Stark Widths of CuI and CuII Lines

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Half widths of 6 CuI and 3 CuII lines have been measured using a plasma jet generated by a modified capillary discharge technique. The presented values are normalized for an electron density of $1.10^{17}\,cm^{-3}$ and a temperature of 20 000 K and are compared with results of other investigations.

Linewidths and profiles are frequently used for spectroscopic determination of plasma parameters. Although atoms and ions of copper can be found in various technical plasmas, only a small number of line broadening parameters are known for this element. To some extent this might be due to difficulties which arise when appropriate plasmas for such measurements are to be produced.

Applying a modified capillary discharge technique, we have measured Stark widths of some CuI and CuII lines. The plasma source is a jet emerging at the end of a capillary, the inner wall of which (length 60 mm, diameter 5 mm) consists of a mixture of BaO, Cu_2O and paraffine. The barium ions in the plasma serve for the temperature determination which is carried out by measuring relative intensities of the BaII lines 4525 Å and 5854 Å (upper levels 5.24 eV and 2.72 eV), using the transition probabilities reported in [1]. The concentration of hydrogen produced by decomposition of the paraffine in the plasma was found to be sufficient for a determination of the electron density from the profile of H_β (using the tables given in [2]). The discharge is ignited with help of a thin wire mounted axially between the two electrodes, located at distances of a few centimeters each from the end of the capillary. A detailed description of the set up is given in [3], including a discussion of the advantages of this method over other capillary discharge techniques and over techniques of sliding sparks along surfaces of liquid jets or threads, as used for such purposes earlier (see also below).

The plasma parameters can be changed by varying the charging voltage of the capacitor bank (15 to 30 kV), the ringing period of the discharge current (20 to 200 µs, controlled by adjusting the circuit inductivity), the time of observation relative to the start of the breakdown, or the distance between the side-on observation plane and the end of the capillary.

All spectra are taken photographically at different times during the first half period of the discharge current using a rotating-mirror-technique as described in [3]. The exposure time is strictly adjusted not to exceed 1/20 of the half period. Radial distributions of the plasma parameters are obtained by Abel inversion of the side-on measured data. To check the optical depth of the emission lines, the measured peak intensities are proved to be lower than 5% with respect to the corresponding black body radiation. The evaluated electron densities are within the range $5 \cdot 10^{17}$ to $8 \cdot 10^{17}\,cm^{-3}$. The temperatures vary between 18 000 and 24 000 K. All measured line widths are converted into values at an electron density of $1 \cdot 10^{17}\,cm^{-3}$ and a temperature of 20 000 K by using Lindholms formula [4]. Table 1 shows the results. Our values are compared with those found by other authors, after these values have also been normalized in the same way to the electron density $1 \cdot 10^{17}\,cm^{-3}$. The reduction to the same temperature was carried out as far as this was possible from the data given in the references.

In all cases the cited authors performed the generation of the plasmas with help of pulsed currents too. Fleurier and Maulat [5] measured linewidths at electron densities ranging from $2 \cdot 10^{16}$ to $2 \cdot 10^{17}\,cm^{-3}$ and temperatures between 5000 and 20 000 K. The other authors had partly similar conditions. Since there might arise problems for an easy access to this literature the experimental conditions of their investigations will be briefly described below.

Keller [6] used the plasma column around a 25 mm long and 0.5 mm thick liquid thread of a special copper-containing solution, created by a peripheral sliding discharge along the surface of the thread. This plasma source and the electrical circuit is very similar to that described in [7] (capacity of condensor bank 21 µF, charging voltage 30 kV, short circuit ringing period 116 µs). The electron density was also drived from the profile of the H_β line. The n_e-values covered a range between $3 \cdot 10^{17}$ and $7 \cdot 10^{17}\,cm^{-3}$.

The electrical discharge circuit used by Lux [8] was similar to that of Keller, but the short circuit ringing period could be varied between 30 and 300 µs. A special type of an electrical wire explosion was used as plasma source, the so-called axial discharge (see e.g. [9]). Thorough investigations of

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this explosion type are reported in [8], [10] and [11]. Lux determined the electron density by 2-wavelengths interferometry. Electron densities between $8 \cdot 10^{17}$ and $2 \cdot 10^{18}\,cm^{-3}$ and temperatures between 23000 and 30000 K were achieved. Also at these high electron densities the half widths dependency on n_e was proved to be linear within the experimental uncertainty of about 20% (mainly caused by the Abel inversion procedure).

Langthaler [12] used a discharge circuit with the following data: Capacitor bank of 20 µF, charging voltage 14 kV, short circuit ringing period 24 µs. The plasma was a jet generated by a pulsed capillary discharge, comparable to some extent to our plasma source. The capillary had a length of 7 mm and an inner diameter of 7 mm and consisted of pressed Mg_2NO_3 powder. Hollow electrodes were attached to the ends of the capillary. This technique was first applied by Heyde and Kusch [13] to perform similar measurements. The investigated ranges of electron densities and temperatures were $2 \cdot 10^{17}$ to $2 \cdot 10^{18}\,cm^{-3}$ and 17000 to 23000 K. The determination of the electron density was carried out by measuring the half width of the MgII line 4481 Å, using the n_e-dependency found by Helbig [14]. An axially mounted copper wire served for the ignition of the discharge, the copper atoms could be brought into the plasma in this way too.

As can be seen from Table 1, the values of the different investigations for the CuI line 4275 Å agree well. The maximum deviation from our value (being near the average of the others) is 18%. As far as the other 3 compared CuI lines are concerned, the values of Fleurier and Maulat [5] show the smallest deviations from our results, being at the maximum 22%. The uncertainty of our values is of the same order. It should be noticed that the discharge circuit and measuring system used by these authors were completely different in comparison to all the other ones. Strong deviations from the values of the other authors (maximum 53% for line 4587 Å of [8]) cannot be simply explained by inexact knowledge of the temperature because the influence of this parameter on the half width is only weak.

The half widths of two of the CuII lines can be compared with those given in [5]. In case of the line 4044 Å a good agreement is found, whereas the two values for the line 4556 Å differ much. This discrepancy demands an explanation on the basis of further investigations, which should be performed anyhow: CuII lines occur in several types of plasmas of technical interest, e.g. switching sparks. Therefore the knowledge of reliable CuII line broadening parameters frequently turns out to be useful for the evaluation of the state of these plasmas.

Table 1. Stark widths of CuI and CuII lines for $n_e = 1 \cdot 10^{17}\,cm^{-3}$ (wavelength and full half width in Å).

Wave-length	Half width					
	This work		Ref. [8]	Ref. [6]	Ref. [12]	Ref. [5]
I 4275	0.44	±20%	0.47	0.37	0.42	0.52
I 4378	0.67	±20%	–	–	–	–
I 4509	0.91	±20%	–	–	–	–
I 4540	0.88	±20%	0.56	0.48	–	0.69
I 4587	0.76	±20%	0.36	0.41	0.55	0.69
I 4651	0.58	±20%	–	0.43	0.45	0.46
II 4044	0.15	±25%	–	–	–	0.17
II 4228	0.11	±25%	–	–	–	–
II 4556	0.13	±25%	–	–	–	0.40

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