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VARIATIONS OF ABNORMAL GLOW DISCHARGE PROPERTIES WITH CATHODE HEATING

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Abstract. In this paper the influence of cathode temperature on abnormal glow discharge properties is examined. A Grimm type glow discharge with no cathode cooling, operating in argon was used. Spectral line intensities of argon and cathode material are measured simultaneously with cathode temperature and were observed to change significantly. Change of discharge voltage with measured cathode temperature is also reported. The behavior of the discharge was the same for two different cathode materials. Variations of the discharge properties may be attributed to the rise of gas temperature due to the heat transfer form the cathode.

1. INTRODUCTION

In this paper the influence of cathode temperature on abnormal glow discharge properties is examined. A Grimm type glow discharge with no cathode cooling, operating in argon was used. Spectral line intensities of argon and cathode material are measured simultaneously with cathode temperature and were observed to change significantly. Change of discharge voltage with measured cathode temperature is also reported. The behavior of the discharge was the same for two different cathode materials. Variations of the discharge properties may be attributed to the rise of gas temperature due to the heat transfer form the cathode.

Glow discharges are widely used today for many different purposes. One of them is the use of glow discharges for analysis of solid samples by optical emission spectrometry or mass spectrometry. In these sources sample material is sputtered leading to detection of sample atoms or ions in the discharge. Grimm type lamp, used in this experiment, is used for optical emission spectrometry.

Fair knowledge of discharge properties is needed if the discharge is to be applicable for analytical purposes. On the other hand, all processes that may influence discharge properties must be taken into account when analyzing and

modeling these sources. The Grimm abnormal glow discharge source operating in argon has so far been the subject of many analysis see for instance [1-3]. Many different processes may contribute to gas heating in glow discharges. Electric field accelerates the ions and electrons which then collide elastically with atoms of working gas giving rise to gas temperature. Sputtering of cathode material may also contribute to gas heating. It is well known that the cathode, in glow discharges, may reach a temperature much higher than room temperature due to the bombardment by heavy particles [1,4] and [5]. In order for the discharge to operate stably, cathode is usually cooled. Since it is heated the cathode contributes to the energy transfer to the gas [1, 6]. Concrete value of cathode temperature surface determines the boundary condition in the heat equation [1], but is usually not well known. Higher cathode temperature increases the gas temperature, at constant pressure this means lower gas density and a change of discharge parameters. Further more at constant current, voltage becomes higher giving rise to average electron energy [1, 6, 7]. Through this order of events, rise of cathode temperature changes the current--voltage characteristic and the intensity of spectral lines emitted form the discharge.

This paper presents results of an experiment that investigates the influence of cathode temperature on the Grimm type discharge properties operating in argon. This was done by measuring the discharge voltage and spectral line intensities of working gas and sputtered atoms with simultaneous measurement of the cathode temperature.

2. EXPERIMENTAL SETUP

The experimental setup is presented schematically in Fig.1. The discharge source is a modification of the Grimm type glow discharge, described in detail elsewhere [2]. Here, for completeness, minimum details will be given. Anode is hollow, 30 mm long with 8.00 mm inner diameter. Cathode is 7.60 mm wide and 10 mm long made of copper (99.998%) or Ti (99.5%) and placed in a 12 cm long cathode holder made of brass. In standard operation the cathode holder is water cooled, but here no cooling was used. Before every measurement the discharge operated for an hour at low current.

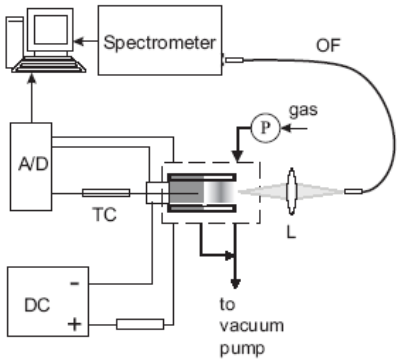

FIGURE 1. Experimental setup.

A gas flow of about 300 cm^3/min of argon (purity 99.995%) is sustained at a selected pressure of 6 mbar. To run the discharge a current stabilized power supply with voltage up to 1.1 kV was used. A ballast resistor of 15 kΩ is placed in series with the discharge.

The measuring end of a K-type thermocouple was placed in a drilled vacancy inside the cathode reaching 1.7 mm distance from the surface. Signal from the thermocouple was led to the multi channel A/D converter. Discharge voltage was measured by a high voltage probe connected to the mentioned A/D converter. Values of voltage and temperature were taken with 2 Hz sample rate.

Spectral line intensities were recorded end on by projecting the image of the discharge to the optical fiber, which was connected to the entrance slit of 1 m Cherny-Turner monochromator, see Fig. 1, equipped with CCD multichannel detector. This configuration enabled simultaneous monitoring of cathode temperature, discharge voltage and line intensities.

