Chapter 2
Theory and Experimental Techniques

THEORY AND EXPERIMENTAL DETAILS
2.0 Theory and experimental techniques

During the present investigation, various experimental techniques have been used to study the thickness, electrical, structural and optical behaviors, their characteristics i.e. pit formation, dielectric properties (metal-oxide-semiconductor, metal-semiconductor, and metal-insulator-metal) of Zirconium nitride films. A brief detail of these techniques and theory are presented in this chapter.

2.1 Thickness measurement

Thickness measurement is one of the significant parameters, which mainly determines optical and electrical properties of the film. As a matter of fact, almost all the properties of a thin film are found to be functions of thickness.

The film thickness may be measured by in-situ monitoring of the rate of deposition, or after the film is taken out of the deposition chamber. The techniques of the first type, is often referred to as “monitor” methods, which generally allow both monitoring and controlling of deposition rate and film thickness.

There are various other methods to measure the thickness of the film, after the deposition process i.e. optical techniques such as optical interference, ellipsometry, and spectrophotometer are some of them. The most commonly used methods are (1) Ellipsometry, (2) Stylus method, and (3) Multiple beam interferometers.

The stylus (Talysurf) method [1,2] is a surface profile measurement technique. This is one of the mechanical methods of measuring the thickness of a given film. The stylus consists of a diamond with a rounded or four-sided pyramid tip fastened to a level arm i.e.

* Talysurf comprises of a fine diamond tip of radius 0.7 to 1.3um, which is gently pressed on to the surface (with a pressure of nearly 100 kp/cm²).
A step is created in the film, whose thickness has to be measured by masking a little portion of the substrate before deposition process. The thickness of the film is measured by moving the small diamond stylus across the test groove formed in the material or over the edge of a step from the deposit of a substrate.

Variations in the movements of a mechanical stylus can be amplified electronically so that step heights and surface irregularities of ~10Å can be measured. The arm is delicately balanced so that load on the stylus is very small. The vertical movement of the stylus on this film is detected, amplified $10^5$ to $10^6$ times and then converted into electrical output by a transducer system. The amplitude of the electrical signal will be proportional to the thickness of the film. The main disadvantage of this method is that, under the pressure of the stylus, films of soft materials slightly deform.

**Optical-interference methods**

If optical constants of a given film are known, then thickness can also be calculated. Among these methods, photometric and spectrophotometer techniques find widespread applications as these methods are based on optical-interference phenomenon. However, this technique can be used effectively for transparent thin films. All the thickness measurements in this work have been carried out using stylus method only.

### 2.2 Structure of the film

X-ray diffractometry is a technique for the characterization of thin films [1,3,4] since it provides a very broad range of information about the material in its thin film form. The data that can be interpreted from an XRD includes lattice constants / parameters, crystal structure (single crystal, polycrystalline, amorphous), crystallographic orientation, crystallographic defects, stress and strains in the films. XRD can reveal more information about the film than any other single type of characterization. It is purely non-destructive and film does not get damaged due to prolonged exposure to X-rays.
The incident X-rays undergo diffraction according to Bragg’s relation

\[ n \lambda = 2d \sin \theta \]  

(2.1)

Since wavelength (\( \lambda \)), diffraction angle (\( \theta \)) are known from experiment, the lattice spacing ‘d’ can be evaluated [3,4]. The value of \( \lambda = 1.5418 \) Å for Cu K\( \alpha \) radiation whereas \( \lambda = 1.7902 \) Å for Co K\( \alpha \) radiation. The obtained values (SCINTAG X-RAY DIFFRACTOMETER) are compared with available standard patterns ASTM charts or JCPDS [5] data to index each of the peaks.

Thus the existence of diffracting planes of the film can be established [6,7]. The width of the peak also gives some useful information. The full-width at half maximum (FWHM) can be used to determine grain size [D] using the Scherrer formula [8].

\[ D = \frac{0.9 \lambda}{B \cos \theta} \]  

(2.2)

where \( \lambda = \) Wavelength of X-rays \((1.5418 \times 10^{-10} \) m),

\[ B = \left[ (\Delta 2 \theta)^2 - (b)^2 \right]^{\frac{1}{2}} \]

where \( \Delta 2\theta \) is the full width at half maximum (radians), ‘b’ is the instrumental broadening taking the peak at 2\( \theta \) (radians) and ‘\( \theta \)’ is the angle at which the peak occurs.

