Study of the temperature and electron density of the cadmium sulfide plasma produced by the exploding wire technique using optical emission spectroscopy

Haneen T. Abed 1, Hammad R. Humud 2

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

Abstract. The current study was conducted to reveal the most important parameters of the plasma which are the temperature and density of the electron, the plasma response, the Debye length and the number of particles inside the Debye sphere of the cadmium sulfide by a spectrometer. The results of the electron temperature (Te) and the electron density (ne) were discussed. The results of the cadmium sulfide plasma were discussed. It is generated by using the explosive wire and with different currents.

1. Introduction
Explosive wire is a method used to generate plasma from high current effects by conducting high-quality electric current and transmits the current to a metal wire and is blown on a metal base to cause the wire to sludge, which results in the ionization of the area of the explosion and produces plasma [1]. The wire is normally made out with a diameter of less than 0.5 mm, which is gold, aluminium, iron, platinum or metal [2]. We note a number of previous studies on explosive wires. Gold et al. (2002) [3] used a short (1 mm in length) and ultrathin (10µ m in diameter) Pt wire to investigate micro scale explosive vaporization of water on an ultrathin Pt wire close to its superheat limit. Despite the experimental challenges presented by the phenomena's very short time and length scales, it was possible to obtain novel visualizations and simultaneous pressure and temperature measurements in the vapor micro region, taking a step forward in understanding the complex behaviour of explosive vapor nucleation, formation, and subsequent collapse. P. Sen et al. (2003) [4] identified a novel method for producing Cd, Ag, Fe, and Al nanoparticles by exploding their respective wires, which was triggered by high current densities. X-rays were used to identify the particles. X-ray diffraction (XRD) and atomic force microscopy are two types of diffraction techniques (AFM). They were able to obtain nanoparticles with sizes ranging from 20 to 100 nanometres. A. Alqudami et al. (2008) [5] used an exploding wire technique with a wire–plate device and 12 V batteries to successfully synthesize Ag–Au alloy nanoparticles with an average size of 12+ 2 nm. The formation of nanoparticles alloy with an Ag:Au composition ratio of 80:20 is confirmed by X-ray photoelectron spectroscopy measurements, which agrees with U.V Visible absorption results. Krasik et al. (2009) [6] used microsecond and nanosecond generators to study underwater electrical wire explosions. They demonstrated that increasing the rate of energy input into an exploded wire allows for increased wire temperature and shock wave amplitude. Up to 200eV/atom of estimated energy deposition into Cd and Al wire material was achieved, and the average deposited electrical energy per atom decreased as wire diameter increased. They also discovered that 15% of the deposited energy is converted into the mechanical...
energy of the water flow. For the Ti-Cr alloy, Wonbaek Kim et al. (2009) [7] used an electrical wire explosion of electrode posted metal wires. They discovered that the Cr-coated Ti wire had a 25 percent Cr content. The explosion products included -Ti and TiCr2 equilibrium phases, as well as a metastable Ti-rich phase. Saba (2016) [8] designed and built a charged capacitance exploding wire device in water, ethylene, and PVP to manufacture Cadmium, aluminium, and silver nanoparticles using wires of various diameters. The diameter of pure metal nanoparticles increases with increasing wire diameter, as shown by XRD. Aluminium nanoparticles are smaller than silver nanoparticles. Plasmon peak is located at 400 nm for silver nanoparticles and 590 nm for Cadmium nanoparticles in UV-visible absorption. The plasma was investigated by a spectroscopy [9], where the electron temperature and electron density were collected. The strength ratio between the two lines [10] is the form used in this study. This process is carried out between two transitions of the beam in balanced conditions, local thermal energy levels and local thermodynamic temperature balance. The temperature released from the form of transmitted radiation can be deduced by the equation (1). A ratio of strength is used for the same form between the two lines.

\[ \frac{I_{ij}}{I_K} = \left( \frac{g_i A_{ij} \lambda_{kl}}{g_j A_{kl} \lambda_{ij}} \right) \exp \left[ \frac{E_k - E_i}{KT} \right] \] …………(1)

The electron density per cubic centimeter was calculated using the Stark Effect method and the following equation is using [6].

\[ n_e = \left( \frac{\Delta \lambda}{2W_s} \right) N_r \] ……………………………………………………………..(2)

Ws is theoretical line full width stark broadening parameter, Nr reference electron density approximately=10^{17} cm^{-3} [11].

