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Kinetic Simulation of Helium Emission Spectra Compared Against Experimental Results

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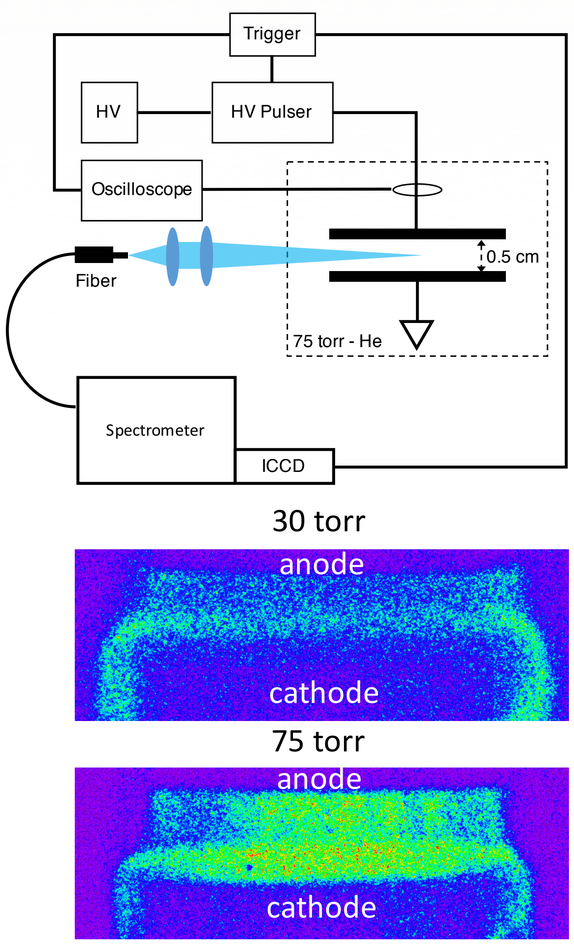
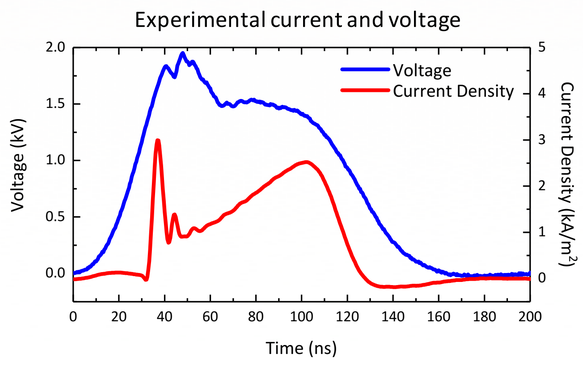
Introduction

Recent work at Sandia National Laboratories has included photonic processes into a multi-dimensional, fully kinetic low-temperature plasma tool[1]. This method relies on an approach that discretely models photons as particles in the simulation domain[2]. This specific implementation allows for the simulation of emission spectra from a non-equilibrium excited state density distribution generated by electrical discharge and capture effects that are not easily modelled with other approaches, such as self-absorption. Time-resolved emission spectra from a pulsed, parallel plate helium discharge was captured experimentally and compared against a one-dimensional simulated emission spectrum under similar conditions (p = 75 torr). The results demonstrate the transient, non-equilibrium behaviour of the plasma even under uniform field conditions and show good agreement between simulated and experimental behaviour.

Experimental Setup

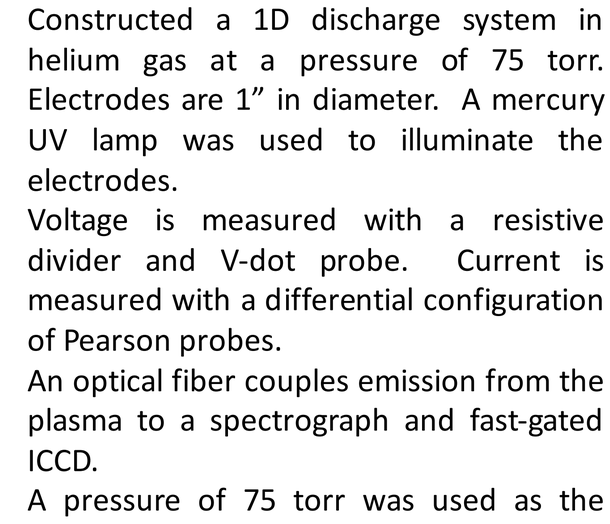




- Constructed a 1D discharge system in helium gas at a pressure of 75 torr. Electrodes are 1” in diameter. A mercury UV lamp was used to illuminate the electrodes.
- Voltage is measured with a resistive divider and V-dot probe. Current is measured with a differential configuration of Pearson probes.
- An optical fiber couples emission from the plasma to a spectrograph and fast-gated ICCD.
- A pressure of 75 torr was used as the discharge imaged using fast-gated visible imaging indicated a more 1D-like discharge than at a pressure of 30 torr.

