International Journal of Research in Science and Technology http://www.ijrst.com

(IJRST) 2013, Vol. No. 3, Issue No. II, Apr-June **ISSN: 2249-0604**

THE STUDY OF COLD PLASMA GENERATION AT ATMOSPHERIC PRESSURE IN VARIOUS WORKING MEDIA

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ABSTRACT

In physics and chemistry, ***plasma*** *is a state of matter similar to gas in which a certain portion of the particles are ionized. Heating a gas may ionize (reduce the number of electrons in) its molecules or atoms, thus turning it into plasma, which contains charged particles: positive ions and negative electrons. Ionization can be induced by other means, such as strong electromagnetic field applied with a laser or microwave generator, and is accompanied by the dissociation of molecular bonds, if present.*

The presence of a non-negligible number of charge carriers makes the plasma electrically conductive so that it responds strongly to electromagnetic fields. Plasma, therefore, has properties quite unlike those of solids, liquids, or gases and is considered a distinct state of matter. Like gas, plasma does not have a definite shape or a definite volume unless enclosed in a container; unlike gas, under the influence of a magnetic field, it may form structures such as filaments, beams and double layer. Some common plasmas are stars and neon signs. In the universe, plasma is the most common state of matter for ordinary matter, most of which is in the rarefied intergalactic plasma (particularly intracluster medium) and in stars.

INTRODUCTION

In contrast, non-thermal plasmas are capable of operating effectively at low temperature. Electrons of sufficient energy colliding with the background gas can result in a low level of dissociation, excitation and ionization without an appreciable increase in the gas enthalpy. This is the realm of cold plasmas in which the electron temperature can exceed the temperature of the heavy particles by several orders of magnitude. Because the ions and the neutrals remain relatively cold, this characteristic provides the possibility of using these plasmas for low temperature plasma chemistry and for the lighting industry. In such cases, the plasma chemistry is driven by the electrons, which cause ionization, molecular excitation and production of radicals. The advantage of low bulk gas temperature is exploited when the surroundings of the plasma cell are required to be protected from heat and when the kinetics of the processes need to be controlled. The huge field of lighting and display industry [Marshak, 1984; Waymouth, 1991; Dakin, 1993; Lister *et al.*, 2004; Zissis and Rouffet, 2006] relies heavily on the cold plasma technology, as most of the optical radiation sources in the world use non-thermal plasma on a large scale for the generation of radiant optical energy which is one of the most abundant forms of energy available to the mankind. Our world cannot be conceived without an optical light source. Most of the light that we live by-outdoors as well as indoors, both during the day and at night–comes from the plasmas, the electrically charged gas that results when numerous atoms are broken down into electrically charged particles. Outdoors during the day the light comes from the sun, which is nothing but the plasma; at night along with some sunlight reflected by the moon and some star light, there are fluorescent lamps and high intensity arc discharge lamps to light the way which are again plasma based. Thus, both during the day and night, most of the light comes from the plasma only. Light is also crucial for other areas of our lives. It is important for plant growth and for the liberation of oxygen by photosynthesis, the sun's plasma thus being responsible for much of our food and for the very air that we breathe. All in all, optical light system is an important socio-economic factor and its development is an integral part of any sustainable development and of any program involving improvement of the quality of life.

Human genius has created a large number of its own optical radiation sources for generating optical energy. These optical radiation sources, besides serving the basic purpose of providing light are also very vital in a great variety of scientific, industrial, technological and medical applications and in several other diversified fields of science and technology. Cathode ray tubes emit impulses that activate screens of computer monitors and television. X rays are used not only as a diagnostic tool in medicine, but also as an analytical tool in the inspection of manufactured products and other composite structures. Microwaves are used not only in cooking or as a means of heating rubber or plastic but also in a wide variety of communication applications. Infrared radiations are used in heating, in analytical chemistry and in electronics.

During the last two decades, in addition to the radiations in the above mentioned regions of the electromagnetic spectrum, the field of ultraviolet radiation has gained a major impetus in diverse areas of science and technology. Although ultraviolet (UV) radiations have been in use for decades in areas including the medical field, photochemistry, photobiology, microelectronics, and the analytical fields; but more recently these radiations have found applications in advanced areas such as photon induced material processing, Very Large Scale Integration, communication and information technology and industries based on electronics and photonic technologies which often require ultraviolet optical radiation sources [Boyd *et al.*, 2003; Griesbeck *et al.*, 2003; Kogelschatz, 2004].

UV optical sources [Rice, 1997; Malik *et al.*, 2001; Laroussi *et al.*, 2002] not only play an important role in the scientific and industrial circles, but also have a tremendous impact on our society. In the 21st century, the contribution of UV optical sources to other fields has become essential to address growing global environmental problem. In the field of environmental technology, UV optical sources are widely utilized for ozone generation, for elimination of pollutants in air (chlorofluorocarbons, dioxins, etc.), treatment of drinking water, and also in wastewater treatment.

