Studies on the Effects of Doping on the Electrical and Thermal Conductivities of Polystyrene.

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ABSTRACT

The electrical and thermal conductivities of polystyrene (PS) doped with graphite and charcoal have been studied. Ten grams of polystyrene was mixed with varying concentrations, 0%, 0.05%, 0.1%, 0.5%, 0.75%, 1%, 1.25%, and 1.5% of each of graphite and charcoal. The mixture was molded and compressed to produce doped polystyrene samples. The electrical and thermal conductivities of the doped samples were tested. Results indicate that the conductivities of the doped samples increased with increase in percentage dopants. The electrical conductivities of the doped samples vary but at higher concentration, 1.25%, charcoal performed better. The thermal conductivity of the graphite doped polystyrene is higher than that of charcoal in each percentage dopants.

(Keywords: thermal properties, conducting polymers, polystyrene, doping)

INTRODUCTION

Metals are characterized by the presence of free electrons and can conduct electricity; non-metals have few or no electrons and cannot conduct electricity, while semiconductors are in between the two. Plastics are generally known as good electrical insulators [1]. Insulators break down for two reasons, firstly, the higher the voltage they must sustain, the greater the strain imposed upon their inter-atomic bonds and hence on their insulating properties. Every insulator has a voltage of a given thickness, beyond which it will break down and conduct either across its surface or throughout the bulk of the material. Secondly, the hotter the insulator, the greater the agitation within its crystal structure and the more likelihood there will be free electrons [2]. Organic insulator decomposes at a temperature of a few hundred degrees centigrade, but ceramic insulators when very hot may conduct quite well. The more firmly restrained the electrons are in a material, the better its insulating properties.

At times, minute amounts of impurities or dopants may be introduced to an insulator to improve conductivity to desired amount and the process is known as doping [3]. These dopants or impurities either introduce mobile or free electrons into the insulator [4]. The conductivity of the doped material approaches the conductivity of the best available conductor, that is, silver. At room temperature, the conductivity of polyacetylene approaches the conductivity of copper on a weight basis and exists in cis-configuration at 195^{O}K and trans- at room temperature [5].

A doped conductive polymer is used in paint coating to resist corrosion and as photovoltaic to create coating that produce electricity. Conductive polymers are very useful in surface applications [6]. Thermal conductivity values of polymers are low in the range of 0.1-0.5N/(m.k) [7]. Furthermore, crystalline polymers have higher thermal conductivities than amorphous polymers.

MATERIALS AND METHODS

Basic Theory

Polystyrene sample was collected from Amexco Electronic Shop, Onitsha, Anambra State, Nigeria, while the graphite and charcoal were obtained from drycell batteries and firewood, respectively.

Preparation of Samples

Ten (10g) grams of the polystyrene was weighed into a 250ml beaker and heated at temperature between 150^{o}C - 250^{o}C using an electro-thermal heater with continuous stirring. Measured quantities of the dopants were added into the polymer and the two mixed. The mixture was poured into the mould and compressed immediately to give the shape of the mould. The formulation is shown in Table 1.

Table 1: Formulation of Polystyrene Doped with Graphite and Charcoal.

Type 1		Type 2	
PolyStyrene (g)	Graphite (%)	PolyStyrene (g)	Graphite (%)
10	-	10	-
10	0.05	10	0.05
10	0.10	10	0.10
10	0.50	10	0.50
10	0.75	10	0.75
10	1.00	10	1.00
10	1.25	10	1.25
10	1.50	10	1.50

Characterization of the Sample

(a) The electrical conductivity of the sample was carried out by using 500mega ohms MASTECH multimeter 005-1349. Each sample prepared was tested with the equipment by placing it between the two opposite rods of the multimeter and its resistance taken. Resistivity is the opposition given to flow of current per unit length of material of uniform sectional area and the reciprocal of resistivity was measured as:

$$K = I/R \qquad \textbf{(1)}$$

Where k = Electrical conductivity
R = Resistance

(b) Thermal conductivity was carried out using Elmer 2AK kathrometer. The results were obtained from the equation below.

$$q = kdt/dx \qquad \textbf{(2)}$$

Where q = heat flux (w/m^2)
dt/dx = temperature gradient (k/m)

RESULTS AND DISCUSSION

The results of electrical and thermal conductivities of the polystyrene doped with various percentages of graphite and charcoal are shown on Tables 2 and 3.

