Study of Impact of Annealing Temperature on Electrical Properties of Screen Printed NiO Thick Films

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***Abstract-* The current research work is focused on the study the impact of annealing temperature on electrical properties of NiO thick films prepared by screen printing method. The films were prepared on glass substrate using commercially available NiO nanopowder. The prepared thick films of NiO were annealed at 100, 200, 300, 400, and 500 °C for 3 hours using muffle furnace. The electrical properties of NiO thick films was investigated on the basis of film's resistivity, activation energy and temperature coefficient of resistance. The electrical parameters were studied using static electrical system and half bride method circuit. The thickness of film was measured using mass difference method and thickness of films was found in micrometer range. The resistivity, thickness and other electrical parameters were found to be different in each sample. It has been investigated that, as an annealing temperature of the films increased the resistivity, TCR and thickness of NiO thick films were increased.**

***Keywords:* Thick films, half bride method, electrical parameters, thickness, activation energy.**

1. INTRODUCTION:

Nanomaterials are gaining a lot of attention from scientists because of their many applications. Because to the decrease in their size, they have a much larger surface area, making their optical and electrical properties extremely sensitive to surface geometry [1]. Nickel oxide (NiO) nanoparticles have been widely studied among the numerous nanometal oxides due to their outstanding chemical stability and favorable opto-electrical characteristics. The cubic structure of NiO makes it an antiferromagnetic material. As a result, that NiO is used in antiferromagnetic materials [1, 2]. NiO is a binary compound composed of nickel and oxygen. It is a metal oxide semiconductor that exhibits interesting electrical, optical, and magnetic properties [3]. NiO is a wide-bandgap p type metal oxide semiconductor and is commonly used in various applications due to its unique characteristics [4, 5]. The resistivity of metal oxide semiconductors (MOS) varies depending on the specific material and its properties. Metal oxide semiconductors are a class of materials that have semiconducting properties but are based on metal oxides. One of the most well-known examples of a MOS are ZnO and NiO. In general, the resistivity of metal oxide semiconductors is higher than that of traditional semiconductors like silicon or germanium, making them less conductive. The resistivity of MOS can range from around $10^{\wedge 3}$ to $10^{\wedge 8}$ ohm-cm, depending on factors such as temperature, impurity doping, and defect density in the material. The band gap of NiO is an important parameter that determines its electrical behavior. The band gap of NiO is around 3.6 to 3.8 electron volts (eV), making it a wide-bandgap semiconductor [2, 4]. The concentration of charge carriers (electrons or holes) in NiO can be controlled through doping or other methods. The carrier concentration affects the conductivity and other electrical properties of the material. MOS have become increasingly popular due to their unique properties and potential applications in electronic devices, sensors, and optoelectronics. The resistivity of a specific MOS material can be measured different methods [3-6]. Like other semiconductors or MOS, the electrical properties of NiO can change with temperature. Its resistivity typically decreases with increasing temperature due to thermal excitation of charge carriers. The electrical properties of NiO can be modified through various techniques, such as doping with different elements or controlling the growth conditions during fabrication, annealing, calcination and synthesis methods. As a result, researchers can tailor the electrical characteristics of NiO for specific applications in electronic devices, gas sensors, catalysts, and other technologies [4-8].
In the present study, NiO thick films were prepared on glass substrate by screen printing technique. The electrical properties of NiO thick films are investigated. Also reported the important electrical parameters of NiO thick films.

2. EXPERIMENTAL WORK:

2.1 Development of NiO thick films using screen printing technique:

In the current research work, commercially available (AR grade 99.9% purity) NiO nano powder was used for the preparation of NiO thick films. The films were prepared on glass substrate. Glass substrates were properly clean by distilled water and acetone and then kept in under IR lamp for 40 minutes. The 70 %: 30% inorganic (NiO) and organic material (Ethyl cellulose + Butyl Carbitol Acetate) ratio was used for the development of films [9, 10]. By using standard screen printing set up NiO thick films were prepared. The development of thick films of pure NiO is shown in Figure 1.

