Current advancement in electrically conductive polymer composites for electronic interconnect applications: A short review

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Abstract. The development of conductive polymer composites along with their advantages are rapidly growing to meet current demands in electronic applications. There are many types of matrix and filler that had been extensively researched in order to find the most suitable materials that can be utilized for electronic interconnect applications. Previous works carried out by researchers within the field revealed that by using melt blending techniques such as twin screw compounding and compression moulding can be used to develop conductive composite polymer such as from polypropylene (PP) incorporated with graphite as conductive filler. The conductivity of the composite can be measured using the 4-point probe technique. This short review aims to provide the latest insight in the area of electrically conductive polymer composites focused on the types of matrix and filler, processing and utilisation in electronic interconnect and other potential applications.

1 Introduction

Polymers such as low density polyethylene (LDPE), High-density polyethylene (HDPE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS) are known with their ability as an insulator rather than conductor material. Polymers are electrically insulating materials with conductivity values as low as $10^{-7}$-$10^{-14}$ S cm$^{-1}$[1]. According to the electronic industries association (EIA) standard 541, a plastic material would be classified as conductive one if it has got the ability to protect against electrostatic discharge (ESD; surface resistivity between $10^{5}$ and $10^{12}$ ohms sq$^{-1}$) or electromagnetic interference/radio

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frequency interference (EMI/RFI; surface resistivity of $<10^5$ ohm sq$^{-1}$) [2]. This problem can be solved by incorporation of conductive filler with the matrix or known as conductive polymer composites (CPC’s). The method currently used to increase the electrical conductivity of polymers is to fill them with specific conductive additives, such as metallic powder, metallic fibers, carbon black ionic conductive polymers and intrinsically conductive polymeric powders such as polypyrrole.

1.1 Interconnect applications

Recently, the electronic technology is growing rapidly. Non-degradable polymer-metal composites have been studied for interconnect materials in electronic packaging. Basically, conductive composite materials provide many benefits compared to traditional interconnect technology such as low-temperature processing conditions that reinforce the use of heat-sensitive and low cost of components and substrates, less hazardous environmental waste, lower cost processing, reduced stress on the substrates, and the ability to pattern fine-pitch interconnects, facilitating the miniaturization of electronics system [3].

1.2 Conductive polymer composites

In the past decades, conductive polymer has attracted great attention among researcher due to application such as electromagnetic interference shielding where it used in cell phone cases, antistatic protectors [4,5] which it used for electrostatic mats, packaging of sensitive electronics), sensors in the microelectronic field [4] and conducting adhesives in electronic devices [5]. This had been discovered by Hideki Shirakawa, Alan McDiarmid, and Alan Heeger in 1977, where the polymer material was polyacetylene. The investigation for more potential material has been found such as polypyrrole (PPy), polyaniline (Pani), polythiophene (PT), poly(3,4-ethylenedioxythiophene) (PEDOT), trans –polyacetylene, and poly (p-phenylene vinylene) (PPV) [6]. Polymer composites made up of two components which is a polymer matrix and filler. For conductive polymer composites, it consists of polymer matrix with conductive filler such as organic filler, inorganic filler and intrinsically conducting polymer. The conductive fillers contribute for the electrical properties and the polymer matrix contribute to the physical and mechanical properties. The conductivity of composites depends critically on the volume content of the filler [7]. Fig 1 shows the schematic diagram of possible conductivity pathways in composite polymer. Conductivity pathways is formed when conductive particle form a path along the other with particle and it allows electricity to flow.

![Schematic diagram of possible conductivity pathways in composite polymer](image)

Fig. 1. Schematic diagram of possible conductivity pathways in composite polymer

Conductive polymer composites can be divided into two which is intrinsically conductive polymer and an extrinsically conductive polymer. The intrinsically conductive polymer is polymeric materials that conduct electric current without any additional
conductive substance and it represent a special class of material with electronic and ionic conductivity [8] while for the extrinsically conductive polymer composite.

