Investigation of HF Mercury Low-Pressure Discharge Plasma – Wall Interaction[1]

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Abstract – Different types of mercury light sources are widely used as intensive spectral line emitters, especially in the VUV and UV spectral regions. In the light source technology, the discharge plasma interaction with the wall is a very important question. Our work is concerned with the preparation and investigation of high-frequency mercury light sources excited by means of outer electrodes, so called, electrodeless light sources. In this work we consider our experience in the technology of the electrodeless mercury light sources. The interaction process with the discharge vessel is investigated using spectroscopic emission measurements of the filling elements and the wall surface diagnostics by means of the atomic force microscope. The necessary quantity of the mercury filling is estimated to reach a considerably long working life.

1. Introduction

There has been an active period of research of high-frequency electrodeless light sources (HFELS) because of their wide use in both science and technology [1, 2]. High-frequency electrodeless plasma sources are based on the high-frequency electrodeless discharge, which is excited by means of electrodes, located outside the plasma. In dependence on the excitation scheme, inductive or capacitance-coupled plasma can be created. Such types of plasma sources are used for different applications. Mercury HFELS found successful application in food and environment analysis, surgery, UV-illumination, optical magnetometry, isotope separation etc. Our research is concerned with the preparation of the HFELS of new quality filled with mercury isotope and having specific radiation qualities for different scientific goals [3]. Last time there is a growing increasing interest also in the usage of mercury-argon electrodeless discharge for lighting applications. Because of lack of electrodes it seems like these light sources are living forever but there is another process restricting source lifetime: interaction of filling element with walls of the vessel. This process depends strongly on the light source operating conditions and on the filling.

Special methods have to be used in our group to eliminate the mercury bound with glass balloon. There are different ways to influence this process: a) the specific wall material can be chosen; b) different buffer gases can be added in known amount; c) special treatment of the lamp vessel can be performed; d) with other technological methods. In this work we concentrate us to investigations of the filling metal (mercury) interaction with the lamp wall. The working life measurements were performed in dependence of the filling amount.

2. Experimental

To hold an optimum pressure of Hg in the discharge, it is possible to prepare light source with a short side branch and to fill up it with the corresponding optimum the element which all will be completely exploited for the discharge.

In order to find out the optimum and to study the plasma interaction with a wall, we have prepared HFELS samples from quartz with a spherical form of 20 mm diameter with mercury in a metal phase of different amount. The inductive coupled discharge was induced in the light source placed in the coil of inductor. The discharge was operated by means of high-frequency electromagnetic field of about 100 MHz frequency. Changing the coil current, I, from 50 mA to 220 mA, the power of the HF-discharge can be changed.

There arises a problem of dosing this amount of mercury as the metallic phase in the light source. Commonly two methods of Hg dosing are used. One method is based on heating of the source vessel during the filling time, online with vacuum-system, at the fixed temperature [4, 5]. The other method is the filling of the mercury in a composed form, mostly performed in the fluorescent lamp technology [6, 7].

We use two approaches to investigate the interaction process between the plasma and the source walls. The first is a pure spectroscopic method and the second is the wall surface measurements by means of an atomic force microscope.

In the first method, the spectra, emitted from the inductive coupled discharge were registered regularly

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in the time to see the temporal spectral line intensity changes. The spectral line intensity is direct proportional to the amount of emitting element. Two types of intensity measurements were done: 1) short term measurements; 2) long term measurements.

For the measurements of the intensity of spectral lines, the radiation emitted from HFELS was passed through a monochromator, amplifier and registered by means of a CCD matrix (whole spectra from 200 to 800 nm) or photomultiplier (single line). Mainly 253.7 nm resonance line was used to control the intensity changes in time. Special software was constructed which allowed registering spectra automatically.

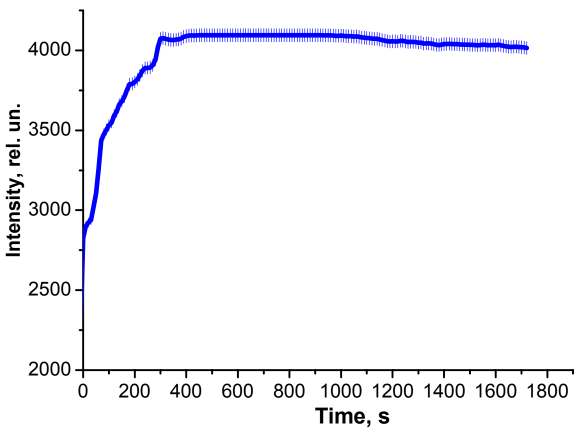

Fig. 1. Example of the short-term intensity measurements of Hg 253.7 nm line as a function of time

In Fig. 2, the results of the long-term intensity measurements are demonstrated for three different initial filling amounts of mercury: 0.046, 0.46 and 4.6 µg. Fig. 2. shows the mercury 253.7 nm line intensity as a function of time. We found that the amount of mercury filled up into the light source to achieve a sufficiently long lifetime must bee much larger than necessary for the metal vapor needed for discharge. The reason for this is binding of some part of mercury with the wall material of the light source vessel during the operation, which makes unavailable mercury to become the vapor. Besides, to delay the mercury bound in the glass the rare gas also must be added more than necessary, for an optimum discharge.