However, grain size by this calculation is approximate (average value) for the film. The shift in the reflection from the standard value can be used to estimate the total residual stress in the film assuming that the shift is not due to any instrumental errors.

The expression that relates the stress ‘\( \alpha \)’ to the observed interplanar spacing “d”, the standard ‘d\( \_0 \)’ and the elastic constant E (Young’s modulus) and gamma (\( \gamma \)) the Poisson’s ration of the material (bulk) is

\[ \alpha = \left[ \frac{E}{1 - \gamma} \right] \left[ \frac{d - d\_0}{d\_0} \right] \]  

(2.3)
When ‘α’ is positive, the stress is tensile. When ‘α’ is negative, the stress is compressive. The expression assumes bulk values of elastic constants of the material. Therefore, the magnitude of the stress calculated may not be accurate; however the direction of the stress is correct.

2.3 Optical properties

A spectrophotometer may be employed to measure the transmitted or reflected intensity as a function of the wavelength and thus record positions of maxima and minima. The basic spectrophotometer is a double beam, ratio-reading instrument, providing digital presentation of absorbance, transmittance, and reflectance on an electronic display.

The ZrN films prepared in this investigation were characterized for their following reflectance properties.

1. Spectral reflectance in the wavelength region 300 nm to 800 nm.
2. Refractive index (n)
3. Extinction co-efficient (k)
4. Absorption co-efficient (α)

The spectral reflectance of the films was measured in the wavelength region of 300-800nm using HITACHI 330 model spectrophotometer. Using the reflectance data, n, k and α of the film were calculated [2].

The refractive index (n) of the film is given by the relation,

$$\lambda_{\text{max}} = \frac{2 n_1 t}{m} \quad \text{For condition } n_0 < n_1 < n_2$$

(2.4)

where \(n_0, n_1, n_2\) are refractive index of air, film and substrate respectively, ‘m’ is the order of reflectance maxima, and ‘t’ is the thickness of the film (in Å).
The extinction coefficient is determined using the equation,

\[ K = \frac{\alpha \lambda}{4 \pi} \]  

(2.5)

where, \( \alpha = \frac{2.303}{t} \log \left( \frac{1}{R} \right) \)

where ‘\( \alpha \)’ is absorption co-efficient, ‘R’ is percentage of reflectance

### 2.4 Scanning electron microscopy (SEM)

The SEM is the best tool to investigate the surface smoothness and to find the grain size of particles. The SEM provides the investigator with highly magnified image of the surface of a material that is very similar to what one would expect if one could actually see the surface visually. This tends to simplify image interpretations considerably, but reliance on intuitive reactions to SEM image can, on occasion, lead to erroneous results. The resolution of SEM can approach a few nm.

This maintains the three dimensional appearances of the textured surfaces, a phenomenon due to the high depth of field of scanning instruments the combination of high resolution, an extensive magnification range, and high depth of field make the SEM uniquely suited for the study of surfaces. As such it is an indispensable tool in Materials Science Research and Development.

#### 2.4.1 Surface morphology

Electron microscopy is one of the most powerful techniques to characterize the materials on the single and polycrystalline forms. The accuracy of most electron beam techniques depends on the lateral uniformity of the samples over dimensions of at least the size of the incident beam. To ensure the applicability of these electron beam techniques, surface uniformity has to be examined using SEM. In addition to that, this also gives information regarding the estimation of grain size, surface features like cone formation, hillocks, voids due to electro-migration and presence of surface defects such as dislocation, pits and faults [9,10,11].

SEM is powerful and versatile because (a) it has 6 modes of operation, which provide information about many different groups of properties of solid objects and (b) the information is obtained essentially as electrical signal suitable for electronic data
processing to provide quantitative values of many different properties as well as for presentation in various types of micrographs.

