Comparatively Study of Electrical Properties of As-Prepared and Annealed MgO Thick Films Developed by Screen Printing Method

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Abstract
The annealing process is vital for optimizing the performance of metal oxide semiconductors in various applications, including transistors, sensors, photovoltaic cells, and transparent conducting oxides. Properly controlled annealing conditions can significantly enhance the material's functionality, making it suitable for high-performance electronic and optoelectronic devices. The annealing process for thick films is a thermal treatment designed to improve their electrical and other properties. The aim of present research work is to study the impact of annealing temperature on the electrical properties such as resistivity, temperature coefficient resistance and activation energy of MgO thick films. Films were prepared by screen printing method. Annealed MgO thick films typically exhibit higher electrical conductivity compared to their as-prepared films. This increase is attributed to during the annealing process, enhances charge carrier mobility. This study underscores the importance of the annealing process in optimizing the electrical properties of MgO thick films. The obtained results suggest that, the enhanced electrical properties of annealed MgO thick films make them suitable for various applications, including dielectric materials, insulators, and components in electronic devices.

Keywords: Annealing, thick films, activation energy, conductivity, optoelectronic devices.

Introduction

Metal oxide-based sensors have emerged as a versatile and robust technology with a wide range of applications in various fields, including environmental monitoring, industrial automation, healthcare, and more [1, 2]. The need for gas sensors capable of detecting colorless, odorless, and potentially hazardous gases, such as carbon monoxide, has become increasingly acute due to pressing health and safety concerns. Electric characterization of metal oxide semiconductors is essential for understanding their electronic properties and optimizing their performance in various applications, including sensors, transistors, and other electronic devices [3-5]. Electrical characterization helps in understanding the electronic properties of metal oxide semiconductors. This includes their conductivity, mobility, and carrier concentration, which are essential for optimizing their performance in devices like field-effect transistors (FETs) and sensors. Electrical characterization allows for the identification of defects and non-ideal behaviors in devices. This information is crucial for engineers and researchers to refine fabrication processes and improve the overall performance of electronic components. MOS are widely used in gas sensing applications due to their sensitivity to changes in electrical resistance when exposed to different gases. Characterization helps in tailoring these materials for specific sensing applications, enhancing their effectiveness [4-6].

Magnesium oxide (MgO) has been extensively investigated due to its unique properties, such as high melting point, chemical stability, and wide bandgap, which make it attractive for various applications [7, 8]. In particular, the F- and M-defect centers found in MgO produce energy levels within the band gap, which make it attractive for application in plasma displays for increasing secondary electron emission and reducing flickering effects. The study of the electrical properties of magnesium oxide thick films has garnered significant attention due to their potential for various applications. Reactive dissolution and its effects on electrical conduction, morphological change, and chemical transformation. MgO has a very high melting point of about 2852°C (5166°F), making it suitable for use in high-temperature environments. MgO is an excellent electrical insulator with a high dielectric strength, making it useful in electronic and electrical applications [8, 9]. MgO is transparent in the infrared spectrum and has good optical clarity, making it useful in optical applications. Research into nanoscale MgO is ongoing, as it may exhibit unique properties different from bulk MgO, potentially leading to new applications in areas like catalysis and nanocomposites [10, 11]. The study of role of MgO in carbon capture and storage (CCS) and its potential for environmental remediation continues to be an active area of research.

Thick film technology is a well-established process used in the fabrication of electronic components, sensors, and other devices [12]. It involves the deposition of layers of materials, typically in the range of a few micrometers to several hundred micrometers thick, onto a substrate. This technology is distinct from thin film technology, where the deposited layers are usually less than a micrometer thick. Thick films are generally more durable than thin films, able to withstand mechanical stress and environmental conditions [13, 14]. The screen printing process is relatively low-cost and suitable for mass production. Thick film technology can be used with a wide range of materials and substrates, making it applicable to many different industries. Thick film technology continues to be a crucial process in the production of reliable and durable electronic components, offering a balance between performance, cost, and versatility [12-14]. The present research work is provided the brief idea of impact of annealing temperature on electrical properties of MgO thick films prepared by screen printing technique.

