Tunneling time delay detection based on polarization-resolved THz detection

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Abstract—Employing a novel polarization-resolved detection, we precisely measured the polarization of terahertz emission from ionized gases in two-color field composed of circular polarized fundamental beam and linear polarized second harmonic. It shows that the polarization of the THz emission rotates with the phase delay and forms an attoclock. The polarization angular deviations of THz emissions in different laser intensities and different atoms reveal the distinct tunneling time delays. The polarization-resolved THz detection can be used to study tunneling ionization.

I. INTRODUCTION

Tunneling is one of the primary phenomena in nature. The question of whether tunneling process takes a finite time or is instantaneous has been subject to ongoing debate since quantum mechanics established. In recent years, employing ultrafast-laser technology, experiments could be carried out to research the ultrafast processes in strong-field light-matter interaction[1]. The tunneling ionization can be split in two steps: bound electron tunneling and free electron acceleration in laser field. The final drift momentum depends on the laser field at the time of tunneling, thus the tunneling delay time can be deduced based on the angular streaking of electrons and ions using the attoclock technique. Nearly all attoclock experiments have been performed with a cold target recoil ion momentum spectrometer (COLTRIMS). Due to the performance of COLTRIMS, high angular resolution of the electron streaking is hard to achieve.

To reveal the dynamics of the ionized electron in the light-matter interaction, electromagnetic radiations have also been monitored in experiments, such as high-order harmonic generation (HHG) and terahertz pulse. In the case of symmetry-broken laser field, the electron momentum distribution is asymmetric. The acceleration in laser field and the rescattering with the parent ion of the electron both can contribute terahertz emission[2]. Using a circular polarized two-color field, the electron trajectory can be coherently controlled by the phase delay of the laser field, similar to the hands of a clock[3,4]. The polarization of terahertz emission, which is determined by the electron trajectory, represents the average angle of the electron momentum. As much higher gas pressure can be used here than in COLTRIMS, the terahertz emission has a definite polarization angle.

II. EXPERIMENTAL DETAILS AND RESULTS

To eliminate the propagation effects, such as chromatic dispersion, Gouy phase shift, plasma effect and so on, a gas jet with a diameter of 50 um is used as gas source. We present a polarization-resolved THz detection scheme based on electro-optical sampling to realize sensitive and precise THz measurement. It directly measures the amplitude and polarization angle of the terahertz field and provides the same convenience as the conventional method. The technique significantly reduced statistical errors and enabled milliradian terahertz polarization measurements, which provide us the possibility to precisely measure terahertz emission in various laser intensities.

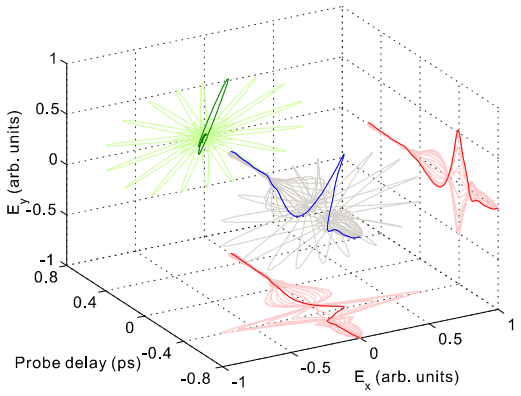

Fig. 1. THz time-domain waveforms for different relative phases.

In the case that the fundamental beam is circularly polarized and the second-order harmonic is linearly polarized, THz time domain waveforms for different phase delay are shown in Fig.1. The THz emissions are all nearly linear polarized. As reported in reference, THz polarization can be coherently controlled by the phase delay of the two-color field. As we increase the phase delay of the two-color field, the THz field strength changes slightly, and the polarization angle increases steadily.

Fixing the phase delay of the laser field, the scanning of the polarization angle variation versus total pump power for xenon, argon and neon has been precisely made. The deviations have been found within our experimental precision. It shows the THz polarization angle is dependent on both the field intensity and the gas type, which suggests the different tunneling time delays.

III. SUMMARY

Employing a polarization–resolved THz scheme, THz emission induced by circularly polarized femtosecond pulse and the linear polarized second harmonic has been precisely studied. The results show the THz polarization angle reveals the tunneling time delay.

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