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CHAPTER – V

ELECTRONIC PROPERTIES OF SURFACE MODIFIED MgO THIN FILMS WITH H⁺ IMPLANTATION

5.1 INTRODUCTION

Metal–insulator–semiconductor (MIS) structure attracts the interest as its capacitance (based on surface space charge of semiconductor) is sensitively influenced by effective voltage applied on metal electrode. Since, the reliability and stability of all the semiconductor devices are intimately related to their surface interface, an understanding of surface physics with the help of MIS diodes is of great importance to device operation [1-4]. It is well known that, unless specially fabricated, a Schottky barrier diode posses a thin interfacial native oxide layer between metal and semiconductor that strongly influence the current-voltage characteristics [5, 6]. Deviation form ideal behavior of these devices is common due to several sources of errors such as effect of interface state density, series resistance, formation of barrier height and bias voltage [7, 8].

Moreover, the frequency dependent electrical conductivity should not allow the charge carriers at the interface states to follow the ac signal at high frequencies [9, 10]. The surface states can easily follow the ac signal, at low frequencies and yield an excess capacitance, which depends on the relaxation time of the surface states and the frequency of ac signal. In turn, this will cause dispersion in frequency response of the dielectric constant (ε’), dielectric loss (ε”) and dielectric tangent (tan δ), whose physical origin has still not been achieved [11, 12]. These interface states usually cause a bias shift and frequency dispersion in electrical conductivity and therefore, the frequency dependent electrical and dielectric characteristics are very important according to accuracy and reliability result.

In fact, large intrinsic field can exist in a thin insulating film sandwiched between electrodes having different work functions [13]. This field within the insulator arises because of the contact potential difference between the two electrodes, which in turn produce an asymmetrical potential barrier between the two electrodes. If a gradually increasing voltage is applied across the electrodes of one of the junction, with the electrode of lower work function negatively biased, then the initial increase in voltage decreases the intrinsic field to zero. Further increase of potential gradually
increases the intrinsic field in the negative sense until a critical field is attained, causing the junction to breakdown. If a voltage bias of opposite polarity is now applied to the second junction, increasing the potential between the electrodes gradually increases the field in the insulator without reversing the field from the intrinsic value until breakdown occurs. Therefore, knowledge of the difference in work function of the electrodes facilitates computation of the difference in barrier height at the respective metal-insulator [14].

Recently, the I-V characteristics of MIS sandwiched structures have been the subject of intensive works [15-19], in particularly, considering the effect of series resistance [16, 17]. In MIS structures with thick insulator layer greater than 50 Å, the interface states are equilibrium with semiconductor and with thickness less than 10 Å, interface states are equilibrium with metal [20, 21]. These interface states usually cause a bias shift and frequency dispersion of the current-voltage (I-V) curves [22]. Because of the relatively low level of conductivity in dielectric films, present paper will be concerned primarily with conduction in sandwiched structures in which the dielectric is bounded by two electrodes, one metal and one semiconductor electrode.

The Al/MgO/p-Si (MIS) structures used in this study were fabricated using boron-doped single crystals silicon wafer with (100) surface orientation having thickness of 1.2 mm and 2-5 Ωcm resistivity using the spray pyrolysis technique. Even though there is difficulty in fabrication of hetero-structures with good interface quality, some researches have been reported about the feasibility of making MgO/Si structure without inter-diffusion [23-27]. For the fabrication process, Si wafer was degreased in organic solvent of CHCl/CCl₂, CH₃COCH₃ and CH₃OH consecutively. Preceding each cleaning step, the wafer was rinsed thoroughly in de-ionized water of resistivity of 18 MΩcm. Later they were etched in hydrofluoric acid in order to remove the residual oxide. After drying, the wafers were transferred to the substrate holder for MgO thin film deposition. The substrate holder was placed over a heater and the distance between the substrate and nozzle was adjusted for uniform coating (30 cm). Magnesium acetate in ethanol was used as the precursor of MgO with an acid catalyst and tri ethylene glycol (TEG) to facilitate high temperature processing. The precursor was sprayed into fine droplets from the atomizer and was carried to the substrate by a compressed carrier gas (0.4 kg/cm²). The sprayed solution of magnesium acetate was thermally decomposed into oxide layer on the silicon
substrate. Magnesium oxide (MgO) films were implanted with 1.5 MeV Hi+ ion to various fluences in the range 10^{13}-10^{15} ions/cm^{2}.

