Surface morphology and effect of particle sizes on the electrical conductivity of Fe Al_2O_3composite

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Abstract

A composite samples of $FeAl_2O_3$were synthesized by using mixture of paraffin wax and a powder of Al_2O_3 (0.07gm.) with iron granular Fe(0.01 gm.) of different particle sizes (63μm, 73μm, 212μm and 300μm). Where paraffin wax was melted using a temperature source (heater) with 328 K, then the granular volume of composite $FeAl_2O_3$ powder was added to paraffin wax by manual mixing until the mixture was homogeneous and then deposited on slices of aluminum in laboratory conditions. The Characteristics of (current-voltage) were measured to various particle sizes. The electrical conductivity was estimated as a function of various temperature range. The conductivity values of this composite doped of $FeAl_2O_3$ increasing with temperature increases. Also the activation energies Ea for the composite samples have been found ($4.1x10^{-4}$ $-2.9x10^{-4}$) eV. Beside that the mechanisms of electrical conductivity were studied and identified in support of Schottky and Frankel effect mechanisms.

Keywords: Al_2O_3Powder; Iron granular; Conduction Mechanism; I-V characteristics.

1. Introduction

The use of inorganic materials in optoelectronic devices have still considered commercial although the polymeric materials are widely being used in various devices as insulating materials and for important scientific and technological applications according to their properties such as light weight, mechanical flexibility ,versatile of chemical structure , low manufacturing cost and mass production. The researches in this field take two main branches; Firstly, is to get new materials to having suitable electrical properties that serve as an effective layer. Secondly is to fabricate the device using an easy and efficient technique. Accordingly, the results obtained from investigating the electrical properties of the devices are based on satisfying the two later conditions. One of the main scientific concerns at present is the study of the important physical parameters including the electrical properties of composites and blend [1−3]as well as the effect of the thermal insulator matrix material on electrical properties and the magnetic properties of the metal− insulator compound [4−6] and it is considered one of the important and sensitive method in studying the properties of physical medium[7,8,9]. The process of identifying conduction mechanisms are determined due to the measurements (current − voltage) characteristics and (conductivity − temperature)curves [10,11]. The conduction mechanism in the metal−insulator compound may be depended on the thickness or the degree of deformation of the synthesized materials as well as the applied of the electric field intensity. The different physical properties of the host material can be modified with different quality and concentration of organic filler used [12,13].

Metallic and semiconductor fillers such as graphite and carbon black are used to modify the electrical and thermal properties[14,15]. In past few years studies on optical and electrical characteristics of composite materials have been the subject of considerable research efforts due to their wide applications in the various technological devices. The physical properties of composite materials and determination of carrier concentration, as well as the mobility of $Sb_2(Te1-xSex)_3$ thin films, have been studied[16,17]. films The influence of sodium zircon ate nanoparticles on the chemical structural and electrical properties of PVA nanocomposite films have been reported [18]. The effect of cobalt chloride on the electrical properties of poly [O-Toluidine]was reported[19-20]. Synthesis and study characteristics as well as the optical properties of (PANI) filled by Graphene nanofilms were also investigated [21,22,]. In the present article the preparation and the study electrical properties of $FeAl_2O_3$ / paraffin wax composite film (Al_2O_3=0.07 gm) and (Fe=0.01gm) for various particle's size (63μm,73μm,212μm and300μm).The characteristic of (current-voltage) was measured at temperatures range (293-323 K).Also the electrical conductivity was estimated at those temperature levels.

2-Experimental method

The films $FeAl_2O_3$ composite were synthesized from mixture of paraffin wax and a powder of Al_2O_3 and Fe .The fillers of Fe element powder was filtering by micro sifted using granular sieves whose size is 63μm to 300 μm, then 0.07 gm of aluminum oxide mixed with a granular iron element for each size by using a pie dish and a mixing spatula. Then a 0.01 gm of paraffin dough was added to the mixture. After that, the composition consisting of paraffin paste and aluminum oxide with the iron were deposited on the aluminum slices of dimensions $(2.5x4)cm^2$. These slices were left in the laboratory conditions for 24 hours. Then, the aluminum electrodes were deposited in the shape of circles whose radius is 1 mm by using the evaporation system under the low pressure of 10^{-5}torr.After completion of electrode deposition, the samples were put on Base of the special electrode measuring circuit which is consisting of a chamber containing electrodes made of copper. These electrodes are separated by the electric measuring circuit which is consisting of regulated voltages supplied by PHYWE 2592 power. Also, the digital hot plate was used to raise the temperature degree of the samples. The current values were measured by digital-meter type measuring amplifier D53200 L.H.Co. The temperature sensor of samples is placed directly over the layer films. The thickness of the composites samples was measured and indicated in table(1).

Table (1) the thickness of samples

Practical size		Thickness mm
Al_2O_3 gm	Fe gm	
0.01	0.01	0.442
0.01	0.03	0.444
0.01	0.05	0.446
0.01	0.07	0.448

3. The results and Discussion

3.1. The surface morphology

The study of the surface and the homogeneous distribution of the film give desirable properties to be used in several applications, including solar cells and in communication devices, as well as in its use in the manufacture of compact television screens and optical switches devices. The images films of $FeAl_2O_3$ composite of were illustrated in figure 1 corresponding to 63µm, 73µm, 212µm and 300µm particles size respectively. It gives morphology for films. It was showed that the roughness of the surfaces of these films are low and formed a smooth surface with increasing the particle sizes of $FeAl_2O_3$composite films and the surfaces **re**veal without pinholes and porosity. The films exhibited a better surface with a very low deformity which indicated that the composites were complete forming $FeAl_2O_3$ from mixing paraffin wax with a powder of Al_2O_3 and iron. Figure1 shows the, uniform scanning in the direction of the x-axis and polynomial fitting of the surface as a function of different particles sizes.