Table 2: Electrical Conductivity of Polystyrene Doped with Graphite and Charcoal.

Percentage concentration of dopants (%)	Polystyrene doped with graphite ($\times 10^{-1}$S/cm)	Polystyrene doped with charcoal ($\times 10^{-1}$S/cm)
0	0	0
0.05	0	0
0.1	0.02	0.08
0.5	0.1	0.12
0.75	0.17	0.16
1	0.3	0.27
1.25	0.48	0.56
1.5	0.61	0.9

Table 3: Thermal Conductivity of Polystyrene Doped with Graphite and Charcoal.

Percentage concentration of dopants	Polystyrene doped with graphite ($\times 10^{-1}$S/cm)	Polystyrene doped with charcoal ($\times 10^{-1}$S/cm)
0	0	0
0.05	4.3	1.41
0.1	4.42	1.67
0.5	4.6	1.9
0.75	5.88	2.14
1	7.53	3.05
1.25	8.13	8.1
1.5	15	10.4

The doping of polystyrene with graphite and charcoal enhanced the conductivities in that the amorphous nature provides more room for electron mobility. The doping with a carbon allotrope arranged hexagonally with rings formed by δ bonds and singly occupied p-orbitals perpendicular to the plane of the rings interact to form a delocalized π orbital involving all the carbon atoms in a layer. The delocalized π orbital of the graphite accounts for its intrinsic electrical properties [8].

Electrons are delocalized along the conjugated backbone of conducting polymers through a lap of π orbitals giving rise to the extended π-system with a filled valence bond. Some dopants may introduce extra electrons (electron rich) to the π-system and are called n-doping while some will introduce holes (electron depleted) and are known as p-doping.

Doping of conjugated polymers generates high conductivities by increasing a carrier concentration. Phonon helped hopping even as graphite increase the carrier concentration in polymer. Amorphousness increases the range of hopping. The increased carrier concentration bridged the wide energy gap between the full valence bond and the empty band and empty conductive band of the polymer. The graphite provides its own at a lower energy level which facilitates movement of electrons into the conductive band of the dopant from the valence bond of the polymer thus creating hole [8]. The movements of these holes cause electrical conduction within the polymer.

The electrical and thermal conductivities of the doped polystyrene increase with increase in the concentration of the dopants. The increase may be due to compactness provided by increase in concentration of the dopants which increase heat transfer through phonon. The behavior of polystyrene which was very outstanding could be because of dipolarity movement which makes a negligible contribution to the thermal conductivity of its parent form [9] but could be said to have made significant contribution to the thermal conductivity of the doped polystyrene due to its interaction with the delocalized electron in the graphite.

The density contributes to the thermal property of polystyrene. The free electrons in the graphite could have improved the dipolarity thereby increasing significantly the contribution of electron mobility in conduction through the graphite doped polystyrene. The hexagonally arranged structure of graphite would have contributed to the improvement of the polystyrene density also which will improve thermal conductivity by wave movement (phonon) or inter atomic heat transfer. The conductivity of polystyrene doped with charcoal increase at higher concentration of 1.25%. Heat transfer through electron might have played minimal role in thermal conductivity of the polystyrene doped with charcoal.

CONCLUSION

The electrical and thermal conductivities of polymer were enhanced by varying concentrations of graphite and charcoal. The extent of enhancement depends on the nature and properties of polystyrene and the dopants used. Polystyrene doped with graphite showed better thermal conductivity than the one doped with charcoal but at higher concentration, 1.25%, conductivity of polystyrene doped with charcoal increase. The electrical conductivity of polystyrene doped with graphite and charcoal vary, with charcoal doped polystyrene performing better at higher concentration.

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