Measurements of electron temperature, and ion density, in a mixture of $O_2$ and Ar plasma

P. G. Reyes$^1$, E. Mendez$^1$, D. Osorio-González$^1$, F. Castillo$^2$, H. Martínez$^3$.

$^1$Facultad de Ciencias, Universidad Autónoma del Estado de México, Toluca, Estado de México, México.
$^2$Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Apartado Postal 70543, C. P. 04510, México D. F., México.
$^3$Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México, Apartado Postal 48-3, C. P. 62251, Cuernavaca, Morelos, México.

E-mail: pgrr@uamex.mx

Abstract. Optical emission spectroscopy was applied for plasma characterization of a gas mixture glow discharge of $O_2$ and Ar at a total pressure of 1.0 Torr, power of 150 W, and with 40 l/min flow rate of gases. The main diagnostic techniques applied to determine the plasma parameters were optical and probe diagnostics. We study the dependence of the electron density and temperature as a function of the relative $O_2$ concentration. The emission bands and lines were measured using a monochromator in the wavelength range from 200 to 1000 nm. We also study the dependence of the principal band intensities observed as the relative $O_2$ concentration was increasing from 0 to 100 % of the mixture.

1. Introduction

The electron temperature and the electron density are important parameters that describe the operating conditions of low-pressure discharges. Techniques based on optical emission are commonly used to measure those parameters [1–3]. These techniques are usually effective, convenient to use, and non-intrusive. The knowledge of the plasma characteristics is required to understand fully the effects of the different physical processes taking place in the plasma and to deduce from them its properties. These diagnostics includes electrical probes and optical spectroscopy. Usually, only probes are used for measuring the density and temperature of electrons and ions [4,5].

On the other hand, the glow discharge in pure oxygen and its mixture with different rare or molecular gases in pressure range of several Torr can be utilized in miscellaneous applications (e.g. in sterilization, deposition of thin layers, lasers, etc.). The study of the oxygen properties in this pressure range is therefore a very important topic.

With respect to contemporary trends in the application of the plasmas of oxygen and its mixtures a complex study for medium pressures has been started. It is known that the material of the tube wall influences oxygen discharges, namely by the occurrence of surface re-association processes leading to the loss of oxygen atoms, which is important in a lot of applications [6,7].

However, since, there are no systematic studies undertaken to monitor by plasma emission spectroscopy the active species generated in the glow discharge, therefore, it is the aim of the present work to perform analysis of glow discharge by electrical and optical characterization employing pulsed plasma of a mixture of $O_2$ and Ar gases as a function of the relative $O_2$ percentage.
2. Experimental details
A DC glow discharge plasma in a mixture of Ar and O₂ gases was generated in a plasma apparatus of the Laboratorio de Física Avanzada, Facultad de Ciencias, UAEM. This experiment is described in detail in [8,9,10]. The reactor consisted of two copper circular plane electrodes, 3 mm thick and 30 mm in diameter. The electrodes are positioned at the centre of the reaction chamber with 20 mm gap spacing. The gas was introduced into the reaction chamber through the lateral flange. A lateral flange was used for the pressure sensor (MKS, model 622A). The plasma chamber was initially evacuated to a base pressure of $1 \times 10^{-6}$ Torr with a turbo-molecular pump (Alcatel model ATP80) backed by a mechanical pump (Varian D5302, model 949-9325) and purged with the working gas at a pressure of 4.0 Torr. Ultrahigh pure gases (Praxair 99.999 %) were used in the course of the measurements. In another flange, a quartz window was used to monitor the active species generated in the glow discharge by plasma emission spectroscopy; this was performed using a ACTON (SpectraPro 2150i) monochromator equipped with a 1200 lines mm⁻¹ holographic grating. The spectrum (200-900 nm) of the emission cell was recorded with a photo multiplier (Hamamatsu model PD471). The wavelength scan interval was 0.1 nm and the dwell time was 500 ms. The data was obtained in a single accumulation with a 0.5 s integration time. The DC plasma was produced in a mixture of Ar and O₂ gases at a pressure of 1.0 Torr. The discharge power supply (Bertan Serie 105) was maintained at an output of 375 V and a current of 0.4 A (150 W), which was measured using a digital Fluke multimeter model 8864. Langmuir probes are commonly used as a diagnostic tool for the determination of plasma parameters, such as electron temperature and ion density. The double Langmuir probe employed in this work consists of two 33 cm length and 0.2 mm radius tungsten wires, which were located inside a 31 cm glass capillary. The wire tips were extended 2 mm beyond the glass capillary.