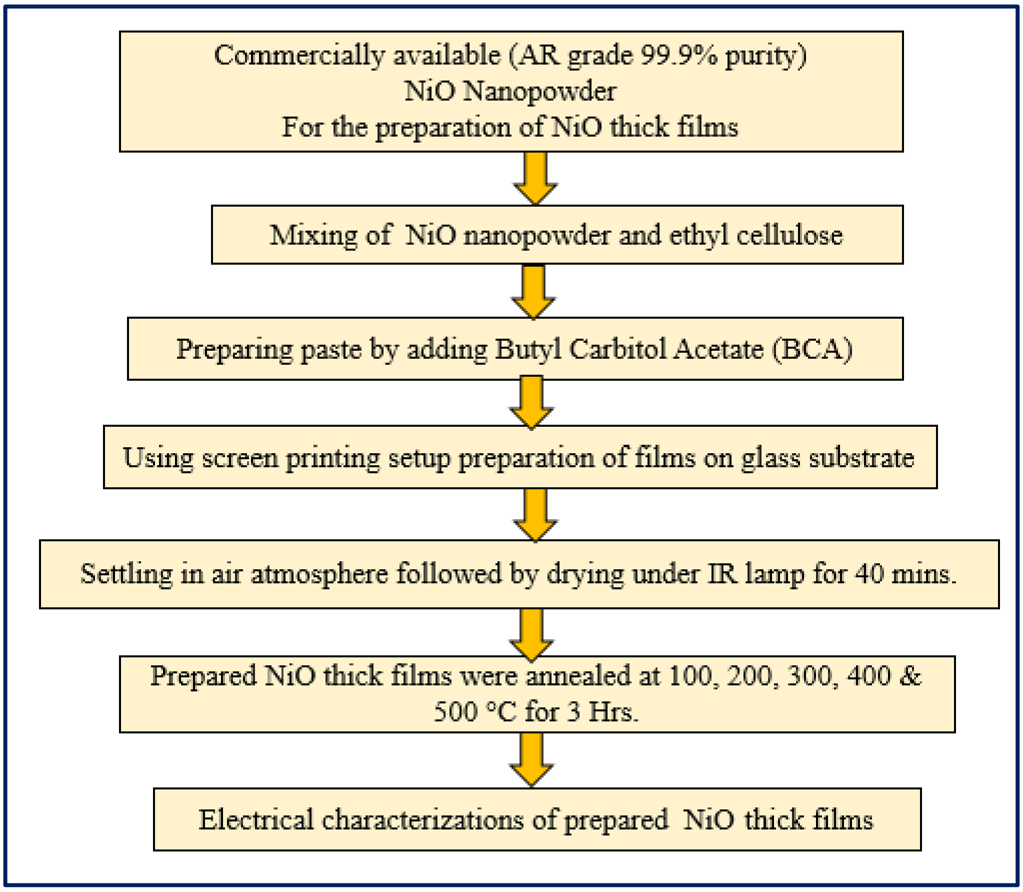

Figure 1. Steps of preparation of NiO thick films

2.2 Measurement of film thickness:

There are many methods for measuring thickness of the films, however the mass difference method takes shorter amounts of time and requires less cost. Thus, the thickness of prepared NiO films was determined using the mass difference method (Eq. 1) [11]. The thickness of prepared NiO films was found to be µm range.

$$\text{Thickness} = \Delta W / A \times \rho \qquad \text{............ (1)}$$

Where,

ΔW = Weight difference of the film before and after deposition.

ρ = Density of NiO,

A = Area of the films (Breadth = 1.25 cm, Height = 2.5 cm)

All examined electrical outcomes of NiO thick films are tabulated in Table 1.

3. RESULTS AND DISCUSSION

In this current discussion section, the prepared thick films of NiO annealed at 100, 200, 300, 400, and 500 °C are labelled as S1, S2, S3, S4 and S4 respectively.

3.2 Electrical characterizations:

Static electric systems and the half bridge method were used to characterize the electrical properties of thick NiO films. At both high and low temperature ranges, the metrics resistivity, TCR, and activation energy were determined. System consist of variable D.C. power supply (APLAB 0-30V, 2A) was employed to enable the user to choose the required voltage; the voltage across the standard reference resistance was measured by digital multimeter. A glass dome or chamber, a 2000 watt nichrome heating coil, and a digital temperature indicator compose the system. The characterization system consists of a glass chamber and a heater coil constructed of nichrome wire. The electric coil was used to increase the temperature from room temperature to 350°C by varying its voltage using a dimmer stat [11, 12]. The schematic diagram of the static electrical characterization system is presented in Figure 2.