Also, photon induced material processing [Esrom and Kogelschatz, 1992; Bergonzo and Boyd, 1993; Esrom *et al.*, 2000; Kogelschatz *et al.*, 2000] using ultraviolet optical sources offers an unprecedented potential. These sources have been used in several areas including surface modification, material deposition/coating of metals, dielectrics (high and low dielectric constant materials), and semi conducting layers, hardening of paints, lacquers, and adhesives, for printing and lamination, in automotive and equipment engineering.

UV radiation sources also have a potential impact on textile and polymer technology [Ersom *et al.*, 1992; Mehnert *et al.*, 2002] where they are used in surface treatment, e.g. surface modification of polymers, dry etching of polymers, synthesis of hydrophilic polymers to increase adhesion between metal and polymer, surface cleaning and surface etching including three-dimensional applications, and textile finishing. Furthermore, they are used in several photon initiated scientific and industrial applications [Lomaev *et al.*, 2006a] such as in the field of photo-chemistry, e.g. for photo-chlorination, photo-sulpho-oxidation, photo-nitrosylization, photo-oxidation, photo mineralization, actinometry etc., in photo-medicine, such as for the treatment of skin conditions, tanning etc., in photobiology for photo inactivation, photo regulation and photo destruction.

Keeping in view the enormous potential applications of ultraviolet optical sources, in brief, it can be deduced that the development of ultraviolet optical sources is a task of great significance. In order to carry out photon initiated scientific and industrial applications, large area ultraviolet optical radiation sources are required. Therefore, during the last few decades, considerable efforts have been extended by technologists and engineers to the generation of energetic VUV and UV photons, which represent radiations in the UV region of the electromagnetic spectrum. A great deal of work has now been focused on the designing and development of several optical sources, major ones being the non-thermal plasma based excimer optical sources. In the present work also, the primary focus of research will be on the study of design issues of cold plasma based VUV and UV sources. But, before proceeding further towards defining the objectives of this research work, it is necessary to have a fundamental understanding of the UV spectrum, its classification and also a comparative study of the various sources of UV generation.

OBJECTIVES

Keeping in view the growing importance of non-thermal plasma based excimer sources; the present work has been planned with the following objectives:

- To study possible application of non-thermal plasma sources for excimer generation and to investigate miscellaneous process parameters to devise a DBD reactor.
- To investigate electrical equivalent model of the DBD and to determine the discharge excitation parameters of excimer generation scheme.
- Implementation of the electrical equivalent network model in Matlab Simulink tool to study the electrical behavior of the DBD reactor.

- To study the frequency response of DBD, and consideration of load matching conditions of DBD plasma load.

LITERATURE REVIEW

Electrical discharges have been known to the mankind for more than a century, beginning well before the discovery of electrons. Until the discovery of the transistor and the development of integrated circuits, the use of ionized gas was essential for the control of electric current within the electrical power and communication industries, creating the interdisciplinary field known as gaseous electronics. Although most of the gaseous components within electronic systems disappeared with the development of semiconductor technology, but still the manufacture of semiconductor devices is dependent upon the use of gas discharge through plasma processing technique. Moreover, understanding of ionized gas is still essential to the lighting and display industries, despite the advent of light emitting diode, solid state lasers and liquid crystal displays. Although the application of an electrical discharge in plasma chemical reactions has a long history, but the synthesis of excimer using DBD technology is a relatively new field. One of the most important early empirical landmarks in the history of DBD electrical discharges was the invention of silent discharge by Werner Von Siemens in 1857. Siemens proposed a novel type of electrical gas discharge that could generate ozone from atmospheric oxygen or air. This was achieved by subjecting a flow of oxygen or air to the influence of a dielectric-barrier discharge maintained in a narrow annular gap between two coaxial glass tubes by an alternating electric field of sufficient amplitude. Since the electric current was forced to pass through the glass walls acting as dielectric barriers the discharge was referred to as the dielectric-barrier discharge. Some oxygen molecules in the air flowing through the discharge gap between the glass tubes were converted to ozone. The novel feature of this discharge apparatus was that the electrodes were positioned outside the discharge chamber and were not in contact with the plasma.

HYPOTHESIS

The thesis begins with a general introduction providing an overview of the electromagnetic spectrum of ultraviolet radiation followed by a short discussion of the various UV sources and their limitations, and reviews the related literature.

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which are plasmas with a temperature such that they radiate strongly at visible wavelengths. Most of the ordinary (or baryonic) matter in the universe, however, is foundin the intergalactic medium, which is also a plasma, but much hotter, so that it radiates primarily as X-rays. The current scientific consensus is that about 96% of the total energydensity in the universe is not plasma or any other form of ordinary matter, but a combination of cold dark matter and dark energy.

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