

SPECTROSCOPIC DIAGNOSTICS OF FREE AIR ARC IN DIFFERENT REGIMES*

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Abstract. A plasma spectroscopy experiment is described and its performances are given. Ways of excitation different regimes of free-burning plasma at atmospheric pressure is analyzed in detail. Low voltage DC arc (smoothed) was used for excitation of free-burning zinc-vapor plasmas at atmospheric pressure. Abilities of the system are analyzed and plasma temperatures with graphite electrodes and zinc vapors were determined by using Zn I spectral lines ratios. Tikhonov regularization procedure was applied in problem of determine a radial intensity of spectral line *i.e.* radial temperature distribution was obtained.

Key words: plasma spectroscopy, spectral line ratios.

1. INTRODUCTION

Arcs at atmospheric pressure, sustained by electric field, including those in open air are typical and widespread examples of dense low-temperature equilibrium plasmas [1]. It should be mentioned, however, that in the arc fringes, and especially fast moving arcs (gliding arcs), non-equilibrium plasma conditions can also be found and can be utilized for technical applications [2]. Main reason that plasmas, generated and maintained at atmospheric pressure, become again an area of interest in the 1980s, was mostly driven by application such as high power lasers, opening switches, novel plasma processing and sputtering, absorber and reflector of electromagnetic radiation, remediation of gaseous pollutants, medical sterilization and biological decontamination and excimer lamps and other non-coherent light sources [3]. Electrode material evaporated under the action of current enters electrode gap in an electric arc. Since the ionization potential of the electrode material is lower compared to the atoms of the ambient gas, those metal

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atoms have substantial effect on the processes of heat, mass, and electron transfer in the plasma [4]. A detailed and complete knowledge of plasma temperature field and its dependence on the plasma operating parameters such as discharge current, regime of arcs excitation etc., are needed.

2. EXPERIMENTAL SET-UP

Optical emission spectroscopy (OES) measurements in a UV-visible range 200–560 nm were done. The scheme of the experimental set-up is shown in (Fig. 1), comprises a 2m spectrograph (with a possibility to extend to double light path), and a 1024×256 pixel CCD camera (PIXIS 256). The side on light from plasma (1) is directed through the system of lens (2) at the entrance slit of the PGS-2 spectrograph with the grating (6) of 651 lines/mm and the blaze wavelength at 300 nm. The deflection mirror (4) sends the light beam to the lower part of the concave mirror (5) and after reflection of the grating to the upper part of the mirror (5), finally re-directs the light to the CCD array of the camera (7).

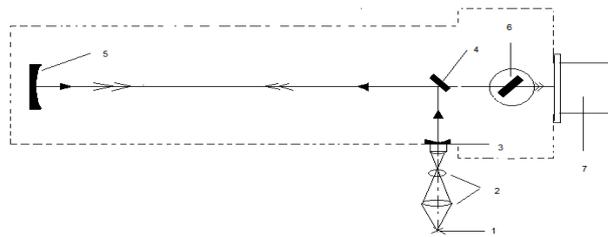


Fig. 1 – Experimental set-up for OES of plasmas.

2.1. PIXIS CAMERA

PIXIS is a fully integrated camera system. The camera contains all of the electronics necessary to read out and control the CCD device. It houses precision analog-to-digital converters, positioned close to the CCD for lowest noise and has USB 2.0 electronics to interface with the host computer. Significant reduction of dark current is achieved through thermoelectric cooling of the CCD array. The camera operates by using WinSpec/32, Princeton Instrument's 32-bit Windows software package, designed specifically for spectroscopy. With the pixel size of 0.026 mm and dispersion of 0.74 nm/mm in the first order of diffraction gives spatially resolution of 0.02 nm, and for using higher orders of diffraction and doubled light paths this resolution is much higher. During the data acquisition, the CCD array is exposed to a source and charge accumulates in the pixels. After the

defined exposure time, the accumulated signal is read out of the array, digitized and then transferred to the host computer. Upon data transfer, the data is displayed and stored via the application software.

