SPECTROSCOPY OF ELECTRIC ARC DISCHARGE PLASMA WITH ADMIXTURES OF W, Mo, Cr

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Plasma of electric arc discharges between composite Cu-W, Cu-Mo and Cu-Cr electrodes in argon flow and their spectra were studied by optical emission spectroscopy. Since values of oscillator strengths for W I, Mo I and Cr I presented in various databases are significantly different, selection of spectroscopic data for these elements (particularly oscillator strength) was expected to be useful for plasma diagnostics. The Boltzmann plot method was used as a tool for selection of appropriate spectral lines and their spectroscopic data. The main result of the paper are lists of W I, Mo I and Cr I spectral lines and spectroscopic data, which can be recommended for purposes of diagnostics of plasma with such metal impurities.

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INTRODUCTION

Composite materials on a base of copper with addition of refractory metals are widely used as electrode or contact materials in electric industry applications (e.g. relays, commutators, circuit breakers etc.). Plasma emission spectrum of electric arc discharge between such materials contains spectral lines of Cu (which are well studied) and refractory metals (W, Mo and Cr). So such plasma can be used as spectroscopic tool for analysis and selection of W I, Mo I and Cr I spectral lines and their spectroscopic data.

Spectroscopic data selection for atomic spectral lines among all existing literature sources presents the separate issue of plasma diagnostics. Critical analysis of up-to-date works on determination of spectroscopic data of copper atomic lines was performed [1], which allowed to carry out their selection. Table 1 presents Cu I spectral lines and their spectroscopic data (level energies, oscillator strength) that were selected and recommended for diagnostics of plasma with addition of copper.

Values of oscillator strengths for W I, Mo I and Cr I from various sources are significantly different, so it is reasonable to carry out their careful selection. Brief overview of published works, deals with spectroscopic data W I, Mo I and Cr I, has place in [2].

In order to apply diagnostic techniques of optical emission spectroscopy, first, it is required to select 'convenient' spectral lines for plasma analysis, which must meet following criteria: these lines are supposed to be isolated in the emission spectrum and to be intensive enough for their guaranteed registration. Moreover, the difference between excitation energies of their upper levels must be as large as possible, since it allows determining the temperature with minimal error.

As it was mentioned before, the emission spectrum of copper is well studied, so one can use plasma of arc discharge between composite electrodes on copper base to carry out the selection of spectral lines and corresponding spectroscopic data of other elements, which are present in plasma. Boltzmann plot method was considered as a tool for selection of W I, Mo I and Cr I spectral lines and their spectroscopic data.

When plasma is in local thermodynamic equilibrium (LTE), then the slopes of Boltzmann plot lines corresponding to each spectroscopic plasma component must be the same. This slope depends on the excitation temperature of thermal plasma. In such manner, values of oscillator strength for W I, Mo I and Cr I spectral lines, which are in the best correspondence with the slope determined by intensities of Cu I spectral lines in Boltzmann plot, can be chosen.

It should be noted that spectroscopic investigations of electric arc discharge plasma, which contains vapours of more than one chemical element, require accurate selection of spectral lines for diagnostics. Particularly, Mo I, W I and Cr I spectra contain the large number of closely-spaced spectral lines with comparable intensities. In case of spectral device with low resolution capability, such lines can be registered as one non-separated line.

Such problem can be solved by accurate account of each component's contribution into the total intensity of non-separated spectral line, or by application of device with high spectral resolution for investigation of spectral lines' profiles, for instance, device with cross dispersion.

Table 1

List of recommended Cu I spectral lines and corresponding spectroscopic data for diagnostics of plasma with addition of copper vapours [1]

λ, nm	E_k, eV	E_i, eV	$g_k f_{jk}$
427.5	4.84	7.74	0.9097
465.1	5.07	7.74	1.4218
510.5	1.39	3.82	0.0197
515.3	3.79	6.19	1.6466
521.8	3.82	6.19	1.9717
570.0	1.64	3.82	0.0057
578.2	1.64	3.79	0.0130
793.3	3.79	5.35	0.4246
809.3	3.82	5.35	0.6120

1. EXPERIMENTAL INVESTIGATIONS

1.1. SPECTROSCOPIC DATA OF MO I LINES

For selection of Mo I spectral lines and corresponding spectroscopic data, plasma of electric arc discharge of 3.5 A current in argon flow was studied. Composite Cu-Mo electrodes produced by technology of electron-beam vaporization with further vacuum condensation. Content of molybdenum in the electrodes composition varies from layer to layer and ranges from 1 to 20 % with average value of 12 %.

