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Study of PEC Solar Cell with Variation in Volume of Electrolyte

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ABSTRACT

Large fluctuations in energy prices have been a distinguishing characteristic of the Indian economy since the 1970s. Turmoil in the Middle East, rising energy prices in the United States and evidence of global warming recently have reignited interest in the link between energy prices and economical effect. There is acute shortage of energy in the country. This leads to huge energy demand, which is apparent in frequent load shedding, power failure, closure of factories, man-hour loss and decrease in production. Part of the problem is related to the insufficient energy resources leading to the shortage in supply which is not able to meet the growing demands of power in the rapidly expanding industrial, transport, agricultural and urban sectors. Solar energy seems to be correct answer to this entire problem. It is an urgent demand of the time to develop cheaper and efficient solar cell. On that path $MoSe_2$ is a promising material towards its application in photoelectrochemical solar cells. The $MoSe_2$ crystals grown by direct vapor transport technique will be used to prepare a PEC solar cell. Various compositions of different electrolytes are chosen to get a better response of the $MoSe_2$ based PEC solar cell. Here the authors report their investigations on the $MoSe_2$ base photoelectrochemical Solar Cells with varying the volume of electrolyte which shows that the increase in volume of electrolyte increases the efficiency of the PEC solar cell.

Key words: Photoelectrochemical, volume, efficiency.

I. INTRODUCTION

Solar power in Gujarat:

Gujarat has been a leader in solar power generation and contributes 2/3rd of the 900 MW of photovoltaic in the country. The State has commissioned Asia's biggest solar park at Charanka village. The park is already generating 214 MW solar powers out of its total planned capacity of 500 MW. The park has been functioning on a multi-developer and multi-beneficiaries' paradigm and has been awarded for being the most innovative and environment-friendly project by the CII.

With a view to make Gandhinagar a solar city, the State government has launched a roof-top solar power generation scheme. Under this scheme, the State plans to generate five megawatts of solar power by putting solar panels on about 50 state government buildings and on 500 private buildings. The State has also a plan to emulate this project in Rajkot, Surat, Bhavnagar and Vadodara in 2013

The State plans to generate solar power by putting solar panels on the Narmada canal branches. As a part of this scheme, the State has already commissioned a one-megawatt solar plant on a branch of the Narmada Canal near Chandrasan area of Anand taluka. This also helps by stopping 90,000-liter water/year of the Narmada River from evaporating.

Our effort towards renewable sources of energy:
Now it is global need to develop eco friendly, sustainable, durable and economically cheaper source of energy. Photoelectrochemical (PEC) solar cell could be the answer [2,3]. Solar energy is available in most part of the world.

Especially in India intense solar radiation is available throughout the year. Our goal is to develop a simple and cheaper technology which can convert solar energy into electrical energy.

II. EXPERIMENTAL

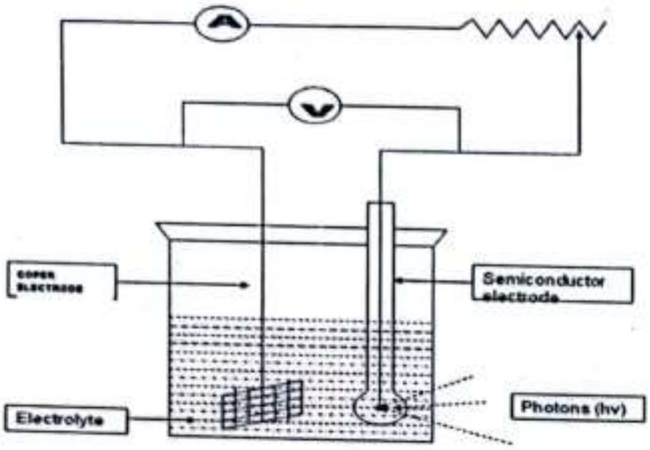

Fig.1.Experimental set up of PEC solar cell

Experimental set up of PEC solar cell is shown in above the diagram. PEC solar cell is very advantageous against it solid state counterpart. Fabrication of PEC solar cell is very simple. Economically it is very advantageous. We are using $MoSe_2$ as a semiconducting electrode. Its resistance against corrosion is very high. Energy gap of the material plays an important role to get better efficiency. Energy gap of $MoSe_2$ falls in the maxima of the solar radiation [4,5]. So it is very beneficial to get better efficiency.

