Revista Brasileira de Aplicações de Vácuo, v. 22, n. 2, 45-49, 2003.

CHARACTERIZATION OF AN INDUCTIVELY COUPLED ARGON PLASMA

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Keywords: inductively coupled plasma; E-H mode transition; optical emission spectroscopy.

ABSTRACT

In this work inductively coupled argon plasmas, generated by an external coil, are studied in the low pressure range. The E mode to H mode transition is observed and analysed using the DC self bias potential and the luminous intensities of three argon spectral lines, measured by optical emission spectroscopy. According to our results, during the mode transition the electron density of the plasma suddenly increases, and the average electron energy is higher in the E mode than in the H mode.

1. INTRODUCTION

Inductively coupled plasmas (ICPs) were first used in high-pressure plasma applications such as spectra-chemical analysis, crystal growth and plasma deposition. Only recently, ICPs have also been applied for low pressure plasma assisted applications such as plasma etching and plasma surface modification. The great interest in ICPs is because these systems provide high density plasmas and that they allow independent control of ion energy and plasma density. Therefore, Inductively Coupled Plasmas have been studied more intensively the last years. However, several ICP characteristics are not yet well understood [1-3].
Many authors have reported that, when increasing the power to the inductive source, a sudden plasma density jump occurs, which seems to be characteristic of ICPs, and associated it to a transition of the operation mode. In the literature we find that if low power is applied to the inductive source, the plasma is capacitively coupled but, if high power is applied, the plasma is inductively coupled (by means of the azimuthally induced RF electric field). These two modes are commonly called E-mode (capacitive) and H-mode (inductive) [1-3,5].
In this paper, results are shown that were obtained with optical emission spectroscopy and through measurement of the DC self bias voltage, for argon plasmas. The attention was focussed on the effect of coil and electrode power on the analysed intensities, in order to better observe and characterize the mode jump.

2. EXPERIMENTAL

For this work, a planar coil ICP reactor was used, shown in figure 1. The cathode had a diameter of 150 mm, which was powered by an RF generator (at 13.56 MHz) through a matching network. In this matching circuit, there was a blocking capacitor, enabling the measurement of the DC bias voltage. In the RF power line, next to the cathode, a voltage probe was inserted, in order to monitor the DC bias voltage and the DC plasma potential (if one assumes that the DC value of the plasma potential equals half of the maximum value of the voltage on the cathode).
Another RF power supply (also at 13.56 MHz) was connected through a similar matching network to a three-turn water cooled planar aluminium coil (approximately six inches in diameter) placed opposite to the cathode, outside the reactor, isolated by a dielectric, tempered borosilicate glass plate.
Thus the coil power (determining mainly the plasma density) and the cathode power (determining mainly the ion energy) were independently controlled.
Optical emission spectroscopy was used to measure emission intensities from the plasma, using an optical fibre placed close to a glass window on the reactor sidewall.

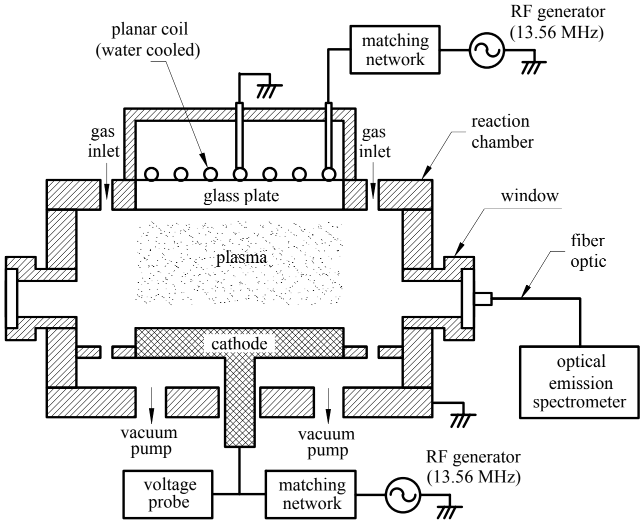

Figure 1 – Schematic diagram of the ICP reactor.