1.3 Flexible/stretchable conductive polymer composites

Flexible is defined as the capability of being flexed or bend without any braking or known as brittle while stretchable is a capability of being stretched. Research on flexible or stretchable polymer conductive become interesting due to the need of development of electronics technology. It has been utilized to have its own interesting properties, and diverse applications such as electrode material in electrostatic actuators, impregnation material for making conductive fabric, and circuit components in microelectronics or making electronic polymer devices had been found [9]. Jeroen van den Brand et al. found the basic principle of stretchable technology where the electronic functionality is distributed onto islands that are interconnected to each other by meander-shaped interconnects and this system was embedded into a stretchable rubber in order to keep the rubber together and to protect the device [10]. The advantages of this technology is that it uses flex foil manufacturing technologies [11]. This proved that this technology has gained its own interest in the electronic industry.

1.4 Fillers for conductive polymer composites

Fillers have been widely used and studied widely for their potential use in many applications. The conductive filler is one of the filler that has been used in preparing conductive polymer composites where it can make composite become conductive. There are many types of conductive filler that used to increase the conductivity of polymers composites for examples carbon based such as graphite, carbon nanotube (CNT), and carbon black, and metal materials such as copper. Among of the materials, CNT, carbon nano fiber (CNF), and graphene has received greater attention of a research community because of their superior multifunctional properties compared to conventional fillers [12-15].

1.4.1 Graphite

Generally, graphite is used as an electro conductive filler because the cost is moderate and it also has good conductivity [16]. It is crystal form of pure carbon that much resembling of mica sheets of strongly linked atoms with very weak bond between the sheets. Graphite can be divided into 3 types which are natural graphite, synthetic graphite, and modification of graphite.

| Table 1 Different of type of graphite [17] |
|-------------------------------------------|
| Natural graphite | Synthetic graphite | Modification graphite |
| Can be divided into 3 categories based on its shape which is amorphous, flake and highly crystalline | It has two categories which are electro-graphite and artificial graphite | There three classes of modified graphite: graphite intercalated compounds (GICs), graphene oxide (GO) and expanded graphite (EG) |
| Originates from crude oil deposits that through time, temperature and pressure | Produced by treating carbonaceous precursors such as coal, petroleum and synthetic or natural organic | |

According to Rzeczkowski et al. [18], the highest conductivity of 36.4 S/cm was obtained for PP-based composites that consist of 55 wt% of graphite and 25 wt% carbon black prepared by melt mixing and 23.2 S/cm for PP-based composites that prepared by using solution mixing. The effect of different type of graphites grades and particles also play important role in order to get good conductivity. Graphite with flake-like shape has highest conductivity where the conductivity is 20.6 S/cm [19].

1.4.2 Carbon nanotube (CNT)

Carbon nanotubes are great interest as a filler for polymer composites due to their unique properties such as high electrical and thermal conductivity, ultrahigh mechanical strength, high ratio length/diameter (~1000) at nano-sized value of diameter. It has low density, high specific surface area and also have high aspect ratio. It can divide into two type which are single well or multiple wells. Nanotubes with single well are known as single-wall carbon nanotubes (SWCNTs) while the ones with more than one well are multiwall carbon nanotubes (MWCNTs) [25]. CNTs is one of the good material that we can observed due to the resistivity that relatively low (10^{-2}-10^{-3} \Omega \text{ cm}) [20]. Although, CNT is a good conductive filler, CNT have very high aspect ratios and strong Van der Waals attractions between each other, and this make the CNT have the tendency to agglomerate.

1.4.3 Copper

One of the metallic material which is copper is the most common conductive filler had been used to produce conductive polymer composites due to the cost is low than others metal material. It is a metallurgy powder that rank at third after iron and steel. important uses for copper materials include friction materials, electrical parts, filters, additives to iron, aluminium, powder alloying, catalysts, paints, and pigments. The four cardinal techniques to producing copper powders are atomization, oxide reduction, electrolysis, and hydrometallurgy. Of the above methods, atomization and oxide reduction are presently applied on a large global scale [21].

