Spectroscopic Diagnostics of Exploding Aluminum Wire Plasma in Distilled Water

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Abstract

This work aims to study the exploding aluminum wire plasma parameters by using optical emission spectroscopy method. The emission spectra of the aluminum discharge plasma have been recorded and analyzed. The plasma electron temperature (T_e) was calculated by Boltzmann plot, and the electron density (n_e), by Stark broadening for aluminum wire of diameter 0.3 mm and different current 75,100, and 160A in distilled water. The aluminum line 656.279 nm was used to calculate the electron density by Stark broadening. It was found that the electron density (n_e) increase from $28\times10^{16} cm^{-3}$ to 60×10^{16} cm^{-3} with increasing current from 75 to 160 A, while the electron temperatures increase from 0.986 to 1.614 eV for the same conditions. The optical emission spectrum (OES) emitted from the plasma have a peak located at 653 nm corresponding to H_α line for hydrogen atoms, and others peaks belong to Aluminum (AlI and AlII lines), and Oxygen (OI and OII lines). The relationship between the plasma electron temperature, emission line intensity and number density were studied.   [DOI: 10.22401/JNUS.21.2.13]

Keywords: exploding wire; spectroscopy; Boltzmann plot; plasma characteristics.

Introduction

Optical emission spectroscopy is one of plasma diagnostics method. It is used to obtain information about the nature of plasma, such as the chemical compositions and plasma electron density and electron temperature [3]. Emission spectrum often consists of a number of characteristic atomic or ionic spectral lines [4].

The spectral line intensity (I_{ji}) can be described as[3]:

$$I_{ji} = \frac{N}{U(T)} g_j A_{ji} h \upsilon_{ji} e^{-E_j/k_\beta T_e} \quad .... (1)$$

where g_j is the density of states, E_j is the upper level energy, A_{ji} transition probability between the transition states of upper level (j) and lower level (i) and T_e is the electron temperature. Thus the electron temperature of plasma can be calculated using Boltzmann relation [5]:

$$ln\left(\frac{I_{ji}\lambda_{ji}}{g_j A_{ji}}\right) = \left(-\frac{E_j}{KT_e}\right) + \left(\frac{N(T)}{U(T)}\right) \quad .... (2)$$

where λji, is the wavelength corresponding to the transmission between level j and level i. While, the electron density can be calculated, utilizing stark broadening relation [6]

$$n_e(cm^{-3}) = \left[\frac{\Delta\lambda}{2\omega_s(\lambda,T_e)}\right] N_r \quad .... (3)$$

Whereas, $\Delta\lambda$ is the FWHM of the line, and ω_s is the Stark broadening parameter, that can be found in the standard tables N_r is the reference electron density which equal to 10^{16} cm^{-3} for neural atoms and 10^{17} cm^{-3} for singly charged ions. There are many parameters used to characterize the plasma such as Debye length (λ_D) which calculated as follows [7]:

$$\lambda_D = \left(\frac{k_\beta T_e}{4\pi e^2 n_{0e}}\right)^{1/2} \quad .... (4)$$

Plasma frequency which calculated as follows [8].

$$\omega_p = \sqrt{\frac{N_e q_e^2}{\epsilon_o m_e}} \quad .... (5)$$

The number of particles in a Debye sphere (N_D) [8]

$$N_D = n_e \left[\frac{4\pi\lambda_D^3}{3}\right] = \frac{1.38\times10^6 T_e^{3/2}}{n_e^{1/2}} \quad .... (6)$$

where T_e in K

Plasma was produced by different techniques one of them is wire explosion, which has recently gained high attention [1]. Plasma formed by exploding wires using high

electric energy pass throw the wire within short time in different ambient. Several parameters have a control in exploding wires technique such as voltage, current, material type , wire dimension, and the medium in which the explosion is performed, [2].

