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An investigation on optical properties of capacitive coupled radio-frequency mixture plasma with Langmuir probe

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ABSTRACT

The properties of Capacitively Coupled Radio Frequency (CCRF) plasmas for mixture gases have not already been known. Therefore, our goal in this paper is to understand the characteristics of mixture gas discharges in the different ratio of capacitive coupled discharge at low pressure. For this aim, the single Langmuir probe can be used to estimate the electron temperature and the electron density of the mixture discharge in a capacitive coupled discharge plasma system at low pressure. The characteristics of helium (He) and electronegative oxygen (O_2) mixture plasma is determined by the single Langmuir probe. The ratio of the ion saturation current to electron saturation current is investigated with obtaining values from this probe. The optical emission measurements have been taken to minimize the deficiency of the Langmuir probe diagnostics.

1. Introduction

The capacitive coupled plasma (CCP) can be formed as higher stability under the low pressure [1]. CCP plasma has advantages and also disadvantages. For example, it can supply producing of high voltage sheath and high ion energies. These discharges allows electron density of 10^9–10^{10} cm^{-3}. In the CCP, the ion-bombarding energy cannot be determined as independently of the ion flux. CCP is produced for the film etching, deposition, cleaning and surface modification with RF power supply in the industry and also the high frequency CCP discharges are widely used at higher electron density and lower ion bombardment energy on the powered electrode in some studies [2–4]. The discharge physics and chemistry at the radio frequency (RF) capacitive coupled reactors are investigated for determining of the behavior of plasma used in the material processing [5,6]. Because of the basic mechanisms as electron heating, plasma formation process, the electron temperature has not been well-known. However, they are very important research subjects [7]. The large area parallel plate capacitive coupled reactors can be used for the plasma enhanced chemical vapor deposition (PECVD) method and generally the areas of RF powered and grounded electrodes are the same. Therefore, the deposition rate can be increased by increasing of RF power [8]. Polymer photoresist films can be stripped and the properties of biocompatible surfaces can be improved by oxygen and oxygen containing plasmas [9,10]. The ions in the RF discharge heavily influence from the electric field at low pressure. However, the ions are affected slowly from the electric field in the high frequency RF discharge [11]. The ion temperature is usually at the room temperature, however the electron temperature is around a few electron

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volts. Therefore, the uncontrolled damages cannot occur during manufacturing of the substrate [12]. The film composition is related to a function of deposition parameters and plasma characteristics [13].

One of the important parameters is electron density for defining of the operating conditions of a discharge. The measurements of electron density and temperature can be taken into account the diagnostics of plasma. Therefore, the Langmuir probe is tool by which the plasma can be diagnosed [14]. In case of rare gases, the capacitive coupled RF discharge has been extensively obtained from helium (He) and argon (Ar) gases, but neon (Ne) is not often used for discharge for the higher cost of Ne. Therefore, electron distribution function (EDF) of Ar and He can been measured with Langmuir probe [15]. The changes of EEDFs with increasing gas pressure are measured for a capacitive coupled O2 and Ar plasma. The results can be compared for these plasma [16]. At low pressure, the main spectral features reported are the wavelengths of the atomic He transitions at 388.87 and 728.13 nm. The atomic emission intensities showed a maximum for inductive system when the pressure is about 0.62 mbar. The optical emission spectrum (OES) of capacitive discharge and inductive discharge has been compared in detail [17].

The Langmuir probe measurements are the oldest and most widely used for all plasma diagnostic techniques [18]. The current-voltage (I–V) characteristics of Langmuir probes can be used to diagnostic the parameters of the generated plasma parameters. It is easy to interpret data of the I–V characteristics obtained from steady-state, isotropic, unmagnetized plasmas [19]. The potential distribution in gas discharges can be measured with an electrostatic probe. Then, the features of the low temperature plasmas can be investigated with the general method developed by Langmuir and his collaborators [20,21]. There are a lot of advantages for Langmuir probe according to other diagnostic methods.

The reliable results of the capacitive RF discharges are taken with compensating the RF fluctuations of the plasma. The resonant blocking inductors and an additional metallic cylinder suppress RF probe currents. This metallic cylinder connected capacitive to the probe in front of the inductors in order to reduce the capacitive impedance between the probe tip and the plasma [22,23].

As a Langmuir probe, a small electrode can be immersed in the plasma and it is biased by a linear, high voltage ramp. The wire collects the current, I and then it can be measured as a function of the bias voltage, V. Therefore, the voltage current characteristic curve is obtained and it gives the several useful plasma parameters. After a bipolar, the symmetric voltage ramp is applied to the Langmuir probe and the induced current is recorded, the I–V characteristic curve can be collected [24]. The mean free path of electrons is much shorter than the size of the probe for the high pressure plasmas. The known probe theory is not used for the high pressure plasmas and also it is successfully valiable for the low pressure [25]. This theory is based on the thin collisionless sheath approximation. Literature contains the applications of the Langmuir probe diagnostic method to the investigation of plasma properties at low-pressure and atmospheric-pressure plasma jet systems [26]. Some studies compare the plasma parameters inferred from the classical Langmuir probe procedure, from different theories of the ion current to the probe, and from measured electron energy distribution function [27]. The determination of ion mass for low-pressure plasmas has been proposed by using Langmuir probe measurements [28]. The electron temperature, electron velocity, ion velocity, and ion density have been investigated using the Langmuir probe for various RF powers [29].

As far as we know, the literature does not contain the experimental data about the parameters of helium-oxygen mixture plasma in the RF capacitive discharge at low pressure. The investigation is much information of helium and oxygen discharges in the literature. But up to now the data are actually absent on the optical and electrical properties of RF-capacitive discharge in the oxygen and helium mixture at low pressure.

This paper is organized as follow: first, we present the introduction part. After that, we describe the experimental setup for this study. Next, the measurements of plasma parameters obtained by Langmuir probes are introduced and the optical emission spectroscopy (OES) is given to determine the parameters of mixture plasma at low pressure. Finally, the innovation and importance of this study are emphasized in the conclusion.

2. Experimental setup

Gas discharges are created by applying RF power to the neutral and electronegative gases. The scheme of the experimental setup is illustrated in Fig. 1. The capacitive coupled RF discharge system is used to generate the mixture discharge of helium and oxygen gases. The reactor is made from a quartz glass and its shape is cylindrical with length of 20 cm and diameter of 6 cm. The cylindrical quartz glass vacuum chamber has 6 arms made from stainless steel. The length between two arms is 20 cm in this vacuum chamber. For this reason, the power supply is connected to one of two flanges at the one side of the reactor via Advanced Energy RF matching box and Cesar generator in the capacitive system. The other electrode is also connected to ground. The discharge is obtained at the 13.56 MHz with RF generator and an automatic impedance matching network. The reflected RF power is kept under 1%.

The vacuum chamber is evacuated down to 4.0×10^{-2} mbar using RV8 Edwards vacuum pump reinforced with turbo pump. The vacuum gauge controller is connected to chamber and vacuum pump. Therefore, the gas pressure of this chamber is recorded from 0.029 mbar to 0.270 mbar.

The RF power applied here is varied from 10 W to 150 W. The flow rate of O2 and He gas is controlled by EL-Flow mass-flow controller. Oxygen and helium gas flow rates are selected between 0.02 l/min–0.06 l/min to generate the plasma.

To diagnostic the plasma, the electron number density and electron temperature were measured using the Impedans Langmuir probe located in the middle region between the electrical electrode and grounded electrode. The obtained I–V characteristics curve gives more information us about the plasma. In order to obtain the I–V characteristics curve, the voltage