

A Spectroscopic and structural study of FeCoSb alloy

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Abstract

Fe, Co and Sb nanopowders were fruitfully prepared by electrical wire explosion method in Double distilled and de-ionized water (DDDW) media. The formation of iron, cobalt and antimony (FeCoSb) alloy nanopowder was monitored by X-ray diffraction. The x-ray diffraction pattern indicates that there are iron, cobalt and antimony peaks. Optical properties of this alloy nanoparticles were characterized by UV-Visible absorption spectra. The absorption peak position is shifted to the lower wavelengths when the current increases. That means the mean size of the nanoparticles controlled by changing the magnitude of the current. The surface morphological analysis is carried out by employing Scanning Electron Microscope (SEM). Particles with varies size were observed also from the images the some particles have uneven shapes with agglomerate and the other have spherical shape. The exploding FeCoSb alloy wire plasma parameters is study by optical emission spectroscopy. The emission spectra of the plasma have been recorded and analyzed. The plasma electron temperature (T_e), was determined by Boltzmann plot, and the electron density (n_e), by Stark broadening for wire with diameter 0.3 mm and current of 75A in distilled water.

Key words

Fe alloy, FeCoSb alloy, exploding wire, nanoparticles, optical properties

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دراسة طيفية وتركيبية لسبيكة FeCoSb

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الخلاصة

تم تحضير جسيمات ال Fe و Co و Sb النانوية بنجاح بطريقة الأسلاك المتفجر كهربائيا داخل الماء مقطر مرتين ومنزوع الايونات (DDDW). تم إجراء الدراسة التركيبية لجسيمات الحديد والكوبالت والانتيمون (FeCoSb) النانوية بواسطة حيود الأشعة السينية. وظهر نمط حيود الأشعة السينية وجود قمم الخاصة بالحديد والكوبالت والانتيمون. أما الخصائص البصرية لهذه الجسيمات النانوية تم توصيفها بواسطة UV-Visible absorption spectra. يلاحظ إن قمة الامتصاص تزاح إلى أطوال موجية أقل عند زيادة التيار. وهذا يعني إن متوسط حجم الجسيمات النانوية المحضرة يتم التحكم فيها عن طريق تغيير قيمة التيار. باستخدام تقنية المجهر الإلكتروني الماسح SEM تم تحليل المورفولوجي السطح. يلاحظ من خلال صورة المجهر الإلكتروني الماسح SEM إن الجسيمات المتكونة ذات أحجام مختلفة وقسم ذات أشكال غير منتظمة متجمعة مع بعضها والقسم الأخر ذات شكل كروي. تم دراسة معالم البلازما المتولدة من تفجير أسلاك سبيكة من FeCoSb. طيف الانبعاث للبلازما تم تسجيله وتحليله. تم البلازما، باستخدام مخطط بولتزمان تم تحديد درجة حرارة إلكترون (Te)، واتساع ستارك Stark broadening لحساب كثافة الإلكترون (n_e) للبلازما المتولدة من تفجير سلك قطره 0.3 ملليمتر وبمقدار تيار 75 أمبير داخل الماء المقطر المعالج ايونياً.

Introduction

Nanoparticles have been a source of enormous attention because of their novel electrical, optical, physical, chemical and magnetic properties. There are a many of reports of physical and chemical processes for fabrication of nanoparticles one of them is by using plasma (exploding wire method) [1]. The nanoparticles have momentous possible for a wide range of applications like composite materials, catalysis, magnetic recording media, magnetic fluids, optoelectronic materials, fuel cells and sensors [2, 3]. FeCoSb alloys are attracting greatly attention because their extraordinary physical, chemical, and magnetic properties. Recently, FeCoSb alloy nanoparticles have unique properties that be different from those of the bulk materials [4, 5]. These novel properties are because high surface to volume ratio, morphology, small particle size and surface coating of nanoparticles. FeCoSb alloy nanoparticles have interesting application like biomedical and catalytic applications [6].

