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Mott conductivity in nanocluster carbon thin films

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Electrical conductivity measurements have been carried out on Nanocluster carbon thin films in the temperature range of 123K- 303K. These films are deposited onto silicon substrate by room tempearture based Cathodic Arc process. Extracted parameters and analysis of data verified that Mott's variable range hopping(VRH) conductivity describes the transport mechanism for Nanocluster carbon thin films in this temperature range.These also suggests that density of states at the fermi-level is constant at this temperature range. Typical density of states found to be 1.527×10^{17} cm^{-3} eV^{-1}.

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1. Introduction

Nanocluster carbon thin films are mixed phased materials containing both sp^2 and sp^3 bondings[1,2]. These films exhibits properties which varies from insulating to semiconducting in nature owing to different types of bondings. Nanocluster carbon have shown to emit electrons at low fields and thus find application in vacuum nanoelectric field[1,3-5]. The development of methods for modification of electrical properties is important to use this film for other purposes in various device fabrications. Nanocluster carbon thin film transport mechanisms are explained by thermally activated conduction mechanism at high temepature and hopping conduction mechanism due to defects and impurities at low temperatures.

In this work, we carried out electrical conductivity measurements for Nanocluster carbon thin films in the temperature range of 123K-303K. It has been shown that in the forbidden band region, conductivity is governed by Mott's variable range hopping conductivity at studied temperature range due to defects.

2. Experimental

In present study, Nanocluster carbon film are grown using cathodic arc deposition system at room temperature [6]. In cathodic arc process, an arc is initiated by touching the graphite cathode with a small carbon striker electrode and withdrawing the striker. this produces energetic plasma with high ion density.

Nanocluster carbon films were deposited on (n+) silicon. Fig. 1 shows SEM image Nanocluster Carbon grown using Cathodic Arc process at low temperature with cluster sizes of 5nm-200nm.

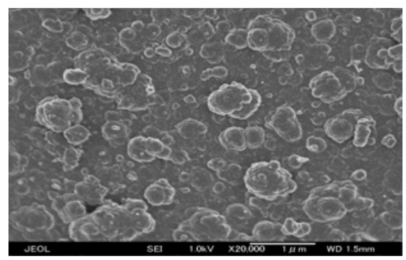

Fig. 1. SEM image nanocluster carbon grown using cathodic arc process at room temperature.

The films were typically grown to a thickness of 90-110 nm. The thickness was measured using a thickness profiler. For electrical measurements ,metal contacts for coplanar configuration based measurements were deposited using a contact mask arrangement, with a channel gap of 500 μm using thermal evaporation, at a base vacuum of 1.5×10^{-7} Torr. Temperature based conductivity measurement were done using Keithley 617 electrometer. Linear-voltage characteristics were obtained up to the voltage of 10V to check ohmic contacts as shown in Fig. 2.

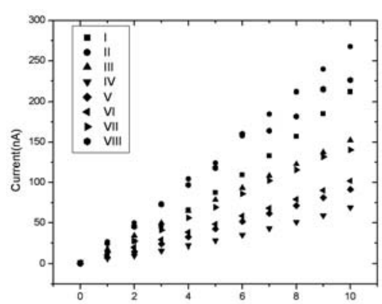

Fig. 2. Linear current-voltage characteristic of nanocluster carbon thin films exhibiting ohmic nature of contact.

3. Results and discussion

Electrical conductivity of Nanocluster carbon thin film has been studied for complete range of 123K-423K. The temperature dependence of the conductivity at higher temperature in the range of 304K-423K is goverened by extended state conduction. This conduction mechanism is due to thermal activation of the charge carriers at high temperature given by

$$\sigma = \sigma_0 \exp\left(\frac{-E_a}{kT}\right) \quad (1)$$

where σ_0 is a parameter depends on the semi-conducting nature and Ea is the activation energy. A typical plot of conductivity versus inverse temperature is shown in Fig. 3.

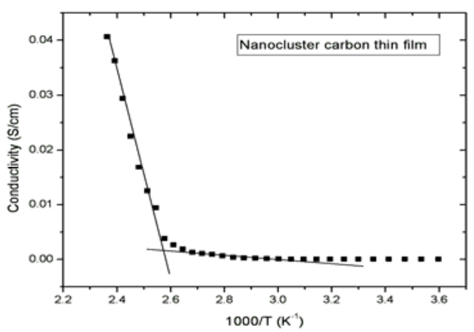

Fig. 3. A typical Arrhenius plot of the c onductivity of nanocluster carbon thin film in the temperature range of 123K-423K.