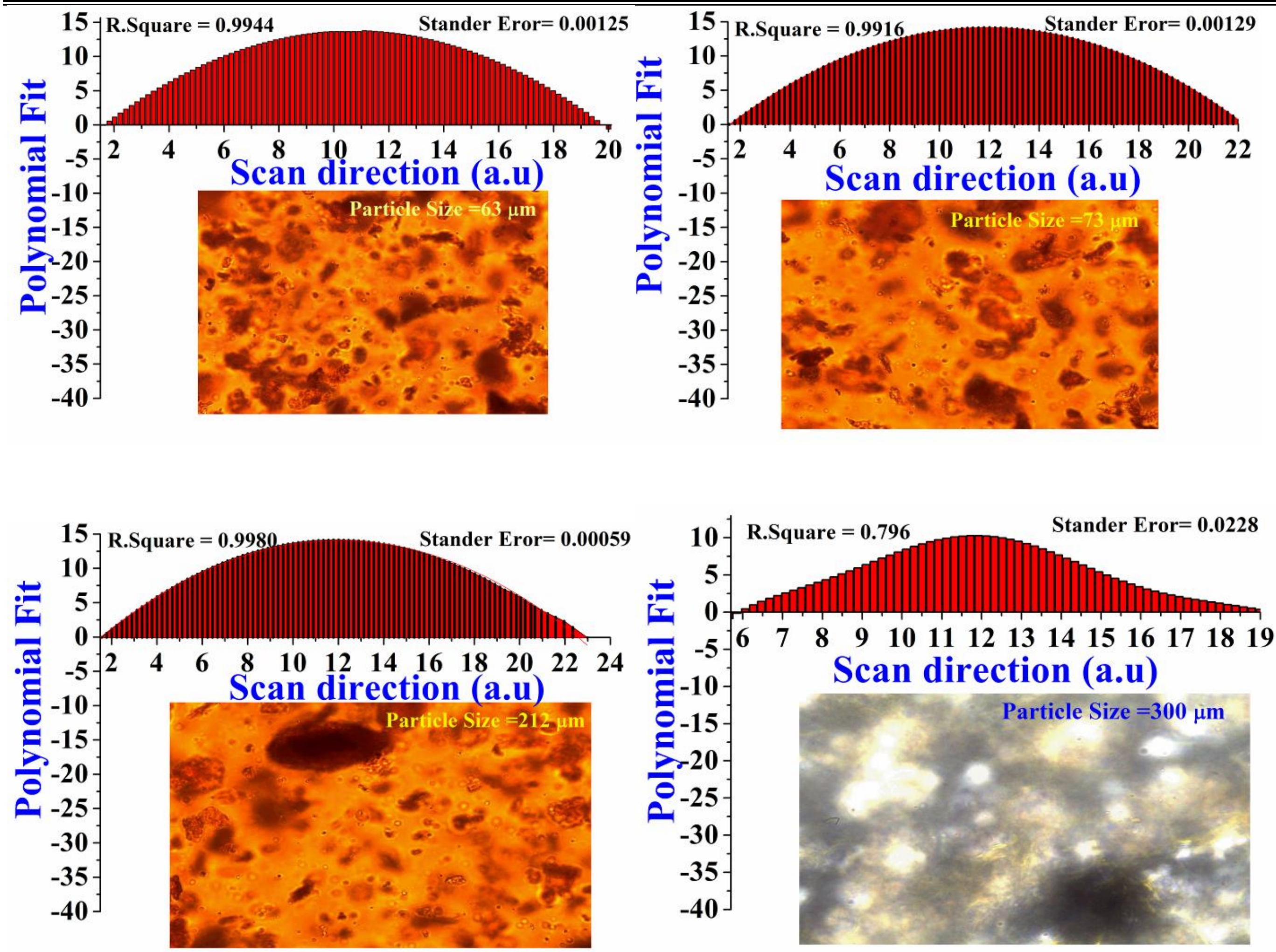
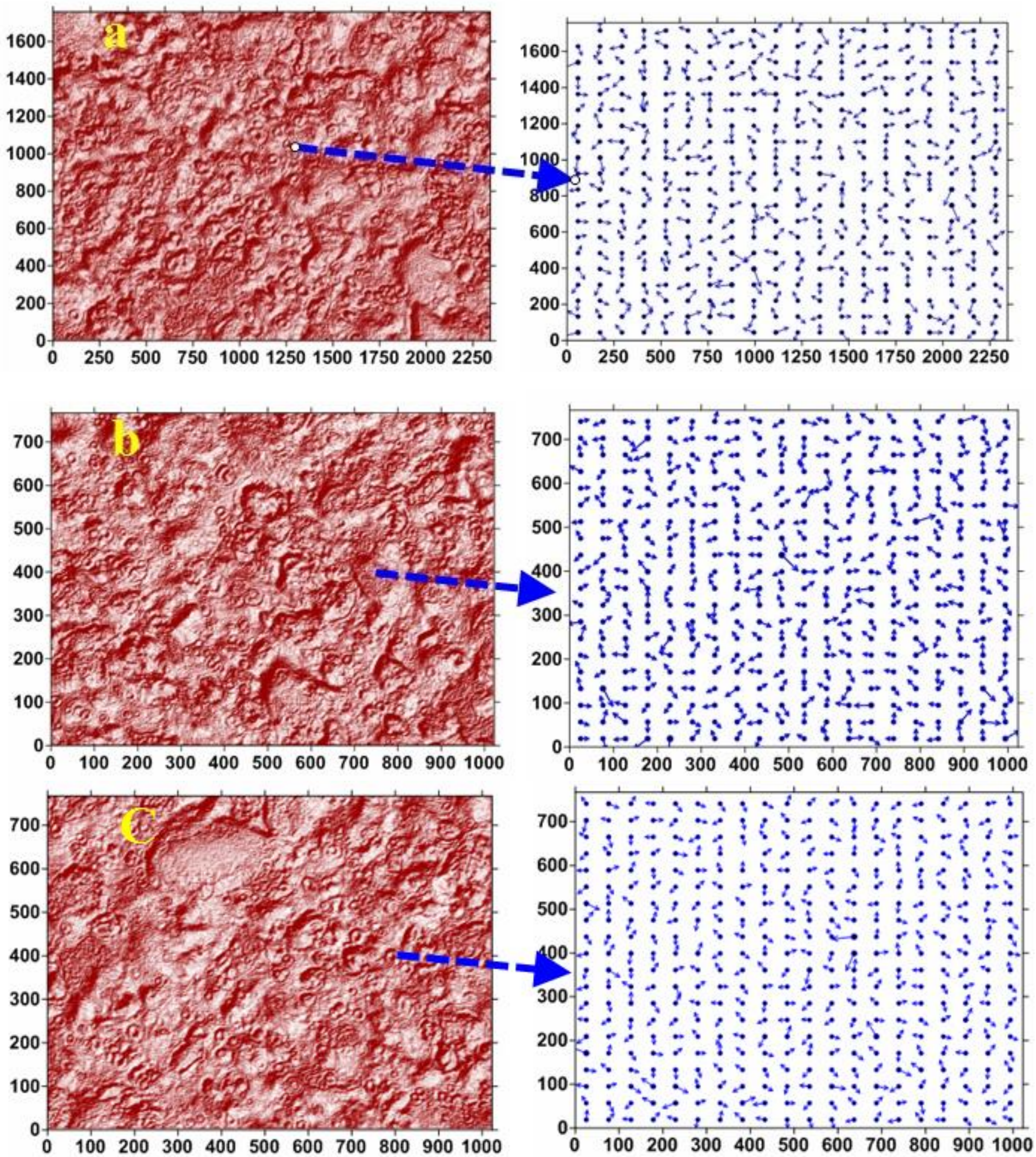