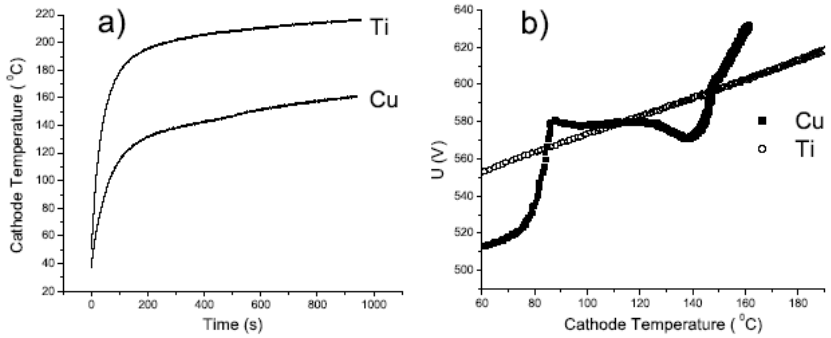

FIGURE 2. Measured dependences for two different cathode materials: a) Cathode temperature vs time; b) Discharge voltage vs cathode temperature; Discharge conditions: $I = 18$ mA, $p = 6$ mbar of Argon

3. RESULTS AND DISCUSSION

Exchangeable cathode holder enabled us to investigate the influence of cathode material by performing two separate measurements, with two cathode materials: titanium and copper. In both cases the discharge current was kept stable at I=18 mA at pressure of 6 mbar, with argon as a working gas. The cathode had neither external cooling nor heating. The temperature we have recorded may be presumed to be several degrees lower than at cathode surface due to the temperature gradient in the cathode material along the 1.7 mm distance.

Obtained cathode temperature dependence on time is given in Fig. 2a. Temperature shows a steep rise in the first tens of seconds and rises slowly for several minutes till it reaches its maximum value. This may be expected since there ought to be a short period needed to establish the continuous heat transfer form and to the cathode. After this period cathode temperature reaches a steady-state value. Cathode made of titanium is heated much faster and reaches higher maximum

temperature than the copper cathode (Fig. 2). This effect comes from a large difference in heat conductivity of these two materials (Ti: 22 W/Km, Cu: 400 W/Km).

Voltage dependence on cathode temperature is given in Fig. 2b. Calculations by Revel in [6] and by Bogaerts in [1] show that an increase in the cathode temperature leads to an almost linear increase in the argon gas temperature. For a fixed current and gas pressure model shows an increase in discharge voltage [6] with increase of gas temperature. Results in Fig. 2b correspond to this, showing rise in discharge voltage for both cathodes. However the curve dependence is quite different for two materials. Discharge voltage with copper cathode shows at first a period of instability corresponding to fast rise of temperature in Fig. 2a, after that it rises slowly and has another jump at high temperature. Operating with titanium cathode, discharge shows a much smoother, monotonous rise of voltage. After the temperature perturbation, the discharge tends to stabilize itself, reaching its steady state parameters after some short time [4]. Due to the large difference in thermal conductivity of titanium and copper cathode, the discharge behaves differently.

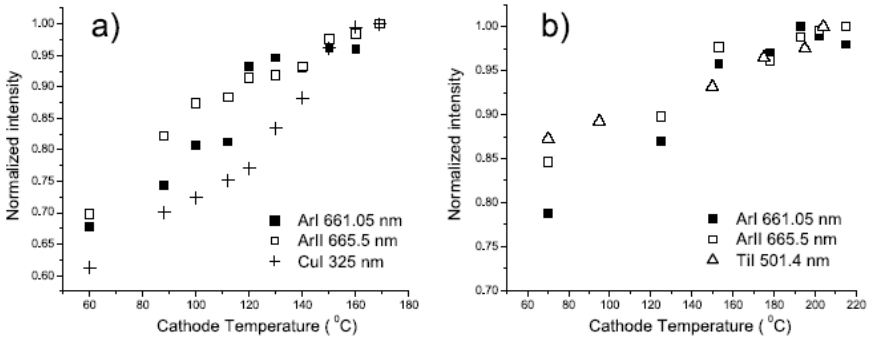

FIGURE 3. Measured line intensities dependance on cathode temperature: a)Discharge with Cu cathode; b) Discharge with Ti cathode; Discharge conditions: $I = 18$ mA, $p = 6$ mbar of Argon

Difference in sputtering yields for two materials must also be taken into account.

Results of spectral line intensities measurements are given in Fig. 3a - for copper cathode and Fig. 3b - for titanium cathode. Line intensities of argon and of cathode material are normalized at their maximum reached value for the sake of comparison. Again, the change is more drastic with copper cathode, both copper and argon lines are changed from about 60% to 100% with cathode heating. Discharge operating with titanium cathode shows a smaller change of about 80% to 100%. In both cases lines of cathode material follow the same behavior as lines of the working gas. It may be concluded that excitation of all lines is changed by the same mechanism i.e. rise of cathode temperature gives rise to gas temperature and changes electron energy distribution which is reflected on atom excitation.

4. CONCLUSION

Experimental investigation of influence of cathode temperature on abnormal glow discharge is reported in this paper. Discharge used is of Grim type operating in argon with non--cooled cathode made of copper and titanium. Simultaneous measurements of cathode temperature, discharge voltage and spectral line intensities were performed. It is shown that rise of cathode temperature gives rise to discharge voltage. Curve dependence of voltage on cathode temperature is significantly different for two cathode materials.

Line intensities of working gas and cathode material are also increased with cathode heating. Increase of discharge voltage and line intensities is attributed to rise of gas temperature and consequent change of electron density and energy distribution.

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