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# On the density of argon metastables in a cylindrical magnetron discharge

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The experimental results are presented regarding spatial distribution of the argon metastable atoms density and corresponding temperature in a cylindrical magnetron discharge with aluminium target. The measurements were performed using a tunable diode laser system with narrow line width (1 MHz), allowing us to obtain good resolution of the absorption spectral line. The main broadening process of the spectral lines in the discharge is Doppler one due to the thermal energy of the particles and rather low gas pressure. The laser was tuned linearly around wavelength 811.531 nm, which corresponds to the absorption wavelength for argon metastables atoms.

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## 1. Introduction

Magnetron discharges are frequent used in thin film deposition processes [1, 2]. In film deposition processes, the position of the substrate relative to the plasma source is important for both deposition rate and thin film quality. Accordingly, a spatial characterization of magnetron plasma is of great interest and can be connected with deposited films properties.

The investigation of plasma parameters by means of tunable diode laser absorption spectroscopy (TDLAS) [3-5] provides detailed information about elementary plasma processes through the very high spatial and temporal resolution.

In this paper, the experimental results on the spatial distribution of argon metastable atoms ($3p^54s(1s_5)$) and corresponding temperature using a tunable diode laser system and absorption spectroscopy technique are presented. Experiment was performed in a dc magnetron discharge during sputtering of aluminium using argon as a working gas. The measurements were made for discharge current intensities in the range 5 ÷ 350 mA and gas pressures between 0.4 and 2.6 Pa corresponding to different discharge regimes.

## 2. Experimental setup

The experimental set-up essentially consisted of a vacuum chamber housing a magnetron plasma source and the laser system (Fig. 1). The vacuum chamber was a cylindrical reactor closed by optical windows at each side. The plasma source was a cylindrical dc magnetron with an aluminium target. During experiments, the target was water-cooled. To prevent aluminium contamination of the windows, internal diaphragms have been used in order to protect them.

The vacuum chamber was evacuated by a turbo molecular pump to a base pressure of $2.6x10^{-5}$ Pa. Argon was used as the working gas in the pressure range of 0.4 ÷ 2.6 Pa. A gas flow controller provides gas flow while the pressure inside the vacuum chamber was measured by mean of a Pirrani gauge and a capacitive manometer. The dc power supply was operated in the current control mode.

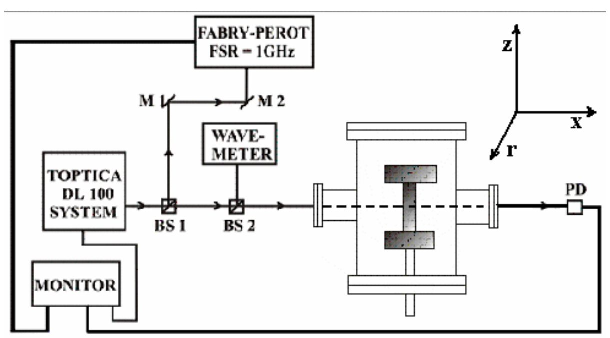


*Fig. 1. Experimental set-up.*

The laser system consists of a tunable diode laser and the control unit for diode temperature and diode current (Toptica DL 100). The diode laser used an extended cavity laser set-up with optical feedback into the laser diode from the fist order of a spectrally selective grating. The laser beam was guided through the plasma reactor and measuring devices by using two beam splitters (BS1,BS2) and two mirrors (M1, M2) as in figure 1.The laser system with narrow line width (1 MHz) allowed us to obtain an absorption profile which was recorded with a photodiode detector PD. Due to the relatively low gas pressure and plasma density one may assume that the main broadening process of the spectral lines in the discharge is Doppler one so that information about the thermal energy of the particles can be obtained [6]. The laser was tuned linearly around 811.531 nm. It corresponds to the absorption wavelength for argon metastable atoms, (transition $3p^5 4s(1s_5)$ – $3p^5 4p(2p_9)$) [7] and scanning of the entire Doppler absorption profile was possible.

