Glow discharge mixture of Ar/He

P. G. Reyes[1], C. Torres[1], A. Gómez[1], J. Torres[1], H. Martínez[2], J. Vergara[3]

[1] *Laboratorio de Física Avanzada, Facultad de Ciencias, Universidad Autónoma del Estado de México, C.P. 50000, Toluca, Estado de México, México, pgrr@uaemex.mx*

[2] *Laboratorio de Espectroscopia, Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, A.P. 48 3, C.P. 62251, Cuernavaca, Morelos, México.*

[3] *Instituto Profesional de la Región Oriente, Universidad Autónoma del Estado de Morelos, C.P. 62715, Xalostoc, Morelos, México.*

Glow discharge mixture of Ar/He at a pressure of 266.66 Pa is experimentally investigated by optical emission spectroscopy and double Langmuir probe at various mixture compositions. The species observed were He I and Ar I. The electron temperature was found to be less than 10 eV, and the ion density in the order of 10^{10} cm^{-3}.

Keywords: Glow discharge, gas mixture, Grotrian diagrams.

1 INTRODUCTION

The low-pressure He glow discharge and its mixtures with rare gases play an important role in sputtering processes [1]. An attempt has been made to substitute part of the Ar process gas by He. Since He is much lighter than Ar, which reduces the energy loss in the interaction process and therefore increases their impinging energy. The atoms in the excited state are capable of emitting radiation when electrons make a transition from a higher to a lower quantum state, emitting a photon; the photon energy is equal to the difference of energy between the two atomic states. That is spontaneous emission, which is represented as: $A^* \rightarrow A^+ + h\nu$, where the asterisk indicates an excited state. As each atom returns to a lower energy state, energy is emitted in the amount of the difference between the energy levels of the transition frequency. The set of all frequencies is the emission spectra of the species. The well-defined wavelengths emitted by the atoms are known as spectral lines [2, 3]. Photon emitters may be atoms or ions in an excited state. The particles present in the glow discharge mixture of Ar/He are: Ar I, He I, neutral atoms and free electrons, the resulting transitions of excited and ionized atoms fall in the visible and in the infrared range. The Ar I present transitions with change and without change of core, the energy to produce the transition with core change is higher than needed without change. The transitions depend on the total orientation of the nuclear spin. Helium excited atoms present known optical transitions as single and triplet. Grotrian diagrams are useful for visualizing the allowed transitions between energy levels of atoms. In these diagrams the energy is indicated in the ordinate and the angular momentum quantum level in the abscissa. Not all possible transitions are allowed, this is a consequence of the selection rule that allows only transitions between levels in which the orbital angular momentum of this changes is $\Delta l = \pm 1$ [4, 5, 6]. In the present work, glow discharge mixture of Ar/He is experimentally investigated by optical emission spectroscopy and double Langmuir probe at various mixture compositions.

2 EXPERIMENTAL SYSTEM

The schematic diagram of the experimental setup is described in previous work [7, 8]. The discharge cell consists of two movable parallel electrodes enclosed in a stainless steel vacuum chamber. The two electrodes were made of copper disc of 2.5 cm of diameter with 20 mm gap spacing. The plasma chamber had a volume of 1.16×10^{-2} m^3 and it was pumped down by a vacuum system to a base pressure of 1.33×10^{-4} Pa (Turbomolecular pump Alcatel ATP80 and mechanical pump Varian DS302). A continuous dynamic flow of Ar–He gas mixture (ultra-pure gases, Praxair 99.99%) was let in the system through needle valves at the desired pressures. While keeping the total pressure of 266.66 Pa, the concentration of Ar gas in the mixture was done by changing the He partial pressure (measured by a capacitive barometer MKS, model 622A). The total pressure of Ar/He Plasma discharge is constant during the experiments. To keep a current constant of 10 mA (measured by a digital Fluke multimeter model 8846A), independent of the gas mixture, a ballast resistance (R = 5 kΩ) was used, it was done by changing the power supply voltage (Spellman SA4) between to 2.7 W (for 100% of Ar) and 3.0 W (for 100% of He). A lateral flange was used to monitor the glow discharge by optical emission spectroscopy; the spectrum (200–1100 nm) was measured using a spectrometer Ocean Optics HR4000CG-UV-NIR (resolution of 0.75 nm FWHM). The signal has been corrected taking into the account the spectral sensitivity of the spectrometer. The probe (-60 V to +60 V) was aligned parallel to the cylindrical axis of the discharge tube and can be moved in the forward and backward directions in the center of the plasma by using a manual micrometer motion feed through.