The SEM is not only a family of the different kinds of microscopes but it is also a family of micro-analytical measuring systems. The instrument used in the present investigation was JSM5600LV SEM/EDAX system. The samples were mounted on the holders and the sample chamber is evacuated. A source of electron is focused into a fine probe that is rastered over the surface of the specimen. As electrons penetrate the surface, a number of interactions occur that can result in the emission of electrons or phonons from the surface.

Appropriate detectors can be used to collect a reasonable fraction of electrons emitted and the output can be used to modulate the brightness of a CRT whose X and Y inputs are driven in synchronism with the X-Y voltages rastering the electron beam. In this way an image is produced on the CRT. The image can be photographed and used for our analysis.

2.5 Energy dispersive analysis of X-rays (EDAX)

In SEM it is customary to use “energy-dispersive” X-ray spectrometers. These employ Li drifted Si detector. These are blocks of high-resistivity material with a large electric field applied. Incident X-ray photons produce current pulses in a manner very much like the action of the older Geigh-Muller tubes. The height of the pulse is proportional to the energy of the photon and since $E=\gamma\frac{hc}{\lambda}$, inversely proportional to $\lambda$. A pulse-height analyzer is used to count the pulses. The energy (wavelength) of a peak in the X-ray spectrum indicates the elements concerned. The height of the peak is a measure of the concentration of the element in the energy dissipation volume “Point analyzer” can be carried out to determine the chemical composition.

This micro analysis is quick and convenient and mainly used for material identification and for checking whether limits are at best 1 part in 10 to the power of 4, and light elements are less easily detected than heavy ones.
2.6 Electrical properties

Electrical conduction properties of thin metal, insulating and super conducting films have long been of practical importance and theoretical interest for a very long time. Regardless of class of material involved, its physical state, whether it is in bulk/film form, an electric current density $J$ (amps/cm$^2$) is said to flow when a concentration of carriers $n$ (number/cm$^3$) with charge $q$ moves with velocity ‘v’ (cm/sec) past a given reference plane in response to an electric field ‘E’ (V/cm). Magnitude of current flow,

$$J = nqv$$

(2.6)

$$= nquE \quad \text{(Because v=uE)}$$

By Ohm’s law, ($J=\sigma E$), conductivity ‘$\sigma$’ or reciprocal of resistivity ($\rho$), $\sigma = 1/\rho = nqu$.

A number of techniques have been employed to measure electrical properties of thin films.

(a) For insulating films, where current flows through film thickness, electrodes are situated on opposite film surfaces

(b) Small evaporated / sputtered circular electrodes frequently serve as a set of equivalent contacts [substrate being the other contact].

Techniques for measuring thin film electrical resistance [12,13] are (a) four point probe technique for measuring sheet resistance (Fig 2.1) and (b) Van der Pauw technique for measuring resistivity of arbitrarily shaped films (Fig 2.2).
For more conductive metal and semiconductor films, it is common to place all electrodes on the same film surface. Such measurements employ 4 terminals- 2 to pass current and 2 to pass voltage.

A very convenient way to measure the sheet resistance of a film is to press a 4-point metal tip probe assembly into the surface as shown in Fig 2.1. The outer probes are connected to current source and inner probes detect the voltage drop.

Electrostatic analysis of the electric potential and field distributions within the film yields,

\[ R = \left(\frac{\rho \times L}{W \times t}\right) \]

\[ R = \left(\frac{\rho}{t}\right) \times \left(\frac{L}{W}\right) \]

\[ R = R_s \times \left(\frac{L}{W}\right) \]  \hspace{1cm} (2.7)

where sheet resistance \( R_s = \left(\frac{\rho}{t}\right) \), resistivity \( \rho = (R_s \times t) = \left(\frac{k \times V \times t}{I}\right) \), i.e. resistivity \( \rho = R_s \times t \) (\( \mu \Omega \text{cm} \)). Where ‘t’ stands for thickness, ‘\( R_s \)’ sheet resistance is independent of film dimensions other than thickness. ‘k’ is a constant dependent on the configuration and spacing of the contacts

\[ K = \frac{\pi}{\text{Ln}2} = 4.53 \]

Thus, sheet resistance, \( R_s = 4.53 \left(\frac{V}{I}\right) \).
The probe can be made from thin tungsten wires (approx 0.05 cm dia), which are sharpened electrolytically and fixed in a refractable plexiglass header by suitable cement. Commonly used point spacing is $s=0.159$ cm. Thus, 4-point probe methods measure the average resistivity of the film on a substrate; provided film is either isolated from substrate or its resistivity is much lower than that of the substrate. 4-point probe assemblies are available commercially with square as well as the more common linear contact arrays. All our measurements have been carried out using the above-mentioned techniques. The other method is Van der paw method.

