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Research Article

Study of Polymer Matrix Composites for Electronics Applications

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Polymer matrix composites (PMCs) may be found in nearly every facet of modern society, from electronic components to a broad range of accessories. Polymer matrix composites contain materials that include a matrix polymer. It is also made up of multiple continuous and short fibres that are held together in the organic polymer matrix. In this article, the development, properties, and production of polymer matrix composites along with electronics applications were discussed. The matrices in recent developments of polymer matrix composites have been made of thermosets or thermoplastic materials. The properties of a PMC such as a matrix and reinforcement offer great strength and rigidity, and it is largely employed to increase fracture toughness. The process of manufacturing composites has a significant impact on the product design and outcome. The ability to make a product from a variety of manufacturing techniques is unique to the composites industry. Polymer-based materials were employed in a variety of applications, including the automobile industry, aircraft industry, marine, sports good equipment, electronics applications, and biomedical applications. The great potential of filler reinforced polymer composites used for microelectronic applications. Woven glass fibre cloths and reinforcing materials such as paper, glass fibre matte, and fillers are used to fabricate printed circuit boards. Thermoplastics and thermosets are used in electronic packaging material which increases efficiency and offers more stringent requirements. Polymer composites have good thermal conductivity and desirable dielectric properties which improves microelectronic performances. Nanocomposites are composites in which nanofillers were distributed inside a polymer. The compatibility and interface between the filler and matrix play a significant effect in modifying overall characteristics in polymer nanocomposites.

1. Introduction

Traditionally, composite materials have been produced to use as structural materials. Composite materials were gaining more electronic applications as the electronic industry grows [1]. The majority of engineering disciplines will be engrossed by digitalization, which will have a greater effect on broad wireless communication with high-speed data transfer [2–4]. Due to the huge differences in property requirements between the two classes of composites, their design criteria for electronic and structural composites were distinct. The structural composites focus heavily on modularity as well as good strength. Low thermal expansion, low electrical conductivity, high thermal conductivity, and low dielectric constant are all important features of electronic composites. Electronic composites focus on processability for small parts, which includes coating and stand-alone films, whereas structural composites concentrate on processability for big parts, such as panels. Furthermore, in order for the composites to work optimally, the matrix material must be reinforced by micro- and nanoparticles known as fillers [5]. Filler is a substance that is applied with materials to enhance processing characteristics, adjust product qualities, and lower the cost of the compound [6]. Filler seems to be an additional substance that is used to cover a cavity as well as add bulk. Those fillers were utilized to enhance the mechanical and tribological capabilities as well as the thermal and dielectric properties [7]. Epoxy-based polymers provide engineering materials with a wide range of industrial applications due to their exceptional mechanical characteristics, high adhesive strength, and minimal creep; nevertheless, they are brittle. As a result, different percentages of nanofillers have been employed for inclusions. Several basic and experimental types of research mostly in the field of polymer nanocomposites have been conducted over the last few years. Composites reinforced with nano- and microparticles were growing rapidly in the material industry due to their improved mechanical characteristics and reduced weight as compared to traditional materials like stainless steel and aluminum. This article is structured that the development of polymer matrix composites is described in Section 2. The properties of polymer matrix composites are discussed in Section 3. The production of polymer matrix composites is illustrated in Section 4. Electronics applications of polymer matrix composites are discussed in Section 5. Finally, there are some concluding comments in Section 6.

2. Development of Polymer Matrix Composites

Composite materials have been the only material that meets the demands of the industry. Such materials are developed in accordance with the desired qualities. Composites were categorized into polymer matrix, metal matrix, and ceramic matrix composites depending upon matrix materials [8]. All these composites play a significant part in current technology owing to their high mechanical, physical, and thermal characteristics. Polymer composite matrixes have improved mechanical properties and rigidity and are reusable with a high surface-to-volume ratio [9]. The polymer composite material is made from a natural polymer grid that holds together a series of smaller constant filaments. Polymer matrix composites have been designed to transport loads between matrix material and filaments [10]. As illustrated in Figure 1, polymer matrix composites are categorized depending on the types of the matrix material used. Metal matrix composites (MMC) were flexible by nature and offer better flexibility, durability, hardness, and dimensional stability, with aircraft components being the most noteworthy use [11]. A reinforcing substance is dispersed to the metal matrix to form metal matrix composites. To avoid a chemical interaction with the matrix, the reinforcement area might be coated. Ceramic matrix composites (CMCs) are a form of composite material that also happens to be a type of ceramic. They are made up of ceramic fibres that are encased inside a ceramic matrix. Both the fibres and the matrix can be made from ceramic material, including carbon and carbon fibres, which could be considered ceramic material. Ceramic composites increase the material's fracture toughness [12]. Carbon composites reinforced with carbon fibres get good elasticity and therefore can endure temperatures of over 2000° Celsius [13].