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For this paper, argon plasmas were analysed at three different pressures (10 mTorr, 100 mTorr and 200 mTorr), with a constant flow rate of 10 sccm. For each pressure, the coil power and the electrode power were varied from 0 to 200 W. The DC bias voltage, DC plasma potential and intensities of three Ar spectral lines, namely 750.4 nm, 811.5 nm and 842.5 nm were measured. The purpose of measuring these spectral lines was to use their intensities as an indication of electron density and electron energy distribution of the plasma. The energy necessary to excite electrons is highest for 750.4 nm emission, followed by the 811.5 nm emission, while for the 842.5 nm emission, least energy is necessary for the electron excitation. Hence, relative changes of emission intensities may indicate changes in the electron energy distribution function of the plasmas [1].

We neglected, however, the fact that for low-pressure plasmas there is usually a rather significant spatial variation of the electron energy distribution function (argon emission spectra, for instance, are sensitive to these alterations). However, since we are more concerned with trends and qualitative issues than with quantitative results, this problem does not influence the results published in this paper [4].

3. RESULTS AND DISCUSSIONS

Figures 2, 3 and 4 show results obtained for the DC bias voltage for pressures of 10 mTorr, 100 mTorr and 200 mTorr, respectively, as a function of coil power, with the cathode power as parameter.

The DC bias voltage became more negative with increasing cathode power, but became more positive (even higher than 0 V) with coil power. In fact, one may observe that around 100 W of coil power, the increase of the DC bias voltage was more pronounced than at other coil powers. For 10 mTorr plasmas, this DC bias voltage change – or this DC voltage jump - was largest between 110 W and 150 W of coil power; for both higher pressures, it was so between 50 and 100 W coil power (except for the 0 W electrode power).

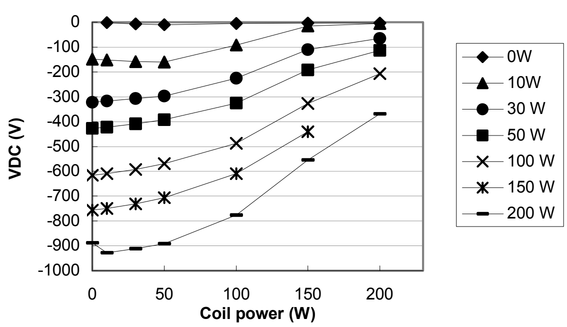


Figure 2 - DC bias potential vs. coil power, with cathode power as a parameter - Ar plasma at 10 mTorr.

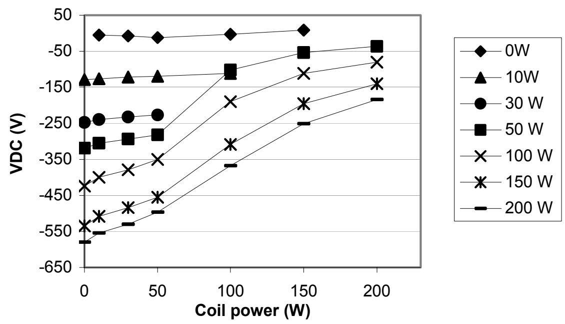


Figure 3 - DC bias potential vs. coil power, with cathode power as parameter – Ar plasma at 100 mTorr.

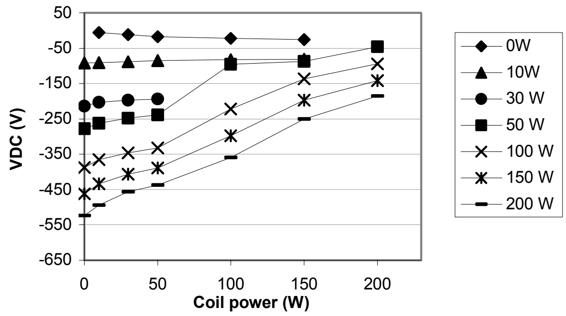


Figure 4 - DC bias potential vs. coil power, with cathode power as parameter - Ar plasma at 200 mTorr.

Figures 5 to 13 show the intensities of the three observed spectral lines for the three analysed pressures. It is important to state again that the observed intensities are not a direct measure of the electron density in the plasma, but rather an indication of it, so we are more concerned with the trends than with the value of the intensities itself.

