Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

Sensor Monitoring System for Space Environment Temperature Simulation

Ramachandra
ETF-II Division,
ISRO Satellite Centre
Old Air Port Road, Bangalore, India

Venkatesh
MDP-Division,
ISRO Satellite Centre,
Old Air Port Road, Bangalore, India

***Abstract*—Space grade temperature sensors are used in space environment applications; these are used in satellite for monitoring and controlling various subsystems hardware. The temperature is an important parameter to monitor and maintain health of a satellite and its subsystems. In this paper, the details of experiment carried out for measuring temperature using carbon paste film is described. Carbon paste material is used to sense the temperature and its study is carried out and compared with existing conventional sensors. Compared to the conventional sensor carbon paste based sensors are smaller in size, consumes low power and has less mass. Carbon paste is a resistive material, is of thin film of carbon, which can be utilized for sensing the temperature. The principle of sensing using carbon paste for the measurement of temperature is based on the conduction of carbon molecules. The carbon paste acts as sensing elements which is designed in different geometry patterns and was fabricated on PCB (FR-4). The fabricated sensing geometries are versatile, simple to fabricate, and light in weight. The entire fabrication process is simple, without requiring clean room facilities. In this paper, experiment carried out and shown that the resistance of carbon paste film increases linearly with increase in temperature and their results are compared with conventional sensor. The average Temperature Co-efficient of Resistance (TCR) value observed in this experiment is 0.0008 /^{0}C.**

Keywords*— *Carbon paste, carbon resistor; Carbon Nano Tube(CNT); Printed Circuit Board (PCB); Temperature Coefficient of Resistance (TCR); Space grade sensors; Thermal Vacuum Chamber; Peryline coating;

1. INTRODUCTION

The success of space missions depends on performing, monitoring and controlling different functions in onboard of any space craft. Also, modern spacecraft exhibit an increased tendency towards autonomy; most of the on-board functions are still controlled on ground. For the control of spacecraft, a large amount of information has to be obtained by numerous on-board sensors, linked to the control centre on ground and processed. Sensing is not a mere control on-board function on satellites, but in many cases, the mission objectives itself. Out of the total number of sensors used in the satellites, 50% of the sensors are used for the temperature measurement alone [4]. Generally spacecraft's and its subsystems are tested and qualified for the space environments. At ground level tests, thermal vacuum performance test is one of the critical tests and are simulated on ground, to qualify the space hardware. During the thermal vacuum performance 10 to 100 numbers of spaces grade sensors and all to sense the temperatures on space hardware's thermal shroud and thermal lines. During spacecraft level tests, nearly 200-500 numbers of onboard temperature sensors are used to measure temperature and control parameters of spacecraft. Harness mass of these sensors, which in turn affects additional gas load. This can cause to reach ultimate vacuum level of the chamber.

The existing space qualified sensors used are metallic resistance thermometry, Semiconducting resistance thermometry, Semiconductor diodes, Thermistors, Thermocouple for the temperature measurements. Carbon resistors are widely used at very low temperatures [3]. Since although there are different thermometers, yet there are very popular because of their small size and low power being exceedingly inexpensive and less reproducibility than the metallic resistance. The carbon material has low out-gassing property and has excellent high & low temperature with-standing capability, which is an added advantage for vacuum compatible material. The characteristics of the temperature sensors, operating range, sensitivity, accuracy and other properties like interchangeability, effects of thermal cycling and ionizing radiation effects [4]. Different types of sensors for the various space systems and highlighted difference in technical requirement between the sensor used in terrestrial and space application [5]

In this paper, the experiments conducted on small sized carbon film based sensors are designed, experimented and their results are analyzed. The results shown that carbon paste sensor can be used to measure the temperature in space environments. This will help to replace existing sensors and its harness. To design new small size based sensor to monitor the temperature of the thermal shroud/package and also to reduce harness and its mass inside the thermal vacuum chamber. In near feature wireless node can be used in conjunction with multiplexed methods for further simplifies connecting wires and reducing the mass.

2. BACKGROUND

Thin film sensor play a significant role in the science and technology area for development of various sensors, such as temperature sensors, pressure sensors, gas sensors, humidity sensors etc. Temperature sensors are widely used in environmental applications for measuring the temperature for specific applications. Among different techniques one technique is used for change in the resistance of material, such as platinum, carbon, nickel, etc. In nano material, Carbon Nano Tubes (CNT) and silicon material provides (exhibits) properties of temperature measurement.

