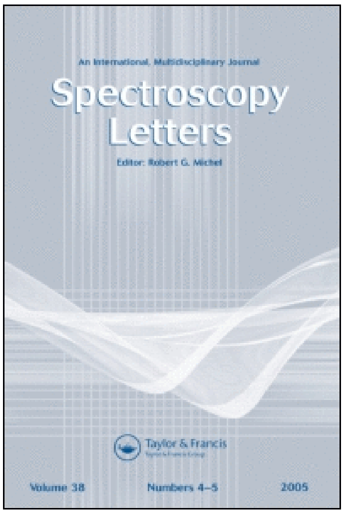

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Junde Wang[a]; Baoming Li[b]; Binghe Gu[a]; Jianqi Zhang[b]; Xinhua Huang[b]; Jiannian Dong[b]; Hongzhi Li[b]
[a] Laboratory of Advanced Spectroscopy, Nanjing University of Science & Technology, Nanjing, P.R. China [b] National key Laboratory of Ballistics, Nanjing University of Science & Technology, Nanjing, P.R China

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THE STUDY ON THE ARC PLASMA TEMPERATURE MEASUREMENT BY OPTICAL EMISSION SPECTROSCOPY WITH FIBER OPTICAL TRANSMISSION

Keywords: Arc Plasma; Temperature Measurement; Spectroscopic Constant;

Junde Wang*[,1], Baoming Li [2], Binghe Gu [1], Jianqi Zhang [2], Xinhua Huang [2], Jiannian Dong [2], Hongzhi Li [2]

[1] Laboratory of Advanced Spectroscopy, Nanjing University of Science & Technology
Nanjing 210014, P.R.China
[2] National key Laboratory of Ballistics, Nanjing University of Science & Technology
Nanjing 210014, P.R.China

Abstract

A method for transmitting radiation of the arc plasma with multimode fused quartz fiber onto the spectrograph has been studied. The plot of the Boltzmann function in emission spectral analysis is used for measuring temperature of the arc plasma. The measured temperature of the arc plasma is 5946.6K from least square linear regression of $ln[\lambda I/(gA)]$ and E_i for a number of the emission line intensities of the excited copper atom. Its regression coefficient and measured precision are -0.97% and 1.7%, respectively. The advantages of the method of the diagnostic temperature for the arc plasma are absolute measurements of the temperature, remote sensing,

*Author to whom correspondence should be addressed.

precision and suitable for mal-environment, such as high temperature, toxic, explosion, strong magnetic or/and electrical fields.

In addition, we have discussed the effect of the spectroscopic constants, such as transition probability, $\boldsymbol{A}$, the statistical weight of the upper level, $\boldsymbol{g}$, and the energy of the upper level, $\boldsymbol{E_i}$, of copper lines on calculating temperature with a plot of the Boltzmann function in detail. The results show that the accurate measurement of the temperature for the arc plasma is obtained only when the spectroscopic constants are selected correctly.

I. INTRODUCTION

We all know the temperature of the arc or spark plasmas, such as the muzzle flash, in-bore arc plasma, railgun plasma, electrothermal and electromagnetic accelerators [1--6], are between 4000K and 14000K, even more high. Besides its high temperature, there are a large quantity of the particles of the carbon in the plasma. Thus, we can not use the common optical methods and instruments, such as CARS[7], Laser-induced fluorescence [8,9] etc., to make the temperature diagnostics. Up to the present, we think the plot of Boltzmann function, i.e., the multi-line method in atomic emission spectroscopy is a better method for measuring plasma temperature. In addition, to use remote measurement is suitable for some mal-environments, such as explosion, high temperature and toxic etc.

The aims of the paper are : (1) multimode fused quartz fiber is used for transmitting the radiation of the arc plasma onto the spectrograph, (2) the results obtained by above method compare with the results from the method that the plasma light illuminates directly onto the spectrograph, i.e., common lens transmission, (3) we discuss the effect of the spectroscopic constants chosen, such as transition probability, the statistical weight and the energy of state, on calculating temperature of arc plasma with a plot of the Boltzmann function.

In this paper, we had measured the temperature of the arc plasma by a plot of the Boltzmann function with a multimode optical fiber spectrograph and the common lens transmission spectrograph. Our experiments prove good results of measured temperature of the arc plasma can be obtained only when those spectroscopic constants are chosen correctly.