III. RESULT AND DISCUSSION

Presently we are working on PEC solar cell with $MoSe_2$ as a semiconducting electrode and copper as a reference electrode. We have used combination of 0.035M I_2, 0.5M NaI and 0.5M Na_2So_4 as an electrolyte. We have taken volume of the electrolyte as variable parameter while semiconducting electrode and counter electrode of the cell remain constant for each experiment. We have found some interesting result which are shown blow.

Table: 1Experimental data (volume of electrolyte 250 ml).

I_L (mw/cm^2)	V_{oc} (mv)	I_{sc} (μA)	P_{MAX} (nW)	F.F	Efficiency (η %)
10	514	33.7	8085	0.47	4.04
20	500	42.6	7590	0.36	1.90
30	481	43.2	6825	0.33	1.14
40	481	46.2	6875	0.31	0.86
50	490	46.7	8085	0.35	0.81
60	484	48.4	8175	0.35	0.68
70	493	50.2	7325	0.30	0.52
80	484	53.3	8600	0.33	0.54
90	482	50.7	8600	0.35	0.48
100	498	50.4	9600	0.38	0.48

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110	492	53.4	9225	0.35	0.42
120	495	54.5	9825	0.36	0.41

For each value of illumination intensity I_L photo current I_{ph} and photo voltage V_{ph} has been measured. During the experiment photo current I_{ph} and photo voltage V_{ph} is changed using port resister of 1 MΩ and 200KΩ. Then using measured values of Iph and V_{ph} we have found out P_{max} , Efficiency and fill factor is been carried out using their formula. Same experiment has been repeated for electrolyte volumes of 100ml, 150ml, 200ml, & 250ml..Table 1 and Fig. 2 shows data and characteristic curve for electrolyte volume of 250ml.It can be seen from the graph that as illumination intensities I_L increases photocurrent also increases. Increase in illumination intensities I_L generate extra photoelectron from the semiconducting electrode. These extra photoelectrons generate additional photocurrent that can be seen from fig 2 and fig.3. Open circuit voltage has been measured for each value of illumination intensities I_L. Here I_L is varying from 10mW/cm² to 120 mw/cm².

Table: 2 Experimental data (volume of electrolyte 150 ml).

I_L	V_{oc}	I_{sc}	P_{MAX}(nW)	F.F	Efficiency (η
10	512	34.6	6055	0.34	3.03
20	534	41.1	9135	0.42	2.28
30	503	40.3	7490	0.37	1.25
40	527	41.7	7910	0.36	0.99
50	507	42.8	7105	0.33	0.71
60	521	43.1	8130	0.36	0.68
70	481	43.4	6875	0.33	0.49
80	515	39.4	8040	0.40	0.50
90	502	37	6900	0.37	0.38
100	510	39.3	6840	0.34	0.34
110	514	46.7	7575	0.32	0.34
120	516	49.1	8540	0.34	0.36

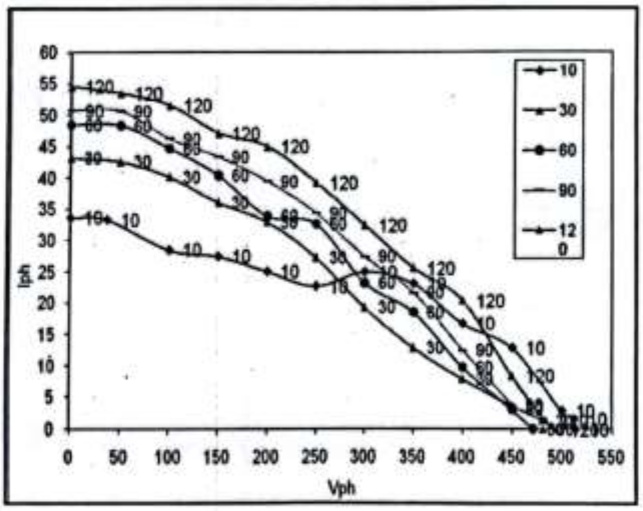

Fig.2. photocurrent I_{PH} → photo voltage V_{PH} characteristic of PEC solar cell for all I_L (volume of electrolyte-250ml)

Characteristic curve of photo current and photo voltage is illustrated in the above diagram. This agrees with the theoretical aspect of PEC solar cell [7,8]. Here illumination intensities I_L occupy the values from 10 mW/cm² to 120 mW/cm² for each volume of the electrolyte Using potentiometer for various resisters I_{ph} and V_{ph} was being found out. For certain value of V_{ph}, Iph remains almost constant.