3 RESULTS

From the measured experimental current-voltage characteristic curve obtained by double Langmuir probe, it is possible to get electron temperature (T_e) and ion density (n_i) [7]. In Figure 1, the electron temperature measured at different argon percentages in the gas mixture are shown.

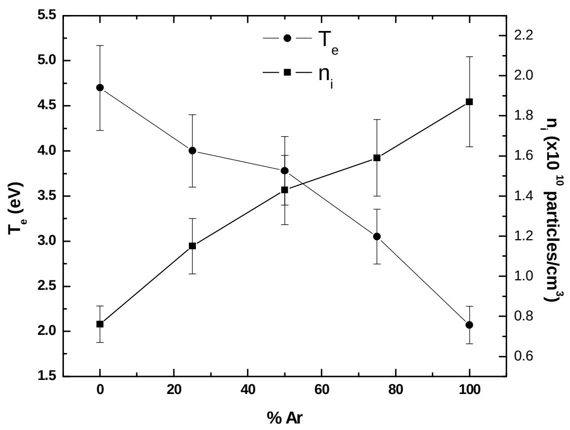

Fig.1: T_e and n_i as a function of Ar percentage

It can see from Figure 1 that the electron temperature displays a slightly decreasing behavior with Ar addition. The ion densities obtained as a function of argon percentage in the mixture are displayed in Figure 1. Note that, the ion density shows an increasing behavior with the argon percentage. A typical OES measurement for a mixture of 25 %Ar/75% He at a total pressure of 266.66 Pa is displayed in Figure 2, showing the intensities of all observed emission lines.

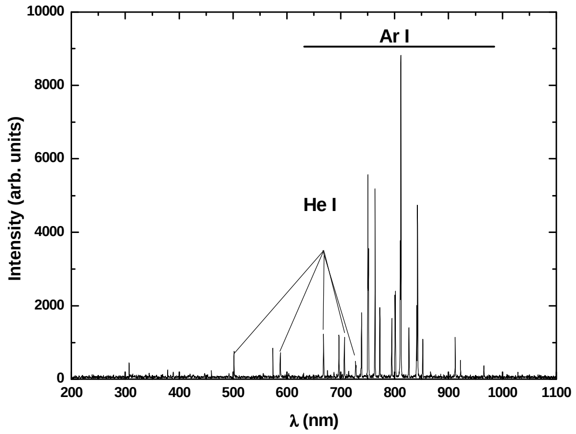

Fig.2: Emission spectra measurements of the mixture 25%Ar/75%He

This allows the analysis of the most luminous area, which corresponds to the negative glow near the cathode dark space. Only the most intense spectral lines of the Ar I and He I within the 200-1100 nm range are quoted. From figure 2, the Ar I (811.80 nm) line is the most intense line. This analysis was performed for all mixtures reported in this work. It observed the same lines but with different intensities depending on the Ar concentration.

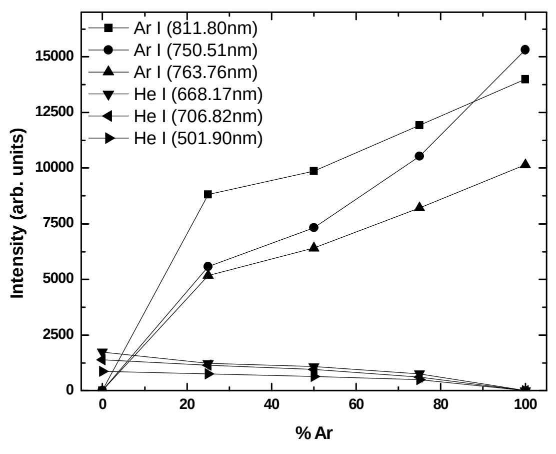

Fig.3: Intensity of principal peaks of the mixture as a function of Ar percentage

