THE INVESTIGATION OF DIFFERENT DISCHARGE MODES IN HIGH FREQUENCY ARGON-ZINC DISCHARGE*

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High-frequency electrodeless lamps emit bright line spectra, thus being used in different scientific devices. Each device requires specific set of parameters for the light source, influenced by form, applied voltage and other properties. In this work we investigate influence of lamp side-arm on the intensity and stability of lines and look at differences between E and H discharge modes.

Key words: high-frequency electrode-less lamps, zinc, discharge, E- and H- mode, emission stability measurements.

1. INTRODUCTION

High-frequency electrode-less lamps (HFEDLs) are line spectrum emitting light sources, that are widely used as bright radiators of narrow and intensive spectral lines, covering spectral region from ultraviolet to infrared. Our work is concerned with their preparation and investigation, to understand processes in radio-frequency (RF) inductively coupled low-temperature plasma and to optimize these light sources for usage in atomic absorption spectrometers [1].

For RF inductively coupled plasma two different modes of discharge are distinguished – capacitive E-mode, also called predischarge and inductive H-mode also known as ring discharge [1, 2].

The E-mode at low RF power is maintained by electrostatic field, and is characterized by low electron density and weaker light emission.

The H-mode on the opposite operates at high RF power, thus having high electron density and bright light emission, and is maintained by electromagnetic field, induced by current flowing in RF coil [1, 3, 4]. Because of its characteristics H-mode is more investigated, while studies of weaker E-discharge are less popular [3].

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Usually lamp ignition starts with predischarge (E-mode) and by increasing the applied power, the critical value can be reached, where the transition to H-mode starts. When the transition occurs, jump of current and sudden changes in plasma properties can be observed. E-H mode transitions are of a high interest, and there can be many papers found in this field [3-6].

In our previous works we investigated the plasma-surface interaction in such lamps [7-9], while in this work we focus on properties of HFEDLs filled with zinc and argon, as we investigate another two of the aspects influencing the operation of the light source – lamp geometry and mode of discharge.

Similarly as for mercury and other heavy metals, lamps with zinc are frequently used in pollution analysis and monitoring devices [1], in addition, their other applications include but are not limited to other analytical instrumentation and wavelength calibration [10]. In [11] the possibility to replace mercury by zinc in high-pressure discharge lamps is discussed, concluding, that zinc is attractive as replacer not only by environmetal point of view, but also by its comparable properties.

2. EXPERIMENT

2.1. HIGH-FREQUENCY ELECTRODE-LESS LAMPS

In general the vessel of HFEDL is made of SiO_2 glass and filled with a working element and buffer gas at low pressure. Usually working element is in form of metal vapour and for buffer gas a rare gas such as argon or xenon is used.

The lamp contains a bulb and a short side-arm (Fig.1a). Depending on requirements of application, sidearm can be sealed of and such lamp is called as being „without side-arm" (Fig.1b).

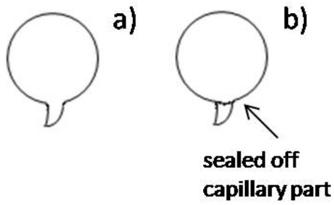

Fig. 1 – Schematic representation of HFEDLs with (a) and without (b) side-arm.

The lamp bulb is located in a high-frequency excitation generator coil to induce an inductively coupled electrode-less discharge. The frequency of generated electromagnetic field is about 100 MHz.

In this work two types of HFEDLs were investigated: SiO_2 bulbs of 10 mm diameter with and without 3 mm long side-arm. Lamps were filled with zinc as working element and argon as buffer gas.

2.2. SPECTROMETERS

Measurements were performed using two different spectrometers:

Spectrometer 1: AVANTES AVS-PC2000 plug-in spectrometer with 2048-element linear CCD-array detector (wavelength range 190–850 nm). It was used for intensity stability measurements of spectral lines and for registration of full lamp spectra in given range. Resolution of AVANTES spectrometer is 0.3 nm. Experimental set-up for stability measurements can be seen in Fig. 2.

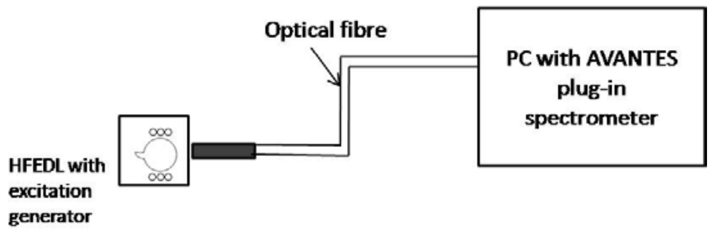

Fig. 2 – Experimental set-up for stability measurements with AVANTES spectrometer.

