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RESEARCH ARTICLE

Study of Electrical Properties of Multilayers of Bi_2Te_3 and Sb_2Te_3 Compounds.

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ABSTRACT

In Present era there is a need to develop modes and methods for harvesting of waste heat. Telluride compounds are very good thermoelectric materials. They have shown excellent thermoelectric properties around 100^0 C-200^0 C. Studies have shown that their multilayer designs show better thermoelectric properties. In this work we report multilayer thin films of Bi_2Te_3 and Sb_2Te_3 compounds of single layer thickness of about 30-40 nm which were fabricated using thermal evaporation technique on glass/ Si substrate. The electrical properties i.e. hall measurements, carrier concentration, carrier mobility, conductivity have been studied at room temperature. Thermoelectric behavior is analyzed on the basis of see beck coefficient for which our samples show better result.

Key words: *Thermoelectric materials, Hall Effect measurement, Fuch-Sondheimer theory, galvanometric size theory.*

INTRODUCTION

In the age of nanotechnology, the size of any electronic device becomes dense or compact. A large number of devices are installed in a small area so it must be tackled at micro or nano scale. It is observed that nan scalematerials exhibits excellent thermoelectric properties rather than bulk or composites (Rowe, 2006; Sharma & Purohit 2016). In present almost 80% of the world's population faces a problem of harmful effect of pollution, global warming and energy crisis. So, it is a very big problem and a big need in taking care of these issues. At present the use of thermoelectric materials are less due to high cost and low efficiency. So, a huge gap is identified in need and availability of thermoelectric materials. So, for researchers it is a challenging task to develop new materials of low cost and high efficiency. In this paper thin films of Bi_2Te_3 and Sb_2Te_3compounds in Nanodimension have been developed and analyzed. Bismuth Telluride behaves as a topological insulator but its surface shows conducting states. (Das & Nahid 2015; Chen, *et al*., 2009, Hasan & Kane, 2010; Caha, *et. al.,* 2013; Long Ren, *et al*., 2015) physically it behaves like a semiconductor & when it is doped with Se or Sb then it behaves like an efficient thermoelectric material having. It has been used in thermoelectric generators, in space exploration to convert heat from radioactive material into electricity etc. Semiconductors are good thermoelectric effect as compared to metals because metals have very low values of seebeck coefficient. As Bi_2Te_3 and $Sb_2Te_3$are narrow band gap semiconductors with E_g = 0.165eV and 0.21 eV having trigonal structures with high melting points (585^{0}C, 620^{0}C) respectively (Arora, *et al.,* 2017 and Goldsmid, 2004). The efficiency of thermoelectric devices depends on figure of merit (ZT) which plays an important role in thermoelectric technology. Figure of merit (ZT) is defined as $ZT = S^2\sigma T/K$, where S is the seebeck coefficient, σ is the electrical conductivity, K is the thermal conductivity. For achieving high figure of merit the Seebeck coefficient (S) and electrical conductivity (σ) should be high and with low thermal conductivity (K). High Figure of merit (ZT) (around 3 to 4) can convert more than 40% part of waste heat into electricity (Takashiri, 2007). But it is very difficult to attain ZT around (3 to 4) because the parameters related with ZT are independent. Bi_2Te_3 and Sb_2Te_3show excellent thermoelectric properties and recent studies have shown that multilayer thin films show large thermoelectric power (Anwar, *et al.,* 2016). The study of Electric properties i.e. Hall Effect is an essential parameter for thermoelectric studies. It is used to find whether a semiconductor is p-type or n-type and to find carrier concentration, carrier mobility and conductivity of the sample. This present work tries to increase the value of ZT (greater than 1 or more) which can be very suitable for thermoelectric applications.

EXPERIMENTAL DETAILS

Multilayers of Bi_2Te_3 and Sb_2Te_3 thin films were deposited on glass and silicon substrate by thermal evaporation method at room temperature. There are many techniques for the deposition of thin films but Vacuum evaporation is relatively simple and inexpensive technique with good figure of merit. Thin films of monolayers of Bi_2Te_3 and Sb_2Te_3 Bi_2Te_3 - Sb_2Te_3(˜ 240 nm) were deposited under vacuum condition (10^{-5} torr) in the chamber. The substrate were cleaned from Acetone. The rate of the deposition was maintained at the rate of (1 -2) A^0/sec. The thickness of the thin films was controlled by quartz crystal monitor. After deposition process the films are annealed at 200^0C for 15 min. The films are characterized by X-ray diffraction (XRD) to determine crystallinity and surface morphology of the films are determined by Atomic Force Microscopy (AFM) at (IUAC, Delhi). Electrical properties were measured by Hall coefficient setup of thickness (30-40 nm), Bilayer Bi_2Te_3 - Sb_2Te_3(˜ 60 nm) and 8 layers.