### 3. Results and discussions

Measurements of argon metastable atoms density were performed with pure argon as working gas for three different gas pressures and different discharge current intensities, between 5 and 350 mA, respectively. At this stage, the relative value of metastable density has been measured as area of absorbance curve, $k(\lambda)=\ln(I_0/I_t)$ where $I_t$ and $I_0$ are the laser intensities collected with the photodiode PD, with and without plasma. Consequently, the arbitrary units were used in the diagram of metastable density versus control parameters. Two different approaches were used regarding the graphical representations of distributions. In the first one we take into account the variation of the density as a function of discharge current and radial position

In figure 2 the radial distribution of argon metastables density is displayed as a function of discharge current for three different pressure values 0.4, 1.3 and 2.6 Pa, respectively. Over the investigated range, the maximum density increases with argon gas pressure. The maximum of argon metastable density is reached at a distance of 4 mm from the target surface, for all investigated gas pressures. The distance of 4 mm is then related to the geometrical characteristics of the magnetron discharge, due to magnetic filed configuration. By increasing the gas pressure, this peak appears at lower values of the discharge current, but still at 4 mm from the target surface. Following the density variation corresponding to fixed radial position and increasing discharge current intensity one can see that the density increases to a maximum and then decreases.

In order to explain this result one must take into account two main processes. The first it is the fact that fast primary electron flux originated at the cathode region and responsible of the excitation process and population of the metastable state, is radially decreasing due to both cylindrical symmetry of the discharge and space limitation of the trapping effect of the magnetic field. The second process is related to the depopulation of the metastable state, which is mainly produced by non-radiative collisions between those metastable atoms and the neutrals.

Thus, considering a constant partial pressure of working gas the growth in argon metastable density can only be caused by corresponding increase of electron density. The decrease is caused mainly by both non-radiative and radiative collisions with gas atoms and sputtered metal atoms. The current growth diminishes the metastable atom density, especially for the pressures of 1.3 and 2.6 Pa (Fig 2. b) and c)), due to increasing density of sputtered metallic atoms. A direct effect of the increased metallic atom density is that other concurrent reactions may appear, such as excitation and ionisation of metallic atoms by collision with electrons. For a pressure of 0.4 Pa (Fig 2.a)) this effect is smaller, due to the higher free main path of both metastables and buffer gas or metallic atoms. On contrary, for a pressure of 2.6 Pa (Fig. 2. c)) the effect is stronger and the maximum of metastable atoms density is achieved at a discharge current as low as 20 mA.

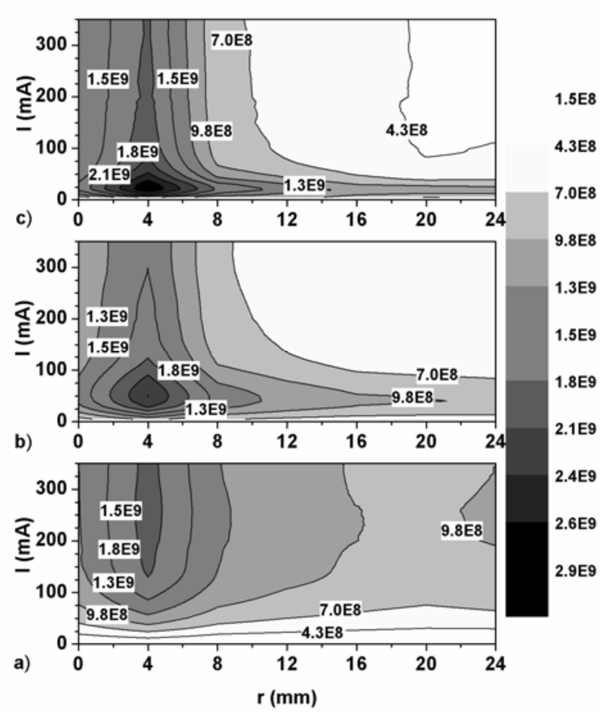


***Fig. 2.*** *Radial distribution of argon metastable density as a function of discharge current intensity. Z=0, a) p0.4 Pa, b) p=1.3 Pa, c) p=2.6 Pa;*