Fig. 1,a shows Boltzmann plot for Cu I (Table 1) and Mo I spectral lines. Solid line is drawn through points, which correspond to Cu I spectral lines, and dashed line – through points corresponding to Mo I spectral lines.

Selected values of oscillator strengths for Mo I spectral lines, which provide the best match of slopes in Boltzmann plot (Fig. 1,b), are presented in Table 2.

Radiative transition probability A_{ik}, oscillator strength f_{ki}, product of statistical weight of energy level by oscillator strength $g_k f_{ki}$ or decimal logarithm of this product $\lg(g_k f_{ki})$ are given in different sources. In order to simplify the analysis, all spectroscopic data were converted into products of oscillator strengths by statistical weights.

Table 2

List of recommended spectral lines of Mo I, excitation energies and corresponding products of oscillator strengths by statistical weights

λ, nm	E_k, eV	E_i, eV	$g_k f_{ki}$	Reference
441.169	2.08	4.89	1.512	[8]
473.144	2.62	5.24	1.551	[6]
476.016	2.65	5.25	2.031	[6]
550.649	1.34	3.59	1.149	[7]
553.303	1.34	3.58	0.854	[7]
557.044	1.34	3.56	0.460	[7]
603.066	1.53	3.59	0.359	[5]

1.2. SPECTROSCOPIC DATA OF W I LINES

With the aim of spectral data selection, the plasma of electric arc discharge of 3.5 A current in argon flow between composite Cu-W electrodes (Cu:W – 50:50) was studied.

On the basis of analysis of plasma spectrum [9] of electric arc discharge between composite Cu-W electrodes (Fig. 2,a), following W I spectral lines were preliminarily selected for diagnostics: 429.4; 430.2; 468.0; 475.7; 484.3; 488.6; 498.2; 500.6; 501.5; 505.3; 522.4, and 551.4 nm.

Boltzmann plots for Cu I and W I spectral lines are shown in Fig. 2,a. One can see that spectroscopic data listed in work of [10] are in good agreement with linear approximation, but give temperature, which significantly lower than that obtained using Cu I lines. This can be explained by the fact that plasma temperature (T = 4300 ± 150 K) obtained by Kirsanova [10] is lower than typical temperature under similar experimental conditions (5500…9000 K depending on metal content). Thus, there is a systematic error of calculation of absolute values of transition probabilities of W I lines in cited work.

Slight deviation from linear approximation in the neighborhood of W I lines 522.46 and 551.4 nm can be explained by large number of spectral lines and intensive continuum emission, which may lead to increased registered intensity in comparison with real intensity of spectral line.

However, since the location of points corresponding to W I spectral lines 468.05; 484.38; 488.69; 498.26; 500.615; 501.531; 505.33 nm is in good agreement with the slope obtained from the copper lines. These lines can be used in diagnostics of plasma with addition of tungsten.

The best match in slopes of copper and tungsten lines in Boltzmann plots (Fig. 2,b) is achieved using the spectroscopic data from work of [12] (Table 3).