RESULTS AND DISCUSSION:

Electric Properties:

The variation in electrical properties like carrier mobility, carrier concentration, Hall coefficient and conductivity with thickness are shown by bar graphs in (Fig.1). Results shown in (Fig.1.1) that carrier mobility of the samples decrease from single layer to 8 layers but increase drastically for 300 layers, whereas carrier concentration in (Fig. 1.2) is maximum for 8 layers and decrease for 300 layers which is obvious because higher is the carrier concentration lower will be the mobility of charge carriers. The increment in carrier mobility for 300 layers is may be due to partly size effect and structural defect. These defects are namely impurity centers, voids, and grains are of higher order in case of thin films and these defects concentration will decrease due to filling of voids in higher thickness range. Hence crystallinity of the thin films obtained better (Das & Nahid, 2015; Saxena, *et al.*, 1987).The carrier conc. is the order of 10^{20}/cc signifies some metallic behavior of the samples.

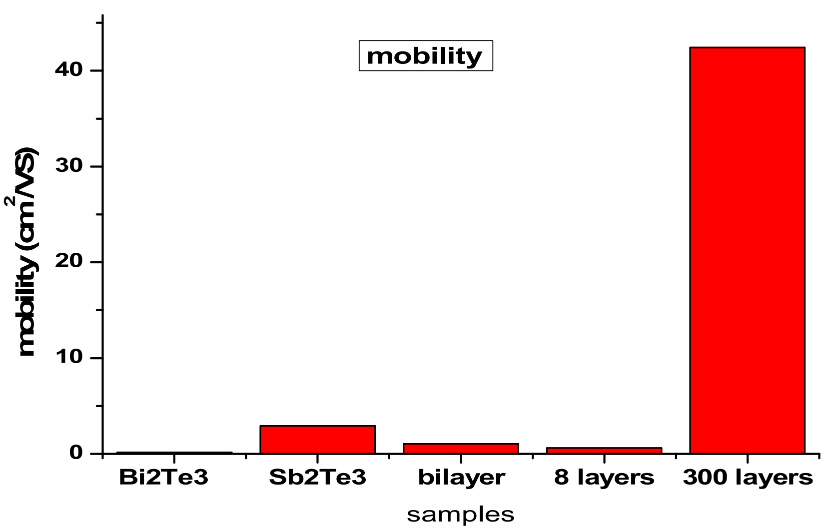


Fig. 1.1: variation of mobility with Thickness