In Carbon Nano Tubes studying the electric resistance as a function of temperature varies between -200^{0}C to 150^{0}C, A.Di. Barto lomeo *et al* [6] has demonstrated monotonic change carbon nano tubes suitable for temperature. Sensors operate in wide range for fast time response, small size and low power consumption. He also mentioned that carbon nano tubes have a good time response, which is highly desirable for in-house measurement systems with rapid change in temperature. Temperature and pressure MEMS based optimized the sensitivity of both sensors David Schmidt *et.al* [7], he fabricated and tested using platinum film geometries to optimize the sensitivity of the sensing element and also provide that significance difference between maximizing temperature sensitivity and minimizing self heating. The noise is measured by creating stress and temperature interconnection of copper to prove that two different functional sensors with flexible film. In the micro temperature sensor**,** Chi–Yuuan Lee *et.al* proposed naval approach is integrating micro temperature sensors in a strain less steel based micro reformer in order to evaluate inner local temperature distributions and enhance the reformer performance [8].Platinum films are being successfully used as temperature sensors. Fred Lacy *et al*, he shown that sensor materials exhibit different properties or characteristics when their dimensions decrease in sub micron size. [9].

Carbon nanotubes are as used as sensing element for temperature is shown by Sywia WALCZAK *et.al.* He made novel construction of flexible textronic temperature sensors, designed to measure temperature. Sensors are made of screen printing techniques with cost effective using polymer composite with carbon black filler [10].

3. CARBON PASTE BASED SENSOR

3.1 Carbon paste film based sensor

Working principle of the carbon based sensor is that, its electrical resistance changes with temperature and pressure. The signal drop across these devices is measured by passing constant current and further calibrating for measurement of temperature. The sensing range of the carbon paste thin film depends on temperature exposure on the material, base width, thickness, substrate material on which the patterns are designed and also depends on the different physical sizes, shapes of the patterns. Fig-1, R1, R2, R3, and R4 & R5 shows the geometries which are fabricated to measure the resistance change of the carbon paste film with temperature. We used PCB (FR-4) of thickness 0.5mm as the structural support to conduct experiments.

Fig.1 (a), group-1 below shows sensing patterns of different types and are fabricated (constructed) on the thin PCB. The fig1 (b) shows the cross section of the sensor and fig 1(c); shows the sensor film fabricated on PCB (FR-4). The change in temperature will cause the change in film resistance. The change in electrical resistance is measured through end leads. The leads are bonded (soldered) on the copper pads (PCB) to provide good conductivity.

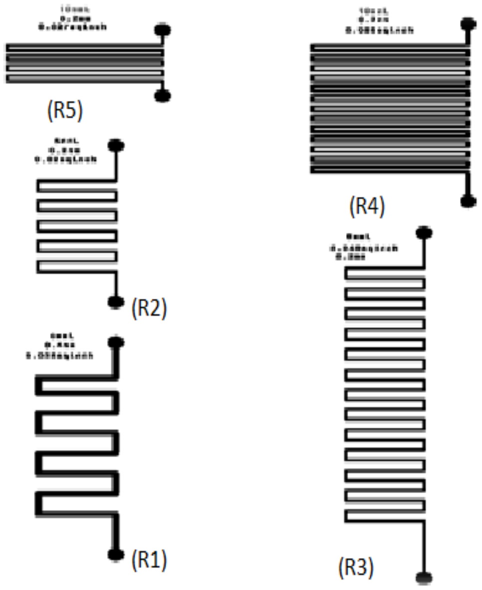
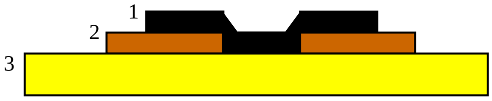


Fig.1(a). Typical proto type top view of designed patterns(group 1).



1 – Thermo sensitive Corbon Paste Film
2 - Copper Contact
3 - Substrate (PCB FR 4)

Fig 1 (b). Cross sectional view of fabricated carbon film on PCB

Fig.1(c). The sensor fabricated on PCB (Without paryline coated).

The electrical resistance of the fabricated patterns is calculated using, width, thickness, length, and resistivity of the carbon paste material. The calculated and realized values are tabulated in Table-1. The difference between the calculated and recorded values is attained due to practical errors in realization process and nonhomogeneity in the film structure.

Table.1. Temperature sensor parameters

R Nos	Track Thickness (µm)	Track Width (µm)	Track length (mm)	Sheet Resistance Rs=250Ω (Ω/ sq-mil)	Resistance R=ρL/wt (kΩ)	** R_{25} (kΩ)
R1	14.0	1000	57	250	25.44	21.6
R2	10.14	400	62	250	95.9	93.4
R3	12.50	400	170	250	212.5	207
R4	12.40	300	200	250	336	330
R5	15.50	300	75	250	115	108
** Realized and measured						

3.2 Carbon pattern fabrication process

Typical Proto types of different geometries are fabricated as group 1 which is shown in the fig-1(R1, R2, R3, and R4 & R5). The geometries are designed for different resistance values at room temperature. These patterns help us to provide and thoroughly investigate/examine the change in resistance due to corresponding change in temperature at different temperature set points.