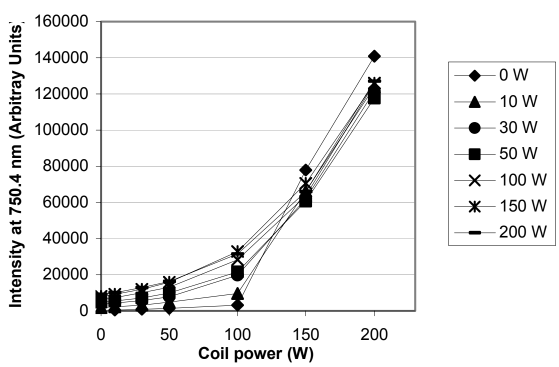


Figure 5 - Emission intensity at 750.4 nm vs. coil power, with cathode power as a parameter – Ar plasma at 10 mTorr.

Comparing these figures (5 to 13), one notes that as the pressure was increased, the emission intensities increased, as could be expected within the investigated pressure range. The figures show that certainly for high coil powers, the coil power was much more important than the electrode power.

From figures 2 to 13 one can readily observe that for the same coil power, at which the DC bias potential jumps, the intensities also presented a sharp increase. This is a clear indication that there was a correlation between the DC bias potential and the plasma density.

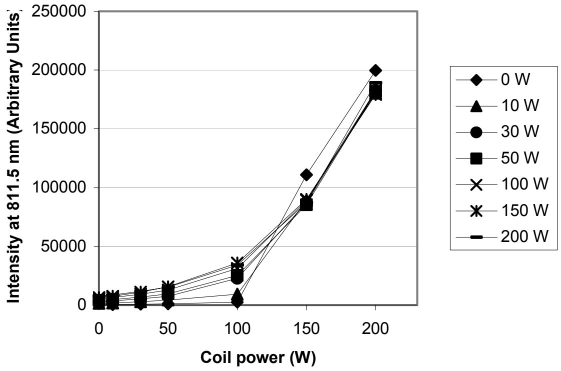


Figure 6 - Emission intensity at 811.5 nm vs. coil power, with cathode power as a parameter - Ar plasma at 10 mTorr.

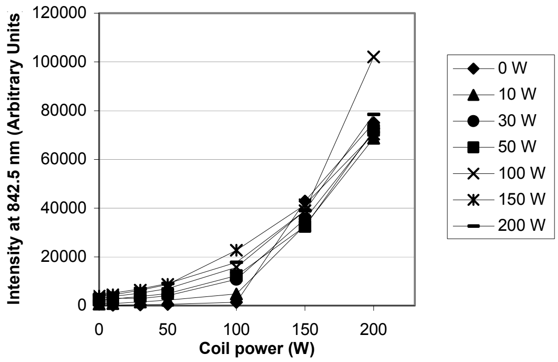


Figure 7 - Emission intensity at 842.5 nm vs. coil power, with cathode power as a parameter - Ar plasma at 10 mTorr.

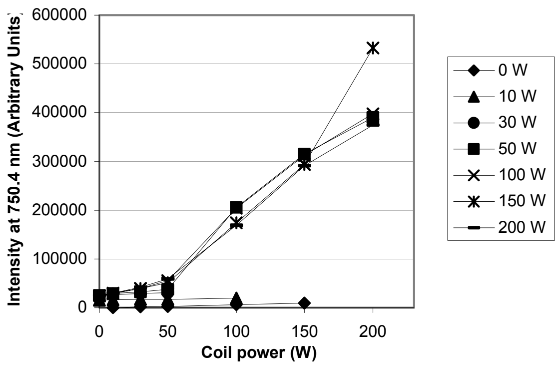


Figure 8 - Emission intensity at 750.4 nm vs. coil power, with cathode power as a parameter – Ar plasma at 100 mTorr.

