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Shielding Efficacy of Polymeric Nano-Structure

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ABSTRACT

In recent decades, polymers have gained superior eminence owing to range of applications. Their range of applications covers a broad spectrum including energy storage, anticorrosive materials, sensors, electromagnetic electrostatic charge dissipation, electromagnetic interference (EMI) shielding, organic light emitting diodes, photovoltaic, and catalyst supporting material. The EMI shielding and microwave absorption properties of polymers can be elucidated in terms of electrical conductivity and presence of localized charges escorting strong polarization and relaxation effects. Electromagnetic interference shielding fits to the class of intelligent packaging. EMI is an undesirable electromagnetic induction provoked by extensive use of alternating current or voltage inducing signals in nearby electronic circuit. The interference may bring about human health effects. The varieties of details are covered relative to polymer nano-structured nanocomposites.

Keywords: *Polymer; nanocomposite; EMI; shielding.*

INTRODUCTION

Polymers having conjugated structure of alternating single and double bonds possess π-electron system and enhanced oxidized or reduced state and reversible redox activation in a suitable environment. Generally, charge is localized over several repeating units [1-3]. Nowadays, conducting polymers have range of applications in electronic displays, microwave absorption, corrosion protection coating, super capacitors, batteries, sensors, and electrodes [4-6]. They have extended π-conjugation with single- and double-bond alteration along its chain. Such polymers have been characterized due to good corrosion resistance, low cost, controllable conductivity, high temperature resistance, and ease of bulk preparation. These properties render them shielding materials against electromagnetic interference (EMI) [7, 8]. In this regard, polymers with non-redox doping, economic feasibility, and good environmental stability have been employed. The properties can be further tuned by controlled polymerization conditions [9, 10]. Polymers with integral specific strength and fine dispersion in binding matrix may form composites for commercially useful applications. In this re-view, special attention have been given to polymer-based nano-structured materials. The nanocomposites are reviewed covering up-to-date traits of EMI shielding materials.

ELECTROMAGNETIC WAVE SHIELDING

Increasing demand of electronics, and telecommunication systems in scientific, commercial, and military fields has elevated the problem of artificial electromagnetic environmental pollution, therefore causing electromagnetic interference (EMI). These electromagnetic radiations may perturb the operation of electrical devices through interference degrading the performance of house hold and other electrical devices. These radiations generate several health threats. To remedying these problems, numerous research efforts have been carried out during previous decades [11-15]. A variety of materials has been proposed for EMI shielding or absorbing electromagnetic waves. Metals such as steal, copper and aluminium have shown effectiveness for shielding these waves. Metals generally have very high shielding efficiency of about 40-100 dB. Shielding materials generally attenuate waves through reflection, absorption, and multiple internal reflections (Fig. 1). The remaining waves may transmit for further interference. Among these mechanisms, reflection and absorption block the most of interfering waves. Furthermore, the absorption has better practical applicability as compared to reflection.