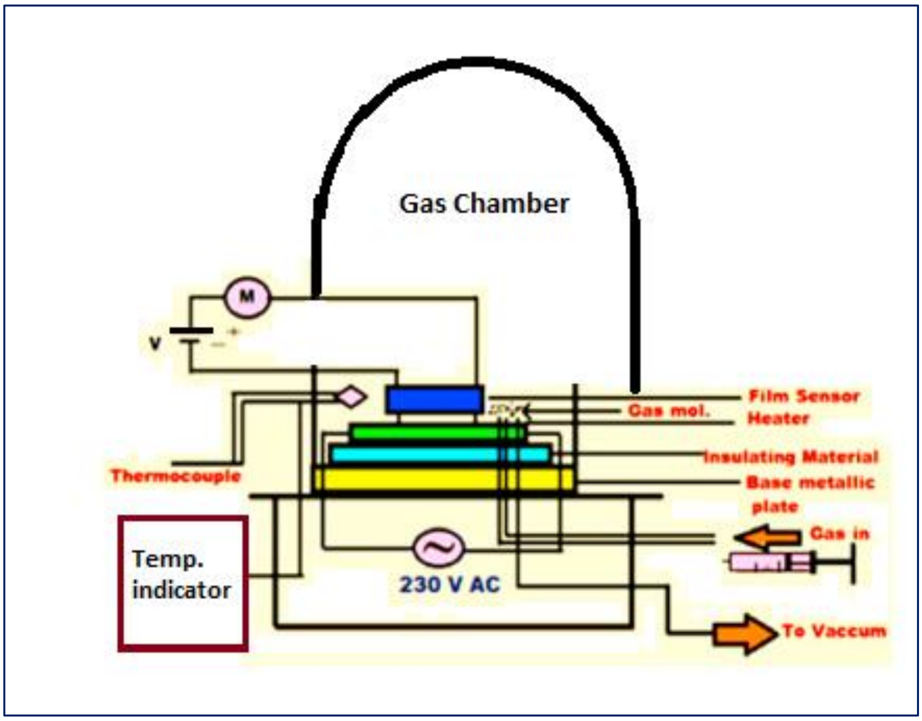

Figure 2: Schematic diagram of static electrical characterization system

3.1 Resistivity:

The resistivity of these films can be influenced by parameters such as the substrate material, film thickness, annealing temperature, synthesis methods, fabrication process of thick or thin films and the presence of any dopants or impurities [9-11]. The resistivity of the film NiO thick films was determined by using equation 2.

$$\rho = \left(\frac{R \times b \times t}{l}\right)\Omega - m \qquad \text{............. (2)}$$

Where,

ρ = Resistivity of prepared film,

R = resistance at room temperature,

b = breadth of film,

t = thickness of the film,

l = length of the film.

The resistivity of the film can be measure by four-point probe measurements or van der Pauw measurements, and half bride method. The resistance versus plot of NiO thick films annealed at 100, 200, 300, 400, and 500 °C shown in Figure 3. From Fig. 3, as ambient temperature of the film is increased the resistance of the films is decreases in all sample cases, this attributed prepared film samples shows the semiconducting nature [11, 12].

