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Study Of Dielectric Properties Of A Polymer Blend At Microwave Frequency

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Abstract: Polymeric materials have attracted much attention in both academic and industrial research fields. The intensive use of polymer has led to the development of materials for specific applications. We have incorporated PMMA, Poly(methyl methacrylate) in the matrix of PSF(polysulfone), making PSF/PMMA blend and studied the dielectric properties. The measurements were taken at 8.92 GHz frequency and at 35^0 C temperature. Impact of blending have been recorded in all the dielectric parameters of polysulfone . Blending has also resulted in appreciable change in the values of optical constants that were evaluated on the basis of experimental data .

Keywords: Polysulfone; Poly(methyl methacrylate); Dielectric ; Optical constant; Blends ;

INTRODUCTION

Polymer and polymer blends , the wonder materials are becoming an essential part of today's materials due to the advantages such as low weight, corrosion resistance, high fatigue strength and faster assembly. Blends offer the possibility of combining the unique properties of available materials and thus of producing materials with tailor made properties, which often has advantages over the development of completely new polymeric materials. These are extensively used as materials in making aircraft structures, electronic packaging to medical equipment and space vehicle to home building. There is much interest in the development of inexpensive new polymer materials with an appropriate weight, appropriate electric conductivity and/or appropriate impact value for use in various applications.

The importance of polymers is mainly because polymers are still regarded as a cheap alternative material that is manufactured easily. Ceramic materials are typically brittle, possess low dielectric strength and in many cases are difficult to be processed requiring high temperature. On the other hand, polymers are flexible, can be easily processed at low temperatures and exhibit high dielectric break down fields.

As the central processing units (CPU) of personal computers become faster, in the near future, they are projected to reach a few tens of gigahertz (GHz). In wireless telecommunication systems, microwaves in the range of GHz have extensively been used. The electromagnetic interference (EMI) of unwanted waves, which cause malfunctions in electronic equipment, has been of concern up to the frequency range of GHz. When electrical components are miniaturized, the need for well characterized dielectric measurements on thin materials become important.

Dielectric spectroscopic studies are very useful to understand the concept of intermolecular solute–solute interaction and solute–solvent interactions along with their molecular conformations. Nowadays polymers are gaining wider use as dielectric materials. Because of the easier processing, flexibility, able to tailor made for specific uses and better resistance to chemical attack.The polymers can be fabricated fairly easily into thin film by solution casting and spin coating, immersion in organic substrate, electron or UV radiation and glow discharge methods. It is mainly due to lower thermal properties such as glass transition and melting temperature which contribute to a lower temperature processing windows. Both dielectrics with low and high dielectric constant are essential in electronic industries.

Low dielectric constant is required basically as insulators. They are known as passivation materials. Their applications ranged in isolating signal-carrying conductors from each other, fast signal propagation, interlayer dielectric to reduce the resistance-capacitance (RC) time delays, crosstalk and power dissipation in the high density and high speed integration.

They are of necessity in very dense multi-layered IC's, wherein coupling between very close metal lines need to be suppressed to prevent degradation in device performance. This role involve packaging and encapsulation. In electronic packaging, they separate interlayers and provide isolated pathways for electronic devices connection in multilayer printed circuit boards. As the trends are towards miniaturization in microprocessor fabrication, any decrease in relative permittivity will reduces the deleterious effect of stray and coupling capacitances.

For assesing the dielectric behaviour of the material it become significant to find its dielectric constant $\in_r$ and dissipation factor (*tan* δ). A significant body of data has been reported for how these parameters vary in polymers and polymer blends in the megahertz range. Relatively little data currently exists for polymers' and blends' dielectric behaviour at frequencies above 1 GHz.

For the present study, blend of PSF and PMMA has been prepared and investigations in the form of thin film has been taken at at 8.92 GHz frequency and at 35^0 C temperature. With the help of experimental data we evaluated various dielectric parameters.

EXPERIMENTAL

Polysulfone (PSF) is a polymer thermoplastic material having high thermal stability and good mechanical strength. It is tough, rigid, high strength, and transparent, retaining its properties between -100^0C and $+150^0$C. The density of PSF is 1.24 g/cm^3. Its glass transition temperature is about 185^0C . PSF is used in electrical and electronic applications, medical components requiring repeated sterilisation, microwave cookware and under bonnet and aerospace components.

