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DIAGNOSTICS OF DC GLOW DISCHARGE IN A LONGITUDINAL MAGNETIC FIELD

Abstract. This article presents the results of a study of the characteristics of direct current (DC) glow discharge in an external longitudinal magnetic field. The Langmuir electric probe and emission spectrometer are used as diagnostics of glow discharge plasma. Using the current – voltage characteristic (VAC) of a stratified glow discharge plasma, the main plasma parameters, such as electron temperature, concentration of plasma particles were determined under various magnetic field conditions. With a relatively large magnetic field, it was determined that the concentration of plasma particles increases and the electron temperature decreases. It was also determined using the spectroscopic method that the luminosity of the discharge (intensity) of a DC glow discharge increases with increasing value of the magnetic field. A qualitative interpretation was made to explain the change in plasma parameters under various conditions of the magnetic field.

Keywords: DC glow discharge, plasma, magnetic field, Langmuir (electric) probe, spectrometer

Introduction

At the moment, it is difficult to overestimate the importance of studying plasma physics. A huge number of laboratories of universities around the world are engaged in research of plasma processes. In the future, these studies are widely used in the industrial sector in the form of technical applications: lighting, modern plasma nanotechnology; fine ion cleaning of the surface of materials, etc [1-2].

Low-temperature plasma is the subject of numerous studies. Interest in it is caused by the possibility of wide application in gas lasers, plasma chemical reactors, energy converters, voltage switches, etc. Successful application of plasma objects is impossible without a deep understanding and quantitative description of the processes occurring in them. The construction of physical models fully reflecting the behavior of plasma systems is based on the knowledge of the corresponding plasma parameters. In this regard, the development of plasma diagnostic methods is of great interest and practical importance [3].

Of particular interest is the study of plasma behavior in a magnetic field. Since plasma is an ionized gas consisting of charged particles, the presence of a magnetic field has a significant effect on all processes occurring in plasma [4-9].

A probe method for plasma diagnostics was proposed and substantiated by Langmuir [10]. The essence of the method is as follows: the current of charged particles is measured on a small charged electrode, which is placed in the plasma, and the dependence of the current on the electrode potential is obtained. Under certain conditions, the main plasma parameters — temperature, concentration of charged particles, and space potential — are determined from the probe characteristic under certain conditions.

One of the advantages of the probe method is the simplicity of measurements, where complex special equipment is not required. The main disadvantage of this method is the perturbation of the plasma by the probe, which leads to a change in the distribution function and space potential in a certain region around the probe. According to the probe theory, it is assumed that these perturbations are localized near the probe, so that they have little effect on the state of the plasma and on the gas discharge regime in most of the volume under consideration. This is due to the fact that in sufficiently dense plasma the probe is surrounded by a layer of charged particles that shield it from the rest of the volume.

Among the various methods for studying plasma, spectral diagnostics occupies a special place, since it provides non-contact and rapid measurements. This method is based on the analysis of the intensity and shape of the spectral lines of atoms, ions and molecules present in the plasma. The characteristic lines can determine the composition of the plasma; Doppler broadening and shear can be used to determine particle velocities and temperature; in absolute and relative radiation intensity - temperature and electron concentration; using the Zeeman and Stark effects, magnetic and electric fields.

Description of Experimental setup & Results

The experimental setup consists of several integrated subsystems that must work together to achieve our research objectives. The main subsystems of the experimental setup are: an experimental discharge tube, a coil of Helmholtz systems, a vacuum vessel and associated vacuum systems, a plasma generation system (power supply), a laser system, a measuring system (ammeter, voltmeter), an electrode system (anode, cathode, and metal probe) and video surveillance system. The general scheme of the experimental setup is shown in Figure 1. The experiment was conducted in the laboratory of dusty plasma and plasma technology IETP. At the beginning, a residual pressure in the working volume of 10-3 torr is provided from the discharge tube using a HiCube vacuum system. Gas pressure is measured using a PMT-6-3M sensor. Then a plasma-forming gas (Ar) is launched into the volume. A stabilized rectifier BC-22 is used as a plasma source. When a high voltage is applied to the electrodes, a gas breakdown occurs and a stratified glow discharge is established in the tube. The gas pressure was 0.23 Torr. The discharge current was 1.3 mA. This condition was chosen to determine the parameters of glow discharge plasma, which showed an interesting behavior of dust structures and was not observed in other similar experimental works [8–9]. The magnetic field is created by a Helmholtz coil. Induction of a magnetic field depends on the current flowing in the solenoid. With a current value of 1.9 A, the maximum magnetic field in the center of the solenoid is B = 32 mT. Probe and optical diagnostics were carried out in the center of the solenoid (see Figure 1).

