Uniqueness of *in-situ* Single Shot Technique Using Femtosecond Laser Pulses for Measuring Absolute Carrier-Envelope Phase(CEP)

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Abstract

Carrier-Envelope Phase(CEP) is an important feature in ultrafast laser spectroscopy. CEP is the phase shift between carrier wave and intensity envelope of laser pulse. In nonlinear optics, full characterization of a laser pulse is critical to determine the moment an electron is ionized from an atomic or molecular system. To obtain absolute CEP, Wen Li's lab developed a single-shot carrier envelope phase measurement apparatus utilizing the angular streaking technique.

Keywords
Carrier-Envelope Phase(CEP), laser pulse, angular streaking, CMOS, VMI chamber

1. Introduction

Lasers are widely used from manufacturing to health fields. Barcode reader, Precision cutting, lasik surgery, laser treatment to destroy cancer cells, telescope all are the application of laser technology. However, when it comes to studying chemical reactions at molecular level we need ultra fast lasers. Ultrafast lasers enable us to study atoms at molecular level. Chemical reactions in molecules occur less than a second of time frame. Human eye cannot see the fast motion of chemical reaction which requires creating a method to see these phenomena. That is when ultrafast spectroscopy comes into play. All lights visible and non-visible are electromagnetic waves. The longer the wavelength of the wave the higher its compose of energy. In addition, the shorter the wavelength the lesser its energy. In ultrafast spectroscopy we use compressed infrared laser with high energy to ionize molecules and study the electron dynamics of the molecules. The reason to use ultrafast laser is because of electron dynamics. Since electrons move faster in a molecule, ionization in molecules occurs very quickly. That is why we need ultrafast laser, in this case femtosecond laser, to image electron scattering during ionization. Additionally, electron scattering can also tell us the structural information of its parent molecule. In principle, laser is light and light is a form of energy. Since light can be used as an energy source, we can use it to study its effects on molecules.

2. Experimental Procedure

In general, Intense femtosecond laser pulse is used to excite the molecular structure of an atom. In this experiment we use Krypton gas(Kr). Other molecular compounds, for example, methyl iodide(CH_3I), Nitrogen gas (N_2) can also be used depending on the experiment. The laser pulse acts as a "pump" to make the atoms in the molecule oscillate. As a result, the electrons in the atom's orbital shells get enough energy from the laser to move out of their shell. To measure the motion, we send another laser pulse which is being sent right after the first laser pulse. The second laser pulse is called "probe". The probe helps us determine the position of the electrons in an atom. By changing the time delay between pump and probe we can get different positions of electrons. Repeating these processes through laser pulses we can construct frame by frame images of electrons. These electron dynamics can only be seen using a fast frame camera. In this case CMOS(complementary metal-oxide semiconductor) camera is used to image. Every time when electrons are hit by laser pulses, CMOS camera image the position of electrons on a computer [2].

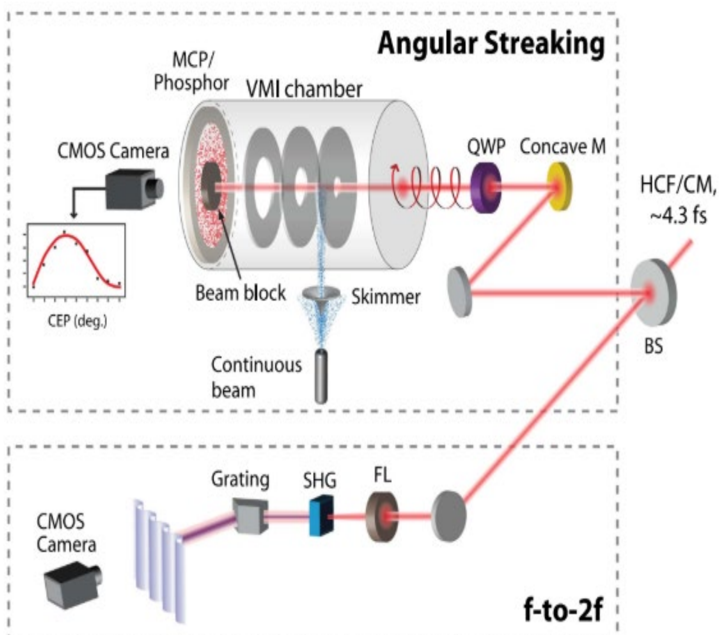

Figure 1: Schematics of our setup [1].