Spectrometer 2: JobinYvon SPEX 1000M (grating 1600 l/mm, focal length 1 m) with charge-coupled device matrix detector (2048x512 Thermoelectric Front Illuminated UV Sensitive CCD detector, Symphony), wavelength range 200-850 nm. This spectrometer has resolution of 0.008 nm, and it was used to register intensities of selected spectral lines to investigate their behavior depending on excitation generator power and discharge mode. Experimental set-up for these measurements can be seen in Fig. 3.

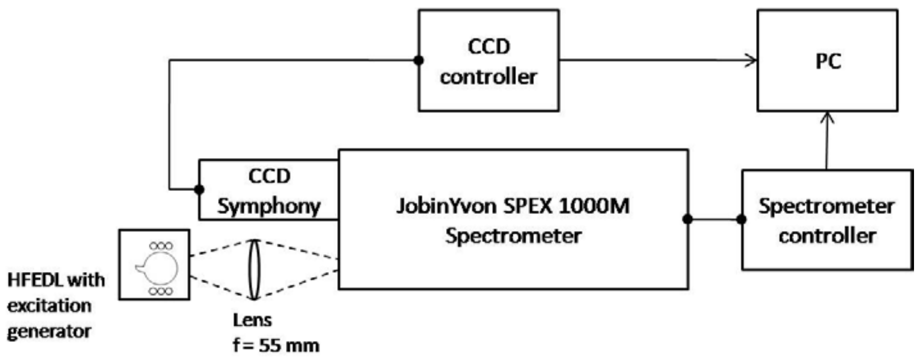

Fig. 3 – Experimental set-up for spectra registration with JobinYvon spectrometer.

2.3. MEASUREMENTS

2.3.1. Intensity stability measurements

As mentioned above spectrometer AVANTES AVS-PC2000 was used to register data describing stability of spectral line intensities. Each of the experimental light sources was put in the excitation generator and ignited.

Spectral line intensity changes in time were registered as follows: generator voltage was set to a certain value (starting from 23V up to 29V), lamp was left to stabilize for 20 minutes (experience shows that 5 minutes for stabilization almost always are enough), after whom voltage was changed to next higher value.

2.3.2. Measurements of spectral line intensities

For registration of intensities spectrometer JobinYvon SPEX 1000M was used as it allows better separate line distinction than AVANTES.

Selected zinc and argon lines were measured in both E and H discharges. Their dependance on excitation generator voltage was observed by changing it in the range of 21V to 29V. After each change of voltage the light source was left to stabilize for several minutes.

3. RESULTS

3.1. STABILITY OF SPECTRAL LINE INTENSITIES

Measurements showed that stability of spectral lines depends on geometry of light source. In Fig. 4 intensity changes of two zinc lines and two argon lines are presented. While intensity of argon lines is stable in time and changes insignificantly depending on generator voltage, unstable behavior is observed for zinc – intensities change both in time and by increasing the voltage.

The decrease of spectral line intensities at higher values of excitation generator voltage can be explained by zinc migrating away from plasma discharge zone towards the coldest part of the light source – side-arm.

As can be seen in Fig. 5, the intensity stability for both elements is good, when the side-arm is sealed off, since there is no place for zinc to migrate towards to and because of higher concentration of zinc atoms, it is possible to acquire more intense spectral lines of zinc.

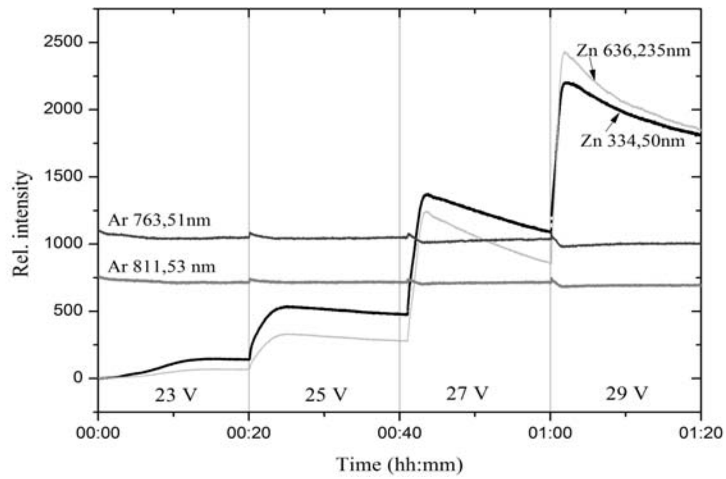

Fig. 4 – Stability of Zn and Ar spectral lines in HFEDL with side-arm.

