DIELECTRIC PROPERTIES

5.1 Introduction

Thin film technology enables the production of large capacitance in small volume. There is an ever widening demand for thin film capacitors in microelectronics, which is keeping pace with the present trend towards microminiaturisation. The capacitors which have high working voltages and ability to stand down to low and high temperatures at a wide spectrum of frequencies are always desirable. Extensive studies of the dielectric properties of both organic and inorganic thin films deposited by various techniques have been made [1,2]. As these studies also throw light on the electrical conduction and optical phenomena, the dielectric properties of some insulating and semiconducting films of wider applications have also been investigated [3-6]. In the present investigation the dielectric properties of perylene and p-terphenyl films have been studied in detail.

5.2 Theory of Dielectrics

5.2.1 Coulomb's law

Coulomb's law summarises the phenomenon of interaction between two charges \( q_1 \) and \( q_2 \) separated by a distance, \( d \) in a medium of permittivity \( \epsilon \) as

\[
F = \frac{q_1 q_2}{4\pi \epsilon d^2} \quad (5.1)
\]

where \( F \) is the force of attraction or repulsion.

Also

\[
\epsilon = \epsilon' \epsilon_0 \quad (5.2)
\]
where $\varepsilon_0$ is the permittivity of free space $= 8.854 \times 10^{-12}$ Farads/metre and $\varepsilon'$ is the relative permittivity or dielectric constant of the medium.

The permittivity of a medium, according to Maxwell's equation is

$$ \mathbf{D} = \varepsilon \mathbf{E} $$ \hspace{1cm} (5.3)

where $\mathbf{D}$ is the displacement vector and $\mathbf{E}$ the electric field at that place. $\mathbf{D}$ gives a measure of the extent to which the surroundings modify the field and also is equal to the surface charge per unit area.

Suppose a parallel plate condenser of area $A$ with $d$, the distance of separation of the plates in vacuum. Let $V$ be the potential applied to it and $Q$ the charge carried. Then the electric field is $V/d$ Volts/metre.

Hence

$$ \varepsilon = \frac{(\mathbf{D}/\mathbf{E})}{\varepsilon_0} = \left(\frac{Q/A}{V/d}\right) = \frac{Q/V \times d/A}{V/d} $$

But

$$ Q/V = C $$

Therefore,

$$ \varepsilon = C \frac{d/A}{V/d} $$ \hspace{1cm} (5.4)

5.2.2 Dielectric constant

The dielectric constant of a substance is entirely dependent on the intrinsic property of the constituent ions. In the absence of electrode effects, the dielectric constant consists of the following components,

$$ \varepsilon' = \varepsilon'_{ex} \varepsilon'_{o} \varepsilon'_{n} \varepsilon'_{d} $$ \hspace{1cm} (5.5)

where $\varepsilon'_{ex}$, $\varepsilon'_{o}$, $\varepsilon'_{n}$ and $\varepsilon'_{d}$ are contributions of extrinsic features, electronic polarisability, ionic polarisability and ionic deformation respectively.
For parallel plate condenser, neglecting the edge effect, from equations 5.2 and 5.4

\[ e' = \frac{Cd}{\varepsilon_o A} \]  \hspace{1cm} (5.6)

where \( C \) is the capacitance, \( d \) the thickness of the dielectric, \( \varepsilon_o \) the permittivity of free space and \( A \) the area of the capacitor.

### 5.2.3 Dielectric loss

The alternating current in an ideal capacitor is out of phase with the applied voltage and actually leads by \( \pi/2 \). The electric flux density \( D \) will also change but it lags behind the phase related to the applied voltage. If the applied sinusoidal field is \( E = E_o \cos \omega t \), the scalar equation becomes

\[ D = D_1 \cos \omega t + D_2 \sin \omega t \]  \hspace{1cm} (5.7)

where \( \delta \) is the phase angle, \( D_1 = D_o \cos \delta \) and \( D_2 = D_o \sin \delta \).

For most dielectrics, however, \( D_o \) is proportional to \( E_o \) and the ratio \( D_o/E_o \) is generally frequency dependent.