Figure 1 shows our modified setup to measure CEP using angular streaking technique. In order to get enough data of electrons from a single-shot laser light we use a 2D imaging detector composed of microchannel plates(MCP) and a phosphor screen. This helps to take 2D images of electrons. In a typical VMI setup, the laser beam is parallel to the plane of the detector which only takes 1D images. In our VMI setup, the laser beam is directly pointed at the detector which makes it possible for 2D imaging. Ultrashort pulses are generated by a Ti:sapphire amplifier. This amplifier first broadens the laser pulses by 3o femtosecond(fs) and then compressed by chirped mirrors(CM). This is how we get short pulse duration. In order to figure out the absolute CEP of each laser pulses we use a quarter wave plate(QWP) to make the laser pulses elliptically polarized [1]. This elliptically polarized laser light then goes to velocity map imaging(VMI) chamber. Through continuous beam Krypton gas goes into the VMI chamber and hits with laser pulses. The detector detects those scattering electrons and shows the 2D images of electrons on the computer.

Figure 2: Electrons image from single shot laser pulse.

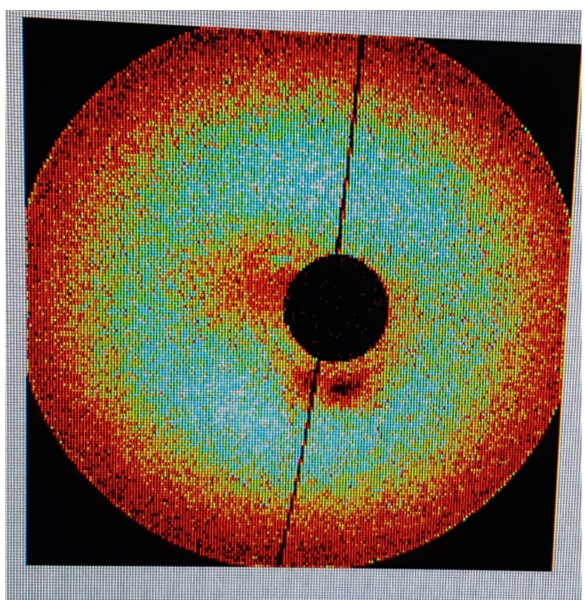

Figure 3: Accumulation of electrons from more than one thousand laser pulses.

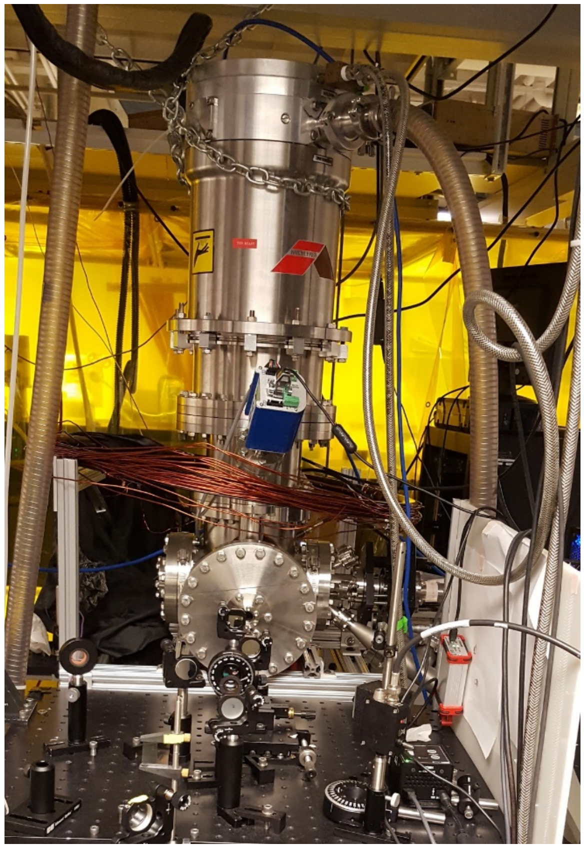

Figure 4: Modified velocity map imaging(VMI) chamber.