Fig.1.Scanning in the direction of the x−axis vis surface fitting of the $FeAl_2O_3$films, (a) 63µm, (b):73µm,
(c) :212µmand (d): 300µm.

Figure 2 shows the small raw complete homogeneity of iron powder in the film and free of cracks and islands through the drawing of all the films, we notice that the small arrow indicates the homogeneous distribution and the absence of unwanted iron powder clusters and their intertwining with alumina.In addition, no obvious aggregation was observed from iron in the film samples.


a
b
C

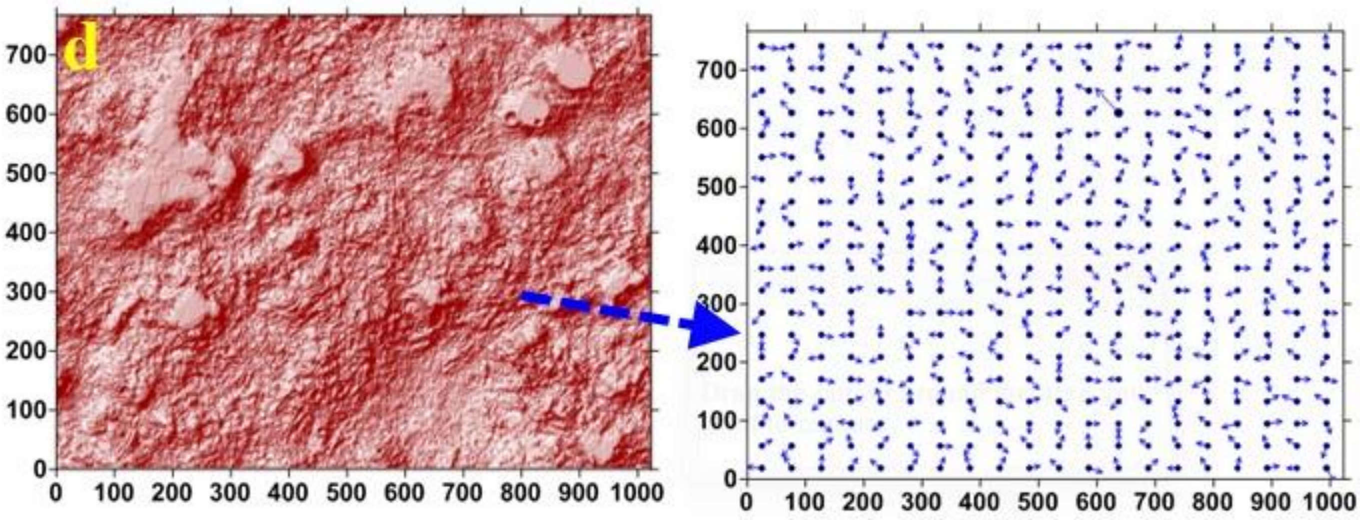


Fig. 2. Homogeneous distribution of the Fe Powder in $FeAl_2O_3$films, (a) 63μm,(b)73μm,(c)212μm
and (d)300μm.

3.2- Measurement of electrical properties.

The current-voltage characteristic was conducted at various temperatures (293-318)K and at weights of Al_2O_3=0.07 gm and Fe=0.01 gm for different particle sizes which are shown in figure3 to figure 5 respectively. It is noted from the figures that, when a raise the temperature of the samples causes to rise in current, and, the shapes have the linear behavior which showed ohmic behavior at all applied voltage. Not down values of current and voltage (which Agrees with the current), it is followed by increasing the temperature of the sample to a temperature higher than its predecessor, which is leave for a while of 30 min. to reach the degree of thermal stability, then repeating the measurements more than once of current-voltage, until the highest permissible temperature range is reached.