3. RESULTS AND DISCUSSION

3.1. Electrical measurements
The evaluation algorithm for obtaining the electron temperature was run in the following manner. First the probe characteristic curve is differentiated two times and then smoothed. Smoothing was performed following the procedure described by Savitzky and Golay [11]. For each of the obtained current-voltage characteristic curve at each percentage of O₂, the electron temperature, $T_e$, is calculated using the equation given in [12]. Following that, a theoretical curve is fitted to the entire measured experimental current-voltage characteristic data curve as given by [13,14] by adjusting only the ion density, $n_i$.

![Figure 1](image1.png)  
**Figure 1.** Electron temperature as a function of O₂ percentage.

![Figure 2](image2.png)  
**Figure 2.** Ion density as a function of O₂ percentage.
Figure 1 shows the electron temperature measured at different percentage values of O\textsubscript{2} in the gas mixture. It shows an increasing pattern. This increasing pattern is rather slow, starting at a 6.8 eV electron temperature for 0 % O\textsubscript{2} and reaching 12.0 eV for 80 % of O\textsubscript{2} in the mixture. Then the electron temperature decreases reaching a value of 10.4 eV at 100 % O\textsubscript{2}.

The correlation between the variation of the electron temperature and the relative number of oxygen atoms should be pointed out. Electron impact dissociation is the main source channel for ground state oxygen atoms for the present conditions. Decreasing the Ar amount results in an increase of $T_e$, thus in the high-energy part of the electron distribution function and, consequently, in the rate of molecular dissociation. Similarly, the measured ion density as a function of the O\textsubscript{2} percentage is shown in figure 2. Note that, compared with electron temperature, the ion density clearly decreased.

3.2. Optical Emission Spectroscopy Analysis

A typical spectroscopic emission measurement of the mixture O\textsubscript{2}-Ar glow discharge plasma in a pressure range between 0.0 and 1.0 Torr in percentage of O\textsubscript{2} is displayed in figure 3. This allowed analysis of the most luminous area, which corresponds to the negative glow near the cathode dark space [15]. Considering the population of O\textsubscript{3}, O\textsubscript{2}, O\textsubscript{2}\textsuperscript{+}, O, Ar and Ar\textsuperscript{+} emission bands and lines to be the most abundant, this would imply that the main process for the production of these species is the electron impact dissociation or ionization excitation. The intensities of six main emission bands from the mixture O\textsubscript{2}-Ar glow-discharge plasma at 0.4 A discharge current is plotted in figure 4 as function of the percentage of oxygen.

The interplay between the formation and the destruction processes is rather complicated, it depends on many parameters, and a full kinetic model is required in order to get a deeper insight in understanding the mechanisms resulting in the formation of excited O\textsubscript{3}, O\textsubscript{2}, O\textsubscript{2}\textsuperscript{+}, O, Ar, and Ar\textsuperscript{+}. Within the experimental parameters of the plasma studied in this work, the plasma generated under each parameters of power and pressure reach an equilibrium at which the above-mentioned radicals are the dominant species.

From figure 4, the intensity of 777.34 nm O displays an increasing behavior as % O\textsubscript{2} increases, while the emission bands and lines (421.2 nm O\textsubscript{2}, 439.8 nm O\textsubscript{2}\textsuperscript{+}, and 473.7 nm Ar\textsuperscript{+}) show a decreasing behavior as % O\textsubscript{2} increases. The emission band (316.4 nm O\textsubscript{3}) and line (810.9 nm Ar) display a strong decreasing of the intensity from 0.2 to 0.4 % O\textsubscript{2}, and then display an almost constant behavior as a function of % O\textsubscript{2}.

