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Spectroscopic Diagnosis of Arc Carbon and Magnesium Plasma

Nada K. Hussein*, S. J. Kadhem

Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract

This research aims to investigate parameters for magnesium (Mg) carbon (C), and carbon/magnesium plasma produced by the exploding electrical wire (EEW) technique. In this work, C and Mg nanoparticles were synthesized. The plasma spectra with three different current values (50, 75 and 100A) were recorded using optical emission spectroscopy (OES). The plasma electron temperature (Te), electron density (ne), plasma frequency (fp), Debye length (λD), and Debye number (ND) provided by arc discharge plasma were calculated. Boltzmann plots were used to calculate the electron temperature (Te); electron density (ne) was calculated by Stark broadening . The results showed that the electron temperature and electron density increased with the increase of current. For carbon plasma, Te increased from (1.243 to 1.533) eV, and ne increased from (8.762 to 9.857) cm-3. Te for magnesium plasma increased from (0.508 to 0.724)eV and ne increased from(6.700 to 10.420) cm-3. When the magnesium strip was exploded in carbon suspension, Te increased from (0.744 to 0.851) eV, and electron density was raised from (5.738 to 9.304)cm-3.

Keywords: carbon plasma, magnesium plasma, plasma diagnostic, Boltzmann plot, Plasma parameters.

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تشخيص الطيف القوسي لبلازما الكربون مغنيسيوم

ندى عبد الكريم حسين* , صبا جواد كاظم

قسم الفيزياء, كلية العلوم, جامعة بغداد، بغداد، العراق

الخلاصة

الهدف من هذه البحث التحقق من معلمات البلازما لبلازما الكربون والمغنيسيوم الناتجة بتقنية تفجير الأسلاك .في هذا العمل تم تشكيل جسيمات الكربون والمغنيسيوم وكاربيد المغنيسيوم النانوية. سجلت أطياف البلازما بواسطة التحلل الطيفي للانبعاثات البصرية بثلاث قيم للتيار (50,75,100)امبير. تم حساب درجة حرارة الإلكترون (T_e) كثافة الإلكترون(n_e), تردد البلازما(f_p),طول ديباي(λ_D)ورقم ديباي (N_D) المتحققة بواسطة بلازما التفريغ القوسي. . تم استخدام مخطط Boltzmann لحساب درجة حرارة الإلكترون (T_e) وكثافة الالكترون (n_e) عن طريق توسيع Stark.النتائج أظهرت للكربون ان درجة حرارة الإلكترون (T_e) تزداد من ev (0.508 to 0.724) و (n_e) تزداد من (8.762 to 9.857)cm^{-3} (T_e) لبلازما المغنيسيوم تزداد من (0.508 to 0.724)

*Email: Nada.Hussein1204@sc.uobaghdad.edu.iq

ev و n_e تزداد من cm^{-3} (6.700 to 10.420).عندما كان شريط المغنيسيوم ينفجر في عالق من الكربون, T_e كانت تزداد من ev(0.744 to 0.851),وكثافة الإلكترون تزداد من (5.738 to 9.304 . cm^{-3})

1. Introduction

Exploding wires are used as detonators for explosives, as momentary high-intensity light sources and in the production of metal nanorods [1,2]. Underwater electrical wire explosion UEWE is accompanied by sophisticated processes related to phase transitions of exploding wire metal-liquid-vapour plasma, generation of strong shock waves SSW in the surrounding water medium, and intense radiation fluxes. One must be aware that all exploding wires do not have the same behavior. There is no "ideal" wire explosion. The gross features of an explosion depend upon the design and operating conditions employed. One should be aware that a change in even a single parameter (e.g., in wire material or dimensions, in energy input, in the environment) may affect the discharge and explosion behavior that one process, rather than another, becomes important. For consistent and comparable results with a particular system, the behavior of the system over a range of operating conditions should be determined by systematic observation [3].
Through this process (EEW), plasma parameters can be studied by analyzing the radiation emitted from the plasma. The effect of experimental conditions like voltage, current pulse, material type, the wire dimensions, the medium in which the explosion is performed, etc., can also be studied [4], which may control the entire process. Employing this technique, underwater electric arcs have shown to cause strong explosions; with pulse current amplitudes of a few hundred amperes, the explosions are driven by electrodynamics forces, which scale with the square of the current [5].
When one magnesium strip touches another in a carbon suspension, a very high current over a very short period of time causes the explosion of magnesium strip and the carbon rod forming plasma. In this way, nanoparticles can be produced from a mixture of carbon and magnesium [6].

