Chapter 5

Applications of Thick Film Thermistor
In this chapter, different applications of NTC thermistor are elaborated. It is well known that thick film thermistors are incorporated in the design of variety of hybrid circuits for microelectronic and sensors produced with the main purpose of thermal compensation for shift of electrical parameters of active and sensing devices. For this purpose, thermistor chips of different shapes and sizes are prepared using thick film technology [6]. Some of the examples are pressure sensor for automotive applications, in a TV receiver as a temperature compensation of the current to eliminate crossover distortions in a TV picture, IR detector, thermistor as a heater and so on. However, in this work, the possibility of only two applications of the prepared thick film thermistors for as a heater and for IR detection is also explored.

The resistivity of certain materials varies predictably with temperature, making them suitable for the use as temperature sensors. If the material gets heated due to the electric current passing through it and if it preserves a uniform temperature distribution during heating, then its total resistance would accurately reflect its temperature, allowing it to simultaneously act as both a temperature sensor and a heater. Such heater/sensor would eliminate the need for two metal films (heater and sensor) on a chip, reducing the real-estate usage of electronics and rendering the chip more readily adaptable for higher levels of integration. The following section describes the study of resistive material i.e thermistor for a heater application.

5.1 Thermistor as a Heater

One of the most interesting and useful property of an NTC thermistor is the behavior of the voltage drop ‘V’ measured across the device as the DC current ‘T’ passing through the thermistor is increased. As the current flows through a thermistor, some electrical energy is converted to heat which turned the thermistor gets self heated. The most commonly used application of the self heated thermistor is a flow meter [198-201].
The power \( P \) generated in this process is related to both the voltage across the resistor \( V \), and the current flowing through the resistor \( I \). Therefore, the Power is given by \([6.202]\)

\[
\text{Power (P)} = \text{Current (I)} \times \text{voltage (V)} \tag{5.1}
\]

where, \( P \) is measured in \text{watts}, \( I \) in \text{amperes} and \( V \) in \text{volts}. As the heat is generated by the flow of current through the thermistor, the total energy expended over a time of \( t \) seconds is providing that \( I \) and \( V \) are reasonably constant over the period of time.

\subsection*{5.1.1 Experimental Setup}

To study the heater application of thermistor, the thermistor paste composition (TA35C) of 1KΩ/□ sheet resistance was selected. Using this paste composition, thick film thermistors of 1 mm x 1 mm size were screen printed on the pre-fired silver electrodes onto the alumina substrate, then dried and fired at 850 °C for 10 min in BTU furnace. The I-V characteristics of the fired thermistor films was measured using the constant current source (Keithley model- 220, max current = 100 mA). Regulated power supply (Aplab 7222S, max current = 2.5 Amp). Data acquisition system (DAQ) (Agilent. Model 34970A) with K type thermocouple (Agilent make) with accuracy of 1 °C. Different values of currents were passed through the thermistor films and the voltage along with corresponding change in temperature across the thermistor films were acquired using the data acquisition system. Initially, the input current (up to 100 mA) was supplied through the constant current source (Keithley) which was later replaced by Regulated power supply source (Aplab make). The schematic of this system is shown in figure 5.1.
Figure 5.1: Schematic of the measurement setup used for thermistor as a heater application.

5.1.2 Results and discussion

When current was passed through the thermistor film, the temperature of the thermistor films increases and hence, voltage across thermistor films was changed. Figure 5.2 depicts the current verses voltage relationship for thermistor film sample. From the figure, it is seen that as the current increased, the voltage drop across the thermistor also increased. However, at 60 mA of current, the voltage reaches to a maximum/peak value 47.56 Volt which is denoted $V_{\text{max}}$ after that the voltage decreased even there is increase in the current (i.e up to 300 mA). However when the current was further increase to 350 mA, thermistor was unable to withstand this high current, resulting breakage of thermistor film. Figure 5.3(a,b) shows the effect of high current passed through the thick film thermistor. The silver electrode was also turned to brownish due to heating effect (Figure 5.3 (a)). Another adverse effect due to high current (i.e. current crowding) is shown in (Figure 5.3 (b)). As there is a great disparity between the thermistor and conductor resistivity, current crowding may be occurred that turned the aging of electrode. The current flows into the conductor at its leading edge, rather than being distributed over the overlap region which results in the current crowding [106].
Figure 5.2: I-V characteristics of the thick film thermistor.

Figure 5.3 (a, b): Effect of high current on the thick film thermistor.
Temperature Vs current characteristic of thick film thermistor is shown in figure 5.4. Here it is observed that for the current range of 1mA to 9 mA, the power dissipated is too low to heat the thermistor. However, at higher currents (≥ 10mA), due to joule heating, the temperature raised to above the ambient temperature. It is seen from the figure that the maximum temperature achieved by the thermistor is 340 °C, and further increase in current leads to the breakage in the thermistor film. Hence, a constant current of 300 mA was passed through the thermistor sample for 12 hrs and it was observed that the film thermistor was able to withstand this current (i.e. 300 mA) without the breakage or damage in the thermistor film. However, due to this high current, the temperature of the thermistor was slightly increased to 345 °C. Therefore, the prepared lead free thermistor can be used as a heater up to 340 °C (±5).

