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Dielectric Constant/Dielectric Loss Measurements in Vectra-A, Liquid Crystal Copolyester

Sapna Kalia[1,*], Vandana Sharma[2], J.K. Sharma[2], Rajesh Kalia[3]
[1]Department of Physics, Dayanand Mahila Mahavidyalaya, Kurukshetra-136118, Haryana, India
[2]Department of Physics, Maharishi Markandeshwar University, Mullana (Ambala)- 133207, Haryana, India
[3]Department of Applied Science, University Institute of Engineering and Technology, Kurukshetra-136119, Haryana, India

Abstract

The most significant advantage of studying the charge storage mechanism of Vectra-A, Liquid Crystal Copolyester through Dielectric Spectroscopy (DS) is their complex structure, which can be physically or chemically tailored for specific applications which make it suitable for charge storing devices like Micro-Electro-Mechanical Systems *(MEMS). The variation of dielectric constant (ε') and dielectric loss (ε'') in the temperature interval (25 ºC to 250 ºC) for pristine samples of Vectra-A at different frequencies (1 kHz to 1 MHz) have been investigated.*

Keywords: *Conducting polymer (CP), dielectric constant (ε'), dielectric loss (ε''), dielectric spectroscopy (DS),* Micro-Electro-Mechanical Systems *(MEMS) Vectra-A Liquid Crystal Copolyester*

****Author for Correspondence*** E-mail: skalia19@gmail.com

INTRODUCTION

Polymer-based electronics is attracting the attention of researchers because of their conducting behavior with various doping level and enhanced thermal stability. The applications of such conducting polymers are in the charge storing devices like Micro-Electro-Mechanical Systems (MEMS) [1, 2]. Vectra-A, Liquid Crystal Copolyester is one of the polymers that possess conducting properties after being doped with iodine vapors [3, 4]. Moreover, its thermal stability is also investigated by annealing it at different times [5]. Fundamental investigation of dielectric response yields a wealth of information about different molecular motions and relaxation processes. A unique characteristic of Dielectric Spectroscopy (DS) is the wide frequency range from 10^{-5} Hz to 10^{11} Hz over which polymer respond to an electric field [6, 7]. This remarkable breadth of the frequency range is the key feature that enables to relate the dielectric response to slow frequency and fast high-frequency events.

In DS technique, the dielectric constant, as well as dielectric loss, is measured as a function of frequency and temperature. Dynamic processes from dipoles and charge carriers as kinetics and interactions are merged in a signal plotted against the frequency and temperature [8]. The dynamic processes can be identified by their characteristics frequency of relaxation. The present work carried out for the study of dielectric constant and dielectric loss of pristine samples of Vectra-A.

MATERIAL AND METHOD

The Vectra-A, ivory in color, is procured in the form of a rod having a diameter of 18 millimeters from Good fellow, England. The glass transition temperature of Vectra-A is around 110 ºC and it melts at 280 ºC. It is copolyester of polyhydroxybenzoic acid (PHBA) and polynaphthoic acid (PHNA). In Vectra-A, the incorporation of 2, 6-naphthalylene moieties in 4-hydroxybenzoic acid results in the structural defect and reduction in rigidity of chain. Naphthalene modifiers bring the desired characteristics to the poly (hydroxybenzoic acid) molecule that is a reduction in the melting temperature and the addition of naphthalene group to a hydroxy benzoic group does not change its mechanical, thermal and chemical resistant properties. The dielectric measurements were made at

frequencies ranging from 1 kHz to 1MHz using Agilent 4284A, a precision LCR meter. The sample placed in two probe setup was kept in a digital temperature controlled furnace for heating in steps *i.e.* at a certain temperature sample was kept for almost 10 minutes and the corresponding measurements of capacitance (C) and dissipation factor (D) were made.

RESULTS AND DISCUSSION

Figure 1 and 2 illustrate the behavior of dielectric constant (ε') and dielectric loss (ε'') with the temperature range 30 ºC to 250 ºC, for pristine samples of Vectra-A at frequencies varying from 1 kHz to 1 MHz.

In Figure 1, the curve obtained can be distributed into three regions of temperature:

I) Low-temperature Region (25-50 ºC)

In low-temperature region with the increase in temperature there is a decrease in dielectric constant (ε'), this is according to Kirkwood model which governs the variation in dielectric constant (ε') with temperature in this region [9]. According to Kirkwood's model, in the operational temperature range, if the molecular configuration, as well as inter and intra molecular interactions, are not changed, the dielectric constant is determined by 1/T rule *i.e.* the dielectric constant (ε') should decrease with increasing temperature [9–11].

II) Intermediate Temperature Region (50–150 ºC)

In the intermediate temperature region (50–150 ºC) dielectric constant (ε') increases with temperature the increase in temperature. The dielectric constant (ε') increases this region due to dipolar relaxation as obtained in glass transition temperature around 110 ºC of Vectra-A [12]. In this region, the dielectric constant (ε') increases with the increase in temperature which is due to dipolar polarization. The dielectric constant (ε') decreases with increase in frequency that is due to increase in crystallinity. The crystallinity increases above glass transition temperature [13]. Hence two opposite mechanism in this region makes dielectric constant (ε') nearly independent of temperature [5, 13].