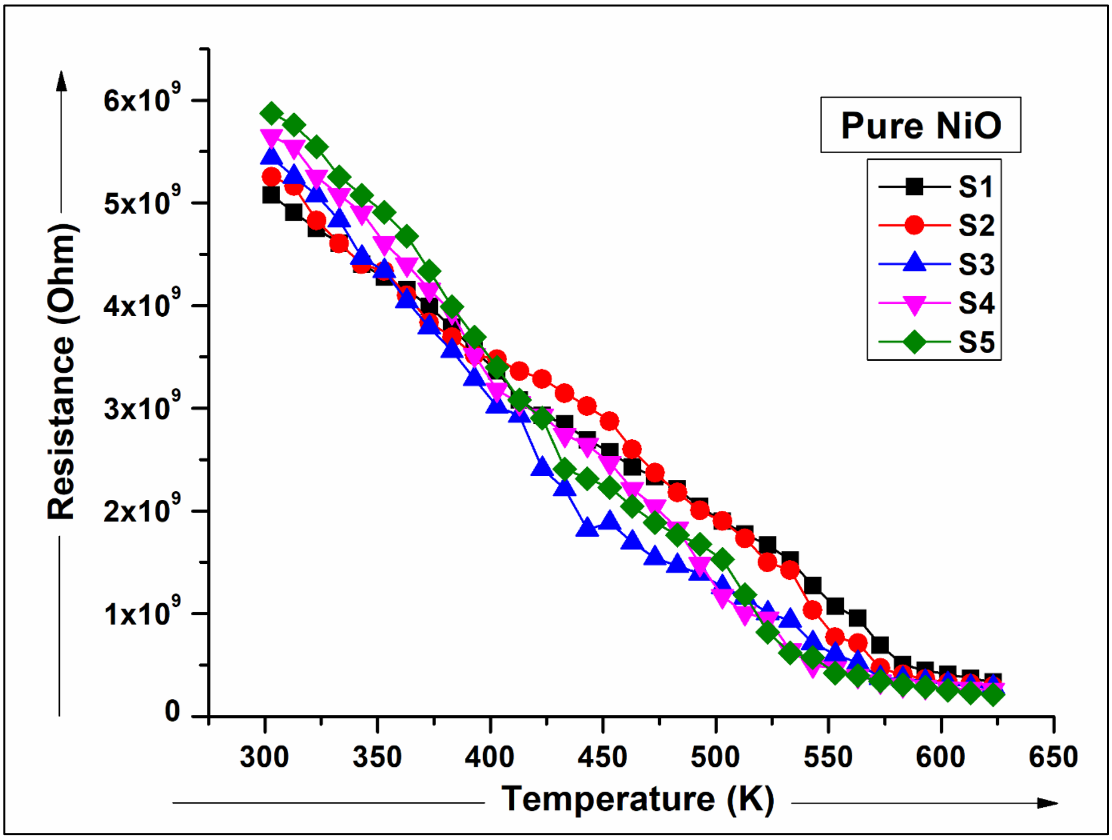

Figure 3: Resistance versus Temperature plot of NiO thick films

Resistivity is one of the important parameter for gas sensors. For metal oxide semiconductors it require high for gas sensing applications, because the gas sensing working principle of metal oxide semiconductors is strongly depends on change in resistance of the film in air and in gaseous atmosphere [12, 13]. Figure 4 shows the plot of annealing temperature versus resistivity of NiO thick film samples. From Fig.4, it is observed that the resistivity of NiO films is increased by increasing the annealing temperature. This increase in film's resistivity could be due to the decrement of electron concentration with increasing the temperature of thick films [14].

