DOE Plasma Science Center

Visiting Graduate Student/Post-Doctoral Researcher Fellowship Report

Title of Project:	Spatially resolved, non-invasive electric field measurements by four wave mixing in a fast ionization wave with sub-nanosecond resolution	
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Dates of Visit:	**Start: 08-11-2014**	**End: 11-09-2014**

I. Description and Importance of Research Issues Investigated During Visit

This collaboration focused on electric field measurements in a fast ionization wave (FIW) at near atmospheric pressure in pure hydrogen. These are high-voltage, short pulse duration discharges. They have some key advantages over other types of non-equilibrium plasmas. For example the stability due to the short pulse duration is very high since the pulses are typically too short to heat the plasma up to a point where a glow-to-arc transition would occur. Also the uniformity as compared to similar types of discharges like e.g. streamers is very high which enables more accurate measurements of discharge parameters in a repetitively pulsed operation mode. A high grade of ionization, excitation, and dissociation of molecules is achieved due to a high reduced electric field (E/N). Due to those characteristics, these discharges are often used for plasma assisted combustion (PAC) which is a major focus of the Non-Equilibrium Thermodynamics Laboratory (NET-Lab) at the Department of Mechanical and Aerospace Engineering (MAE) at the Ohio State University (OSU) where this experiment was conducted over a course of three months. All these properties make it worth investigating these kinds of discharges more closely. One of the major aspects of such a discharge is the electric field which governs the basic physics of the discharge. It accelerates the charged particles that are created inside the discharge and determines for instance the amount of energy electrons can actually dissipate in dissociation of molecules and creation of reactive species that support combustion. Especially in the wave front ionization due to electron impact is a key element. Consequently, electric field measurements can exceptionally versatile in the attempt of understanding the complex dynamics and behavior

of these discharges. So far several studies investigating FIW dynamics have been conducted, including studies of fundamental kinetic processes, mechanism of FIW formation, sub-nanosecond imaging, and visible and UV emission spectra. Further, indirect electric field measurements using calibrated capacitive probes have been performed. However, in this collaboration electric fields are measured directly utilizing a laser spectroscopy based four wave mixing technique which is similar to CARS. Compared to measurements using capacitive probes, the technique measures directly the electric field, provides much higher spatial and superior sub-nanosecond temporal resolution while still being non-invasive. Also polarization sensitive measurements were performed in order to determine the direction of the field vector. A setup already present at NET-Lab was modified to fit the task of conducting measurements in an FIW discharge setup developed during this stay. To complete the picture, sub-nanosecond 2D emission measurements of the FIW were conducted as well.

II. Discussion of Research Outcomes and Findings Resulting from Visit

The discharge is operated between two thin electrodes mounted at a distance of 1 mm on a dielectric plate. Figure 1 shows a characteristic set of independent time resolved electric field measurements at three different locations along the propagation path of the ionization wave.

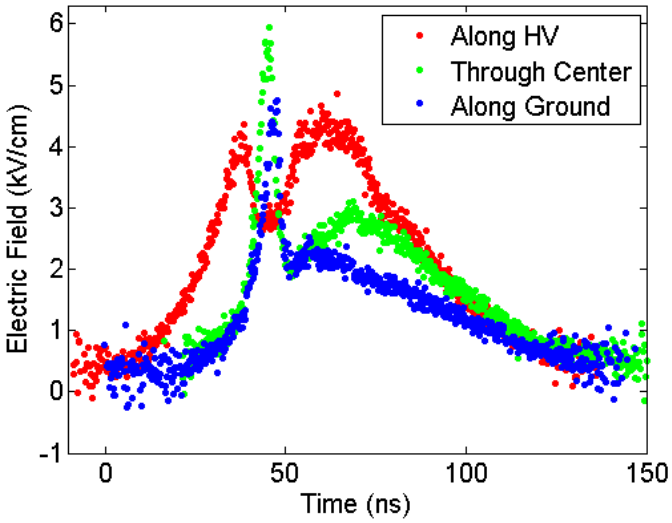

Figure 1: Temporally resolved electric field measurements at different locations on the plate