2. Experimental Part
In this study the plasma spectrum resulting from the explosion of the cadmium wire with a cross-sectional area of 0.3 mm² was examined on a base of cadmium of 0.3 mm thickness inside a solution of aqueous sodium sulfate (75 ml of distilled water dissolved inside one gram of sodium sulfate) and when the wire was melted by energy The high current (75,100,125) ampere was the medium ionized in that region to produce the plasma. The results were compared with the theoretical data of the NIST website [12]. Spectroscopy of optical emission was used to analyze the results. Because it is fast, lightweight, has no moving parts, and requires little power, the diode-array form was used in plasma diagnostics. Figure (1) illustrates a common model. The light is bright. Through a fiber optic cable, signal is gathered and carried into the instrument [13], where it is spread out into a rainbow of colors using a diffraction grating [14]. The scattered light strikes an array of photodiode [15], each of which responds only to the wavelengths that strike it. A charge coupled system (CCD) is used to bind the diodes [16]. Photodiodes take advantage of the photovoltaic effect at the semiconductor-metal interface.

![Figure 1](image)

(a) (b)

**Figure 1.** show that (a) Na2S solution, and (b) exploding wire technique.

3. Results and discussions
Different currents are used to detect light emitted by plasma generated by explosive wire. The spectrum distribution is traced as intensity against wavelength. The emission spectrum of a cadmium
target plasma produced by the detonation of a cadmium wire with a cadmium target within an aqueous sodium sulphate solution at different streams, peaking at 125 A inside the solution, is shown in the figure (2). The spectrum is made up of a variety of spectral lines that are unique to each atom. Strong standard lines for CII, OII, CdI, SII, NI, and NII were compared in the spectral range (396—996) nm. The cadmium emission spectrum as a result of the explosion within the solution is depicted in the diagram. The intensity of the emission lines tends to be influenced by the current value in a clear and important way. Since the mass ablation rate of the target increases with increasing the current value, the intensity of the spectral lines increases. By increasing the current, more of it would be absorbed into the plasma, resulting in more ablation and higher plasma emission spectral line intensities. Since the mass ablation rate of the target increases with increasing the current value, the intensity of the spectral lines increases. By increasing the current, more of it would be absorbed into the plasma, resulting in more ablation and higher plasma emission spectral line intensities.

The ratio method was used to calculate electron temperatures (Te) between two spectral lines. As shown in the figure(3a), this approach includes peaks from the same atomic species and ionization step for the cadmium wire in solution we chose two peaks for CdI at (479.99123 nm and 508.58217 nm). The NIST[12] database provided the weights and transition probabilities used in the experimental charts for each object. The stark expansion equation was used to measure electron densities equation (2). Collisions with charged species cause line expansion and a change in the peak wavelength, resulting in a striking broadening of the spectral lines in the plasma. The determined values of electron temperatures (Te) using the ratio equation between two lines equation (1) indicate that the electron temperature rises with increasing current, as shown in figure (3). Te is similar to equilibrium at higher current values of the wire. Plasma shielding happens as the plasma decreases the transfer of high current energy along the direction of the beam. Since electrons gain enough energy at high currents to travel to higher levels in the material, the electron density decreases as a function of the number of electrons per cubic centimeter.
Figure 3. The variation of $T_e$ and $n_e$ for different current cadmium wire and 0.3 mm$^2$ surface area

The target’s measured electron temperature ($T_e$) and electron density ($n_e$) at various current values are shown in the table 1.