After identifying the crystalline quality, high purity Al metal (99.999%) with a thickness of 0.2\,\mu m was thermally evaporated over H+ implanted MgO coatings to a predefined area (3.14 mm^{2}). Aluminium was chosen as electrode material because of its small grain size in comparison with film thickness [28]. Resulted Al/MgO/p-Si MIS structure (Fig. 5.1) was then engaged for electrical conductivity measurement using a single power supply and two sensitive detectors, one for current and the other for voltage measurements. In the present study, the circuit used for measuring current and voltage of MgO specimens that offer high electrical resistance is shown in Fig. 5.2. The impedance measurements were carried out in the frequency range 40 Hz to 100 kHz using HP 4192 A LF impedance analyzer at the test signal of 40 mV rms in the temperature range 30-90 °C.

5.2 I-V MEASUREMENTS IN H+ IMPLANTED MgO FILMS

Polycrystalline magnesium oxide thin films deposited on p-type silicon substrates were irradiated with 1.5 MeV. H+ ions accelerated by a Tandem Peletron accelerator to a dose range of 10^{13}-10^{15} ions/cm^{2} at room temperature. After identifying the structural modification using XRD, the upper aluminium electrode was deposited by thermal evaporation in vacuum. The junction area is 3.14 mm^{2} and the deposited Al electrodes are of thickness 0.23 \,\mu m. The temperature dependent current-voltage measurements were carried out on the MIS capacitor structure in a test chamber. The current-voltage (I-V) measurements were carried out using precision electrometers. The measurements were performed before and after H+ implantations.

According to the thermionic emission theory for a metal-insulator-semiconductor Schottky diode, the applied forward bias and current can be written as [29],

\[ I = I_n \exp \left( \frac{q(V-IR_s)}{nkT} \right) \left[ 1 - \exp \left( -\frac{q(V-IR_s)}{kT} \right) \right] \tag{5.1} \]

where, ‘V’ is the applied voltage ‘n’ is the ideality factor ‘Rs’ is the series resistance including bulk and contact resistance and ‘I_n’ is the reverse saturation current.

Fig. 5.3 shows the semi logarithmic current-voltage (I-V) characteristics of the MIS junction before and after H+ implantation at room temperature. The value of the current is observed to increase with the increase in the radiation dose. Depending
upon the bias voltage and ion fluence, the rise in forward current is of the order of 3 to 4. The ideality factor is a measure of the conformity of the diode current to be pure thermionic emission, and is calculated from the slope of the linear region of the forward bias ln I-V plot according to equation 5.2,

\[ n = \frac{q}{kT} \frac{d(V-IR_s)}{d(ln I)} \]  

(5.2)

where, \( \frac{d(V-IR_s)}{d(ln I)} \) is the slope of the linear region of ln I-V plots. As the slope of the I-V characteristic curve increases with irradiation fluence, the ideality factor also increases with increasing irradiation dose. These behaviors of the ideality factors suggests that the current transport mechanism consist of both the trap assisted tunneling and the thermionic emission [29]. The image force effect, recombination generation, and tunneling may be other possible mechanisms that could lead to an ideality factor value greater than unity [30-35].

Similarly, the zero bias potential barrier is calculated from the intercepts of the forward bias ln I vs. V plot for each irradiation dose. The I-V data reveals a decrease in zero bias barrier height with increasing irradiation dose. This results accounts for the increasing carrier density in the depletion region there by increasing the forward current in the MIS structure.