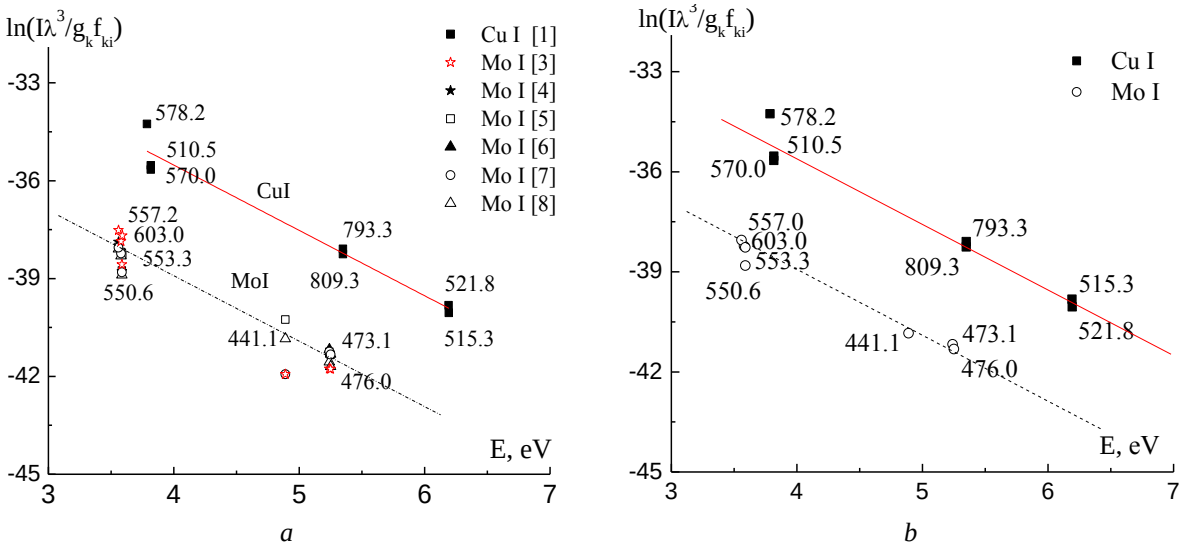

Fig. 1. Boltzmann plot involving Cu I and Mo I spectral lines(a) and selected spectroscopic data (b) for the axial point of the middle cross-section of plasma of electric arc discharge between Cu-Mo electrodes at current 3.5 A in argon flow

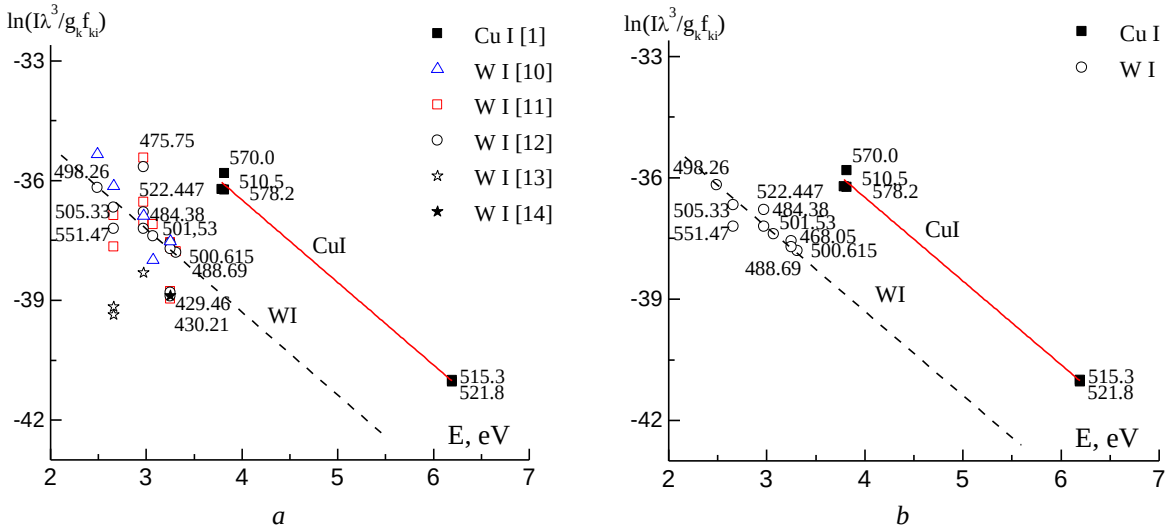

Fig. 2. Boltzmann plot involving Cu I and W I spectral lines(a) and selected spectroscopic data (b) for the axial point of the middle cross-section of plasma of electric arc discharge between Cu-W electrodes at current 3.5 A in argon flow

Table 3

List of recommended spectral lines of W I excitation energies and corresponding products of oscillator strengths by statistical weights

λ, nm	E_k, eV	E_i, eV	$g_k f_{ki}$	Reference
468.05	0.60	3.25	0.032	
484.38	0.41	2.97	0.034	
488.69	0.77	3.31	0.032	
498.26	0.00	2.49	0.005	
500.615	0.77	3.25	0.031	[12]
501.531	0.60	3.07	0.018	
505.33	0.21	2.66	0.022	
522.466	0.60	2.97	0.025	
551.47	0.41	2.66	0.010	

1.3. SPECTROSCOPIC DATA OF Cr I LINES

Plasma of electric arc discharge of 3.5 A current between Cu-Cr-W electrodes was studied to perform the selection of Cr I spectral lines and corresponding spectroscopic data. Electrodes were produced from metal powders with mass ratio of components Cu:Cr:W – 49:49:2. Spectral lines of W I are practically absent in the spectrum, except the weak line W I 522,4 nm, due to the low content of this metal in electrode composition.