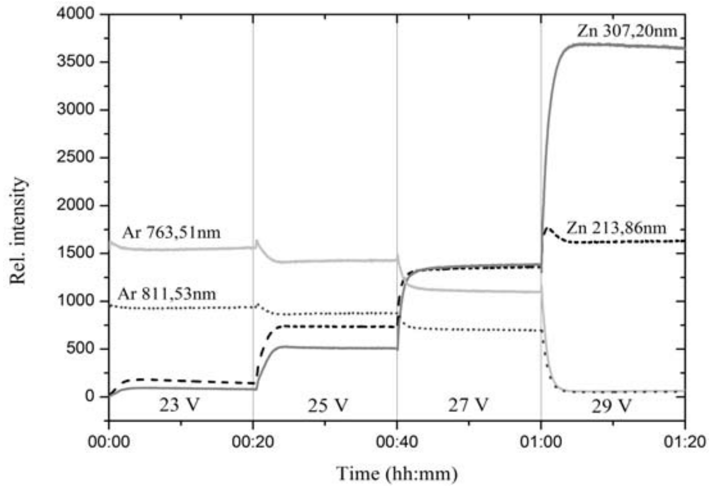

Fig. 5 – Stability of Zn and Ar spectral lines in HFEDL without side-arm.

3.2. INTENSITY

In Fig. 6a and 6b full spectra for lamps with and without side-arm in range from 200 nm till 850 nm are shown. It is observable easily that spectral lines for both – working element and buffer gas are more intense for lamp with sealed side-arm.

Because of higher concentration of zinc atoms, concentration of electrons has increased and energy from electromagnetic field is delivered to the light source more efficiently.

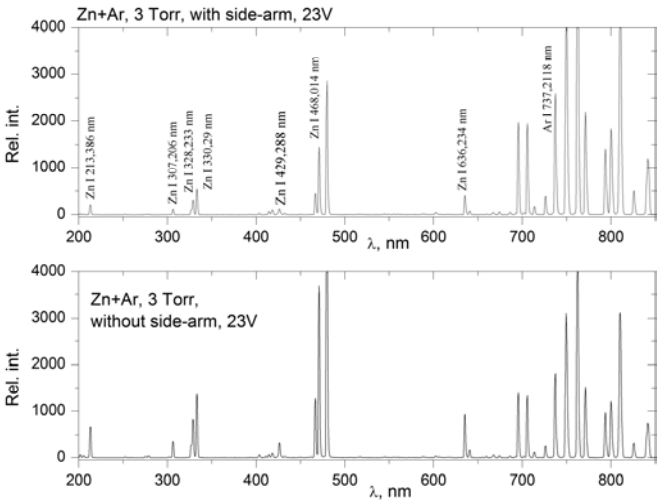

Fig. 6 – a) spectrum of Zn+Ar lamp with a side-arm, b) spectrum of lamp with-out sidearm.

Lamp spectra during two different discharge modes were also registered. While H-discharge is more of a interest, as it provides higher intensities for working element, E-mode can provide properties that could be used for certain applications.

Figures 7 and 8 represent HFEDLs behavior in H-discharge mode. It is seen that the Ar spectral line intensities for lamps without side-arm are higher and the change of intensity is almost negligible when changing the power of the excitation generator.

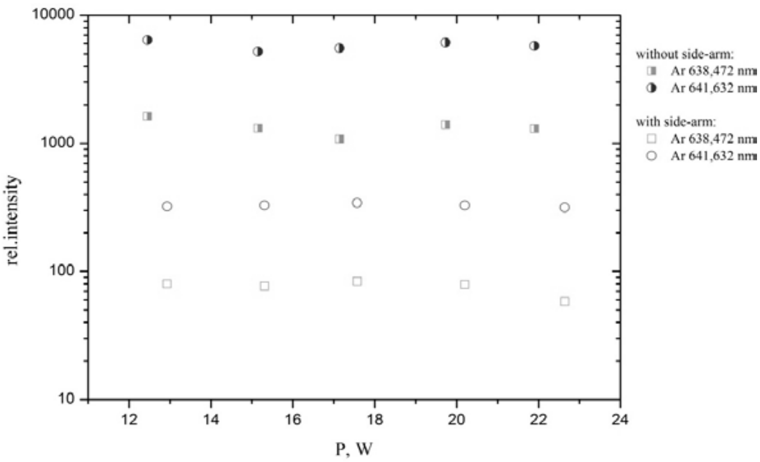

Fig. 7 – Intensities of several Ar spectral lines depending on power applied to generator in H-discharge mode.

