SLATT UNDERGRADUATE RESEARCH FELLOWSHIP
FINAL REPORT

SCHOLAR NAME:	Thomas Coates
FACULTY ADVISOR:	Dr. Sergey Leonov
PROJECT PERIOD:	Spring 2021
PROJECT TITLE:	*Probe waveform and nanosecond imaging comparative analysis for volumetric space charge waves*
CONNECTION TO ONE OR MORE ENERGY-RELATED RESEARCH AREAS (CHECK ALL THAT APPLY):	**(X) Energy Conversion and Efficiency** **( ) Sustainable and Secure Nuclear** **( ) Smart Storage and Distribution** **( ) Transformation Solar** **( ) Sustainable Bio/Fossil Fuels** **( ) Transformative Wind**

MAJOR GOALS AND ACCOMPLISHMENTS

Summarize your research goals and provide a brief statement of your accomplishments (no more than 1-2 sentences). Indicate whether you were able to accomplish your goals by estimating the percentage completed for each one. Use the next page for your written report.

RESEARCH GOALS	ACTUAL PERFORMANCE AND ACCOMPLISHMENTS	% OF GOAL COMPLETED
Adjustments to experimental setup	All parts of the system were evaluated for possible contribution to jitter, and changes were made so that the system could be used at negative polarities.	100
Imaging of the corona discharge with high resolution	The streamer corona electrical discharge pattern was acquired using a high-speed Basler camera and LaVision IRO calibrated to fire in conjunction with an alternating-current spark ignitor. The data was processed to recognize any common and variable features, including corona shape and size.	100

RESEARCH OUTPUT

Please provide any output that may have resulted from your research project. You may leave any and all categories blank or check with your faculty advisor if you are unsure how to respond.

CATEGORY	INFORMATION
EXTERNAL PROPOSALS SUBMITTED	(Sponsor, Project Title, PIs, Submission Date, Proposal Amount)
EXTERNAL AWARDS RECEIVED	(Sponsor, Project Title, PIs, Award Date, Award Amount)
JOURNAL ARTICLES IN PROCESS OR PUBLISHED	The Journal paper is discussed to be submitted to "Plasma Physics" Journal
BOOKS AND CHAPTERS RELATED TO YOUR RESEARCH	(Book Title, Chapter Title, Authors, Submission Date, Publication Date, Volume #, Page #s)
PUBLIC PRESENTATIONS YOU MADE ABOUT YOUR RESEARCH	(Event, Presentation Title, Presentation Date, Location)
AWARDS OR RECOGNITIONS YOU RECEIVED FOR YOUR RESEARCH PROJECT	(Purpose, Title, Date Received)
INTERNAL COLLABORATIONS FOSTERED	(Name, Organization, Purpose of Affiliation, and Frequency of Interactions)
EXTERNAL COLLABORATIONS FOSTERED	Princeton University Laser Diagnostics Group, Prof. Arthur Dogariu
WEBSITE(S) FEATURING RESEARCH PROJECT	(URL)
OTHER PRODUCTS AND SERVICES (e.g., media reports, databases, software, models, curricula, instruments, education programs, outreach for ND Energy and other groups)	Abstract submitted for Oral presentation: Skye Elliott, Arthur Dogariu, Thomas B. Coates, Sergey Leonov, "Volumetric Electric Charge Dissipation after Streamer Corona by EFISH and Probe Measurements" to 63rd Annual Meeting of the APS Division of Plasma Physics, 8-12 November 2021, Pittsburgh, PA

RESEARCH EXPERIENCE

Please let us know what you thought of your research experience: Did this experience meet your expectations? Were lab personnel helpful and responsive to your needs? What else could have been done to improve your experience or achieve additional results?

I enjoyed my time in the lab, and found the research very enlightening. One benefit of this research is that it supplemented my studies in my Physics E&M class, giving me a unique experience of circuit designs in action. It has definitely met my expectations, providing engaging research. Dr. Leonov and other personnel I worked with were very helpful, guiding me in my project and showing genuine support of my scholarly development inside and outside of my research. Dr. Leonov provided clear expectations of what he hoped for me to achieve in the lab, and was always supportive of my efforts. I could not ask for a better experience; I am glad to feel proud of my work and fulfilled by it.