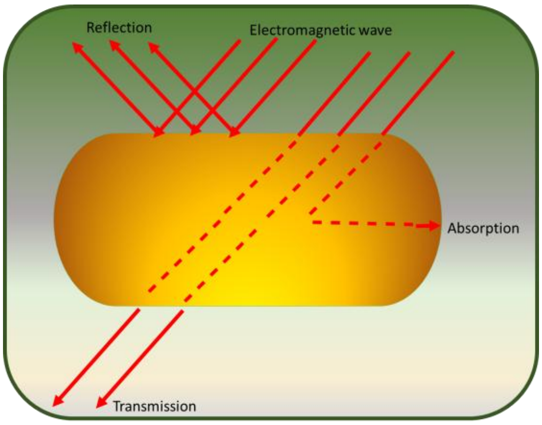

Figure1. *Electromagnetic phenomenon*

Shielding In Polymer

The metallic materials usually have processability problems due to heavy weight and corrosion ability. To overcome these obstructions of conventional shielding materials, lots of attention has been paid to alternative novel shielding or absorbing materials. In recent years, different polymeric materials have been used due to light weight, corrosion protection, processability, low cost, and easy synthesis [16-18]. One problem associated with insulating polymeric materials is that they accumulate static charge which may cause explosion due to sparking. One appropriate solution to overcome problems of metallic shielding materials and insulating polymers is to make these polymeric materials conducting. The conducting polymeric materials have shown superior shielding properties than metals as they can absorb EMI waves along with reflection. Likewise, the problem of accumulation of static charge can be solved by grounding the conducting surface by increasing the skin depth through controlled conductivity of these materials [19, 20]. Moreover, these polymeric materials can be doped using metal fibers, metal powders, carbon fibers, carbon black, carbon nanotube, graphene, or other carbon nanostructure (Fig. 2).

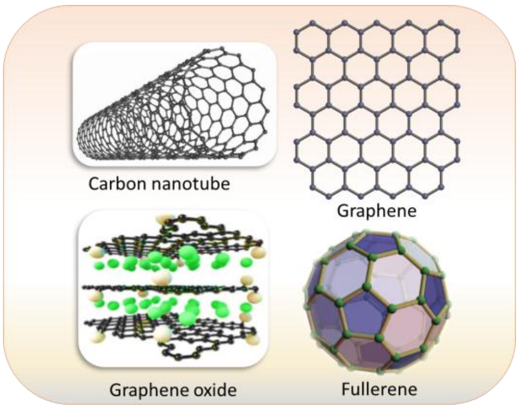

Figure2. *Nanostructure*

The absorption of EMI waves can be further enhanced using these polymeric nano-materials. Recently, use of intrinsically conducting polymers like polyaniline, polypyrrole, and poly-*p*-phenylene-benzobisthiazole (PBT) etc. with nanofiller have been reported with improved performance over conventional polymers [21]. The main characteristics of the conducting polymers are conjugated structure of alternating single and double bonds, the nature of π-electron system, enhancement in oxidized or in reduced state and reversible redox activation. The fundamental and central process of doping depends upon geometric parameters such as bond length and bond angle. Conducting polymers, due to excellent electric characteristics and ease of processability, have been found suitable for microelectronic device fabrication. Conducting polymers have, thus, engrossed much attention due to their ease of preparation, high electrical conductivity, good environmental stability and wide variety of applications.

Nanostructure for Shielding

Polymer/nanostructure nanocomposite have been prepared using different techniques on lab scale (Fig. 3). In polymer/nanostructure nanocomposite, multiple-reflection have been considered between the external surfaces of nanostructure such as CNT. A multi-layer shield is commonly used when a high EMI shielding is required. The intrinsic impedance of the carbon sheets and polymer layer are 0.8Ω and 240Ω , respectively. For estimating EMI shielding of polymer/nanostructure nanocomposite, a model has been developed by Kaiser [22].