5.3 A.C IMPEDANCE AND MODULUS SPECTROSCOPY STUDIES ON H⁺ IMPLANTED MgO THIN FILMS

5.3.1 A.C Complex Impedance Measurements

Impedance spectroscopy is a powerful technique to characterize many electrical properties to evaluate and separate the contribution of the over all electrical properties in the frequency domain due to electrode reactions at the electrode/film interface and migrations of ions through the grains and across the grain boundaries in a polycrystalline material. In the present study, dielectric properties (material impedance, electrical relaxation process, dielectric behavior, electrical modulus, etc) of MgO are analyzed using the complex impedance spectral analysis. The simplest method of measuring the dielectric properties of a material is to subject an electric field and to record the polarization developed in the sample with time. When electrodes are applied to the two sides of the sample, the capacitance between them is greater than that defined by the electrodes. This is due to the edge capacitance beyond
the electrodes and the capacitance to ground of the high electrode. Also, the magnitude of the edge capacitance depends on the size of the specimen and is proportional to the electrode perimeter. Edge capacitance effect arises due to the size of the electrodes and is smaller if the electrodes are unequal. In addition to edge capacitance, ground capacitance also adds to the effective capacitance of the structure and it depends on the distance of the high electrode from the grounded surface of the equipment. The effect of both capacitances can be eliminated by the use of micrometer electrodes.

The complex impedance and complex electric modulus formalism have been discussed for the characterization of electrical properties of some electro ceramic materials [36-40]. The technique is based on analyzing the ac response of a system to a sinusoidal perturbation and subsequent calculation of impedance as a function of the frequency of the perturbation. The frequency dependent properties of a material can be described as complex permittivity ($\varepsilon^*$), complex impedance ($Z^*$) complex admittance ($y^*$), complex electric modulus ($M^*$) and dielectric loss or dissipation factor ($\tan \delta$). The real and imaginary parts of these complex parameters are interrelated as,

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$  \hspace{1cm} (5.3)

where,

$$\varepsilon' = \frac{Z'^*}{\omega C_0 (Z'^2 + Z''^2)}$$ \hspace{1cm} (5.4)

$$\varepsilon'' = -\frac{Z'''}{\omega C_0 (Z'^2 + Z''^2)}$$ \hspace{1cm} (5.5)

$$M^* = M' + jM'' = \frac{1}{\varepsilon'} = j\omega \varepsilon_0 Z'$$ \hspace{1cm} (5.6)

$$Z^* = Z' - jZ'' = \frac{1}{j\omega C_0 \varepsilon^*}$$ \hspace{1cm} (5.7)

$$y^* = Y' + jY'' = j\omega C_0 \varepsilon^*$$ \hspace{1cm} (5.8)

$$\tan \delta = \frac{\varepsilon''}{\varepsilon'} = \frac{M''}{M'} = \frac{Z''}{Z'} = \frac{Y''}{Y'}$$ \hspace{1cm} (5.9)

where, $\omega = 2\pi f$ is the angular frequency and ‘$C_0$’ is the geometrical capacitance of the films i.e., $C_0 = \varepsilon_0 (A/d)$, where ‘$\varepsilon_0$’ is the permittivity of free space ($8.85 \times 10^{-12} \text{ F/m}$)
and ‘A’, ‘d’ are the area of the top electrode and thickness of the dielectric layer respectively.

Impedance analysis has been widely used to study the dielectric behavior of polycrystalline ceramic material. In general, the dielectric properties of materials arise due to intra-grain, inter-grain and other electrode effects. In dielectrics, the motion of charge could take place by charge displacement, dipole reorientation, space charge formation etc. [41, 42]. In order to understand the electric properties of a sample, grain, grain boundary and electrode combinations must be separated out. To achieve this, appropriate equivalent circuit representation has been formulated in terms of impedance.

In the present study, the impedance, dielectric and modulus analysis are carried out by forming metal-insulator-semiconductor (MIS) structure. Magnesium oxide thin films acts as the insulating layer between the silicon and aluminium electrodes. The effect of implantation on MgO film surface with H⁺ ions and their dependence in impedance and dielectric properties have been analyzed. Obtained results are summarized in the coming sections.

