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Influence of Photon and Ion Induced Secondary Yields on Transient Plasma Formation

Andrew Fierro
Applied Optical and Plasma Sciences
Sandia National Laboratories
Albuquerque, NM, USA
andrew.s.fierro@ieee.org

Christopher Moore
Electromagnetic Theory
Sandia National Laboratories
Albuquerque, NM, USA
chmoore@sandia.gov

Matthew Hopkins
Applied Optical and Plasma Science
Sandia National Laboratories
Albuquerque, NM, USA
mmhopki@sandia.gov

Edward Barnat
Applied Optical and Plasma Sciences
Sandia National Laboratories
Albuqueruque, NM, USA
evbarna@sandia.gov

Paul Clem
Electrical Science & Experiments
Sandia National Laboratories
Albuquerque, NM, USA
pgclem@sandia.gov

***Abstract*—The influence of different quantum yields for photons and secondary emission yields for ions striking a surface is investigated. Using a one-dimensional particle-in-cell simulation, these secondary emission coefficients are varied to observe the impact on discharge current. The discharge is assumed to occur in pure helium gas at a pressure of 75 torr. To handle binary particle interactions, the Direct Simulation Monte Carlo (DSMC) method is utilized. The model includes electron-neutral interactions, neutral-neutral interactions, and photon-neutral interactions. It is observed that the discharge current in the early stages of discharge is heavily dependent upon the quantum yield due to photon impact. In the later stages of discharge, the current depends on both the quantum yield and secondary emission coefficient for ion impact.**

Keywords—plasma, photons, secondary emission, simulation

I. Introduction

In classical Townsend discharges, a feedback mechanism is required for the plasma to reach a self-sustaining state. Specifically, at least one new electron must be generated at the cathode such that the discharge can continue. If one new electron is not generated at the cathode, the discharge will die out. In this work, the influence of two feedback mechanisms are studied. The two processes investigated for feedback are (1) the secondary emission of electrons due to ion impact and (2) the emission of electrons due to photon impact. This study shows that even small changes in the photoemission or secondary emission yield have a large influence on discharge currents. Furthermore, the influence of each feedback mechanism may be qualitatively observed as the discharge progresses. In general, it was found that photoemission has a large impact at the beginning phase of the discharge, regardless of the secondary emission yield. Later in the discharge, both effects play a role in the discharge current.

II. Simulation Model

A. Overview

This investigation utilizes Aleph, an electrostatic Particle-in-Cell (PIC), Direct Simulation Monte Carlo (DSMC) code. A simple one-dimensional model is used, and the background gas is assumed to be helium at a pressure of 75 torr and temperature of 300 K. The cathode is held at zero ground potential and the anode is supplied with a time-dependent voltage pulse (see Fig. 1). Electron-neutral interactions are handled with the DSMC method. To start the simulation, a small seed of electron density (5×10^8 cm^{-3}) is placed within 100 microns of the cathode. A discrete photon model has been developed that allows for accurately accounting for photon emission and propagation from excited states [1]. This enables the inclusion of resonance emission that occurs in helium and the photoemission process occurring at the cathode. In general, all particles are allowed to leave the simulation domain except for neutral, ground-state helium atoms. In the case of ions striking the cathode, a fixed yield coefficient is provided regardless of ion energy. For photons impacting the cathode, only those with wavelength shorter than 100 nm are allowed to cause photoemission of electrons. For a helium plasma system, three intense atomic emission lines appear between the wavelength ranges of 50 nm – 60 nm. Additionally, another emission line at 67 nm from the helium molecule also contributes to photoemission at the cathode.

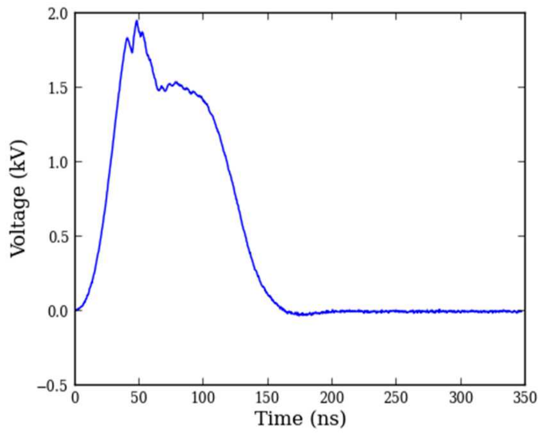

Fig 1. Voltage Waveform that is provided as a Dirichlet boundary condition to the anode