II. EXPERIMENT

The optical system used in this work is shown in Fig.1. It consists of a spectrograph and radiation transmission system.

1. Spectrograph

The spectrograph is a Zeiss medium-performance quartz spectrograph. The spectral range of the spectrograph is from 200 to 600 nm.

2. Radiation Transmission

In this work, we utilize two kinds of transmitting radiances onto the spectrograph. One is multimode fussed quartz optical fiber transmission , so called optical fiber transmission. Other is common collecting lens transmission or so called lens transmission. The collecting lens focuses the radiance of the arc plasma on the entrance slit of the spectrograph.

3. Arc Plasma Generator

The basic circuit of a.c. arc plasma generator is shown in Fig.2. The operation principle of the a.c. arc plasma generator refers to [10]. In this work, the arc current is 8A. The breakdown voltage of the arc gap, A_2, is about 10 kV.

III. THE PRINCIPLE FOR MEASURING TEMPERATURE

From the theory of atomic emission spectroscopy[11,12], the relationship between the arc plasma temperature and the relative intensity of the spectral line is given by

$$\ln[\lambda I / (gA)] = C - E_i / (kT) \quad (1)$$

where λ is the spectral wavelength, I is the relative intensity, g is the statistical weight of the upper level, A is the transition probability, E_i is the energy of the upper level, k is Boltzmann's constant and T is the temperature of the arc plasma. The g, A and E_i can be obtained from the handbooks of the spectroscopic constants, chemistry and physics.

For measuring precisely temperature of the arc plasma, the a number of spectral lines for a element measured are used. For a given

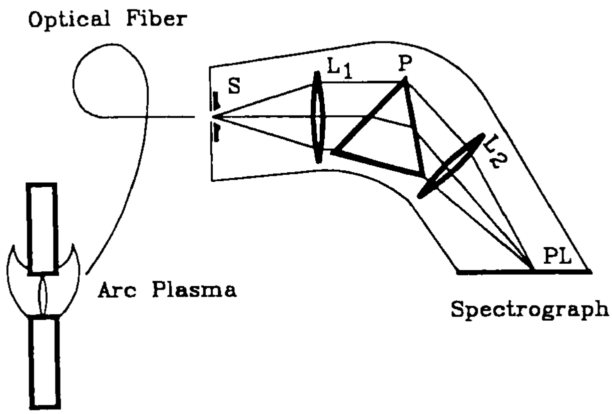

Fig.1. Schematic diagram of the optical system

Spectrograph: Ziess medium quartz spectrograph, S-Slit, L_1-Collimating lens, P-Quartz prism, L_2-Camera lens, PL-Photographic plate holder.

Radial transmission system: Multimode fussed quartz optical fiber or the lens.

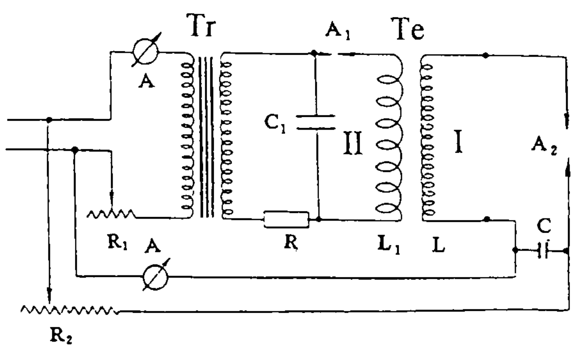

Fig.2. Schematic circuit diagram of the a.c. arc generator with Tesla transformer transmission of the ignition current

The circuit I : arc plasma current circuit(or work current).

The circuit II: Tr - Transformer of 3 kV;

Te - Tesla transformer of 10 kV.

spectrum a plot of the Boltzmann function, the logarithmic term, versus E_i yields a straight line whose slope, S ,is equal to $-1/(kT)$, assuming a Boltzmann distribution in the populations. Thus we can obtain the arc plasma temperature from the slope, S , of the straight line. We write

$$T = -1 / (kS) \tag{2}$$

IV. RESULTS AND DISCUSSION

1. Temperature Measurement with Optical Fiber Transmission

The optical fiber transmission is used in the optical system.