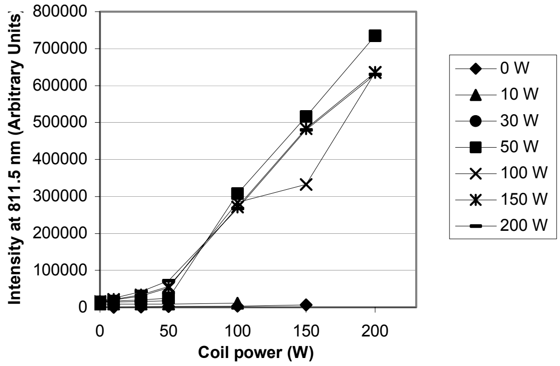


Figure 9 - Emission intensity at 811.5 nm vs. coil power, with cathode power as a parameter - Ar plasma at 100 mTorr.

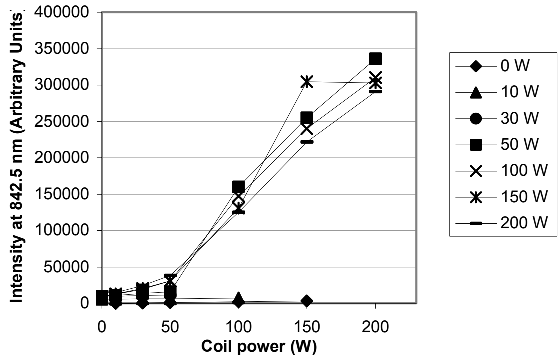


Figure 10 - Emission intensity at 842.5 nm vs. coil power, with cathode power as a parameter - Ar plasma at 100 mTorr.

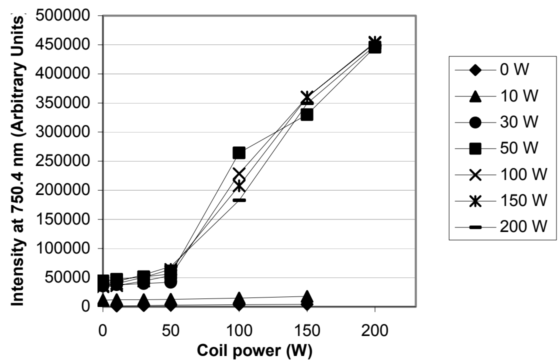


Figure 11 - Emission intensity at 750.4 nm vs. coil power, with cathode power as a parameter – Ar plasma at 200 mTorr.

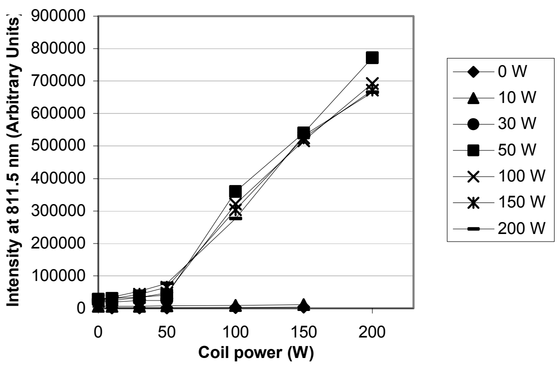


Figure 12 - Emission intensity at 811.5 nm vs. coil power, with cathode power as a parameter – Ar plasma at 200 mTorr.

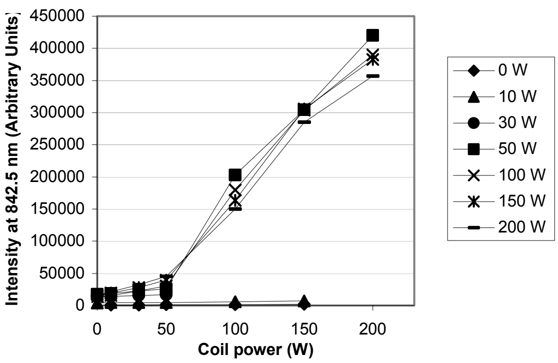


Figure 13 - Emission intensity at 842.5 nm vs. coil power, with cathode power as a parameter –Ar plasma at 200 mTorr.

Another interesting observation, is that for higher pressures (100 mTorr and 200 mTorr) and low cathode power the emission intensity jump could not be observed, where as for the 10 mTorr plasma, even with no cathode power the emission intensity jump occurred.