Fabrication process may be explained as below. 1) Copper pads are generated on copper cladded FR-4 substrate using conventional lithography technique as shown in fig 1&2. Sensor patterns are realized using screen printing technique, high resistivity carbon paste is used. 3) Samples are annealed at 80^0C for 30 min for relieving the stresses. 4) Conductive wires are soldered on to copper pad for testing.

Electrical continuity of the tracks is checked by ohmmeter and their resistance was measured. The initial experiments on group-1 resistors R1-R5 and then its resistance change with temperature measurement is conducted in Hot and Cold chamber. The result plots are shown in fig 4.1(a) – fig4.1 (e). By analyzing the plots, its consistency of reading and repeatability is found to be not stable this is because the external environmental conditions may play changes in the resistance of the can film. These carbon films particularly absorb water particle from atmosphere. Hence modified group-2 sensor geometry patterns are fabricated, to get an optimum response.

To prevent the effects of environmental condition and also on carbon paste better stability and repeatability of readings, a thin Parylene film was coated on sensing area/entire PCB. The sensing patterns are then annealed at 80 °C for 30 minutes for relieve stresses. The fabricated patterns are shown fig-2 (R6 – R12 labeled in the photos).

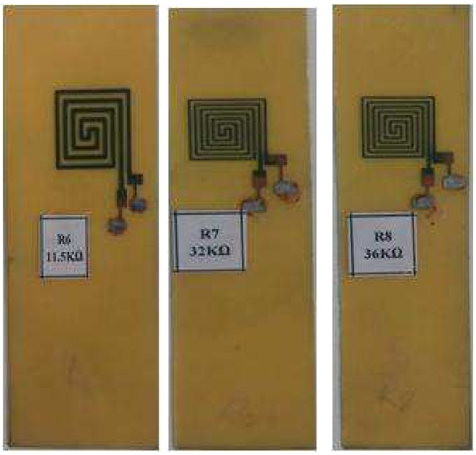


Fig.2a. Typical top view of proto type-of the designed loop patterns, R6, R7 & R8: sample of group-2 is as shown above (with parylene coated).

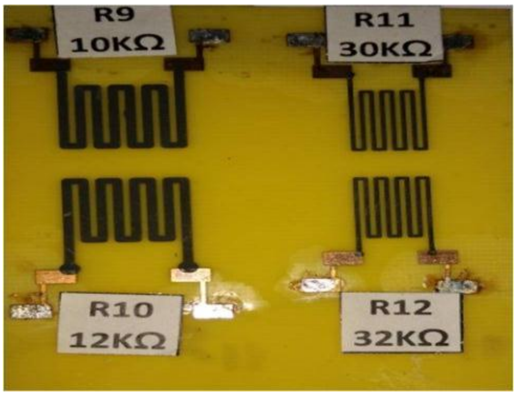


Fig.2b. Typical top view of proto type-of the designed patterns R9, R10, R11 & R12: sample of group-2 is as shown above (with parylene coated).

3.3 Pattern Resistance realization

The aim of this section is to bring out a strategy to optimise the geomentrical pattern for maximum response**.** The carbon resistive film tracks provide required resistance of the sensor. The electrical resistance of the carbon track is proportional to length and inversly proportional to cross sectional area. The corresponding equation is given

$$R = \rho \frac{l}{a} \qquad (1)$$

Where ρ= Resistivity of carbon, L= Length of the track, a= cross sectional area. Thermo resistive effect of thin metal films can be taken as advantage to measure temperature accurately.

The resistance obtained from the fabricated pattern is calculated by using equation (2)

$$R = \rho \frac{l}{wt} = RsNs \qquad (2)$$

For the conductive line having material resistivity ρ, length l width w, and thickness t, the pattern may be made as per requirement, by reducing or increasing L, w, t. As per the data sheet provided by manufacturer the resistivity of carbon paste Rs is 250Ω/sq- mil and Ns is the number of loops.

An increase in material length will increase the initial resistance, which in turn increases overall temperature sensitivity and decreases self heating, likewise, increasing the cross-sectional area of a material decreases initial resistance which will decrease the overall temperature sensitivity .