In figure 3 the spatial distribution of argon metastable density is displayed for three different discharge current values, at a pressure of 1.3 Pa. As it can be seen the maximum density is achieved in the Z=0 plane, corresponding to the middle of the target, at a distance of 4 mm from target surface. In the case of small discharge current values this region is the only one which appears luminescent, in the form of a torus around the middle of the target. We investigated this spatial distribution for discharge current intensities between 5 and 300 mA, and it was found the maximum density of the argon metastable atoms at 50 mA discharge current intensity (Fig 3.b).

As said before, the decrease is caused by the presence of new type of atoms, sputtered aluminium atoms in this case, that introduce new reactions of consumption in the balance.

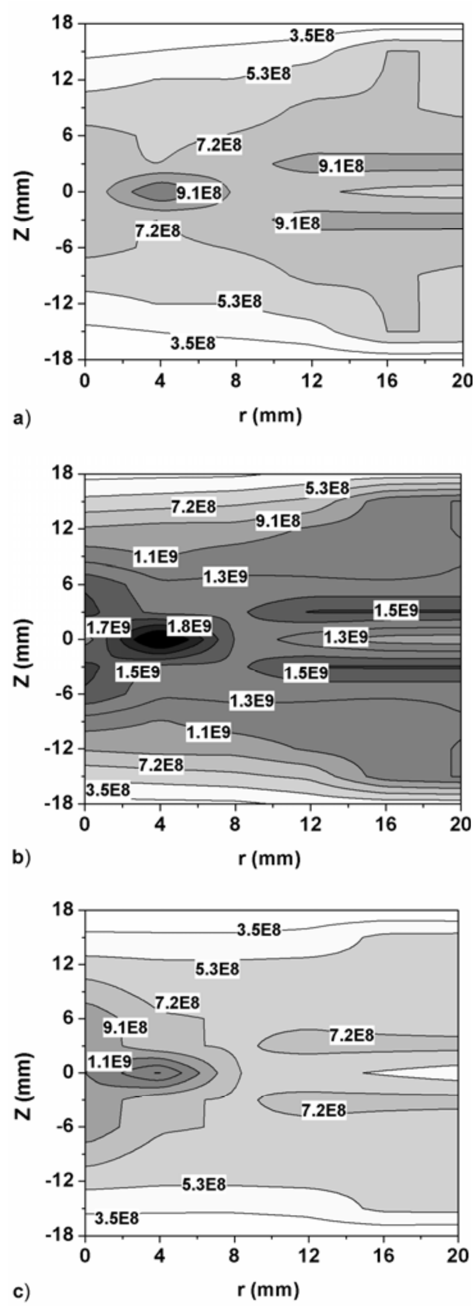


***Fig. 3.*** *The spatial distribution of argon metastables density (a.u.) for different discharge current values (p=1.3 Pa, a) I=10 mA, b) I=50 mA, c) I=300 mA);*