5.3.2 Impedance Analysis

Nyquist plot analysis is used to characterize bulk grain, grain boundary and electrode interface contribution from the successive semicircles of impedance exhibiting in the complex plane. This enables one to study the grain or bulk resistance (Rg) and grain boundary resistance (Rgb), which are useful in understanding the charge transfer phenomena.

For the present MIS structure, only one semicircle in the intermediate frequency region is seen which is ascribed to the grain boundary contribution. This type of impedance variation can be represented as an equivalent circuit, which consists of a resistive element in parallel with a capacitor. This is the most common interpretation for polycrystalline materials like MgO, having a contribution of grain boundary. The frequency at the semicircle maxima $\omega_{\text{max}}$ for each RC element is given by,

$$\omega_{\text{max}} = 2\pi f_{\text{max}} = (RC)^{-1} = \tau^{-1}$$  \hspace{1cm} (5.10)
where, $\tau = RC$ is the relaxation time for the respective regions. Usually, the capacitance of the grain boundaries is larger than that of the bulk grain. Therefore, the relaxation time

$$\tau = RC = \rho \varepsilon_r \varepsilon_0$$  \hspace{1cm} (5.11)

is larger for the grain boundaries. The grain boundary resistance of the sample is extracted from the Nyquist plot, which is of the order of megohm ($28.19 \text{ M}\Omega$). The capacitance value for the grain boundaries is calculated by noting the frequencies at the Debye peak maxima and is found to be in the order of picofarad (14 pF). This result is in agreement with the reported values for the TiO$_2$ thin film capacitors [43].

The relaxation time of the process is about $3.95 \times 10^{-4}$ sec, which is due to the rotational fluctuations of molecular dipoles. If the frequency of the applied electric field corresponds to reorientation time ($\tau$) of molecular dipoles, the imaginary part of impedance shows a characteristic pattern. In addition, the semicircular arc starts at the origin; hence, no series electrode resistance is included in the equivalent circuit representation.

The a.c. impedance behavior of H$^+$ ions implanted MgO thin films have been studied by forming thin film capacitor. The H$^+$ implanted MgO thin films to a fluence of $10^{15}$ ions/cm$^2$ were sandwiched between aluminum electrode and the substrate (p-Si). The area of the top electrode is 3.14 mm$^2$ and the ion implanted MgO layer thickness is 0.497 $\mu$m. The impedance studies were performed in the frequency range 40 Hz – 100kHz at temperatures between 30 $^\circ$C and 90 $^\circ$C using an impedance/gain phase analyzer.

Fig. 5.4 shows the complex plane plot of the complex impedance $Z''$ Vs. $Z'$ for the MgO-H$^+$ sample at room temperature. A semicircular arc in the intermediate frequency region reveals the dominance of grain boundaries rather than the bulk grain. As the grain size is reduced to nanometric level due to ion implantation, the contribution of grain impedance is relatively small compared to that of grain boundaries. The complex plane plot of MgO-H$^+$ is a non-ideal semicircle, whose center is displayed below the real axis. For a pure non-dispersive Debye process, the centre of the semicircle is located on the real axis. In poly dispersive relaxation, one expects circular arcs with end parts on the real axis and the centre below the real axis. Therefore, the Argand plane plot (Fig. 5.4) confirms the poly-dispersive nature of the dielectric relaxation.
Table 5.1

Impedance parameter of the fabricated MIS structure

<table>
<thead>
<tr>
<th>Impedance parameter</th>
<th>Al/MgO-H⁺/Si at temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Grain boundary resistance (R_{gb}) (MΩ)</td>
<td>3.57</td>
</tr>
<tr>
<td>Grain boundary capacitance (C_{gb}) pF</td>
<td>22.30</td>
</tr>
<tr>
<td>Grain boundary relaxation time (τ) x 10⁻⁵ sec</td>
<td>7.96</td>
</tr>
<tr>
<td>Bode plot slope (capacitive behavior) (30 °C)</td>
<td>-0.9</td>
</tr>
<tr>
<td>Barrier layer capacitance at 1 kHz (30 °C) (pF)</td>
<td></td>
</tr>
</tbody>
</table>

From Table 5.1, it is observed that the grain boundary resistance, capacitance and relaxation time decreases with temperature. The values of grain boundary resistances and relaxations are plotted against inverse of temperature, that yield Arrhenius plots as shown in Fig. 5.5. The slope of the lines gives the grain boundary and grain boundary relaxation activation energies. The grain boundary activation energy E_{gb} = 0.35eV and the grain boundary relaxation activation energy ε_{gb} = 0.36 eV are obtained from the plot.