Figure 3 also shows the variation of spectral intensities of the lines Ar I and He I as a function of Ar percentage. It observes that the He I lines always have the lowest intensity. The electronic configuration of the Ar is $1s^2 2s^2 2p^6 3s^2 3p^6$, with the K and L closed layer. Optically active electrons are 6, and they are in the closed sublayer $3p^6$, whose quantum numbers are $n=3$, $l=1$, $m_l=-1, 0, 1$, $m_s=-1/2, 1/2$. The six electrons have the same probability of accessing higher energy state, for a core $3p^5$ we have S = ½, L = 0, 1, and multiplicity 2. In accordance with the rules of Hund combination that provides the state base kernel is L = 1, where there is a doublet of the level.

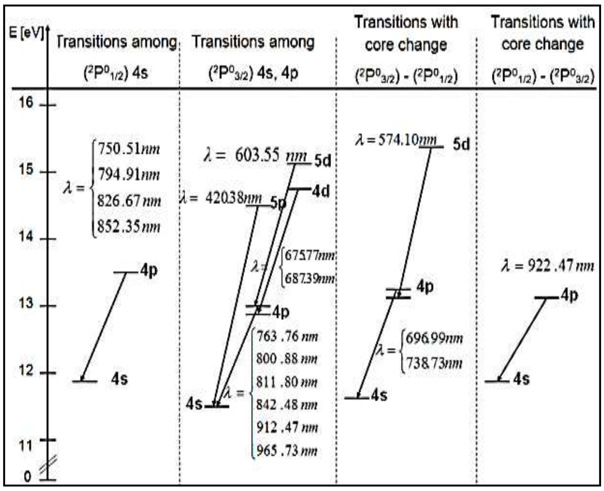

Fig. 4: Grotrian diagrams of Ar atom, with core $3p^5$ and state based L = 1

Figure 4 shows the electronic transitions that occur most often in the glow discharge. The states are doublets and are grouped into transitions with change in the core $3p^5[^2P_{3/2}]$-$3p^5[^2P_{1/2}]$, $3p^5[^2P_{1/2}]$-$3p^5[^2P_{3/2}]$, and without change in the core $3p^5[^2P_{3/2}]$, $3p^5[^2P_{1/2}]$.

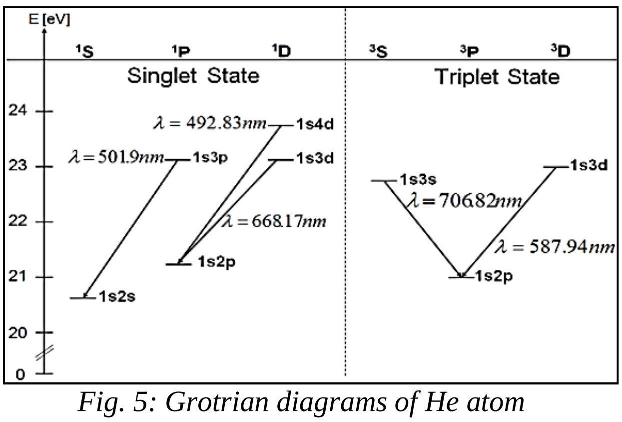

Fig. 5: Grotrian diagrams of He atom

The most probable transitions that happen are without core change, due to that the energy is less than the required with core change. The transitions depend on the total orientation of the nuclear spin. A splitting fine structure 4p is observed, which it causes that the state transition involved becomes a doublet, whose energy separation is about 0.1687 eV for transition with no change in the core and 0.1469 eV transition for change in the core. In figure 5 it is possible to observe the types of electronic transitions that occur in the discharge, for helium.

4 CONCLUSIONS

The glow discharge of an Ar-He mixture was studied. The principal lines observed were of He I and Ar I. The electron temperature was found in the range of 2.07 to 4.70 eV, and the ion concentration in the order of 10^{10} cm^{-3}. The electron temperature displays an decreasing behavior as a function of the increase in the Ar concentration, whereas the ion density clearly increased. This behavior may be explained because if Argon concentration increases in the mixture, there are more electrons in the system which leads to an increase in the density of generated ions, this increase requires lower electron temperatures to provide the required ionization rate.

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