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Optical Emission Spectroscopy for Studying Fe Plasma Parameters Produced by Exploding Wire Technique in Carbon Nanotubes - Water Colloid

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Abstract

The goal of this work is to study plasma parameters for Fe plasma generated by exploding wire (EEW) in carbon nanotubes-water colloid with three current values (50, 100 and 150)A. In this research, the plasma electron temperature (T_e), the electron density (n_e), electron density (n_e), plasma frequency(f_p), Debye length (λ_D) and Debye number (N_D) were found for Fe produced by Arc discharge plasma. Boltzmann plot was used to calculate the plasma electron temperature (T_e);electron density (n_e) was calculated from Stark broadening. It was found that the electron temperature values increased from (0.4134 - 0.415) eV and the electron density increased from(0.93 - 1.16)× 10^{17}cm^{-3}.

Keywords: Fe plasma, explosive wire, plasma diagnostic, Boltzmann plot, Plasma parameters.

التحليل الطيفي للانبعاثات الضوئية لدراسة معلمات بلازما الحديد المنتجة بتقنية الأسلاك المتفجرة في عالق من أنابيب الكربون النانوية والماء

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الخلاصة

الهدف هو دراسة معلمات البلازما للحديد المتولدة عن طريق تقنية تفجير الأسلاك في عالق من أنابيب الكربون النانوية والماء بثلاث قيم للتيار (50 ، 100 ، 150) أمبير. في هذا البحث تم ايجاد درجة حرارة الإلكترون في البلازما (T_e) ، وكثافة الإلكترون (n_e) ، وتردد البلازما (f_P) ، وطول ديباي(λ_D) ورقم ديباي (N_D) للحديد الناتج عن بلازما التفريغ القوسي. . تم استخدام مخطط Boltzmann لحساب درجة حرارة الإلكترون في البلازما (T_e) ، وتم حساب كثافة الإلكترون (n_e) عن طريق توسيع Stark. تزداد قيمة درجة حرارة الإلكترون منeV (0.415 - 0.4134) وترتفع كثافة الإلكترون من 10^{17}cm^{-3} ×(0.93 −1.16)

Introduction

Plasma physicists have commonly used the phenomenon of exploded wires (electro explosion of wires or EEW) for the generation and containment of plasma . Several parameters such as voltage, current pulse, material type, wire dimensions, the medium in

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which the explosion is performed, etc. control the entire process. Employing this technique, underwater electric arcs have been 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. Plasma formation from exploding individual wires or multi-wire arrays and a plate of the same metal is powered by a very high current over a very short time through thin when the metallic wires touch the plate.[1]

One of the most essential methods used in plasma diagnostics is optical emission spectroscopy. In this method, the radiation emitted from the plasma beam is analyzed to determine the plasma parameters. Optical emission spectroscopy is used to obtain information about the nature of plasma, like electron temperature, density of the plasma, plasma species and chemical compositions. The main goal of this research is to use optical emission spectroscopy to study plasma coefficients using spectral lines emitted from iron atoms surrounding the plasma.

To calculate(Te), Boltzmann plot could be used as the following equation [2].

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

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 the level i to the lower level j, E_i is the excitation energy (in electron volts), k is Boltzmann constant, N state population densities [3].

Electron density can be determined by Stark broadening of emitted lines or using the linear density ratio of different emissions for the same element [4]. The following equation is used to calculate the electron density(in m^{-3}) from Stark broading [5]:

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

ω_s the theoretical line, measured at the same reference electron density,?????? is the full-width Stark enlargement parameter.

The responses of charged particles (ions and electrons) to decrease the impact of electric fields are applied to Debye shielding. This shielding grants quasi-neutrality special property for, plasma. A distance (λ_D) called the Debye length, can be calculated from the following equation [6].