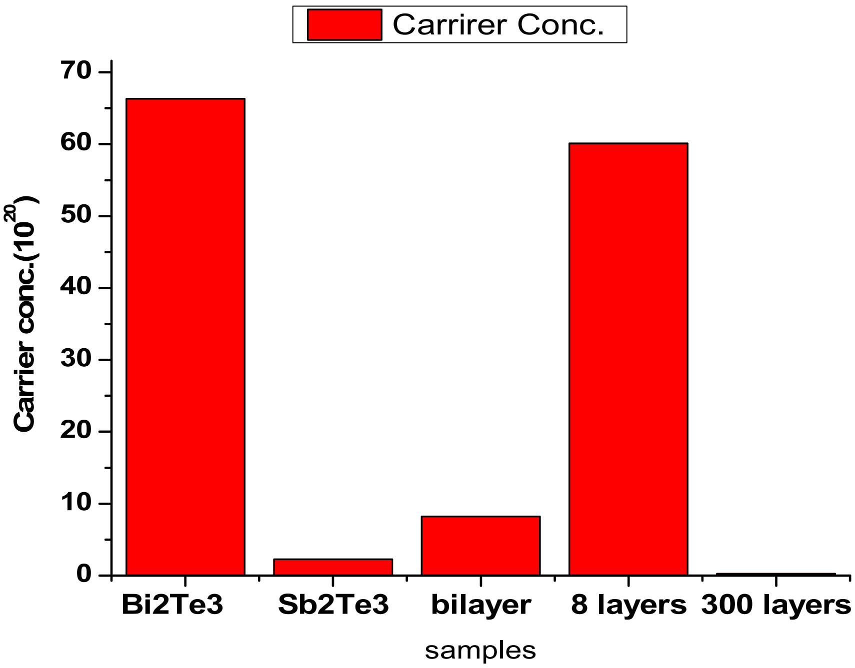


Fig. 1.2: Variation in Carrier conc. With Thickness

Hall coefficient of the thin films Shown in (Fig.1.3) measured by van der pauw's method. The dependence of Hall coefficient with thickness follows galvanometric size theory and dependence of thickness corroborates the Fuchs-Sondheimer size effect theory.According to this theory the current in thin films is mainly determined by the electrons moving almost parallel to the surface and the resistivity is reduced with decreasing thickness. The value of Hall coefficient decreases with thickness upto 8 layers and increased for 300 layers which is opposite to the behavior of carrier concentration as $R_H = 1/ ne$. negative value of hall coefficient for Bi_2Te_3 show n-type carrier and positive value for other samples show p-type.

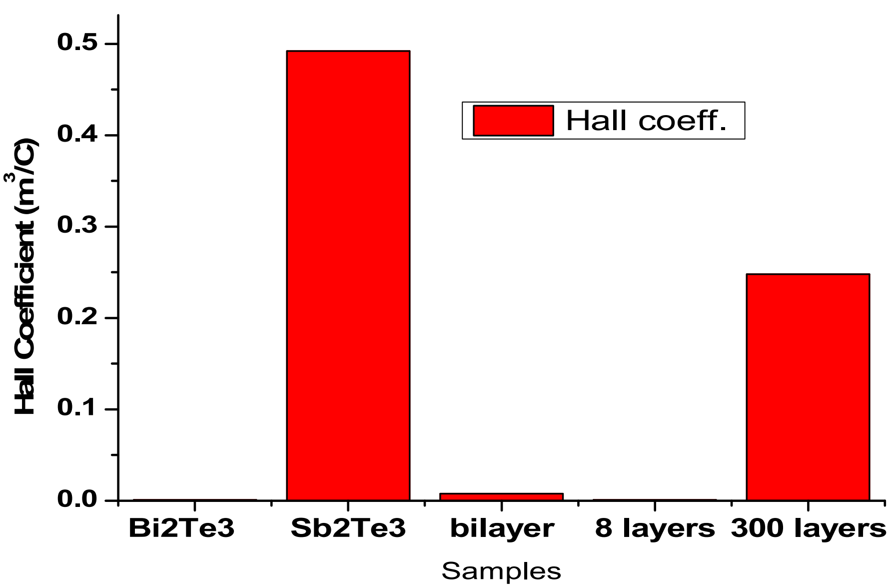


Fig.1.3: Variation in Hall Coefficient with Thickness

Conductivity is also increases upto 8 layers and decrease drastically for 300 layers which is shown in (Fig.1.4). This is due to attaining semiconducting nature in 300 layer sample.