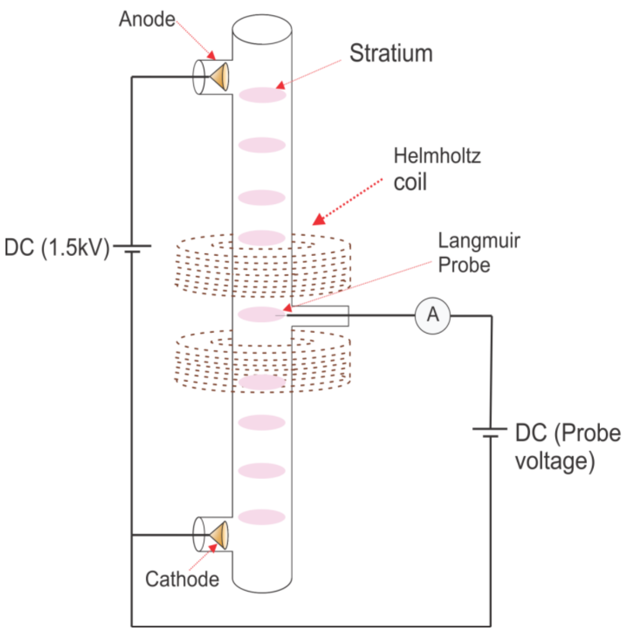

Figure 1 – Experimental setup for probe diagnostics.

The probe is made of nichrome wire with a diameter of 100 microns. To determine the electron temperature and concentration, as well as other plasma parameters, the current-voltage characteristic of the probe was used at different values of the magnetic field (Figure 2).

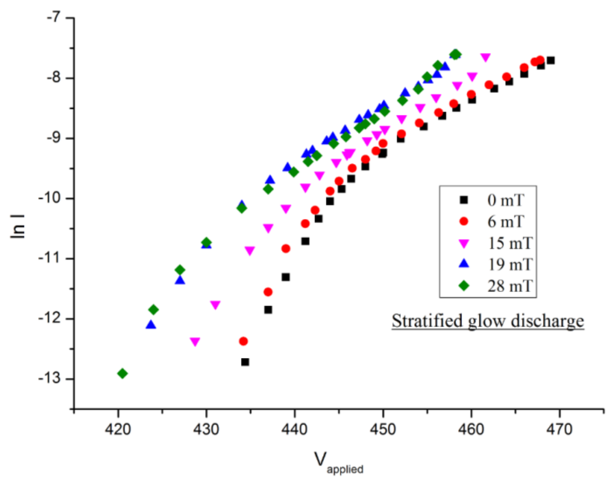

Figure 2 – Current-voltage characteristic (logarithmic scale) of the probe under different magnetic field conditions. (Experiment parameters: P=0.23torr, I=1.3 mA (Ar))

Detailed information of the probe and the method for determining the plasma parameters are shown in [15].

The results obtained using the probe are shown in Figure 2. As can be seen from the graph, a significant difference in the current – voltage characteristics of the probe does not appear at various magnetic field inductions. This suggests that the plasma parameters do not change at relatively weak values of the magnetic field. The main plasma parameters for various values of the magnetic field are shown in Figure 3. As can be seen from the table, the measurement was carried out at five points of the magnetic field (0; 6; 15; 19; 28 MT). As the magnetic field increases, it is seen that the plasma concentration increases, and the electron temperature decreases.

As the magnetic field increases, ambipolar diffusion decreases in a direction perpendicular to the magnetic field. The probability of collision of electrons with atoms increases, therefore, ionization also increases. As a result, electrons lose their energy more due to ionizing collisions during their drift due to the E × B effect. This leads to a decrease in the electron temperature from 4.1 to 3.45 eV. With increasing magnetic field, the floating potential takes on less negative values. At relatively high magnetic fields, electrons become more limited, and therefore the plasma potential becomes more negative in order to compensate for the rate of ion loss and maintain plasma quasi-neutrality.

In [11], the ion current density in the wall was measured. As the field increases, the ratio of the density on the wall to the density on the axis decreases with increasing magnetic field. In order for the number of electrons per unit length of the discharge to remain constant, the concentration must increase. It should be noted that we use direct current (direct current discharge) discharge.

