Measurement of Copper Vapors in Water-Argon Thermal Plasma Jet

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Plasma jet generated by water-argon plasma torch is enriched by copper evaporated from the anode surface. In this contribution we present results of measurement of emission spectral lines of neutral copper along the jet. We are able to monitor presence of copper vapors in the jet and in addition we use copper lines to obtain excitation temperature. This temperature seems to represent kinetic temperature of turbulent downstream regions of the jet with good accuracy.

Keywords: DC arc, plasma jet, copper atoms, excitation temperature

1 INTRODUCTION

Electric arcs are formed between metallic electrodes, which must resist high power load; therefore, produced plasma is often contaminated with some amount of metallic species. Indeed, experimental investigation of arc plasmas containing metal vapors is subject of many papers, e.g. [1-4]. Importance of this topic can be seen also on attempts of theoretical calculation of properties of such plasmas, e.g. [5, 6]. They show that even small addition of metallic species into the typical plasma forming medium (argon, oxygen, nitrogen, etc.) can have substantial influence on plasma characteristics. This paper is devoted to spectroscopic measurement of copper atoms in the plasma jet generated by the water-argon plasma torch.

2 EXPERIMENTAL SETUP

Schematic view of direct current water-argon torch is shown in Fig.1a. Details about this torch can be found also elsewhere [7, 8]. The arc is stabilized by the argon in the cathode region and by the water vortex surrounding substantial part of the arc column. The arc current can be varied between 200 A and 600 A and the argon flow rate between 8 slm and 40 slm. Rate of water evaporation into the plasma is about 0.3 g/s. All measurements in this work were done for 500 A and 12 slm of argon.

Cathode, made of thoriated tungsten, is protected by the argon flow; therefore its erosion is negligible and its lifetime is long. On the other hand, anode is a copper disc with thickness 16 mm. It is rotating with the frequency 50 Hz in order to assure uniform erosion and is cooled by water. The anode is located outside of the torch body 2 mm from the nozzle exit in horizontal direction. Anode is the source of copper vapors studied in this work.

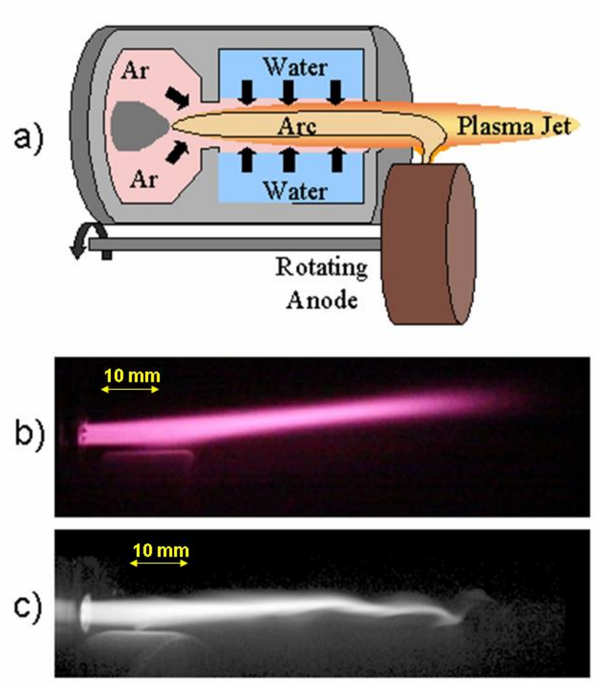

Fig.1: Water-argon plasma torch and jet: a) schematic view of the torch, b) image of the plasma jet (camera Canon EOS 450D, exposure time 1 ms), c) image of the plasma jet (high-speed camera Photron, exposure time 0.29 μs). Both images taken at arc current 500 A and argon flow rate 12 slm

The nozzle connecting arc chamber with surrounding environment has diameter 6 mm. From this description and from Fig.1a it is evident that we are able to observe part of the arc between nozzle and anode, and also free jet downstream the arc expanding to the surrounding atmosphere. Fig.1 contains also two images of the plasma jet; first one (Fig.1b) shows the photograph taken by the camera Canon EOS 450D with exposure time 1 ms. Typical pink colour is caused by the excess of continuum radiation in ultraviolet end of visible spectrum together with the strong lines in the red region (mainly H_α). Image in Fig.1c was taken by high speed camera Photron producing monochromatic images; exposure time 0.29 μs reveals structure of the jet in one specific moment (turbulent character of the jet can be seen in movie with 225 000 frames per second, from which this image comes). One of the interesting features of this image is possibility to clearly observe restricted anode attachment.

