = I/4\omega^2$ is the ponderomotive energy of the free electron in the laser field.

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However, due to the limitation of the harmonic cutoff, it is hard to produce the isolated x-ray sources from the single weak (10^{14}W/cm^2) laser pulse. Thus, in the last decade, much effort has been paid to extending the harmonic cutoff, such as the two-color or the three-color field scheme [10-12], the chirp pulse scheme [13], and Thz controlling method [14] etc. However, in most of the above methods, the fundamental fields are also beyond the 10^{15}W/cm^2, which are not easier to be obtained in laboratories.

Recently, the plasmonic field enhancement in the vicinity of metallic nanostructures has attracted a lot of interest [15-18]. As an alternative technique for harmonic generation and extension, it is not necessary to utilize extra cavities to amplify the input pulse power, and the local electric fields can be enhanced by more than 20 dB [19]. The underlying mechanism of the plasmonic field enhancement harmonic emission can be well described as follows: when a low intensity input pulse couples to the plasmon mode, as shown in **Figure 1**. There is a collective oscillation of free charges around the vicinity of the metal nanostructure, and the negative charges are redistributed around one apex and the positive charges around the other one, resulting in a large resonant enhancement of the local field. Consequently, by injecting rare gases into this enhanced field, the HHG can be produced or extended [15,20]. For instance: (i) from the experimental side, Kim et al [15] shows that the output laser field has been enhanced by three orders of magnitude compared with the input pulse (10^{11}W/cm^2), and a 17th order harmonic has been obtained. However, the outcome of the Ref 15, has been put under controversy more recently [16-18], i.e. whether the harmonic emission is in fact the coherent (HHG) or only an incoherent atomic line emission. (ii) From the theoretical side, by using the linearly spatial-dependent laser fields, the generation of even harmonics, the selection of quantum paths and the wavelength dependence of the harmonic yields, etc, have also been investigated [21,22].

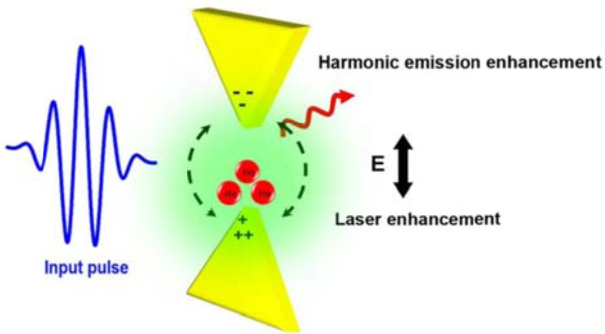

Figure 1: Schematic illustration of linear electric field enhancement and harmonic emission using a nanostructure of bow-tie elements.