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# Improvement of surface electrical conductivity in poly carbonate composite by nitrogen ion implantation

Kyung Kyoon Kim[1], Jeong Suk Kim[2,*], Jin Hyo Park[1],
Duck Kun Hwang[3], Woon-Yong Choi[4], Sung-Hoon Ahn[4] and Myung-Chang Kang[5]

[1]*School of Mechanical Engineering, Pusan National University, Jangjun-dong San 30, Busan 609-735, Korea*
[2]*School of Mechanical Engineering / Engineering Research Center for, Net Shape and Die Manufacturing, Pusan National University, Jangjun-dong San 30, Busan 609-735, Korea*
[3]*Gyeongnam Regional Headquarters, Small Business Corporation, 298-7, Doodae-dong Changwon, Gyeongnam, 641-210, Korea*
[4]*School of Mechanical and Aerospace Engineering & Institute of Advanced Machinery and Design, Seoul National University, Sillim-dong San 56-1, Seoul, 151-744, Korea*
[5]*Materials Solution National Core Research Center, Pusan National University, Jangjun-dong San 30, Busan 609-735, Korea*

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**Abstract**

This study is to investigate the nitrogen ion implantation process in PC (Polycarbonate) composite for improving surface electrical conductivity. The suggested process is applied for the thin wall shape polymer which is composed of low carbon black and carbon fiber in order to increase electric conductivity. The acceleration voltage which is relatively low 3~50 keV in ion implantation process is used to obtain the thin conductive surface layer around 2 micrometer. The surface electrical conductivity of PC composite is realized up to below $10^6$ $\Omega/cm^2$ by controlling ion dose without degrading mechanical properties. This technology can be adopted to make conductive plastic product which is applicable for static electricity prevention and electromagnetic wave masking. In order to evaluate the effect of surface modification of PC by nitrogen ion implantation, its surface resistance, tensile strength, tensile elongation, and half-life have been measured. The properties of PC/CF and PC/CB increased surface resistance and tensile strength. Also, the properties of PC/CF and PC/CB significantly decreased tensile elongation and half-life.

*Keywords*: PC composite; Nitrogen ion implantation; Surface electrical conductivity

## 1. Introduction

Recently, the industry of semiconductor and electronics has been rapidly expanding, and the demand of engineering plastic products is increasing. Typical polymer material is good electric insulator, and the static electricity occurs when rubbing the surface, contacting with different material, or exfoliating. The static electricity, occurred by rubbing surface, produces over 30,000 volts which affect semiconductor and electronics products. Accordingly, the static electricity often causes error and malfunction of semiconductor and electronics products.

Therefore, engineering plastic for electric static dissipation is used for fabrication of electronic products, which requires $10^3$~$10^{10}$ $\Omega/cm^2$ of electric conductivity. Table 1 shows the fabrication methods of fabricating electrically conductive polymer.

The first method is the mixture of conductivity

*Corresponding author. Tel.: +82 51 510 2334, Fax.: +82 51 518 7207
E-mail address: juskim@pusan.ac.kr

polymers. This mixture has electric conductivity itself, but its commercial usage is limited and has low economical efficiency. The second method is the fabrication of conductivity polymer composite. This method is commercially utilized, but mechanical properties decrease as the amount of conductive materials increases and has limitation in the design of products. The third method is conductive material coating. It has high cost and limited kind of usable polymer in this class.

Generally, the fabrication method of conductive polymer composite is used. However, it has some problems; the decrease of manufacturability and impact strength due to the increase amount of conductive materials such as metal fiber, metal particle, carbon fiber, and carbon black. In addition, an excess of conductive materials such as carbon black is separated from the polymer surface and causes error of electric products. Therefore, noble fabrication method of materials with electric static dissipation that has low content of conductive material, low cost, and good mechanical properties is required [1-5].