Materials and Methods

The commercially available nanopowder of MgO was purchased from sigma enterprises, Nashik. For the preparation of thick films inorganic and organic chemicals were used with proper ration which is 70% (Inorganic) and 30% (organic) [16, 17]. Inorganic chemical includes MgO nanopowder or nanoparticles and organic chemicals includes butyl carbitol acetate (BCA) and ethyl cellulose (EC). Using standard screen printing technique thick films of MgO were prepared on glass substrate. All prepared films were dried under IR lamp for 15-20 minutes to remove organic binders or chemicals used for preparation of paste. After successfully preparation of films few films were annealed at 400 ºC and remaining are used as- prepared films for electrical characterizations [17, 18]. By employing half bridge method the electrical properties of prepared films were studied [18, 19]. Fig. 1 shows the schematic diagram of half bridge method.

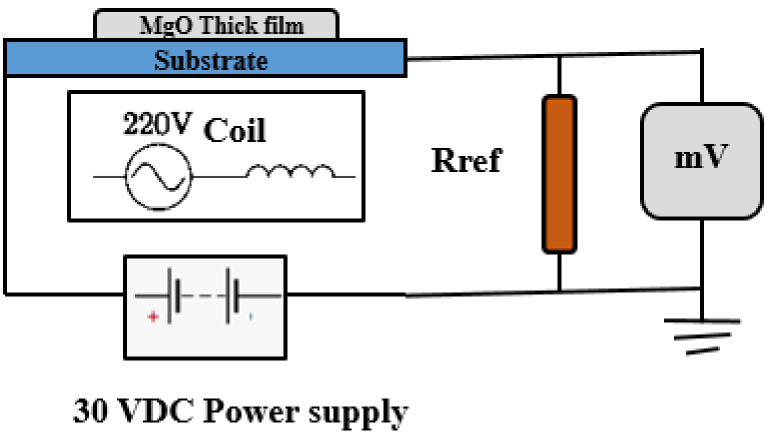

Fig. 1. Schematic diagram of half bridge method

Result and discussions

The resistivity, temperature coefficient of resistance, and activation energy are key parameters that define the electrical behavior and performance of metal oxide semiconductors. Understanding these properties is crucial for optimizing their use in various applications, including sensors, electronics, and energy devices [20, 21]. The electrical properties such as resistivity, temperature coefficient resistance and activation energy of prepared MgO thick films are studied in this work and elaborated all finding in brief in this section.

Resistivity: Resistivity is a measure of how strongly a material opposes the flow of electric current. It is the intrinsic property of a material that quantifies how difficult it is for electrons to move through it. In gas sensors, for instance, the resistivity of the metal oxide changes when it interacts with a target gas. Lower or higher resistivity is significantly impact the sensor's sensitivity and detection limit. Fig. 2 shows the resistance versus temperature plot of prepared MgO thick films [22, 23]. Eq. 1 is used to estimate resistivity of prepared films.

$$\rho = \left(\frac{R \times b \times t}{l} \right) \Omega - m \qquad (1)$$

Where, ρ = Resistivity of prepared film, R = resistance at normal temperature, b = breadth of film, t = thickness of the film, L = length of the film.