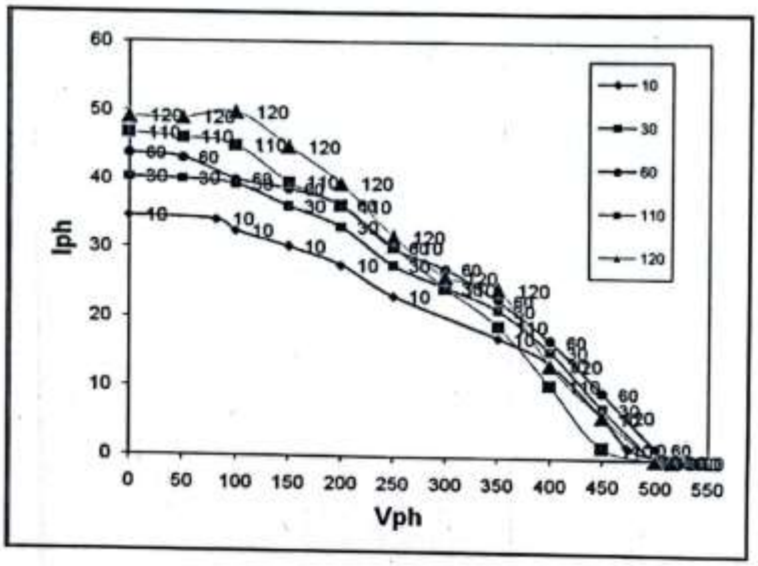

Fig.3. photocurrent I_{PH} → photo voltage V_{PH} characteristic of PEC solar cell for all I_L(volume of electrolyte-150ml)

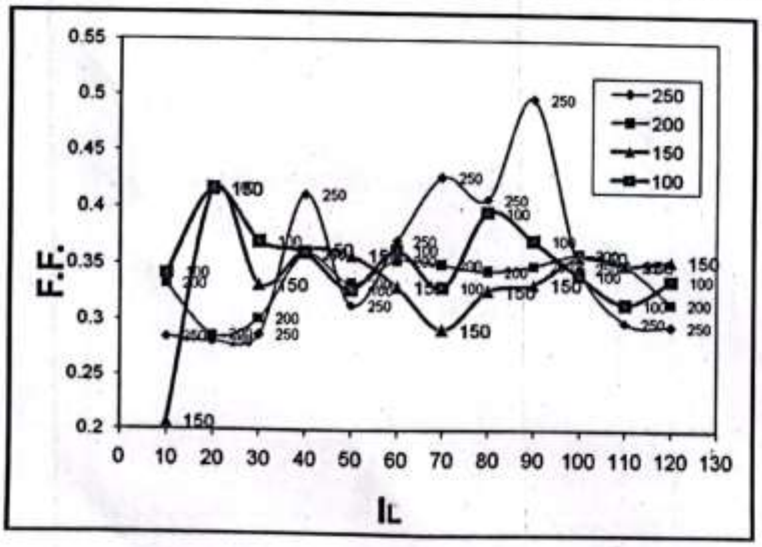

Fig .4.fill fector F.F. → Illumination intensities I_L

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Variation in fill factor with respect to illumination intensities is illustrated in the above diagram. Fill factor has been carried out using following formula [8,9].

$$F.F. = \frac{P_{max}}{I_{sc} \; X \; V_{oc}} \qquad (1)$$

For each value of I_L, P_{max}, V_{oc} and I_{sc} were measured. And for each situation fill factor was being calculated which are shown in table 1 & table 2. From the diagram we conclude that for I_L = 90 mW/cm^2 for volume 250ml fill factor attain maximum value [8,9].