FINAL WRITTEN REPORT

Description of project and objectives

A streamer corona electrical discharge is commonly realized in many practical devices and technologies dealing with high-voltage electricity. In some cases, such a discharge is intentionally generated for surfaces/materials processing, plasma medicine, creation of electronic devices, and more. In many other cases, the corona discharge appears as a parasitic phenomenon, leading to malfunctions and failures. Knowledge on the streamer corona discharge pattern and dynamics is urgently required for development of proper control procedures. Recent studies show that surface electric charge deposited by the high-voltage pulse discharge greatly affects the discharge parameters and morphology. In addition, a similar behavior was found for a volumetric single-pin discharge. This type of discharge produces volumetric electric charge waves concomitant with a redistribution of the electric field that significantly influences the discharge pattern.

In general, an understanding of the effects of space charge on the discharge characteristics is important for the study of low-temperature plasmas. However, it has been largely under-explored due to the unavailability of a proper measurement tool. This work in particular includes the visualization of the discharge morphology with a nanosecond resolution by means of an advanced ISSD Andor iStar camera. The major objective of this work is to correspond the acquired images to the electric field morphology and the pulse high-voltage generator waveform. The targeting of this goal is completely within the scope of the ND Energy activity.

Research tasks consisted of experimental efforts, numerical simulations, and data analysis, including:

- streamer corona discharge imaging with a high temporal resolution, down to 10ns
- adjustment of the experimental set-up parameters to diminish secondary effects

Findings and results

The experimental setup for this research consisted of a Basler Ace acA2040 camera, CT4028 high voltage probe, LaVision IRO with a UV NIKKOR lens, Berkeley Nucleonics 577 Pulse Generator, Berkeley Nucleonics 625 DDG, Teledyne LeCroy Wavesurfer 4034HD Oscilloscope, TREK 20/20C-HS high voltage amplifier, a 10kV ignitor/trigger, and a high voltage ignitor/tesla coil. The camera was set to capture an image of the corona discharge upon a trigger pulse from the DDG and pulse generator, and relevant probe information, as well as the camera monitor, would be displayed on the oscilloscope screen (Figure 1).