3.4 Parylene Coated Films for the Environmental Protection.

Parylene is the generic name of a unique polymer series. The basic parylene is poly-para-xylene, a completely linear, highly crystalline material. The Parylene polymers are deposited from the vapor phase by a process which in some respects resembles thin film deposition. Which is conducted at pressures of 10^{-5}torr or below, the Parylene are formed at around 0.1torr. Under these conditions the mean free path of the gas molecules in the deposition chamber is in the order of 0.1 cm. Therefore, unlike vacuum metalizing, the deposition is not line of sight, and all sides of an object to be encapsulated are uniformly impinged by the gaseous monomer. This is responsible for the truly conformal nature of coating. The process consists of three distinct steps as outlined for Parylene. The first step is vaporization of the solid dimmer at approximately 150° C. The second step is the quantitative cleavage (pyrolysis) of the dimmer at the two methylene-methylene bonds at about 680°C to yield the stable monomeric diradical, para-xylylene. Finally, the monomer enters the room temperature deposition chamber where it simultaneously adsorbs and polymerizes on the substrate.

Parylene coating thickness of 2-3µm carried out on all the designed patterns to minimize the effect of humidity at ambient environment. After parylene coating the devices are baked at a temperature of 80^0C for about 30 minutes to get stable performance. The different types of fabricated patterns are shown in the fig-2. Section 3.7 is better here.

3.5 Experimental Setup.

Initially, preliminary patterns as shown in fig-1(group-1) were fabricated. Subsequently these devices were tested and results obtained from these experiments were not stable and repeatable. Later various re–iterations were carried out, the modified sensor design (Group-2) are made as already discussed in the earlier sections. These Group-2 sensors have been used for all our future analysis. Various fabricated patterns so designed were studied for different ranges of temperature. The results obtained were analyzed to select the one with maximum sensitivity for further study of sensors. The fabricated sensors shown in fig-2a&b are placed in an environment test chamber. A separate thermocouple sensor was fixed close to sensing pattern on the PCB board for measuring the reference or actual temperature.

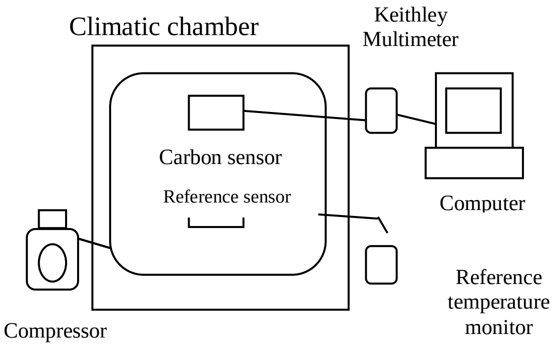


Fig.3a. Test experimental set up for Carbon Sensor

3.6 Temperature Co-efficient of Resistance (TCR) of Carbon Sensor Pattern

The temperature co-efficient of resistance α for the carbon paste is normally defined as average resistance change per deg C over the range of interest divided by resistance at referance temperature(ΔR/Ro) and is given by equation

$$(\Delta R/R_0)\ /\ \Delta t = \alpha \qquad (3)$$

The temperature co-efficient is expressed in ohms/deg C. Here, α defines the sensitivity of carbon element as it defines the temperature change of 1Ω of carbon.

The relationship between initial or reference temperature T and the Resistance R_0 of material is given by

$$Rt = Ro[1 + \alpha(\Delta T)] \qquad (4)$$

Rt = Resistance at t degree C of material (αT)
Ro = Resistance at 0 degree Celsius.
α = Temperature Co-efficient of Resistance.
ΔT = difference in temperature = (Rt – R_0).

Based on the above equation (3) & (4), for the given temperature, the change in resistance is measured. Temperature Co-efficient of Resistance (TCR) is one of the important characteristics of carbon and it was practically determined for each of the fabricated pattern. For carbon (graphite) , negative TCR is 0.0008 /^{0}C. This means that the resistance of carbon will raise or drop 0.08% /°C of its initial resistance per every degree Celsius.

Table.2. TCR was experimentally calculated for temperature sensors.

Sensing R Nos	R @ 0˚C (kΩ)	R @ 80˚C (kΩ)	ΔR (0-80˚C) (Ω)	ΔR= (Rt-R0)/ΔT (Ω/◦C)	***TCR*** (ppm/°C)
R6	11.5	12.5	1000	12.5	0.0009
R7	32.2	34.5	1800	21	0.00091
R8	36	38.5	2500	31.5	0.0008
R9	10	11.1	1100	15	0.0008
R10	12	13.2	1200	15	0.0078
R11	30	32.5	2500	31	0.00074
R12	32	35.5	3500	73.5	0.0009

From this experiment results, an average of TCR is found to be the 0.0008/^{0}C, which indicates of positive TCR for Carbon paste. Calculated values are shown in the table 2. above. TCR of metal will vary as the temperature or film thickness changes [8]

3.7 SEM analysis of Carbon paste sensor:

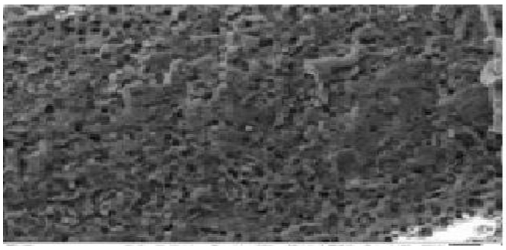


Fig.3a. SEM image of Post-thermal cycling of conductive carbon track. Sample-2, magnification: 1000X.