***Efficiency of PEC solar cell:**

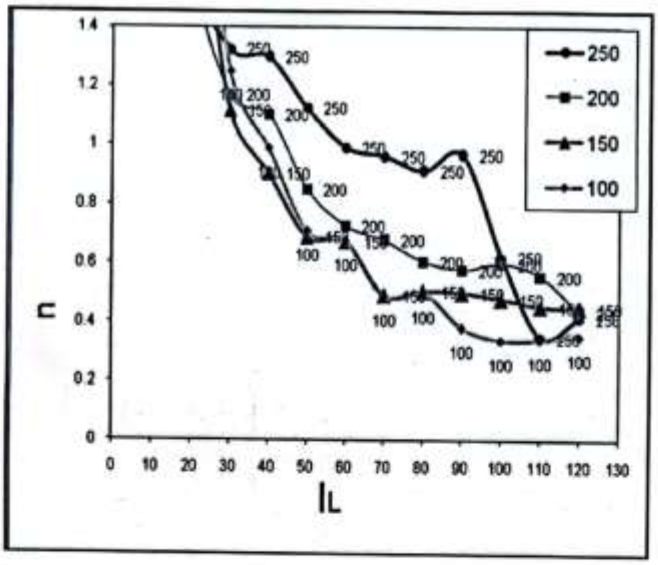

Fig .5.efficiency η → illumination intensities I_L (for volumes of electrolyte 100m,150ml,200ml &250ml)

Efficiency of PEC solar cell has been carried out for each value of I_L and for different volumes of an electrolyte Using following formula.

$$\eta = \frac{P_{max}}{I_L \; X \; Area} \text{x}100\% \qquad (2)$$

We have used semiconducting material of the size 2 mm X 1 mm. Effect of variation in illumination intensities and volume of electrolyte is shown in the above diagram. we conclude that as I_L increases efficiency tends to decrease. For I_L = 10mW/cm^2 PEC solar cell attains maximum efficiency. Result found in the experiment is shown in the table 1 & table 2. We also conclude that for certain illumination intensities as volume of the electrolyte increases efficiency of the PEC solar cell also increases. Increase in volume of electrolyte increases number of ions per unit volumes. These increase in ion density contribute to photocurrent and ultimately increases efficiency of the solar cell [7,8].

CONCLUSION

1. Potential of Solar power production in India is very huge. Technology must be improved to increase solar energy production to certain level.
2. The solar Photo voltaic power is very less comparing to the developed countries.
3. In our experiment we found that the efficiency of PEC solar cell decreases with illumination intensities.
4. The decrease in efficiency is because of corrosion on the cooper electrode.
5. By changing the volume of electrolyte we can increase the efficiency of PEC solar cell.

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Various Properties of DVT grown $MoSe_2$ Crystals

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ABSTRACT

The $MoSe_2$, a member of group-VI has come out to be one of the most promising materials towards its various applications. Molybdenum Diselenide ($MoSe_2$) have been grown using direct vapour transport technique (DVT). Resistivity and Hall Effect Measurement: The variation of resistivity with temperature, activation energy and anisotropy properties were analyzed. Hall Coefficients, Carrier concentrations and mobility have been calculated using Hall Effect experiment. The variation of resistance with pressure for $MoSe_2$ crystals has been analyzed. TEP Measurements: Measurements of thermoelectric power in temperature range 300K – 425K confirms that $MoSe_2$ possess n-type conductivity. The variations thermoelectric and electrical properties with temperature are discussed.

Keywords: Direct vapour transport technique (DVT), Resistivity, Hall Effect, Thermoelectric power (TEP).

I. INTRODUCTION

(i) Resistivity and Hall Effect Measurement
(ii) TEP Measurements
(i) Resistivity and Hall Effect Measurement

According to the band theory, the energy levels of semiconductors can be grouped into two bands, the valence band and the conduction band. In the presence of an external electric field it is the electrons in the valence band that can move freely, thereby responsible for the electrical conductivity of the semiconductors. In case of intrinsic semiconductors the Fermi level lies in between the conduction band minimum and valence band maximum. Since the conduction band lies above the Fermi level, at 0K, when no thermal excitations are available, the conduction band remains unoccupied. So conduction is not possible at 0K, and resistance is infinite. As temperature increases, occupancy of the conduction band goes up; thereby resulting in decreases of electrical resistance of the semiconductor .The temperature dependence follows an exponential relation with temperature which is denoted by following equitation. [1].

$$R = R_0 e^{(-\alpha)/T} \ldots\ldots\ldots\ldots\ldots (1)$$

The electrical resistance of the crystals along the basal plane was determined by Van der pauw method. Hall measurements were carried out to determine Hall coefficient, mobility and carrier concentration [2-4].

(ii) TEP Measurements

TMDCs have been used for many years as solid state lubricants, photovoltaic/photocatalytic solar energy converters, Schottky and liquid junction solar cells, catalysts in many industrial applications and in secondary batteries etc [5-6]. Increasing potential for use of transition metal dichalcogenide materials in Schottky devices, photovoltaic and photo electrochemical (PEC) solar cells is because of their Inherent resistive nature to photo corrosion. They have also found use in Schottky barrier devices, photovoltaic and photo electrochemical solar cells as a flexible electronic material in recent years [4-6].