The preparation methods influence the properties of nanoscale metal such as iron particles. There are chemical and physical methods are used to produce metal and metalloid nanoparticles in the form of powders and colloids [7, 8]. In the present study we report the characterization and unusual optical of Fe, Co and Sb

nanoparticles prepared from the FeCoSb alloy using the exploding wire technique. Physical-chemical description has considered X-ray diffraction (XRD), UV- visible and scanning electron microscopy (SEM). Also The plasma which produced by exploding wire method characteristics were investigated based on optical emission spectroscopy (OES).

Experimental setup

In this work, FeCoSb alloy wire with diameter of 0.3 mm was exploded in Double distilled and de-ionized water (DDDW). The explosion was carried out with three values of current 50, 75 and 150 mA. The source voltage available was 35 volts. Referring to Fig.1, a reaction beaker with volume 500 mL was used as the explosion chamber as shown in Fig.1. When the first electrode (wire) touched the second electrode (plate) the wire vaporized, and convert into plasma. The material for wire and plate is the same but with reverse polarity. The exploded wire is related to the perfect geometry during the wire guide. The plates were set on the base of reaction beaker which filled with 100 ml of DDDW. The electrical circuit leftovers open until the contact is made by the wire on to the plate mechanically resulting in the wire explosion through a non linear process in very short time. The nanoparticles disperse in the DDDW solution.



Fig.1: The system of explosion wire in liquid media.

The wires have been exploded by bringing the alloy wire into speedy contact with the plate. The wire is exposed to several sparks and is being replaced after several contacts. The electrical explosion wire (EEW) process is very energy exhaustive since

only relatively low voltages are applied, and also results in huge quantities of nanoparticles being formed from both the consumed electrodes. The experimental parameters are summarized in Table 1.

Table 1: Summary of experimental parameters.

Wire Materials	FeCoSb alloy
Wires diameter	0.3mm
Applied current	50-75 and 150 A, DC
Wire length	20 cm
Metal plate	(70 x 40) mm and thickness of (2 mm)
Liquid type	DDDW (Double distilled and de-ionized water)
Liquid volume	100 mL

Fig.2 shows image of FeCoSb alloy colloid, prepared by electrical explosion wire technique, in DDDW media. We noted from the figure that

the nanoparticles are attracted to the magnet. That mean the composi contains Iron nanoparticles.

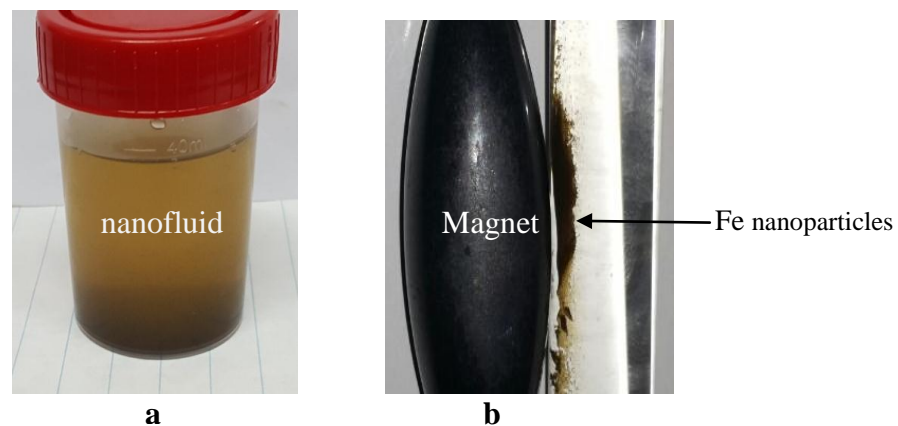


Fig. 2: a) Image of FeCoSb alloy colloid prepared by EEW in DDDW. b) Image of FeCoSb nanoparticles which attracted to the magnet.