Simulation Setup

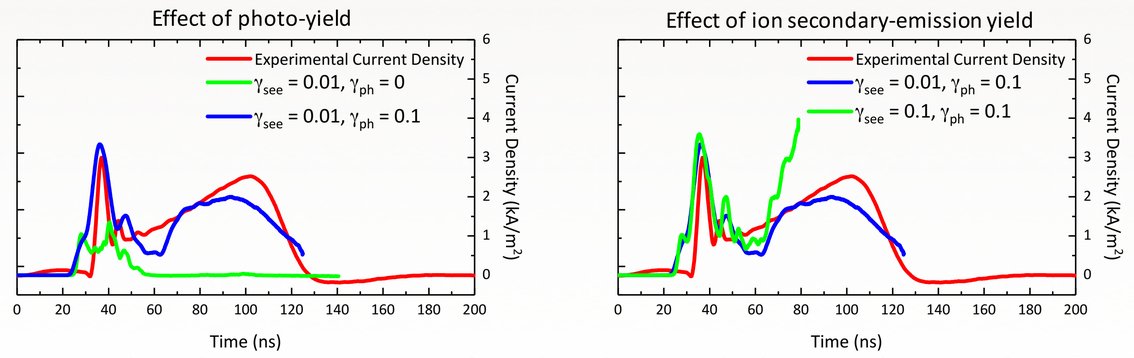
- A 1D simulation was run with a voltage input boundary condition from the measured experimental waveform.
- Use a discrete photon implementation that discretely tracks photons in the simulation domain. Emission spectra is generated through collection of photons in the domain.
- Secondary processes include photoemission and ion-induced secondary emission from the cathode.



- Helium background gas at a pressure of 75 torr. Cross sections are available in literature[3].

Variation in simulated conditions

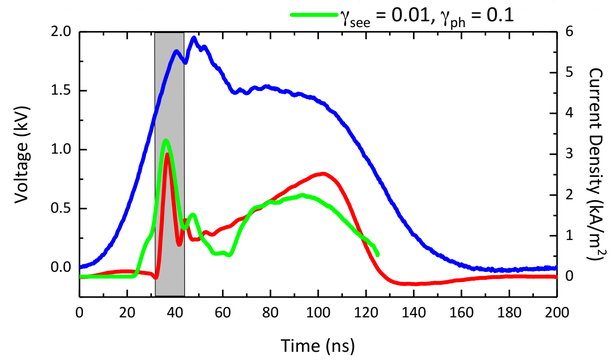
- Experimental jitter requires that timing of spectra comparisons between simulation and experiment be controlled through comparison of discharge currents.
- It has been found that variation in a number of parameters affects the simulated discharge current.



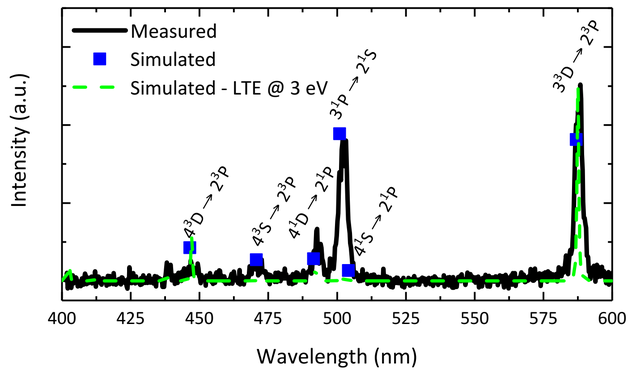
- Current best-fit parameters are found with a seed electron density of 10^{16} m^{-3} within 1 mm of the cathode, γ_{see} = 0.01, and γ_{ph} = 0.1
- Currently investigating the effect of other spatial variations of the initial electron density.

OES Validation Results

- Using the best fit parameters for the current, simulated emission spectra was generated at the same time that an experimental spectra was captured.
- Emission spectra was compared at approximately t = ~30 ns as this was when the best agreement between simulated and experimental current was obtained.



Experimental and simulated current and voltage waveforms, grey indicates the experimental camera gate



- Experimental and simulated spectra agree well for the wavelength range between 400 nm and 600 nm.
- The $3^1P \rightarrow 2^1S$ transition @ ~501 nm is only accurately reprodced by including self-absorption for the ground state 3^1P transition @ ~53.7 nm.
- Also shown is the calculation assuming an equilibrium distribution of excited states.

References

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2. A. Fierro, J. Stephens, S. Beeson, J. Dickens, A. Neuber, “Discrete photon implementation for plasma simulations,” Phys. Plasmas , 23, 013506, 2016.
3. Y. Ralchenko, R. Janeiv, T. Kato, D. Fursa, I. Bray, F. Heer, “Electron-impact Excitation and Ionization Cross Sections for Ground State and Excited Helium Atoms,” Atomic Data and Nuclear Data Tables, 94, 603, 2008.

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