**Figure 3.** Spectrum emission measurement of the mixture O\textsubscript{2}-Ar.

**Figure 4.** Abundance of elements as function of O\textsubscript{2}.
The intensities observed in this work for these species could indicate that although they were produced in the plasma, they are initially in their excited states and decay radiatively or via collisions in reactions with other species.

The behavior of the emission intensities may be correlated to the changes in the ion density and electron temperature. If the pressure is increased, there are more products atoms than gas-phase molecules (fewer reactions, more products), which produced an increment in the ion density (see figure 2) and that increment in the ion density requires a lower electron temperatures (see figure 1) to provide the required ionization rate.

4. Conclusions
The experimental study mainly focused on measurements of electron temperature, ion density and optical characterization of a gas mixture glow discharge of O$_2$ and Ar at total pressure of 1.0 Torr, a power of 150 W, and a flow of 16.5 l/min. The emission from the DC plasma was scanned in the range of 200–900 nm. It was found to consist of lines and bands corresponding to O$_3$, O$_2$, O$_2^+$, O, Ar and Ar$^+$. The electron temperature and ion density were determined by a double Langmuir probe. The electron temperature was found in a range from 6.8 eV to 12.0 eV, and the electron concentration in the order of $10^{10}$ cm$^{-3}$. The intensity of 777.34 nm O displays an increasing behavior as % O$_2$ increases, while the emission bands and lines (421.2 nm O$_2$, 439.8 nm O$_2^+$, and 473.7 nm Ar$^+$) show a decreasing behavior as % O$_2$ increases. The emission band (316.4 nm O$_3$) and the line (810.9 nm Ar) display a strong decreasing of the intensity from 0.2 to 0.4 % O$_2$, and then display an almost constant behavior as a function of % O$_2$.

Acknowledgments
The authors are thankful to A. Bustos, A. González, R. Bustos (ICF-UNAM), and José Rangel (ICN-UNAM) for technical assistance. This research was supported by UAEM 2648/2008U y 2362/2006U.

References
[1] Donnelly V M 2004 *J. Phys. D: Appl. Phys.* 37 R217
[2] Zhu X M and Pu V K 2007 *J. Phys. D: Appl. Phys.* 40 2533
[3] Garamoon A A, Samir A, Elakshar F F, Nosair A and Kutp E F 2007 *IEEE T. Plasma Sci.* 35 1
[4] Gudmundsson J T, Takashi Kimura, Lieberman M A 1999 *Plasma Sources Sci. Technol.* 8 22–30
[5] Xi-Ming Zhu and Yi-Kang Pu 2007 *J. Phys. D: Appl. Phys.* 40 5202–5
[6] Schmiedl L, Kaňka A and Hrachová V 2006 *Czech. J. Phys.* 56 B1040–4
[7] Aflori M, Dimitriu D G and Dorohoi D 2004 31th EPS Conf. on Plasma Phys. (London, UK) ECA 28G P–4.057
[8] Martinez H and Yousiif F B 2008 *Eur. Phys. J. D* 46 493
[9] Martinez H and Castillo F *Phys. Stat. Sol. C* 5 (4) 897–900
[10] Reyes P G, Mendez E F, Osorio-Gonzalez D, Castillo F and Martinez H 2008 *Phys. Stat. Sol. C* 5 (4) 907
[11] Savitzky A and Golay M J E 1964 *Anal. Chem.* 36 1627
[12] Amemiya H 1988 *Japan J. Appl. Phys.* 27 694
[13] Swift J D and Schwar J R 1969 *Electric Probes for Plasma Diagnostics* (New York: Iliffe Books Ltd)
[14] Brockhaus A, Brochhardt C and Engemenn J 1994 *Plasma Sources Sci. Technol.* 3 539
[15] Pearse R W B and Gaydon A G 1976 in *The identification of molecular spectra* (Cambridge: University Printing House)