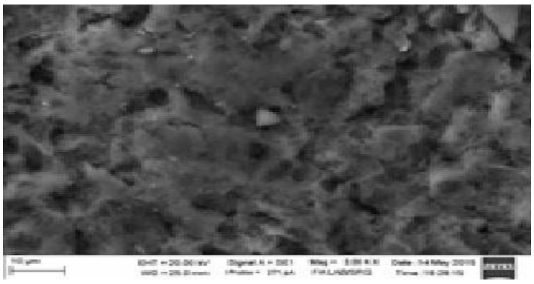


Fig.3b. SEM image of Post-thermal cycling of conductive carbon track. Sample-2, magnification: 3000X

The Scanning Electron Microscope (SEM) images shown in Fig 3a and 3b show the molecular bonding of carbon molecules for certain temperature. The bonding strength of materials varies with temperature.

4. RESULTS AND DISCUSSIONS

4.1 Electrical Properties of without coated Carbon Film:

Resistance data obtained from the Carbon sensor in hot and cold chamber was measured with respect to temperature change. The chamber temperature was varied from -60^{0}C to +80^{0}C for 5 Thermal Cycling (TC) cycles and the corresponding resistance v/s temperature of these sensors were measured and tabulated. The Figs. 4 a, b, c, d & e show the temperature response of carbon films. These plots show that the repeatability values of resistance is poor. The change in environment factor such humidity is the cause for this type of poor repeatability. The results obtained with paryline coated samples are shown in the following fig 4.2 a, b; c, d, e & f. and these results are discussed in the following section.

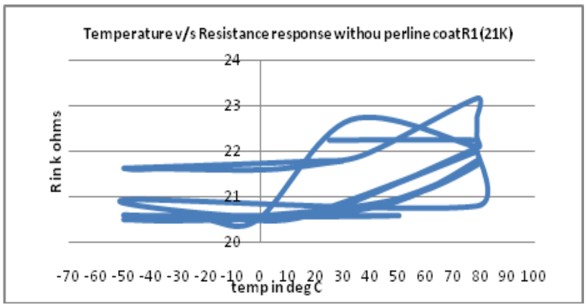


Fig. 4.1 (a).Resistance response for 5 TC of R1 (21K)

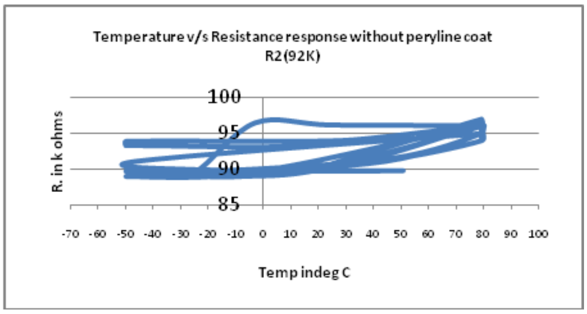


Fig.4.1(b).Resistance Response for 5 TC of R2 (92K)

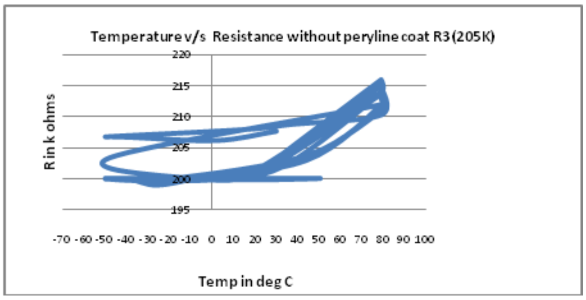


Fig.4.1(c).Resistance response for 5 TC of R3(205K)

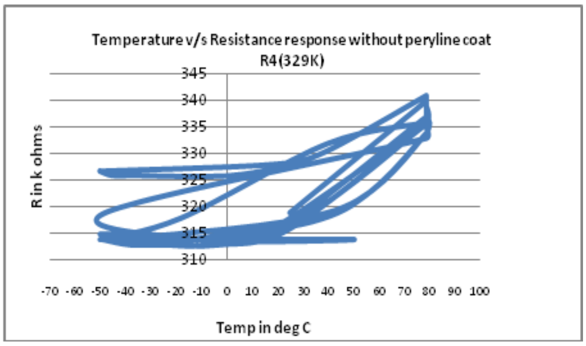


Fig.4.1(d).Resistance response for 5 TC of R4 (329K)