UV-Visible absorption spectrum of Fe nanofluid

Fig.3 illustrated the absorbance of nanofluid that prepared from alloy wire at different current. It is clearly from this figure that the optical properties depend on the amount of current. The

absorption peak position is shifted to the ultraviolet region when the current increased that means the diameters of the particles decreases with the current increases.

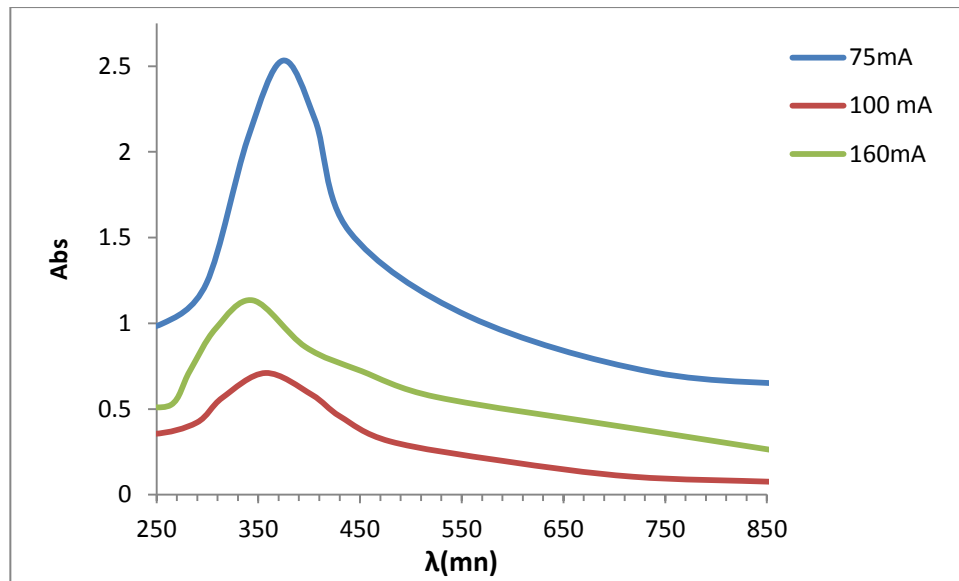


Fig. 3: Absorbance within UV visible for FeCoSb alloy nanofluid from alloy wire with 0.3mm diameter in DDDW at three different values of current.

X- ray diffraction (XRD)

The crystal structure of the FeCoSb alloy-nanoparticles dispersed in DDDW is examined with X-Ray diffraction. Fig.4 shows the XRD pattern of the alloy nanoparticles dispersed in DDDW. The XRD pattern as a 2θ plot scanning from 20° – 80° was recorded to determine crystallinity and structure. The peak obtained around 44.5° corresponds to the (110) line of Fe (FCC). The peak position of the Fe nanoparticles planes (200) was

at 66.16° and it were shifted to slightly higher 2θ values. Another signals centered around 61° is detected, thus including the presence of face- centered-cubic (FCC) cobalt nanoparticles corresponds to the (200) line. There are three peaks at 29.852° , 48.892° and 55.871° characteristic of (220), (100) and (101) diffraction plan of hexagonal centered cobalt. The peaks centered at 21.3° and 35.213° corresponds to the (003) and (014) line of Sb.