### 2.7 Metal-semiconductor (M-S) contacts

#### 2.7.1 Introduction

Conductive films are required to provide interconnection between contacts on devices and between devices and the outside world [11]. All metallization directly in contact with semiconductor is called contact metallization. Metallization will not only be current carriers but also play an active role in determining device properties, as in the case of gate electrode/Schottky barrier diode. Some of the desired properties of metallization for integrated circuits in VLSI/ULSI are

(a) Low resistivity,
(b) Easy to form,
(c) Easy to etch for pattern generation,
(d) Should be stable in oxidizing ambient; oxidizable,
(e) Mechanical stability; good adherence, low stress,
(f) Surface smoothness,
(g) Stability throughout processing, including high temperature sinter dry/wet oxidation, gettering, passivation, metallization,
(h) No reaction with final metal,
(i) Should not contaminate devices, wafer or working apparatus,
(j) Good device characteristics and lifetimes, and
(k) For window contacts-low contact resistance, minimal junction penetration, low electro migration.
Metallization plays two important roles:

(a) It controls the speed of the circuit by virtue of the resistance of the interconnection runners.
(b) It controls the so-called flat-band voltage $V_{FB}$, which is the voltage required to counter balance the work function difference between metal and semiconductor so that flat band condition is maintained in semiconductors. Flat band voltage also contributes to threshold voltage $V_t$.

### 2.7.2 Types of metal–semiconductor contacts

Any device based on metal-semiconductor contacts can either form an active rectifying contact or an ohmic contact [9,11,13]. An ohmic contact is an M-S contact, which offers minimum contact resistance (relative to bulk or spreading resistance of the semiconductor) to current flow in either direction over a wide temperature range. Thus, a good ohmic contact does not perturb device characteristics and is stable both electrically and mechanically. Contact resistance is very less compared to device resistance.

A Schottky barrier contact/rectifying contact is also an M-S contact, which offers low resistance to current flow in one direction and very high resistance in the opposite direction. It is widely used as fast switch for protecting circuit elements from high-voltage transients in IC technology.

The most important property of a M-S interface, from the standpoint of electronic device applications, is potential barrier or barrier height, between fermi level in the metal and majority carrier band edge of semiconductor at the interface. Barrier height plays a central role in the electrical properties of the M-S interface because it determines the current–voltage (I-V) characteristics of the structure.

### 2.7.3 Schottky barriers

Work function ($\Phi_m$) of a metal is the energy required to remove an electron at the fermi level to the vacuum outside the metal. When negative charges are brought near the metal surface, positive (images) charges are induced in the metal. When this
image force is combined with an applied electric field, the effective work function is somewhat reduced. Such barrier lowering is called Schottky effect.

Thus, Schottky effect is the image-force-induced lowering of the potential energy for the charge carries emission when an electric field is applied. Although the Schottky effect is only a part of the explanation of metal-semiconductor effects, rectifying contacts are generally referred to as Schottky barrier diodes.

When a metal with work function \( (q\phi_m) \) is brought in contact with a semiconductor having a work function \( (q\phi_s) \), charge transfer occurs until the fermi levels align at equilibrium.

**For example:**
Consider 2 cases (a) where the semiconductor is made of n-type (where \( \phi_m > \phi_s \)), (b) where the semiconductor is made of p-type (where \( \phi_m < \phi_s \)).

In \( (\phi_m > \phi_s) \), i.e. when a Schottky barrier formed by sandwiching an n-type semiconductor with a metal having large work function, the semiconductor fermi level is initially higher than that of the metal before contact is made. To align the 2-fermi levels, electro static potential of semiconductor must be raised (electron energies must be lowered) relative to that of the metal.