**Table 1.** Plasma parameter (temperature and density of electron) with different current

| Current (A) | FWHM (nm) | $T_e$ (eV) | $n_e \times 10^{17}$ (cm$^{-3}$) |
|------------|-----------|------------|---------------------------------|
| 75         | 5.25      | 1.21       | 2.6                             |
| 100        | 4         | 1.23       | 2                               |
| 125        | 2.06      | 1.23       | 1.02                            |

Conclusion

1. The strength of the plasma emission spectral lines generated by the detonation of the cadmium wire was strongly influenced by the surrounding conditions. It has been discovered that the amplitude increases with rising current at various current values.
2. Making plasma columns out of highly concentrated electrons, ions, and neutral particles with explosive wire for metal targets is a very useful process. The target plasma spectra resulting from detonation are observed to have strong spectral lines in the air environment, and their strength increases with increasing current.
3. The value of the electric current has been found to influence plasma coefficients such as electron temperature and electron density.
4. The results revealed that $T_e$ values increased in the plasma generated by the explosive wire, while $n_e$ values decreased.

References

[1] P. Wankhede, P. K. Sharma, and A. K. Jha, Synthesis of Copper Nanoparticles through Wire Explosion Route, J. Eng. Res. Appl., vol. 3, no. 6, pp. 1664–1669, 2013.
[2] Y. Krasik, S. Efimov, A. Fedotov, D. Sheftman, A. Sayapin, V. T. Gurovich, and A. Grinenko, Underwater Electrical Wire 64 Explosion, ICPIG, vol. 29, pp. 1–4, 2009.
[3] Azzaoui Mohammed, etude de spectroscopy atomique et moléculaire dans un pulvérisateur cathodique magnétron. Mémoire de Magister Université de Ouargla 2013.
[4] B. Held ; « physique des plasmas froids », dunod ,Paris 2005.
[5] A. Dinklage, T. Klinger, G. Marx, L. schwikhard, plasma physic springer, Berlin 2005.
[6] K. Wonbaek, P. Je-shin, and S. Chang-yul, — Ti-Cr Nanoparticles Prepared by Electrical Wire Explosion, J. Mater. Trans., vol. 50, no. 9, p. 2344 to 2346, 2009.
[7] A. Mohammed, Preparation of Metals Nanoparticles (Cu, Al, Ag) by the Exploding Wire Technique in Different Liquids and It’s Characterization, University of Baghdad, College of Science, Msc thesis, 2014.
[8] M. Musadiq, N. Amin, Y. Jamil, M. Iqbal, M. A. Naeem, and H. Akif, —Measurement of electron number density and electron temperature of laser-induced silver plasma,‖ Int. J. Eng. Technol., vol. 2, no. 1, pp. 32–43, 2013.
[9] M. G. Umran Inan, Principles of Plasma Physics for Engineers and Scientists, vol. 1. New York: Cambridge University Press, 2011.
[10] H. M. Jafri, S. Beenish, F. Kazmi, M. U. Farooq, S. A. Munir, T. Beijing, and T. Beijing, Optical Emission Spectroscopic Diagnostics of Sodium Impurities in Water Using High Current Density Underwater,‖ Sci.Int.(Lahore), vol. 28, no. 2, pp. 927–930, 2016.
[11] D. Briggs and M. P. Seah, Practical Surface Analysis By Auger and X -Ray Photoelectron Spectroscopy, John Wiley & Sons L, New York, or I Also
[12] C. D. Wagner, W. M. Riggs, L. E. Davis, J. F. Moulder, G. E. Muilenberg, Handbook of X – Ray
[13] “NIST National Institute of Standards and Technology USA, electronic database.”
[14] J. G. C. Veinot, M. Ginzburg and W. J. Pietro, Chem. Mater. 9,2117 (1997).
[15] N. Herron, Y. Wang and H. Eckert, J. AM. Chem. SOC. 112, 1322 (1990).
[16] I. Uchida, J. Phys. SOC. JPN, 21 645 (1966). [23] H. Tang, M. Yan, H. Zhang, M. Xia, D. Yang, MATER. Lett. 59, 1024 (2005).
[17] A. A. Vuylsteke and Y. T. Sihvonen, Phys. Rev. 113, 40 (1959). [25] B. Liu, G. Q. Xu, L. M. Gan, C. H. CHEW, W. S. Li, Z. X. Shen, J. APPL