2. OES Measurement of Electron Temperature

In most of the prior application of the OES method for electron temperature measurements [7]. The optical emission spectroscopy (OES) is the most popular technique to investigate gas discharge (plasma) [8]. One of the existing methods to measure the electron temperature is Boltzmann plots assuming local thermodynamic equilibrium (LTE) fulfilment. To calculate(Te), the traditional Boltzmann plot technicality could be used employing the following equation[8]:

$$\ln(\lambda_{ji}I_{ji}/hcA_{ji}g_{ji})=-1/kT(E_i)+In(N/U(T \qquad (1)$$

where I_{ji} is the intensity, λ_{ji} its wavelength, g_i is statistical weight. A_{ji} is the transition probability for spontaneous irradiative emission from level i to lower level j, E_i is the excitation energy (in electron volts), k is Boltzmann constant.
Stark broadening of spectral lines in plasma resultsfrom the collisions. The electron density can be determined by a Stark broadening of an emission line or using the linear density ratio of different emissions for the same element [9].The emitting atoms with electrons and ions, resulting in a broadening of the line and a shift of the peak wavelength which is considered as the dominant mechanism for the line broadening, can be used for the determination of electron number density using the following equation:

$$n_e=(\Delta\lambda/2\omega_s)N_r \qquad (2)$$

where ωs is The theoretical line
The responses of charged particles (ions and electrons) to decrease the impact of electric fields applied to Debye shielding. This shielding grants quasi-neutrality which is a

particular property for plasma. A distance (λD) called the Debye length, can be calculated from the following equation [10]:

$$\lambda_D=(\varepsilon_0 KT/n_e e^2)^{1/2} \quad (3)$$

where: ε_0 is the permittivity of free space, e is the electron charge, T_e is the electron temperature.

The number of particles (N_D) inside the sphere of Debye can be found using the equation [11]:

$$N_{D=}\ 4/3\pi\lambda^3{}_D n_e=1.38\times10^6 T^{3/2}/n_e^{1/2} \quad (4)$$

Where T is in K.

3. Experimental part

Vast amounts of energy are squeezed through a thin strip of magnesium in the explosion wire technique, which is greater than the strip material's evaporation energy. The energy input time is less than the time required for current diffusion into the strip.

The system used in this work consists of a 12 cm vertical carbon rod and two parallel carbon rods (6 cm long) fixed horizontally in a beaker containing deionized water. The spectrum of the carbon plasma, resulting from the contact of the vertical rod, which is connected to a negative end of a power supply, with the two horizontal rods, connected to the positive end of the power supply, was recorded for three values of the explosion current (50, 75, and 100) A. Carbon suspension was used as a medium for magnesium strip explosion. Two strips of magnesium connected to the negative electrode and the other to the anode inside the carbon suspension and distilled water exploded when the two strips made contact. This way produced mg/C nano-bar. The spectra were recorded for three values of electric current (50,75,100) A.

The emitted spectrum for plasma was transported by optical fibre and analyzed with a spectrometer linked to a computer to record the spectra, which were used to study the effect of current on the produced properties (c, mg, and mg+c plasma). The data was checked and compared to data from the (NIST) [12]. Figure 1 shows the schematic diagram for the wire exploding system.