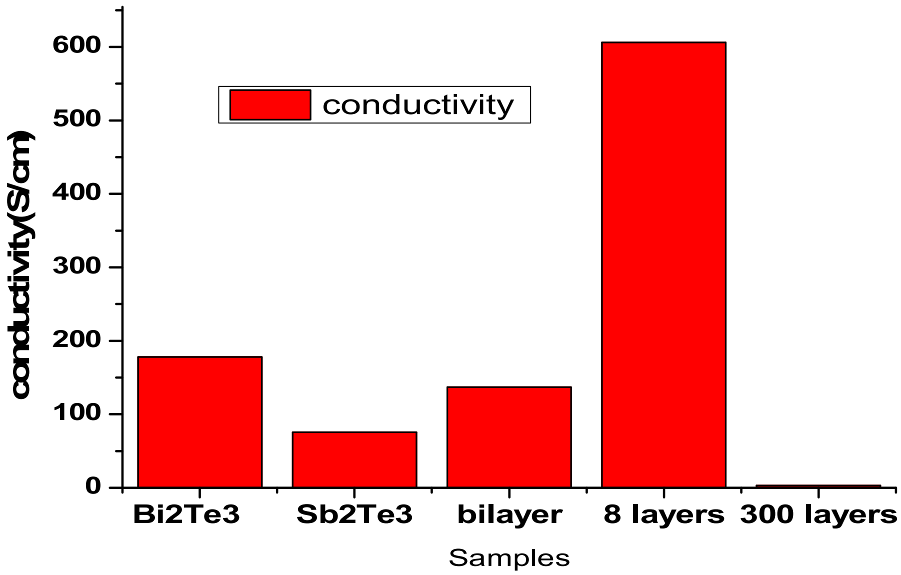


Fig. 1.4: Variation in Conductivity with Thickness

CURRENT VOLTAGE VARIATION

The I–V curve in Fig.2 shows linear behavior for Bi_2Te_3 and $Sb_2Te_3$and Bilayer Bi_2Te_3 - Sb_2Te_3 . we observed that it show some metallic nature for these samples (Arora, *et al.,* 2017). As thickness of the samples increases upto 8 layers the slope of the curve increase which show maximum conductivity but 300 layers sample show nonlinear behavior and its slope was going to decrease which show minimum conductivity which is due to its semiconducting nature. The results shows that as thickness increase upto 300 layers the sample behave like a semiconductor and its bandgap increases that's why its conductivity decreases.

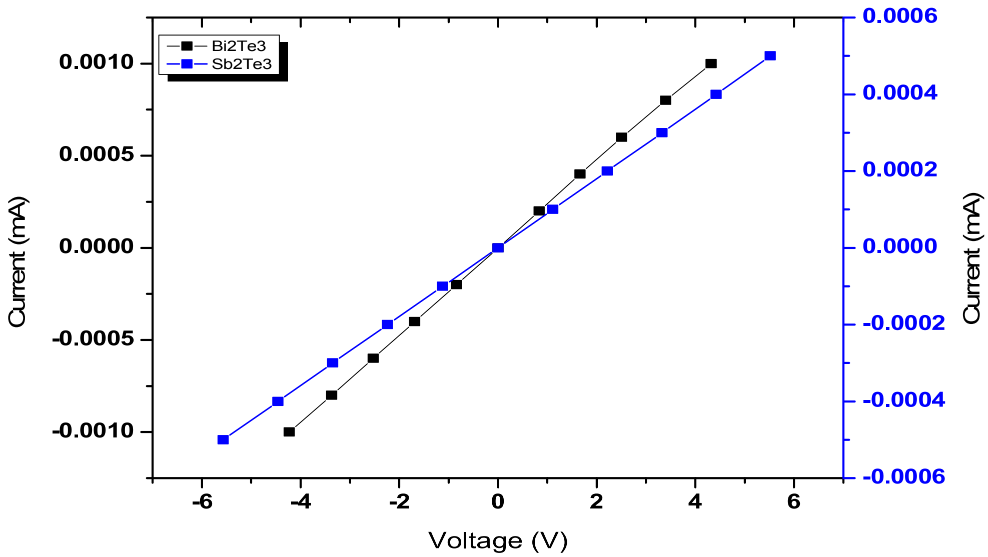
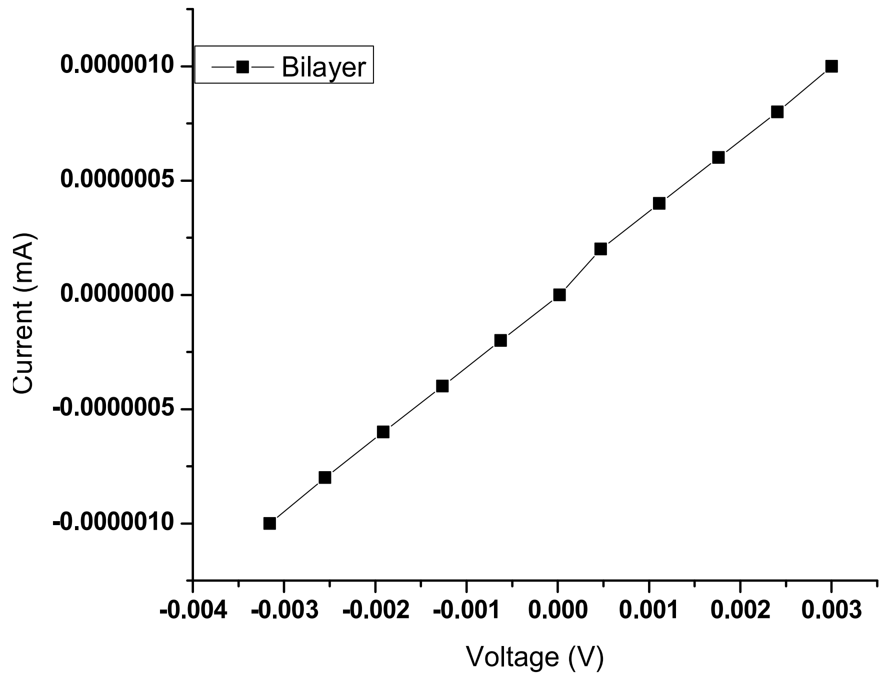


FIG: 2: I –V curves of the samples of different thickness at room temp.