B. Chemistry

The chemistry set utilized in this work is from the published work of Ralchenko, *et al.* [2]. A tabulated set of cross sections for electron-neutral interactions are input into the simulation for $n \leq 4$. Excited states with higher principal quantum numbers ($n \geq 5$) are assumed to have negligible impact on the results. Spontaneous emission rates are collected from the NIST database [3]. A large list of rate reactions are included for the generation of helium molecule ions and excited states. These rates are available in literature. The simulation also includes the self-absorption of the three

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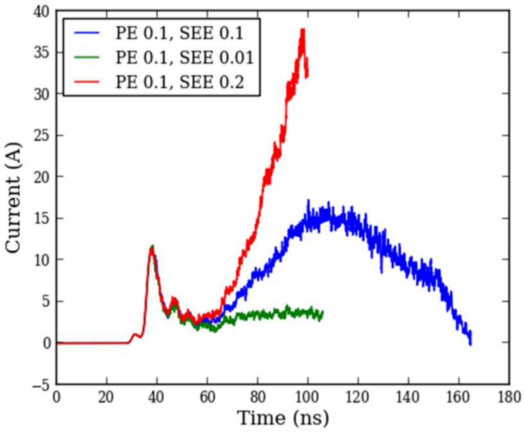

Fig 2. Simulated discharge currents for transient helium plasma formation at a pressure of 75 torr. Different curves show the influence of the ion-induced secondary emission yield coefficient while holding the photo-yield coefficient constant.

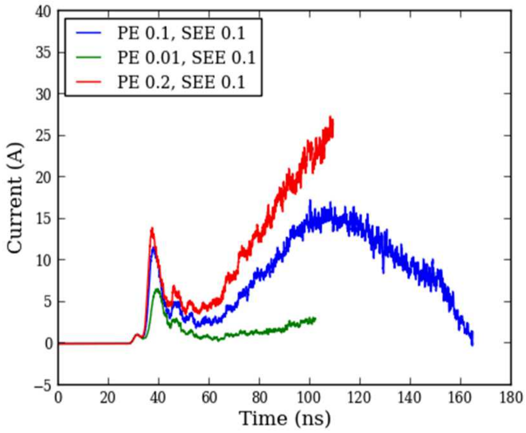

Fig 3. Simulated discharge currents for transient helium plasma formation at a pressure of 75 torr. Different curves show the influence of the photo-yield coefficient while holding the ion-induced secondary yield coefficient constant.

intense atomic helium lines. This is important to include due to their high energy and short absorption mean free path whicheffectively increases their diffusion time to the electrode surfaces.

III. Results

The results for varying the ion-induced secondary emission yield are shown in Fig. 2. In this case, the photo-yield coefficient is held constant and the ion-induced secondary yield coefficient is simulated with the values of 0.01, 0.1, and 0.2. In all three cases, the initial current spike at approximately t = 40 ns is unchanged. This hints that the photoemission from the surface is the dominant mechanism for electron feedback in this time regime. However, as the discharge progresses ($t > 60$ ns), a large effect on the discharge current is observed as the ion-induced secondary emission yield coefficient is increased. It is likely that on the short timescales where the ion-induced secondary emission coefficient yields little difference in the simulations, ions do not reach the cathode in sufficient quantity. Eventually, ions begin to stream into the cathode as sheath formation occurs. At about 110 ns, the voltage begins to reduce, and the discharge current begins to decrease.

Varying the photoemission yield while holding the ion-induced secondary emission yield constant shows similar late-time behavior (Fig. 3). It should be noted that the blue curves in both Fig. 2 and Fig. 3 are results from the same simulation. In general, the late time behavior is similar to that of increasing the ion-induced secondary emission yield coefficient. Increasing the photo-yield increase the late-time discharge current. In the extreme case of making the photoemission yield 0.2, a smaller effect on discharge current is observed than when compared to increasing the ion-induced secondary emission yield to 0.2. Specifically, the discharge current in the ion case reaches nearly 40 A at 100 ns and only 20 A at 100 ns for the photon case. However, it is observed that the initial current spike is decreased as the photon induced secondary yield is reduced. While the resonant photons are heavily self-absorbed, it appears that some may still reach the cathode on short timescales. Additionally, the helium molecule emission may also contribute in this regime.

IV. Conclusion

A one-dimensional PIC/DSMC simulation was constructed and used to investigate the effect of secondary electrons arising from photon and ion impact. It was found that in the early stages of discharge, the ion-induced secondary emission had little impact on the overall discharge current. However, later in the discharge both the ion-induced and photon-induced secondary emission plays a role in the discharge current. These results underscore the necessity for accurate secondary electron emission coefficients.

This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government

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