Poly (methyl methacrylate), PMMA, is a transparent, polar, strong, amorphous polymer. It has been widely employed in industrial and domestic applications. Owing to its transparency, it is often used in applications that require good optical properties e.g. in ventilators, windows of aeroplane, lenses for automobile lighting, transparent dome etc. It is also used in optical fibres, biological specimen preservation, dentures, contact lens etc. The density of PMMA is 1.2 g/cm^3. Its glass transition temperature (T_g) is about 100 °C

Polysulphone (PSF) supplied by Gharda Chemicals Ltd. Bharuch, Gujarat (India) and poly (methyl methacrylate) or (PMMA) supplied by HiMedia Laboratories Pvt. Ltd., Mumbai (India) were used for this study. Thin films of PMMA and PSF were prepared by solution cast method. For preparing blend of polysulfone and PMMA, the granules of PMMA and PSF were dissolved in common solvent i.e. dichloromethane, and stirred thoroughly for a few hours to ensure mixing. The mixed solution was used to prepare blend membrane by solution cast method. Blend of PSF/PMMA in the ratio 40:60 was prepared.

The conventional transmission line and cavity resonance methods of dielectric measurements are difficult to use for thin samples because in that case the radio frequency (rf) signal has a weak interaction with the specimen. For microwave measurements of dielectric parameters of thin films, we have used the technique developed by Dube. Dielectric measurements have been made at microwave frequencies by mounting a thin film of the specimen longitudinally at the centre of a rectangular waveguide. The advantage of this method is that it does not impose any restrictions on the length of the sample.

RESULTS AND DISCUSSION

The dielectric behavior of a material is usually described in terms of the dielectric function, $\in^* = \in_r + \in_i$, where, $\in_r$ is the dielectric constant and $\in_l$ is the dielectric loss. Dielectric measurements, such as the dielectric constant and the dielectric loss, reveal significant information about the chemical and the physical states of polymers. These properties are drastically affected by the presence of another polymer or a dopant in the polymer.

The dielectric constant is a measure of ability of the material to be polarized or energy stored, while the loss factor is a measure of the ability of the material to heat or energy loss by absorbing energy . In the present work the relative dielectric permittivity and dielectric loss have been measured at microwave frequency 8.92 GHz. From the experimental data obtained during measurements we evaluated the dielectric parameters. In table 1, dielectric constant ($\in_r$), dielectric loss ($\in_i$), loss tangent (tanδ) and relaxation time(τ) have been reported for PMMA and PSF and their blends at 8.92 GHz frequency and at 35^0 C temperature for 100 μm thick films.

In table 2, a.c. conductivity (σ), absorption index (K) and refractive index (n) have been reported for PSF/PMMA blend 40:60, of thickness 100 μm at 8.92 GHz frequency and at 35^0 C temperature.

Table 1 : *Microwave Dielectric parameters and relaxation time for PSF/PMMA blends .*

Composition of PSF/PMMA Blend	Dielectric Constant $\in_r$	Dielectric Loss $\in_i$	Loss Tangent *tan* δ	Relaxation Time $\tau \times 10^{13}$Sec.
100%+0%	2.99	0.213	7.11×10^{-2}	12.7
40%+60%	2.66	0.238	8.90×10^{-2}	15.9
0%+100%	2.52	0.057	2.25×10^{-2}	4.0

Table 2 : *A.C. Conductivity, absorption index and refractive index for PSF/PMMA blends* .

Composition of PSF/PMMA Blend	Conductivity σ (mho/m)	Absorption Index *K*	Refractive Index *n*
100%+0%	10.5×10^{-2}	3.55×10^{-2}	1.73
40%+60%	11.81×10^{-2}	4.45×10^{-2}	1.64
0%+100%	2.8×10^{-3}	1.13×10^{-2}	1.58

Dielectric constant and dielectric loss

The polarization mechanism operating in the gigahertz frequency is purely electronic or orientational with relaxation times smaller than the time period of the applied signals. Interfacial polarization, which is the basic reason for the dispersion in dielectric permittivity at radio frequency regime, has no role to play in microwave frequencies as it does not produce dispersion in εr because of its much smaller relaxation time.