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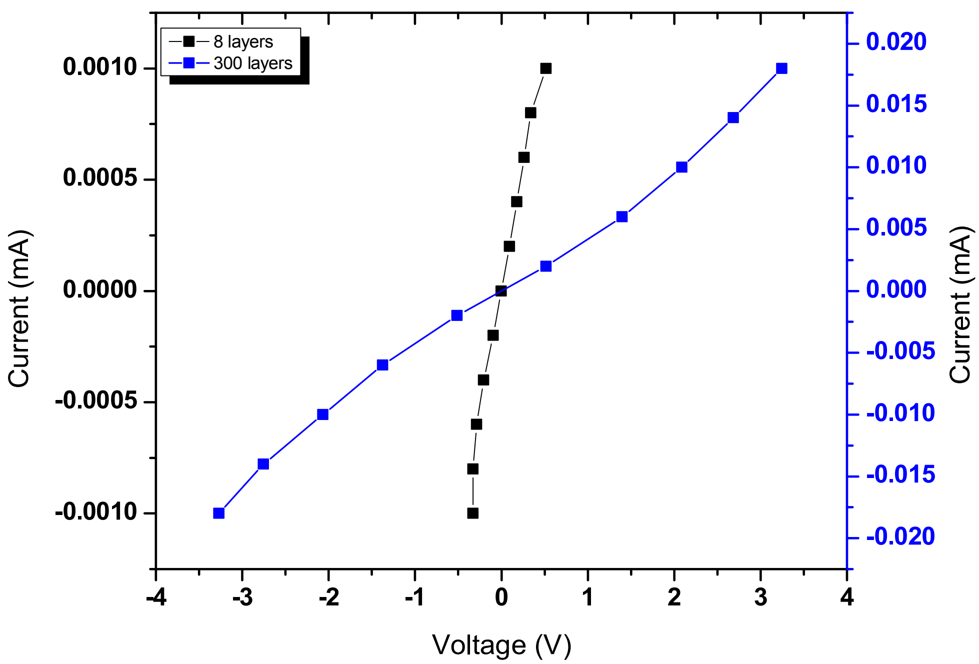

Fig.2: I-V curves of the samples of different thickness.

SEEBECK COEFFICIENT

The variation of seebeck coefficient with thicknes is shown in Fig. 3.The value of seebeck coefficient is maximum for bilayer sample and its value is to be 220µV/K. It has been repoted that highest figure of merit ZT = 2.4 was in ultrasonic thin layers of two alternating layers (Goncalves, *et al.,* 2017 and Venkatasubramamian, *et al*., 2001). Then its value decreases for 8 layers to 50 µV/K but after that its value increased to 12 µV/K for 300 layers.

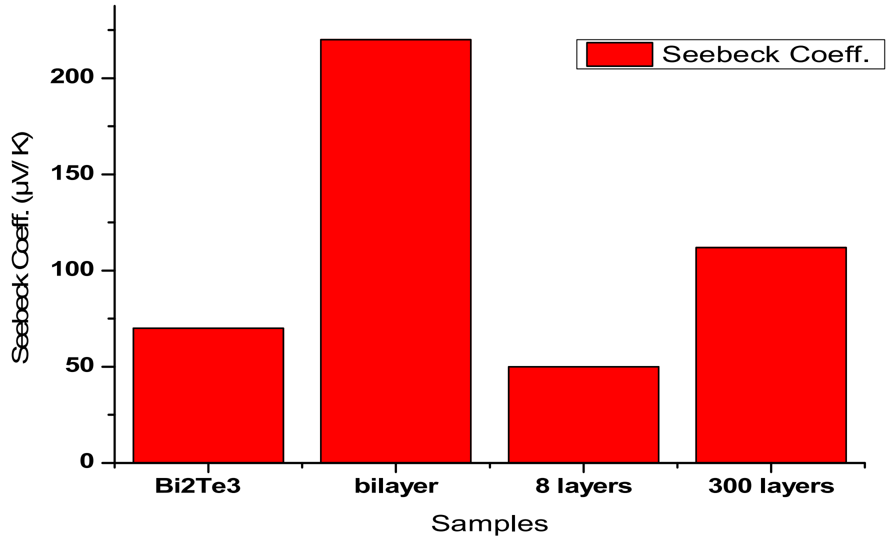

Fig. 3: variation of seebeck coefficient with thickness.

