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Measurement of Hall Coefficient of A-Quaterthiophene (A-4T) Thin Films and To Determine the Type Majority Charge Carriers in It

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Abstract: α-4T thin films of various thicknesses are prepared by thermal evaporation method. The Hall coefficient and bulk charge carrier concentration of as deposited and annealed α-4T thin films of thicknesses 50 nm, 100 nm and 200 nm have been measured using Hall measurement system (HMS). The Hall coefficient and bulk concentration of α-4T thin films are found to be positive. The results confirm that in α-4T thin film the majority charge carriers are holes which are responsible for its electrical conductivity. It confirms prepared are p-type semiconductors.

Keywords: α-4T; thermal evaporation; annealing; Hall effect; Hall coefficient; bulk concentration

I. Introduction

Oligothiophenes are widely considered as an interesting material in organic electronic industry because of their high stability to withstand oxidation [1]. Oligothiophenes attract remarkable attention as an organic semiconductor. It shows nonlinear optical, electrical, and liquid crystalline properties. These properties are dependent on various film deposition parameters. Their physical properties can be attained by incorporating minor structural modifications by altering parameters like deposition rate, film thickness, substrate temperature, annealing temperature and annealing time. Among oligothiophenes, α-quaterthiophene (α-4T) is widely studied because of its promising applications in organic electronic industry.

Quaterthiophene (α-4T) is a good photosensitive organic material which shows considerable absorption in the short wavelength region of the UV-visible spectrum. α-4T thin film is suited for organic and optoelectronic device applications. Organic semiconductors [2-11] are useful in microelectronics and nanotechnology. α-oligothiophenes [12-13] (α-Nt) are oligomers of thiophenes. Among them α-4T [14-15] is highly promising for applications in thin film transistor devices [16]. The solubility of α-4T makes it a more potential candidate for solution phase film deposition. The capability of α-4T to dissolve in organic solvents at room temperature is advantageous. Hence it can be used easily to process organic semiconducting material.

Oligothiophene consists of thiophene sub units bonded each other by σ bonds via its □ carbon atoms to form oligomers of thiophene. Four thiophene sub units are bonded to form α-quaterthiophene (α-4T) molecule. Since it has high vapour pressure, it is possible to form thin films by thermal evaporation [17] by vapour deposition technique on sublimation in high vacuum. It has good electrical characteristics suitable for the fabrication of organic field effect transistors (OFETs) [18-24], organic photovoltaics (OPVs) [25-26], organic light emitting diodes (OLEDs) [27-

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30], solar cells [31-37] and electro chromic devices (ECDs). Organic electronics is an emerging field in electronic industry where organic semiconductors can be used in the fabrication of electronic devices [38-41].

II. Experimental details

α-Quaterthiophene powder of 96% purity from Sigma Aldrich has been used as source material in the preparation of α-4T thin films. Hind Hivac coating unit (Model 12A4-D) has been used for the preparation of thin films. Thermal evaporation technique has been employed in vacuum coating unit for the deposition of thin films. The thin films of α-4T of thicknesses 50 nm, 100 nm, 169 nm and 200 nm have been deposited on thoroughly cleaned glass substrates of dimensions 75 mm x 25mm x 1.35 mm. substrates are well cleaned in light soap solution and soaked well in dilute nitric acid. It is washed thoroughly in distilled water and subjected to ultrasonic agitation in acetone for 2 to 5 minutes. Thereafter it is rinsed with isopropyl alcohol and dried using hot air. It is further subjected to HT cleaning provided with vacuum coating unit for 2-5 minutes. These glass substrates which are totally free from any sort of contamination have been used for the deposition of thin films. α-4T powder has been placed in pre-cleaned molybdenum boat of dimension 23 x 13x 11 mm and the cleaned glass substrates are placed at distance of 20 cm above the boat and well enclosed by the bell jar of the coating unit. Using rotary pump, a fore vacuum of 10^{-3} m.bar as measured by pirani gauge has been created inside the vacuum chamber to fulfil the pre-requisite vacuum for the operation of diffusion pump. A high vacuum of 10^{-6} m.bar as indicated by penning gauge has been produced using the diffusion pump inside the vacuum chamber. α-4T thin films have been deposited at deposition rate of 2 Å/sec till the thickness monitor indicates the formation of α-4T thin film of required thickness. The prepared thin films of thicknesses 50 nm, 100 nm and 200 nm have been annealed in vacuum at 60 ºC, 80 ºC, 100 ºC and 120 ºC. The thin films are cut into pieces of dimensions 1 cm x 1 cm. Electrical contacts are made on each thin film using silver paste. The Hall coefficient and bulk charge carrier concentrations of the as-deposited and annealed films are measured using Hall measurement system (Ecopia 3000).

