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Dielectric and Electromagnetic Interference Shielding Analysis of PVDF-Gr Composites in Radio Frequency Region

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Abstract
The main objective of this work is to develop a conducting composite film for coating of various electronic devices to provide effective electromagnetic interference (EMI) shielding for various applications. Here we present and analyse the dielectric properties of Polyvinylidene fluoride (PVDF) and graphite (Gr) composites in radio frequency ranges (100 KHz-10MHz). The PVDF-Gr composites were prepared by solvent casting method. The PVDF-Gr composite films exhibited high dielectric properties at a certain addition of graphite in radio frequency regions. The main advantage of these composite incorporates their light weight, flexibility and low cost. The EMI shielding properties of the PVDF-Gr composites was evaluated theoretically using ε', tan δ, and σ in the radio frequency region.

Keywords- Electromagnetic Interference, Polymer Composite, Solvent Casting, Radio Frequency.

1. Introduction

In our society the problem of electromagnetic interference (EMI) is increasing day by day with advancement in the technology. The effects of electromagnetic interference can be reduced by making those device electromagnetic compatible (EMC) (Rathi and Panwar, 2018). Electromagnetic compatible means a device works satisfactory without interfering from any other device in a confined frequency space. To make a device electromagnetic compatible is the need of EMI shielding. Electrical conductivity is a basic requirement for an EMI-shielding material. Due to their high electrical conductivity metals are particularly suitable as shielding material, however, drawbacks of using metal as a shielding material are there weight, and also metals are prone to corrosion.

A way to overcome these problems is the formation conducting composite film with the incorporation of small volume fractions of non-metallic electrically conducting fillers such as graphite (Celzard et al., 1997; Celzard et al., 1998; Panwar et al., 2007), graphite oxide (Chen et al., 2003), CNT (Kymakis and Amaratunga, 2006), and Graphene, reduced graphene (Potts et al., 2011; Noh et al., 2015) with non-conducting plastic matrix using mechanical mixing and hot compression moulding, solvent casting, and insitu-polymerization. The

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dielectric constant of conducting polymer composites also increases with the addition of conducting filler. High dielectric constant and dissipation factor of polymer composites are required in high frequency regions for electromagnetic interference (EMI) shielding applications. The graphite (Gr) is a cost-effective material and is used as a conducting filler material for development of conducting polymer composite in this paper.

In our work, the composites were prepared by solvent casting method. This method of fabrication of composite film is simple and less time consuming. The composites consisted of Polyvinylidene fluoride (PVDF) as the insulating polymer matrix and graphite (Gr) as the conducting filler. PVDF is the homopolymer of 1, 1-di-fluoro-ethene. The key benefits of using PVDF are its low weight, mechanical flexibility and corrosion resistance. Graphite powder (Gr) with a thickness of 100–150 nm and a diameter of 1–20µm were used as conducting filler. The advantage of using graphite is its easy availability and cost effectiveness. Due to these specific properties of PVDF and Gr, PVDF–Gr conducting polymer composites can be utilized as material for EMI shielding applications. The dielectric constant, dissipation factor and AC conductivity of these composites were analysed as a function of radio frequencies (100 KHz to 10 MHz) then EMI shielding properties were calculated theoretically.

2. Experimental

A. Materials

The PVDF powder (M_w 440,000 g/mol) was purchased from Sigma Aldrich. Natural graphite flakes with average particle size of 10–20 µm, supplied by Graphite India Ltd. The conductivity of the graphite flakes was 1.33×10^4 s/cm with density 1.75 g/cm^3.

B. Preparation of Composite

The PVDF polymer and Gr filler powders were dry mixed thoroughly for 4 h in a glass beaker with a magnetic stirrer. The speed of magnetic stirrer was kept around 400 rpm with heating. This process coated the conducting graphite powder on the surface of the PVDF particles, and is also referred to as the pre localization of the conductive phase. This mixing improves the homogeneity of the spatial distribution of the conductive particles and their uniform coating thickness on the PVDF particles. The 3wt%, 5wt%, and 10wt% (Three samples) of graphite filled polymer composites were prepared with solvent casting method as shown in Figure 1. The mixed PVDF and Gr powder was dissolved in DMF and mixed thoroughly for 4 h in a glass beaker with a magnetic. After that, the blend solution was cast onto a glass petri dish. It was kept under vacuum at 80^{0}C for 24h and then at 100^{0}C for 12h to remove the solvent. The film membrane was stripped off from the glass petri dish after cooling.