II. EXPERIMENTAL/METHODOLOGY

(i) Resistivity and Hall Effect Measurement

The dc resistivity (ρ) of $MoSe_2$ crystals perpendicular to c-axis and parallel to c-axis was investigated by using dc resistivity apparatus. It can be investigated by the following techniques: (1) Van der Pauw technique and (2) four probe resistivity method. The resistivity of the specimens can be measured at different temperatures by four probe method. We have used four probe resistivity methods for our investigation. The high temperature dc resistivity measurements performed on the basal plane in the direction parallel to c-axis and in the temperature range 378K-823K. The crystals having irregular shape and larger size were normally selected for investigating their electrical behavior through four probe resistivity method[1-2]. The resistivity at each temperature was evaluated by using the formula,

$$\rho = 2\pi sR \ldots\ldots\ldots\ldots\ldots (2)$$

Where s is the distance between two probes, and 'R' is the resistance between two probes [3-6].

(ii) Thermoelectric Power measurement

If the temperature difference ΔT between the two ends of a material is small, then the thermo power of a material is conventionally defined as:

$$S = -\frac{\Delta V}{\Delta T} \ldots\ldots\ldots\ldots\ldots (3)$$

Where ΔV is the thermoelectric voltage seen at the terminals.
Here, again, are the formulas for the Seebeck coefficient, with the sign made explicit:

$$S = -\frac{V_{left} - V_{right}}{T_{left} - T_{right}} \ldots\ldots\ldots\ldots\ldots (4)$$

$$\mathbf{E} = S\nabla T \ldots\ldots\ldots\ldots\ldots (5)$$

Where "left" and "right" denote two ends of the material, and where the second equation is understood as vector multiplication. Thus, if S is positive, the end with the higher temperature has the lower voltage, and vice-versa, and the electric field will point in the same direction as the temperature gradient [4]. There is a minus sign in the first equation; this is because the electric field points from the higher voltage towards the lower voltages, whereas the temperature gradient points from the lower temperature towards the higher temperature [5-6].

III. RESULTS AND DISCUSSION

(i) Resistivity and Hall Effect Measurement

The resistivity obtained from the above equation is plotted as a function of temperature and are shown in Figure 1 and Figure 2 for $MoSe_2$ crystal [1, 3].

It is seen that resistivity decreases exponentially with an increase in temperature. The graph indicates a typical semiconducting behavior of material. We conclude from the graph that DVT Grown $MoSe_2$ crystal is a semiconducting material.

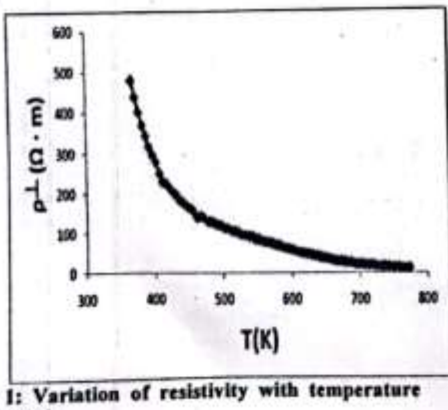

Figure 1: Variation of resistivity with temperature (⊥ to C Axis).

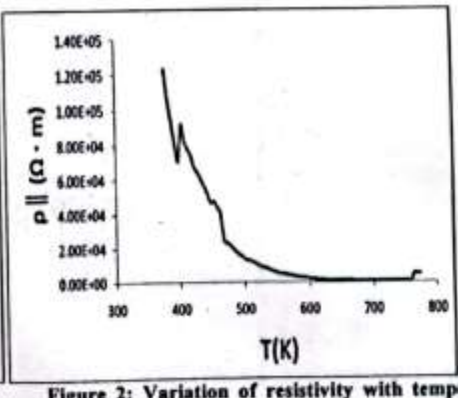

Figure 2: Variation of resistivity with temperature. (|| to C Axis).

Figure 3 and Figure 4 shows the variations of the electrical resistivity ρ (represented as log ρ) against temperature (represented as $10^3/T$). It is clear that the electrical resistivity of all investigated samples decreases with increasing temperature, i.e. exhibits semi-conducting behavior, according to the well known relation

$$\rho = \rho_o \exp(-E_a/kT) \;\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Here ρ_o is a constant and Ea is the activation energy of the resistivity [5-7].