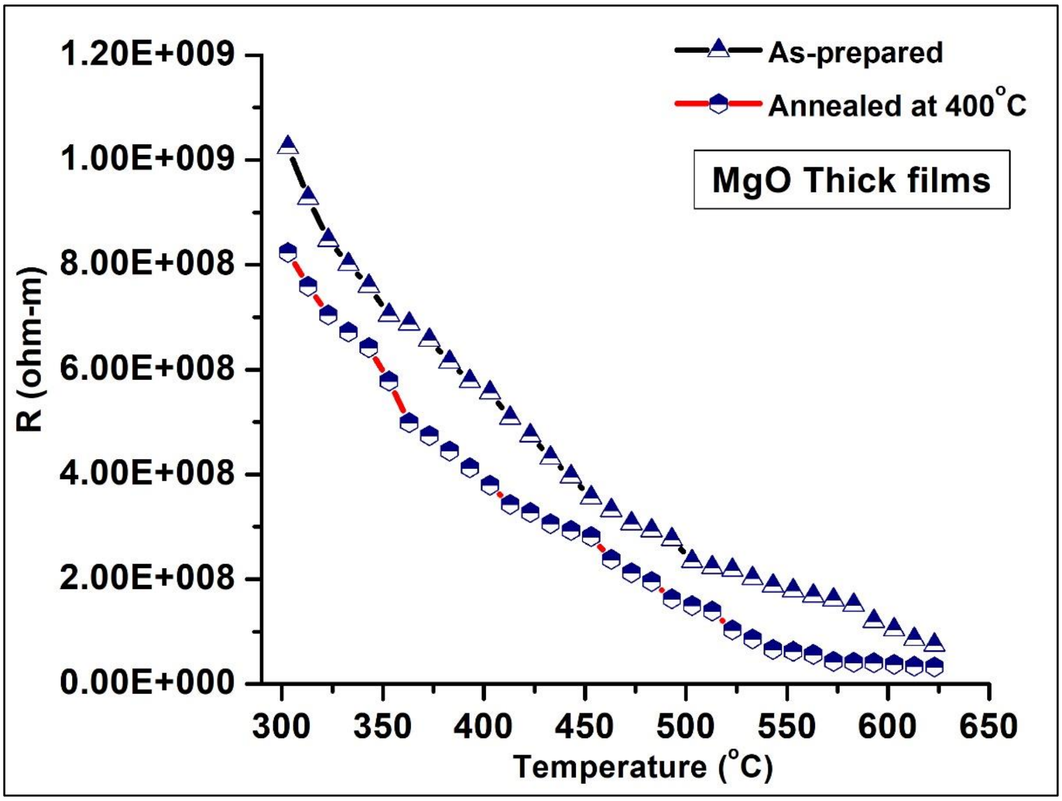

Fig. 2. Resistance versus temperature plot of MgO thick films

Fig. 2 shows the resistance of the film decline with increasing surrounding temperature across the films. The decrease in resistance indicating the semiconducting property of prepared MgO films. The decrease in resistance may be due to the fact that when the surrounding temperature increases, the majority of charge carriers have enough mobility and transfer form valance band to the conduction band [23, 24]. The resistivity of MgO thick films is reported to depend significantly on the annealing temperature. Because annealing temperature is directly impact on the physico electrical property of the material. Fig. 3 showing the impact of annealing temperature on the resistivity of prepared MgO films. It is found that the films calcinated at 400 ^oC shows low resistivity than as-prepaid films. That is due to annealing process the resistivity of the magnesium oxide films decreases therefore conductivity is increases. The resistivity values have been observed to change with varying annealing temperature, indicating that annealing temperatures lead to lower resistivity due to reduced defects. Annealing promotes the removal of defects, enhancing conductivity by improving carrier mobility and reducing resistivity. Annealing process often enhances the stability and reliability of thick films by reducing moisture absorption and improving the film-substrate interface, crucial for long-term performance in applications [23, 25].

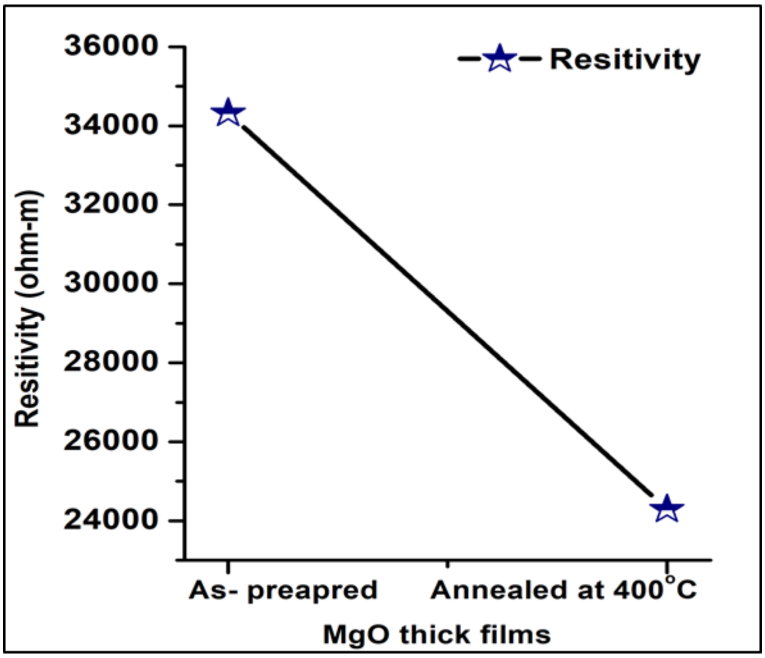

Fig. 3. Resistivity plot of prepared MgO thick films

Temperature Coefficient of Resistance (TCR): TCR indicates how the resistivity of a material changes with temperature. It is typically expressed in parts per million per degree Celsius (ppm/°C). Eq. 2 is used to estimate TCR of films. A positive TCR means resistivity increases with temperature, while a negative TCR indicates it decreases [22]. Understanding TCR allows for the design of compensation techniques in circuits to mitigate the effects of temperature fluctuations, ensuring stable operation in a wide range of environments. The temperature coefficient of resistance for MgO films is an important parameter that indicates how the resistivity changes with temperature. TCR is crucial for applications where temperature stability is required [24, 25].