The matrix with polymer composite is responsible for bonding the fibres together and distributing loads across them. Elastomers, thermosetting polymers, and thermoplastic polymers are all common polymers utilized in composites. The most common variety used now is thermosetting polymers. Commercial polymer matrix composites will be characterized by their thermoplastic and thermoset matrix phases. Polyesters, bismaleimides, vinylesters, polyamides, and epoxies are examples of thermosetting resins. Epoxies constitute the majority of the present market with advanced composites resins, while thermosetting polyesters were extensively employed in fibre-reinforced plastics.

Thermoses provide great dimensional stability, good solvent resistance, and high-temperature resistance due to their three-dimensional cross-linked structure. Several polyesters, polyamide imide, polyetherimide, polyetheretherketone (PEEK), liquid crystal polymers, and polyphenylene sulphide are examples of thermoplastic resins, popularly known as engineering plastics. Thermoplastics are often more durable and cause physical damage than thermoses, but having them has inferior high-temperature strength and chemical stability. From a manufacturing standpoint, thermoplastics hold enormous potential although it is easier and quicker than heating and cooling the materials. Nature fibres have also been widely adopted as reinforcing materials in the production of polymer matrix composites. The polymer matrix composite is responsible for bonding the fibres together and distributing loads across them. The advanced composites in continuous reinforcing fibres are liable for their stiffness and strength. Graphite, glass, and aramid are the most often used fibres nowadays. Alternative organic fibres like oriented polyethylene, were gaining popularity. Glass has the lowest stiffness in continuous fibres, but its tensile strength was comparable to the other fibres, and its cost is far cheaper. Glass fibres are expected to maintain the most extensively utilized reinforcement for high-volume commercial PMC applications. The region in which loads are transferred between the matrix and reinforcement is known as the interphase of polymer matrix composites. The degree of contact betwixt matrix and reinforcement seems to be an indeed design parameter that can range from strong chemical bonds to weak frictional forces. The best suitable coupling is usually between the strong and weak limits for enhancing the fracture toughness of polymer matrix composites.

3. Properties of Polymer Matrix Composites

The polymer matrix composite's properties are determined by the reinforcement, matrix, and interphase. As a result, there are numerous variables to introduce while creating polymer matrix composites. Several factors include not just matrix and reinforcement types, and moreover, they include

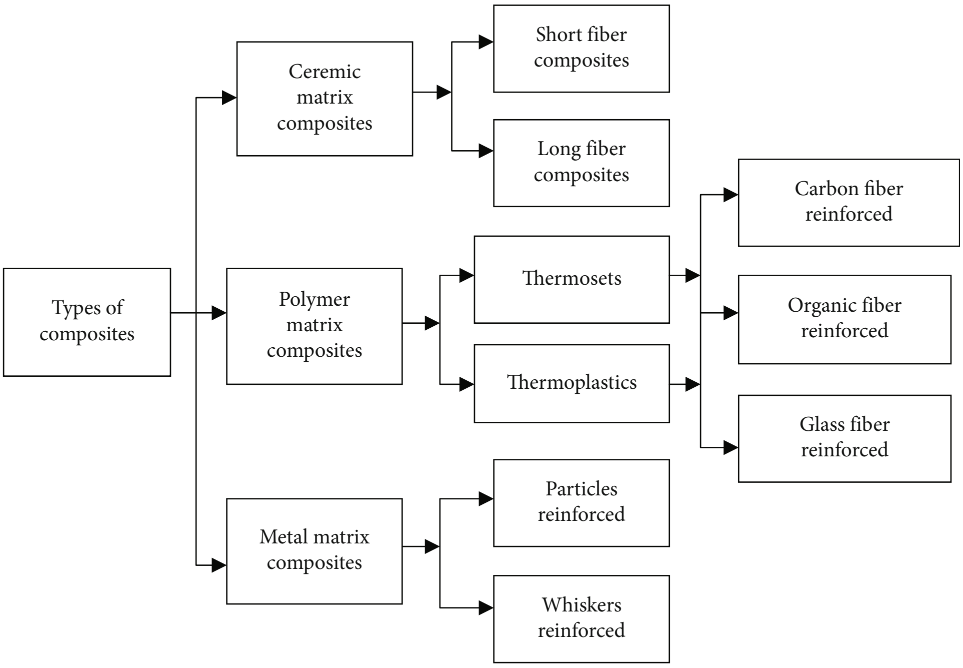

Figure 1: Types of composites materials.

