Effect of Argon Ion Implantation on Dielectric Properties of Polycarbonate

Mahak Chawla*, Nidhi Shekhawat, SanjeevAggarwal, Annu Sharma
Department of Physics, Kurukshetra University, Kurukshetra-1361199, India
K.G.M. Nair
Materials Science Group, Indira Gandhi Centre for Atomic Research, Kalpakkam-603102, India
**E-mail:mahak.chawla@gmail.com*

Abstract

Effect of Ar^+ ions implantation has been investigated on the surface structure and dielectric properties such as dielectric constant, dielectric loss and a. c. conductivity of polycarbonate in the frequency range from 100 kHz-50MHz. The specimens were implanted with 130 keV Ar^+ ions in the fluence ranging from $1x10^{14}$ to $1x10^{16}$ ions cm^{-2}. The dielectric measurements of these specimens show that the dielectric constant decreases whereas dielectric loss and a. c. conductivity increases with increasing ion fluence. This kind of dielectric behavior of implanted specimens indicates towards the conductive layer formation in the implanted surface layers of polycarbonate specimens. These modifications in the dielectric properties have been further correlated with the carbonaceous structure formed on the surface of implanted specimens as evidenced from Raman spectroscopic technique.

1. Introduction

Polycarbonate (PC) is an amorphous and inexpensive polymer known for its excellent optical and mechanical properties. It is widely used in engineering and other diverse disciplines [1-2]. The synthesis of new conducting/semiconducting polymers is of great importance for enhancing their use in electronic devices. Therefore, by changing the dielectric properties (dielectric constant, dielectric loss and a. c. conductivity) of polymers their applications can be further extended [3-4]. Ion implantation is particularly well suited technique for tailoring the dielectric properties of polymers [5].

In the present work, 130 keV Ar^+ ions induced modification on the dielectric behavior and surface structure of PC specimens has been investigated. The dielectric constant, dielectric loss and a. c. conductivity of virgin and implanted PC specimens has been investigated through dielectric spectroscopy. The structural changes produced in implanted polycarbonate specimens has been studied using Raman spectroscopic technique. The possible mechanism behind alterations in dielectric properties due to implantation has been explored in detail.

2. Experimental details

Samples of size 2x2 cm^2 were cut from 250 µm thick sheets of commercially available transparent polycarbonate. Some of these samples were implanted with 130 keV Ar^+ ions to various doses ranging from 1×10^{14} to 1×10^{16} ions cm^{-2} under a vacuum of 1.2×10^{-6} Torr utilizing 150 kV Linear Accelerator facility available at Indira Gandhi Centre of Atomic Research, Kalpakkam, India. A low beam current density of 0.40 µA cm^{-2} was used throughout the experiment. The projected range of implanted argon was 200 nm as per SRIM simulations [6].

The dielectric spectroscopic studies of the pre- and post-implanted samples were carried out in frequency range of 100 kHz-50MHz using WayneKerr 6500B Precision Impedence Analyser at room temperature. Variations in the bonding and structure of Ar^+ implanted specimens were analyzed using Perkin Elmer GX2000 Fourier Transform Raman Spectrometer having Nd^{3+}:YAG laser (λ=1064 nm) for excitation.

3. Results and discussion

Fig.1 shows the variation of dielectric constant with frequency for various ion fluences. Dielectric constant of PC samples decreases with increasing ion fluence. This may be due to the fact that implantation generally leads to the scissoning of polymeric chains, formation of free radicals etc. resulting in the formation of new bonds (double, triple bonds etc.) due to which dielectric constant decreases with ion dose [5]. Also there is a slight decrease in the dielectric constant with increase in frequency. The slow migration of charge carriers may be assumed as the cause of decrease in the dielectric constant in higher frequency regions.

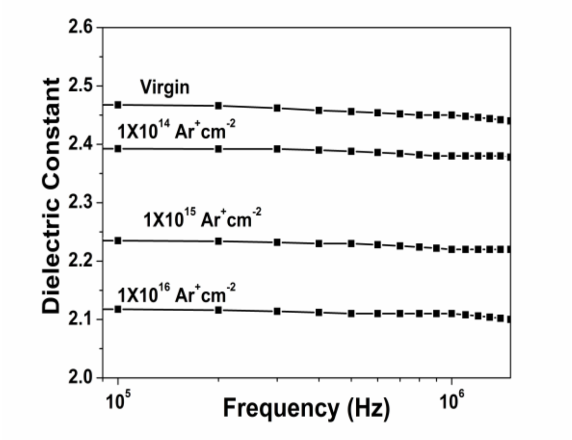

Figure. 1 Variation in dielectric constant with frequency for virgin and implanted PC specimens