2.2. PLASMA GENERATOR

The commercial Universal arc-pulse generator UBI-2, Carl Zeiss Jena can produce different types of electrical discharges (Fig. 2). The input transformer (1), with the secondary coils voltage of 350V, gives AC or DC (through the rectifier (2)) voltages at the air gap (13), where are different discharges generated. To get a low voltage discharges a high frequency voltage of about 20 kV is needed, which in any half-period of alternate current generates a high frequency pulse. It is done when the pulse-transformer (9) gives an ignition voltage to spark gap (10) by discharging its capacitor. The ignition voltage directs through Tesla's transformer (11) to the main circuit. By help of the pulse generator (8), a rhythm in interruptible regimes of discharges and phase angle of the ignition are tuned. Six regimes of creating plasmas are possible: interruptible AC arc with six steps from 100 to 1.6 GHz; interruptible DC arc; low voltage DC arc (smoothed); low voltage spark discharge with changeable polarities and HF spark discharge.

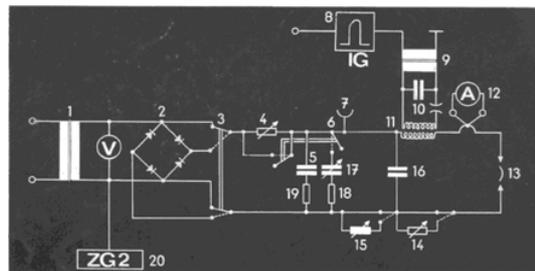


Fig. 2 – The scheme of the universal plasma generator UBI-2.

Powerful capacitors (17), shunted in a step way with (13), ignite low-voltage sparks with the same spectral characteristics as the spark gap of the high voltage generator.

The internal structures of the chamber, where are the open air plasmas generated, and the picture of the DC arc with electrodes of spectroscopic pure graphite, the cloud of zinc vapor and discharge current $I_d = 9A$ are shown in Fig. 3. The DC and DC interruptible arcs are created vertically, between two electrodes whose gaps were in the range of 2–8 mm. The discharge current is changed from 2 to 10A. In one position of the grating, approximately 20 nm of a specter can be taken. Spatial and temporal mapping of the specters are taken. The CCD's exposure time can be regulated and in this experiment it was typically 100 ms.

3. THE ARC TEMPERAURE DETERMINATION

In cases that plasma is in local thermodynamic equilibrium (LTE) or at least partial LTE for the excited levels of some spectral lines [5], the most common method for electron temperature determination is by using relative intensities of atomic and ionic spectral lines in emission spectra (the Ornstein method) [6]. Properly corrected emission intensities (optically thin) can be used to determine the temperatures based on the Boltzmann distribution given by

$$n_i = n_0 \frac{g_i}{Z} \exp(-E_i / kT), \quad (1)$$

where n_i is population of the i th excitation state, g_i is the known statistical weight of the excited state, Z is the partition function, E_i is the excitation energy, k is the Boltzmann constant and T is the absolute temperature.

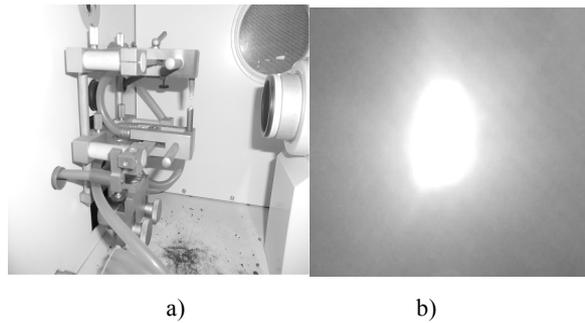


Fig. 3 – The internal structures of the chamber with: a) water-cooled electrodes; b) arc in open air).

Here, zinc lines ZnI 307.21nm; ZnI 307.59nm are used with relatively high excitation potentials-: E_1 -8.08eV; E_2 -4.01eV respectively [7]. The working formulas for the temperature determination was [8]

$$T = \frac{20510}{2.58 - \log \frac{I_{307.21}}{I_{307.59}}}, \quad (2)$$

where I_i are intensities of the chosen lines. On Fig. 4 is present a curve sensitivity for obtaining a temperature according eq.2. The DC arcs in continual mode is created vertically, and the gap between electrodes was 4 mm. Metallic zinc is evaporated due high temperature of the discharge through a brass cathode. The discharge current was 8A. The lines ZnI 307.21 nm; ZnI 307.59 nm are very suitable