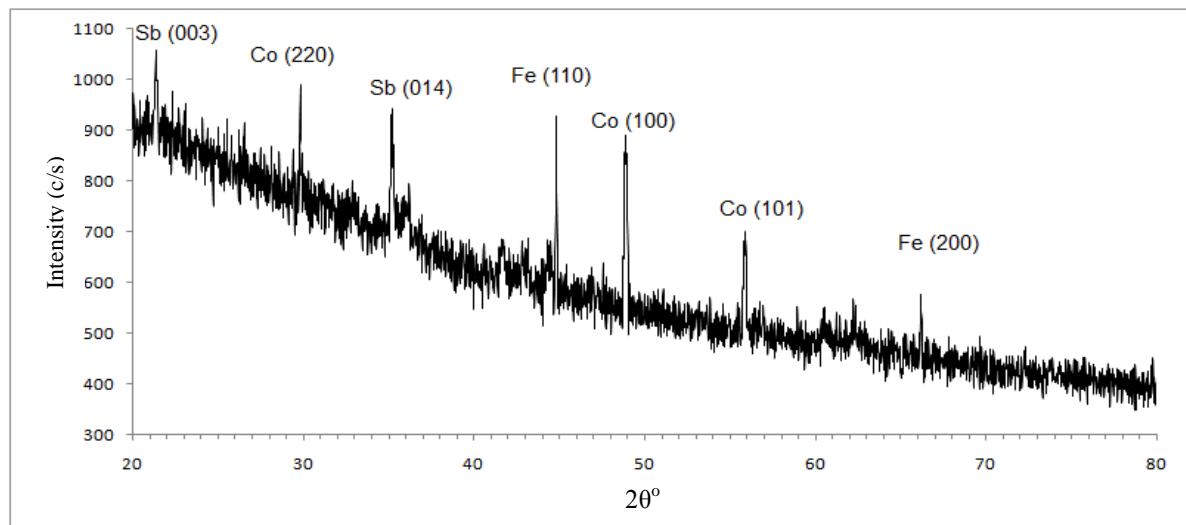


Fig. 4: X-ray diffraction pattern for FeCoSb alloy nanoparticles that obtain by exploded wire method with different diameter in DDDW media.

Scanning Electron Microscopic (SEM)

Fundamental study of samples morphology was obtained using particular electron microscopy. It is possible to observe the external structures of nanoparticles using SEM, and it is performed to the characterize

of the texture of the deposited metal as a thin film on substrate. From the images there are varies size are observed also from the images the some particles have irregular shapes with agglomerate and the other have spherical shape as shown in Fig.5.

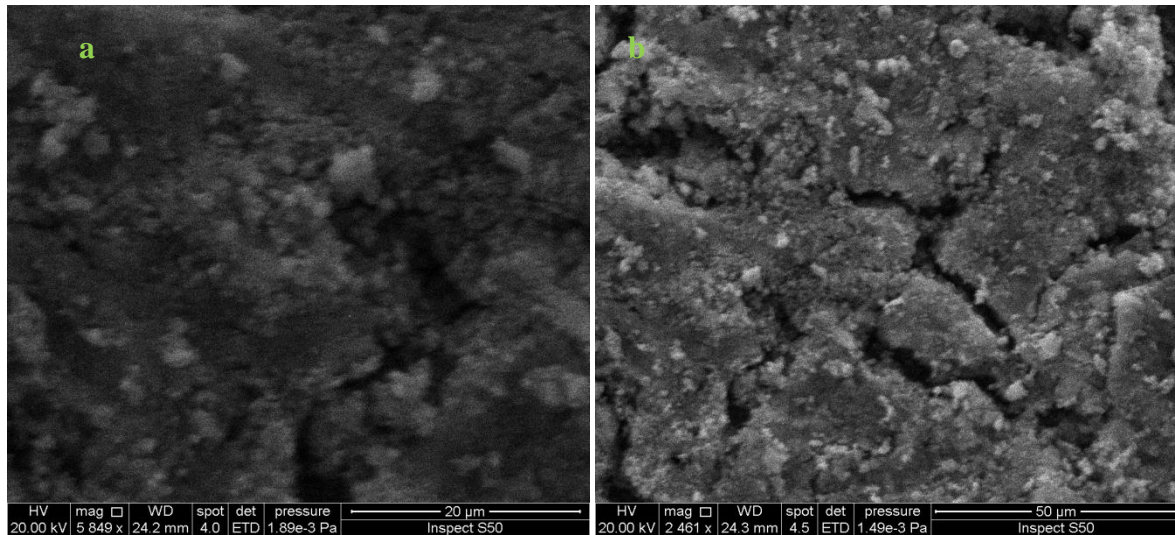


Fig. 5: SEM images for synthesized alloy NPS in water, obtained from 0.3 mm exploded FeCoSb wire at; a) high magnification, b) low magnification.