During the experiment, spectroscopic diagnostics were carried out in which the spectra of optical radiation were obtained in a buffer plasma at various magnetic fields. The parameters of the experiment are similar to the parameters of the experiment that were established during probe diagnostics. Instead of a metal probe, a Solar S100 spectrometer is installed. The spectrometer is connected to the computer through a cable. Using software such as Spectrometer and OriginLab 8, the property of optical radiation was determined.

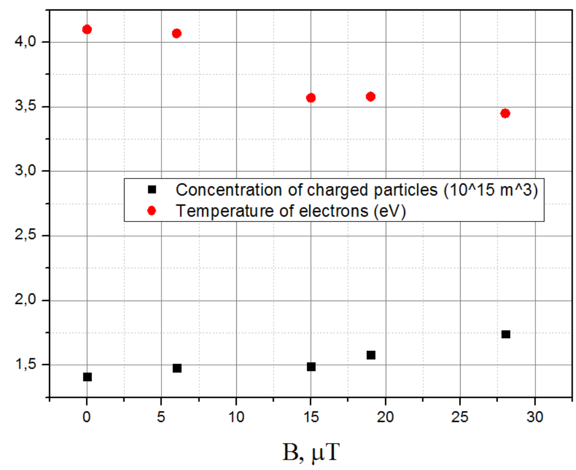

Figure 3 – The parameters of the stratified glow discharge in different conditions of the magnetic field. The results were obtained using plasma probe diagnostics. (Experiment parameters: P=0.23torr, I=1.3 mA (Ar))

Consider the spectrum of optical radiation in a buffer plasma. Figure 4 shows that intense spectral lines of argon (Ar) and copper (Cu) appear.

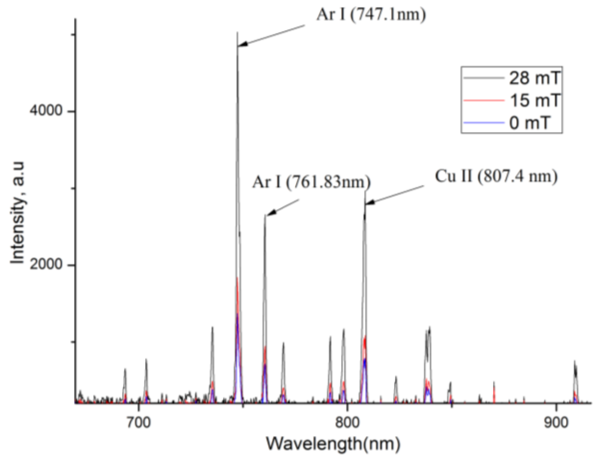

Figure 4 – Optical emission spectra of stratified glow discharge at different magnetic fields

This can be explained by the fact that argon is our plasma-forming gas. The electrode system is made of copper. With increasing magnetic field induction, the spectral line intensity increases. As mentioned above, with an increase in the magnetic field due to diffusion, the collision probability increases, which in turn leads to increased ionization. Perhaps the number of excited atoms increases, which leads to an increase in the discharge intensity.

Conclusion

Probe and spectroscopic diagnostics of a buffer gas discharge plasma were carried out under various conditions of an external magnetic field. The main parameters of the buffer (concentration and temperature of electrons) and complex plasma (distribution of dust particles near the probe) were obtained for various parameters of the external magnetic field.

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Literature review

10 G. Bonizzoni, E.Vassallo (2002, January). Plasma physics and technology; Industrial applications. Vacuum 64, p.327-336

11 Roshan Shishoo (1996, July) Plasma Treatment—Industrial Applications and Its Impact on the C&L Industry. Journal of Industrial Textiles 26, p 0026-10

12 Francis F. Chen (1998, June) Industrial applications of low-temperature plasma physics. Physics of Plasmas 2, 2164

13 U.Konopka, D.Samsonov, A.V. Ivlev, J.Goree, V.Steinberg, and G.Morfill (2000, February). Rigid and differential plasma crystal rotation induced by magnetic fields. Phys. Rev. E *61*, p.1890

14 P. K. Kaw, K. Nishikawa, and N. Sato (2002, February). Rotation in collisional strongly coupled dusty plasmas in a magnetic field. Phys. Plasmas *9*, p.387

15 V. Y. Karasev, A. I. Eikhvald, E. S. Dzlieva, and A. Y. Ivanov (2006). Rotational motion of dusty structures in glow discharge in longitudinal magnetic field. Phys. Rev *74*, p. 066403