Once contact is made, the equilibrium contact potential \( V_o \) prevents further net electron diffusion from semiconductor conduction band into the metal. The potential barrier height \( \phi_B \) for electron injection from metal to semiconductor conduction band is \( \phi_m - \chi \). The equilibrium potential difference (V) or contact potential is reduced from \( V_0 \) to \( V_0-V \), when forward bias is applied. As a result, electrons in semiconductor conduction band diffuse into the depletion region of metal, resulting in a forward current through the junction from metal to semiconductor. The forward diode equation can be as follows.

\[
I = I_o \left( \exp \frac{qV}{kT} - 1 \right)
\]  

\( (2.8) \)
Here \((\varphi_m - \chi)\) i.e barrier is unaffected by the bias voltage. Thus, when reverse biased, \('I_o'\) is proportional to \(\exp^{-\frac{q(\varphi_b)}{kT}}\) i.e. conversely, a reverse bias increases the barrier to \(V_o + V_r\) and electrons flow from the semiconductor to the metal becomes negligible.

Thus, when Schottky barrier on a p-type semiconductor is formed, \(\varphi_m < \varphi_s\), fermi levels at equilibrium requires a positive charge on the metal side and a negative charge on semiconductor side of the junction. The diode equation (2.8) also applies to metal-p-type semiconductor. Here forward voltage is defined with the semiconductor biased positively with respect to the metal. Forward current increases as this voltage lowers the potential barrier to \((V_o - V)\) and holes flow from the semiconductor to the metal.

In both these cases, the Schottky barrier diode is rectifying, with easy current flow in forward direction and little current flow in reverse direction. We also note that forward current in each case is due to the injection of majority carriers from semiconductor into the metal. The absence of minority carrier injection and associated storage delay time is an important feature of Schottky barrier diodes. Although some minority carrier injection occurs at high current levels, these are essentially majority carrier devices. Their high frequency properties and switching speed are therefore generally better than typical p-n junctions [11,14].

Schottky barrier devices are particularly well suited for use in densely packed integrated circuits, because fewer photolithographic masking steps are required compared to p-n junction devices.

### 2.7.4 Ohmic contacts

The other two cases of ideal metal-semiconductor contacts are (a) \(\varphi_m < \varphi_s\) for n-type semiconductor, (b) \(\varphi_m > \varphi_s\) for p-type semiconductor. They are known as non-rectifying contacts/ohmic contacts.

In ohmic metal-semiconductor contact, linear I-V characteristics in both biasing directions are obtained. Ohmic contacts have minimum resistance and they do not have a tendency to rectify signals.
Ideal metal-semiconductor contacts are ohmic when charge involved in the semiconductor in aligning the fermi levels is provided by majority carriers i.e. n-type semiconductor, $\phi_m < \phi_s$, the fermi levels are aligned at equilibrium by transferring electrons from metal to the semiconductor. In ohmic contacts, no depletion region occurs in the semiconductor because the electrostatic potential difference required to align the fermi levels at equilibrium calls for accumulation of majority carriers in the semiconductor.

2.8 Metal-oxide-semiconductor (MOS) structures.

MOS structure is created by superimposing several layers of conducting; insulating and semiconductor materials to create a sandwich-like structure. In MOS structure, substrate is isolated from the metal electrode by a thin insulating layer. The metal electrode/gate electrode controls the working of the complete device. The work function of the metal plays an important role in determining the voltage required to activate the device. It also determines even the current flow.

The dynamic response i.e. switching speed of MOS system is strongly dependent on the parasitic capacitances associated with the MOS device and the interconnection capacitances that are formed by different layers on the device. The first parameter of interest that characterizes the switching behavior of an MOS device is the threshold voltage $V_t$ (threshold voltage is the voltage at which MOS device begins to conduct/turn on).