the relative proportions, reinforcement geometry, and the nature of the interphase. Matrix is a continuous phase polymer that is characterized by a weak link for the PMC structure. Reinforcement is a load-bearing component with the discontinuous phase, and it will be of basalt, glass, quartz, and carbon fibre. Load transmission occurs during the transition between the matrix phases and reinforcements. Rather, the type of matrix and reinforcement employed, the relative proportions of the elements, and their properties in a polymer matrix composite are influenced by reinforcement geometry as well as the interphase structure. In addition, continuous-fibre reinforcement gives polymer matrix composite characteristics a directional feature known as isotropy. Polymer matrix composites will be strongest if it is stressed to parallel to the fibres (longitudinal direction and 0° axial), and they will be weakest if it is stressed to perpendicular to the fibres (transverse direction or 90° axial). Because discontinuous fibres or particles are randomly oriented, the characteristics are found to be more isotropic when they are employed for reinforcement. Compression molding, extrusion, and injection molding were developed for unreinforced plastics, which will be used to build them more inexpensively.

Glassy polymers obey Hooke's law in which they respond under applied stress in a linear elastic manner [14]. It has an elastic strain of less than 1%. Although discontinuous particles or fibres are randomly oriented, the characteristics are found to be more isotropic when they are utilized during reinforcement. Polymer matrix composites do not have the same strength as continuous-fibre polymer matrix composites, but they would be made more affordably by employing unreinforced plastics processes including injection molding, compression molding, and extrusion. Due to the complexity of advanced composites, comparing their properties to those of traditional materials will be challenging. Specific strength and stiffness are simple to compare in the properties of polymer matrix composites, but modern composites offer better specific strengths and stiffness properties than metals. Nevertheless, properties which are easily described with metals are often more difficult to specify for advanced composites. Temperature and humidity factors commonly cause the mechanical properties in polymer composites to degrade. Swelling, a dip in matrix glass transition temperature, and interface degradation are all effects of moisture migration into a polymer matrix. Moisture diffusion together into polymer matrix leads to swelling, reduction in the matrix glass transition temperature, and interface weakening. Electromagnetic radiation, particularly ultraviolet radiation, will damage polymer composite in addition to temperature and humidity, even though UV radiation destroys a C-C bond inside the polymer.

4. Production of Polymer Matrix Composites

The process of producing composites seems to have considerable influence on the development and outcome of the product. Using conventional materials, one begins with something like a blank material, such as a rod, ingot, or sheet, and develops that into the required shape. But for the polymer matrix composites, we cannot process the same procedure. The manufacturing methods for these materials consist of operations such as obtaining polymer matrix composite components with reinforcement, cutting fibres, obtaining reinforcement, and blending components by stamping, pressing, extrusion, and injection. Polymers were reinforced by 8 to 12 m diameter fibres woven in cloth as well as other forms in preformed textiles, whether as continuous chopped or single multifilaments. These fibres are injected, extruded, pressed, or stamped in matrix polymer through a liquid form and finally cured to generate the final composite. Figure 2 illustrates a complete