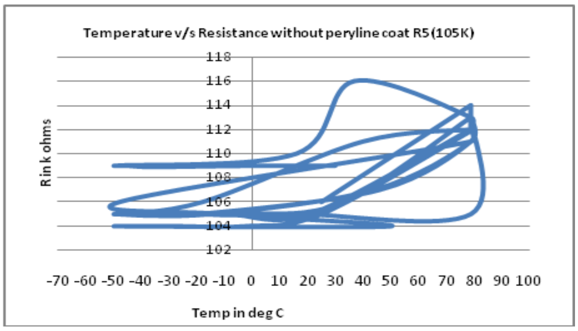


Fig 4.1(e). Resistance response for 5 T/C of R5 (105K)

4.2 Parylene coated carbon films and its results:

The graphs in Figs 4.2(a)-4.2(g) indicate the response of the Parylene coated films when the temperature of chamber is changed from -60^{0}C to +80^{0}C for 10 cycles. Each sensing film resistance is measured with standard Keithley multimeter(Model No 2700). The graph shows good response for the temperature range between 0^{0}C to and 80^{0}C and low response between 0^0C to - 60^0C. Flat response can be clearly seen from the graphs, @ 0^0C indicating use of these films for Low TCR applications such as Strain and Stress measurements between -60 to 0^0C.

The peryline coat on the sensing elements improves the stability, repeatability and response which clearly inferred from the following graphs.

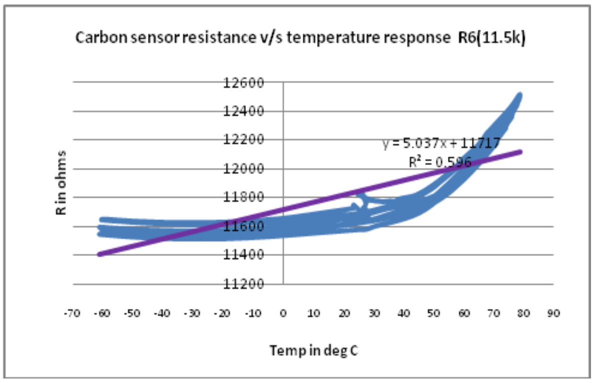


Fig4.2(a).Resistance response for 10 TC of R6 (11.5K)

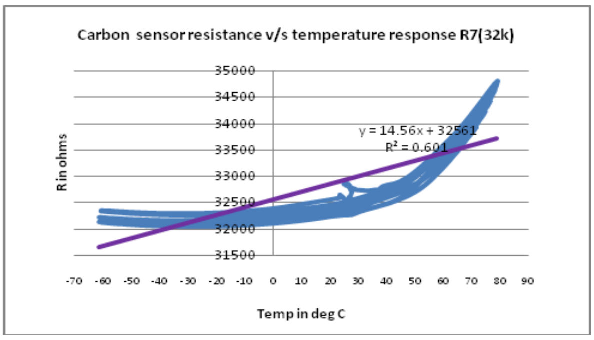


Fig.4.2(b).Resistance response for 10 TC of R7 (32K)

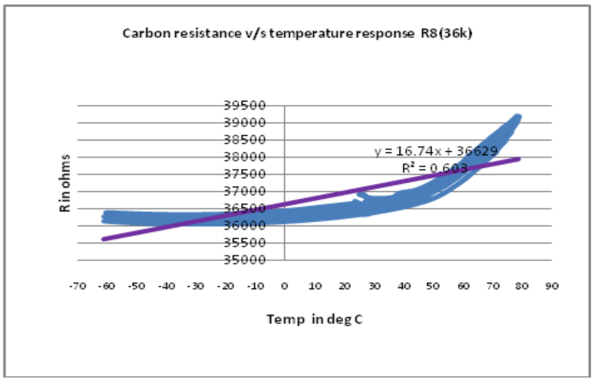


Fig.4.2(c). Resistance response for 10 TC of R8 (36K)

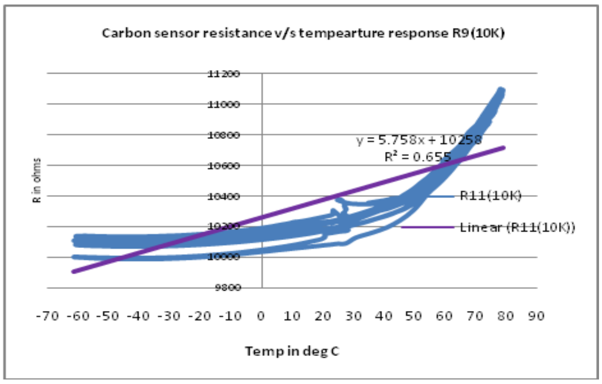


Fig4.2(d). Resistance response for 10 TC of R9 (10K)