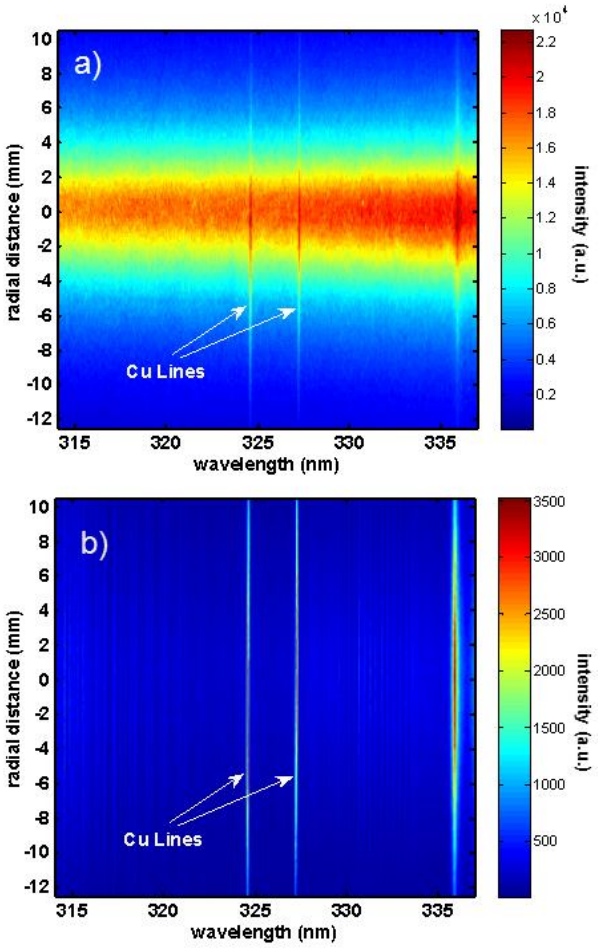

Fig.2: Radial profile of spectrum around spectral lines of CuI (324.75 and 327.40 nm): axial distance a) 40 mm, b) 90 mm

Emission spectra were measured by spectrograph/monochromator Jobin Yvon Triax 550 equipped with iCCD detector with 1024x256 pixels. We used the grating with 1200 grooves/mm providing spectral resolution 0.036 nm/pixel.

3 RESULTS AND DISCUSSION

Erosion of anode due to the arc attachment causes presence of copper atoms in the plasma jet. We measured seven spectral lines of atomic copper at wavelengths 324.75, 327.40, 510.55, 515.32, 521.82, 570.02 and 578.21 nm. First two of them are relatively the most intensive, such that we can observe their radial profile even through the continuum of strongly radiating central part of plasma jet. This is demonstrated in Fig.2 for two axial distances 40 and 90 mm; axial distance is defined as a distance from the exit nozzle of the plasma torch downstream the plasma jet. Similar radial profiles of spectra are shown also in Fig.3 for next three copper lines. In this case for 40 mm lines are weak in comparison with continuum radiation of the jet and can be observed only on the side of the profile closer to anode.