An optimum pressure of mercury for the well-conditioned discharge is about $2–3 \cdot 10^{-2}$ Torr what corresponds to the filling amount of about 0.5 µg (estimated previously in our work [8]). But one can see in Fig. 2 (filled circles) that this amount is not enough to reach a considerably long working life. In this case, the lamp works only 120 hours. As we can see, the amount of mercury should be about 5 µg to reach longer working life. But enhanced amount of both, the working element Hg and buffer gas yields broad and deformed emitted spectral line profiles (caused by both the pressure broadening and the self-absorption) and decreased intensities of the spectral lines.

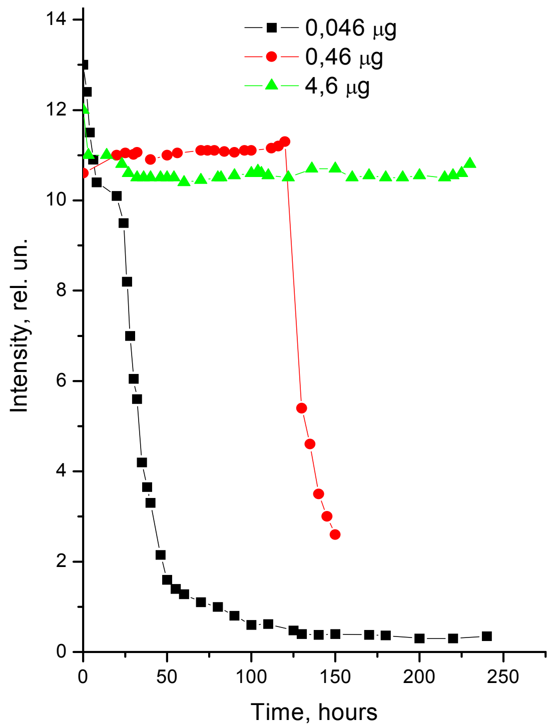

Fig. 2. Long-term measurements of Hg 253.7 nm line intensity temporal changes

3. Measurements by Means of a Conductive Atomic Force Microscope

Topography of the light source wall was studied by means of a home-built conductive atomic force microscope (AFM) in a contact mode [9]. The AFM tips, having a radius of curvature less than 35 nm, were silicon nitride (Park Scientific instruments) cantilevers. No filters were used for image processing except line-to-line leveling. The force constant of each cantilever was measured by calibrated cantilevers and found to be 0.1 and 0.16 N/m for cantilevers of two different dimensions.

In Fig. 3 examples of the lamp wall AFM surface topography images are shown of the light source after some time of the work and before. A comparison of the images proves that the wall is changed significantly during the work.

4. Conclusion

We show in our work that there exists a process shortening mercury electrodeless lamp working life significantly while an interaction with electrodes is eliminated. We show that that the process of the mercury atom bound in the light source walls takes place and due to this fact the filling amount of the mercury in the high-frequency electrodeless lamps has to be larger as necessary for a well-conditioned inductive coupled discharge. Atomic force microscope images of the light source walls prove significant difference of the surface structure before and after light source working.

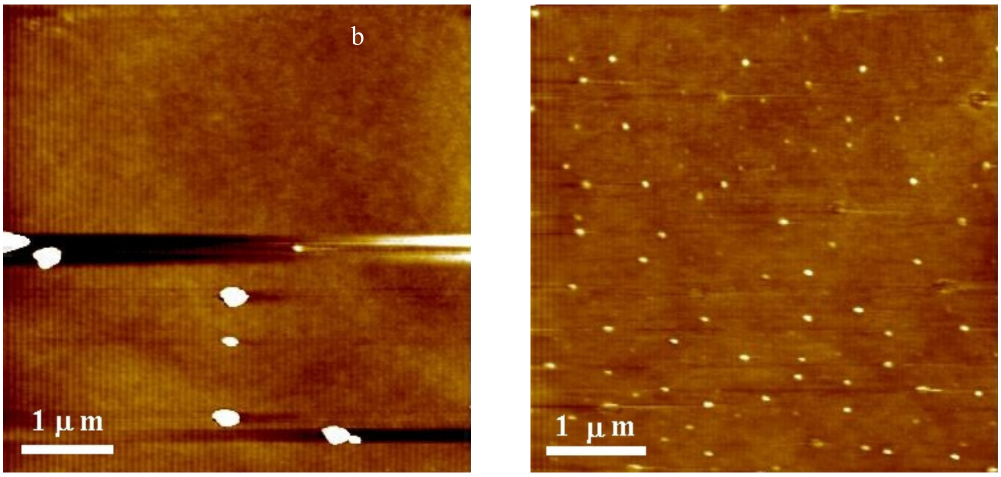

Fig. 3. AFM surface topography image of the light source wall: a – after working; b – before working

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