Experimental part

The explosion of wire is characterized by the energy introduced into the wire, which is higher than the evaporation energy of the material. The energy input time is shorter than the time required for the current to spread into the wire. The basic circuit for exploding the aluminum wires used in produce plasm is shown in Fig.(1). Aluminum wire with diametr of 0.3mm and 20 mm long is used to produce aluminum plasma in 100 ml distilled water. The emitted spectrum produced by the exploding aluminum wire was carried by optical fiber to be analyzed using a spectrometer connected with a computer to record the data, which then used to study the effect of the current on the properties of the produced plasma.
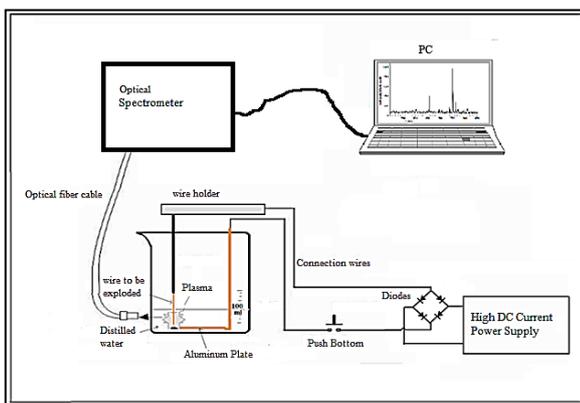

Fig.(1): Schematic diagram for the basic circuit used for the generation and characterization of the plasma.

Results and Discussion

Fig.(2) shows the optical emission spectrum (OES) emitted from the Plasma produced by exploding aluminum wire with diameter of 0.3 mm and different current 75,100 and 160 A. It is noted from the figure that the peak located at 656 nm corresponding to H_α line for hydrogen atoms produced from water molecular dissociate. The others peaks belong to AlI, AlII, OI and OII as the index to each of them. It can be noticed that the peaks

intensities increase with increasing the current this result is in agreement with Wankhede (2013)[1].
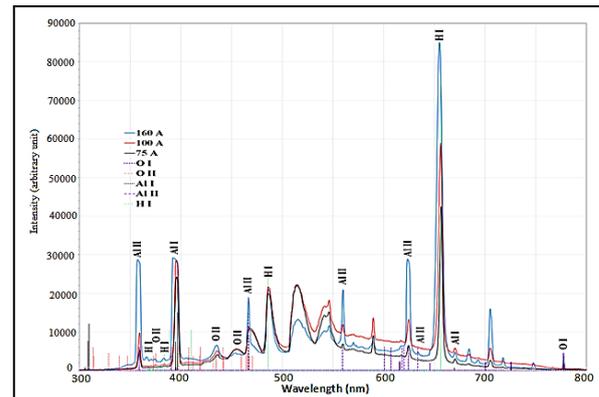
Fig.(2): Emission spectra for Aluminum exploding wire at different current 75,100 and 160A.

The values of electron temperature (T_e) were calculated by Boltzmann plot using four of AlI lines at (359.28, 468.56, 559.88 and 634.55 nm) for different currents, as shown in Fig.(3). The T_e values were deduced from reveres of best fitting line for the relation between $\left(ln \left(\frac{I_{ji}\lambda_{ji}}{g_j A_{ji}} \right) \right)$ versus upper energy level (E_j).The constants values for the aluminum emission lines taken from Sansonetti J. E. and Martin W. C. (2005) [9]. The equations of fitting lines and the R^2 were shown in Fig.(3), where R^2 is the statistical coefficient indicating the goodness of the linear fit.
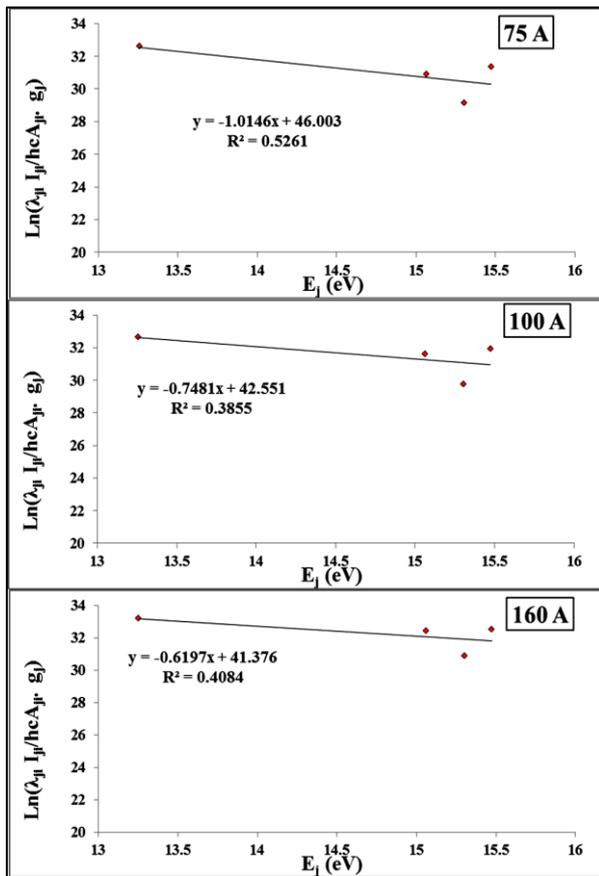
Fig.(3): Boltzmann plot from the Al I lines produced by exploding wire with different current in distilled water and the wire diameter of foro.3mm.
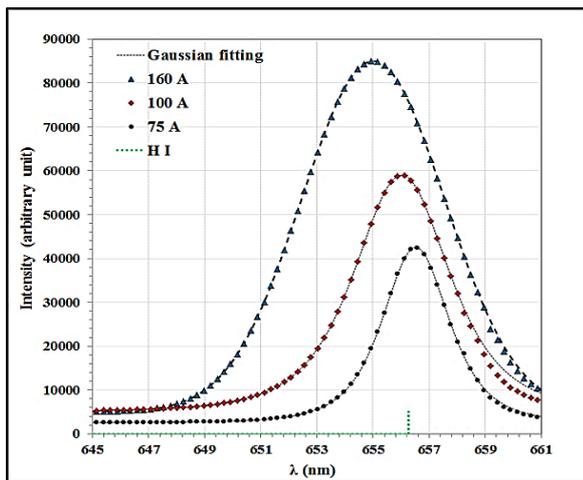