The variation of complex impedance ln (Z) and loss tangent (tanδ) as a function of frequency (ln f) is shown as Bode plot in Fig. 5.6 for MgO-H⁺ films. At low frequency region, log Z variation is not linear with temperature and the energy dissipation parameter (tanδ) is very high. This information suggests the deviation of capacitive nature of electrodes. The slope of the log f vs. log Z is -0.9 at high frequencies. The theoretical slope required for a pure capacitor is -1. The deviation from -1 also indicates the modification of the dielectric MgO layer by ion implantation.
From the above observations, the parallel plate capacitor formed with magnesium oxide implanted with hydrogen ions to a fluence $10^{15}$ ions/cm$^2$ exhibits deviation from pure capacitor. This may be due to the presence of implanted H$^+$ ions that reduces the dielectric nature of the material by reduction in grain boundary resistance from 28.19 MΩ to 3.57 MΩ. This change in grain boundary resistance, in turn alters the other related parameter such as grain boundary resistance and relaxation time. Higher loss tangent values in the low frequency region revealed the possibility of dc conduction, that alters the pure capacitive nature of the Al/MgO-H$^+$/Si structure.

5.3.3 Modulus Analysis

The complex dielectric function $\varepsilon^*$ and its dependence on external electric field frequency and temperature originates from different processes like microscopic fluctuations of molecular dipoles, propagation of mobile charge carriers, polarization due to separation of charges at the interface etc. Contribution of polarization of charges at the interface to the dielectric loss can be orders of magnitude larger than the dielectric response due to molecular fluctuations. The microscopic and macroscopic processes have frequency and temperature dependence of the real and imaginary part of the complex dielectric function. The methods, to quantify the contributions to the dielectric spectra are discussed in this section.

Relaxation process are characterized by a peak in the imaginary part $\varepsilon''$ and a step like decrease of the real part $\varepsilon'$ of the complex dielectric function $\varepsilon^* = \varepsilon' - j\varepsilon''$ with increasing frequency. In contrast, conduction phenomena show an increase of the imaginary part of the dielectric function with decreasing frequency. For pure ohmic conduction, the real part of $\varepsilon^*$ is independent of frequency and for non-ohmic conduction, the real part of $\varepsilon^*$ increases with decreasing frequency.

Further, the investigation of relaxation process that is related to the rotational fluctuation of molecular dipoles can be analyzed with the complex dielectric function $\varepsilon^*$. If the frequency of the applied electric field equals the reorientation time $\tau$ of the molecular dipoles, $\varepsilon'$ decreases with frequency and $\varepsilon''$ exhibits a maximum. The frequency corresponds to $\varepsilon''$ maximum is the relaxation frequency of the fluctuating dipoles. The dipole strength $\Delta\varepsilon$ of a relaxation process can be determined from the loss peak $\varepsilon''$ or from the step in $\varepsilon'$. 
In order to allow accurate assessment of the impedance data, complex electric modulus formalism have been discussed for various dielectric materials [44, 45]. In modulus formalism, the electric modulus \( M^* \) is defined in terms of the reciprocal of the complex relative permittivity \( \varepsilon^* \).

\[
M^* = \frac{1}{\varepsilon^*} = M' + jM''
\]  

(5.12)

where,

\[
\varepsilon^* = \frac{1}{j\omega C_0 Z'}
\]  

(5.13)

\[
M' = \frac{\varepsilon'}{\varepsilon'^2 + \varepsilon''^2}
\]  

(5.14)

\[
M'' = \frac{\varepsilon''}{\varepsilon'^2 + \varepsilon''^2}
\]  

(5.15)

‘C_0’ is the vacuum capacitance of the sample holder.