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

where ε_0 is the permittivity of free space, e is the electron charge, and T_e is the electron temperature. The number of particles (N_D) inside the sphere of Debye can be found from the following equation [7]: $N_{D=}\ 4/3\pi\lambda^3{}_D n_e=1.38\times10^6T^{3/2}/n_e{}^{1/2}$(T in K) (4)

Experimental setup

In explosion wire technique, huge energy, which is higher than the evaporation energy of the wire material, is pushed through thin wires,. The input time of energy is less than the time wanted for the current to diffuse into the wire. Figure 1 shows a schematic diagram for wire explodion system . Iron wires are used in the synthesis of Fe nanoparticles. The system consists of iron wire as the cathode electrode (the negative electrode) of 10 cm length and 0.3 mm diameter , an iron plate which serves as the anode(the positive electrode) with dimensions of 2 x 4 cm and a thickness of 2 mm .The eletrodes are immersed in a 100 ml of carbon nanotubes- double-distilled de-ionized water colloid in a Pyrex glass container under atmospheric pressure. High electric currents with values of (50, 100 and 150)A were passed through the iron wires. The emitted spectrum of the iron exploding wire plasma was carried by optical fibre to be analyzed with a spectrometer that is connected to a computer to record the spectra, to study the effect of current on the produced iron plasma properties. The data were discussed and compared with data from the (NIST) [8].

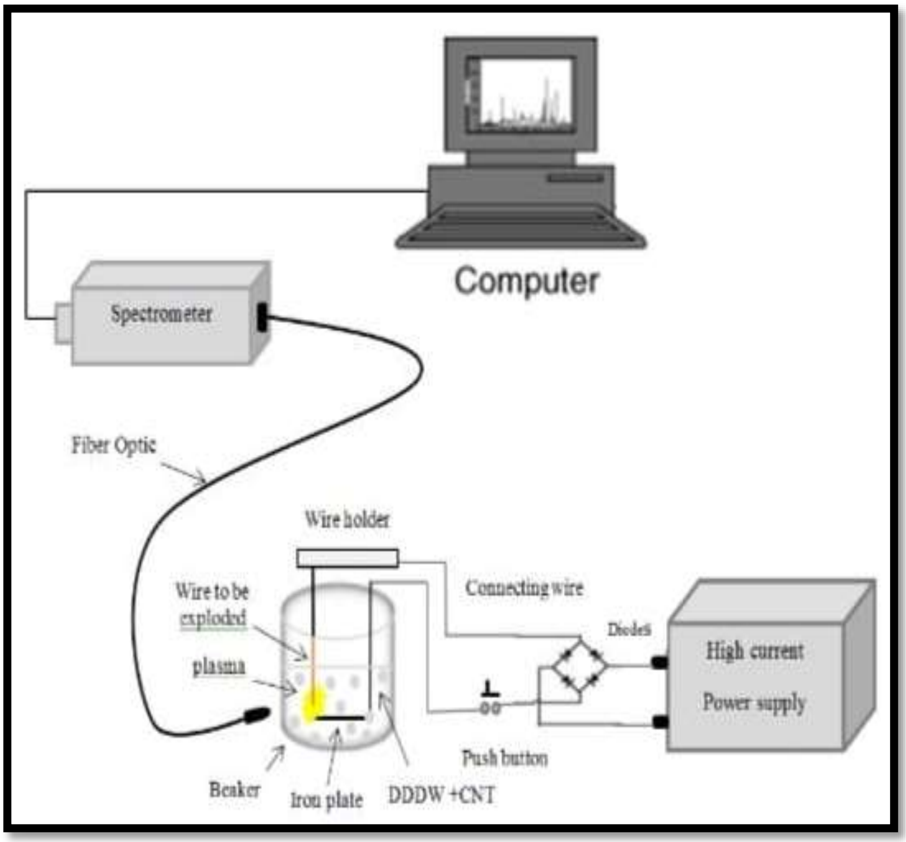

Figure 1-Schematic for the wire explosion system used in the synthesis of nanoparticles and plasma spectrum recording.

Results and discussion

Figure 2 shows the Optical Emission Spectra (OES) for the plasma produced by exploding the iron wires of 0.3 mm diameter using different DC currents of (50, 100, 150) A within a range of (300-800)nm. The spectra show strong atomic and ionic lines for (FeI, FeII, H, OI) [9]. A strong peak is located at about 656.279 nm corresponding to the Hα line for hydrogen atoms and a small peak located at 777.194 nm conformable to oxygen atoms ,both are produced from the dissociation of water molecules. It is clear from the spectra that the intensities of the peaks increase as a result of increasing the current density. This result is in agreement with that of Sawsan [10].

