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Natural fiber reinforced conductive polymer composites as functional materials: A review

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ABSTRACT

Recent progress in the field of intrinsically conductive polymers (ICPs) as well as conductive polymer composites (CPCs) filled with natural fibers is reviewed here systematically. The possibilities of utilizing natural fibers as fillers for ICPs as well as CPCs to form natural fibers-conducting polymer composite materials have wide potentials in the modern industries. The unique characteristics such as electrical conductivity, mechanical strength, biodegradability and recyclability enabled them to be implemented in many novel and exciting applications including antennas, chemical sensors, tissue engineering, neural probes, biosensors, drug delivery, bio-actuators, fuel cells etc. The effects of fiber contents, fiber size, chemical treatment, temperature and moisture content on the dielectric properties of the conductive composites were reviewed. On the other hand, it was reported that relatively short natural fibers could modify the dielectric response of the polymeric matrix, but chemical treatment had negative effects on such composites and could decrease the dielectric loss factor.

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1. Introduction

Materials' tendency to conduct electricity is generally expressed by the term of surface resistivity i.e. how they demonstrate resistance to transferring electrical charges. Polymers

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also show such tendency but the surface resistivity of thermoplastic polymers shows poor conductivity. Therefore, thermoplastic polymers are widely used as insulating wire coatings for several applications [1,2]. However, such poor conductivity can lead to undesirable consequences particularly, building -up and retaining static electrical charges, which may cause a startling shock or electrical spark. Therefore, plastics with anti-static characteristics are highly recommended for many end-use applications, while higher conductivity of plastics is desired for other applications [3–8]. In consequence, material selection process is of paramount importance to achieve successful low-cost engineering design that can fit functional requirements as well as customer satisfaction attributes for various industrial applications. This is usually carried out considering various conflicting criteria and utilizing decision making tools to to reveal the potential of new materials in expanding the possibilities of new modern sustainable applications [2,9–12]. In current technology advancement, new components require low cost-high performance materials capable of withstanding aggressive environments. Recently, the intrinsically conductive polymers (ICPs) (in which the polymer's electronic structure is responsible for their conductivity), as well as conductive polymer composites (CPCs) (in which the addition of conductive fillers provides the conductivity) have special interest in industrial applications particularly, in organic electronic devices where ICPs have strongly contributed to the development of smart materials. CPCs are easily processed and considered to be more economic in compared to ICPs [3,13]. Such unique combination of properties (e.g. dielectric and mechanical strength) is hard to be obtained in one single material. Here, the significant value of conductive polymer composites arises in combining the electrical properties of conducting polymer with the mechanical strength of the filler and the ease of fabrication of the matrix. Such plastics that can conduct electrical charges are desired for other potential applications where the conductivity of metal is not required. Conducting polymers filled with different types of metals make composites suitable for switching devices, electromagnetic shielding of electronic equipment, static charge dissipating materials, conducting adhesives in electronics packaging, cold solders, devices for surge protection and under fill for flip chip [14–17]. Conducting polymer composites have wider technological applications such as in direction finding antennas, self-regulating heaters, chemical detecting sensors, photo thermal optical recording, tissue engineering, neural probes, biosensors, drug delivery, bio-actuators, electronic noses, chemical and electrochemical catalysts, and fuel cells [14–27].

The mechanical and/or electrical characteristics of nonconductive materials such as polymers and composites can be modified through excedentary electric charges [28,29]. The responses of insulating materials that have dielectric properties recall the space charge physics. This new multi-physics approach is based upon the fact that when stresses of any type (electric, mechanical, radiative etc.) are applied to an insulating material they cause an injection of electric charges [30,31]. Consequently, materials with intermediate disorder can store considerable polarization energy (about 5 eV or more per trapped charges) [32–34]. Therefore, an external stress will have the ability to permit detrapping of those trapped charges causing a release of the stored polarization energy, which expresses the occurrence of dielectric breakdown, rupture or wear as catastrophic effects. It is noteworthy here that energy balances should take into account for such trapped charge as it is one of the potential energy sources. Eventually, insulating material's behavior is related to its aptitude to trap electric charges, in other words, the behavior is related to the density and energy of traps that the material have on one hand, and to its capability to diffuse such electric charges without damage on the other.

Amongst different theories and mechanisms set by different scientists to explain their electronic conduction the common ones are band model, hopping and percolation mechanism [35,36]. The band model is one of the most extensively used models as it provides the basis to understand whether a particular material is conductor, semiconductor or insulator. According to molecular orbital theory, two new orbitals of high (antibonding) and low (bonding) energy are produced through overlapping of two compatible atomic orbitals when they are brought closer to each other. In real structural phenomenon there is usually a gap between the top of the occupied valence band and the unoccupied conduction band, termed as band gap. It is assumed to be essential to produce a net electron drift from valence band to conduction band to observe conduction in such material. If the band gap is of reasonable size ($\geq$1.5 eV) no electron will move from valence band to conduction band hence, no conduction will occur, and such materials will be termed as insulator. If this gap is of moderate size ($\leq$1.5 eV) the movement of electrons will occur from valence to conduction band leaving a hole in the valence band, and the materials are called semi-conductors. Within this region, some materials with a very small band gap in which some electrons always get excited to conduction band by thermal means. They are called intrinsic semiconductors. The energy band diagram in polymeric materials is shown in Fig. 1. The third possible way is

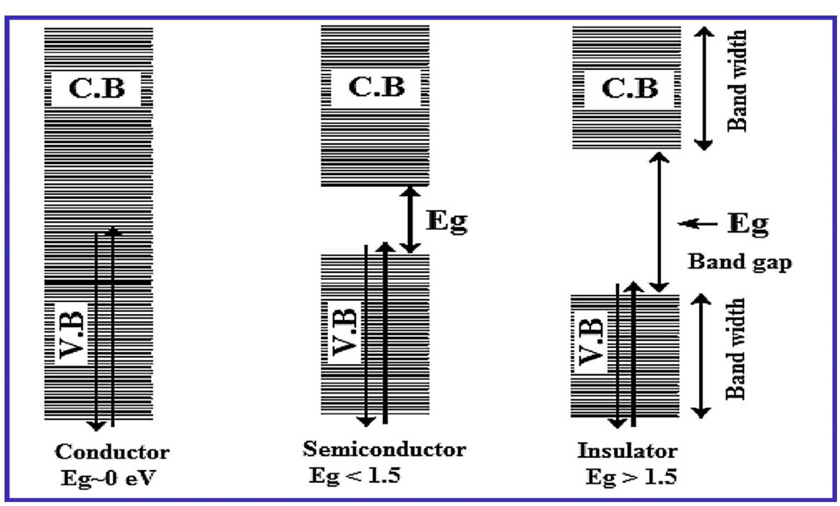

Fig. 1. Energy band diagram in polymeric materials.