Population Kinetics of a Repetitively-Pulsed Nanosecond Discharge

by

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I would like to dedicate this dissertation to someone else.

ACKNOWLEDGMENTS

Who is this?

Preface

This is a dissertation about something; I really hope it's good.

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DBD dielectric-barrier discharge

APP atmospheric-pressure plasma

CHAPTER 1

Introduction

1.1 Overview

Research on atmospheric plasmas has been going on for as long as research on plasmas themselves. However, it was only recently that the necessary diagnostic techniques and computational power existed to properly examine them. In the last few decades there has been a renaissance in work dedicated to atmospheric plasmas, particularly atmospheric pressure plasmas that are out of thermal equilibrium. This is because they are able to treat delicate substrates with none of the thermal damage associated with arcs.

Though several approaches exist to generating atmospheric pressure plasmas (dbd, microwave, rf), particularly interesting are those using nanosecond pulses. The duration of such pulses, as well as their amplitude can be changed to target particular atomic or molecular reactions. This flexibility is highly desirable in the world of plasma processing where selectivity, control, etc. are of utmost importance. However, we are still learning how to measure these particular plasmas. As recently as 1994 [1] the only diagnostic with any meaningful accuracy was propagation velocity.

Several research groups have focused on the development of pulsed nanosecond discharges in air. However, the complex chemistry associated with air plasmas obscures some of the more fundamental questions: how is the pulsed nanosecond plasma formed, how are the excited states of the system populated, what significance is there to reactions after the fast ionization wave, the spatial variation of system parameters, what kind of electron energy distribution can be expected? This study will emphasize spectroscopic measurements of a helium pulsed nanosecond discharge.

simplify for general reader

Such a system retains physical relevance given that helium is a common stabilizing additive to atmospheric pressure plasmas. At the same time, the more simple atomic structure lends itself to a more detailed examination using global models, kinetic simulations, and active spectroscopy. This work will focus its efforts on the description of the spatial variation of the pulsed-nanosecond discharge, an approximation of its electron energy distribution function, and a description of how the neutral atoms are excited.

The remainder of this chapter includes a review of the associated literature, as well as a discussion of basic discharge theory (diagnostic-specific theory will accompany the relevant chapters). Chapter 2 provides the necessary details of the experimental setup as well as some preliminary observations. Next, in chapter 3, absolute measurements of the helium triplet metastable densities are presented. Chapter 4 covers more general emissions measurements. In order to provide a more clear understanding of the meaning of these measurements, we explore them using a global model and a particle kinetics model. Finally, we conclude in chapter 6 with a discussion of how the collection of models and measurements influences our understanding of the pulsed nanosecond discharge.

1.2 Literature Review

1.2.1 History of Atmospheric-Pressure Discharges

History of plasmas, two separate paths: arc and dbd. Thermal vs. nonuniform. Consider how to address other, more exotic atmospheric plasmas, ie microwave, rf, etc.

Like most physical phenomena, plasmas are typically only described under ideal circumstances. This means that neutral collisions, and subsequently, atmospheric plasmas, are often ignored. Neutral collisions tend to obscure the electromagnetic effects that distinguish a plasma from a gas. However, the history of observation and study of plasmas is indelibly linked to atmospheric plasmas. Lightning and static sparks are the most prevalent plasmas on earth. Indeed, the among the first artificial plasmas was a constant atmospheric arc generated in 1802, the work of a Russian scientist named Vasilii Petrov [2].

The work of Petrov was the forerunner to the study of thermal plasmas. Volta's recent invention of the voltaic pile provided the first source of constant and sufficient electrical energy. Using a series of voltaic cells, Petrov was able to draw the first electrical arc between two sticks of carbon. Its blinding light was recorded in a number of historical prints, such as figure 1.1.

Aside from this light, the arcs were characterized by their significant ionization, and high degree of thermal equilibrium. Gas temperatures could reach thousands of kelvin.

In contrast, later work by Werner von Siemens [3], led to the discovery of the so-called "silent discharge," seen in figure

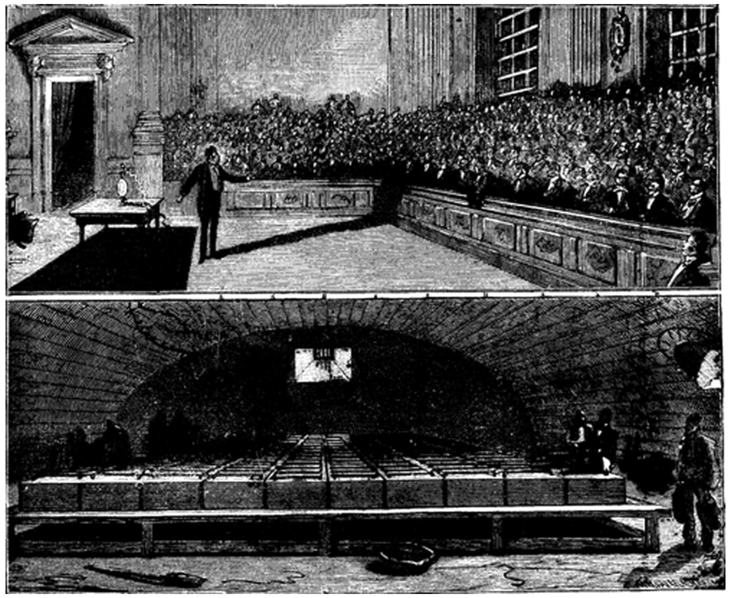

Figure 1.1: This is a test.

. In recent years, the terminology has changed and this type of discharge is now referred to as a dielectric-barrier discharge, or DBD. The DBD was significantly different from the thermal arc. Visually, it was much dimmer, and appeared to be composed of many thousands of individual filaments. Additionally, the DBD did not significantly heat the air, unlike the thermal arc. Finally, the DBD was used in the first commercial plasma application: ozone generation and water purification. Notably, both the thermal arc and silent discharge predated the ‘official’ discover of plasma by Sir William Crookes in 1872.

1.2.2 Repetitively-Pulsed Nanosecond Plasmas

For a substantial period of time, these two discharges represented the range of atmospheric-pressure plasmas (APP). The thermal arc, though useful, could not be used on delicate substrates. It had the additional problem of having relatively little control over its chemical kinetics. Meanwhile, the DBD was relegated to ozone production and polymer processing (relatively low-value applications). Though the DBD had attractive thermal properties, little else was known about how it operated, and how to control its properties. As recently as 2007, the National Academies noted that "the full promise of APPs will be known only if they can be understood and managed based on fundamental scientific principles at two extremes–the nanoscopic kinetic level, where selective chemistry occurs, and the global stability level, likened to aerodynamics."

is this true?

Coincident to this work were studies of short, pulsed discharges. Initial work by J.J. Thompson and ??? was driven by an interest in how breakdown occurred. As shorter pulsers were developed, a number of researchers became interested in the characteristics of pulsed discharges themselves. Loeb noted that the discharge properties were akin to those observed in lightning leaders.

who was original?

who else?

1.2.3 Research Plan

Propose research to fill this gap Specific and cited history of PNDS and related measurements.

1.3 Basic Theory

Basic theory of gaseous breakdown.

CHAPTER 2

Experiment

CHAPTER 3

Metastable Measurements

CHAPTER 4

Emission Measurements

CHAPTER 5

Modeling

CHAPTER 6

Conclusions

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