

Change in the Electrical Conductivity of N⁺ Ion Implanted Polycarbonate

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ABSTRACT

The electrical conductivity of 100 keV N⁺ ion implanted polycarbonate (PC) to the doses 1×10^{15} , 1×10^{16} and 5×10^{16} ions/cm² has been studied. The electrical conductivity of ion beam modified polycarbonate has been found to be an increasing function of the implanted dose. Its value changes from $\sim 10^{-14}$ S, for virgin PC sample to $\sim 10^{-8}$ S for the sample implanted to the dose 5×10^{16} ions/cm². By Raman spectroscopic analysis, the difference in the electrical conductivity has been explained in terms of the difference in carbon structure of the implanted polycarbonate.

Keywords: Polycarbonate, Ion-Implantation, Electrical Conductivity, Raman Spectroscopy.

INTRODUCTION

In polymers, the electrical conductivity is characteristically very low and in most of the electrical applications, they are essentially used as insulators [1-6]. However, there are requirements for increasing their conductivity in a controlled manner. Therefore, the polymer substrates are frequently modified to meet these needs. In the recent years, the ion implantation technique has been effectively used to modify the electrical properties of polymeric materials [7-11]. Ion implantation in polymers is accompanied with various effects like free radical formation, chain-scissioning, cross-linking, carbonization etc. [10-15] which results in the change in structural and electrical properties of these materials.

In this study, the effect of N⁺ ion implantation on the properties of polycarbonate (PC), an optically transparent polymer with chemical structure of the repeating unit shown in Figure 1, has been investigated.

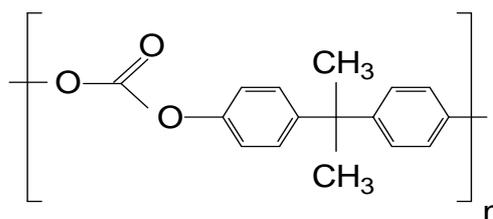


Figure 1: Monomer structure of Polycarbonate polymer

To study the N^+ ion implantation induced effects in PC, the surface conductivity of this polymer has been predicted through V-I measurements using two point probe method. Further, the ion implanted polycarbonate has been characterised through Raman spectroscopy to correlate the observed conductivity behaviour with the induced structural changes.

MATERIALS AND METHODS

The bulk sheet of polycarbonate (monomer composition $C_{16}H_{14}O_3$) of thickness 250 micron was obtained from Goodfellow, United Kingdom and was cut into samples of area $15 \times 15 \text{ mm}^2$. These samples were irradiated with N^+ ions having the energy 100 keV to the doses 1×10^{15} , 1×10^{16} and 5×10^{16} ions/ cm^2 under vacuum ($\sim 10^{-6}$ torr) at room temperature utilizing the Low Energy Ion Beam Facility (LEIBF) at Inter-University Accelerator Centre (IUAC), New Delhi, India. The beam was electrostatically scanned over the entire area of the sample keeping the beam current density below $1.0 \mu\text{A}/\text{cm}^2$. The surface conductivity measurements, at room temperature, were then carried out with two point probe method using Keithley 6517 Digital Electrometer, interfaced with computer.

RESULTS AND DISCUSSION

3.1 Electrical conductivity

Figure 2 presents the current versus voltage plots measured on the surface of virgin and N^+ ion implanted PC samples in the voltage range 0-100V. It is clearly observed from this figure that the current in the virgin sample which is of the order of $\sim 10^{-12}$ A increases to $\sim 10^{-6}$ A at a maximum dose of 5×10^{16} ions/ cm^2 .

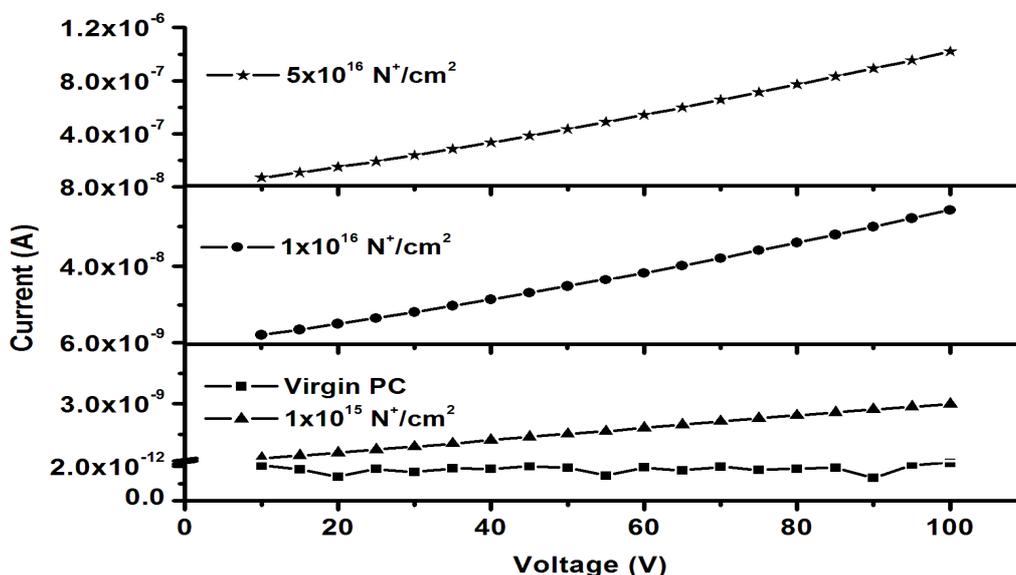


Figure 2: Current versus voltage plots for Virgin and N^+ implanted PC samples

From this data, the surface conductivity of virgin and implanted polycarbonate samples has been calculated using the relation [6]