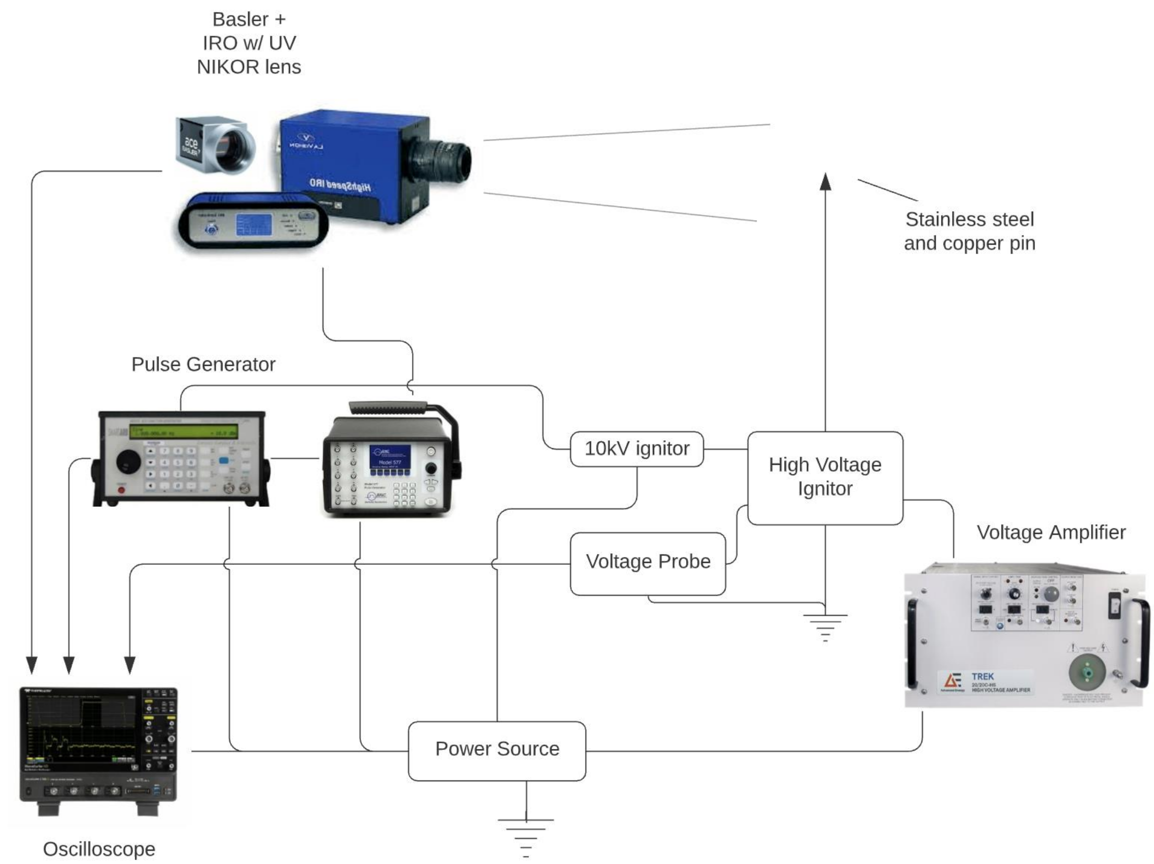

Figure 1. Schematic representation of the experimental setup

The system was tested using both positive and negative polarities to evaluate any possible differences between the two waveforms and the corresponding plasma behavior. A reference image was taken to give a measure of scale and position of the plasmas. The first set of tests were performed at -10kV, or negative polarity. While most plasma behavior aligned with what had been seen in previous experiments (Figures 3 & 4), the plasma during the second negative slope (Figure 5) was unique in that it wasn't cloudlike like I had expected, and instead resembled the streamers formed during the second positive slope in the positive polarity tests. Meanwhile, the images taken at positive polarity (Figures 6-8) followed expected behavior.

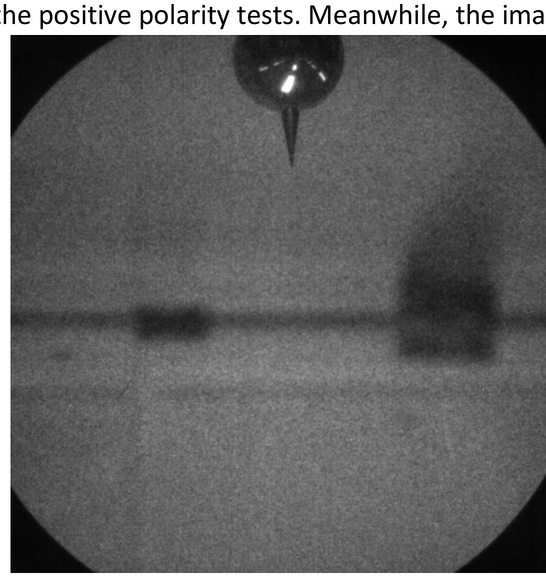

Fig. 2. Reference image; images are upside down due to lensing.

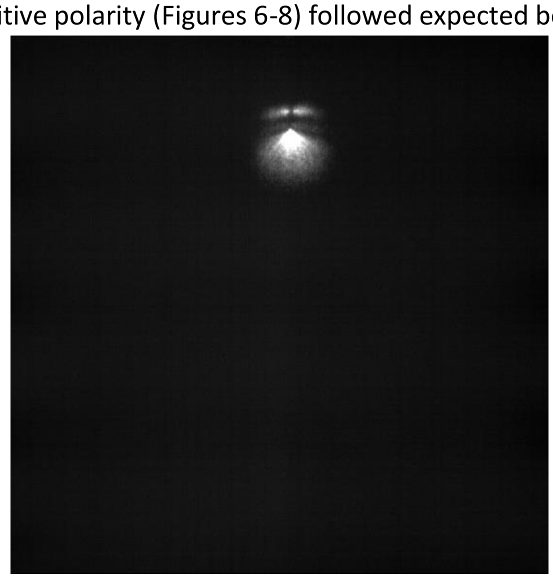

Fig. 3. Cloud formed with negative slope at negative polarity.

Fig. 4. Streamers appear during positive slope.

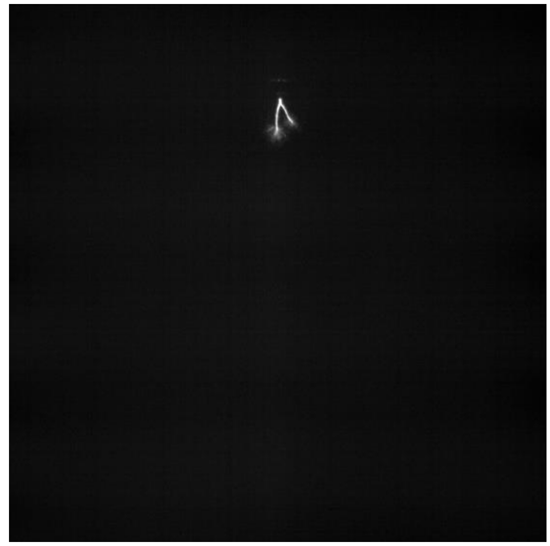

Fig. 5. During second negative slope, streamers are more visible than clouds.