As a result of spectrum analysis, Cr I lines 435.18, 458.01, 464.62, 487.08, 532.83 and 540.98 nm were selected for plasma diagnostics, which are not overlapped and are intensive enough to be experimentally registered.

Analysis of Boltzmann plots allows to carry out the selection of values of oscillator strengths for Cr I spectral lines (Fig. 3). It should be noted that data for spectral lines Cr I 487.080, 532.834, 540.979 nm presented in few sources vary insignificantly, so references to these three works are listed in Table 4 altogether.

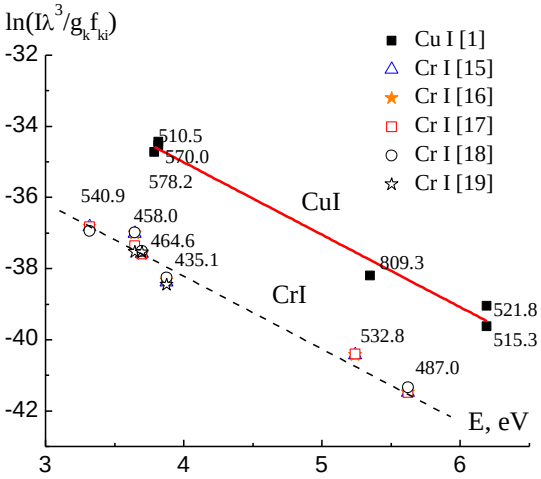

Fig. 3. Boltzmann plot involving Cu I and Cr I spectral lines) for the axial point of the middle cross-section of plasma of electric arc discharge between Cu-Cr electrodes at current 3.5 A in argon flow

Table 4

List of recommended spectral lines of Cr I excitation energies and corresponding products of oscillator strengths by statistical weights

λ, nm	E_k, eV	E_i, eV	$g_k f_{ki}$	Reference
435.177	1.03	3.88	0.331	[18]
458.006	0.94	3.65	0.038	[19]
464.617	1.03	3.70	0.193	[19]
487.080	3.08	5.62	1.12	[15,16,17]
532.834	2.91	5.24	2.88	[15,16,17]
540.979	1.03	3.32	0.189	[15,16,17]

CONCLUSIONS

In this paper, analysis of spectroscopic data from various literature sources of W I, Mo I and Cr I spectral lines was performed. Fundamentals of spectroscopic diagnostics of plasma of electric arc discharge with addition of tungsten, molybdenum and chrome are developed. On the basis of emission spectra analysis

and population of energy levels of metals in Boltzmann plots, W I, Mo I and Cr I spectral lines and corresponding values of spectroscopic data, which are appropriate for the purposes of such plasma diagnostics were chosen.

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СПЕКТРОСКОПИЯ ПЛАЗМЫ ЭЛЕКТРОДУГОВОГО РАЗРЯДА С ПРИМЕСЯМИ W, Mo, Cr

А.В. Лебедь, А.Н. Веклич, Т.А. Тменова

Методами оптической эмиссионной спектроскопии исследована плазма электродугового разряда между композитными Cu-W, Cu-Mo и Cu-Cr электродами. Поскольку значения сил осцилляторов для линий W I, Mo I и Cr I, представленные в разных литературных источниках, существенно различаются, то считалось целесообразным провести селекцию спектроскопических констант данных элементов, для чего использовался метод диаграмм Больцмана. Основными результатами работы являются таблицы спектральных линий W I, Mo I и Cr I, а также соответствующих спектроскопических данных, рекомендованных для диагностики плазмы с примесями этих металлов.

СПЕКТРОСКОПІЯ ПЛАЗМИ ЕЛЕКТРОДУГОВОГО РОЗРЯДУ З ДОМІШКАМИ W, Mo, Cr

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Методами оптичної емісійної спектроскопії досліджено плазму електродугового розряду між композитними Cu-W, Cu-Mo та Cu-Cr електродами. Оскільки значення сил осциляторів для ліній W I, Mo I та Cr I, які наведені у різних літературних джерелах, суттєво відрізняються, то вважалось за доцільне провести селекцію спектроскопічних констант цих елементів, для чого використано метод діаграм Больцмана. Основними результатами роботи є таблиці спектральних ліній W I, Mo I та Cr I, а також відповідні спектроскопічні дані, які рекомендовані для діагностики плазми електродугового розряду з домішками цих металів.