Terahertz Technology into Attosecond Science

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***Abstract*—Although differing in frequency by more than 6 orders of magnitudes, the attoseond burst and THz emission from two-color laser pulses are found both related to the sub-cycle electron dynamics and can be coherently controlled on the equal footing. Through synchronization, the generation of terahertz waves has been clocked in attosecond precision from the intrinsic chirp of high harmonics in our previous work. In this talk we will further discuss how they are correlated for aligned molecules. Then we will show that by manipulating the polarization of the two-color laser pulses, the polarized THz waves can be used as a sensitive indicator of the tunneling time-delay, a fundamental yet debatable concept in attosecond physics. Finally we conclude that blending attosecond physics with THz technology could advance both fields and yield unprecedented understanding of other ultrafast processes.**

I. INTRODUCTION

TERAHERTZ wave generation (TWG) from ionizing gases can be controlled by either shaping the laser pulse or by using two-color and multiple-color laser pulses. The sensitivity of TWG on laser fields suggests that subcycle dynamics are involved and its characterization requires controlling in attosecond time scale, such as detuning the phase-delay between the two-color pulses [1]. Naturally, terahertz technology is connected to attosecond science. In particularly, it is well known that high harmonic generation (HHG) is governed by electron dynamics within a single optical cycle of the driving laser fields, interpreted as the so-called rescattering model. The high harmonics are intrinsically chirped, with emission time delayed by a few tens attoseconds between the neighboring orders. Therefore it provides an attosecond clock to calibrate TWG as shown in our previous work for argon gases in two-color laser pules [2,3]. It is shown that both TWG and HHG are related to the ionization and propagation of electrons in subcycle, but the atomic potential plays more profound role in the former through the laser-assisted forward scattering, differing from HHG where the recombination dominates.

Turning to molecules, the atomic potential is not centrifugal anymore and it will be interesting to know how TWG and HHG depend on the alignment of molecules. With the help of terahertz technology, such as polarization sensitive coherent measurement [4], one could get better understanding of alignment dependence of attosecond electron dynamics. To bring terahertz technology further into attosecond science, we investigate the physics of tunneling, one of the cornerstones of strong field and attosecond physics, by comparing the polarization of THz waves generated from different noble gases in various of laser intensities. Different from other measurement such as angle-resolved photoelectron spectroscopy, the coherent THz detection could provides a unique way of determining the coherence of tunneling electron wave packets, helps better understanding of the time-delay of tunneling ionization, which is so far a controversial concept.

II. RESULTS

Two schemes are used for TWG. In the first scheme, parallel polarized 800nm+400nm two-color laser pulses are focused onto nitrogen molecules, which is pre-aligned by the pump pulse. The generated THz emission is measured against the alignment angle by rotating the polarization of the pump pulse. By tuning the phase-delay of the two-color pulse, the optimal yields and the corresponding optimal phase-delay (OPD) can be determined at each angle. The shift of OPD with alignment suggests difference of electron dynamics in attoseconds [5]. In the second scheme, circularly polarized fundamental pulse in company with linearly polarized second harmonic pulse is used to generate linearly polarized THz pulses from noble gases. It is found that the polarization of the THz pulse is rotating with the phase-delay of the two pulses for all the atoms forming an attoclock [5]. The offset of the polarization for different atoms might be attributed to the different tunneling time-delays as shown in Fig.1.

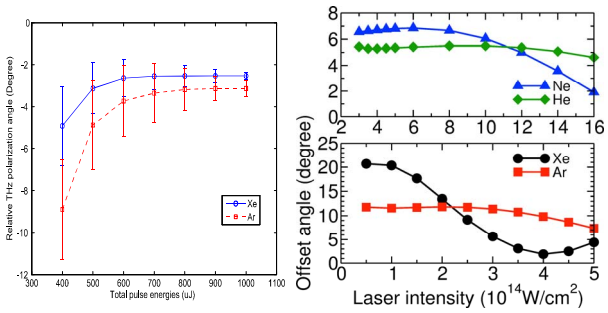

Fig. 1. Experimentally measured (left) and theoretically calculated (right) THz polarization angle offset for Xe/Ar and He/Ne as a function of pulse energy or laser intensity.

III. SUMMARY

In this presentation, we show that both the tunneling time-delay and the alignment-dependent electron dynamics could be resolved by coherent detection of THz waves generated in two-color laser pulses, demonstrating the potential of applying THz technology into attoseocnd physics and vice versa.

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