Therefore, after modification

\[ e'(\omega) = \frac{D_1}{E_o} = \frac{D_o}{E_o} \cos \delta \]  \hspace{1cm} (5.8)

\[ e''(\omega) = \frac{D_2}{E_o} = \frac{D_o}{E_o} \sin \delta \]  \hspace{1cm} (5.9)

The factor \( \sin \delta \) is a measure of the energy absorbed by a dielectric. From the vector diagram of a capacitor shown in Figure 5.1, on assuming \( R \) to be very large,
FIG. 5.1 VECTOR DIAGRAM OF A PRACTICAL CAPACITOR
\[
\sin \delta = \tan \delta = \frac{1}{\omega RC} \quad (5.10)
\]

Tan \( \delta \) is otherwise referred to as the dielectric loss.

The complex dielectric constant is given by

\[
\varepsilon^* = \varepsilon' - j \varepsilon'' \quad (5.11)
\]

where \( \varepsilon' \) is the relative permittivity and \( j \varepsilon'' \) is a component associated with the resistive vector. Now the loss factor is represented by

\[
\tan \delta = \frac{\varepsilon''}{\varepsilon'} \quad (5.12)
\]

and is also given by the ratio of the loss of the current due to the resistance of the medium between the plates to the charging current of the capacitor. For a loss free medium \( \varepsilon'' \) becomes zero.

The complex capacitance of any real dielectric is

\[
C^* = \varepsilon^* C_0 \quad (5.13)
\]

where \( C_0 = \varepsilon_o (A/d) \) for a parallel plate condenser.

The dielectrics usually have a finite parallel resistance \( R \). So the total impedance \( Z \) of the capacitor can be given as

\[
\frac{1}{Z} = \frac{1}{R} + j \omega C \quad (5.14)
\]

For a complex capacitance the impedance

\[
Z = \frac{1}{j \omega C^*} = \frac{1}{j \omega C_0 (\varepsilon' - j \varepsilon'')} \quad (5.15)
\]
From equations 5.14 and 5.15

\[
\epsilon' = \frac{C}{C_0} \quad (5.16)
\]

\[
\epsilon'' = \frac{1}{\omega C_0 R} = \frac{\sigma_D}{\omega \varepsilon_0} \quad (5.17)
\]

\[
\sigma_D = \omega \varepsilon_0 \epsilon'' \quad (5.18)
\]

where \(\sigma_D\) is known as the dielectric conductivity. Dielectric conductivity represents the sum of all the loss mechanisms in the material and is a measure of performance of a dielectric as an insulator.

For a parallel equivalent circuit,

\[
\tan \delta = \frac{1}{\omega C_p R_p} \quad (5.19)
\]

where \(C_p\) is the parallel capacitance and \(R_p\) the parallel a.c. resistance.

**5.2.4 Temperature Coefficient of Capacitance (TCC)**

An important device parameter in the assessment of the expected behaviour in a thin film circuit is the TCC. The ever growing interest in the choice of fitting material for application as capacitors suggests that the TCC of a material needs thorough investigation.

The temperature coefficient of capacitance is defined as

\[
\text{TCC} = \gamma_c = \frac{1}{C} \left( \frac{dC}{dT} \right) \quad (5.20)
\]

\[
\gamma_c = \gamma_p + \beta \quad (5.21)
\]
Equation 5.21 relates the TCC to the temperature coefficient of permittivity $\gamma_p$ given by

$$\gamma_p = \frac{1}{\varepsilon'} \frac{d\varepsilon'}{dT} \quad (5.22)$$

and $\beta$ is the linear expansion coefficient of the dielectric and $T$ the temperature. The TCC is usually expressed in parts per million (ppm) per degree Celsius (or Kelvin).

The value of TCC up to around 650 ppm/K is comparable to dielectric films investigated so far as TFC elements [5]. A value around this range implies further investigation into the material for suitability of application as thin film capacitor (TFC).

5.2.5 Thin film capacitor model

A simple capacitor model is illustrated in Figure 5.2. In the case of a TFC, the system is assumed to have the following elements:

1. An inherent capacity element, $C$ which is unaffected by frequency ($f$) and temperature ($T$).
2. A discrete resistance element, $R$ due to the dielectric material in parallel with $C$ and
3. A series resistance, $r$ due to electrodes, leads, etc.