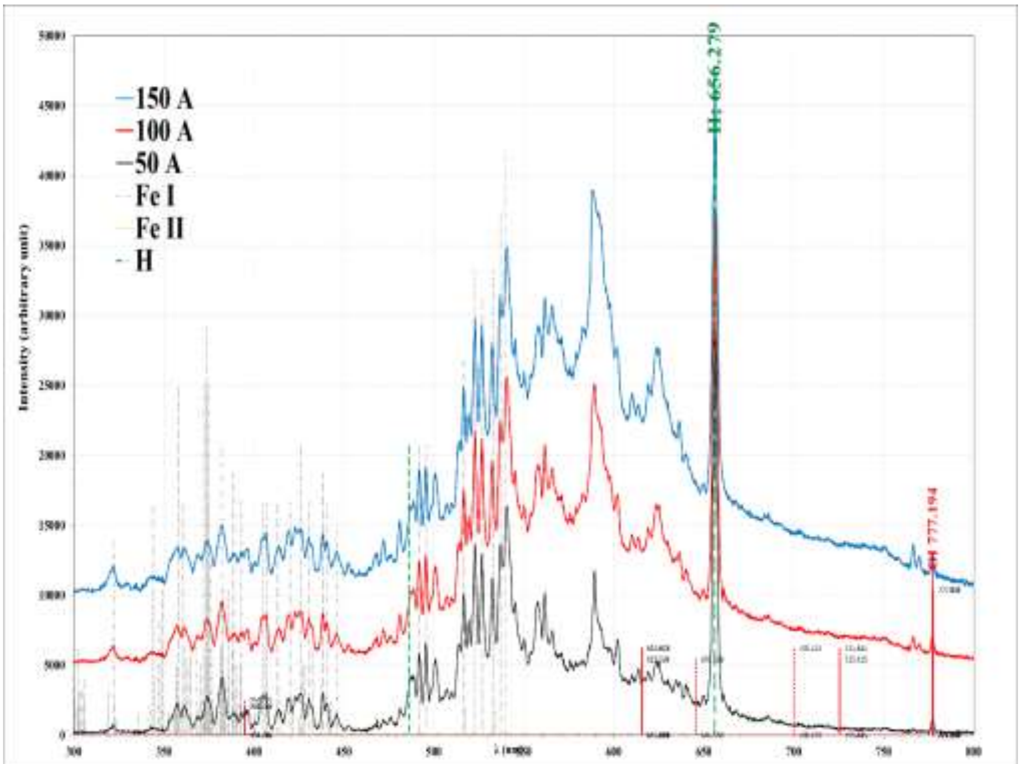

Figure 2-Emission spectra for iron wires with constant diameter and different currents by exploding wire: range (300 – 800) nm.

Figure 3 represents the emission spectra for iron plasma within a wavelength range of (300-550)nm . To calculate the electron temperature (Te), Boltzman plots were drawn for twenty five of FeI lines located at (322.21 , 344.06 , 358.12 , 360.49 , 373.49 , 382.04, 388.63, 393.03, 404.58, 407.1, 413.21, 420.20, 426.05 , 430.79 , 438.35, 440.48, 446.17, 492.05, 495.76, 516.75, 522.72, 526.95, 532.80, 537.15, 539.71) nm for the 0.3 mm wire diameter.