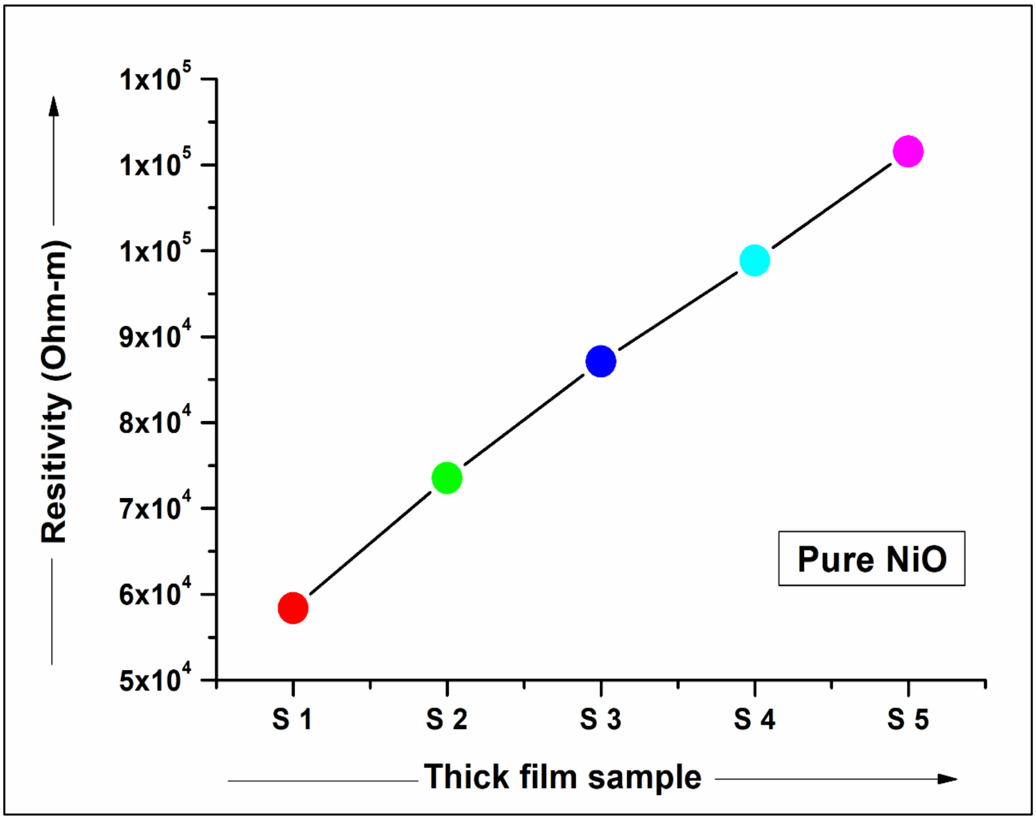

Figure 4: Resistivity versus Annealed samples plot of NiO thick films

The resistivity of films found to be increased as annealing temperature of films is increased. It might be because of the carrier concentration of charges changes during annealing process. The change in the electrical resistivity may be due to the different mobilities of these films annealed at various temperatures. The S5 sample shows maximum resistivity [15, 16]. It is also observed that from Fig. 4, the relationship in between annealing temperature and resistivity is linear. The resistivity of the film also depends upon the thickness of films. Figure 5 shows the thickness versus resistivity plot of NiO thick films. From Fig. 5 it is found that, resistivity of films grown as annealing temperature of films is rise. Film resistance varied depending on thickness and annealing temperature. It is believed that the carrier that exists in the structure has something to do with the conduction mechanism of film. NiO films' annealed surroundings have a significant impact on their electrical characteristics. Higher annealed temperatures and thicker thicknesses, on the other hand, seem to produce films with better crystalline structure and less carrier obstructions [16, 17].

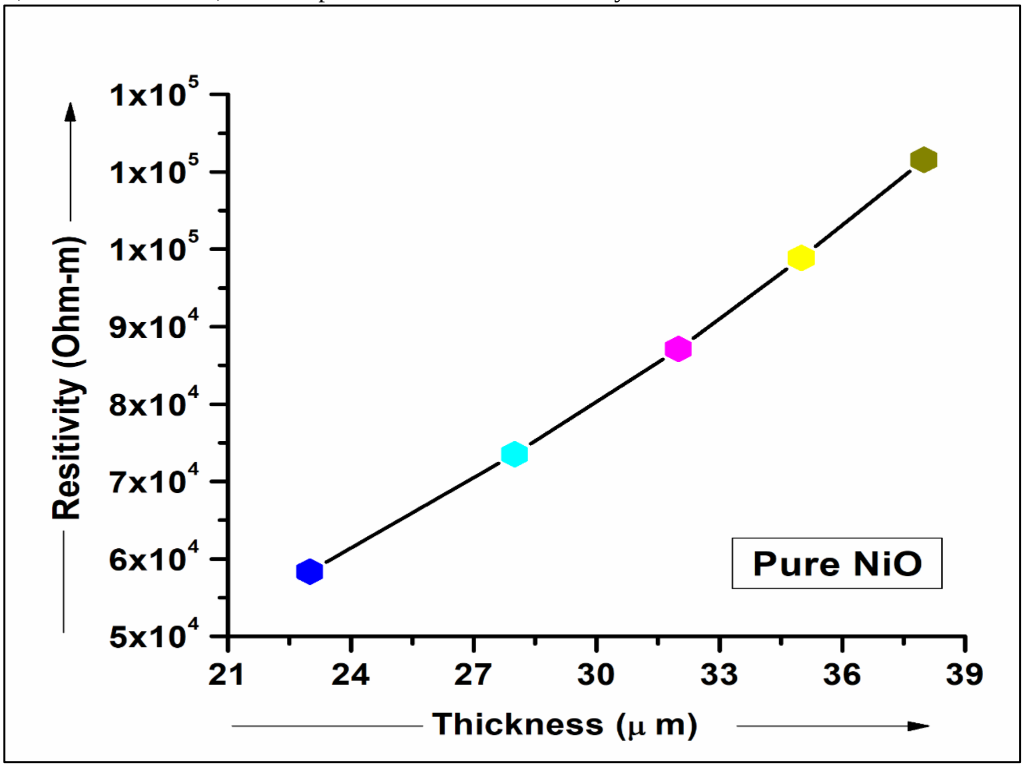

Figure 5: Thickness versus Resistivity plot of NiO thick films

3.2 Temperature Coefficient of Resistance of films:

The electrical characterization of any thick or thin films relies significantly on the TCR of films. TCR is positive for metals, but negative for semiconductors [11, 15]. Using equation 3, TCR of the thick NiO films was calculated.