The TFC model and the equivalent series circuit are illustrated in Figure 5.3. $r$, due to leads resistance etc., will be almost constant and independent of temperature. But, the material resistance, $R$ will be affected by temperature exponentially according to the relation

$$R = R_0 \exp \left( \frac{\Delta E}{kT} \right) \quad (5.23)$$
FIG. 5.2 MODEL FOR A PRACTICAL CAPACITOR

\[ R \quad C \]
FIG. 5.3(a) THIN FILM CAPACITOR MODEL

FIG. 5.3(b) EQUIVALENT SERIES CIRCUIT
In general $R \gg r$.

Impedance of the circuit [Figure 5.3 (a)] in terms of $C$, $R$, $r$ and $\omega$

$$Z = \frac{R}{1 + j\omega CR} + r$$

$$= \frac{R + r(1 + \omega^2 R^2 C^2)}{1 + \omega^2 R^2 C^2} - \frac{j\omega CR^2}{1 + \omega^2 R^2 C^2} \quad (5.24)$$

where $\omega = 2\pi f$

In the simpler equivalent series circuit [Figure 5.3 (b)]

$$Z_s = R_s + \frac{1}{j\omega C_s} = R_s - \frac{1}{\omega C_s} \quad (5.25)$$

where $R_s$ and $C_s$ are equivalent resistance and capacitance respectively.

Equating the real and imaginary parts of the equations 5.24 and 5.25

$$R_s = \frac{R + r(1 + \omega^2 R^2 C^2)}{1 + \omega^2 R^2 C^2} = r + \frac{D^2}{1 + D^2} R \quad (5.26)$$

and

$$C_s = \frac{1 + \omega^2 R^2 C^2}{\omega^2 R^2 C} = (1 + D^2)C \quad (5.27)$$

where $D = \frac{1}{\omega R C}$.

The loss factor, $\tan \delta$ in the case of the series circuit is $\omega C_s R_s$

Therefore,

$$\tan \delta = \frac{\omega (1 + \omega^2 R^2 C^2) [R + r(1 + \omega^2 R^2 C^2)]}{(\omega^2 R^2 C)(1 + \omega^2 R^2 C^2)} \quad (5.28)$$

Simplifying

$$\tan \delta = \frac{1}{\omega R C} + \frac{r}{\omega R^2 C} + \omega r C \quad (5.29)$$

$$= D\left(1 + \frac{r}{R}\right) + \omega r C \quad (5.30)$$
where loss is expressed in terms of $\omega$, $C$, $R$, and $r$.

For all cases $\omega R^2 C >> r$ or $(r/R) << 1$, equation 5.29 reduces to

$$\tan \delta = \frac{1}{\omega RC} + \omega r C = (D + \omega r C) \quad (5.31)$$

When $\omega$ is small $\frac{1}{\omega RC} >> \omega r C$ then,

$$\tan \delta = \frac{1}{\omega RC} = D \quad (5.32)$$

When $\omega$ is large, $\frac{1}{\omega RC} << \omega r C$ and hence

$$\tan \delta = \omega r C \quad (5.33)$$

Thus the inverse or direct proportionalities of the loss factor to $\omega$ in the appropriate frequency ranges is clarified by the equations 5.32 and 5.33.

5.2.6 Electrode or lead resistance

In accordance with equation 5.33, the electrode or lead resistance, $r$ can be evaluated by measuring $\tan \delta$ and $C$ at two different higher frequencies viz.,

$$\tan \delta_1 = \omega_1 C_1 r \quad \text{and}$$

$$\tan \delta_2 = \omega_2 C_2 r \quad (5.34)$$

or

$$r = \frac{\tan \delta_1 - \tan \delta_2}{\omega_1 C_1 - \omega_2 C_2} \quad (5.36)$$

Thus by considering the simple equivalent circuit in correspondence with the physical parameters of the TFC, expressions for the loss factor and the electrode and lead resistance can be derived and the effects of frequency and temperature on the parameters can be studied.
5.3 Measurements

The capacitance and loss factor (tan δ) are the two vital parameters in the study of dielectric properties. These dielectric measurements were performed using a Radart 0.1% Universal Bridge (Type-1204, Eastern Electronics Ltd., Delhi, India) in conjunction with an external, low distortion audio generator (Type TAG 35, Aplab, India). Figure 5.4(a) displays the experimental arrangement used for a.c. studies in audio frequency range.