Activation Energy:

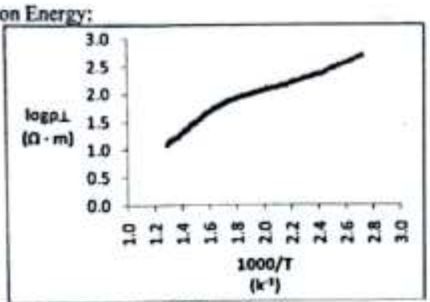

Figure 3: Variation of resistivity with the reciprocal of temperature (⊥ to C Axis)

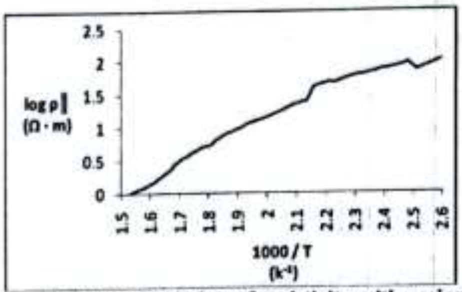

Figure 4: Variation of resistivity with reciprocal of temperature (‖ to C Axis).

Modifying equation (10) we get following relation between resistivity and temperature

$$\log\rho = -\frac{E_a}{2.303k}\left[\frac{1}{T}\right] + A \ldots\ldots\ldots\ldots (11)$$

It indicates that Graph of log (ρ) → 1 / T should be a straight line. The graph of log (ρ) verses 1000/T shows almost a straight line which matches with the graph observed by Mahalway and Evans for $MoSe_2$ [8]. Using standard formula of straight line and eq. (11) we get the following formula for the activation energy,

$$Ea = 2.303 \times k \times \text{slope (eV)} \ldots\ldots\ldots\ldots (12)$$

Here k is a Boltzmann constant. Activation energy is being carried out using slop of the Figure 3 and Figure 4. The activation energy values determined from the Figure 3 and Figure 4 is tabulated in Table 1. The value shows that the activation energy for parallel to c axis is greater than perpendicular to c axis [7-8].

Table 1: The activation energies calculated from Log (ρ) vs. 1000/T.

Activation Energy E_a (eV)		
Sample	(‖ c-axis)	(⊥ c-axis)
$MoSe_2$	0.2854eV	0.2060eV

Anisotropy:

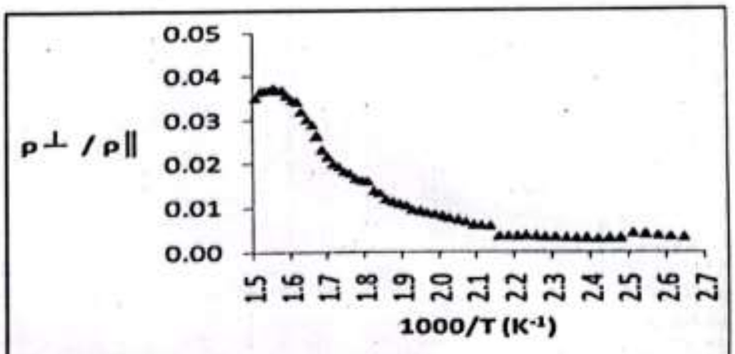

Figure 5: Variation of anisotropy with the reciprocal of temperature

In our investigation anisotropy measurements have been carried out in the temperature range 378K-823K. From the ratio of the data of high dc resistivity measured from parallel and perpendicular to the c-axis. It is seen in Figure 5 that the anisotropy ratio increases with the increase in temperature. This variation of anisotropy with temperature shows an identical behavior to that reported by Zheng et al [2].

Table 2. Results obtained from resistivity, Hall effect and optical absorption measurements for the crystals of $MoSe_2$.

Crystals	$MoSe_2$
Hall coefficient (cm^3/coul.)	14.685
Hall mobility (cm^2/V□ s)	79.36
Carrier concentration (cm^{-3})	4.256×10^{17}

The variation of resistance with pressure for $MoSe_2$ is shown in figure 6. In this case it is seen that the resistance for crystal decreases gradually with pressure up to 8 GPa. However, the samples became more conducting in nature at higher pressures [9]. This decrease of resistance is probably attributed to the charge carriers of valence band contributing to the conduction band carriers. The results of measurements are listed in table 2.