| Fillers | Advantages | Disadvantages |
|---------|------------|---------------|
| Graphite | Positive influence on the mechanical properties, thermal and dimensional stability | Poor filler matrix dispersion |
| Carbon Nanotube | Extreme mechanical properties, excellent thermal conductivity, outstanding electrical conductivity | Homogeneity of the material that contains wide distribution of the nanotubes diameters |
| Copper | Low resistivity, and improved electromigration performance | Easy to oxidizes at low temperature and has self-protective layer to prevent further oxidation |
1.5 Processing of conductive polymer composite

Variety methods and processing can be used to produce conductive polymer composites. However, each of methods give different result at the end properties of composites. To obtain low percolation threshold and boost the composite’s conductivity, conductive fillers should disperse well within the non-conductive polymer matrix without degrading the aspect ratio.

1.5.1 Twin Screw Extruder

Twin screw extruder is one machine that use for melt blending process that attractive to be used use to the advantage of being free of solvents. It made up of a machine that has a screw where material will be feed inside the hopper, and the material will be melt inside the chamber before it was push out from the die by the screw and undergoes pelletizing process and form pellet. Mainly this machine is use to premix the polymer matrix and mix homogenously with conductive filler before it undergoes manufacturing process. Researchers have frequently reported that the conventional process, as well as injection and compression molding, is capable to boost the mechanical properties of the end product [25]. Nevertheless, the mechanical properties increase, the electrical conductivity be liable to decrease.

1.5.2 Compression Moulding

One of popular technique to produce polymer composite products is compression moulding. In early 1950s, this process growth especially in automotive and appliance applications. This technique was first applied to application of glass fiber reinforced polymer in automotive industry which are they produce front panel of GM Corvette in 1953[26]. They are four basic step for compression moulding process which are precharge preparation and placement, mould closure, curing and part release. Compression moulding enable the moulding of complex shapes in the case of very high viscosity of the polymeric mixture, due to loading. In the past, compression moulding was used to assess the influence on the electrical resistivity and morphology of multi walled carbon nanotube/Polycarbonate (MWNT/PC) composites. It one of the process that have low cost process and able to high production rate process.

1.6 Potential application of conductive polymer composites

In market nowadays, conductive polymer composites have become one of the important product that can be applied in various applications. This include in medical, electronic, and automotive application. Several applications that attracts industry has been choose below.

1.6.1 High capacity batteries

The development of the technology has rapidly developed by the time goes. The impact of this rapid development had seen revolution in the manufacturing of devices such as hand phone, laptop and television. Lithium-ion batteries store or release energy by passing lithium ions back and forth through a microporous separator between the positive and negative electrodes (cathode and anode) that intercalate and deintercalate these ions respectively.
1.6.2 Artificial muscle

The needs of surgical robot interacting with medical team and patient or team of robot picking fruit from tree are different from those robots that use to assembles cell phone or electronic devices in a clean room. Nowadays, the development of artificial muscles become an important thing in medical fields. Artificial muscle is an actuator that generally defined by analogy with the skeletal muscle that characterized by its ability to contact in response to a chemical or physical stimulus [27]

1.6.3 Biosensors

The first actual biosensor was developed by Leland C. Clark, Jr in 1956 for oxygen detection [28]. The characteristics of a biosensor are selectivity, reproducibility, stability, sensitivity, and linearity. It has wide range of application such as to detect biomolecules that either indicator of disease or target of drug, prosthetic devices, water quality management, food quality monitoring, soil quality monitoring, and environmental monitoring [29]. Despite of the wide range of application, itself has challenges where difficulties in translating academic research into commercial viable prototypes by industry.

2 Conclusion

Although, the development of conductive polymer composite has been rapidly developing, there is still many parameters such as different type of filler, effect of filler loading and effect of different type of matrix that can be study in order to have a better electrical conductivity with good mechanical properties. From the previous study, there is many type of filler that has been used as conductive filler for example, graphite, carbon nanotube, copper and silver. Future research on others conductive filler materials need to done in order to find the best conductive filler that can give higher conductivity. This is to ensure that the conductivity can support the needs in interconnect application. Therefore, more effort need be taken to fulfil the new methods, materials and technology in interconnect application.

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