The bridge measures the resistive and capacitive components of a capacitor as a series network when the D-Q switch (in the apparatus) is set to D and as a parallel network when set to Q. The expressions relating the equivalent parallel (C_p) and series (C_s) capacitances are

\[ C_p = \frac{C_s}{1 + D^2} \quad \text{and} \quad C_s = C_p \left( \frac{1 + Q^2}{Q^2} \right) \]

where D denotes the loss factor and Q, the quality factor. Throughout the study, the equivalent series capacitance C_s (D-position) was measured and whenever necessary, a series parallel conversion was made. The loss factor of the component is given by

\[ \tan \delta = D_f \times \frac{f}{1000} \]

where D_f is the loss measured on the apparatus at any arbitrary frequency f, in Hertz. The accuracy of the bridge is 0.1%. Tan δ can be measured upto 0.001 and capacitance from 0.1 pF to 110 µF.

To avoid the cumulative effects of various conduction mechanisms, the signal voltage which energised the wheatstone's bridge was always kept below 0.5 V rms. The capacitance and tan δ were measured in vacuum (≈ 1 Pa) in the frequency range 1 to 30 HHz at various temperatures. The temperatures were sensed by a pre-calibrated copper-constantan thermocouple in conjunction with a microvoltmeter. [Type MV-002, Scientific Equipment and Services, India].
FIG. 5.4 EXPERIMENTAL ARRANGEMENT FOR AC STUDIES
(a) IN FREQUENCY RANGE 1 TO 30 kHz
(b) IN FREQUENCY RANGE 50 kHz TO 10 MHz
Dielectric measurements at high frequencies (50 kHz - 10 MHz) were made with circuit magnification meter (Q-meter) coupled with an external oscillator (TF 1245 and TF 1246, Marconi Instruments Ltd., England) [Figure 5.4(b)]. The Q-meter functions on the principle of resonance in which measurements were carried out by the method of substitution. The capacitance and the loss factor were actually determined by using the following relations:

\[
\begin{align*}
\text{Capacitance (C)} &= C_1 - C_2 \\
\text{Loss factor (tan}\delta) &= \frac{(Q_1 - Q_2)C_1}{Q_1Q_2(C_1-C_2)}
\end{align*}
\]

where \(Q_1\) and \(Q_2\) represent the resonant circuit Q values without and with capacitor respectively. Similarly \(C_1\) and \(C_2\) represent the measured tuning capacitance values without and with the capacitor under test respectively, at resonance.

Only small area (0.5 to 1 mm\(^2\)) capacitors with capacitance values less than 300 pF were fabricated for measurements with Q-meter. Care has been taken to minimise the errors due to lead and contact resistances and parasitic inductances during the measurement of C and Q values.

5.4 Results and Discussion

5.4.1 Aging and annealing

Figures 5.5 to 5.8 depict the aging characteristics of capacitance (C) and \(\text{tan} \delta\) for vacuum deposited and ion plated organic (perylene and p-terphenyl) films. The structural changes and redistribution of atoms take place during aging resulting in the reduction of capacitance and loss factor. They were found to decrease rapidly in the initial stage and then slowly with time. The rapid changes in the internal
FIG. 5.5 DEPENDENCE OF CAPACITANCE AND TAN $\delta$
(at 1 kHz) OF VACUUM DEPOSITED PERYLENE
FILM CAPACITOR DUE TO AGING ($t = 1440$ Å)
FIG. 5-6 DEPENDENCE OF CAPACITANCE AND TAN $\delta$
(AT 1 kHz) OF ION PLATED PERYLENE FILM
CAPACITOR DUE TO AGING ($t = 700$ Å)
FIG. 5-7 DEPENDENCE OF CAPACITANCE AND TAN $\delta$ (AT 1 kHz) OF VACUUM DEPOSITED p-TERPHENYL FILM CAPACITOR DUE TO AGING ($t = 700 \text{ Å}$)
FIG. 5-8 DEPENDENCE OF CAPACITANCE AND TAN S (AT 1 kHz) OF ION PLATED p-TERPHENYL FILM CAPACITOR DUE TO AGING (t = 2100 Å)
field of the capacitor may be responsible for the large reduction in C and tan δ values during the initial period of aging. Similar aging effect has been observed by earlier workers [7-10]. An examination of Table 5.1, for a given material, reveals that the stabilisation is attained earlier in the ion plated films than in vacuum deposited specimens. This early attainment of stabilising nature of ion plated films may be due to increase in surface temperature of substrates [11] during ion plating technique. Such a behaviour has already been observed in organic films [12].