The objective of this research is to fabricate electric static dissipation engineering plastic which has good mechanical and electrical properties using ion implantation technology. Ion implantation is a novel surface modification technology that enhances the mechanical, chemical and electrical properties of substrate's surface using accelerated ions [6]. Ion implantation effects on properties of polymer surface such as mechanical and chemical [7]. The theory of ion implantation is defined that a structural change, in that the crystal structure of the target can be damaged or even destroyed. Ion implantation accelerates the ions to the target substrate by a bias voltage. The ions collide to the surface of target substrate with high kinetic energy [8]. When the bias voltage is below 0.5 keV, ions adhere to the substrate. In the case where the bias voltage is between 0.5 keV and 1 keV, sputtering occurs. With high energy (1 ~ 100 keV), ion implantation takes place, and ions penetrate the surface of substrate as deep as hundreds of nanometers from the surface [9-11].

Table 1. The methods of fabricating electrically conductive polymer.

| Technology | Advantage | Disadvantage |
|---|---|---|
| Mixture of conductive polymers | - Material is conductivity itself | - Limited commercial usage<br>- Low economical efficiency |
| Fabrication of conductive polymer composite | - Commercially utilized<br>- Give conductive ability by adding conductive materials | - Lowering of mechanical property<br>- Non-homogeneity of elec-tricstatic dissipation<br>- Limitation in the design of Products |
| Conductive coating | - Enable to express various color | - High cost<br>- Exfoliate by rubbing<br>- Limited availability of usable polymer |

## 2. Experimental apparatus

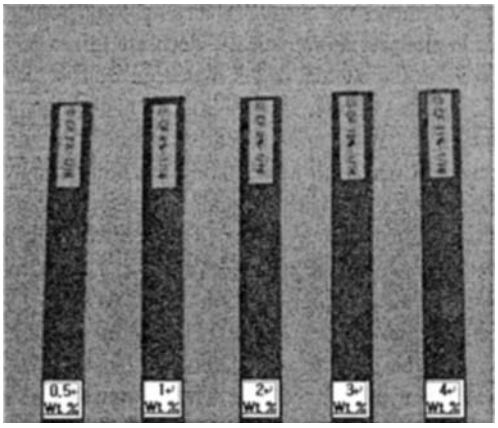
In this research, Polycarbonate (PC) was used as a polymer matrix of the composite. To the CB matrix, either carbon black (CB) or carbon fiber (CF) was added in the 0.5 ~ 15 Wt% range. The composite material fabricated with PC and CB is named as PC/CB and with PC and CF is named as PC/CF.

Fig. 1 shows Nitrogen ions were implanted by gaseous ion implanter equipment with DuoPIGaton ion source (50keV and ion dose of $1\times10^{17}$ ~ $5\times10^{17}$ ions/cm$^2$). Target substrate was turned around to homogeneous ion irradiation and the angle of irradiation was fixed at 0°.

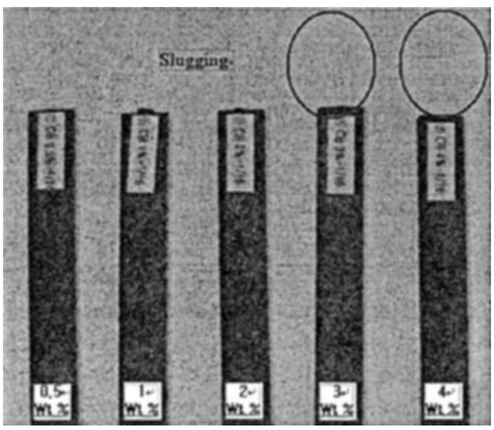
## 3. Experimental results and discussion

In this research, nitrogen ions are implanted to CF/CB composite with surface resistance under $10^8$ $\Omega$/cm$^2$. However, PC/CB becomes slugging when CB content is over 3 wt% as shown in Fig. 2. When CB content is over 10 wt%, the material was difficult to be need for injection molding parts because of increased viscosity.

Fig. 1. Ion implanter system.