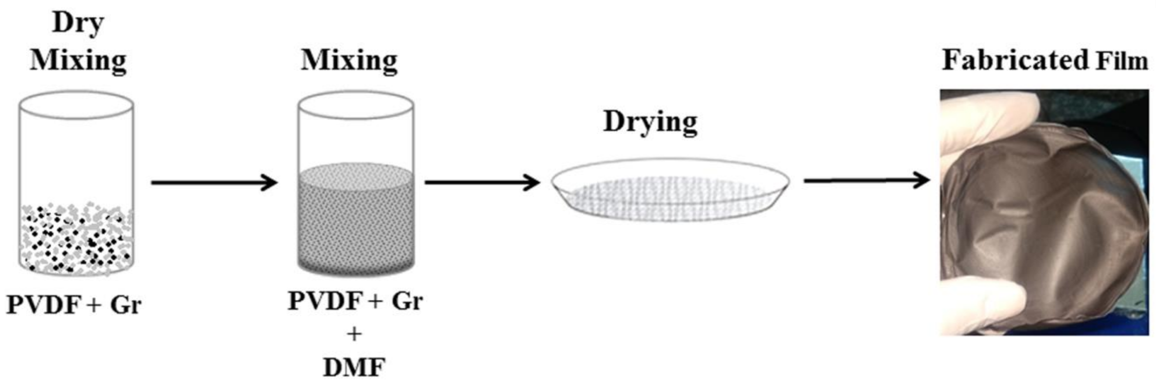

Figure 1. Fabrication process of conducting film

C. Measurement of Dielectric Properties

The dielectric properties (the dielectric constant (ε′) and dissipation factor (tan δ)) of the samples were used to calculate the absorption loss and reflection loss of the composite films. The capacitance (C) and tan δ of the samples were measured in the frequency range of 100KHz–10 MHz, by using an RF Impedance analyzer (Model No. E – 4940 A) with a dielectric material test fixture. The samples were placed in dielectric material test fixture between electrodes and dielectric properties were acquired from RF Impedance analyzer after applying AC signal. The AC conductivity of composites is calculated from the formula $\sigma = \omega \varepsilon_0 \varepsilon' \tan\delta$ where $\omega = 2\pi f$.

D. Calculation of Shielding Effectiveness

Shielding Effectiveness (SE) is the ability of conducting material to attenuate EM wave. The two main mechanism of shielding are reflection and absorption. The third mechanism multiple reflection correction factor comes if absorption is less than 10dB. The calculation of SE consists of simply the addition of the absorption loss, reflection loss, and correction factor (Oussaid, 2009).

$$SE = A+R+C \tag{1}$$

where
A = Absorption Loss
R = Reflection Loss
C = Correction Factor
For the conductive shield with a thickness of t, shielding by absorption can be defined as

$$A = 131\, t \sqrt{f\, \mu\, \sigma} \tag{2}$$

where f is the frequency of operation, μ is magnetic permeability of conductive shield relative to that of free space and σ is the conductivity of shield.

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The reflection term is largely dependent upon the relative mismatch between the incoming wave and the surface impedance of the shield. For the Plane wave the formula for Reflection loss can be defined as

$$R=168-10\log_{10}\left(\frac{f\,\mu}{\sigma}\right) \tag{3}$$

The correction factor represents internal reflections inside a conducting film. As the resultant of multiple-reflection is an increment in transmitted wave, it has a negative influence on overall EMI shielding. Multiple-reflection is negligible when the thickness of a material is much greater than its skin depth. The correction factor can be defined as

$$C=20\log_{10}\left[1-\left(\frac{\eta0-\eta1}{\eta0+\eta1}\right)^2 e^{-2yt}\right] \tag{4}$$

where η0 is the impedance of free space and η1 is the intrinsic impedance of shielding film.

3. Results and Discussion

A. Dielectric Analysis

Dielectric analysis of the PVDF-Gr conducting polymer composites is necessary for the EMI shielding application. To investigate the dielectric behaviour of the PVDF-Gr composites at radio frequencies, the room temperature ε′ and tan δ of the composites were calculated in the frequency range from 100KHz to 10MHz.Fig. 2 (a) shows the ε′ of the composite films as a function of frequency for various contents of Gr. Fig. 2 (b) shows the tan δ of the PVDF-Gr composite films as a function of frequency for various contents of Gr. It was found that the ε′ and tan δ increases with increasing Gr wt%. This is due to the fact that graphite conducting channels were formed between the interfacial region of polymer, which leads to increase dipole moments including the ε′ and tan δ of conducting polymer composite. The σ of PVDF-Gr composites (as shown in Fig. 2 (c)) was also increased with Gr wt% in a similar manner as it depends on the value of the ε′ and tan δ ($\sigma = \omega\, \varepsilon_0\, \varepsilon'\tan\delta$). The PVDF-Gr composite with 10wt% of Gr filled PVDF composite attained highest value of the σ at 10 MHz.