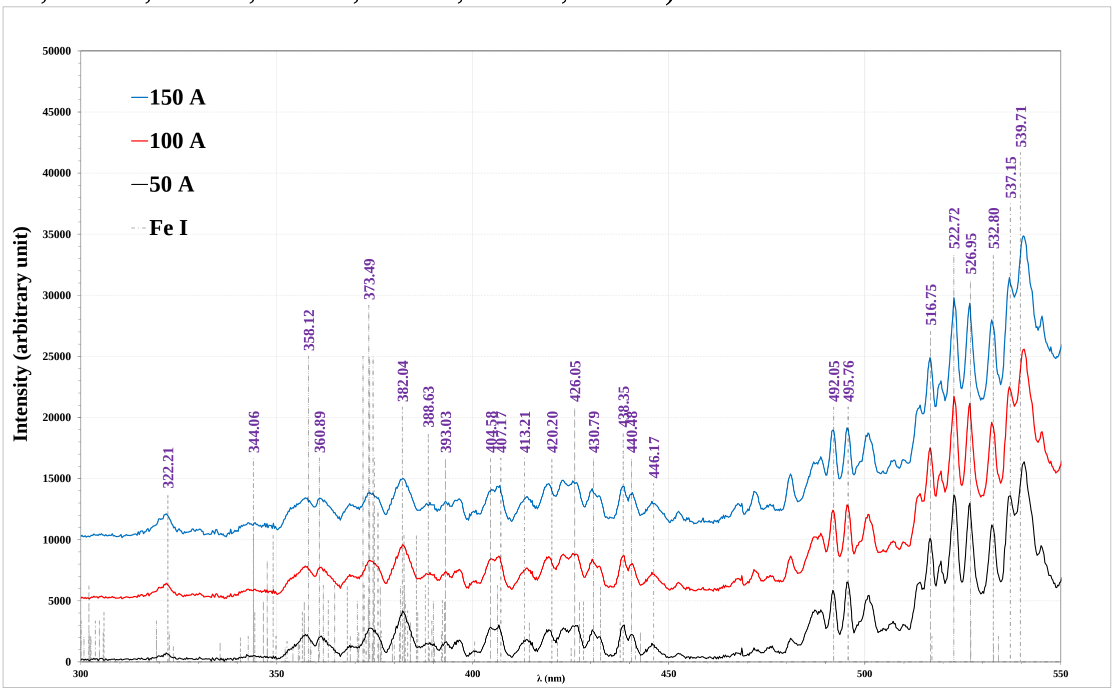

Figure 3-Spectral emissions for iron wires with constant diameter and different currents by exploding wire: range (300 – 550) nm.

Figures (4-a), (4-b) and (4-c) represent the relation between $Ln\ (\frac{Iji\lambda ji}{chgjAji})$ and upper energy level (E_j) for the different values of current. The statistical coefficient (R^2) and the fitting equations are shown on the figures. R^2 indicates the priority of the linear fit. It can be noted that the value of R^2 varies from(0.9495 to 0.9457) eV.