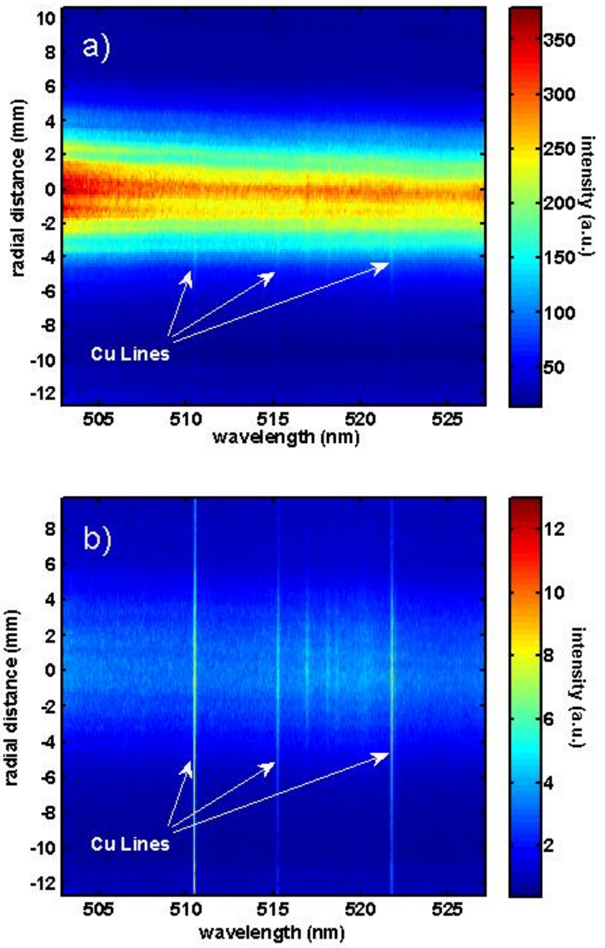

Fig.3: Radial profile of spectrum around spectral lines of CuI (510.6, 515.3 and 521.8 nm): axial distance a) 40 mm, b) 90 mm

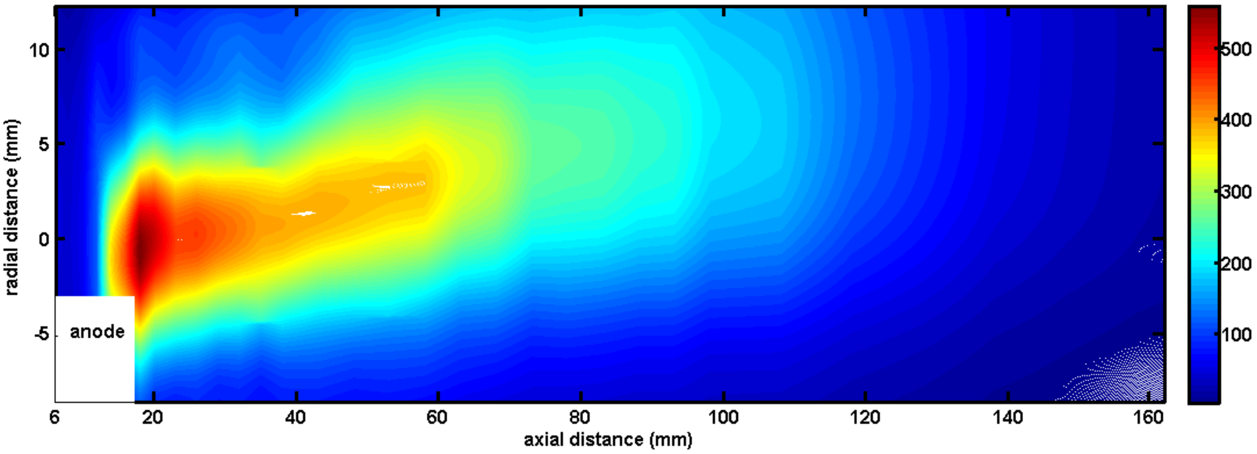

Fig.4: Map of the jet composed as an average value of emission intensities of lines at 324.75 and 327.40 nm. Intensity is in arbitrary units

Intensities of first two lines (324.75 and 327.40 nm) were measured along the plasma jet with the geometric resolution in the axial distance from 2 mm in the anode region to 10 mm in the downstream part. After continuum subtraction and smoothing of the profiles, resulting map of average intensities of these lines was plotted (Fig.4). Zero of the radial distance is defined as the axis of the nozzle. Position of anode is schematically shown. It is evident that region of intensive copper radiation starts at the edge of the anode. It means that the strongest copper evaporation probably takes place in this part. Fig.4 also shows that in spite the radial profiles of copper emission are asymmetrical with respect to jet axis (Figs. 2a and 3a), copper atoms are relatively quickly distributed along the radial profile.