because they are very closed each other and even relative calibration of the system is not needed. Moreover, these two lines are very well choice for the range of expected temperatures. Otherwise, lines, from different ionization states of the same element, are needed to be chosen. As an example of the image specter and its graph, is shown in Fig. 6, with the discharge current of 8A, in the DC regime. Mostly, the calculated temperatures were in the range of 6600–7300C. Radial measurements are also performed by shifting the both electrodes simultaneously and taking the average intensities from different locations. The ratio of the intensities of the measured lines continually decreased if we measured from center to periphery of discharge, as we expected to be. Abelization procedure *i.e.* obtaining radial intensity of spectral line from the spectral intensity was done applying the Tikhonov regularization procedure [9]. From the ratio of the radial intensity of these two Zn spectral lines radial temperature distribution $T(r)$ is obtained (Fig. 5).

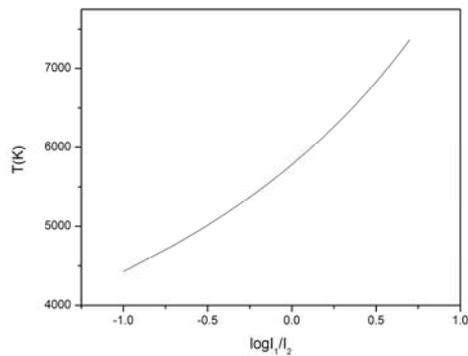


Fig. 4 – Temperature dependence on intensity ratio.

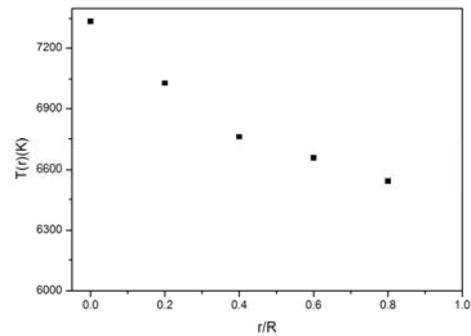


Fig. 5 – Radial temperature distribution.

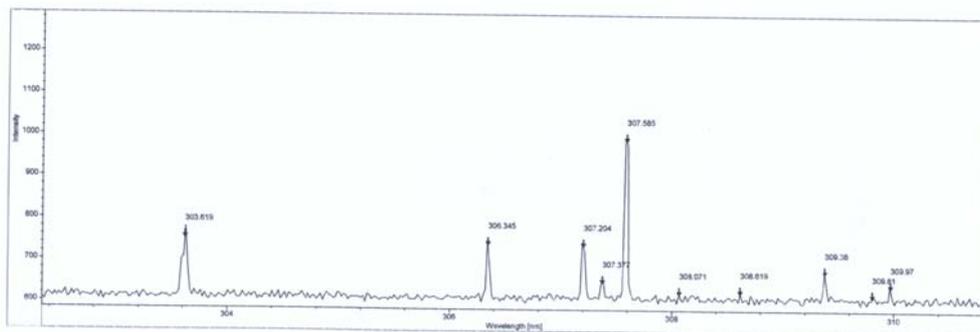


Fig. 6 – The image of the zinc specter and its graph.

4. DISCUSSION AND CONCLUSION

An OES experiment is a power-full tool for characterization the free burning plasmas at the atmospheric pressure. The experimental set-up, designed mainly for spectro-chemical analysis, is used to extract many physical features of the plasma at atmospheric pressure. Experimental results on the plasma temperature field in zinc vapor are described and discussed. Boltzmann distribution of the excited Zn I species was the basis for temperature determination. Tikhonov regularization procedure was applied for obtaining a radial intensity of spectral lines. Main problem in temperature determination was a fact that arc was not stabile at every point along the radius *i.e.* the arc was “dancing”. In some situation arc was stabile, or arc has run into our field of observation or arc has disappeared from our field. To avoid problem arise from this situation a great number of measurements were done at every point along the radius. Since the standard deviation is proportional to inverse root of number of measuring, a large number of measuring transfer a systematic error to a random error. Experimentally obtained results were normalized in order to apply a regularization procedure. Radial temperature distribution was obtained.

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