The modulus data expressed in the complex modulus formalism enables to understand the phenomenon of conductivity relaxation in terms of variation of \( M' \) and \( M'' \) as a function of frequency and temperature. The complex modulus plane analysis is based on the plot of imaginary part of \( M'' \) against real part of \( M' \) over a wide range of frequencies (40 Hz to 100 kHz in the present study). The plot is a single or a series of semicircular arcs. Each semicircular arc represents the parallel combination of resistance and capacitance of grain/grain boundary/electrode interface contribution in the conduction process. The semicircular arc in the low frequency region represents grain boundary/electrode interface contribution and an arc in the high frequency region represents the dominance of bulk grains. Magnesium oxide, the material considered in the present study exhibits a single semicircular arc in the low frequency region representing the dominance of grain boundary impedance. The impedance element representing the film/electrode interface is negligible because of the lower value of contact resistance. Extracting the values of \( R_{gb} \), the grain boundary resistance; \( C_{gb} \), grain boundary capacitance and \( \tau \), the relaxation time are discussed in detail in the previous section. In this section, importance is given to the electric modulus response with frequency at different temperatures. The real and imaginary component of dielectric constant of the material is determined initially to find out the electric modulus \( M^* \).
The variation of $M''$ with frequency exhibits well-resolved peaks at characteristic frequency that depends on temperature. In addition, the peak positions have the tendency to move towards higher frequency side with the rise in temperature. The low frequency side of the $M''$ peak represents the range of frequencies in which the charge carriers can move over a long distance. Due to long-range mobility, the carriers can perform hopping from one site to the neighboring site. High frequency side indicates the range of frequencies in which the charge carriers are spatially confine to their potential well and therefore only localized motion within the well alone be possible. At the peak frequency region, the transition from long-range to short-range mobility is possible.

Similar electric modulus formation $M^*$ has been undertaken to analyze the ion conductivity relaxation process in MgO thin films implanted with $H^+$ ions to a fluence of $10^{15}$ ions/cm$^2$. Using this formalism, the relaxation type and charge carrier parameter such as conductivity relaxation time [47, 48] can be determined. The modulus is defined as the electric analogue of the dynamical mechanical modulus [49, 50] and is given by

$$M^*(\omega) = M_\alpha \left[ 1 - \frac{1}{\alpha} \exp(-\omega t) \left( \frac{d\phi}{dt} \right) \right] \tag{5.16}$$

where, $M_\alpha = 1/\varepsilon_\alpha$ is the inverse of the high frequency dielectric permittivity and the function $\theta(t)$ gives the time evolution of the electric field within the material. The non-exponential conductivity relaxation can be explained by this function $\theta(t)$ (Kohlrausch William Watt (KWW) function) [51], which represent the distribution of relaxation time in ion conducting material given by,

$$\phi = \phi_0 \exp \left[ -\left( \frac{1}{\tau} \right)^\beta \right] \tag{5.17}$$

where, ‘$\tau$’ is conductivity relaxation time and ‘$\beta$’ is Kohlrausch exponent. The smaller the value of ‘$\beta$’, the greater the deviation with respect to Debye-type relaxation ($\beta=1$). The $\beta$-parameter corresponding to the $H^+$ implanted MgO samples have been determined as a function of temperature using modulus formalism.

The modulus spectra of the real $M'(\omega)$ and imaginary $M''(\omega)$ parts of the electric modulus $M^*(\omega)$ for $H^+$ implanted MgO film is displayed respectively in Fig. 5.7 and Fig. 5.8. It is noticed that the real modulus $M'(\omega)$ tends to a frequency independent constant $M_\alpha$ at high frequencies. The transition from long-range to short-
range mobility of ions is manifested by an asymmetric peak in $M''(\omega)$. From Fig. 5.8, it is evident that the maxima of the asymmetric peak shifts toward higher frequencies as the temperature is increased. The frequency $\omega_{\text{max}}$, where the maximum value of $M''(\omega)$ occurs is given by the condition $\omega_{\text{max}} \tau = 1$, where $\tau$ is the most probable conductivity relaxation time that indicates the transition from a short range to a long range mobility at decreasing frequency. The variations in relaxation time with temperature are calculated and are listed in Table 5.2.