Figure 5.4: Current-temperature relationship of the thick film thermistor.

It is seen that the joule heating accompanying the change in resistance due to the power supplied to the NTC thermistor. Therefore, the dissipation constant ‘K’ can be defined as the power (in mW) required to raise the thermistor...
temperature by 1 °C above the ambient temperature. If the Newtonian cooling is assumed, the steady state relationship between the applied electrical power and the thermal power, dissipated in the thermistor material as a heat loss is given by Macklen [6],

\[ P = V \times I = K (T - T_{amb}) \]  

(5.2)

Accordingly, using equation (5.1) the dissipation constant of NTC thermistor was calculated as 28 mW/°C.

The response time of a heater can be obtained from the time required for a heater to change its output value from its initial value to a 90 % of its final settled value. The power which is applied to the device is the major factors which govern the rate at which an NTC thermistor will self heat. Other factors such as the construction of device, the nature and temperature of its surrounding ambient, and its mean of connection in the circuit also affect the heat flow through the device itself or to the surrounding. In the present case, the thermistor film was kept in the semi-closed chamber. Therefore, the heat losses due to conduction, convection and radiations must be present in this case.

To measure the response time of the thermistor as a heater application, 300 mA current was passed through the thermistor and the time required for the thermistor to reach at 340 °C was recorded using the Data acquisition system (DAQ) with a scan rate of 500 ms/scan. The response time of the heater is 2 min 35 sec as shown in figure 5.5.
Recovery time of the heater can be obtained as time required for the heater to reach 10% of its original temperature when the source was removed. To measure the recovery time of the thermistor as a heater, initially the thermistor was kept at its highest withstanding current i.e. 300 mA. At this stage, the temperature of the thermistor body was recorded as 340 °C. The current source was then removed and the change in temperature with respect to time was recorded using DAQ system at a scan rate of 100 ms/scan. The recovery time of the heater was recorded to 45 sec as shown in figure 5.6. The detailed specifications of the thick film thermistor used as heater are given in table 5.1.
Figure 5.6: Recovery time of the heater.

Table 5.1: Specifications of thick film thermistor used as heater.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet resistance</td>
<td>1 KΩ/ (± 2%)</td>
</tr>
<tr>
<td>Heater area</td>
<td>1mm²</td>
</tr>
<tr>
<td>i/p power</td>
<td>8.7 W (± 3)</td>
</tr>
<tr>
<td>Maximum current handling capacity</td>
<td>300 mA</td>
</tr>
<tr>
<td>Maximum voltage</td>
<td>47.56 V (± 2)</td>
</tr>
<tr>
<td>Maximum temperature</td>
<td>340 °C (± 5)</td>
</tr>
<tr>
<td>Dissipation constant</td>
<td>28 mW/sec (± 3)</td>
</tr>
<tr>
<td>Response time</td>
<td>2 min 35 sec (± 5)</td>
</tr>
<tr>
<td>Recovery time</td>
<td>45 sec (± 2)</td>
</tr>
</tbody>
</table>
5.2 Thermistor as an Infrared Detector

The infrared radiation (IR) sensing characteristics of the thick film thermistors are studied in this section. IR radiation is basically electromagnetic in nature and its interaction with matter results in heating and corresponding to rise in temperature of the material. In general, thermistor, due to its high temperature coefficient of resistance, is found to show good responsively to IR radiation. The brief overview regarding thermal IR detectors, the details of the experimentation and characteristics are discussed below.

5.2.1 Overview of Infrared Detectors

There are number of detectors available for IR detection. These are classified into two general categories such as thermal and photon detectors [155]. The radiation emitted by a heated body is also called as thermal radiation since it is emitted by virtue of the temperature of the body. This radiation has a continuous spectrum depending on the body temperature and composition of body. Thermal detection process for infrared detectors involves two processes: in the first process, the radiation is absorbed by the material and phonons are generated causing the lattice to heat up. In the other process, an increase in temperature of the absorbing material causes the changes in the material properties. In most of infrared detectors for the detection of incident radiation, thermoelectric, bolometric and pyro-electric effects are used.

(a) Thermoelectric detectors: A thermoelectric detector uses thermocouples which are connected in series. These are based on Seebeck effect. The temperature difference between the junctions of two different conductors of the thermocouple results in development of voltage between the two conductors. In thermocouple infrared detectors the hot junctions are generally placed in proximity to a radiation absorber and the cold junctions are mounted on a heat sink.
(b) **Pyro-electric detectors:** Pyro-electric detectors have temperature sensitive crystals with an internal dipole moment. Changes in the sample temperature produce the change in internal dipole moment which produces measurable change in surface charge.

(c) **Bolometer detectors:** The change in resistivity caused by the heating effect of the incident radiation is the principle of bolometer detector. Bolometers are of two types; one is metallic and the other is semiconductor based which are commonly known as thermistor and has a large negative temperature coefficient.