16 M. M. Vasiliev, L. G. D'yachkov, S. N. Antipov, R. Huijink, O. F. Petrov, V. E. Fortov (2011, January). Dynamics of dust structures in a DC discharge under action of axial magnetic field. EPL *93*, p. 15001

17 E. Jr. Thomas, B. Lynch, U. Konopka, R. L. Merlino, and M. Rosenberg (2015, March). Observations of imposed ordered structures in a dusty plasma at high magnetic field. Phys. Plasmas *122*, pp. 030701

18 V. Y. Karasev, E. S. Dzlieva, S. I. Pavlov, L. Novikov, S. Maiorov (2018, April). The rotation of complex plasmas in a stratified glow discharge in the strong magnetic field. Plasma IEEE Transactions on Plasma Science *46*, p. 727-730

19 I. Langmuir, C. G. Found, A. F. Dittmer (1924, October). A new type of electric discharge: the streamer discharge. Science *31*, Vol. 60, Issue 1557, pp. 392-394.

20 R. J. Bickerton and A. von Engel (1956). Proc. Phys. Soc. (London) B69, 468

21 D. Bohm, in The Characteristics of Electrical Discharges in Magnetic Fields, A. Guthrie and R. K. Wakerling, Eds. (McGraw-Hill Book Company, New York, 1949), Chaps. 2 and 3.

22 Juan Sanmartin (1970, January) Theory of a Probe in a Strong Magnetic Field. Physics of Fluids 13, p 22-41

23 A. R. Abdirakhmanov , Zh. A. Moldabekov, S. K. Kodanova , M. K. Dosbolayev , and T. S. Ramazanov, , IEEE Transaction on Plasma Science (2019), doi 10.1109/TPS.2019.2906051

24 T. S. Ramazanov, N. K. Bastykova, Y. A. Ussenov, S. K. Kodanova, K. N. Dzhumagulova, and M. K. Dosbolayev (2012, February). The behavior of dust particles near Langmuir probe," Contrib. Plasma Phys., vol. 52, p. 110

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ДИАГНОСТИКА ТЛЕЮЩЕГО РАЗРЯДА ПОСТОЯННОГО ТОКА В ПРОДОЛЬНОМ МАГНИТНОМ ПОЛЕ

Аннотация. В статье представлены результаты по экспериментальному исследованию характеристик плазмы стратифицированного тлеющего разряда постоянного тока во внешнем магнитном поле. Одиночный зонд Ленгмюра и эмиссионный спектрометр использованы в качестве диагностики для оценки различных параметров плазмы. С помощью вольт-амперной характеристики плазмы стратифицированной тлеющего разряда определены основные параметры плазмы, таких как температура электронов, концентрация и плавающий потенциал при различной индукции магнитного поля. Увеличение величины магнитного поля приводит к увеличению концентрации частиц плазмы и снижению температуры электронов. Также с помощью спектроскопического метода установлено, что интенсивность спектральной линии стратифицированного тлеющего разряда возрастает с увеличением индукции магнитного поля. После литературного обзора работы Бикертона и Энгеля, которые с помощью зонда Ленгмюра провели детальное исследование положительной столбы в продольном магнитном поле, была сделана простая интерпретация для объяснения наших результатов эксперимента.

Ключевые слова: тлеющий разряд, плазма, магнитное поле, зонд Ленгмюра, спектрометр.

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МАГНИТ ӨРІСІНДЕГІ ТҰРАҚТЫ ТОКТЫ СОЛҒЫН РАЗРЯДҚА ЖҮРГІЗІЛГЕН ДИАГНОСТИКА

Аннотация. Бұл жұмыста тұрақты токты солғын разряд плазмасының сипаттамасын зерттеуге арналған эксперименттік нәтижелері көрсетілген. Электрлік Ленгмюр зонды және эмиссионды спектрометр көмегімен әртүрлі плазма параметрлерінде диагностика жүргізілді. Вольт-амперлік сипаттама көмегімен әртүрлі магнит өрісінің шамасындағы плазманың негізгі параметрлері, яғни электрон температурасы, концентрация анықталды. Магнит өрісінің шамасы плазма бөлшектерінің концентрациясының артуына және электрон температурасының төменденуіне әкеп соғатыны анықталды. Спектроскопиялық әдіс негізінде магнит өрісін арттырған кезде солғын разрядтың интенсивтілігі артатыны бақыланды. Алынған нәтижелерге сапалы интерпретация жүргізіліп, талқыланды.

Түйін сөздер: тұрақты токты газдық разряд, магнит өрісі, Ленгмюр зонды, спектроскопия