$$TCR = \frac{1}{R_o}\left(\frac{\Delta R}{\Delta T}\right) /^{O} C \qquad \ldots\ldots\ldots\ldots (3)$$

Where,

ΔR = change in resistance,

ΔT = temperature difference between T_1 and T_2 and

R_o = Resistance of the film sample at room temperature.

It has been found that, from Fig. 6, the TCR of sample 1 is lowest and the TCR of sample 5 is maximum. Initially the TCR of films in increased rapidly up to sample 3 then increased smoothly. The TCR of the films grew dramatically as the annealing temperature was raised. It might be because distorted microstructures have mechanisms for restoration and recrystallization [15, 18].

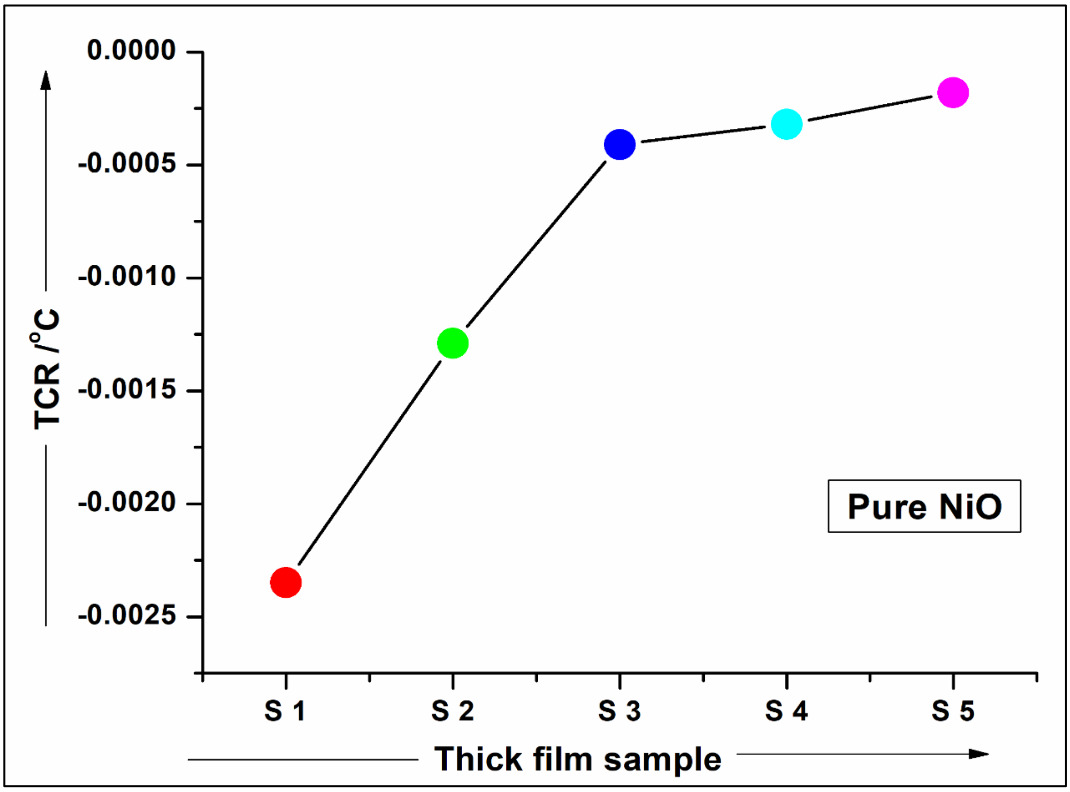

Figure 6: Annealed samples versus TCR plot of NiO thick films

3.3 Activation energy:

The Arrhenius curve of Log Rs versus 1/T for NiO thick films is illustrated in **Figure 7**. As material moves from one conduction mechanism to another, the activation energy in the low temperature area is always lower than the energy in the high temperature area. The decrease in resistivity in the low temperature area is brought on by the mobility of the charge carrier, which depends on the defect/dislocation content [11, 15]. Therefore, the region of low temperature conduction is the common name for the conduction process. The Arrhenius plot's straight-line presence indicates that, as is frequently observed in semiconductors, the conduction is thermally promoted. The thermal energy required to separate charges among two sites would be the conduction activation energy for oxide semiconductors [19, 20]. The activation energy of the film NiO thick films was determined by using equation 4.

$$\Delta E = \frac{\log R}{\log\ Ro} \times KT \qquad \ldots\ldots\ldots\ldots (4)$$

Where,

ΔE = Activation energy,

R = Resistance at elevated temperature,

R_0 = Resistance at room temperature.