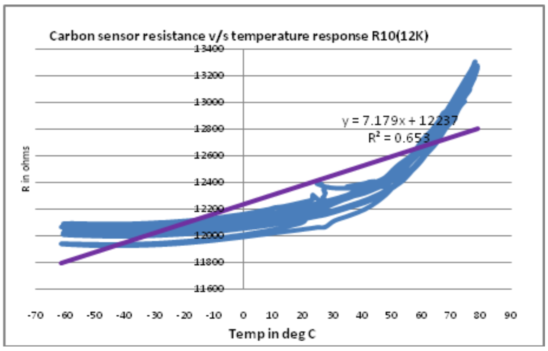


Fig4.2(e).Resistance response for 10 TC of R10 (12K)

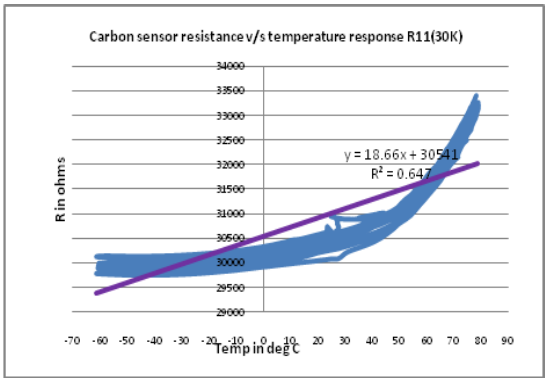


Fig.4.2(f).Resistance response for 10 TC of R11 (30K)

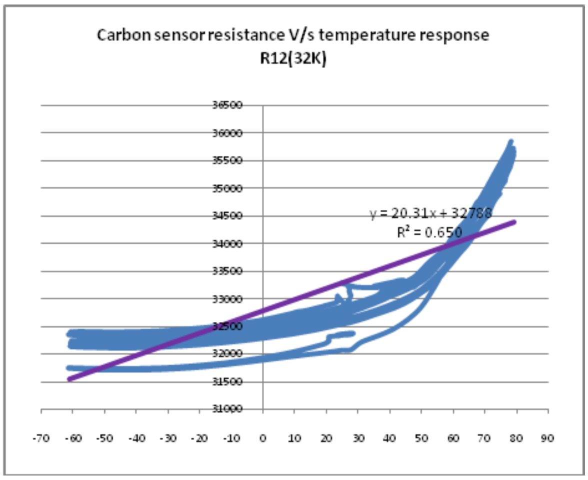


Fig4.2 (g).Resistance response for 10 TC of R12 (32K

Note: The response plots of resistance as a function of the change in temperature.

Thus stability and repeatability were found to be better on comparison with uncoated ones (Group-1). Fig-5& 6 show the relative change in resistance of the carbon resistors as a function of the change in temperature. The data yield a TCR value of 0.0008 /^{0}C.

Current-Voltage (I-V) characteristics of resistance were measured using a source meter Yokogova calibrator (model-CA71). By passing a constant current source through the sensor resistor of 10KΩ and corresponding voltage drop across the resistor is measured by voltmeter. I-V characteristics of the sensors show a linear, ohmic behavior as shown in fig 7 in the temperature range of -60^{0}C to 30^{0}C. The slope of the current-voltage curve represents the resistance of carbon resistor.

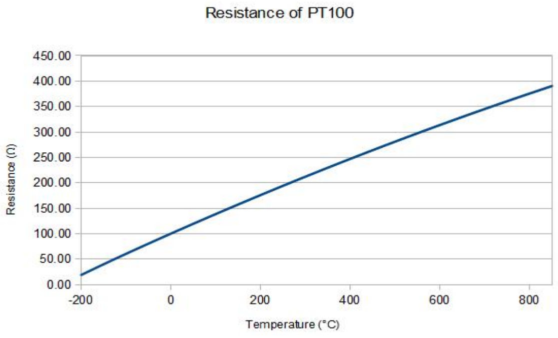


Fig.5.Typical response curve of conventional Pt-100 temperature sensor.

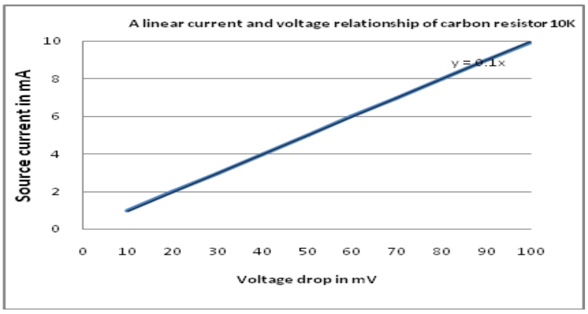


Fig 6.Typical response curve of conventional thermistor temperature sensor.