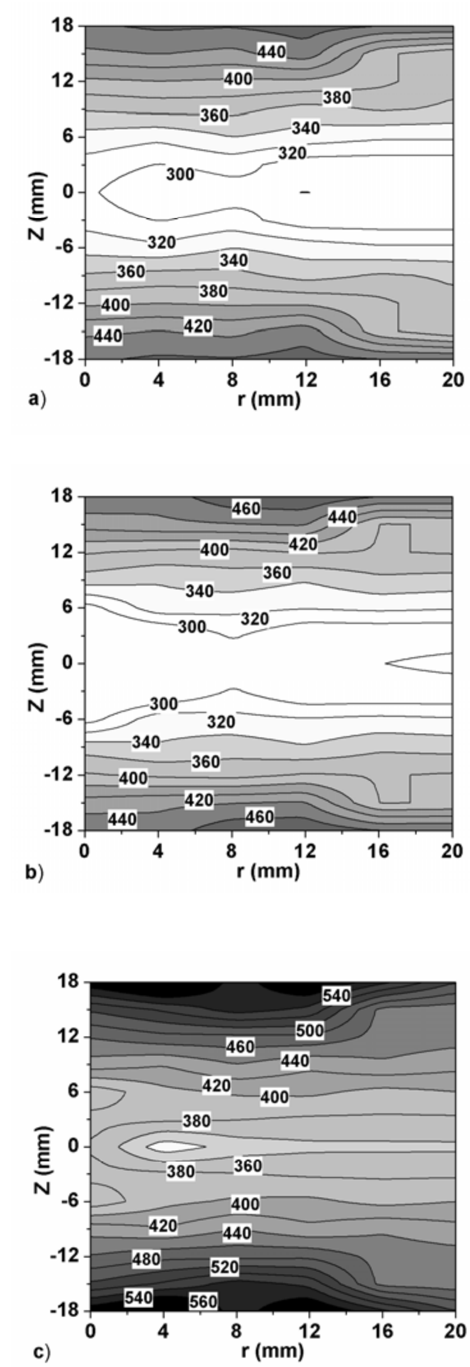


***Fig. 4.*** *The spatial distribution of argon metastables temperature (K) for different discharge current value (p=1.3 Par, a) I=10 mA, b) I=50 mA, c) I=300 mA);*

For a discharge current of 300 mA (Fig. 3. c)) the maximum density is lower, but the distribution keeps the same shape with a maximum corresponding to typical magnetic trap configuration.

In all cases the metastable density decreases towards the margins of the cathode (Z=18), showing a decrease in the electron density. This is mainly due to the enhancement of magnetic field near the surface, which causes a reflection of electrons as for any typical magnetic trap behaviour.

Using absorption technique the temperature of investigated species can be calculated. Supposing a broadening process mainly caused by thermal motion the narrow line width of diode laser allows to scan and find the Doppler broadening of spectral line associated to that specific transition. The temperature of the absorbing atoms is related to the line-broadening trough the formula [8]:

$$T_{Ar}(K) = \left( \frac{\Delta\lambda}{\lambda} \frac{1}{7.16 \cdot 10^{-7}} \right)^2 \cdot M$$

where $\Delta\lambda$ is the width at half maximum of the spectral line, $\lambda$ is transition wavelength and M is mass number of absorbing species. The spatial distribution of temperature in the discharge volume corresponding to same conditions as in figure 3 is plotted in figure 4. In all cases the temperature reaches the minimum in the centre of the discharge, and has a value close to the gas temperature of 300 K due to collisions. The temperature in the centre is slightly bigger for a current of 300 mA (Fig 4. c)), due to increasing power input within the plasma volume.

But, there also exist a heating effect caused by heating of the target. It can be observed at the edge of magnetron plasma close to the target surface and can cause an increase of metastable atom temperature up to 600 K, at 300 mA discharge current intensity (Fig 4.c)

A complementary experiment was realised, not shown here, in order to evaluate this heating effect. Shortly, the experiment consisted in evaluating the temperature near the target surface for two different current values, one very small and one very large. The temperature remains high even for a low discharge current intensity if the data, at low discharge current, were taken, in short time, immediately after decreasing of the discharge current from its larger value so that no relaxation of the target temperature has been produced.

## 4. Conclusions

The laser absorption technique was used in order to obtain spatial resolved distributions of Ar metastables in a cylindrical magnetron discharge. The argon metastable atom density is higher in the middle of the discharge volume and reaches its maximum for a certain couple of parameters pressure, discharge current. However, the radial position of maximum density remains constant for whole range of investigated parameter, depending mostly on the geometrical characteristic of the magnetron configuration. The argon metastable atoms temperature rises with increasing discharge power and is higher close to target where target was heated by argon ions collisions. The absorption technique provides very accurate information on the gas temperature, and can be an important tool in monitoring the temperature near a heating wall

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