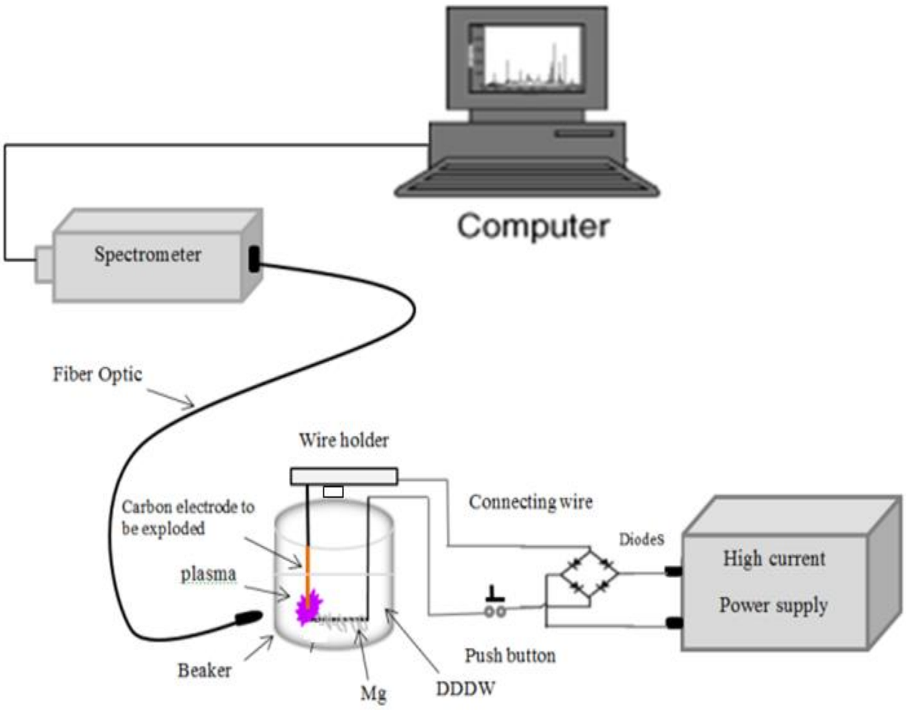


Figure 1- Schematic diagram for the wire exploding system

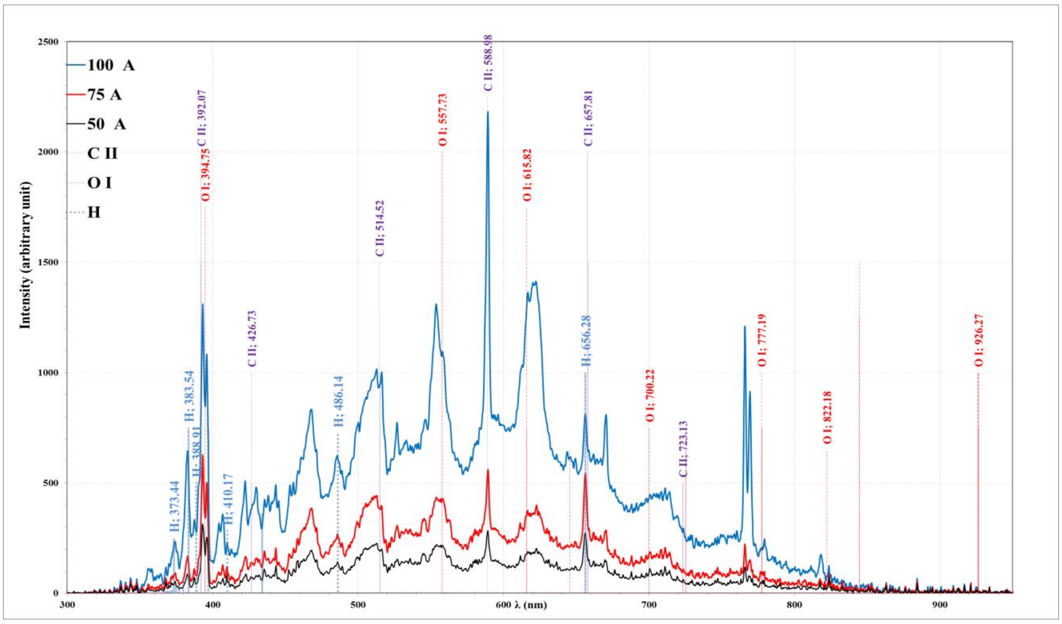


Figure 2-Emission spectrum for carbon plasma for different values of current (50,75,100)A

4. Results and discussions

The optical emission spectrum for magnesium plasma with three different currents is shown in Figure 3. There are several peaks for magnesium atoms and ions in the spectrum, but the highest two peaks are at 448.13 for magnesium ions and 518.36 nm for magnesium atoms. Some peaks appeared in the spectrum for hydrogen and oxygen. Hydrogen atoms peak come from water molecular dissociate. The spectra were recorded within a range from (300-900nm). From the spectra, it can be seen that the intensities of the peaks increase as a result of increasing the current density [13].

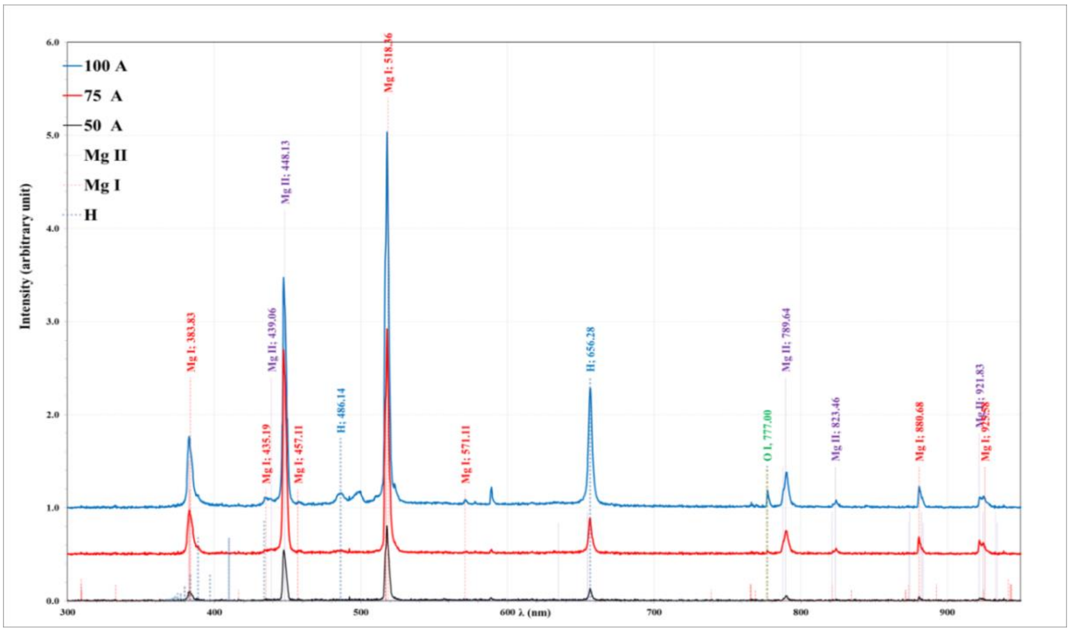


Figure 3-Emission spectra **of** magnesium plasma for three values of current (50,75,100)A