As explained before, the emission intensity jump is associated to the E-H mode transition. According to the literature, the E-mode discharge operation is characterized by low plasma density, and consequently, low emission intensity. During this mode of operation, increasing the coil power, the emission intensity does not increase significantly. A strong emission intensity increase was only noted during the mode transition (figures 5 to 13 show that this increase can be by a factor of four or even higher). After the transition, i.e. in the stable H-mode operation, the electron density continued to increase but not as significantly as during the transition [1-3, 5].

Another interesting behaviour shown in figures 5 to 13, is that in the E-mode of the discharge operation, the emission intensity at 750.4 nm was much higher than at 811.5 nm, but in the H-mode operation the emission intensity at 811.5 nm was higher than at 750.4 nm. This behaviour can be more clearly seen in the relative emission intensities graphs shown in figures 14 to 19. During the E-mode of operation, the ratio between emission intensities at 811.5 nm and at 750.4 nm was smaller than unity, around the transition it reached the unity, and after the transition, in H-mode, it was higher than unity.

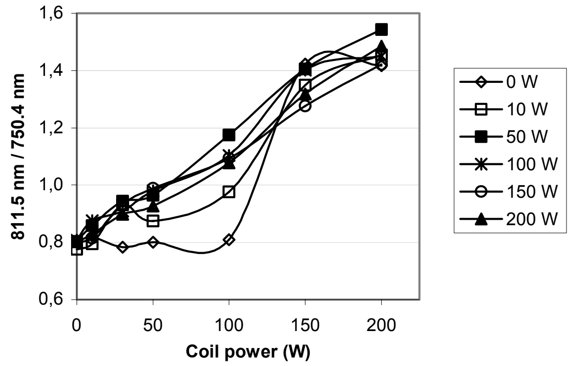


Figure 14 - Relative emission intensities at 811.5 nm and 750.4 nm vs. coil power, with cathode power as a parameter - Ar plasma at 10 mTorr.

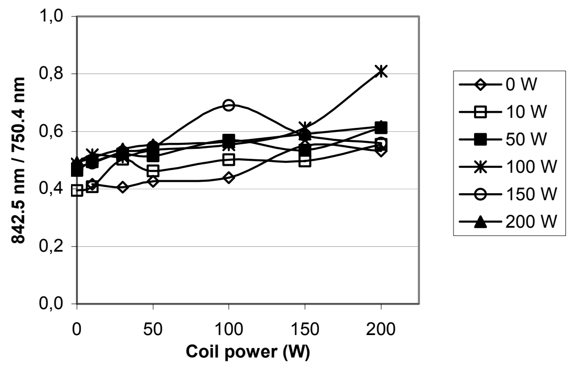


Figure 15 - Relative emission intensities at 842.5 nm and 750.4 nm vs. coil power, with cathode power as a parameter - Ar plasma at 10 mTorr.

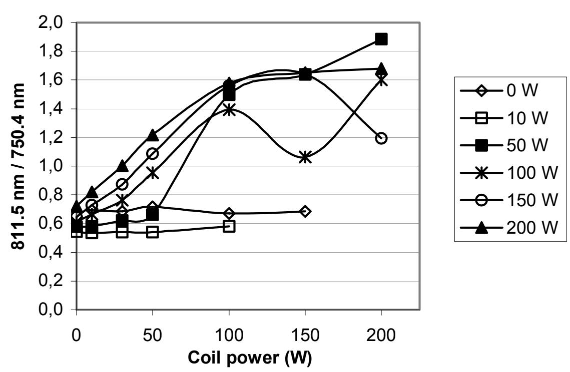


Figure 16 - Relative emission intensities at 811.5 nm and 750.4 nm vs. coil power, with cathode power as a parameter - Ar plasma at 100 mTorr.