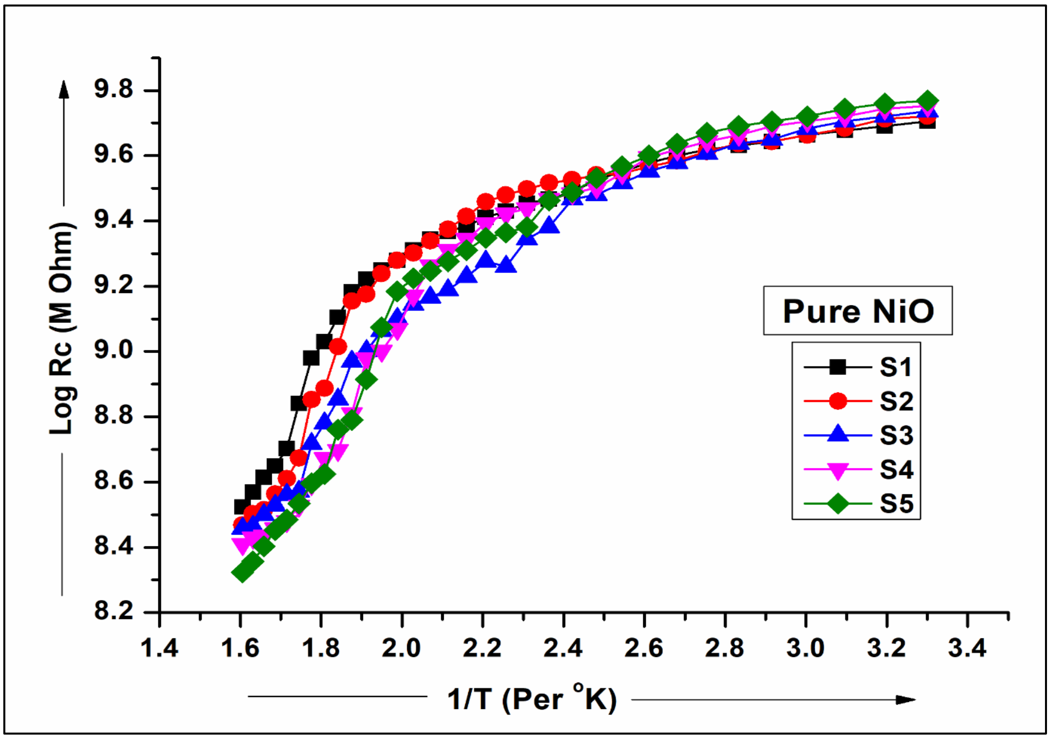

Figure 7: Log Rs versus 1/T plot of NiO thick films

All investigated electrical outcomes of NiO thick films are tabulated in Table 1.

Table-1: Electrical outcomes of NiO thick films.

Sample NiO	Thickness (μm)	Resistivity (Ω-m)	Conductivity (Ω^{-1}-m)	TCR (/°C)	Activation Energy (eV)	
					HTR	LTR
S1	23	58359.57627	1.7135E-05	-0.00235	0.156681	0.036594
S2	28	73544.21053	1.3597E-05	-0.00129	0.16302	0.044261
S3	32	87112.72727	1.1479E-05	-0.00041	0.169434	0.060921
S4	35	98881.60377	1.0113E-05	-0.00032	0.428479	0.032492
S5	38	111574.7059	8.9626E-06	-0.00018	0.283934	0.042418

CONCLUSIONS:

1. The NiO thick films were successfully prepared by using screen-printing technique.
2. Temperature coefficient of resistance is found to be negative to all samples attributed semiconducting nature.
3. The annealing temperature increased the thickness, resistivity and TCR of the films are also increased.
4. The impact of annealing temperature on electrical properties of NiO thick films is successfully investigated.

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