2.8.1 MOS-capacitor characteristics

The capacitance-voltage characteristics of an MOS capacitor depend on the state of semiconductor surface [13,14]. Depending on the gate voltage, the surface may be

(a) Accumulation mode ($V_g < 0V$)
(b) Depletion mode ($V_g \sim 0V$) and
(c) Inversion mode ($V_g > 0V$)

(These conditions are applicable only for p-type substrate).
(a) Accumulation mode

Consider an MOS structure, with p-type semiconductor (substrate). In this structure, an accumulation layer is formed when \( V_g < 0 \text{V} \) (Fig 2.3a). Thus negative charge on the gate attracts holes towards the silicon surface. When accumulation layer is present, the MOS structure behaves like a parallel-plate capacitor. The plate electrode/metal forms one plate of the capacitor; the high concentration of holes in p-substrate forms the second plate. Since accumulation layer is directly connected to substrate, gate capacitance may be,

\[
C_0 = \left( \varepsilon_{\text{ins}} \times \varepsilon_0 \times A \right) / t_{\text{ox}}
\]  

(2.9)

where, \( A \) is the Area of gate (plates) cm\(^2\), \( \varepsilon_{\text{ins}} \) is the di-electric constant (relative permittivity of insulator), \( \varepsilon_0 \) is the permittivity of free space (8.854x10\(^{-12}\)F/m), and \( t_{\text{ox}} \) is the thickness of insulator (cm).

(b) Depletion mode

\( V_g \sim 0 \text{V} \) (or) \( V_g > 0 \text{V} \) \([V_g \sim V_t]\)

\( V_g \) is positive w.r.t. substrate

When a small positive voltage is applied to the gate with respect to the substrate, depletion layer is formed in the p-substrate directly under the gate (Fig 2.3b) and thus capacitance at depletion mode is given by,

\[
C_{\text{dep}} = \left( \varepsilon_0 \times \varepsilon_{\text{ins}} \times A \right) / d
\]

(2.10)

where ‘d’ is the depletion layer depth, ‘\( \varepsilon \)’ is the dielectric constant of semi conducting substrate.

Thus, as depth of the depletion region increases, the capacitance from gate to substrate will decrease. Thus total capacitance from gate to substrate under depletion condition can be regarded as being due to gate oxide capacitance, \( C_0 \) in series with \( C_{\text{dep}} \), specifically

\[
C_{gh} = \left( C_0 C_{\text{dep}} \right) / \left( C_0 + C_{\text{dep}} \right)
\]

(2.11)
(c) **Inversion mode** \( V_g > 0 \) \( V \)

When the gate voltage is further increased, minority carriers (i.e. electron for the p-type substrate) are attracted towards the surface establishing a channel. This effectively inverts the substrate at the surface and creates an n-type channel. The region under the gate changes from p-type to n-type. Thus, it is given the name **Inversion**. Surface inversion yields a relatively high conductivity layer under the gate, which restores the low frequency capacitance to \( C_0 \) (Fig 2.3c). Because of the limited supply of carriers (electron) to the inversion layer, the surface charge is not able to track fast moving gate voltage. Hence the dynamic gate capacitance remains the same as for the maximum depletion situation.

\[
C_{gb} = C_0 \ ; \text{ low frequency (}<100\text{Hz})
\]

\[
= C_0\left(C_0 + C_{dep}\right) = C_{min} \ ; \text{ high frequency}
\]  

\( C_{min} \) depends on the depth of depletion region, which depends in turn on such parameters as the substrate doping density. All the three different regions of operations of an MOS structure, along with its capacitance versus voltage variation curve are as shown in Fig 2.3(d).
Fig 2.3: Modes of MOS capacitor (a) Accumulation mode, (b) Depletion mode, and (c) Inversion mode
2.9 Selection of substrates

A thin film deposition has to be carried out onto a base material, called the substrate. Selection of substrate and perfect cleaning of the substrates is very important. A number of materials such as glasses, silicon wafers, and other semiconductor wafers are readily available as substrates. In the present investigation, polished p-type silicon, n-type germanium and p-type gallium nitride was used as substrates for thin film deposition. The cleanliness of the substrates exerts a decisive influence on film growth and adhesion. A thoroughly cleaned substrate is a prerequisite for the preparation of films with reproducible properties. The choice and cleaning techniques depends on the nature of the substrates, the type of contaminants and the degree of cleanliness required. Residues from manufacturing and packing, lint, fingerprints, oil and airborne particulate matter are frequently encountered contaminants. The process of substrate cleaning requires that bonds are broken between contaminant molecules as well as between the contaminant and the substrate surface. This may be accomplished by chemical means as in solvent cleaning or by...
supplying sufficient energy to vaporize the impurity, for example, by heating or particle bombardment. The procedure involves removal of contaminants without causing damage to the substrate surface. The following sequences of steps have been used for cleaning the substrates surface in the present investigations.