Energy dispersive X-ray analysis

The elemental analysis of the alloy is investigation by Energy Dispersive X-ray spectroscopy (EDX) analysis as shown in Fig. 6. EDX measurement confirms the existence of the alloy in

the film. From Fig. 6, there are many strong peaks for iron, cobalt and antimony but the strongest peak is to iron. The weak peak of Si and Ca shown in the EDX spectra correspond to the glass substrate material.

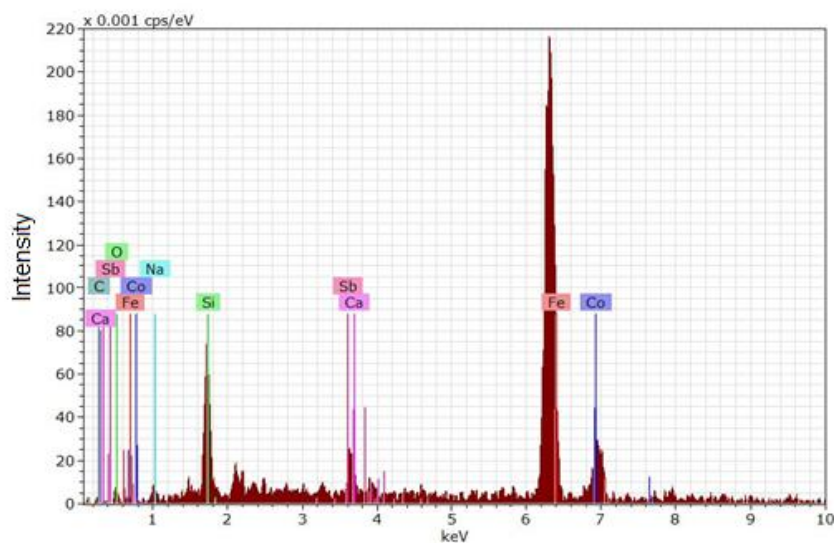


Fig. 6: The EDX energy of the alloy nanoparticles.

The spectroscopic analysis

Fig.7 shows the optical emission spectrum emitted from the Plasma produced by exploding FeCoSb alloy wire with diameter of 0.3mm and current 75A. The emission spectra of this alloy plasma have been recorded and analyzed. The plasma electron temperature (T_e), was calculated by using Boltzman plot method, and the electron density (n_e) was determine by Stark broadening using seven Fe I line at 516.74, 517.15, 522.71, 532.85, 537.1, 537.14 and 540.4 nm for the alloy wire. Also peaks at 217.581 and 556.812nm correspond to antimony (Sb I) and (Sb II) respectively. Small peaks at 258.326 and 345.351nm correspond to Co I and Co II respectively. These elements come from the FeCoSb alloy. Also some of ionic oxygen lines are founded in the inset figure. The T_e values were deduced from reverses of best fitting

line for the relation between $\ln\left(\frac{I_{ji}\lambda_{ji}}{g_j A_{ji}}\right)$ versus upper energy level (E_j). From Fig.8, it can be noticed that the peak located at 540.3 nm corresponding to Fe line for iron atoms produced from the alloy molecular dissociate.

The Fe I line was used to calculate the electron temperature. The T_e value can be calculated using Fig.9 from revers of best fitting line. The constants Values for the iron emission lines taken from reference [9]. The equations of fitting lines and the R^2 were shown in the figure. R^2 is the statistical coefficient indicating the quality of the linear fit.

Table 2 shows the diameter of wire, the calculated electron temperature T_e , electron density (n_e), plasma frequency (f_p) and Debye length (λ_D) for FeCoSb alloy plasma produced by exploding wire for 0.3 mm wire diameters and 75A current.