$$\sigma_s = \frac{\cosh^{-1}(d/2r_0)}{\pi R}$$

where, σ_s = surface conductivity, d = separation between electrodes, r_0 = radius of the circular electrode, R = resistance measured on the conductive surface.

Figure 3 shows the variation in the conductivity as a function of ion fluence and the values of conductivity at different fluences are presented in Table 1.

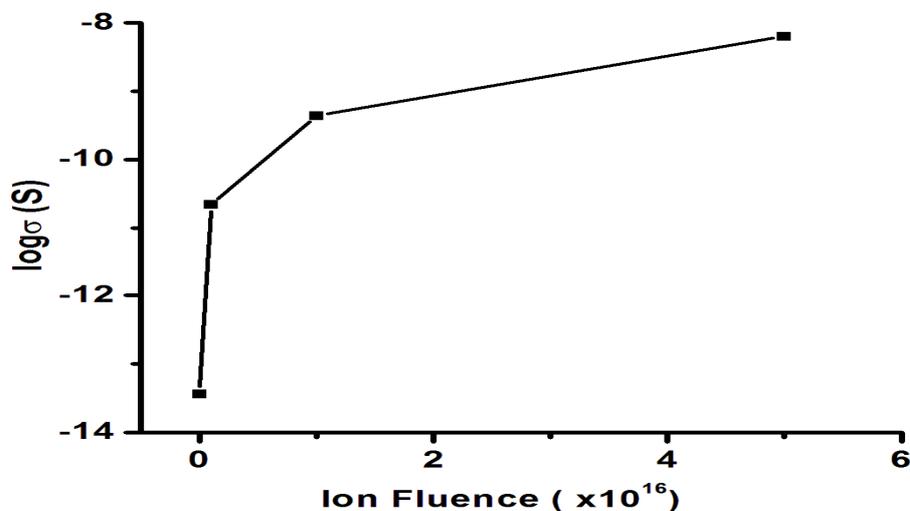


Figure 3: Plot for log (σ) versus the N^+ ion fluence

Table 1: Electrical conductivity of virgin and N^+ implanted Polycarbonate

Dose (ions/cm ²)	σ_s (S)
Virgin	3.64E-14
1.0×10^{15}	2.22E-11
1.0×10^{16}	4.38E-10
5.0×10^{16}	6.40E-09

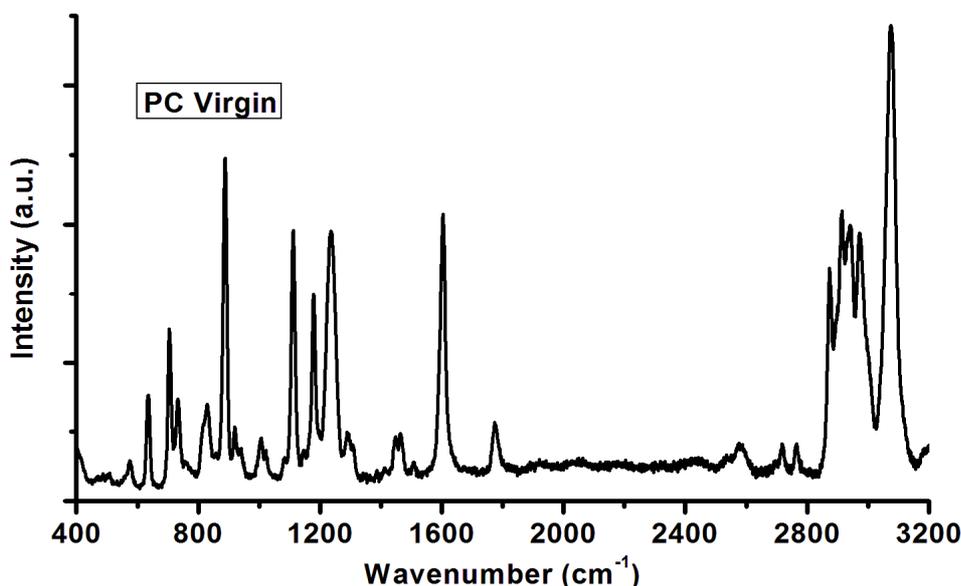


Figure 4: Raman spectra of virgin polycarbonate

From table 1, it is clear that the value of electrical conductivity changes from 3.64×10^{-14} S for virgin PC sample to 6.40×10^{-9} S for the sample implanted to the dose 5×10^{16} ions/cm². In order to understand such an increase in the conductivity of polycarbonate with increasing implantation

dose, in terms of the change in structural behaviour of this polymer, these samples were subjected to Raman analysis.