Fig. 2 shows the dielectric loss behaviour of virgin and implanted PC specimens. The dielectric loss of PC specimens shows an increasing trend with increasing ion fluence. A loss peak positioned nearly at 40 MHz has been observed for virgin and implanted PC samples. Since this peak corresponds to the vibrations of the main chain hence it can be interpreted that even after implantation the main sources of this dielectric loss peak remain almost unaffected [5].

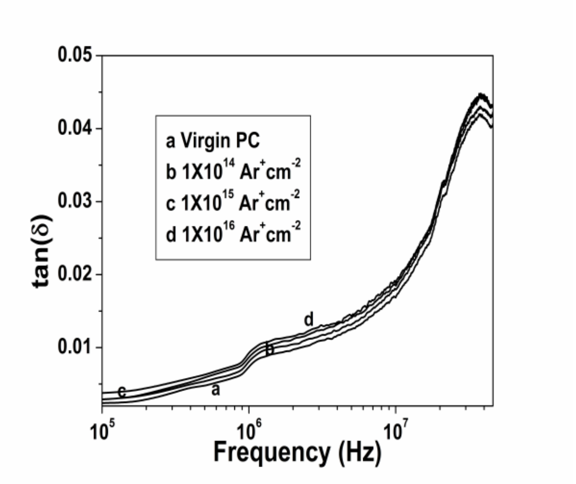

Figure. 2 Variation in dielectric loss with frequency for virgin and implanted PC specimens

Fig. 3 shows the variation in a. c. conductivity of virgin and implanted PC specimens at 40 MHz. The a.c. conductivity of virgin and argon implanted PC specimens has been calculated at 40 MHz by using the following formula [7]:

$$\sigma_{a.c.} = 2\pi f \varepsilon_0 \varepsilon''$$

where σ_{ac} is the a. c. conductivity at frequency, f is the frequency in Hz, ε_0 is the permittivity of free space and ε'' is the imaginary part of the dielectric constant.

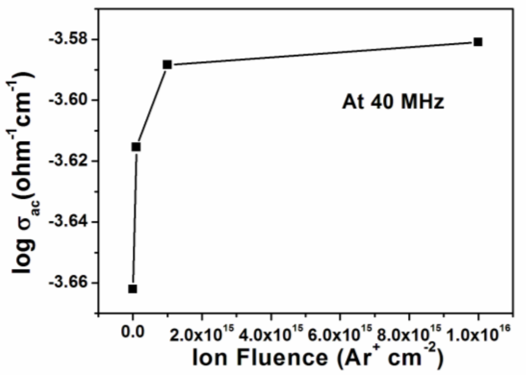

Figure. 3 Plot of a. c. conductivity for virgin and Ar^{+} implanted polycarbonate at 40 MHz

The a. c. conductivity shows an increasing trend with increasing ion fluence. This enhancement in the conductivity of PC may be attributed to the formation of carbon enriched clusters [3, 5] due to implantation. Thus, the formation of π-bonded carbon enriched domains created in the implanted layers of PC may be the main reason behind the modifications in the dielectric constant, dielectric loss and a. c. conductivity.

Fig. 4 presents the Raman spectra of virgin and Ar^{+}-implanted PC specimens.

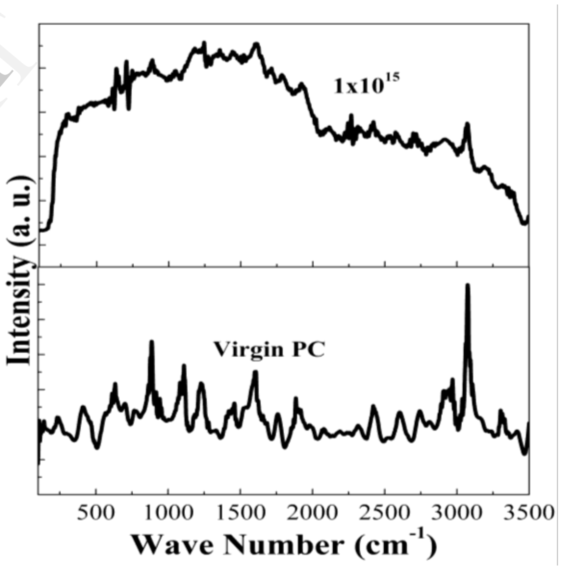

Figure. 4 Raman spectra of virgin and PC implanted at 130 keV to 1×10^{15} Ar^{+} cm^{-2}