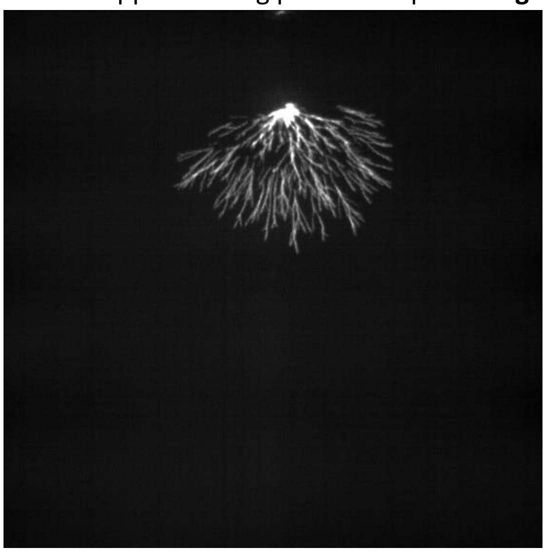

Fig. 6. Streamers form at positive slope in positive polarity.

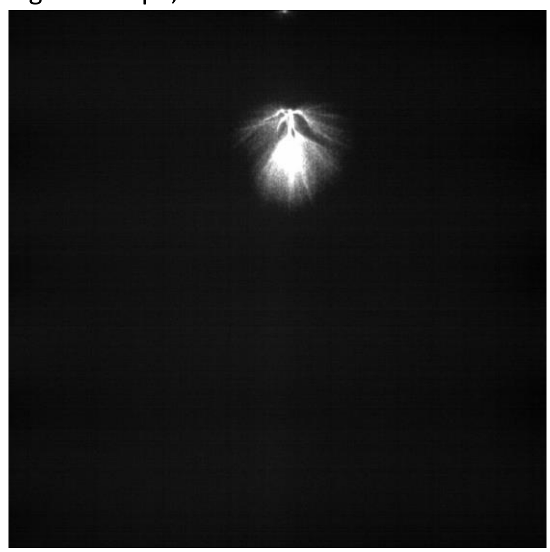

Fig. 7. The streamers that make up the cloud are visible.

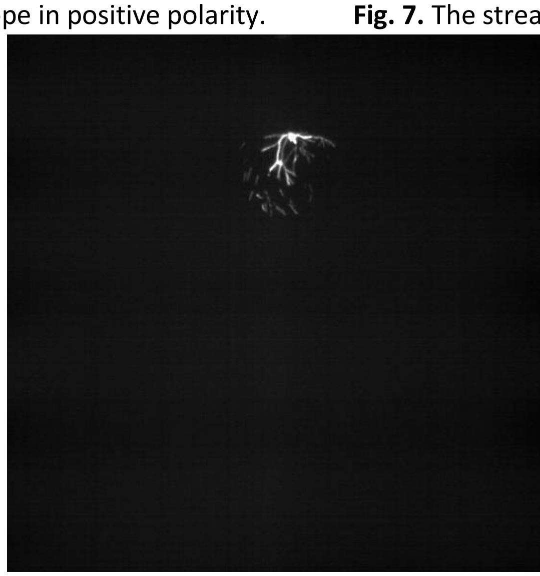

Fig. 8. The second positive slope produces streamers.