An annealing cycle comprises of the gradual increasing of temperature of the capacitor in an oven to annealing temperature i.e., 320 K during first half an hour, maintaining in that temperature for about one hour constantly and then decreasing gradually to room temperature in the next half an hour. Figures 5.9 to 5.12 display the annealing behaviour of freshly formed capacitors with vacuum deposited and ion plated perylene and p-terphenyl films. In each case, the capacitance decreases markedly during the first annealing cycle, but the amount of reduction becomes smaller during the subsequent annealing cycles. Always ion plated capacitors arrive at stability with lesser number of cycles than the vacuum deposited ones.

Figures 5.13 to 5.16 illustrate the annealing behaviour of the fresh capacitors formed with the various organic films with respect to the dependence of loss factor and capacitance on frequency. As annealing progresses with the repeated cycles, tan δ value decreases and reaches a final stabilised value. Here also the attainment of stability is advanced in ion plated specimens in comparison with the vacuum deposited ones.
Table 5.1
The aging period of different organic films for stabilization

<table>
<thead>
<tr>
<th>Film material</th>
<th>Deposition technique</th>
<th>No. of days required for stabilisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perylene</td>
<td>Vacuum deposition</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Ion plating</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Vacuum deposition</td>
<td>55</td>
</tr>
<tr>
<td>p-Terphenyl</td>
<td>Ion plating</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 5.2
The TCC for capacitors fabricated with various organic films

<table>
<thead>
<tr>
<th>Film material</th>
<th>Deposition technique</th>
<th>TCC (ppm/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perylene</td>
<td>Vacuum deposition</td>
<td>8057</td>
</tr>
<tr>
<td></td>
<td>Ion plating</td>
<td>5386</td>
</tr>
<tr>
<td></td>
<td>Vacuum deposition</td>
<td>2830</td>
</tr>
<tr>
<td>p-Terphenyl</td>
<td>Ion plating</td>
<td>500</td>
</tr>
</tbody>
</table>
FIG. 5.9 CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) AFTER SUCCESSIVE ANNEALING CYCLES FOR VACUUM DEPOSITED PERYLENE FILM (t = 5490 Å)
FIG. 5·10 CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) AFTER SUCCESSIVE ANNEALING CYCLES FOR ION PLATED PERYLENE FILM ($t = 350$ Å)
FIG. 5.11 CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) AFTER SUCCESSIVE ANNEALING CYCLES FOR VACUUM DEPOSITED p-TERPHENYL FILM (t = 2270 Å)
FIG. 5-12 CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) AFTER SUCCESSIVE ANNEALING CYCLES FOR ION PLATED p-TERPHENYL FILM (t = 850 Å)
FIG. 5.13 DEPENDENCE OF TAN $\delta$ ON FREQUENCY (1 kHz TO 30 kHz) DUE TO SUCCESSIVE ANNEALING CYCLES FOR VACUUM DEPOSITED PERYLENE FILM ($t = 5490 \, \text{Å}$).
FIG. 5.14 DEPENDENCE OF $\tan \delta$ ON FREQUENCY (1 kHz TO 30 kHz) DUE TO SUCCESSIVE ANNEALING CYCLES FOR ION PLATED PERYLENE FILM ($t = 350$ Å)
Fig. 5-15  Dependence of TAN $\delta$ on frequency (1 kHz to 30 kHz) due to successive annealing cycles for vacuum deposited $p$-terphenyl film ($t = 2270$ Å)
FIG. 5.16 DEPENDENCE OF TAN $\delta$ ON FREQUENCY (1 kHz TO 30 kHz) DUE TO SUCCESSIVE ANNEALING CYCLES FOR ION PLATED p-TERPHNYL FILM ($t = 850 \text{ Å}$)
As-deposited films may contain many defects such as voids, grain boundaries, pin holes etc. Annealing of these films in air or vacuum reduces the defects. The reduction may result in lowering the concentration of charge carriers and thereby enhance the resistivity of the film. This in turn reduces the loss and capacitance. The defects are gradually reduced, cycle after cycle and each atom may occupy a stable position in the interior of the film until the dielectric properties attain constant values. Presence of such defects in the freshly formed dielectric has been reported in the earlier investigations [13-15]. The earlier attainment of stability of dielectric characteristics of ion plated samples in annealing process than that of vacuum deposited ones may be due to the same reasons attributed to the same behaviour observed in the aging or self-annealing activity.