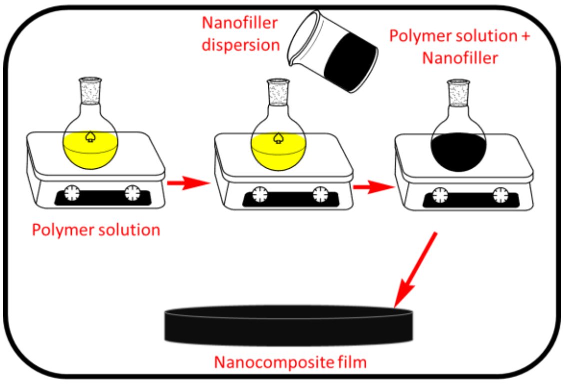

Figure3. *Formation of polymer/nanostructure nano composite.*

The simulation results showed that in X-band frequency range, multiple-reflection between the carbon sheets has negative value, and absolute value of multiple-reflection can be decreased by increasing the thickness of the polymer layer between the carbon sheets. According to the theoretical calculations, decrease in overall EMI SE due to multiple-reflection between the carbon sheets is much smaller to that of between the internal surface of carbon sheet because of the extremely small thickness of the conductive sheet compared to the skin depth. Despite of multiple-reflection decreasing the overall shielding, modeling results suggested higher EMI shieldig for 20 nm carbon-1000 nm polymer-20 nm carbon laminate. This was because of the increased shielding by reflection from additional surfaces. There is an optimum surface area/diameter ratio and spacing between external surface at which the advantage of higher surface area overcomes the negative influence of the multiple - reflection. In polypropylene/multi-walled carbon nanotube (PP/MWCNT) nanocomposite, electrical resistivity of the material and EMI shielding were found to increase with increase in MWCNT loading. The increase in EMI SE can be ascribed to decrease in the electrical resistivity of nanocomposites and the increase in absorption filler volume fraction. EMI shielding was also seemed to increase with increase in PP/MWCNT plate thickness. For samples containing ≥ 5 vol.% MWCNT, the increase in EMI shilding was mainly due to the increase in shielding by absorption [23, 24].

MICROWAVE SHIELDING USING NANO STRUCTURE REINFORCEMENT IN POLYMER

Electrically conducting polymer nanocomposite such as polyaniline/carbon nanotube and poly pyrrole/carbon nanotube have received significant attention for the replacement of metals and inorganic materials for sensors, supercapacitors, actuators, and electromagnetic interference shields due to light weight, corrosion resistance, low cost, and ease of processing. The overall contribution of absorption and reflection of polymer/MWCNT composites towards shielding has been studied [25]. The available characterization tools are incapable of separately evaluating the multiple-reflection effect of polymeric nanocomposite.

The EMI shielding characterization set-up used directly measures the transmitted power (T) and reflected power (R). The absorbed power (A) can be calculated i.e. A = I –(T + R). The measured reflected power R is not only the power that has been reflected from the external surface, but also includes the positive contribution of internal surface reflection and negative contribution of multiple-reflection. For an EM radiation of a specific power, EMI shielding is usually the logarithm of ratio of transmitted power, when there is no shield to the transmitted power when there is a shield (T). Transmitted power, when there is no shield, is equal to the incident power (I). Using the power balance data, the overall shielding is a sum of net shielding by absorption (SE_A) and net shielding by reflection (SE_R). Equations below are mathematical interpretation or clarificationn for shielding effect:

$$\text{Overall SE} = SE_R + SE_A = 10 \log I/I\text{-}R + 10 \log I\text{-}R/T = 10 \log I/T \quad (1)$$

$$SE_R = 10 \log I/I\text{-}R \quad (2)$$

$$SE_A = 10 \log I\text{-}R/T \quad (3)$$

The MWCNT and other nanofiller loading and shielding plate thickness have found to increase the net shielding by reflection i.e. lower than that by absorption. PP/MWCNT nanocomposite with EMI SE above 10 dB can shield by absorption of 62–84% [26]. EMI shielding by absorption increases with increase in shielding plate thickness because of the increase in MWCNT content. However, for multi-phase systems, relation between shielding by reflection and the thickness of the shield is found to be somewhat complicated. For 1 mm and 2.8 mm thick plate, the contribution of shielding by absorption increased with the increase in MWCNT content. EMI shielding effectiveness is usually defined as the attenuation of the propagating electromagnetic (EM) waves produced by the shielding material. Shielding effectiveness measurements are ususally carried out in the frequency range of 8.2–12.4 GHz keeping the input power level at -5dBm. For a certain type of transverse electromagnetic wave propagating inside the shield material with having negligible magnetic interaction, the total shielding efficiency (SE_T) of the shield material can be expressed as:

$$SE_T = 10 \log_{10} P_I/P_T = 20 \log_{10} E_I/E_T = 20 \log_{10} H_I/H_T \quad (4)$$

The rapid enhancement or develpoment from – 0.2 to – 32 .3 dB with the increased MWCNT loading may be explained in terms of increase in conductivity as well as capacitive coupling effects [27-29].

Accordingly, polypropylene/carbon fiber (PP/CF) composites containing various CF contents (0–10 vol.%) were injection-molded. The percolation threshold of composite was lowered from 8.5 to 7 vol. % with CF loading.