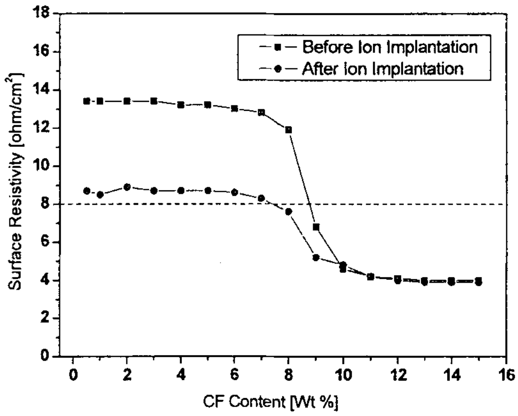



(a) PC/CF composite

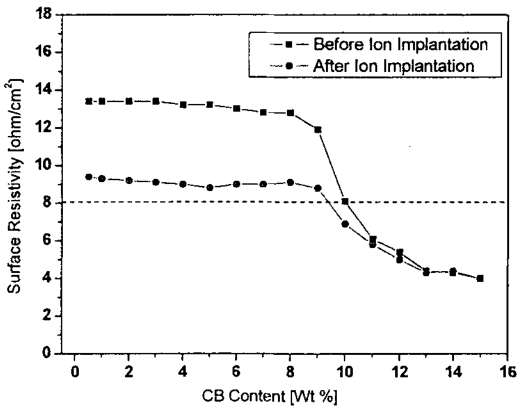



(b) PC/CB composite

Fig. 2. Slugging test after $N^+$ ion implantation at 50 keV.




(a) PC/CF composite

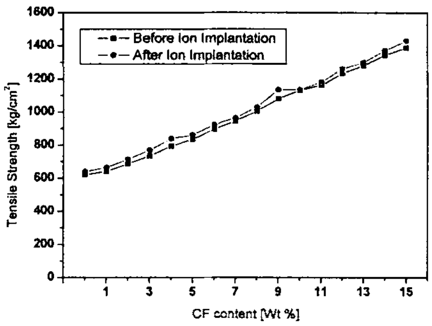



(b) PC/CB composite

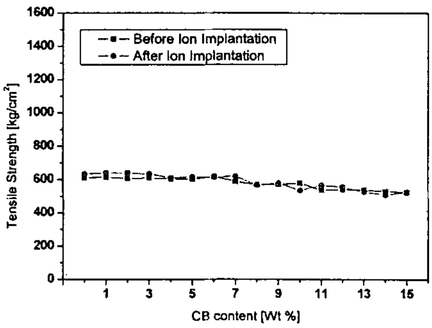
Fig. 3. Change of surface resistance after $N^+$ ion implantation at 50 keV.

Fig. 3 shows the change of surface resistance after N+ ion implantation at 50 keV when CB and CF contents are in the range of 0.5 ~ 15 wt%. The surface resistance of composite was reduced to $10^8$ ~ $10^9$ $\Omega/cm^2$ from over $10^{12}$ $\Omega/cm^2$ when the CF content reached 8wt% as shown in Fig. 3(a). According to previous researches, ion implanted specimens themselves had surface resistance of $10^8$ $\Omega/cm^2$. So, surface resistance improvement by ion implantation can not be obtained when CF content is under 8 wt%. The surface resistance of composite was decreased to $10^{5.2}$ $\Omega/cm^2$ from $10^{6.8}$ $\Omega/cm^2$ at CF content of 9 wt%, and there is no different surface resistance value before and after ion implantation over 10 wt% of CF. The surface resistance of composite was reduced to $10^9$ ~ $10^{10}$ $\Omega/cm^2$ from over $10^{12}$ $\Omega/cm^2$ as the CB content reached 9 wt% as shown in Fig. 3(a). The surface resistance of composite has become $10^{6.9}$ $\Omega/cm^2$ from $10^{8.1}$ $\Omega/cm^2$ at CB content of 10 wt%.

Fig. 4 shows the change of tensile strength before and after ion implantation. As the dose of implanted ion increased, the strength enhancement became larger. The tensile strength was increased from 621 Pa to 1389 Pa as the content of CF increased from 0.5 wt% to 15 wt% as shown in Fig. 4(a). The tensile strength of nitrogen-ion implanted specimens increased about 30 Pa. The tensile strength decreased from 611 Pa to 524 Pa as the content of CB increased from 0.5 wt% to 15 wt% as shown in Fig. 4(b). The different trends between CF and CB are caused by the different shape and aspect ratio of the materials [7]. CF is fiber that provides high contact surface to volume ratio. However, CB is shape that provides very low surface area to contact with the polymer resin for unit volume of the material.

