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Investigations of Electrical Discharge for Nitrogen (N2) and Hydrogen (H2) Gases

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Abstract: *The characteristics of the glow discharge, has been studied of nitrogen and hydrogen gases, at different gas pressures and discharge current. The discharge cell consists of two movable parallel cupper electrodes of 5 cm diameter and gap distance of 3 cm between the two electrodes enclosed in Pyrex glass tube of 7.5 cm diameter. The I-V curve of discharge and V-Pd curve (Paschen's law) of glow discharge were measured. The first (η) and secondary (ω/α) ionization coefficients were calculated. The electron temperature (Te) and the ion density (Ni) were estimated by using double probes method at different pressures and discharge currents. The plasma frequency and Debye shielding were also calculated.*

Keywords: *DC Plasma, gas discharge, electrical discharge, plasma diagnostic.*

Introduction

Plasmas are ionized gases. Hence, they consist of positive and negative ions and electrons, as well as neutral species. The ionization degree can vary from 100% (fully ionized gases) to very low values (e.g. 10^{4}–10^{6}; partially ionized gases). Mixtures of nitrogen and hydrogen are often used in thermal plasma applications. For example, a mixture of 95% nitrogen and 5% hydrogen by volume is a standard gas, known as F5, for plasma cutting [1]. Arc jet thrusters, which are used for satellite propulsion, typically use hydrazine (N_2H_4) or ammonia (NH_3) [1,2] . Ammonia is widely used in the synthesis of metal nitrides, such as ultrafine particles and nanoparticles of aluminum nitride [4,5,6], titanium nitride [7] and silicon nitride [8]. Measurements of gas temperature profiles are known for low-pressure discharge tubes [9]. The electron temperature and electron number density were calculating in present work using the double probe method.The Langmuir probe which was first proposed by Irving Langmuir [10] in 1920 is one of the oldest plasma diagnostic tools [11].

Experimental set up

The experimental setup of the present plasma consists of three main parts, a discharge cell, an electrical discharge circuit and the high vacuum system, as shown in fig. 1. The discharge cell consists of two movable parallel electrodes enclosed in a vacuum vessel. Each electrode consists of a disc of copper of 5 cm diameter coated with Perspex to prevent discharge from the back of the electrode. The vessel consists of a cylindrical Perspex tube with outside diameter 7.5 cm and length 12 cm. It has two open holes: one is connected to the vacuum system and the other to the used gases. The electrical discharge circuit consists of a DC power supply (high-voltage power supply), which operates in the range of0–2000V, 200 mA. The discharge current in the circuit was measured by an SK-6160 digital multi-meter, and the voltage on the discharge tube was measured by a KIT-2704B digital multi-meter. The high vacuum system consists of a two-stage Edward rotary pump, a diffusion pump and vacuum gauges.

The vacuum gauge (Pirani-Pinning 1005) consists of two heads, the first is Pirani (PRM 10 K) for standard pressure gauge of range 760 to 10^{-3} Torr and the second is Pinning model(CO25K)ofrange10^{-3}–10^{-7}Torr.

Results and discussion

Measurement of Paschen's curves indicates that, the minimum breakdown potential (V_{Br}) in the H_2 gas discharge is lower than that in N_2 gas discharge as shown in fig. 2. This due to the ionization potential of H_2 gas (13.53 eV) is lower than of N_2 gas (14.53 eV). Also it is shown that the minimum breakdown potential takes place at Pd =0.5 Torr.cm in nitrogen (N_2) gas and takes place at Pd =1.6 Torr.cm in hydrogen (H_2) gas. fig.(3, 4) show the I-V characteristic curves of the nitrogen (N_2) and hydrogen (H_2) gases and their gas mixtures 10 % - 40 % for H_2 gas. These measurements have been carried out in the range 1 to10 mA. These curves confirmed that, the I-V curves in the range 1 to 10 mA were in the abnormal glow discharge region. The figures also show the increase of the discharge power with increasing the breakdown voltage for hydrogen, nitrogen and their mixture.