3.2 Raman Analysis

Figure 4 and 5 report the Raman spectra taken at an excitation wavelength of 632.8 nm of He-Ne laser for virgin and N^+ ion implanted PC samples respectively.

In the Raman signal of non implanted PC sample (Figure 4), the various peaks observed correspond to the characteristic peaks of polycarbonate [16-19] and thus confirming the monomer structure of this polymer.

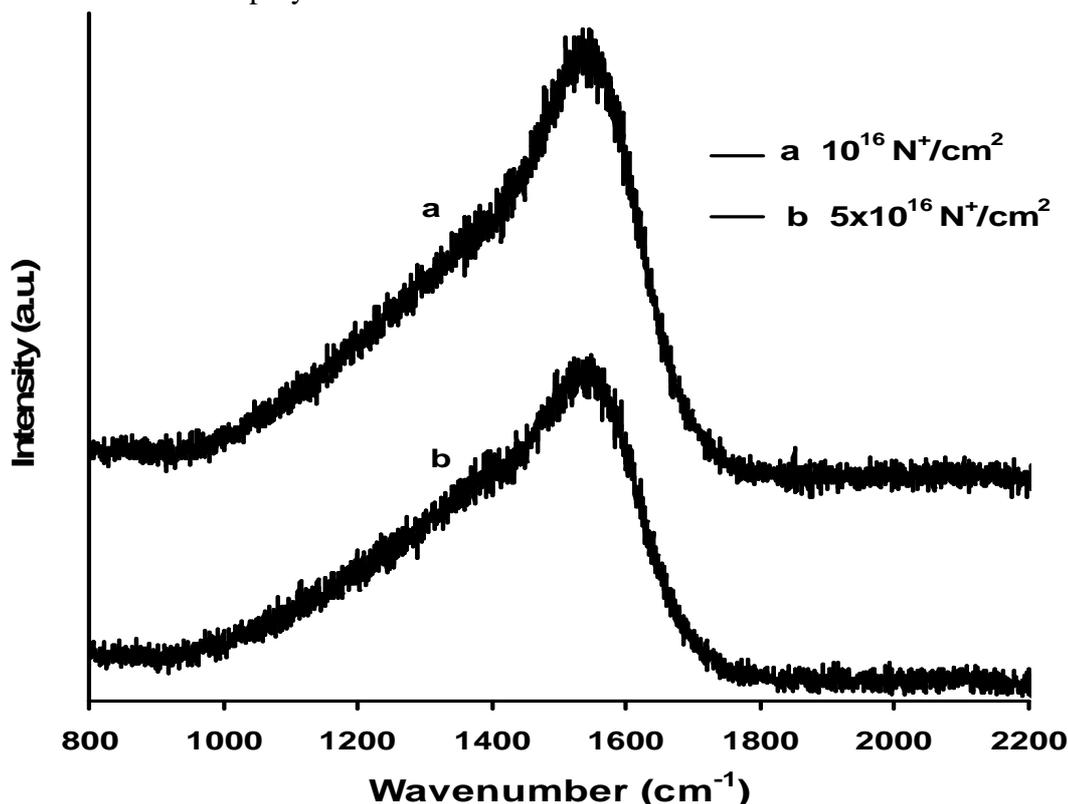


Figure 5: Raman spectra of N^+ implanted polycarbonate.

At an implantation dose of 1×10^{16} ions/ cm^2 , as is evident from Figure 5 (curve a), a large band at around 1550 cm^{-1} appears, with the elimination of the characteristic peaks of polycarbonate. The spectral position and the shape of this band in Raman spectra are consistent with the characteristic G band of hydrogenated amorphous carbon [9, 14, 20]. With the increase in the concentration of nitrogen ions within polycarbonate specimen at a dose of 5×10^{16} ions/ cm^2 (Figure 5, curve b), the intensity of this band reduces indicating further reduction of hydrogen content. Thus, it can be inferred that as a result of ion implantation, a three dimensional carbonaceous network, made up of a system of distorted bonds emerges. These carbonaceous clusters on the implanted surface which are rich in charge carriers [8-14] provide a continuous path for the charge transfer within the insulating polymer chain and thus influence the hopping mechanism within the chain of polymers and results the boosted current through the surface of polymer as an outcome of implantation.

CONCLUSION

The surface electrical conductivity of polycarbonate was found to be increased by approximately six orders of magnitude after N⁺ ion implantation at the fluence of 5x10¹⁶ ions/cm². The formation of a three dimensional carbonaceous network, consisting of disordered bonds, emerges in the implanted regions of the polycarbonate, as confirmed through Raman spectroscopy, is considered responsible for increased surface conductivity as a result of implantation.

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