Fig.(4): Hα peaks at 656.279 nm broadening and there Gaussian fitting using different current.

Fig.(4) shows the aluminum line peak profile at wavelength 656.279 nm. Where full width at half maximum found by using Gaussian fitting to calculate electron density for different samples using Stark effect depending on the standard values of broadening for this line [11]. It can be seen

that the full width increase with current increasing, which indicate to increasing in electron density.

Fig.(5) shows the variation of electron temperature (T_e), calculated by Boltzmann plot, and electron density (n_e), using Stark broadening effect, with different current. This figure shows that the n_e increase from 28×10^{16} to 60×10^{16} cm^{-3} with increasing current from 75 to 160 A while the electron temperatures increase from 0.986 to 1.614 eV for the seame conditions. This result is agreed with [1]. The decrement in concentration cause decreasing in collision which caused to increase in electron temperature, where the electron temperature loses by different ways (elastic, excitation and ionization collisions).
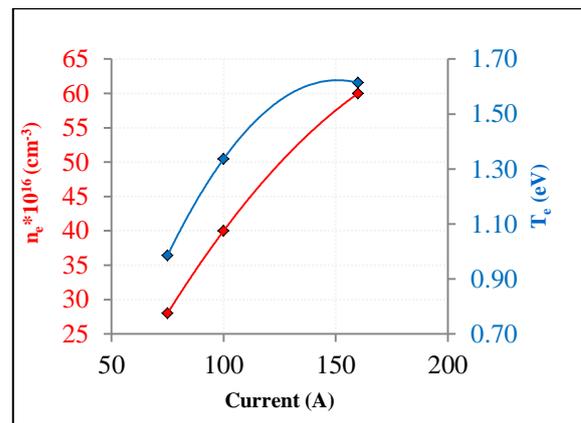

Fig.(5): Electron temperature T_e and electron density n_e for plasm produced by aluminum exploding wire with different current.

Table (1) show the calculated values of Debye length (λ_D), plasma frequency (f_p) and Debye number (N_D) from **aluminum** plasma produced by exploding wire with different with diameters current 57,100,160A.

Table (1)
Plasma parameters calculated from spectroscopy lines for aluminum exploding wire with different current 57,100 and 160A.

Current (A)	T_e (eV)	FWHM (nm)	$n_e * 10^{16}$ (cm^{-3})	f_p (Hz) $*10^{12}$	$\lambda_D * 10^{-5}$ (cm)	$N_D * 10^3$
75	0.986	2.80	28.000	4.752	1.394	3.177
100	1.337	4.00	40.000	5.679	1.353	4.148
160	1.614	6.00	60.000	6.956	1.214	4.492

Conclusions

Study the effect of aluminum wire diameter in exploding wire technique on spectra for produced emissions and the plasma characteristics shows many points as follows:

- Many atomic and ionic aluminum peaks, and a strong peak corresponding to H$_\alpha$ line appeared in all spectra.
- The peaks intensities increase with increasing the current, as a result of increasing the input energy.
- The electron density and electron temperature increase with increasing current.

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