### 5.2.2. Experimental Setup

Generally the thermistors with linear dimensions between 0.1 and 10 mm with the resistance values between 0.1 to 10 MΩ are used for IR sensing applications [6]. Considering this, thick film thermistor of 1 mm x 1 mm dimensions was used for this study. The details of thermistor film preparation are already explained in chapter 2. Thick film thermistor paste composition (2ACE3) was used for this work. The resistance of the sample was measured to 540 KΩ/ .

The experimental set-up used for IR detection and measurement is shown in figure 5.7. The IR detector is characterized using the blackbody radiation in temperature range of 300-373 oK. All the measurements were carried out in the ambient conditions. IR lamp coated with black paint leaving 1 cm² blank area was used as a black body source. This body was positioned exactly above the sensing element i.e. thermistor film so that the IR rays exactly falls on the thermistor film. The temperature of the blackbody and IR sensing element was measured using a thermocouples (Agilent make). The sensor response to IR radiations was measured by positioning the detector at different distances (1 to 5 cm) from the blackbody. As the temperature of the black body increases, the resistance of the sensing element was changed due to the absorbed radiant heat. The data of change in resistance, the detector (sensing element) temperature and black body temperature was collected using the data acquisition system.
5.2.3. Results and Discussion

To find out the responsivity of the detector, the incident power absorbed by the detector is to be calculated. Hence if \( P \) is the power emitted by the source, then \( P \) is given as [203],

\[
P = \sigma T^4
\]

Then the incident power on the detector area \( P_{\text{inc}} \) is given as,

\[
P_{\text{inc}} = \frac{\sigma T_{BB}^4}{\pi} \frac{A_{BB} A_D}{d^2}
\]

where, \( T_{BB} \) is the black body temperature, \( A_{BB} \) is the area of blackbody, \( A_D \) is the area of the detector and \( d \) is the distance between source and detector. The factor \( \pi \) is derived from the analysis of emission of blackbody radiation from an extended source. The detector remits the part of absorbed radiation. Therefore,
this amount of power is to be subtracted from the incident power to obtain the 
effective power, \( P_{\text{eff}} \), which is absorbed by detector is given as.

\[
P_{\text{eff}} = \frac{o A_{\text{BB}} A_{\text{D}}}{\pi d^2} (T_{\text{BB}}^4 - T_{\text{D}}^4)
\]  

(4.5)

where, \( T_{\text{D}} \) is the detector temperature. The effective absorbed power is also 
dependent on the geometric configuration of the incident radiation. In the 
present experiment, the area of blackbody source is much larger than that of the 
detector area. Such type of a convergent geometrical configuration, Cosine 
correction must be applied to the effective incident radiation [203]. Therefore, 
equation 4.5 will be modified to

\[
P_{\text{eff}} = \frac{o A_{\text{BB}} A_{\text{D}}}{\pi d^2} (T_{\text{BB}}^4 - T_{\text{D}}^4) \cos \theta
\]

(4.6)

where, \( \theta \) is the angle of incident with respect to normal incident radiation.

Figure 5.8: Plot of resistance as a function of blackbody temperature \( (T_{\text{BB}}) \) and 
detector temperature \( (T_{\text{D}}) \) when thermistor was in contact with the IR 
source.
Figure 5.8 shows the plot of resistance as a function of blackbody temperature ($T_{bb}$) and detector temperature ($T_d$) when thermistor was in contact with the IR source. It was observed that the resistance decreases exponentially with respect to increase in the body temperature. The effective power of thermistor/sensor for different source to detector distances (d) was calculated using the equation 4.6.

Figure 5.9 shows the graph of resistance Vs effective power of detector. From the above result, it is observed that the effective power absorbed by the thermistor was decrease as the distance between source to detector was increased. The maximum and minimum power was obtained in case of distance d is small (1 cm) and large (5 cm) respectively.

![Graph of resistance Vs effective power of detector.](image)

The characteristics of IR detector viz TCR, responsivity in terms of $(\Delta R/R)/\text{mW}$ was tabulated in table 5.2.
Table 5.2: Electrical characteristics (viz. resistance, TCR, Responsivity) of thick film thermistor.

<table>
<thead>
<tr>
<th>Code name</th>
<th>Area of thermistor (mm$^2$)</th>
<th>Resistance (KΩ)</th>
<th>TCR %/°C</th>
<th>Responsivity /mW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2ACE3</td>
<td>1</td>
<td>540</td>
<td>3.26</td>
<td>28.79</td>
</tr>
</tbody>
</table>

Infrared detectors using thin film technology on silicon [204-209] and quartz [210-211] substrates have been reported. Thick film Infrared detector on alumina substrate was reported by Nitya [155]. It may be noted here that no ‘green’ NTC thermistor materials are available as on date in the electronic market and hence the literature/reports on IR detection are not available. Nitya [155] reported the IR responsivity of lead based NTC thermistor as 87/W whereas in the present case the responsivity is 28.79/ mW which found to be much higher than that of reported by the above researcher.

5.3 Conclusion

It was concluded that, the developed lead free thick film thermistors showed good sensitivity towards IR and hence can be used for applications in IR detectors. Also, the prepared thick film thermistors can be used as a heater application in hybrid circuits.