The Raman spectrum of virgin PC shows many peaks presenting the vibrational bands of the material. Two intense bands observed at 3072 and 2962 cm^{-1} can be ascribed to C-H stretching mode. A series of weak bands observed in the region 2400–2800 cm^{-1} are overtone and combination bands. The medium intensity band at 1765 cm^{-1} is attributed to C=O stretching mode of PC. The bands at the frequencies of 1601 cm^{-1} and 1495 cm^{-1} are due to the phenyl ring vibrations and CH_3 deformations respectively. The bands observed in the 1000-1300 cm^{-1} frequency regions are attributed to C-O-C stretching vibrations. The strong intensity band at 875 cm^{-1} is due to the C-H out of plane bending modes. The analysis of the vibrational bands of virgin PC confirms its monomer structure [8].

After implantation all the bands between the frequency region 500-2500 cm^{-1} are vanished completely. At higher dose, Raman spectra shows one asymmetric broad band, which extends from 1000 to 2000 cm^{-1} .The characteristic disorder 'D' and graphite like 'G' bands of disordered graphitelike structures which usually appears in implanted polymers may have been merged under this asymmetric broad band [9].

The disappearance of band at 3358 cm^{-1} (which is attributed to the presence of free O-H group) after implantation indicates the complete removal of hydrogen in implanted layers. All these findings suggest that after implantation disordered graphitic carbon structure is formed within the implanted layers of PC [2, 9]. These outcomes also support the changes observed in dielectric properties of implanted PC specimens.

Conclusions

Present study shows the reduction in dielectric constant and enhancement in dielectric loss and a. c. conductivity of PC with increasing ion fluence. The structural changes observed using Raman technique indicates the formation of carbon enriched structure in the implanted polymeric matrix. The formation of such carbonaceous islands may have been the major cause behind the changes observed in dielectric properties of implanted specimens.

Acknowledgement

Authors are thankful to Department of Science and Technology (DST), New Delhi for providing kind support. Mahak Chawla is also thankful to UGC for UGC-BSR fellowship.

References

[1] A. Sharma, S. Aggarwal, P. Kumar and D. Kanjilal, "Kr^{++} Ion Implantation – Induced Changes in Optical Properties of Polycarbonate", Taylor & Francis, UK, *Inter. J. Polym. Mater.*, 62, 2013, 1-4.

[2] T. Sharma ,S. Mahendia, S. Aggarwal, S. Kumar and D. Kanjilal, "100 keV nitrogen ion beam implanted polycarbonate: A possibility for UV blocking devices", *Opt. Mater.,Elsevier*, 33, 2011, 1741–1744.

[3] D. L. Wise, G. E. Wnek, D. J. Trantolu, T. M. Cooper and J. D. Gresser, *Electrical and Optical Polymer Systems: Fundamentals, Methods & Applications*, Marcel Dekker, Inc., New York, 1998.

[4] V. N. Popok, "Ion implantation of polymers: formation of nanoparticulate materials", *Rev. Adv.Mater*., Sci. 30, 2012, 1-26.

[5] D. Fink, *Fundamentals of Ion-Irradiated Polymers*, Berlin, Hedelberg: Springer-Verlag Publishers, 2004.

[6] J. F. Zeigler, M. D. Ziegler and J. P. Biersack, SRIM 2008.04 software package, available online at http://www.srim.org

[7] T. Tunc, M. Gokcen and I. Uslu, "Studies on frequency and gate voltage effects on the dielectric properties of Au/n-Si (110) structure with PVA–nickel acetate composite film interfacial layer", Springer, *Appl. Phys. A*, 109, 2012, 649–653.

[8] D. W. Mayo, F. A. Miller, and R. W. Hannah, *Course Notes on the Interpretation of Infrared and Raman Spectra*, Wiley, New York, 2004.

[9] N. Shekhawat, S. Aggarwal, A. Sharma, S. K. Sharma, S. K. Deshpande and K. G. M. Nair, "Surface disordering and its correlations with properties in argon implanted CR-39 polymer", AIP publisher, *J. Appl. Phys.*, 109, 2011, 083513-083522.