Figure 4 shows the optical emission spectrum, within a range from 300 to 900 nm, for magnesium plasma produced by the explosion of magnesium strip with carbon rod at different DC currents. There are strong peaks atoms and ions lines for MgI, Mg II, Hα. The strongest peak is at about 518.36nm, corresponding to MgI. It is clear from the spectra that the intensities of the peaks increased as the current density increased. In all figures, the intensity peaks of the carbon and magnesium plasmas spectra increased with increasing the current density.

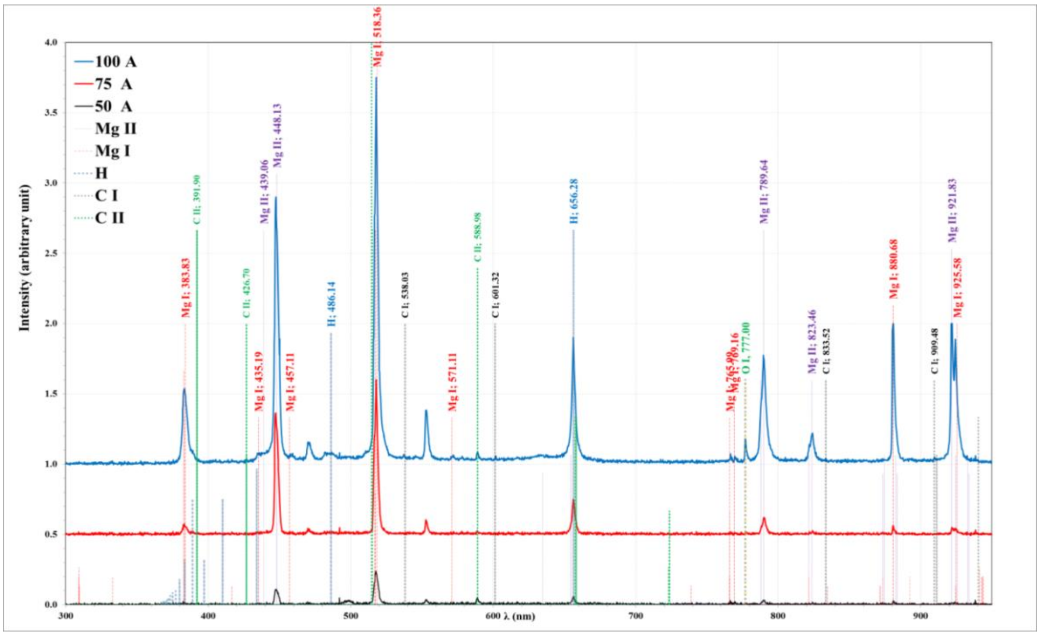


Figure 4-Emission spectrum of magnesium / carbon plasma for three values of current (50,75, 100)A

For all the spectra shown in Figures (2, 3, and 4), it can be noted that the intensities of the peaks have increased as a result of increasing the current density. The increase in the current density means an increase in the atoms provided energy, and thus an increase in the ionization process, i.e. an increase in the electron density.Figures (5, 6, and 7) show the 656.28 nm hydrogen line peak profile for carbon, magnesium and magnesium/carbon plasma, respectively. Using Lorentzian fitting, the full width at half maximum was used to determine electron density for the three plasma with different currents using the Stark effect depending on the standard values of broadening for this line. It can be seen that the full-width decreased with the decrease of current, which indicates decreasing in electron density[14].