It should be noted that intensity gradient between strongly radiating central part of the plasma close to anode and outer parts of the jet is high. Therefore also asymmetry in copper radial distribution is not apparent in Fig.4; in fact this figure shows the image of the jet which is similar to the image from spectrally integrated radiation (Fig. 1b). Main difference is at the nozzle exit where the amount of copper is negligible. Thus Fig.4 gives information more or less about the presence of copper atoms in wide area of visible jet; their distribution, at least relative, is more difficult to assess. Moreover spectra are line of sight integrated and their radial profiles are asymmetrical, therefore local values of copper radiation by means of Abel inversion are not available.

Additional information can be obtained from CuI excitation temperatures which we present for several axial positions, see Fig.5. Between 30 mm and 80 mm only part of the profile closer to anode is possible to get, since in this region most of the lines are available. In the center of the jet and on its other side opposite of anode only two strong lines with almost the same energy of the upper energy level are measured (Fig.2a), which is not sufficient for reliable excitation temperature determination. All seven copper lines are used to obtain full profiles with the width about 20 mm for axial distances from 90 to 160 mm. In Fig.5 zero of the radial distance is defined as the axis of the jet, not axis of the nozzle as in Fig.4. Such choice of coordinate system makes the figure more understandable and it also clearly shows how the temperature profile becomes symmetric with increasing axial distance. Generally, downstream part of the jet has turbulent nature and temperature determination in this region becomes more complicated. Plasma forming components (argon, hydrogen, oxygen) are mixing with surrounding atmosphere (air); corresponding emission spectra of atomic and ionic species, which were successfully used for obtaining of temperature in arc column [9], get weak and less reliable. On the other hand, molecular emissions (mainly OH), which become more intensive, give ambiguous results, as was shown in [10]. Thus it seems that copper lines can be used for experimental temperature determination in this region with relatively good accuracy. Low amount of copper in plasma brings difficulties in observation of CuI spectrum only in the hot upstream parts. In the downstream regions copper lines are sufficiently intensive and optically thin; conditions of local thermodynamic equilibrium should be still fulfilled and problems with reabsorption can be excluded. However, it must be still kept in mind that temperatures are determined from line of sight integrated radiation, which means that in reality each point in radial profile contains contribution from the whole thickness of plasma column.

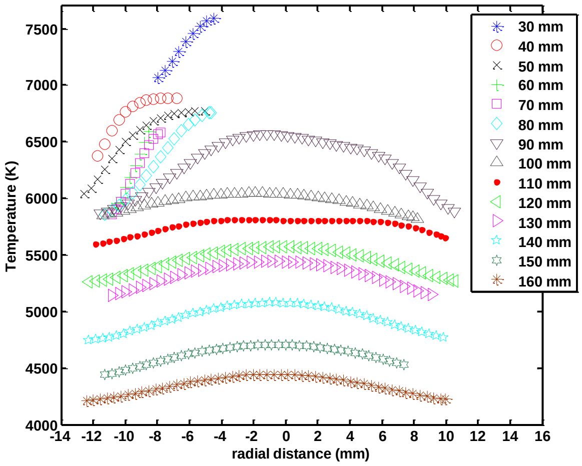

Fig.5: Radial profiles of CuI excitation temperatures for different axial distances

4 CONCLUSION

Copper vapors in thermal plasma jet were studied by optical emission spectroscopy. Analysis of neutral copper emission lines allowed to assess presence of copper in the large area of the plasma jet as well as to determine excitation temperature. In spite of asymmetry of copper intensity radial profiles caused by the anode position, CuI lines can be used as a thermometer mainly in the downstream parts of the plasma jet.

Acknowledgements

This work has been supported by the Grant Agency of the Czech Republic under the project GA15-19444S.

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