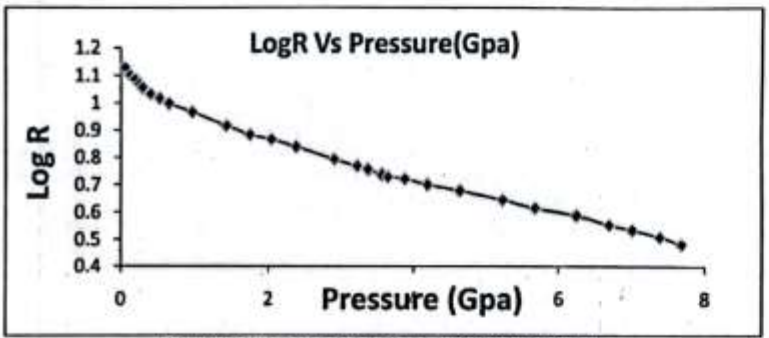

Figure 6: The variation of resistance with pressure

(ii) TEP Measurements

The crystals of $MoSe_2$ were grown by direct vapour transport technique using a two zone horizontal furnace. The crystals grown were found to be in the form of thin platelets having opaque appearance with perfectly shining surfaces. These grown crystals were first characterized by thermoelectric setup developed for this purposes [8, 10].

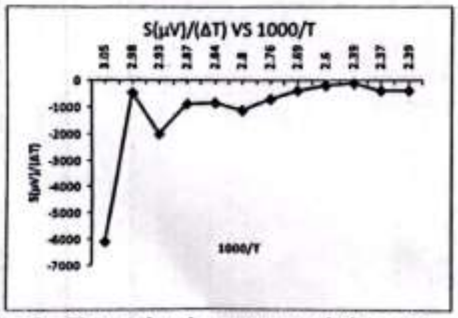

Figure 7: Thermoelectric power variation with inverse of temperature

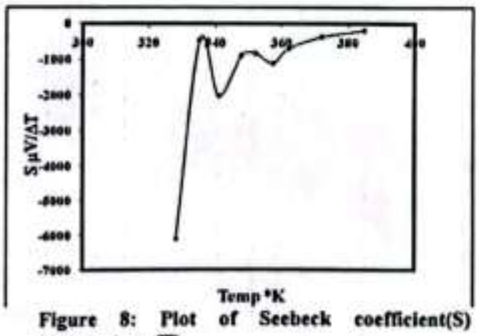

Figure 8: Plot of Seebeck coefficient(S) vs. temperature (T).

The variation of thermoelectric power 'S' for crystals of $MoSe_2$ at different temperatures are shown in Figure 8.

$$S = \frac{k}{e}\left[A + \frac{E_F}{kT}\right] \quad \ldots\ldots\ldots (13)$$

It has been seen that the thermoelectric power 'S' increases with increase in temperature .To study the temperature dependence of the thermoelectric power of a n-type semiconductor the above expression can be used, where k is the Boltzmann constant, e is the electronic charge, A is the constant determined by the dominant scattering process and E_F is the separation of the Fermi level from the top of the valence band. For a small temperature range, E_F is fairly constant and hence from equation if thermoelectric power (TEP) is plotted against the reciprocal of temperature, a straight line is expected from where E_F and A can be determined, from the slope and intercept respectively. Fig. 7 shows the variation of TEP with an inverse of temperature for $MoSe_2$ crystals [10].

The variation of thermoelectric power '*S*' for M_OSe_2 crystals as a function of inverse temperature in the range of 300 K to 425 K is shown in Figure 8. It is observed that TEP increases with temperature, indicating the typical semiconducting behavior of the M_OSe_2. Moreover, the sign of TEP is found to be negative for M_OSe_2 indicating that grown crystals possess *n*- type semiconducting character [10]. The thermoelectric power measurements have been carried out as a function of temperature for as grown $MoSe_2$ crystals starting from ambient to 423 K with experimental set up scientific lab, S.P. University, vvnagar, Anand.

CONCLUSION

- $MoSe_2$ crystal grown by DVT is a semiconductor.
- The activation energies for parallel and perpendicular to c-axis are 0.2854eV and 0.2060eV respectively.
- It is observed that TEP increases with temperature. Maximum TEP is found to be equal to -113.893 (µV)/k. Minimum TEP is found to be equal to -6104.52 (µV)/k.

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