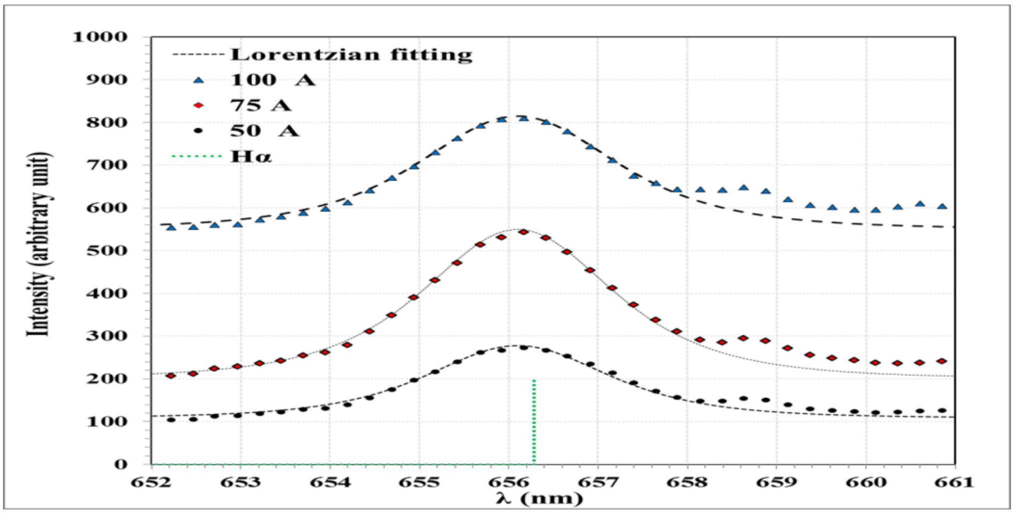


Figure5-Hα 656.28 nm peaks broadening and its Lorentzian fitting for carbon rod of (50 ,75 and100)A currents.

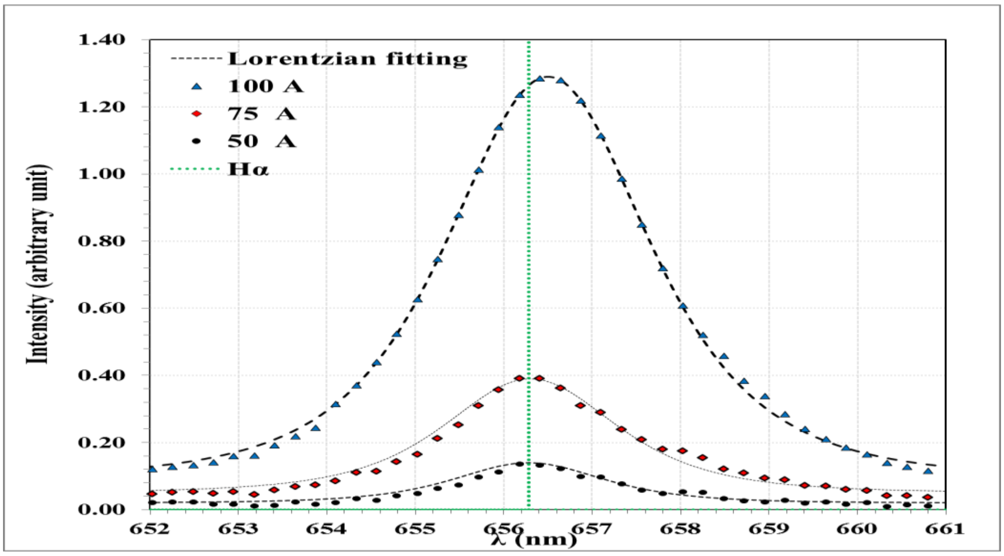


Figure 6-Hα 656.28 nm peak broadening and its Lorentzian fitting for magnesium strip of the three currents (50 ,75 and100)A