**Table 5.2**

**Variation of conductivity relaxation time with temperature**

<table>
<thead>
<tr>
<th>Temperature $^\circ \text{C}$</th>
<th>Conductivity relaxation time ($\tau$) sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>$7.96 \times 10^{-5}$</td>
</tr>
<tr>
<td>50</td>
<td>$7.96 \times 10^{-6}$</td>
</tr>
<tr>
<td>70</td>
<td>$5.52 \times 10^{-6}$</td>
</tr>
<tr>
<td>90</td>
<td>$3.18 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

The variation of conductivity relaxation time obeys the Arrhenius relation $\tau = \tau_0 \exp \left( \frac{\varepsilon_a}{kT} \right)$, where $\varepsilon_a$ is the activation energy for conductivity relation. The activation energy 0.46 eV agrees well with the activation energy for d.c conductivity. This may be due to the fact that an ion has to overcome the same barrier while conducting as well as while relaxing.

Further, the $\beta$-parameter corresponding to the $\text{H}^+$ implanted MgO layer are obtained as a function of temperature from the $M''$ plot. The full width at half height (FWHH = 1.35) is wider than the breadth of the Debye peak (1.14 decades) and this indicates the increase of charge carrier concentration due to implantation of $\text{H}^+$ ions and therefore induce more non-Debye nature to the host material. Also, the $\beta$-parameter not depend on the temperature in the range studied.
5.4 AC CONDUCTIVITY

Measurement of AC conductivity in insulating materials has been extensively used to understand the conduction process in these materials. The generally accepted view is that the AC conductivity is dominated by localized states within the energy gap. Measurement of AC conductivity is therefore a powerful experimental method to obtain information about the localized states. Many workers [52-54] have carried out such measurements on a variety of materials.

In the present study, complex impedance spectroscopy (CIS) has been carried out for describing the electrical processes occurring in a system on applying an AC signal across the sample sandwiched between the electrodes. The output response of such an experimental measurement, when depicted in a complex plane plot, appears in the form of a succession of semicircles representing the contribution to the electrical properties due to the bulk material, grain boundary effect and interfacial polarization. CIS technique is therefore useful to separate the effects arising from each component in a polycrystalline sample very easily. Impedance measurements on a material provide data having both resistive (real part) and reactive (imaginary part) components. It can be displayed in a complex plane plot in terms of any of the formalism like complex impedance, complex admittance, complex permittivity, and complex modules.

Moreover, the peak of the semicircular arc in the complex impedance spectrum provides the relaxation frequency of the material and their respective resistance and capacitances. The bulk conductivity \( \sigma_{dc} \) of a material is a thermally activated process obeying Arrhenius behavior, which can be estimated in terms of the bulk resistance \( R_b \) evaluated from complex impedance spectrum. The bulk conductivity can be calculated in accordance with the relation,

\[
\sigma_{dc} = \frac{1}{R_b} \frac{d}{A}
\]

where, ‘d’ is the thickness and ‘A’ is the area of the sample.

The AC conductivity of the material describing the frequency dependent behavior of the conduction process can be evaluated in accordance with the relation.

\[
\sigma_{AC} = \omega \varepsilon' \varepsilon_o \tan \delta
\]

where, \( \tan \delta \) is the dielectric loss, \( \varepsilon' \) the permittivity and \( \varepsilon_o \) the permittivity in vacuum.
5.4.1 Experimental Details

Thin films of magnesium oxide were obtained by conventional spray pyrolysis technique. Ion implantation with 1.5 MeV H\(^+\) ions to a fluence of \(10^{15}\) ions/cm\(^2\) have been carried out in a 3MV pelletron accelerator. The film thickness ranged in μm and was measured using stylus profiler.