The first ionization coefficient (η) has been deduced by using empirical equation in the range of E/P from 235 to 535 V/Torr.cm for nitrogen (N_2) and in the range of E/P from 64 to 557 V/Torr.cm for hydrogen (H_2) as shown in fig. 5a. The values of η has maximum value equal to 0.0136 V-1 at E/P = 129.125 V/Torr.cm for H_2 gas, while it equal to 0.0129 V-1 at E/P = 337.36 V/Torr.cm for N_2 gas. The results of secondary ionization coefficient (ω/α) have been shown in fig.5 b. The values of ω/α for hydrogen (H_2) gas is higher than that for nitrogen (N_2) gas, this due to the efficiency of electron emission from the cathode by the incidence of ions which increases by decreasing ion mass. The values of ω/α increase from 0.0206 to 0.0922 at E/P increases from 200 V/Torr.cm to 555 V/Torr.cm for H_2 gas, while for N_2 gas it increases from 0.0036 to 0.0234 at E/P varied fig. 6 a, b show the floating potential of nitrogen and hydrogen gas with the distance at three value of the discharge current. The floating potential has maximum value close to the cathode and decrease with increasing the distance to the anode. The electron temperature of the nitrogen and hydrogen plasma (T_e) was calculated. It has been found that in the range of 2.32 to 4.56 eV when the gas pressure varied from 0.46 to 0.15 Torr and discharge current changed from 4 to 10 mA for nitrogen gas (N_2) gas. While T_e in the range of 3.45 to 6.78 eV when the gas pressure varied from 1 to 0.4 Torr and discharge current changed from 4 to 10 mA for hydrogen.

The electron number density ne of plasma of nitrogen hydrogen shown in fig 8a, b. It has been found that the nein the range of $2.3x10^{14}$ to $11.7x10^{14}$ m^{-3} when the gas pressure varied from 0.15 to 0.46 Torr and discharge current changed from 4 to 10 mA for nitrogen (N_2) gas. While it is in the range of $0.57x10^{14}$ to $4.7x10^{14}$ m^{-3} when the gas pressure varied from 0.4 to 1 Torr and discharge current changed from 4 to 10 mA for hydrogen (H_2) gas. n_e increases by increasing the gas pressure; this has been attributed to the increase of the ionizing collisions. Also the T_e and ne have been determined as function of hydrogen gas percentage 10 % to 40 % in the nitrogen gas at different discharge currents as shown in fig 7c and fig. 8c. It has found that, T_e increases when the H_2 gas percentage increases form 10 % to 40 % in the mixture N_2-H_2 gas, this attributed to the electrons uses less energy in the ionization of H_2 gas E_i =13.6 eV than that in the ionization of N_2 gas E_i =14.4 eV.

Conclusion

The Te has been found in the 2.32 to 4.56 eV when the gas pressure varied from 0.46 to 0.15 Torr and discharge current changed from 4 to 10 mA for nitrogen gas (N_2) gas. While Te in the range 3.45 to 6.78 eV when the gas pressure varied from 1 to 0.4 Torr and discharge current changed from 4 to 10 mA for hydrogen (H_2) gas. ne has been found in the range of $2.3x10^{14}$ to $11.7x10^{14}$ m^{-3} when the gas pressure varied from 0.15 to 0.46 Torr and discharge current changed from 4 to 10 mA for nitrogen (N_2) gas. While ne in the range $0.57x10^{14}$ to $4.7x10^{14}$ m^{-3} when the gas pressure varied from 0.4 to 1 Torr and discharge current changed from 4 to 10 mA for hydrogen (H_2) gas.neincreases by increasing the gas pressure; this has been attributed to the increase of the ionizing collisions. Te and ne have been determined as function of hydrogen gas percentage 10 % to 40 % in the nitrogen gas at different discharge currents. It has found that, T_e increases when the H_2 gas percentage increases form 10 % to 40 % in the mixture N_2-H_2 gas, this attributed to the electrons uses less energy in the ionization of H_2 gas E_i =13.6 eV than that in the ionization of N_2 gas E_i =14.4eV

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