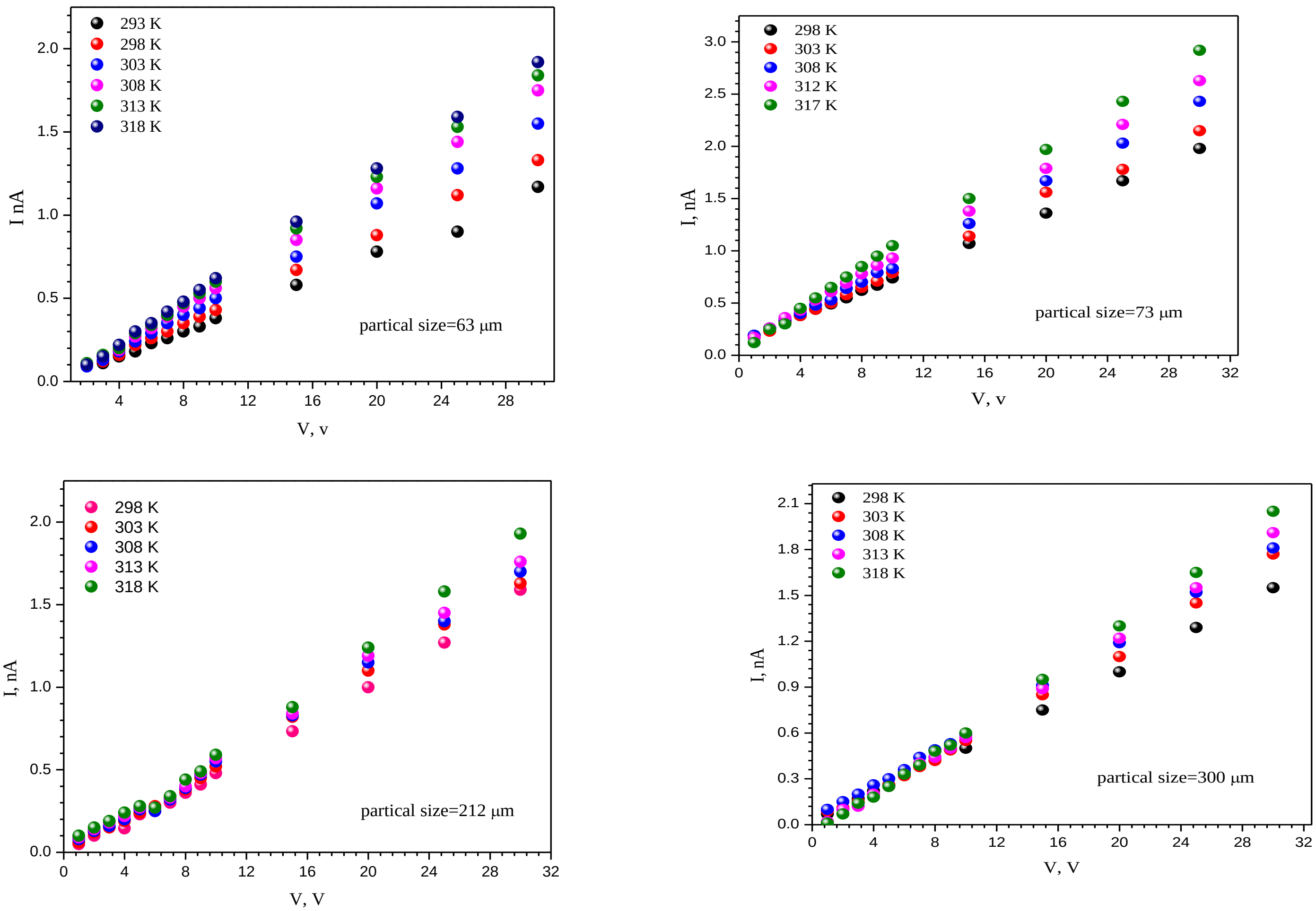


Fig.3. The I–V characteristic for all particles size of composite $FeAl_2O_3$

The relationship between Electrical conductivity and temperature was measured as a function of all particle sizes (FeAl2O3) composites (63µm,73µm

,212μm and300μm) for various temperatures (293−318K).The measurements of the Electrical conductivity showed a rise in electrical conductivity as the temperatures increases. This behavior in semiconductors for composite materials is considered traditional for most studies in this field due to the increased movement of charge carriers through the semiconductor connection. Figure 5 shows the variation of electrical conductivity of $FeAl_2O_3$ composite for a range of temperatures (293−318K) as a function of different particle sizes. It can be noticed that the electrical conductivity increases with the increasing particle sizes for all the ranges of temperature as shown in Table 2.

Table 2. Experimental Values of α's from Schottky and Frankel theories and the dielectric constant for composite samples at Particle size 63 μm.

T K	α_{exp}	α_{sh}	$\alpha_{P.F}$	ϵ
293	0.18	0.058	0.116	0.610
298	0.17	0.057	0.114	0.611
303	0.16	0.056	0.112	0.612
308	0.14	0.055	0.110	0.614
313	0.12	0.054	0.10	0.617
318	0.10	0.053	0.09	0.620

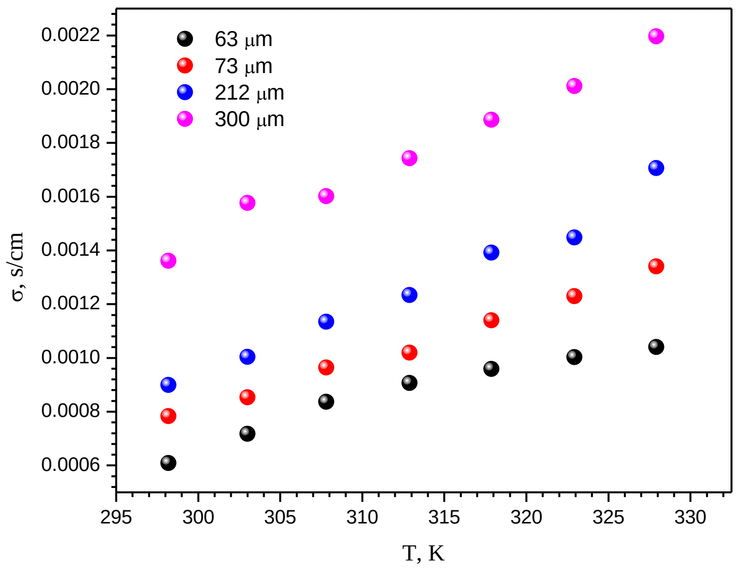


Fig.4. Electrical conductivity for all particles sizes of composite $FeAl_2O_3$ at different temperatures range.