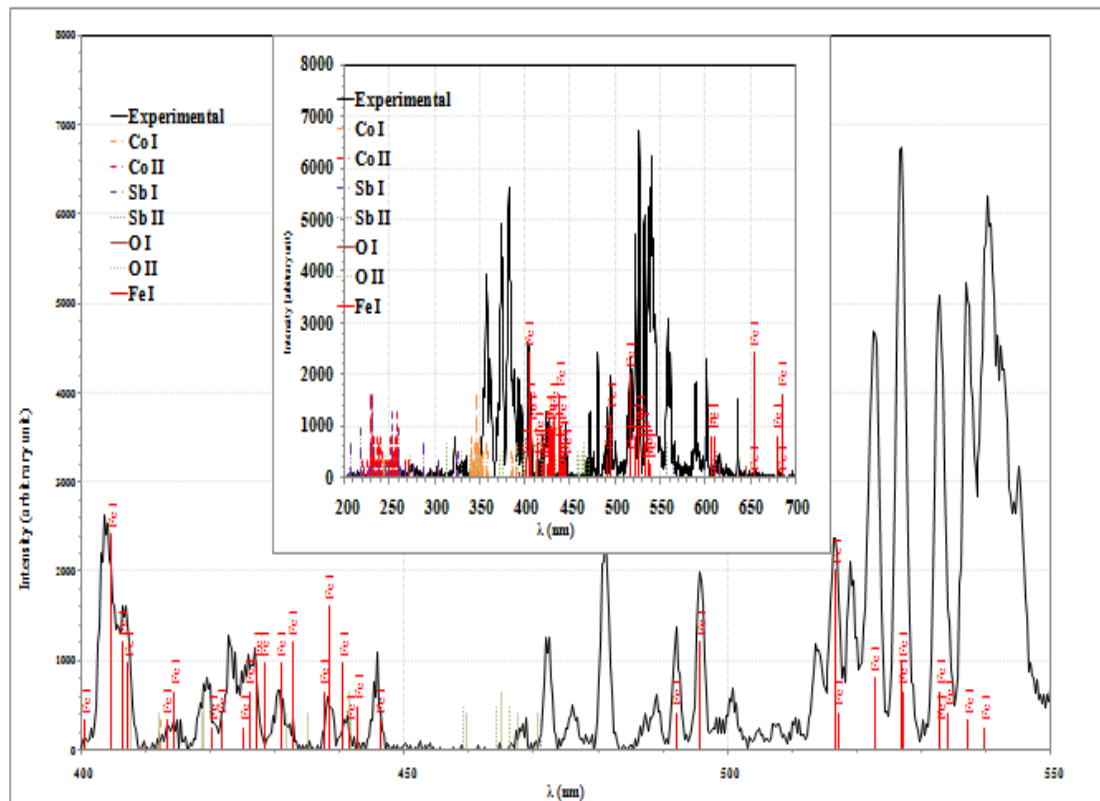


Fig. 7: Emission spectra for FeCoSb alloy exploding wire.

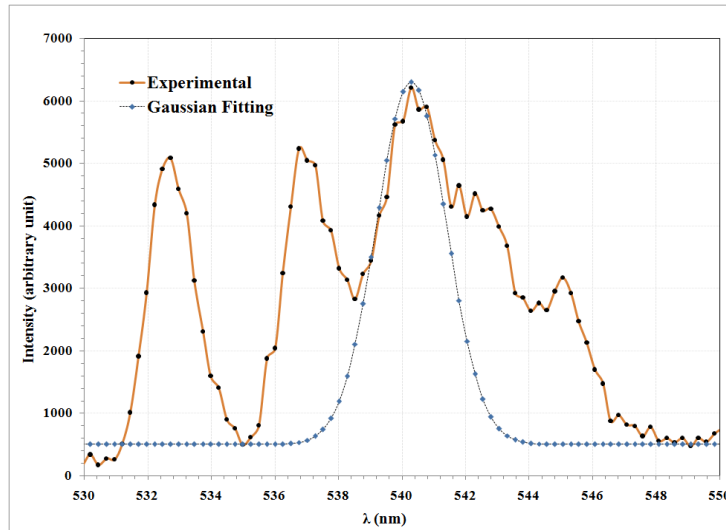


Fig. 8: Fe I peaks at 540.4 nm broadening and there Gaussian fitting.