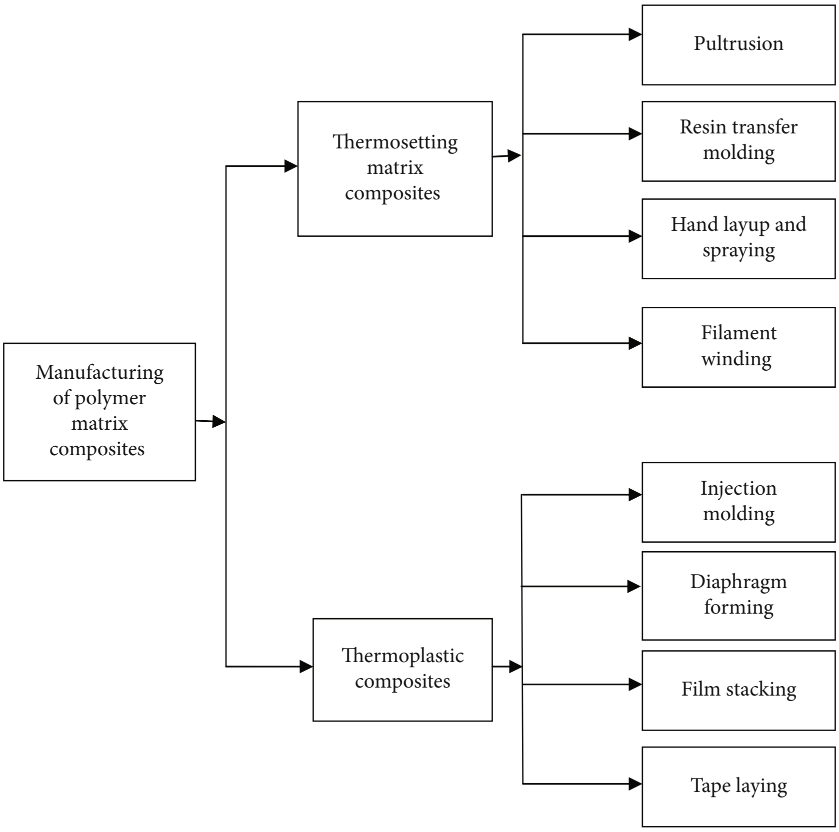

Figure 2: Manufacturing techniques of polymer matrix composites.

categorization of the techniques used to manufacture polymer matrix composites.

Fibre-reinforced plastics generally employ thermosetting polyesters, and the epoxies constitute the majority of the existing market in the advanced composites resins. Thermosets offer strong dimensional stability, good solvent resistance, and high-temperature resistance because of cross-linked three-dimensional structures. The durability and maximum working temperatures for thermosets have improved significantly in recent years. Thermoplastics are made by long and distinct molecules which melt toward viscous liquid under processing temperatures ranging from 500° to 700°F or (260° to 3710°C) and then cool to the semicrystalline, amorphous, and crystalline solid after being formed. Thermoplastics are much more resistant to cracking and cause damage than thermosets but have lower high-temperature strength and chemical stability. From a production standpoint, thermoplastics hold enormous potential since they become faster and easier, and they can heat and cool the materials. Due to this reason, thermoplastic matrixes are desirable to the automobile industry.

Pultrusion is a composite component manufacturing technique that involves pulling layers of fibres soaked in resins with the heated die and generates the required cross-sectional shape without any length restrictions. The pultrusion process is used for high volume productivity, low material scrap rate, and rapid processing. It is used for motor vehicles and spot goods such as ski poles and fishing rods. In the resin transfer molding process, dry reinforcement is preshaped then orientated into the skeleton of a real component called the perform, which is placed in the heated matching die. The curvatures and large complex shapes are made easy in this process, and it is used in a high level of automation. It is used in truck panels, bathroom fixtures, wind turbine blades, and car bodies.

The closed mold process is used in injection molding. Short reinforcing fibres are blended in with the polymers (10-40%). The material used in this process is pushed into a split mold via a feeding system including runners and sprue gate, with the material being pushed there by a feeding screw. The injection molding process will be fully automated, and it is made with high productivity and quality. It is used for electronic products, kitchen products, plastic handles, and water cooler parts. In diaphragm forming, components can be formed with double curvatures and a compliant diaphragm to perform the job for simple components. Between a heating part and a forming section, diaphragm shaping employs sheets with reusable silicon like a carrier of thermopreg fabrics. In this forming, thermopreg fabrics are placed between two silicon sheets. Diaphragm forming is used in the engine covers. The development of these materials will be frequently included in the manufacturing process when fabricating and molding polymer matrix composites into final products.

5. Applications of Polymer Matrix Composites

A polymer is certainly a good material owing to its distinctive qualities which had acquired domination in a wide range of applications. Because of the intrinsic qualities of polymers and their potential for sustainability, there is a certainty that the polymers will be used in many applications. Polymers have increasingly overtaken ceramics and metals in building, aircraft, vehicles, and medicinal uses. As compared to structural ceramics, polymer matrix composites are a better-established technology. Advanced composites currently have an excellent track record in performance and dependability, due to knowledge acquired on military applications such as rocket engine casings and fighter aircraft. In the military and aerospace industries, polymers are becoming the industry's standard structural materials. Polymer matrix composites are used in several applications, including automotive, aerospace, and marine. Polymer matrix composites have been employed in medical devices like MRI scanners, X-ray couches, C scanners, mammography plates, surgical target instruments, prostheses, tables, and wheelchairs. Polymer matrix composites have been used in microelectronics as printed circuit boards, interconnections, encapsulations, substrates, electrical contacts, interlayer dielectric, heat sinks, and connectors.

