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SHORT COMMUNICATIONS

Spectral Characteristics of a 44-kHz Arc Discharge Excited in an Atmospheric-Pressure Argon Flow

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Abstract—Results are presented from experimental studies of an ac (44-kHz) arc discharge excited in an atmospheric-pressure argon jet between two copper electrodes. The first (central) electrode is a water-cooled rod with an axial opening for argon injection, while the second electrode is a loop of a tube lying in a plane perpendicular to the axis of the central electrode. The argon radiation spectra are measured, and the characteristic intensity profiles of the spectral lines as functions of the distance from the end of the central electrode are determined. All the observed transitions in the 245- to 370-nm wavelength range are identified.

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INTRODUCTION

Spectral studies extensively conducted in the past were of fundamental importance for both fundamental and applied science. Quantum mechanics also owes much to atomic and molecular spectroscopy. Among applied achievements, the most significant are laser technologies and emission spectroscopy. The plasma state of matter can be explored primarily by analyzing the emission and absorption spectra. In recent years, spectroscopy became once again one of the most significant branches of physics. There are several reasons for this. Spectroscopy provides efficient means for monitoring the plasma parameters in plasma technologies for nanomaterial production. The development of electronics resulted in a new element base; diode matrices and arrays are close in their properties to photofilms, but allow one to obtain spectral information a few hundred times faster. Modern high-power electronics also acquired a new semiconductor element base, which allowed creating inexpensive high-frequency (10- to 400-kHz) current generators. Plasma generation in this frequency range presents no problem any more, which provides new possibilities for plasma studies.

In the literature, there is vast information on dc and ac discharges in which a nonequilibrium plasma is generated (see, e.g., [1, 2]). These works are stimulated by the search for the possibility of creating highly efficient lasers. The solution of technological problems often requires producing equilibrium, high-thermal-capacity plasmas. Usually such plasmas are generated using an arc discharge. Until recently, graphite-electrode arcs were used for the purposes of emission spectroscopy. However, in this case, the molecular spectrum of cyan covers almost the entire visible spectrum of emission. When using water-cooled metal electrodes, the arc plasma is significantly contaminated due to intense electrode erosion. This is quite undesirable when a plasma uncontaminated by impurities is required (e.g., for medical applications, plasmochemistry, and emission spectroscopy). The main reason for the high level of erosion is inefficient cooling of the electrode surface, on which cathode spots arise. The mechanism for the generation of cathode spots is such that the use of a high-frequency ac power source (instead of a dc or an industrial-frequency source) can prevent the formation of a stable cathode spot. It is known that the time required for small cathode spots to merge into a large one is about 10^{-4}–10^{-5} s [3]. At a frequency of 44 kHz, the lifetime of cathode spots at the surface of a copper electrode is on the order of 10^{-5} s. Therefore, most of the time, the discharge current is attached to several simultaneously existing cathode spots, which improves heat exchange and significantly reduces electrode erosion.

Studies of the plasmas of dc, industrial-frequency, and rf arc discharges were reported in many papers and monographs. However the 10^3- to 10^5-Hz frequency range has not been investigated yet [3]. Here, we present results from investigations of electrode erosion and spectral characteristics of an arc discharge excited at a frequency of 44 kHz in an atmospheric-pressure argon jet between water-cooled copper electrodes.

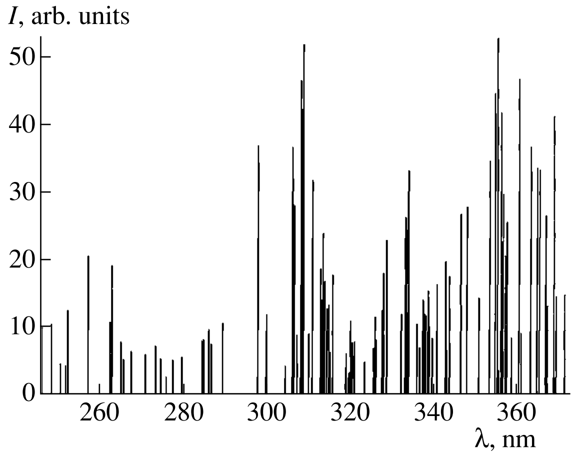

Fig. 1. Argon lines in the emission spectrum of an ac (44-kHz) arc discharge and their relative intensities.