2.9.1 Silicon Cleaning Procedure – RCA cleaning

Contaminants present on the surface of the silicon wafer at the start of processing or accumulated during processing have to be removed at specific processing steps in order to obtain high performance and high reliability semiconductor devices and to prevent contamination equipment, especially high temperature oxidation. RCA cleaning is the industry standard for removing contamination from the wafers. Werner Kern developed the basic procedure in 1965 while working for RCA (Radio Corporation of America). The RCA procedure followed in the present study is given below.

The Si wafers were placed in Teflon carriers. Insoluble organic contaminants in the wafer can be removed by immersing the wafer in the organic clean solution, which is maintained at 75 °C (5:1:1, H₂O: H₂O₂: NH₄OH) for 10 minutes. Remove carrier from the organic clean solution and rinse wafer in the DI water for one minute. Submerge the carrier with wafer in the oxide strip solution (50:1, H₂O: HF) for 15 seconds in order to remove the small silicon dioxide that may be accumulated as a result of organic clean. Then remove carrier from the bath and rinse the wafer in DI water for one minute. Ionic and heavy metal atomic contaminants presents in the wafer may be removed using the ionic clean solution (6:1:1, H₂O: H₂O₂: HCL) for 10 minutes. Remove carrier from the bath and rinse wafer in DI water for one minute. Remove carrier and blow dry with nitrogen.

2.9.2 Cleaning of GaN substrate

The GaN layers for this study were grown by metalorganic chemical vapor deposition on c-plane sapphire substrates. An undoped GaN layer (2 µm thick) was grown, followed by the growth of 1.5 µm-thick n-GaN:Mg. The carrier concentration
was determined to be 1.13×10^{17} \text{cm}^{-3} by means of Hall effect measurements with the Van der Pauw geometry. The GaN layer was first ultrasonically degreased with warm trichloroethylene, acetone and methanol for 5 min each. This degreased layer was then dipped into boiling aquaregia \([\text{HNO}_3: \text{HCL} = 1:3]\) for 10 min to remove the surface oxides and rinsed in deionised water.

2.9.3 Cleaning of glass substrates

Glass substrates were cleaned using laboratory detergent. Subsequently they were washed in running water. At last, substrates were rinsed in distilled water and wiped with soft cloth and with a little trace of acetone.

3.0 Dielectric properties

An important property of a material is its dielectric permittivity. A thorough knowledge of this parameter is essential for solving many problems in semiconductor Physics and particularly in the electric field stimulated emission studies. Apart from this it leads to the analysis of some fundamental physical properties of the system like the presence of impurities, voids, structural defects, polarization mechanism, relaxation mechanism, etc. Most of the dielectric are characterized by four factors namely the relative permittivity, loss tangent, dielectric strength and breakdown.

3.0.1 Dielectric Constant:

Consider a parallel plate capacitor of area ‘A’, separated by distance d in the medium of permittivity ‘\varepsilon’. Let the potential V applied to it and the charge carried by it be ‘Q’. The electric field strength is \(\frac{V}{d}\) (volts/meter), and then the permittivity \(\varepsilon\) of the medium is given by ‘\varepsilon’,

\[
\frac{Q}{V/A} = C \times \frac{d}{A}
\]  

(2.13)
The dielectric constant of a substance is purely the intrinsic property of the constituent ion. The absolute dielectric constant \( \varepsilon = \varepsilon \varepsilon_0 \) and hence \( C = \varepsilon \varepsilon_0 A/d \), where ‘C’ is the capacitance, \( d \) is the thickness of the dielectric, \( \varepsilon_0 \) is the permittivity of the free space and ‘A’ is the area of capacitor.
REFERENCES