SAMPLE NAME	MOBILITY (cm^2/vs)	CARRIER CONC. $*10^{20}$	CONDUCTIVITY (S/cm)	HALL COEFF. (m^3/C)	SEEBECK COEFF. (μv/K)
Bi_2Te_3	0.17	66.3	177.7	-0.00092	-70
Sb_2Te_3	2.94	2.25	75.7	0.492	-
Bilayer	1.04	8.22	137.1	0.00764	220
8 layers	0.62	60.1	606.0	0.00103	50
300 layers	42.4	0.25	3.17	0.248	112

Table 1: Hallcoefficient and Seebeck Coefficient measurements of the samples.

CONCLUSION

The effect of thickness in multilayers of Bi_2Te_3-Sb_2Te_3 ranging from (30nm-12μm) deposited by thermal evaporation technique on glass or silicon substrate at room temperature on electrical and thermoelectric properties has been studied. It was observed in V –I curve that samples upto 8 layers at room temperature show linear behavior without any junction effect. But 300 layer sample show nonlinear behavior by attaining semiconducting property with lower conductivity and better seebeck coefficient value. The Hall coefficient measurements on these films show negative value of Hall coefficient for Bi_2Te_3 and large carrier concentration and positive values for Sb_2Te_3, bilayer Bi_2Te_3- Sb_2Te_3, 8 layers and 300 layers with relatively low carrier concentrations. The results indicate that for multilayer arrangement of the alternate layers of thin films show semiconducting nature which may show relatively better figure of merit (ZT).

REFERENCES

1. Anwar S., Mishra B.K., Anwar S. (2016): Thermoelectric Performance of Bi_2Te_3, Sb_2Te_3 thin film, Advanced Materials Proceedings, CSIR,Bhubaneswar, 1, 191-194.
2. Arora S., Jaimini V., Srivastava S., Vijay Y.K. (2017): Properties of Nanostrructure Bismuth Telluride Thin Films Using Thermal Evaporation Journal of Nanotechnology, 4.

3. Caha O., et.al, (2013): Growth. Structure, and Electronic Properties of Epitxial Bismuth Telluride TopologicalInsulator Films on BaF2 (111)substrates" crystal growth and Design,(2013), 13,3365-3373.
4. Chen Y.L., Analytics J.G., Chu J.H., Liu Z.K., et al.(2009): Sciences, Experimental Realization of a Three-Dimensional Topological Insulator Bi_2Te_3 Sciences, 325,178-181.
5. Das J.K. and Nahid M.A.I. (2015): Electrical properties of thermal Evaporated Bismuth Telluride Thin Films. International journal of Science and Technology, 4, 13-16.
6. Goldsmid H.J. (2004): Recent Studies of Bismuth Telluride & its alloys, *Journal of Applied Physics,* 2198.
7. Goncalves L.M., Couto C., Alpuim P., Rowe D.M., Correia J.H. (2006): Thermoelectric Properties of Bi_2Te_3 / Sb_2Te_3 Thin Films Materials Science, 156.
8. Hasan M.Z. & Kane C.L., (2010): Reviews of modern Physics, 82, 3045-3067.
9. Long Ren et.al, (2015): Large scale production of ultrathin topological insulator bismuth telluride nanosheets by a hydrothermal intercalation and exfoliation route journal of Material Chemistry,(2015), 22,4921-4926.
10. Rowe D.M, (2006): Thermoelectric Handbook: Macro to Nano. CRC &Taylor & Francis: USA 2006.
11. Saxena B.S., Gupta R.C., Saxena J.N.(1987): Fundamental of solid state physics, Pragati Prakashan,Meerut,(1987).
12. Sharma Y.C. and Purohit A. (2016): Tellurium based thermoelectric materials; New directions and prospects. Journal of Integrated Science and Technology, 4, 29-32. `
13. Takashiri M., Shriakawa T., Miyazaki K., Tsukamoto H. (2007): Fabrication & Characterization of Bi_2Te_3 based alloy thin films thermoelectric generators, Sensors &Actuators, 329.
14. Venkatasubramamian R., Siivola E., Colpitts T., and O'Quinn B. (2001): Thin-film thermoelectric devices with high room-temperature figure of meri Nature, 413, 597.