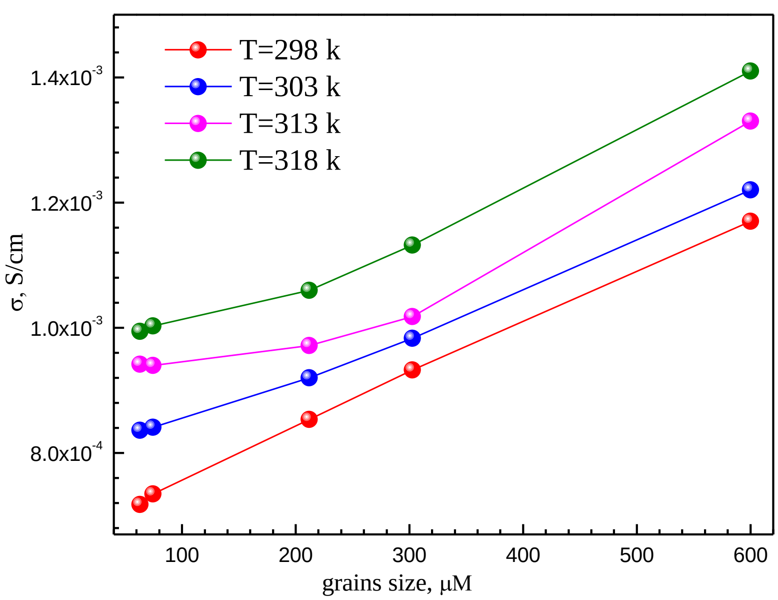


Fig.5. Electrical conductivity as a function of particles size of $FeAl_2O_3$ composites at different temperatures range.

As shown in the previous figure (4), the electrical conductivity was measured by increasing the temperature of the sample .

The activation energy of $FeAl_2O_3$ composite for various temperatures increases with the increasing the particle sizes as shown in Figures 6 and estimated to be ($4.1x10^{-4}$ – $2.9x10^{-4}$) eV.

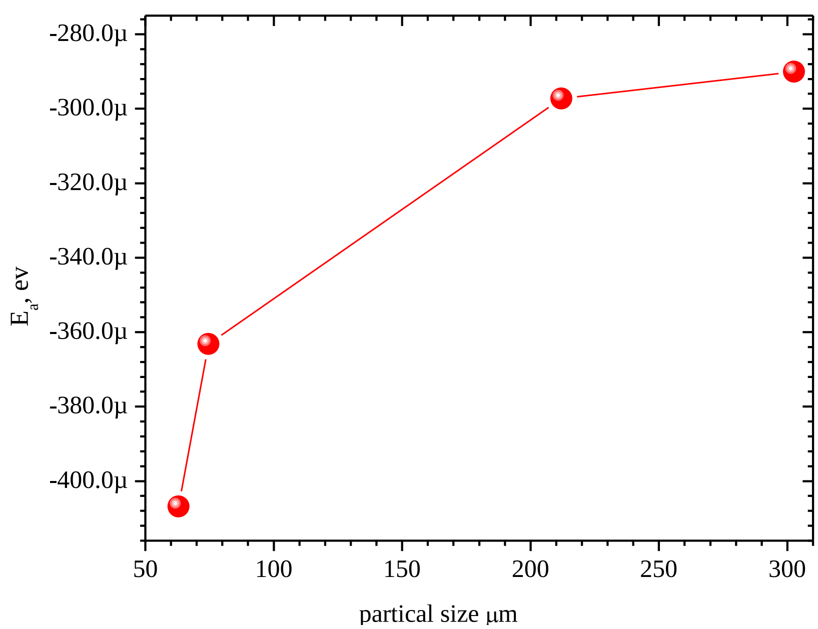


Fig.6. Activation energy of $FeAl_2O_3$ composite as a function of different particles sizes at different temperatures range.

3.3 Test of the of conduction mechanisms:-

According to the measurements of the curves (current – voltage) and (conductivity – temperature) can be identified the conduction mechanisms which control the current transmission through composites materials.

The multiplicity of these mechanisms in the compound metal–insulator and in the film consisting of a specific physical depends on many parameters such as the thickness of the sample, the temperature applied to the samples, the quantity and type of filling, the applied electric field intensity as well as the degree of deformation . The testing method has been done on the FeAl2O3 composite for different particle sizes (63um. to 300).

A– Hopping Conduction Mechanism test that's by drawing the (σ verses $T^{-1/3}$) and(σ against $T^{-1/4}$) for the $FeAl_2O_3$ composite for different particle sizes(63um. to 300).

as shown at figure 7 due to the following relations[23] :

σ= exp ($Ea/KT^{1/3}$) ....(1)

σ= exp ($Ea/KT^{1/4}$).............(2)

It can be seen from figure (7) that, the relationship of conductivity with temperature is non–linear, which indicates the exclusion of this type of conductivity mechanism.