We found that one mechanism is not sufficient to explain the transport mechanism in Nanocluster carbon thin films. At high temperature 304K-423K, it follows extended state transport mechanism. Also, conductivity increase with increase in temperature showing semi conducting nature. Our emphasize is on transport mechanism at temperature range of 123K-303K. Mott's Variable Range Hopping conductivity (VRH) dominates in the samples in the range of 123K-303K range. Mott's VRH conductivity [7] is given by well known formula

$$\sigma = \sigma_0 \exp\left(\frac{-T_0}{T}\right)^S \quad (2)$$

where σ_0 is a pre-exponential factor and T_0 is characteristic temperature coefficient. The value of s depends on the nature of hopping process. In case of the VRH , if density of states is constant at fermi level , then the value of s is ¼ and characterized by equation 2 . T_0 depends upon the density of states $N(E_f)$ and is given by Mott and Davis[8] relation

$$T_0 = \frac{16\alpha^3}{kN(E_f)} \quad (3)$$

where α^{-1} is the decay length represents the spatial extension of the wavefunction $\exp(-\alpha R_1)$ which is associated with localized states , k is Boltzmann's constant , $N(E_f)$ is the density of the states at the Fermi level .Other Mott parameters like average hopping distance R_1 and the average energy of hopping W being related to these parameters by the following formula

$$R_1 = 0.75\left(\frac{3}{2\pi\alpha N(E_f)kT}\right)^{1/4} \quad (4)$$

$$W = \left(\frac{3}{4\pi R_1^3 N(E_f)}\right) \quad (5)$$

Hopping energy(W) , in general , can be defined as the energy required for inelastic tunneling transfer of an electron between two localized electronic states centered at different locations or the energy required between two localized states with assistance of phonons.

A plot of temperature dependency as ln σ vs $T^{-1/4}$ is shown in Figure 4. From the graph , regression statistic had been calculated for Nanocluster Carbon thins films. The regression coefficient is 0.99959 and the standard deviation is 3.622×10^{-4}. These two parameters conforms that the fit is very well and conduction is due to the variable- range hopping.

We have calculated the various parameters like density of states($N(E_f)$) , hopping distance (R_1), Hopping energy(W), and T_0 (measure of disorder) using Mott parameters given by equations 3-5. All the parameters extracted for two temperatures 123K and 303K. For varaible range hopping, the value of W should be of the order of a few kT and αR should be greater than unity or of the order of unity, as suggested by Mott[9-11] and validated from Table 1.It is also observed that hopping distance increases with decrease in temperature while hopping energy decreases with decrease in temperature.

Table 1. Calculated Mott parameters of nanocluster carbon thin films grown using cathodic arc process.

Sample Name	$N(E_f)$ ($cm^{-3}\ eV^{-1}$)	R_1(cm)		W(meV)		α(cm^{-1})	αR_1	
		123 K	303K	123 K	303K		123 K	303K
S89g	1.527×10^{17}	5.372×10^{-6}	4.288×10^{-6}	10.1	19.84	2.66×10^{5}	1.43	1.14

Density of states calculated is same in order of other carbon based materials like nitrogen doped tetrahedral amorphous carbon[12] and boron implanted diamondfilms[13].The electronic transport in disordered material can be divided into three conduction mechanism , namely extended state conduction,band tail conduction and conduction in Localized states. Conduction in Nanocluster carbon thin films in the said temperature range follows the localized state conduction as shown by the fit of Mott's conductivity in Figure 4. Nanocluster carbon films contains both sp^2 and sp^3 sites in the cluster network. Apart from this , it also contains dangling bonds in sp^3 carbon . Sp^2 sites have a tendency to clustering separate π bonding sp^2 rings into a sizable graphitic cluster. The π bonding in sp^2 sites control the electronic properties of the material and σ bonding in sp^3 sites controls the mechanical properties of the material. Based on the J.Robertson cluster model[14] for an amorphous carbon network, π states have no influence on the σ states. Based on the hopping energy calculated in Table 1., it has been concluded that hopping take place near fermi level between two sp^3 localized sites where site energy produce a maximum equilibrium hopping rate.Also at this low temperature band tail hopping cannot takes place as sp^2 cluster is in the potential well of the sp^3 matrix. Thus the hopping conduction takes place between localized levels from sp^3 carbon dangling bonds.

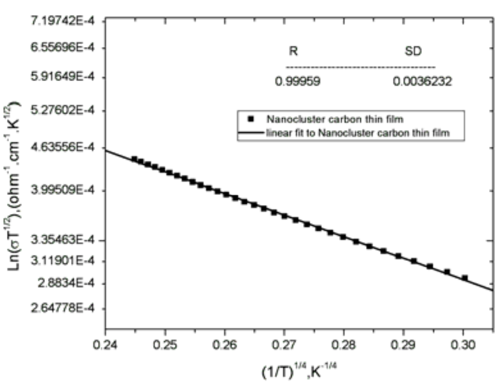

Fig. 4. Plot of ln σ versus $T^{-1/4}$ of nanocluster carbon thin films. Solid lines correspond to the fit of Mott's law to the experimental data.

Finally, we have to mentioned that nanocluster carbon thin films has been deposited using room temperature based cathodic arc process and can be used for any other cheap substrate. Repeatibility of the measurements and the results are primary importance for electronic applications as shown by this films even after 12 months.

4. Conclusions

Nanocluster carbon film has been deposited on silicon substrate using room temperature cathodic arc process. Nanocluster carbon thin films are semi conducting in nature.Conduction between the localized states which follows the variable range conduction contributes to the conductivity successively in the temperature ranges from 123K-303K.The density of states extracted near the Fermi level is found to be $1.53x10^{17}$ cm^{-3} eV^{-1}.. Also this films can be used as an alternative semiconducting layer for Thin-Film Transistor (TFT) for Display applications.

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