5.1. Electronic Circuit Board Applications. Printed circuit board (PCB) production attained high about $51 billion in 2009, owing to the increased demand for electronic products. The fast expansion of the PCB industry, on the other hand, motivates it to emphasize circuit innovation instead of the environmental effect of such materials it uses. A new strategy for development with ecofriendly sustainable fill materials is required [15]. Glass fibre cloth-reinforced epoxy composites are the most popular trade PCB materials because they offer a good balance between mechanical and electrical properties.

Woven glass fibre cloths are used to fabricate the printed circuit boards (PCBs). Fillers, glass fibre matte, paper, nonwoven glass fibres, and nonwoven aramid fibres are the most often used reinforcements in PCB materials. The schematic representation of a printed circuit board is shown in Figure 3 [16]. PCB base materials exist in a variety of forms and sizes. All of them have resin systems, conductors, and reinforcements. Among many of the resins utilized are cyanate ester, epoxy, polytetrafluoroethylene, polyester, and polyimide.

Integrated chips were mounted on the printed circuit board, and interconnections were imprinted across the board, typically by screen printing. To improve the interconnection density, a multilayer with thinner conducting layers as well as interlayer dielectrics has been inserted into the substrate prior to the chip getting mounted. Through soldered connections, wires interconnect electrical contact pads with respect to chips [17]. The chip will be protected and enclosed in a dielectric. Regarding protection, the chip may be enclosed in a dielectric. A thermally conductive metal lid might be used to cover it. Thermal interface material is used in the board and substrate which helps to improve performance for thermal contact. An entire assembly can be housed on the thermally conductive enclosure.

5.2. Electronic Packaging Applications. The electronic packaging in electronic systems is required for circuit protection, signal distribution, heat dissipation, power distribution, serviceability, and manufacturability. Electronic packaging uses a variety of materials to meet these needs, including polymers such as thermosets and thermoplastics, ceramics, and metals. Epoxy thermosets have been extensively employed for encapsulating materials in electronics until their discovery around 1927, and it is used for most packages today [18]. Polymer packaging materials, especially thermosets, make up approximately 95% of the total world electronic packaging industry because of adaptability, cheap cost, and ease of automation. Epoxy molding compounds (EMC) seem to be the preferred material for electronic packaging and effective usage on plastic encapsulated microchips (PEM).

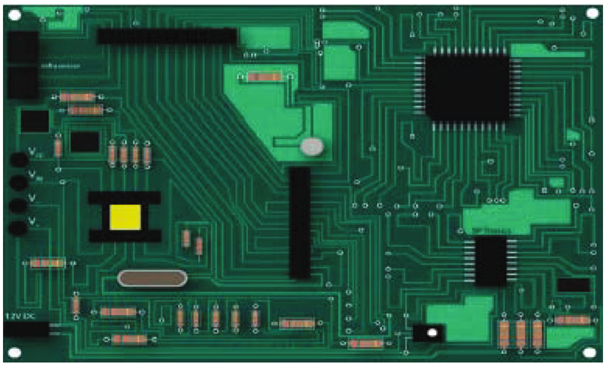

Figure 3: Schematic representation for the printed circuit board.

The thermoplastic usage in electronic packaging material has been mandated by the use of enhanced efficiency of packaging materials as well as the expectation of more stringent requirements over its disposal. Mostly in the 21st century, thermoplastics were considered in packaging because they are less expensive than thermosets, recyclable, reusable, environmentally beneficial, and easy to make in huge volumes. Electronic packaging employs filled polymers as device encapsulation [19]. The electronic equipment failure rate will be raised with temperature. High thermal strains within solder connections are also caused by sudden temperature changes in electronic equipment located in circuit boards, which is among the leading reasons for failure [20]. As a result, thermal management has become more important for the design and operation of electronic equipment.

An improved thermally conductive packing material is necessary when heat dissipation demand increases. Thermally conductive fillers such as alumina, aluminum nitride, and others can ultimately improve the device encapsulation [21]. A HoloMetrix TCA-200-regulated heat flow meter was used to measure thermal conductivity. The ASTM F433 and E1530 standard techniques will be used to evaluate the thermal conductivity that is followed in these tests. Thermal conductivity has been measured at a mean sample temperature of 70°C. Electronic equipment is encapsulated to preserve it from the surroundings, as well as boost its longterm durability.