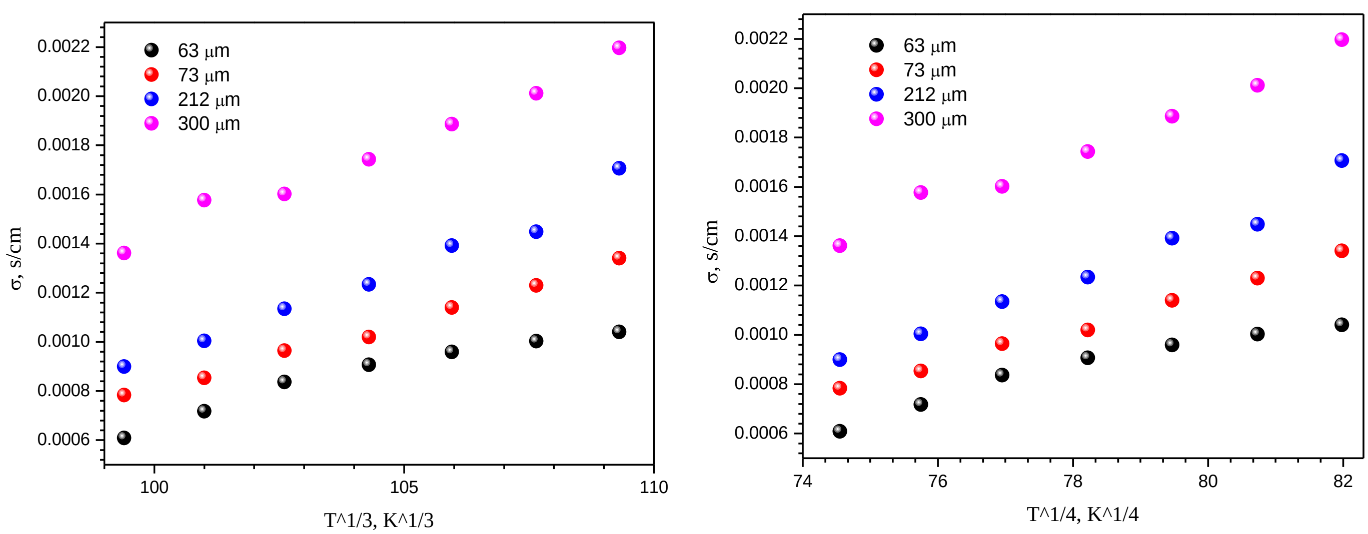


Fig.7.The relationship of conductivity with the reciprocal temperature ($T^{-1/3}$ and $T^{-1/4}$).

B- Schottky & Paul Frenkel Conduction mechanism.

The non-ohmic behavior of current with voltage is one of the reasons that a Schottky or Paul Frenkel mechanism dominant. This mechanism occurs when a voltage is applied to the contact area between the metal and the semiconductor, where electrons are transferred from the metal to the insulator [24]..The increase in the applied electric field with the temperature leads to a decrease in the voltage barrier. So this mechanism is related to the thermal emission of electrons. The voltage barrier depends on the surface layer and the quality of this layer. Both effects Paul Frenkel[25] and glow discharge[26] reduce the voltage barrier to Schottky, but in this case, electrons are released from the capture trap levels to the conduction band in the compound. That is, The effect of both mechanisms are shown to decrease the stress barrier, the Schottky effect is on the surface while the Frenkel effect is inside the compound. At high voltage, Schottky's mechanism related with Paul Frenkel's Schottky's constant α_{sh} is related with Paul Frenkel's constant α_{PF} as [27]:

$\alpha_{sh}=\sqrt{}$ $q3$ $4\pi\epsilon\epsilon_0$

………………… (3)

where q is the electron Charge, ϵ dielectric constant and ϵ_0 is the dielectric Constant in the Space.

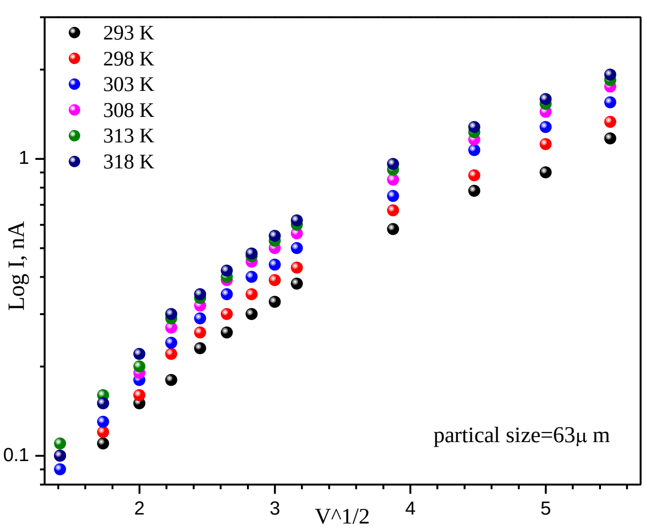
$\alpha_{sh}=$ $1/2\alpha_{P.F}$

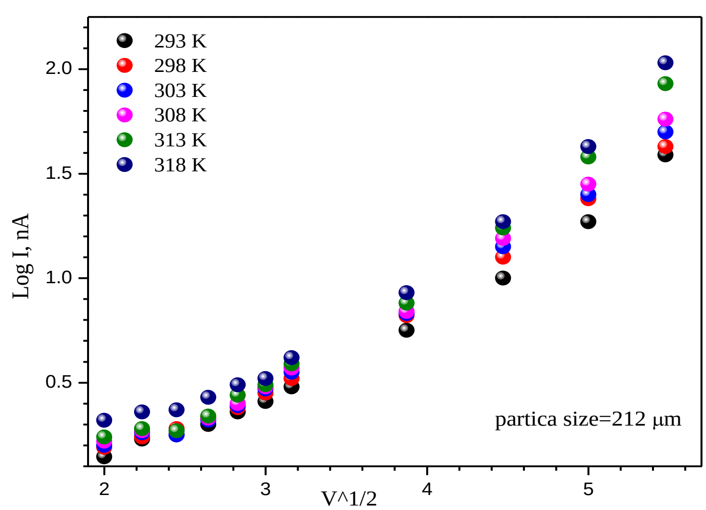
…………………(4)

Figure (8) shows the relationship between the current and the square root of the voltage of the $FeAl_2O_3$ composite for various particle sizes. It can be seen that the relationship is linear at high fields. From the slope of the straight line at high electric fields in Figure 9, the experimental constants' values for Schottky and Paul Frenkel were determined from Equations 3 and 4.The experimental values of αin are shown in Table 2 and Table 3for particle's size of (63 μm and 212 μm.)are being more nearly to theoretical αP.F, that indicates the Paul Frenkel is dominated mechanism, so the applied filed is sufficient to modify the thermally excited electron inside the composite $FeAl_2O_3$ and estimated α's Values from Schottky and Frenkel theories and the dielectric constant for composite samples .