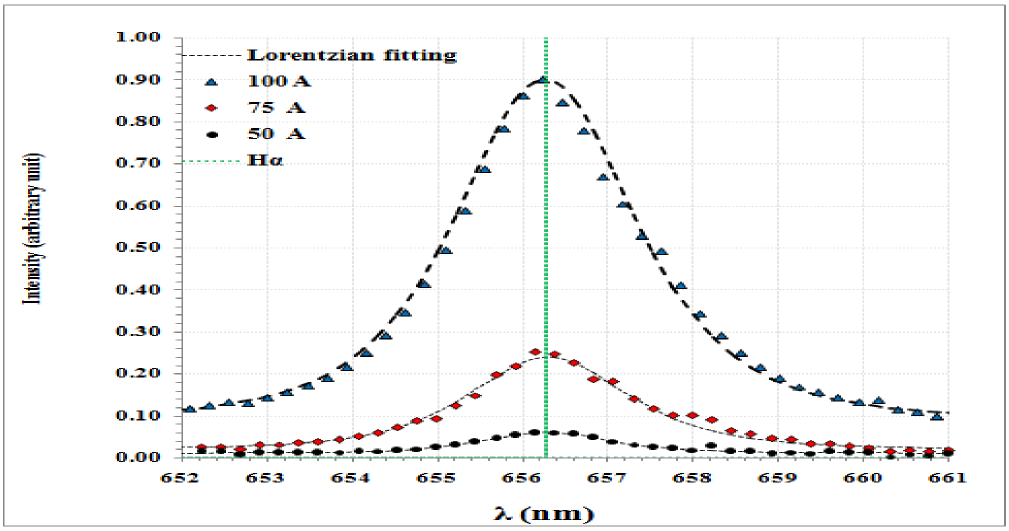
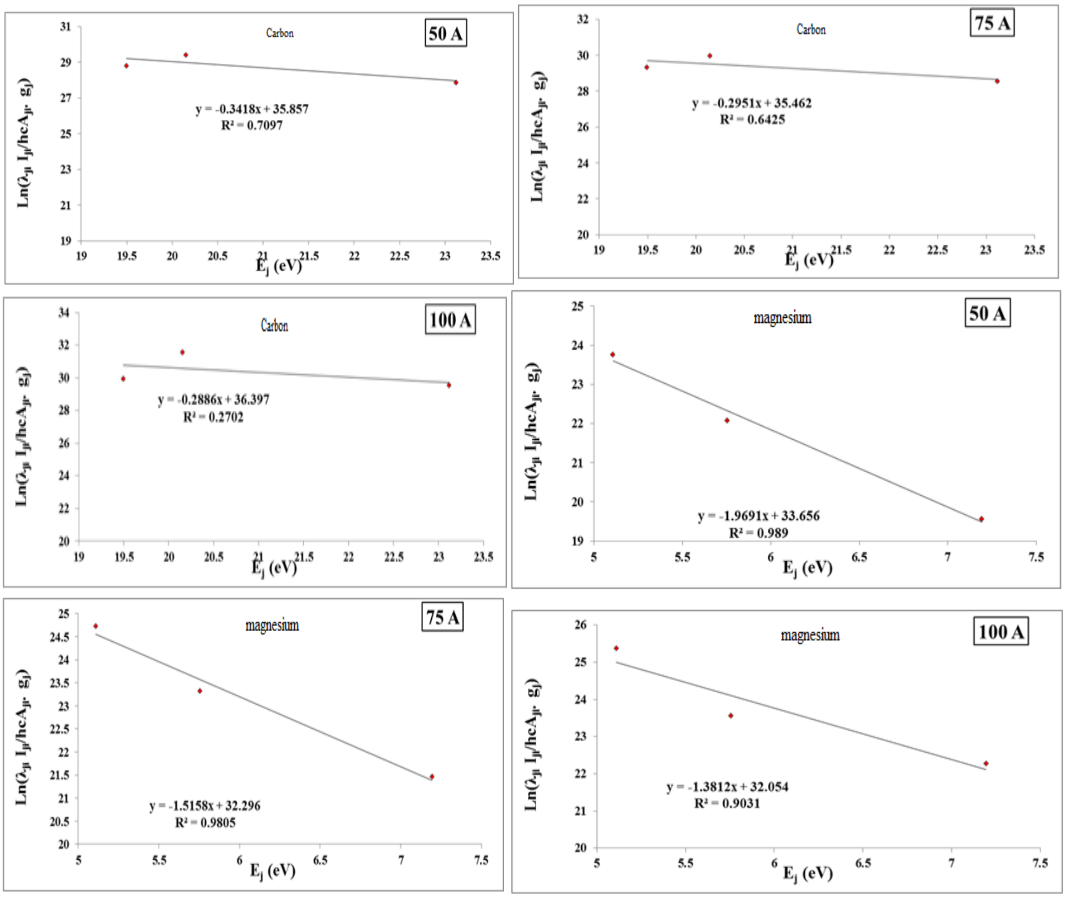


Figure 7-Hα 656.28 nm peaks broadening and its Lorentzian fitting for Mg/C with (50 ,75 and 150) A.

To calculate plasmas parameters, it was assumed that the plasma is in local thermodynamic equilibrium (LTE) and a population of the atoms are excited. The electron temperatures (T_e) were determined from the best linear slope of the Boltzmann plot. Boltzmann plot requires peaks that result from the same atomic species and the same ionization stage. The energies of upper levels, statistical weights, and transition probabilities used for each element's experimental plots were obtained from the National Institute of Standard Technology database (NIST). The electron temperature is equal to the reciprocal of the slope of the fitting line, as shown in Figure 8. R^2 is a statistical coefficient that indicates the good linearity fit and takes a value between (0-1), and the best valuebeing close to 1. Tables 1, 2 and 3 show the values of the different parameters for carbon and magnesium plasma (electron temperature(T_e), the full width at half maximum($\Delta\lambda_{1/2}$), electron density($n_{e)}$, plasma frequency(f_e), Debye length(λ_D), and Debye number for the different current values (50, 75,100) A.

From Figures (9, 10 and 11), it can be noticed that for carbon plasma, the electron temperature increased from 1.243eV to 1.533eV, n_e increased from 8.762 cm^{-3} to 9.857cm^{-3} with the increase of current; for magnesium plasma, Te increase from 0.508eV to 0.724eV and n_e increase from 6.700cm^{-3} to 10.420cm^{-3}; and for carbon/magnesium plasma, Te increased from 0.744Ev to 0.851eV,n_e increased from 5.738cm^{-3} to 9.304cm^{-3}. The electron temperature and electron density were increased with the increase of the current value. From the figures and tables, it can be concluded that the increase of current led to an increase in electron temperature and electron density; this is due to the absorption of energy by the plasma particles.