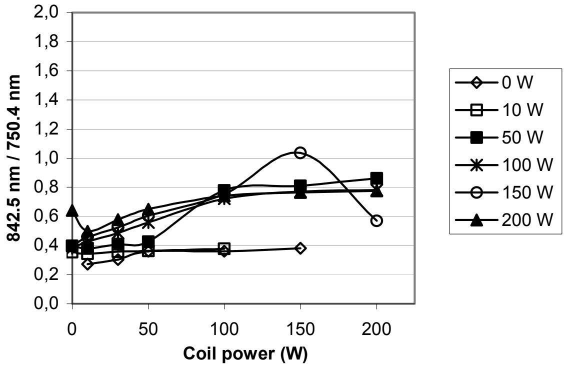
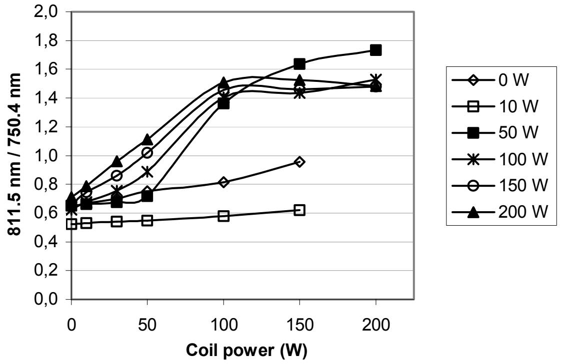
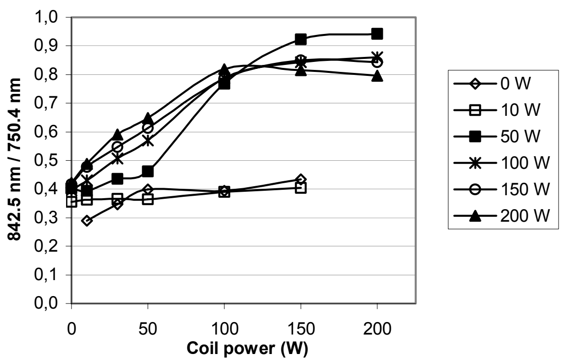


Figure 17 - Relative emission intensities at 842.5 nm and 750.4 nm vs. coil power, with cathode power as a parameter - Ar plasma at 100 mTorr.



(a)

Figure 18 - Relative emission intensities at 811.5 nm and 750.4 nm vs. coil power, with cathode power as a parameter - Ar plasma at 200 mTorr.



(b)

Figure 19 - Relative emission intensities at 842.5 nm and 750.4 nm vs. coil power, with cathode power as a parameter - Ar plasma at 200 mTorr.

The ratio between emission intensities at 842.5 nm and at 750.4 nm was never higher than unity (that is, the emission intensity at 842.5 nm was always smaller than at 750.4 nm). But still, at the mode transition, a strong increase at 842.5 nm was observed compared to 750.4 nm, for the pressures of 100 mTorr and 200 mTorr. For the low electrode powers, where the plasma was in the E mode, the 842.5 nm to 750.4 nm intensity ratio remained low.

These results show that the electron density in the plasma increased significantly during the E-H mode transition. The electron excitation energy for the 750.4 nm emission was higher than for both other emissions; hence the results shown here indicate very strongly that the average electron energy decreased when the plasma changes from E mode to H mode : in the H mode, more argon atoms were being excited by less energetic electrons, than by electrons of higher energy, probably due to a decrease in the average electron energy. The DC bias potential also indicates this characteristic: the modulus of the DC bias potential decreased with increasing coil power, what means that the average electron energy decreased, because when having more energetic electrons in the plasma, the more negative the cathode potential should be in order to keep these electrons from escaping the plasma bulk to the electrode.

4. CONCLUSION

In this work, DC bias potential and emission intensities from ICP systems in the low pressure range have been studied. Both the plasma light emission intensity and the DC bias potential presented jumps when increasing the coil power, i.e., during the E-H mode transition.

The electron density was increased strongly in H mode, but at the same time, there were very strong indications that the average electron density decreased during the E-H mode transition. This behaviour was observed through both emission intensity and DC self bias voltage measurements.

5. ACKNOWLEDGEMENTS

The authors would like to thank CCS at Unicamp for lending necessary equipment, and especially Prof. Dr. Stanislav A. Moshkalyov for his great help. The authors also thank FAPESP and CNPq for financial support.

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