Table 3.Experimental Values of α's from Schottky and Frankel theories and the dielectric constant for composite samples at Particle size212 μm.

T, K	α_{exp}	α_{sh}	$\alpha_{P.F}$	ϵ
298	0.05317	0.0570	0.114	0.6110
303	0.05561	0.0561	0.112	0.6123
308	0.05734	0.0551	0.110	0.6143
313	0.05896	0.0543	0.108	0.6171
318	0.06412	0.0534	0.106	0.6206
323	0.06513	0.0526	0.105	0.6249





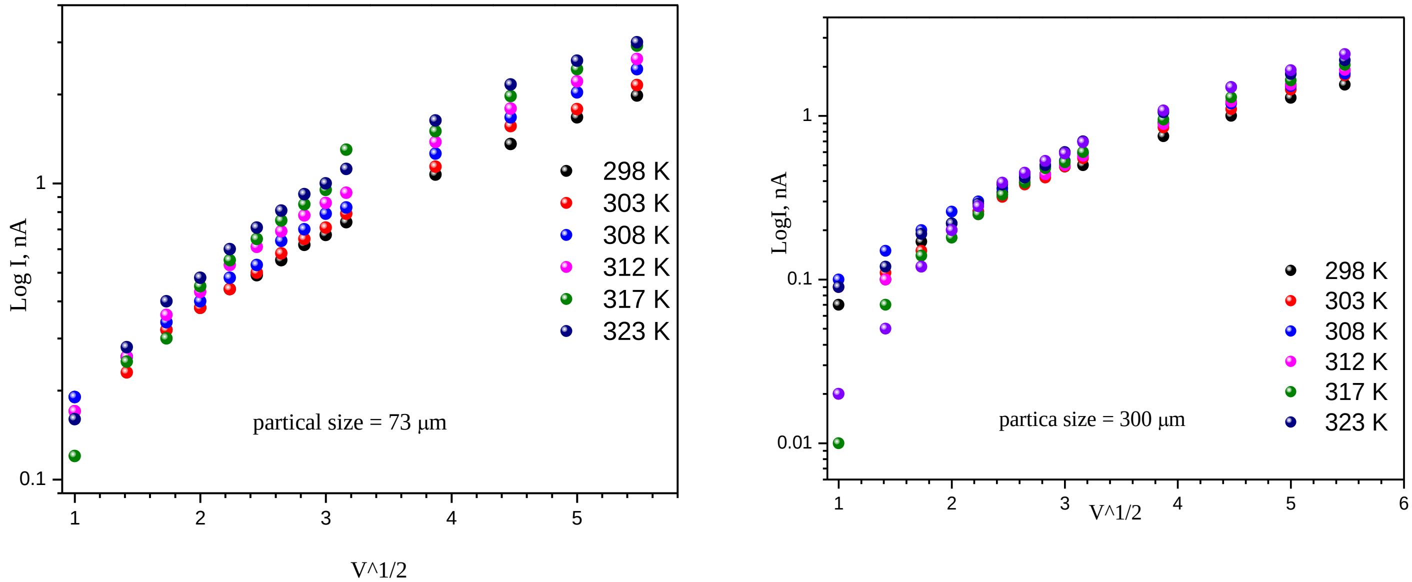


Fig. 8. log(Io) aganist square root of (V)for composite sample.

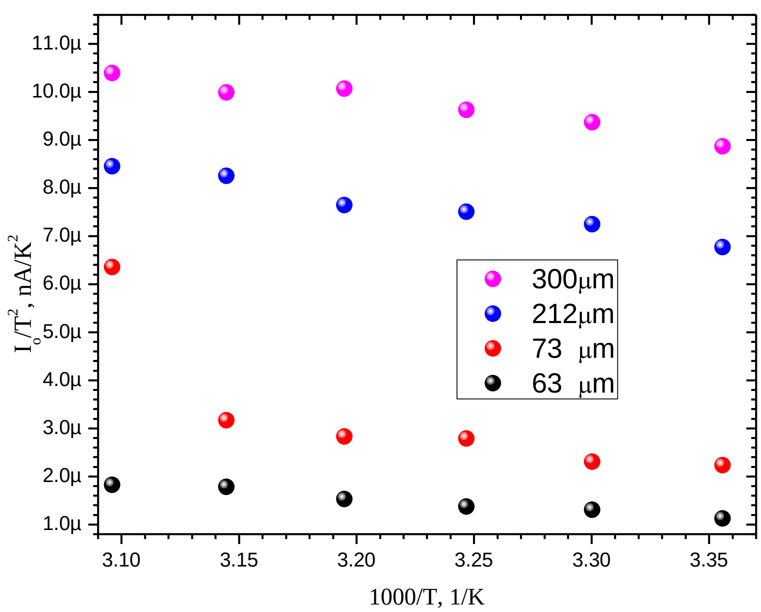


Fig.9. Log Io/T2 against 1/T for $FeAL_2O_3$ composites at various particle size.

From the relationship between log (Io/ T^2) versus reciprocal temperature (Richardson plot), where Io the extrapolation of current value to zero applied field, the lowering of the work function for the thermionic emission due to theSchottky effect can be determined from [28]:

$\Delta\phi=\sqrt{\ eE\ 4\pi\epsilon\epsilon_0}$ ....(5)

These are shown in figure (10) for composites particle size63μm, 73μm, 212μm and300μm, respectively.