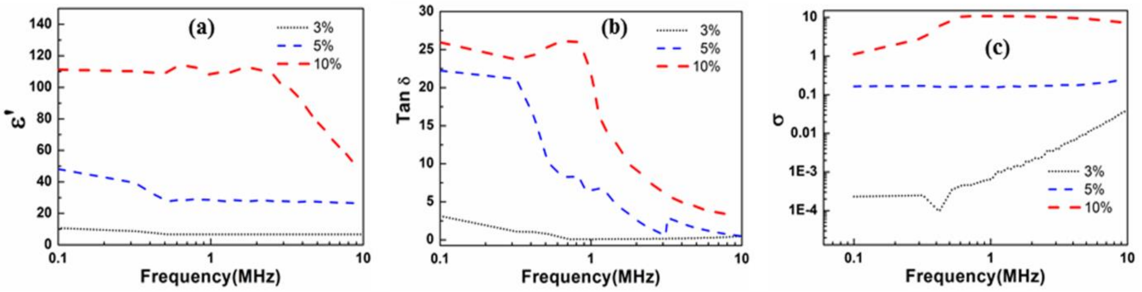

Figure 2. (a), (b), (c) ε′, tan δ, and σ as a function of frequency, for different Gr%

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B. EMI Shielding Analysis

We have already described the method of calculating SE in experimental section of D. The SE depends on the absorption loss, reflection loss, and correction factor, which were calculated using eqs. (1) to (4). Total value of SE of PVDF-Gr is shown in Fig. 3. The value of SE increased with Gr content and decreased with frequency, except the fluctuation in the value of 3wt% of Gr filled composited. The composite having 10 wt% of Gr content depicted highest value of SE. The high value (32 dB) at 100KHz was obtained for 10 wt% of Gr filled PVDF-Gr conducting polymer composite.

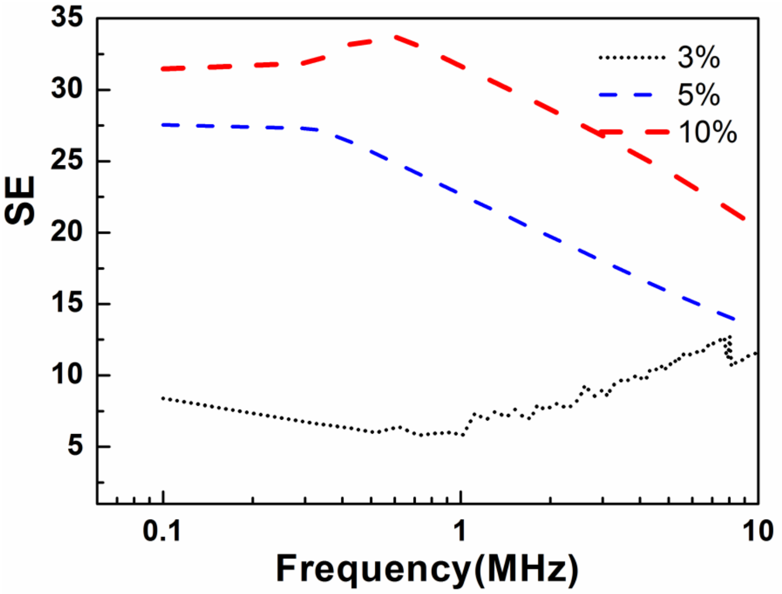

Figure 3. SE as a function of frequency for different Gr wt %

4. Conclusion

In this research, we have developed inexpensive PVDF-Grcomposites using dry mixing and solvent casting method for dielectric and EMI shielding analysis in the radio frequency range. The ε′, tan δ, and σincrease with increasingGr content. The PVDF-Gr composite with 10 wt% of Gr filled PVDF composite attained highest value of the ε′, tan δ and σ. The high value (32 dB) at 100 KHz was obtained for 10 wt% of Gr filled PVDF-Gr conducting polymer composite. However samples of 5 wt% and 10 wt% Gr shows satisfactory EMI shielding result for whole radio frequency region (100KHz– 20MHz).

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