Dielectric constant ($\in_r$), for PMMA at 8.92 GHz and at 35^0 C temperature has been obtained as 2.52 and loss tangent (tanδ) has been obtained as 2.25×10^{-2} for film thickness 100μm, respectively. These results are in agreement with the values of dielectric constant and loss tangent reported by Riddle and Baker–Jarvis.

Dielectric constant ($\in_r$), for polysulfone at 8.92 GHz and at 35^0 C temperature has been obtained as 2.99 and loss tangent (tanδ) has been obtained as 7.11×10^{-2} for 100μm thick films. These results are in agreement with the values of dielectric constant and loss tangent reported by Riddle and Baker–Jarvis.

As we see from table1, for the PSF/PMMA blend of 40:60 composition, reduced value of dielectric constant $\in_r$ than pure polysulfone is obtained. To our knowledge dielectric constant values of PSF/PMMA blend for this composition at microwave frequencies is not reported in literature.

Within polymers holes or voids are present that is termed as free volume.The results show a decrease in the value of dielectric constant in the studied . This may have resulted due to the enhanced free volume. It seems that more voids have been created at the phase boundaries, enhancing free volume. Increased free volume lowers polarization by decreasing the number of polarization groups per unit volume. Such correlation of high free volume and low dielectric constant has been previously reported for polyimides. Blending may have resulted in increased free volume.

Loss tangent for PSF/PMMA blend of 40:60 has been obtained as 8.90×10^{-2}. The origins of microwave dielectric loss in polymers are attributed to dipolar absorption dispersions in both crystalline and amorphous polymers, dipolar losses due to impurities and photon-phonon absorption spectra corresponding to the density of states in amorphous regions of polymer.

Relaxation time and a.c. conductivity

Relaxation processes of a homo-polymer can be greatly modified by blending with another polymer component. From practical viewpoints, it is important to understand and control these relaxation processes because the mechanical, as well as the electrical properties of multi-component polymers are greatly affected by the mixing process.

The relaxation time is calculated by using the relation, $\tau = \varepsilon_i / \omega\varepsilon_r$. For PMMA relaxation time has been obtained in the order of 10^{-13}s. The value is in agreement with the τ values obtained by Khare *et al* and for PSF films the order remains same. Relaxation time for PSF/PMMA blend also come out to be of the order of 10^{-13}s.

However, it comes out to be a bit higher in magnitude in the blend as compared to that of pure PSF. The increased τ value in blend may be due to the intermolecular interactions between PSF and PMMA molecules.
The a.c. conductivity is obtained by using the relation, $\sigma_{ac} = \omega\varepsilon_0\varepsilon_i$. The conductivity for PMMA is less than that of polysulfone whereas the conductivity of PSF/PMMA blend is obtained as 11.81×10^{-2} for 40:60 composition of PMMA in the blend. Hence we observed the modification in a. c. conducting properties. The observations show that addition of PMMA to PSF increases the conductivity over that of PSF. It may perhaps be due to the modification of trap structure introduced by the addition of PMMA. The PMMA molecules in the blend might be producing additional traps of shallow as well as deeper depths, thus providing conducting pathways for the charge carriers.

Refractive index and Absorption index

Using the relations

$$tan\,\delta = \frac{2\ K}{1 - K^2} \quad \text{and} \quad \in_i = 2n^2K$$

The optical constants *viz.* refracting index (n) and absorption index (K) have been calculated by using the dielectric data. In the PSF/PMMA blend where the thickness is 100 μm, an increase in absorption index value is noted. For blend under investigation 'K' comes out to be 4.45×10^{-2}.
The value of refractive index (n) is found to be 1.64 for PSF/PMMA blend which is lower than that of pure PSF.

CONCLUSION

The properties of a polymer can be modified by making a blend with another polymer. The dielectric properties of polysulfone shows change due to incorporation of poly(methyl methacrylate in the PSF/PMMA blend. The dielectric properties of the polymer-polymer blend can be tailored by modifying the composition within the blend. We consider our findings important since they enable quantitative engineering of dielectric hybrid materials to obtain desirable characteristics. This makes polymer blend films very attractive for various functions in electronic circuits operating at microwave frequencies.

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