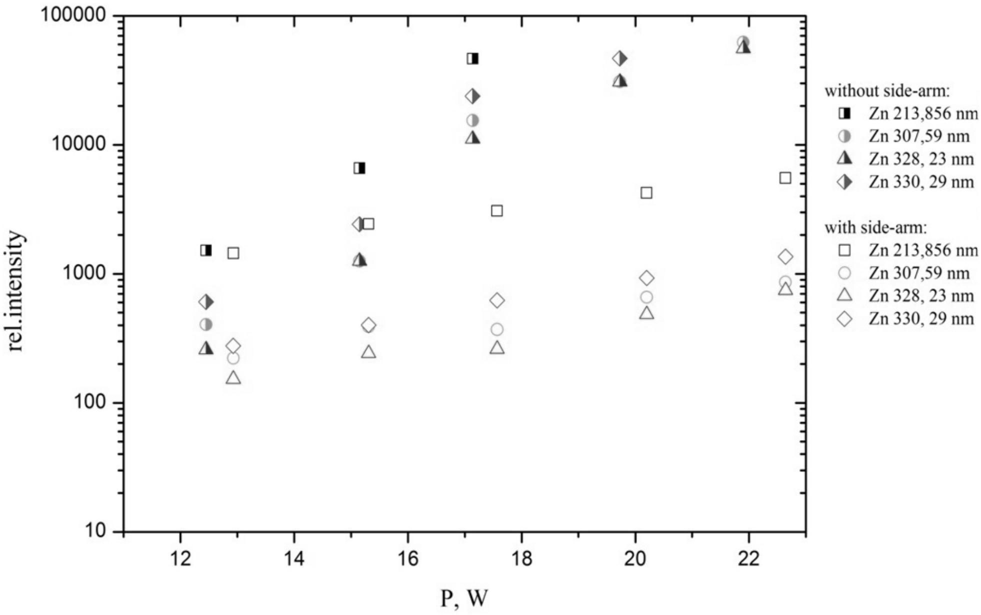

Fig. 8 – Intensities of several Zn spectral lines depending on power applied to generator in H-discharge mode.

Zinc spectral lines are also more intense for lamp with sealed side-arm, however they also show differences depending on generator power – intensities of spectral lines registered in HFEDL without side-arm are increasing more rapidly than those of HFEDL with side-arm. At lower power values the difference between intensities of both lamps is not very explicit, however at higher values the intensities of the Zn lines of lamp without side-arm can be 10 times and even more higher than that of the lamps with side-arm. This effect can again be explained by migration of zinc towards the coldest part of light source.

Figure 9 shows how spectral lines behave in E-mode of discharge. It is seen that argon has higher spectral line intensities, as it can be excited more easily than zinc.

In E-mode excitation generator power influences the intensities insignificantly, letting to conclude that they can be stated as being independent of generator power. It is not shown here but was observed that lamps without side-arm undergo a transition from E-mode to H-mode around 13W, while lamps with side-arm can operate in E-mode at as high as 17W, that corresponds to the highest permitted voltage value for said excitation generator.

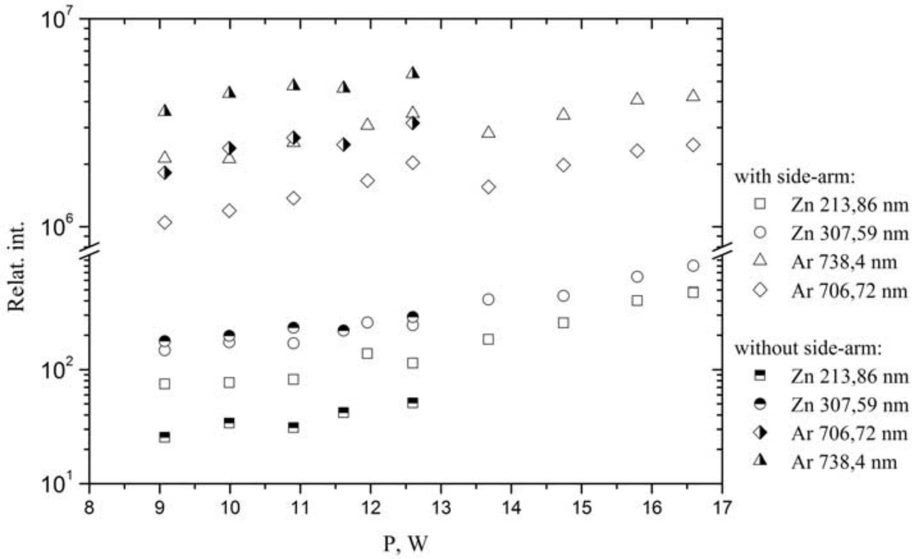

Fig. 9 – Intensities of several Zn and Ar spectral lines depending on power applied to generator in E-discharge mode.

4. CONCLUSIONS

Intensity and stability of HFEDLs are influenced by a set of parameters, including shape of the light source and mode of discharge it is working in. Our investigation shows that sealing of the side-arm of the Zn+Ar lamp results in higher intensities of spectral lines and improves their stability. Lamps with side-arm have to undergo longer process of stabilization for optimal working conditions. During H-mode concentration of zinc atoms is higher leading to higher emission intensity.

For usage in analytical devices H-discharge mode is preferable because of high working element intensity, while both E- and H- modes can provide useful information about processes inside the lamp.

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