III. Results and discussion

In 1987 E. H. Hall observed that when current flows through a conducting material placed in a magnetic field, a voltage is developed in the conductor which is proportional to the current and magnetic field and perpendicular to both current and magnetic field. This phenomenon is known as Hall effect [42-49].

A current I flows through a conducting material of length L, width w and thickness t having a bulk charge concentration n, along the positive direction of X axis is placed in a magnetic field B along the positive direction of Z axis. Then by Hall effect a voltage is developed in the material perpendicular to both the direction of current and magnetic field. This, a voltage known as Hall Voltage, V_H developed across the conductor along the positive Y axis. Assuming the current I is due to the flow of holes of drift velocity v in the conductor, holes experience Lorentz force,

$$F = m (v \times B) \quad 1$$

which is along the negative Y axis direction. As a result, holes get deflected towards bottom surface the conductor and thus a Hall voltage V_H and an electric field E are developed in the of positive direction z axis. When a steady state is reached, force on holes due to electric field and magnetic field balance each other. Then

$$eV_H=evB \quad 2$$

where e is the electric charge of a hole. Current through the conductor is given by

$$I=Avne=(wt)vne \quad 3$$

where A is the area of the of cross section of the conductor. Using above equations

$$V_H=R_H \frac{IB}{t} \quad 4$$

where R_H is the Hall Coefficient. HMS gives Hall voltage for the given current I.

$$R_H = \frac{1}{ne} \quad 5$$

Bulk charge concentration of the material of the conductor is

$$ne=\frac{1}{R_H} \quad 6$$

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Using HMS (Ecopia 3000) the Hall coefficient and bulk charge carrier concentration of as deposited and annealed α-4T thin films of thicknesses 50 nm, 100 nm and 200 nm have been measured and tabulated in table 1. From the table, it is observed that the Hall coefficient and bulk charge carrier concentration are found to be positive. From equations 1, 2, 3, 4, 5 and 6 it is evident that when Hall coefficient and bulk charge carrier concentration are positive the electrical conductivity is due to holes. This confirms that the thin films used are a p-type semiconductors.

Table 1. Hall coefficient and bulk charge carrier concentration of α-4T thin films

Thin film thickness (nm)	Temperature (ºC)	Hall coefficient	Bulk charge concentration cm^{-3}
50	30	1.411E+15	4.424E+03
50	60	1.076E+13	5.803E+05
50	80	4.880E+12	1.280E+00
50	100	1.014E+13	6.155E+05
50	120	5.292E+12	1.179E+06
100	30	2.017E+12	3.094E+06
100	60	1.088E+13	5.735E+05
100	80	7.050E+11	8.854E+06
100	100	1.593E+13	3.919E+05
100	120	1.870E+13	3.338E+05
200	30	3.260E+12	1.915E+06
200	60	8.923E+11	6.996E+06
200	80	2.184E+13	2.858E+05
200	100	1.996E+13	3.127E+05
200	120	1.035E+13	6.029E+05

IV. CONCLUSION

Hall coefficient and bulk charge carrier concentration of as deposited and annealed α-4T thin films of various thicknesses are found to be positive. In α-4T thin films holes are the majority charge carriers and its electrical conductivity is due to holes. The thin film is confirmed as a p-type semiconductor.

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