The locations are at the edge of the high-voltage electrode from where the FIW starts (red), in the center between the electrodes (green), and at the edge of the grounded electrode (blue). The

initial increase of the electric field represents the incoming wave front. This phase is followed by a sharp drop which indicates breakdown. The subsequent second rise in the electric field strength corresponds to a homogeneous glow discharge that occurs after the ionization wave has reached the grounded electrode and a conductive path is established along the discharge gap. These two phases of the discharge, the propagation of the FIW and subsequent homogeneous glow were observed with an ICCD camera with sub-nanosecond resolution. The results of these measurements are shown in figure 2 and 3.

Figure 2: ICCD image of FIW wave traveling between the electrodes (hv left, grounded right)

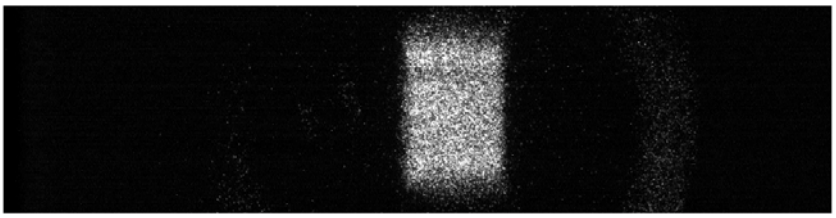

Figure 3: ICCD image of the homogeneous discharge occurring after the FIW passing

After these measurements were completed, polarization sensitive measurements were also performed. Measurements were carried out for horizontal and vertical polarization of the laser electric field at the same three locations as shown above. Additionally six new spots were investigated 0.5 mm and 1 mm further above these locations. It was discovered that the horizontal and vertical electric fields of the FIW drop more quickly when the measurements are performed further away from the plate as seen in figure 4 and 5.

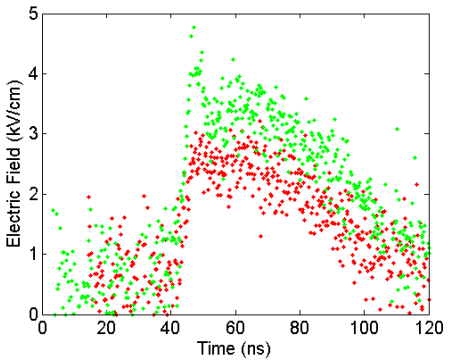

Figure 4: Horizontal components

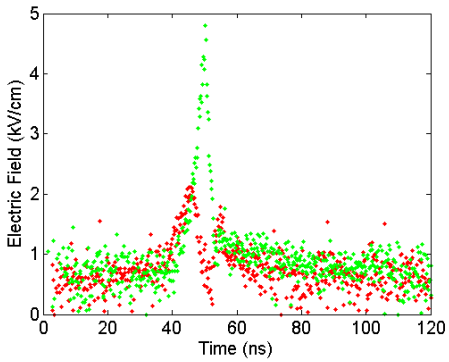

Figure 5: Vertical components

The green data points represent the measured values on the plate, the red data points represent the values measured 1 mm above. It is also clearly visible that the homogeneous discharge has only a horizontal component since it does not show up in the vertical measurement whereas the values for the wave front are comparable.

III. Follow-up to Visit

The results obtained in this research stay will be published in an international peer reviewed scientific journal. They were also presented at one of the biggest conferences in the field, the Gaseous Electronics Conference (GEC) in Raleigh, North Carolina at the beginning of November 2014. They will also be presented at the AIAA meeting in Kissimmee, Florida in January 2015, and at the DPG Spring Meeting in Bochum, Germany in April 2015. Furthermore, there is an intention of further continuation of the collaboration and scientific and personal exchange between the two groups involved in the project at the Ohio State University and Ruhr-University Bochum.