For AC measurements, films were sandwiched between two electrodes. Top aluminium electrode is thermally evaporated on to the MgO film surface to a pre-defined area and the silicon substrate served as the bottom electrode. A programmable LCZ bridge was used to measure the impedance \(Z\), the capacitance \(C\) and the phase \(\phi\) directly. The total conductivity was calculated from the equation.

\[
\sigma_{\text{tot}}(\omega) = \frac{d}{ZA} \tag{5.20}
\]

where, ‘d’ is the thickness of the film and ‘A’ is the area of cross section of the sample. The dielectric constant (\(\varepsilon'\)) was calculated from the equation,

\[
\varepsilon' = \frac{Cd}{A\varepsilon_0} \tag{5.21}
\]

where, ‘\(\varepsilon_0\)’ is the permittivity of free space.

The dielectric loss \(\varepsilon''\) was calculated from the equation,

\[
\varepsilon'' = \varepsilon' \tan\delta \tag{5.22}
\]

where, \(\delta = 90-\phi\) and ‘\(\phi\)’ is the phase angle.

The AC conductivity of H\(^+\) implanted MgO films were measured in the frequency and temperature ranges 40-100,000 Hz and 30-90 °C respectively.

5.4.2 AC Conductivity in H\(^+\) Implanted MgO Thin Films

Fig. 5.9 shows the variation of ac conductivity as a function of frequency at different temperatures for the MgO thin films implanted with H\(^+\) ions to a fluence of \(10^{15}\) ions/cm\(^2\). The conductivity pattern can categorically be split into two parts. At room temperature, the conductivity is low and at higher temperature, the conductivity pattern approaches close to each other in the entire frequency region. At low frequency region, a cross-over frequency showing a change in slope at a particular frequency. The frequency at which a change in slope of conductivity occurs is the hopping frequency. The plateau region corresponds to the frequency independent DC conductivity and dispersion region corresponds to the frequency dependent part.
Further, a small rise in the conductivity with temperature indicates that the electrical conduction in the material is a thermally activated process. At 90 °C, the AC conductivity of the MgO thin film measured at frequency 10 kHz is $7.82 \times 10^{-8}$ S/m, where as in H\(^+\) implanted films, the AC conductivity is enhanced to $1.02 \times 10^{-6}$ S/m for the same measurement conditions. The increase in AC conductivity is mainly due to the extra implanted ions available in the lattice that contribute additional electrical conduction to the sample.

5.5 CONCLUSIONS

Al/MgO:H\(^+\)/p-Si MIS structures were fabricated and I-V measurements were carried out in the range of 20 – 20 x $10^4$ V/cm. In this H\(^+\) implanted MgO films, ionic ohmic region is observed in low fields, space charge effect is observed in moderate fields and Poole Frenkel conduction is seen in high fields. An increase in current with increase in the H\(^+\) radiation doze was observed. The current transport mechanism in MgO:H\(^+\) films is associated with both trap assisted tunneling and thermionic emission. A decrease in zero bias potential barrier height with H\(^+\) fluence was also recorded.

Complex impedance studies have been performed to identify the dielectric behavior of the MgO:H\(^+\) thin films. Nyquist and Bode plot analysis were used to study the capacitive behavior of electrodes. The effect of H\(^+\) ion implantation on impedance parameters have been observed by both the impedance and electric modulus analysis. All the capacitors exhibits non-Debye type relaxation, showing distinct curves of $Z''/Z''_{\text{max}}$ and $M''/M''_{\text{max}}$ and the dipole polarization was only because of conduction of localized carriers.

The AC conductivity of MgO:H\(^+\) films have been studied in the 0.04 – 100 kHz range at different temperatures 30-90 °C. The AC conductivity was found to obey the power law $\omega^s$. The temperature dependence of both AC conductivity and ‘s’ were interpreted by the correlated barrier hopping model. The AC conductivity increased with temperature and frequency. In MgO:H\(^+\) films, the conductivity increased with temperature, however there is no conductivity variation with frequency.
REFERENCES