5.3. Electronic Passive Components. Microelectronic performance can be improved by combining superior thermal conductivity polymer composites having desirable dielectric properties and reduced loss tangent. In recent times, customer demand for high-speed wireless communication has raised due to the growth of broadband wireless transmission systems [22–23]. In densely packed as well as high-speed microelectronic packaging, low-dielectric materials have been commonly utilized [24]. Electronic systems have two components such as active components which are transistors, diodes, and passive components which are capacitors, resistors, and inductors. Passive components that have particularly capacitors have received a lot of attention since their usefulness is steadily increasing in the electronic industry. The basic functions of capacitors include conversion of alternating current into direct current, energy storage, timing, and filtering. Dielectrics determine capacitor features, including capacitance, voltage capability, and loss factor. The electron-nucleus connection is extremely strong in dielectric materials. This material acts as an insulator with a greater energy band gap and higher bulk electrical resistivity.

Despite the fact that many dielectrics do not happen to be insulators, they are conventional dielectrics [25]. Because of the high need for microelectronics reduction, a lot of work has gone into making embedded capacitors that are lighter, more flexible, and smaller. Composites consisting of polymer matrix have been examined as capacitor components owing to their high dielectric constant as well as strong mechanical characteristics. Several methods for increasing polymer dielectric permittivity have been proposed [26]. High dielectric permittivity nanoparticles, for example, barium titanate (BT-BaTiO3) and calcium copper titanate (CCTO CaCu3Ti4O12)), have recently gained widespread acceptance being part of the polymer matrix [27]. Zhang et al. [28] revealed that uniformly dispersed filler inside the polymer matrix composites having stable microstructure may achieve a higher dielectric constant. Field-effect transistors are essential components of many modern electronic devices, such as computer chips [29]. In the microelectronic industry, filler-incorporated polymer nanocomposites were widely employed as packaging materials, insulators, and coating materials.

5.4. Polymer Blend-based Flexible Electronics. According to the latest research, polymer materials are in great demand in flexible electronics, and polymers with good dielectric constant play an important part [30]. The polymer blend consisting of poly(2-cyanoethyl vinyl ether) (CEPVA) and poly(methyl methacrylate) (PMMA) has been proposed using a comparatively good dielectric constant [31]. The fabrication of polymer blends using a good dielectric constant has been extremely essential from an electrolyte and electronic standpoint. Identifying polymers with electrolyte properties is strongly influenced by the presence of polar groups. The designs for polymer blend with a good dielectric constant are essential in flexible electronics as well as polymer electrolytes in batteries, and also supercapacitor technologies. For high frequencies, the fabricated polymer-based samples during $\varepsilon = 6.48$, the dielectric constant is considerably large. Polymer blending is a feasible method for creating designing a specific polymer for electronics. This technology can be considered a novel approach for designing preferred polymers with specified dielectric constant. The mixing of 15% weight for poly(2-ethyl-2-oxazoline) (POZ) using chitosan (CS) produces polymer blends among relatively good dielectric constants. The integration if POZ into CS results in adequate rise throughout the polymer blends dielectric constant by appropriate concentration as well as a reduction for higher concentrations.

6. Conclusion

This article discusses the development, production, and properties of polymer matrix composites in addition to their electronics applications. Polymer matrix composites are gaining a lot of attention mostly in the scientific community and in the industry because of the numerous ways to control their characteristics due to their applications, which include the selection of matrixes and fillers. Polymer composites have been used to create a component base in modern electronics which integrates excellent electrical characteristics with flexibility and extensibility. The printed circuit board uses glass fibre cloth-reinforced epoxy composites because of its excellent mix of mechanical and electrical qualities. Polymers like thermosets, thermoplastics, ceramics, and metals are among the materials used in electronic packaging to achieve the requirements. The passive component especially capacitors have received much interest as their utility in the electronic industry grows. The majority of the capacitor properties are determined by the dielectrics. The fabrication of polymer blends using a good dielectric constant has proven essential for flexible electronics. Polymer composites with additional fillers have proven to be a promising material for microelectronics as well as industrial applications. The filler arrangement and alignment effects will improve the thermal and dielectric characteristics of the polymer matrix. There is extensive research that was performed based on polymer matrix composites, but for electronic application, only limited research has been reported. In this article, polymer matrix composite-based electronics applications like printed circuit boards, electronics packaging, passive electronic components, and polymer blend-based flexible electronics are discussed. To increase the microelectronic devices, the productions of low dielectric constant materials are highly essential. Microelectronics devices require the development of dielectric materials having an ultralow loss tangent. As a result, considerable research will be required in the future to develop ultralow loss dielectric materials.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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