3. Results

Krypton gas has low ionization potential which in turn gives us a high-count rate for experimental results. We do as many laser shots as we can to calculate absolute CEP. Each pulse has different CEPs, we take the average CEP of that pulse and do the same thing for the rest of the pulses. This gives the absolute CEPs of each pulses. CEP can be obtained by this function : $E(t)= E_o\, e^{(-t/\tau)^{2}} \cos(\omega t + \Phi)$ [1].

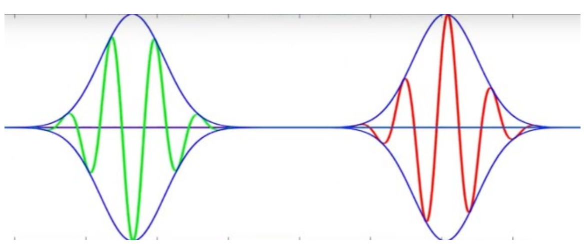

Figure 5: Single pulse CEPs

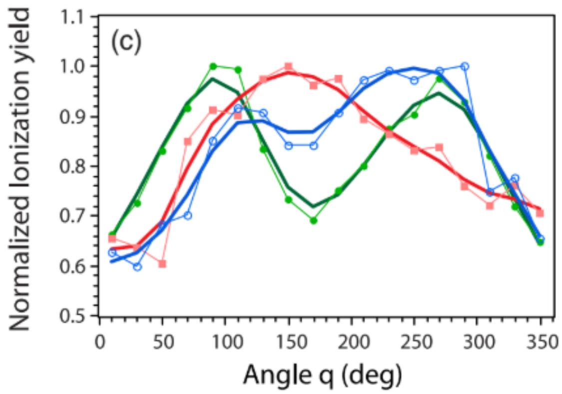

Figure 6: Green curve is the Absolute CEP of each laser pulse [1].

4. Conclusions and Future Work

The future applications of laser technology are endless. As new methods of laser technology emerge we would be able to create better resolution of images of tiny particles. Through this project I have come up with an idea to use matrix-assisted laser desorption ionization time of flight (MALDI TOF) on infected COVID-19 virus cells. I have seen how laser is being used to destroy cancer cells in patients. If we can implement MALDI TOF technique onto COVID-19 infected cells to see the effects of fast laser on the cells we might be able to find the many causes and properties of the COVID-19. MALDI TOF is a mass spectrometry that uses laser to analyze organic molecules. As the COVID-19 virus spreads around the world it is a critical moment for the scientific community to be part of this kind of research. I think Biophysics can play a significant role in this research as it will allow to study both biological and physics point of view on COVID-19. The validity of this proposed idea can only be possible through experimental procedures which are yet to be discovered.

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References

[1] Debrah, Duke, et al., Direct in-situ single-shot measurements of the absolute carrier-envelope phases of ultrashort pulses, Optics Letters, 1-3, 2019.
[2] Lee, Suk, et al., Coincidence ion imaging with fast frame camera, Rev. Sci. Instrum., 123303-2-123303-7, 2014.

Biography

Abidur Rahman is a rising junior of Department of Computer Science at Wayne State University. He is working towards his Bachelor's degree in Computer Science. He has worked in nanofabrication and electron dynamics at his current university. Outside of class, he has worked on bioinformatics research to study the genomics of diseases. He also has listed 3 times under Dean's list for his academic excellence in his coursework.