The freshly prepared capacitors always have large internal stresses and during annealing this stress is relieved. This stress relief is probably associated with local structural arrangement. Annealing also causes the removal of adsorbed moisture and absorbed gases. Similar trend of annealing effect has been observed by earlier workers [16-23].

Annealing characteristics of multilayer silicon oxide and aluminium films were studied by Robert et al., [16]. They have suggested that only 5% of reduction in capacitance may be due to the physical expansion of the dielectric film caused by annealing whereas the remaining reduction may be attributed to the decrease in permittivity. In the present study, as the materials chosen are with low melting point the contribution due to physical expansion may be considered as a negligible quantity. Hence the reduction of capacitance may mainly be due to the decrease in permittivity.
5.4.2 Effects of frequency and temperature

Figures 5.17 to 5.20 show the temperature dependence of capacitance in the frequency range (1 to 30 kHz) for the different organic film capacitors, represented in logarithmic plots. As the temperature increases, the change in the capacitance is more rapid at lower frequencies. The observed trend could be caused by sort of interfacial space charge built up which could be effective at low frequencies [24, 25].

In Figures 5.21 to 5.24, the variation of \( \tan \delta \) with frequency for the various organic films have been shown. The loss value has decreased with increase in frequency at each temperature. When the temperature is increased, the loss also increases. In the Goswami model [5] of a thin film capacitor, the intrinsic resistance of the film material is expressed as dependent on temperature. With increase in temperature, this resistance decreases and leads to the greater loss indicated in experimental results. Similar behaviour has also been observed in various organic dielectrics [26–28]. The TCC values estimated for different film capacitors have been presented in Table 5.2.