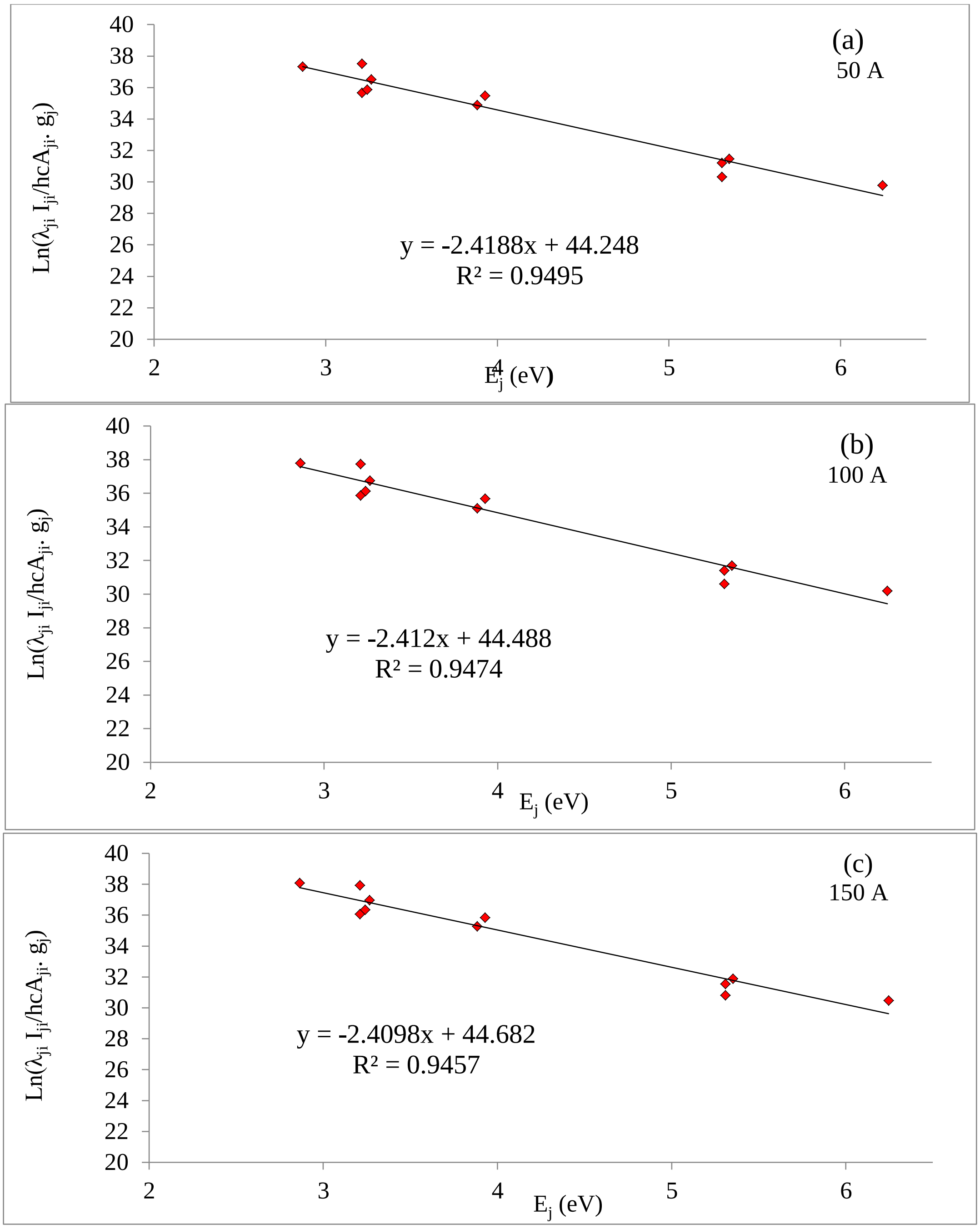

Figure 4-Boltzmann plot for FeI lines produced by exploding Fe wire at different currents.

Figure 5 shows the 656.279 nm hydrogen line peak profiles. Using Lorentzian fitting, the full width at half maximum was found in order to determine the electron density, using Stark effect, for the three samples with the different currents depending on the standard values of the broadening of this line [11]. It can be seen that the full-width at half maximum decreases with the decrease of current, which indicates the decrease of the electron density.

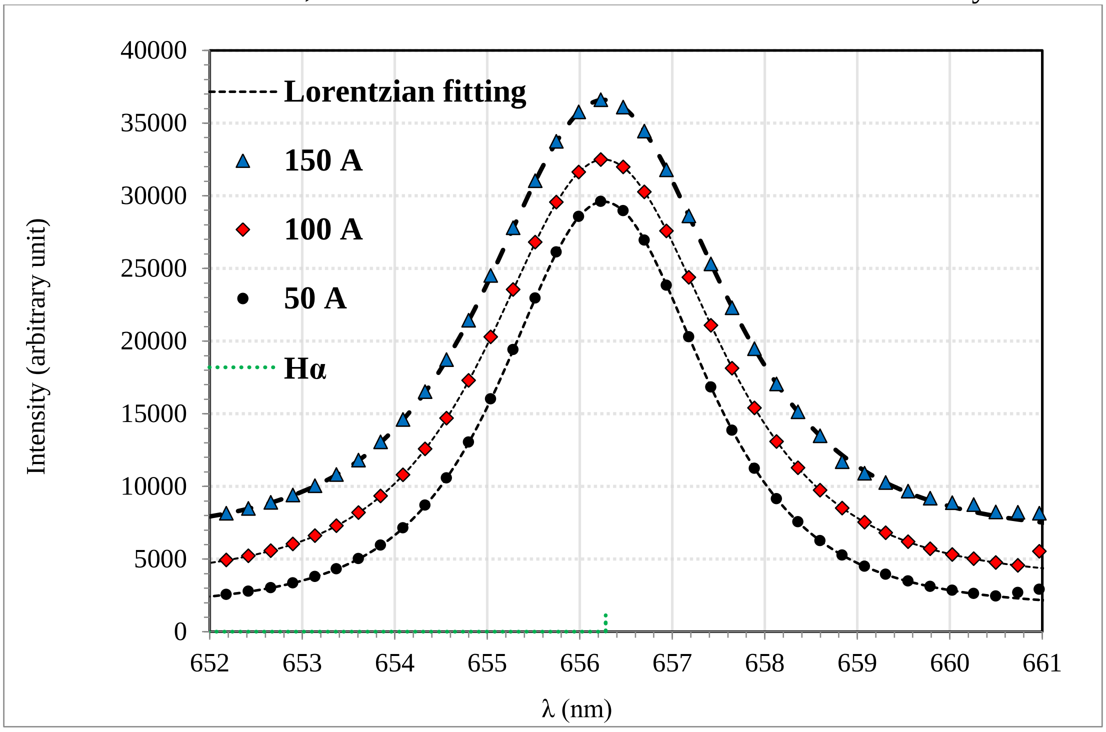

Figure 5- Hα 656.279 nm peaks broadening and there Lorentzian fitting for 0.3mm wire diameters and currents of (50 ,100 and 150)A.