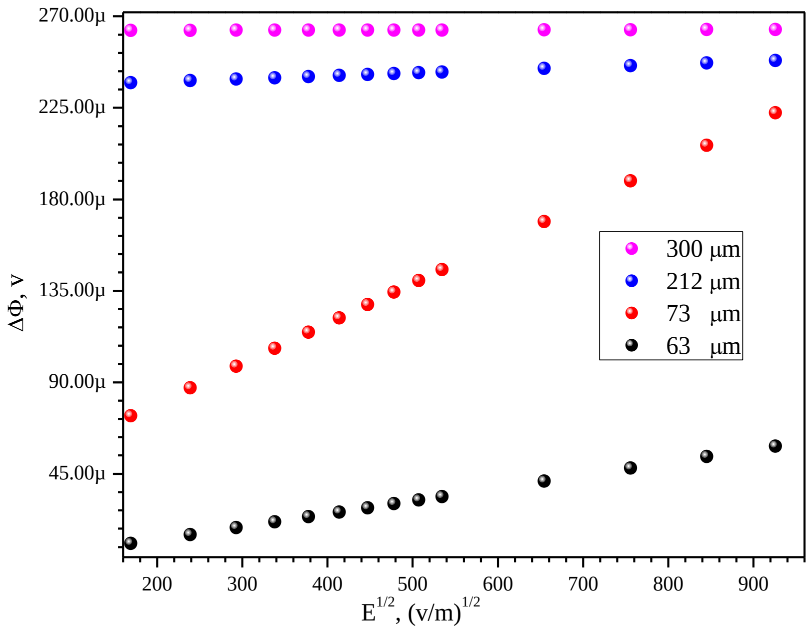


Fig. 10. Lowering potential barrier Vs. $E^{1/2}$ for $FeAL_2O_3$composites.

C- Ion Conduction mechanism test:-

ion conduction mechanism tested by drawing the (− Lnσ $T^{1/2}$) against (1000/T)K and then investigated due to the following formula[29,30]:

$$\sigma = \sigma_{\circ}\sqrt{T}\,\exp(-E_a KT) \qquad \text{.........................} (6)$$

where σ_0 constant, *Ea* is the activation Energy, *K* Boltzmann constant and T is the sample temperature.

Figure(11) shows the drawing of ln (σ $T^{1/2}$) verses (1000 /T)K, of the $FeAl_2O_3$ composites for various particle sizes. A number of other mechanisms have been investigated, such as the ion conduction mechanism and the tunneling mechanism, and it was found graphically that both mechanisms are not applicable in our present study because the graphical curves of the practical results do not apply with the theoretical foundations of both mechanisms.

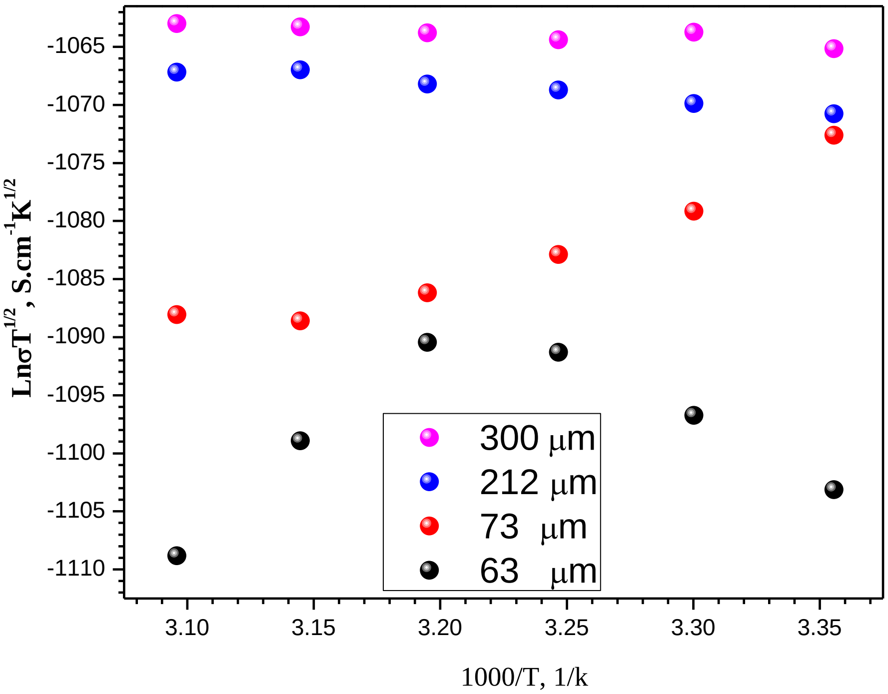


Fig.11. Ln (σ $T^{1/2}$) against (1000/T)K for the $FeAL_2O_3$composites for ionic conduction test.

4. Conclusion

The electrical properties of $FeAL_2O_3$ Composite films where Fe=0.01 gm, AL_2O_3=0.07gmfor various particles size ,63μm, 73μm, 212μm and 300μm, were investigated in the temperature range of (293K-323K) .This is done by measuring the I-V characteristics and current-temperature dependence relations. Schottky's conduction mechanism was noted as a reveal one explained its electrical characteristics due to the comparing between α's constants and studying the dependent of conductivity with different work functions. According to the conductivity mechanism theories of electrical conduction, the current versus square root of applied voltage indicated that the Schottky's conduction mechanism is dominated. The activation energy was determined to be ($4.1x10^{-4}$–$2.9x10^{-4}$) eV. The experimental value of the barrier is coverage from the theoretical value. Other mechanisms were also tested according to the behavior of the electric field (current and voltages) not in accordance with the general ionic equation (hyperbolic sine functions), it was excluded from the expectations in this study.

The tunneling mechanism is also not applicable in the present study since it requires very thin films and the current is independent of temperature but we have thick films about 0.448 mm. and the current is dependent on temperature.

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