The copper lines and their spectroscopic constants used in this work are listed in Table 1. The statistical weight, g , and transition probability, A , and energy level transition are get from Corliss and Bozman[13].

Measured relative intensities of copper lines are listed in Table 2.

The Boltzmann plot for temperature measurement of the arc plasma is shown in Fig.3.

The temperature measured $T = 5946.9$K,

The linear equation is

$$\ln[\lambda I / (gA)] = -1.951E_i + 16.886,$$

The correlative coefficient $\gamma = -0.965$.

The experiment obtains very good linear relationship between $\ln[\lambda I/ (gA)]$ and E_i. The method of measuring temperature gives a relative standard deviation of 1.7%.

2. Temperature Measurement with Lens Transmission

When both the optical system with common lens transmission and the spectroscopic constants listed in Table 1 are utilized, the measured relative intensities of copper lines are listed in Table 3. The Boltzmann plot for temperature measurement of arc plasma is shown in Fig.4.

The arc plasma temperature measured $T = 5903.4$K.

The linear equation is

$$\ln[\lambda I/ (gA)] = -1.966E_i + 19.66,$$

Table 1. Transition probabilities and energy levels for the copper lines

Spectrum	Wavelength	Energy level transition	Energy of the upper level		gA
	nm	K	K	eV	10^8/sec
Cu I	510.55	11203-30784	30784	2.65	0.051
Cu I	515.32	30535-49935	49935	4.30	4.7
Cu I	521.82	30784-49942	49942	4.30	5.8
Cu I	529.25	43514-62403	62403	5.38	3.2
Cu I	570.02	13245-30784	30784	2.65	0.014
Cu I	578.21	13245-30535	30535	2.63	0.054

Table 2. The relative intensities of copper lines
(The optical system with optical fiber transmission)

Cu I (nm)	510.55	515.32	521.82	529.25	570.00	578.21
ln I	2.12	2.76	4.33	1.75	1.75	2.60

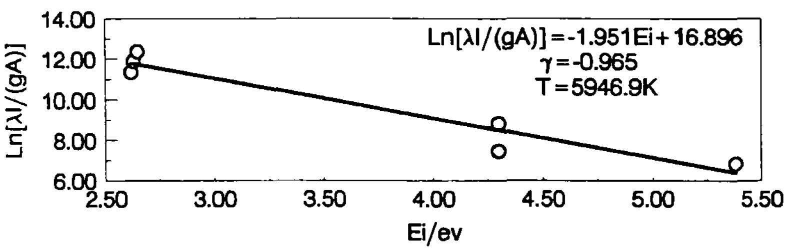

Fig.3. Boltzmann plot for temperature measurement using optical fiber transmission and spectroscopic constants get from [13]

Table 3. The relative intensities of copper lines
(The optical system with common lens transmission)

Cu I (nm)	510.55	515.32	521.82	529.25	570.00	578.21
ln I	3.62	4.31	5.30	3.57	3.80	3.52

linear.

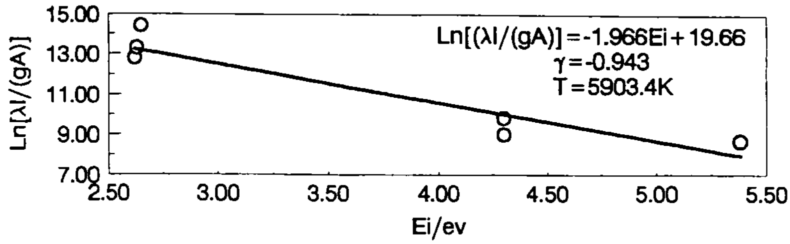

Fig.4. Boltzmann plot for temperature measurement using common lens transmission and spectroscopic constants get from [13]

The correlative coefficient $\gamma = \boldsymbol{-0.943}$.

The relationship between $\boldsymbol{ln[\lambda I / (gA)]}$ and $\boldsymbol{E_i}$ also is very good.

From above experiments we can see the temperatures measured from the optical systems with optical fiber or common lens transmissions are in very good agreement. The temperatures of 5945.9 and 5903.4K agree with [14].