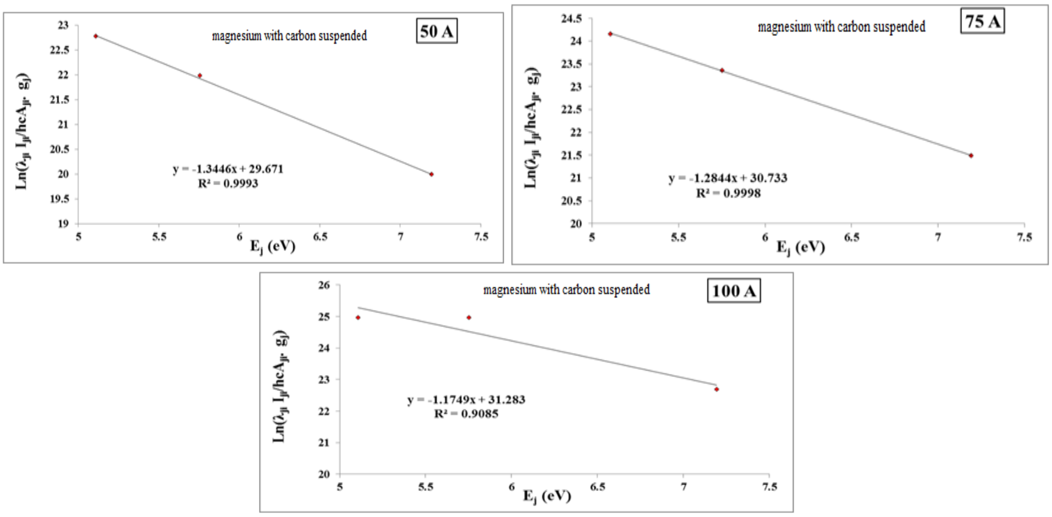


Figure 8-Boltzmann plots for magnesium and carbon lines produced by EEW at different currents.

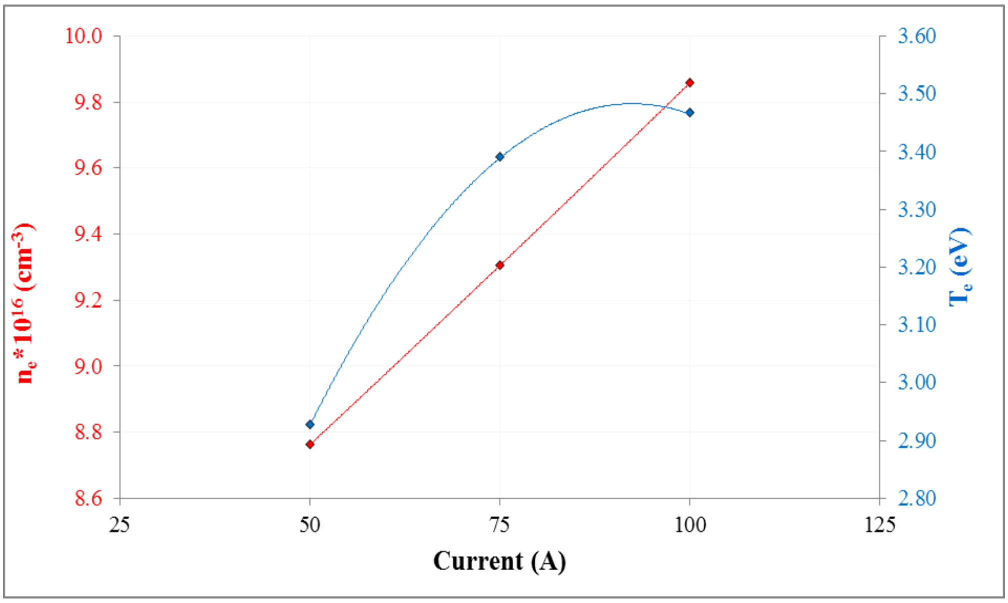


Figure 9- T_e and n_e variation of carbon plasma with current.