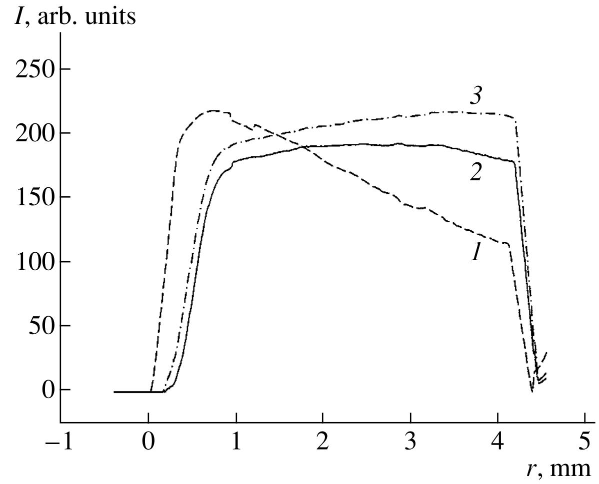

Fig. 2. Profiles of argon spectral lines as functions of the distance r from the end of the central electrode: (*1*) λ = 328.170 nm (4*p*–4*d* transition), (*2*) λ = 356.766 nm (4*s*–6*p* transition), and (*3*) λ = 356.329 nm (4*s*–6*p* transition).

EXPERIMENTAL

We investigated the spectral characteristics of the plasma of an arc discharge excited at a frequency of 44 kHz in an atmospheric-pressure argon flow. The discharge operated between an electrode in the shape of a loop of a copper tube and a copper electrode with an axial opening, through which argon was injected [4]. The emission spectra were recorded at a current of 13 A and an electrode voltage of 120 V.

Relative intensities of spectral transitions

Transition	Relative intensity, %
3*d*–4*p*	0.64
3*d*–5*p*	4.37
3*d*–6*p*	2.34
3*d*–4*f*	6.67
3*d*–5*f*	6.69
3*d*–6*f*	1.28
4*s*–4*p*	3.07
4*s*–6*p*	18.92
4*s*–7*p*	1.67
4*s*–8*p*	4.5
4*s*–9*p*	2.76
4*s*–10*p*	0.68
4*s*–11*p*	2.57
4*s*–13*p*	0.52
4*s*–4*f*	3.23
4*s*–6*f*	0.59
4*s*–7*f*	0.46
4*s*–8*f*	2.55
4*p*–6*s*	1.11
4*p*–4*d*	24.57
4*p*–5*d*	7.27
4*p*–6*d*	0.38
4*p*–5*f*	1.02
4*p*–7*f*	2.11

The spectral information was acquired using the technique described in [5]. The spectra were recorded on a film and then were scanned and digitized. The luminosity produced by the radiation source corresponded to the linear segment of the blackening curve of the film. The spectra were measured in the range 245–370 nm. Using the spectral lines of copper and iron (which are present in the discharge plasma due to electrode erosion) as reference lines, we calibrated the entire spectral range under study. Such a calibration allowed us to identify the argon spectral lines.

RESULTS AND DISCUSSION

Figure 1 shows the argon lines and their relative intensities in the 245- to 370-nm wavelength range, and the table presents the relative intensities of the spectral transitions (the ratios of the total relative intensities of all the spectral lines of a given transition to the total intensity of all the argon lines within the spectral range under analysis). It can be seen from the table that the most intense transitions are 4*p*–4*d*, 4*s*–6*p*, 4*p*–5*d*, 3*d*–5*f*, and 3*d*–4*f*. A characteristic feature of the discharge spectrum is the presence of radiation corresponding to transitions between different levels. There are transitions to both the lower (4*s*) and intermediate (4*p* and 5*d*) levels, in contrast to glow and rf discharges, in which transitions from the higher levels to the lower ones prevails [2].

We plotted the intensity profiles of all the argon spectral lines in the spectral range under study as functions of the distance from the end of the central electrode. An analysis of these profiles shows that there are three characteristic types of profiles (see Fig. 2).

The erosion of the plasma generator electrodes was estimated by extrapolating the dependence of the intensity of the 510.554-nm copper line on the copper concentration in the plasma. We prepared graphite matrices with a copper content from 0.00001 to 0.1% and obtained a linear dependence of the intensity of the above line on the copper concentration. It was found that, at a current of 13 A and frequency of 44 kHz, the mass of the material evaporated during 160 s from the cathode surface was 2×10^{-11} kg. This corresponds to an electrode erosion of 10^{-14} kg/C.

CONCLUSIONS

Thus, our experiments have shown that, at a current of 13 A and frequency of 44 kHz, the concentration of the electrode material in the discharge plasma is very low, the line intensity varies insignificantly along the discharge, and the discharge radiation contains spectral lines corresponding to transition between different levels. Such a discharge can be used for spectral analysis, as well as a light source in emission spectroscopy, plasmochemistry, and medicine.

In the future, we plan to perform studies in wider ranges of the discharge current frequencies and plasma radiation wavelengths.

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