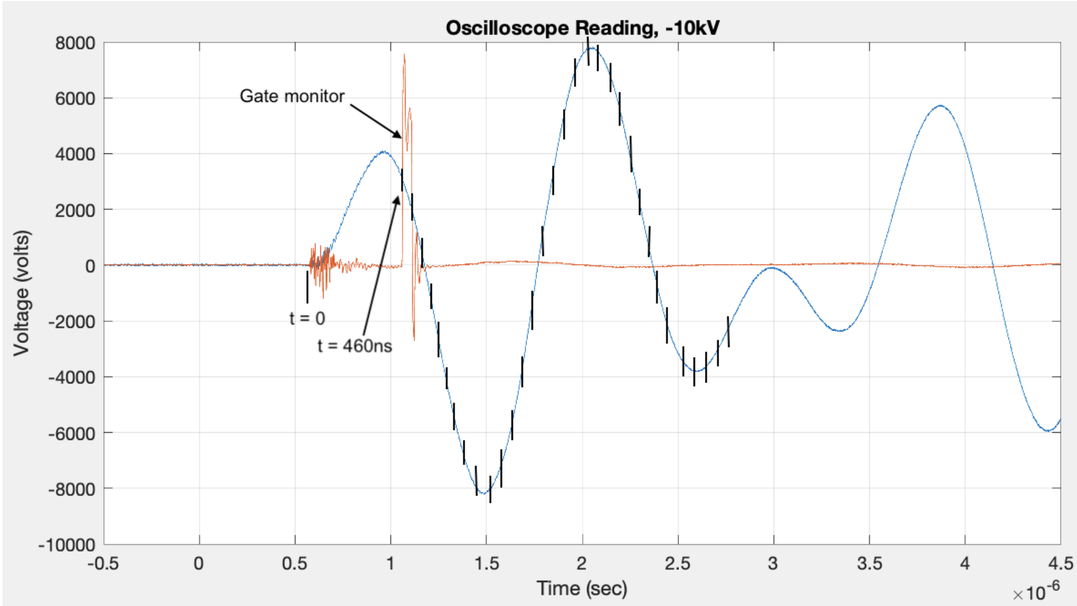

Fig. 9. Example of a negative polarity waveform. The delay time for each series is 50ns after the previous, starting at 460ns.

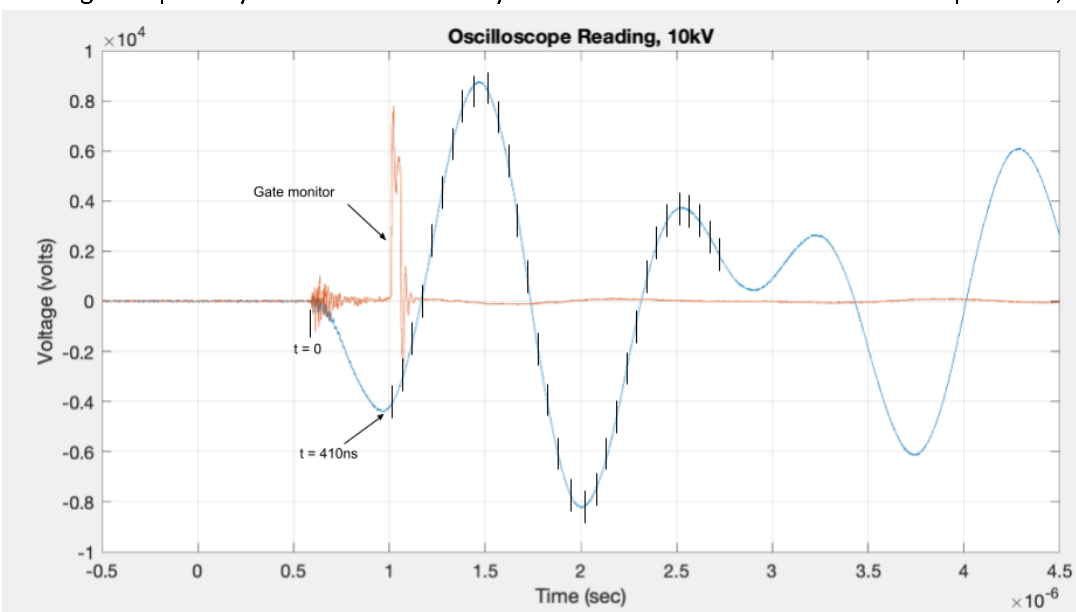

Fig. 10. Example of a positive polarity waveform. The timings used for each image series are indicated by vertical lines.

Conclusion: the project objectives were 100% achieved, including the ones indicated below.

1. All parts of the system were evaluated for possible contribution to jitter, and changes were made so that the system could be used at negative polarities.
2. The streamer corona electrical discharge pattern was acquired using a high-speed Basler camera and LaVision IRO calibrated to fire in conjunction with an alternating-current spark ignitor. The data was processed to recognize any common and variable features, including corona shape and size.