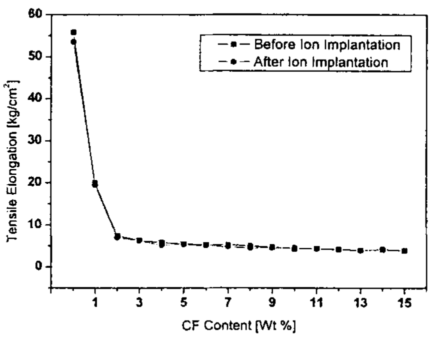



(a) PC/CF composite

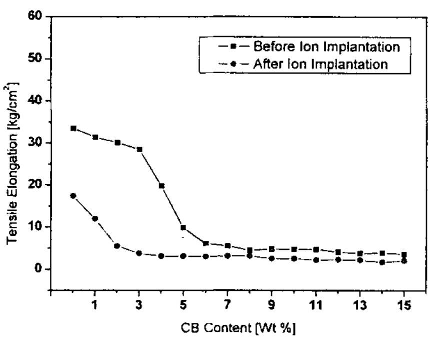



(b) PC/CB composite

Fig. 4. Change of tensile strength after $N^+$ ion implantation at 50 keV.




(a) PC/CF composite

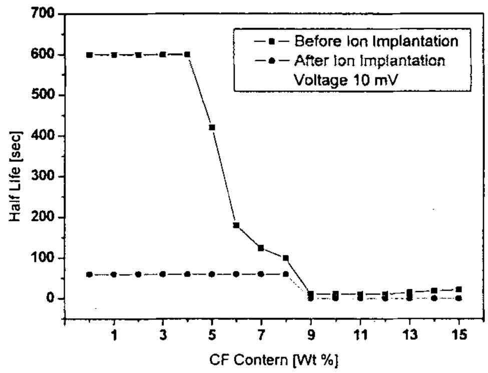



(b) PC/CB composite

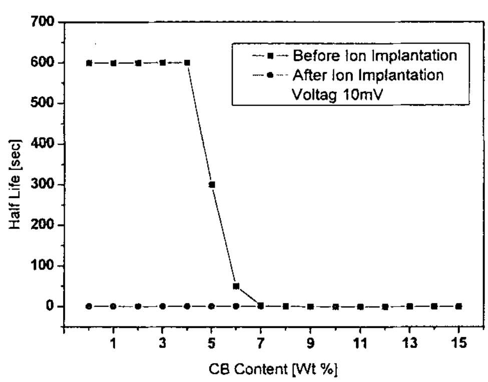
Fig. 5 Change of tensile elongation after $N^+$ ion implantation at 50 keV.

Fig. 5 shows the change of tensile elongation. The tensile elongation dramatically decreased from 55 Pa to 6 Pa as the content of CF increased from 0.5 wt% to 2 wt% as shown in Fig. 5(a). It means that the content of CF has a significant influence on tensile elongation while ion implantation has not. As shown in Fig. 5(b), the tensile elongation decreased from 33 Pa to 6 Pa as the content of CB increased from 0.5 wt% to 6 wt%. The tensile elongation dramatically decreased after ion implantation up to 5 wt%.

Fig. 6 shows the change of half-life at 10 mV voltage. The half-life is the amount of time taken to lose half of applied voltage. The shortened half-life leads to low error of products. The half-life decreased from 600 sec to 10~20 sec as the content of CF increased from 5 wt% to 7 wt% as shown in Fig. 6(a). The half-life decreased to 60 sec after ion implantation and decreased to 0 sec from 9 wt%. The half-life decreased from 600 sec to 0 sec as the content of CF increased from 4 wt% to 7 wt% as shown in Fig. 6(b). The half-life decreases to 0 sec after the ion implantation.




(a) PC/CF composite




(b) PC/CB composite

Fig. 6. Change of half-life after $N^+$ ion implantation at 50 keV.

## 4. Conclusions

In order to evaluate the effect of surface modification of PC by nitrogen ion implantation, its surface resistance, tensile strength, tensile elongation, and half-life have been measured.

The surface resistance of PC/CF increases to $10^{1.6}$ $\Omega/cm^2$ at CF content of 9 wt% and PC/CB increases to 30 $kg/cm^2$ for the tensile elongation of PC/CB decreases significantly up to 5 wt%. The half-life of PC/CF and PC/CB specimen decreases to 0 sec by nitrogen ion implantation.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