$$TCR = \frac{1}{R_o}\left(\frac{\Delta R}{\Delta T}\right) \ /^{o}C \qquad (2)$$

Where, ΔR = change in resistance between temperature T_1 and T_2, ΔT = temperature difference between T_1 and T_2 and R_o = room temperature resistance of the film.

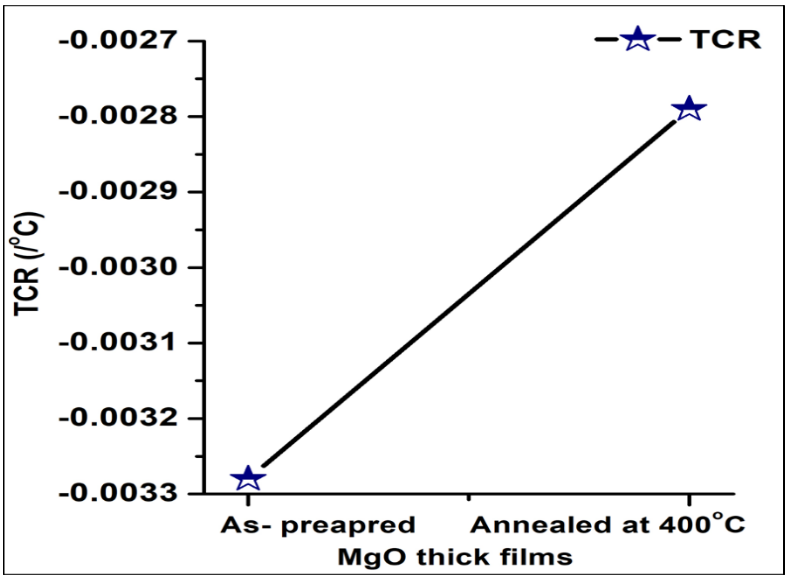

Fig. 4. TCR plot of prepared MgO thick films.

Fig. 4. Reveals the TCR plot of prepared MgO thick films. It is found that, TCR of annealed MgO thick films is found to be increases compare to the as-prepared thick films. It could be because of as-prepared thick films

often have residual stresses due to the deposition process. Annealing process relieve these stresses, leading to changes in the film’s electrical properties [23]. The reduction of stress is alter the band structure slightly or modify carrier scattering mechanisms, impacting the resistivity's temperature dependence.

Activation Energy: Activation energy in the context of metal oxide semiconductors refers to the minimum energy required to excite electrons from the valence band to the conduction band, enabling electrical conduction. The activation energy gives insight into the conduction mechanism in metal oxide semiconductors [25, 26]. Activation energy is crucial for selecting appropriate metal oxides for specific applications. For instance, in thermoelectric materials, an optimal activation energy is needed to balance the Seebeck coefficient and electrical conductivity. MgO thick films, activation energy is determined from the Arrhenius plot of resistivity versus temperature. Fig. 5 illustrate the Arrhenius plot of MgO thick films. Eq. 3 is used to estimate activation energy of prepared films [26, 27].

$$\Delta E = Ae^{-Ea/kBT} \quad eV \qquad (3)$$

Where, ΔE = Activation energy, T = Temperature in Kelvin and A = Arrhenius prefactor.