5.4.3 High frequency features

High frequency studies of dielectric properties have been independently performed and the experimental results are shown in Figures 5.25 to 5.28. The capacitance is found to remain constant in all the films for the frequency (50 kHz to 10 MHz) range studied. It seems that the frequency dependent interfacial phenomena become ineffective at higher frequencies. The capacitance characteristics hence display a frequency independence in this region, reflecting on the intrinsic details of the dielectric material. The behaviour of \( \tan \delta \) is also similar in all cases and has a tendency to decrease with the increase in frequency.
FIG. 5.17 CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) FOR VACUUM DEPOSITED PERYLENE FILM CAPACITOR AT DIFFERENT TEMPERATURES (t = 1160 Å)
FIG. 5.18  CHANGE OF CAPACITANCE WITH FREQUENCY
(1 kHz TO 30 kHz) FOR ION PLATED PERYLENE
FILM CAPACITOR AT DIFFERENT TEMPERATURES
(\( t = 1000 \AA \) )
FIG. 5-19  CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) FOR VACUUM DEPOSITED p-TERPHENYL FILM CAPACITOR AT DIFFERENT TEMPERATURES (t = 1690 Å)
FIG. 5.20 CHANGE OF CAPACITANCE WITH FREQUENCY (1 kHz TO 30 kHz) FOR ION PLATED p-TERPHENYL FILM CAPACITOR AT DIFFERENT TEMPERATURES (t = 1520 Å)
FIG. 5.21 DEPENDENCE OF $\tan \delta$ ON FREQUENCY (1 kHz TO 30 kHz) FOR VACUUM DEPOSITED PERYLENE FILM CAPACITOR AT DIFFERENT TEMPERATURES ($t = 1160 \text{ Å}$)
FIG. 5.22 DEPENDENCE OF TAN $\delta$ ON FREQUENCY (1 kHz TO 30 kHz) FOR ION PLATED PERYLENE FILM CAPACITOR AT DIFFERENT TEMPERATURES ($t = 1000 \text{ Å}$)
FIG. 5.23 DEPENDENCE OF TAN $\delta$ ON FREQUENCY (1 kHz TO 30 kHz) FOR VACUUM DEPOSITED p-TERPHENYL FILM CAPACITOR AT DIFFERENT TEMPERATURES ($t = 1690$ Å)
FIG. 5.24  DEPENDENCE OF TAN $\delta$ ON FREQUENCY 
(1 kHz TO 30 kHz) FOR ION PLATED $p$-TERPHENYL 
FILM CAPACITOR AT DIFFERENT TEMPERATURES 
($t = 1520$ Å)
FIG. 5.25  CHANGE OF CAPACITANCE AND TAN $\delta$ WITH FREQUENCY (50 kHz TO 10 MHz) FOR VACUUM DEPOSITED PERYLENE FILM CAPACITOR AT ROOM TEMPERATURE (301 K) ($t = 1340$ Å)
FIG. 5.26 CHANGE OF CAPACITANCE AND TAN $\delta$ WITH FREQUENCY (50 kHz TO 10 MHz) FOR ION PLATED PERYLENE FILM CAPACITOR AT ROOM TEMPERATURE (301 K) ($t = 1900 \, \text{Å}$)
FIG. 5.27 CHANGE OF CAPACITANCE AND TAN $\delta$
WITH FREQUENCY (50 kHz TO 10 MHz) FOR
VACUUM DEPOSITED p-TERPHENYL FILM
CAPACITOR AT ROOM TEMPERATURE (301K)
($t = 4100 \text{ Å}$)
FIG. 5.28 CHANGE OF CAPACITANCE AND TAN $\delta$ WITH FREQUENCY (50 kHz TO 10 MHz) FOR ION PLATED p-TERPHENYL FILM CAPACITOR AT ROOM TEMPERATURE (301 K) (t = 1950 Å)
5.4.4 Effect of thickness

Figures 5.29 to 5.32 depict the thickness dependence of the apparent dielectric constant for the different organic films fabricated in the present work. In all the organic films, the dielectric constant shows a steep rise at lower thickness and gradually attains saturation value at higher thickness. The presence of voids and discontinuities may be responsible for the decrease in dielectric constant for the thinner films [29]. When the film becomes sufficiently thick for the voids to disappear, the dielectric constant becomes thickness independent [30]. The thickness independent dielectric constants of various films are presented in Table 5.3. It is clear from Table 5.3, the steady values of the dielectric constant reach at lower thicknesses of ion plated films than those of vacuum evaporated ones, which may be due to the increased density [11] of ion plated films for a given thickness. The observed trend of thickness dependence for dielectric films has been reported by several workers [31-37].
FIG. 5.29  THICKNESS (t) DEPENDENCE OF DIELECTRIC CONSTANT (ε) FOR VACUUM DEPOSITED PERYLENE FILMS
FIG. 5: THICKNESS (t) DEPENDENCE OF DIELECTRIC CONSTANT (ε) FOR ION PLATED PERYLENE FILMS
FIG. 5-31 THICKNESS ($t$) DEPENDENCE OF DIELECTRIC CONSTANT ($\varepsilon$) FOR VACUUM DEPOSITED p-TERPHENYL FILMS
FIG. 5-32 THICKNESS (t) DEPENDENCE OF DIELECTRIC CONSTANT (ε) FOR ION PLATED p-TERPHENYL FILMS
Table 5.3
The thickness independent dielectric constants for different organic films

<table>
<thead>
<tr>
<th>Film material</th>
<th>Method of formation</th>
<th>Thickness independent dielectric constant</th>
<th>Thickness of the film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vacuum deposition</td>
<td>6.60</td>
<td>2100</td>
<td></td>
</tr>
<tr>
<td>Perylene</td>
<td>Ion Plating</td>
<td>6.62</td>
<td>1900</td>
</tr>
<tr>
<td></td>
<td>Vacuum deposition</td>
<td>3.40</td>
<td>2250</td>
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<tr>
<td>p-Terphenyl</td>
<td>Ion plating</td>
<td>3.42</td>
<td>1950</td>
</tr>
</tbody>
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