3. The processing experiment data by spectroscopic constants[16]

Hankins et al.[15] had used the spectroscopic constants listed in Table 4 taken from [16] for temperature diagnostics of a dense electrothermal launcher plasma by Boltzmann plot using the relative intensities of copper lines. When we utilize the spectroscopic constants listed in Table 4 to process the experimental data listed in Tables 2 and 3, the Boltzmann plots for temperature measurements are shown in Figs. 5 and 6, respectively.

For optical system with optical fiber transmission:

Linear equation is

$$\boldsymbol{ln[\lambda I/(gA)] = -1.281E_i + 16.396},$$

The correlative coefficient $\gamma = \boldsymbol{-0.716}$,

The arc plasma temperature measured $\boldsymbol{T = 9059.2}$K.

Table 4 Transition probabilities and energies of upper levels for the copper lines from [16]

Spectrum	Wavelength nm	Energy of upper level eV	*g*	*A* 10^8/sec	*gA* 10^8/sec
Cu I	510.55	3.82	4	0.020	0.080
Cu I	515.32	6.19	4	0.60	2.40
Cu I	521.82	6.19	6	0.75	4.50
Cu I	529.25	7.74	4	0.109	0.436
Cu I	570.02	3.82	4	0.0024	0.0096
Cu I	578.21	3.79	2	0.0165	0.033

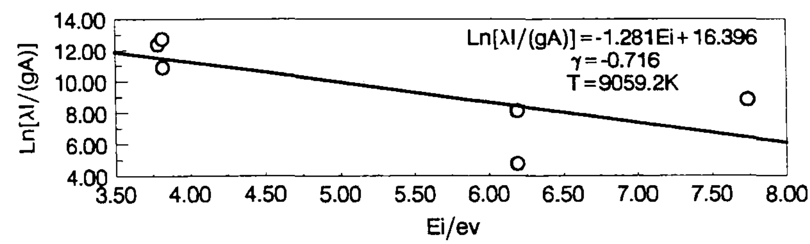

Fig.5. Boltzmann plot for temperature measurement using optical fiber transmission and spectroscopic constants get from [16]

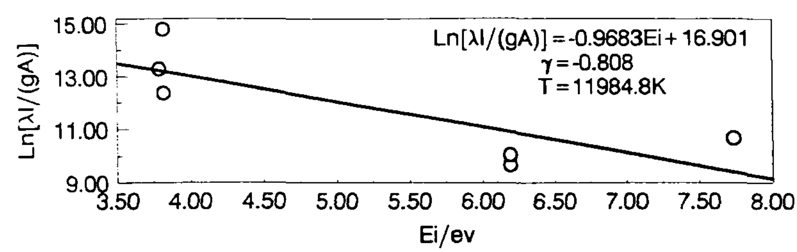

Fig.6. Boltzmann plot for temperature measurement using common lens transmission and spectroscopic constants get from [16]

For optical system with common lens transmission:
Linear equation is

$$ln[\lambda I/(gA)] = -0.9683E_i + 16.901,$$

The correlative coefficient $\gamma = -0.808$,
The arc plasma temperature measured $T = 11984.8$K.

Above experimental results show: (1) We all know that the maximum temperature for this kind of the arc plasma does not exceed 6500K[17]. So measured temperatures of 9059.2 and 11984.8K are incorrect; (2) For a given spectrum a plot of the Boltzmann function taken spectroscopic constants from [16], the logarithmic term, versus E_i yields a straight line that both the linear and the correlative coefficient are very bad. It leads to a bad repeatability of measured temperatures for the same arc plasma .

Therefore, from the experiments it is unsuitable that the spectroscopic constants taken from [16] for copper lines are used for processing the plot of the Boltzmann function to measure the temperature of the arc plasma because it will lead to a great error of the temperature measurement.

V. CONCLUSIONS

The method of multi-line temperature measurement in atomic emission spectroscopy, i.e., so called the plot of the Boltzmann function, can be used satisfactorily for temperature diagnostics of the arc plasma.

It is very important that the spectroscopic constants are selected correctly when the arc plasma temperature is measured by the method of the plot of the Boltzmann function.

Optical spectroscopic system with optical fiber transmission has main advantages: flexible, remote sensing and suitable for some mal-environments of the measurement, such as high temperature, toxic, strong magnetic or / and electrical fields.

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