The morphology of the samples was analyzed scanning electron microscopy (SEM). The microstructure was also affected by the presence of dissolved gas in the composite melt and viscosity of the melt was decreased by the addition of gas. It was noted that with 7.5 and 8.75 CF vol.%, the conductivity of the skin region of the composites were higher than those of the corresponding solid cores. The range of anisotropy was decreased from $8.7\times10^7$to 7.3×10^2 to 9.7×10^3 to 2×10^1 in the composites. At higher frequencies, the permittivity was slowly increased by the increase of the CF content and ranged between 2.3 and 33.8 at 0.1 MHz.

Overall, the permittivity of the composites was higher than that of corresponding solid counterparts. EMI shielding had greater values at higher nanofiller contents [30-32]. Saini et. al. [33] designed nanocomposite of polystyrene with polyaniline coated multi-walled carbon which inherit dielectric and magnetic attributes or features from PANI and MWCNT respectively. The nano composite showed absorption dominated total shielding effectiveness of −45.7 dB (>99.99% attenuation) in 12.4-18.0 GHz range suggesting utility for making efficient microwave absorbers. The surface morphology was observed using SEM, whereas bulk morphological details were gathered from high-resolution transmission electron microscope (HR-TEM). The percolation threshold was only 0.5 wt.%, which was significantly lower than the value for pure polyaniline (~2.0 wt.%). As the PANI–MWCNT concentration in the material increased, the SE_T was increased from -10.9 to -24.1 dB due to increase in both SE_R and SE_A. Among polymers, such as polymethyl methacrylate (PMMA), p-phenylenevinylene (PPV), polypyrrole (PPy) and polyaniline (PANI), polyaniline was found most promising for EMI shielding due to ease of polymerization and good supercapacitive characteristics [34-40]. The supercapacitive characteristics of PANI/CNT composite have been reported as specific capacitance of 312 F g^{-1} with 92 wt.% PANI [35]. The 400 F g^{-1} was achieved for 80 wt.% PANI coated on MWCNT. The study of the microstructures and the specific capacitances of PANI/SWCNT composites were reported. The specific capacitance was found to depend on the microstructure of the nanocomposites [41-45]. Doping of nanostructure with polymer usually raises the conductivity considerably, but may be detrimental to the mechanical properties. In attempts to the mechanical properties, blends of PANI with other polymers such as poly(p-phenylene tercphthalamide) and poly-ω-aminoundecanole have been produced [46, 47]. There is need to introduce the reinforcing fillers that enhances mechanical properties of polymer while keeping a positive impact on the overall electronic and EMI shielding properties. In this regard, the use of carbon nanotube, graphene, and other conductive reinforcement has been investigated (Fig. 4).

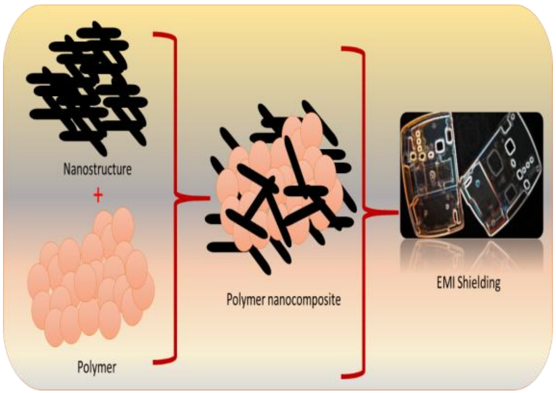

Figure4. *Texuring of polymer nanocomposite for electromagnetic shielding.*

CONCLUSION

In this article, insulating as well as intrinsic conducting polymers have been discussed with special focus on nano-structured filler reinforcement. This review includes the advantages of polymer / nanostructure nano composite over metals and conventional polymeric materials for EMI shielding. Details are also provided on EMI shielding mechanism with various dimensions. Further the polymer / carbon nanofiller nanocomposite have been discussed covering the aspects of latest research in this area.

Additionally, polymer / nanostructure nano composite have been taken into detailed consideration with reference to EMI shielding mechanism.

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