Figure 6 illustrates the relation between electron temperature (T_e) and electron density (n_e) for the different values of current. The electron temperature T_e rises slightly from 0.4134 eV to 0.4150 eV and n_e increases from $0.93\times10^{17}cm^{-3}$ to $1.16\times10^{17}cm^{-3}$ with increasing the current from 50A to 150A . This result agrees with that of Sawsan [11].

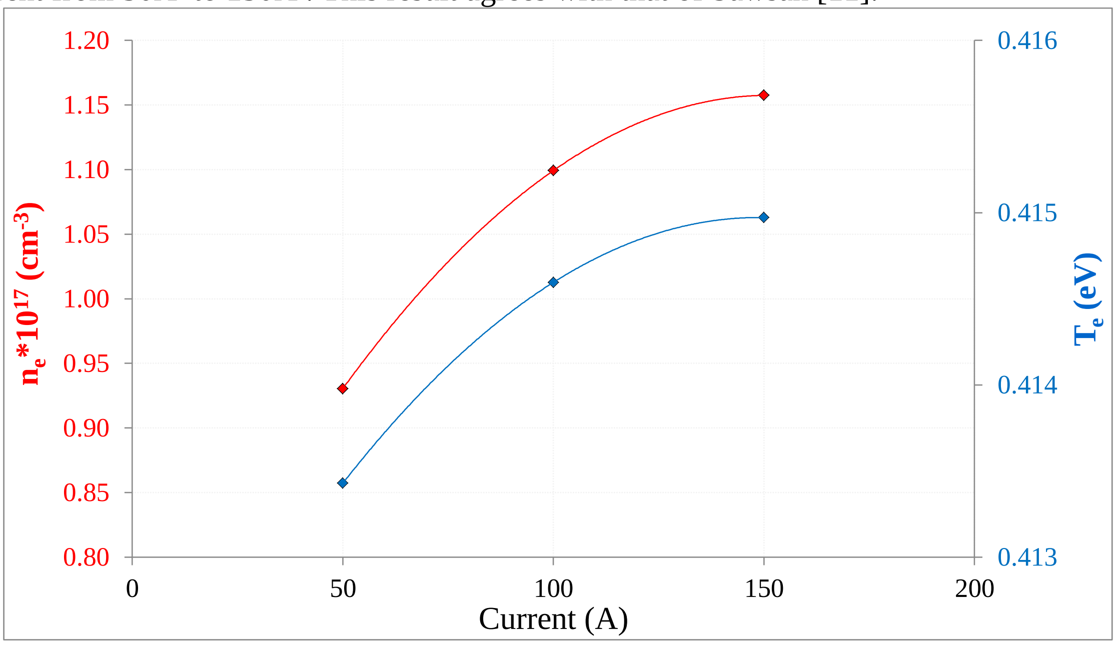

Figure 6-The variation of T_e and n_e for the 0.4mm diameter iron wire and for 50 , 100 and 150 A currents.

Table 1 shows the calculated values of Debye length (λ_D), plasma frequency (f_p) and Debye number (N_D) for the emission from the iron exploded wire . It is noticed that n_e and T_e increase with increasing current due to increased current density, which leads to increase temperature.

Table 1-Calculated plasma parameters from spectroscopy lines intensity of the 0.3mm diameter iron exploded wire for 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)	Nd
50	0.4134	2.5	0.93	2.739	1.566	1.497
100	0.4146	2.8	1.10	2.977	1.443	1.383
150	0.4150	2.9	1.16	3.055	1.407	1.350

Conclusions

Exploding wire system was used to produce iron plasma. The spectrum lines emitted from the plasma depends on the operational conditions. It was found that the emission intensity increased with the increase in the value of the applied current . The electron temperature (T_e), $\Delta\lambda$ or (FWHM), electron density (n_e), and the plasma frequency(f_p), increased with the increase in the applied current due to the increased power supplied to the system.

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