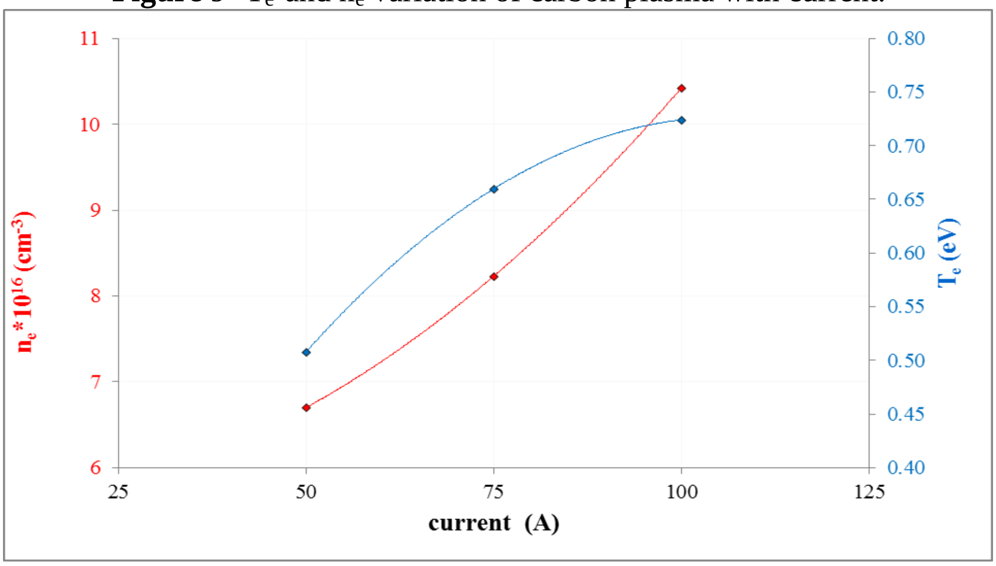


Figure 10-Te and ne variation for magnesium plasma with current

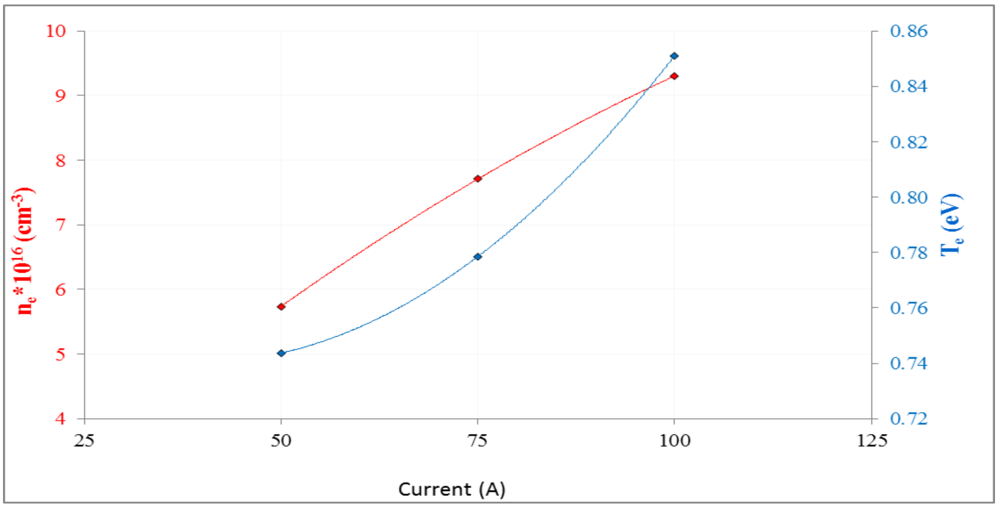


Figure 11-T_e and n_e variation for carbon/ magnesium plasma with current.

Table 1- Carbon plasma parameters for the different values of current

Current (A)	Te (eV)	FWHM (nm)	n_e*10^{17} (cm^{-3})	f_p (Hz) $*10^{12}$	λ_D $*10^{-6}$(cm)	N_d	Idelity
50	1.243	2.400	8.762	8.406	0.885	3	0.178648085
75	1.474	2.500	9.304	8.662	0.935	3	0.153717009
100	1.533	2.600	9.857	8.916	0.927	3	0.150675179

Table 2-Magnesium plasma parameters for the different values of current

Current (A)	Te (eV)	FWHM (nm)	n_e*10^{17} (cm^{-3})	f_p (Hz) $*10^{12}$	λ_D $*10^{-6}$(cm)	N_d	Idelity
50	0.508	2.000	6.700	7.351	0.647	0.760	0.399967
75	0.660	2.300	8.230	8.147	0.665	1.015	0.329746
100	0.724	2.700	10.420	9.167	0.619	1.037	0.325048

Table 3-Carbon/-magnesium plasma parameters for the different values of current

Current (A)	Te (eV)	FWHM (nm)	n_e*10^{17} (cm^{-3})	f_p (Hz) $*10^{12}$	λ_D $*10^{-6}$(cm)	N_d	Idelity
50	0.744	1.800	5.738	6.802	0.846	1.455	0.259371239
75	0.779	2.200	7.709	7.885	0.747	1.344	0.273372877
100	0.851	2.500	9.304	8.662	0.711	1.399	0.266255385

Conclusion

Optical emission spectroscopy is a good way to diagnose plasma. It was used to determine carbon, magnesium, and carbon/magnesium plasma parameters produced by exploding wire in distilled water. The results showed that the electron temperature (T_e), electron density (n_e), and plasma frequency (f_p) all rise when the current increased. The intensity spectra of carbon and magnesium plasmas were raised with the increase of the current density. This means an increase in the number of excited atoms. The increase in current density led to an increase in the energy supplied to the plasma particles. There was a high-intensity peak at 656.28 nm corresponding to H_α line, which indicates the dissociation of water molecules by plasma effect. It was noted that the full-width increased with increasing the current indicating an increase in electron density.

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