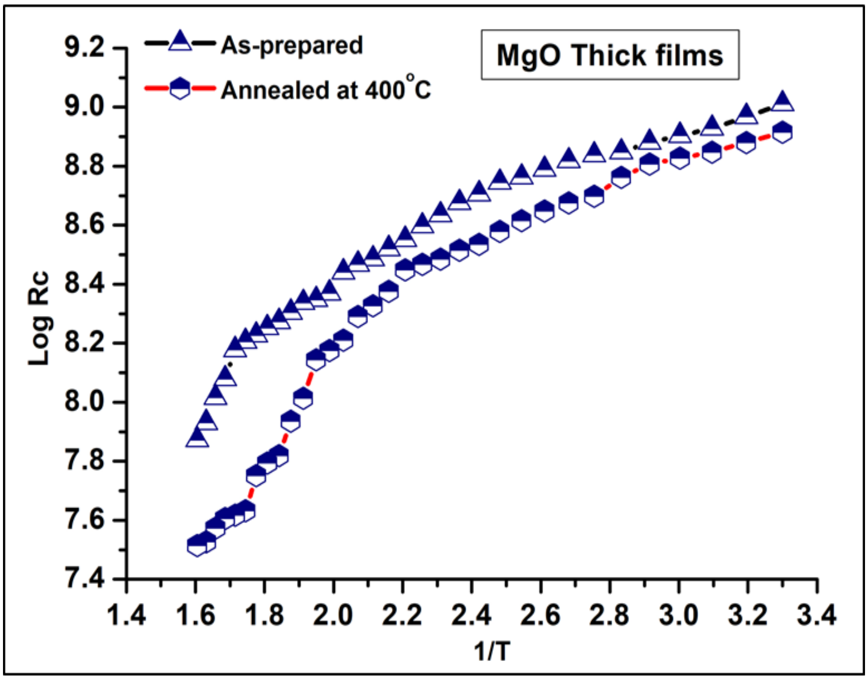

Fig. 5. Arrhenius plot of MgO thick films

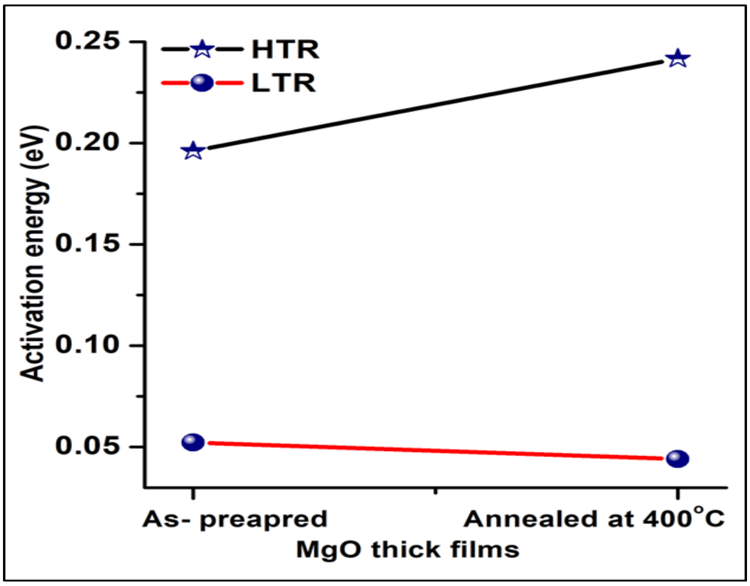

Fig. 6 shows activation energy of MgO thick films at higher temperature region (HTR) and lower temperature region (LTR).

Higher activation energies typically suggest that the material behaves more like an insulator at room temperature, while lower activation energies indicate semiconducting behavior. The activation energy influences how a material's conductivity changes with temperature. Materials with low activation energy will show significant changes in conductivity with small temperature variations, which can be exploited in temperature-sensitive devices [23, 27]. In gas sensors, the activation energy is related to the sensitivity of the sensor. Lower activation energies are result in faster response times as less energy is needed to initiate the conductivity changes upon gas adsorption [27, 28].

Table 1: Electrical outcomes of MgO thick films

MgO thick films	**Thickness (μm)**	**Resistivity (Ω.m)**	**TCR (/°C)**	**Activation energy (eV)**	
				HTR	**LTR**
As-prepared	67	34320.1	-0.00328	0.1960	0.0523
Calcinated at 400ºC	59	24288.3	-0.00279	0.2417	0.0441

Conclusions:

1. MgO thick films were developed on glass substrate by screen printing method.
2. The impact of annealing temperature on MgO thick films was studied.
3. Developed films shows semiconducting nature.
4. The resistivity of annealed films found to be lower than as-prepared thick films.
5. The TCR was found more to the annealed films than as-prepared thick films.
6. Finally, it is concluded that, annealing temperature effects on electrical properties of MgO thick films and the after annealing the electrical properties are helpful for different applications such as gas sensor, optical and bio sensors.

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Conflicts of Interest: The author declare no conflict of interest.

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