4.3. Convention sensor Response

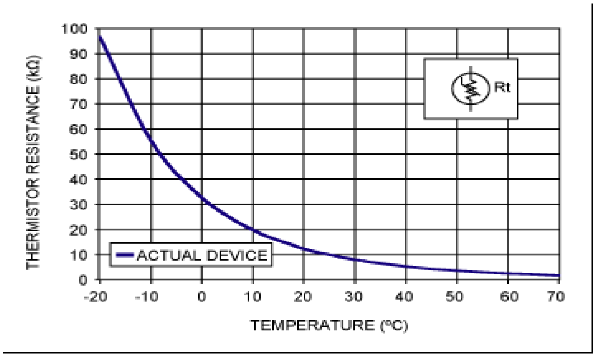


Fig.7. Voltage current characteristics response

5 DISCUSSION AND CONCLUSION

In this paper, change of electric resistance of carbon paste (film) with respect to temperature has been analyzed in detail which opens up in exploring the possibility of using carbon paste material as new sensing element for applications like measurement of temperature and pressure. The test results shows a semi-linear change in resistance, and the results obtained from the experiments indicate the suitability of carbon films for temperature sensor~~s~~ applications in particular for higher temperature application. The results showed that the new sensor response lies between the platinum temperature detectors and the thermistors. Carbon material was protected from the surrounding environment by using parylene coating which significantly improves the stability and repeatability of these devices. Carbon film offers several advantages like higher resistance change, small size, faster response, low power and low cost compared to conventional materials.

Testing of different carbon film geometries provide that the information need to be optimized between maximum temperature sensitivity and minimizing the self heating effect.

6 FUTURE SCOPE OF WORK

Carbon film in inter digital pattern may also be fabricated for further investigation of humidity measurement applications. Even though carbon material was found to be sensitive only over a small temperature range, there is a scope of improvement by further fine tuning its response. The temperature co-efficient of resistance (TCR) may not be as good as platinum temperature sensors but the performance may be improved by mixing carbon paste with platinum or any other nano material to achieve better performance. Mixing of a suitable external material will further augment the stability and linearity of carbon film which may be explored in future studies.

7 ACKNOWLEDGMENT

The authors would like to thank Dr. M.M Nayak Visiting Professor, CeNSE, Indian Institute of science (IISc), Bangalore for his guidance and support extended to realize these experiments. The author also would like to acknowledge contributions from all supporting staff of ETF, HMC and PCB Labs for their invaluable support at every stage of sensor development. It would not be possible to successfully complete this work without support and encouragement DGM, GM, CGM and Director, ISRO satellite centre.

REFERENCES

[1] Rodney's. Ruoff, Dong Qian, Wing Kam Liu, "Mechanical properties of carbon nanotubes: Theoretical predictions and experimental measurements". C.R physique 4 (2003) 993-1008 published by Elsevier SAS.

[2] D.D.L Chung "Review Electrical applications of carbon materials, Journal of materials Science 39 (2004) 2645-2661.

[3] S.Kar and R.G Sharma "Cryogenic Temperature Sensors" Defence science Journal, Vol.57,No 3,May 2007, pp. 195-208

[4] Bernad huffenbach, sandi Habinc, Pierrik Vuilleumier,Space "Applications for Smart sensors"

[5] Houri Johari, Jeffary.S.Yokum, Cosme Furlong, and Ryszard.J.Pryputniewicz "Mems sensors for Measurements of temperature, pressure, and relative humidity"

[6] A Di Bartolomeo, , F. Giubileo, M. Sarno, C.Altavill, D Sannino, L.Iemmo, F.Babbo, S. Piano, A.M. Cucolo, and P. Ciambelli., "Multiwalled carbon nanotube films as temperature nano sensors" NSTI- Nanotech , www.nsti.org, ISBN 978-1-4200-8503-7 Vol 1

[7] David Schmitt and Yingzi Lin "Design of Flexible MEMS Pressure and Temperature sensing film" 6th international Workshop on advanced smart materials and smart structure technology ANCRiSST july 25-26 2011

[8] Chi _Yuan Lee, Chien-Hen Lin and Yi-Man Lo "Fabrication of a flexible Micro temperature Sensor for micro reformer applications. Sensor ISSN 2011, 11,3716

[9] Fred Lacy, " Investigating thin films for use as temperature sensors," WCECS Oct 24-26, 2007, San Francisco, USA

[10] Sylwia WALCZAK, JacekGOLEBIOWSKI, Szymmon MILCARZ "Design of flexible Textronic temperature sensors," PRZEGLAD ELEKTROTECHNICAZNY, ISSN 0033-2097, R.91 NR 2/2015.