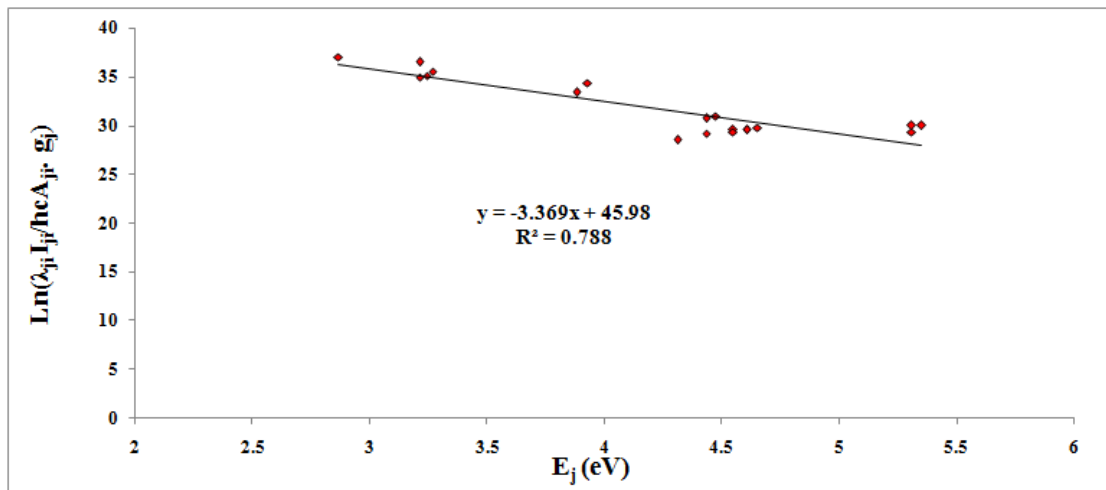


Fig. 9: Boltzmann plot from the Fe I lines produced by exploding wire.

Table 2: Plasma parameters calculated from emission spectrum lines emitted from FeCoSb alloy plasma produced by exploding wire.

Wire diameter	0.3 mm
electron temperature T_e	0.300 eV
FWHM	2.60 nm
electron density (n_e)	$1.44 \times 10^{18} \text{ cm}^{-3}$
plasma frequency (f_p)	$1.1 \times 10^{13} \text{ Hz}$
Debye length (λ_D)	$3.4 \times 10^{-6} \text{ cm}$
The number of particles in a Debye sphere N_d	0.235×10^3
Plasma ideality	0.874

The 540.4 nm iron line peak shows in Fig. 8. The full width at half maximum was found by Gaussian fitting. From the measured width which depending on Stark effect and

the standard line width for this line. The electrons density were calculated by the equation [8, 9]:

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

Plasma frequency which given by [10]:

$$\omega_p = \sqrt{\frac{N_e q_e^2}{\epsilon_0 m_e}}$$

Also the number of particles (N_D) in a Debye sphere [10]:

$$N_D = n_e \left[\frac{4\pi\lambda_D^3}{3} \right] = \frac{1.38 \times 10^6 T_e^{3/2}}{n_e^{1/2}}$$

where: T_e in K.

Conclusions

Metal and metalloid nanoparticles can be produced by one step simple, effective and low cost technique that is the Electrical Explosion Wire (EEW) technique and it may be applied in air and liquid. Mean particle size could be controlled by proper selection of the current, and breakdown strength of the medium. The peaks properties as peak position and peak intensity are reliable indicators for identifying the size and concentration. SEM image gives good information about the shape, size and the size distribution for the nanoparticles.

The nanoparticles formed from the wire have spherical shapes with agglomerate. Fe, Co, and Sb components in the alloy nanopowders are uniformly dispersed. X-ray examination included the peaks of the three elements in the alloy.

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