III) High-temperature Region varying from 150-250 ºC

In high-temperature region (150–250 ºC), there is an increase in dielectric constant (ε') with an increase in temperature up to 220 ºC. The increase in dielectric constant (ε') with an increase in temperature is due to the space charge phenomenon. The space charge phenomenon comes into play because the charge carriers get trapped by unsaturated ester and carbonyl groups [5]. Also, The Maxwell-Wagner-Sillars effect in liquid crystal polymers, which arises due to the presence of amorphous as well as crystalline phase, is significant [14, 15].

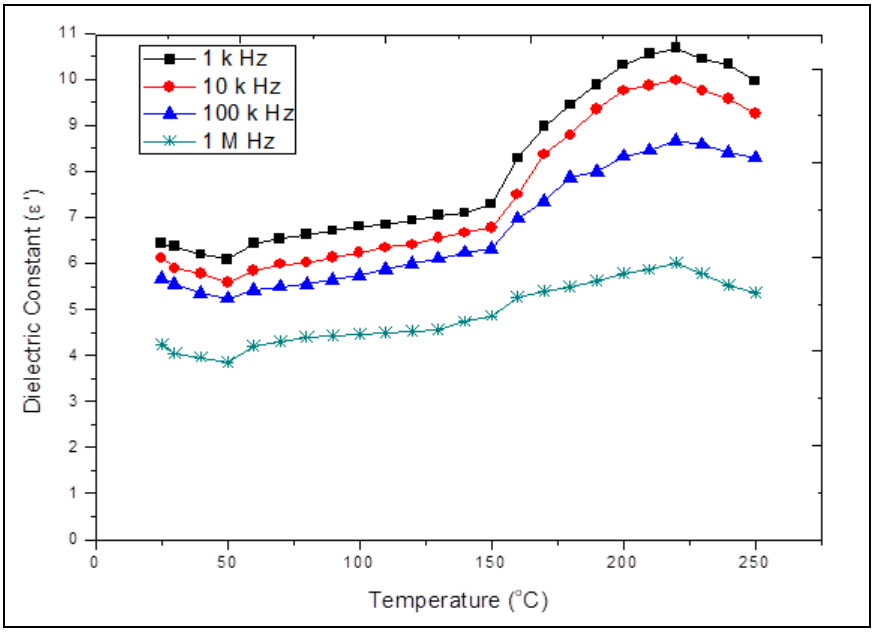

Fig. 1: *Variation of Dielectric Constant (ε') with Temperature for Pristine Vectra-A Samples at Frequencies; 1 k Hz, 10 k Hz, 1^{0}0 k Hz and 1M Hz.*

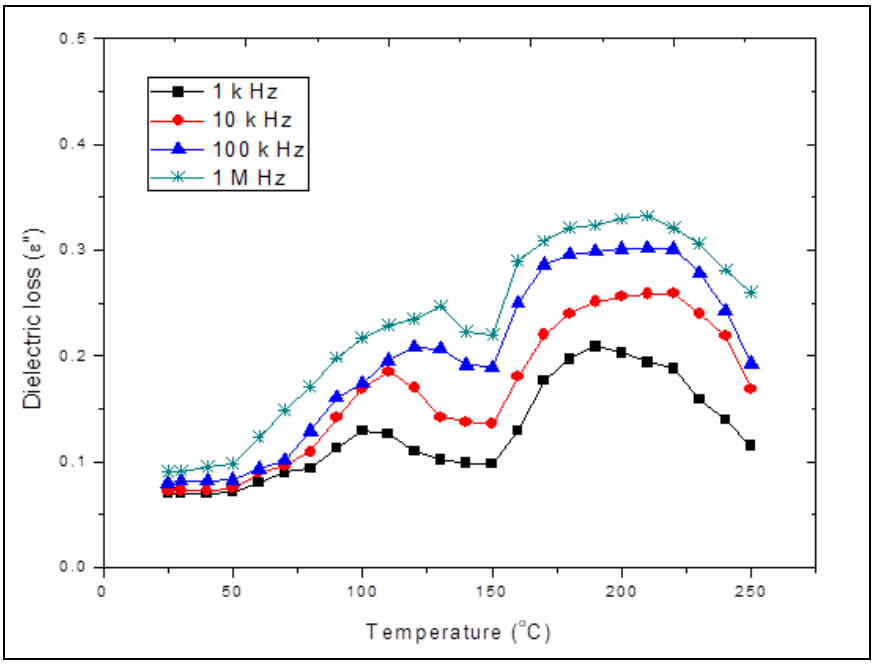

Fig. 2: *Variation of Dielectric Loss (ε'') with Temperature for Pristine Vectra-A Samples at Different Frequencies; 1 k Hz, 10 k Hz, 100 k Hz and 1 M Hz.*

There is a decrease in dielectric constant (ε') above 220 °C because in this region the crystalline phase enters into the melt region of Vectra-A. The onset of melting in Vectra-A is already discussed in the TSDC analysis and is in accordance with Chung *et al*. [13].

The variation of dielectric loss (ε'') *vs.* temperature (T) for three temperature regions that are low temperature region (25–50 °C), middle temperature region (50–150 °C) and high temperature region [150–250 °C] are illustrated in Figure 2. The dielectric loss (ε'') *vs.* temperature (T) of Vectra-A for low-temperature region (25–50 °C), shows no dielectric loss peak in middle-temperature region (50–150 °C) there is peak observed owing to glass transition temperature and at high-temperature region (150–250 °C) space charge peak is observed because conduction current that is followed by a decrease in dielectric loss (ε'') with an increase in temperature. The results obtained for dielectric loss (ε'') are in agreement with a variation of dielectric constant (ε') with temperature for pristine samples of Vectra-A.

CONCLUSION

The behavior of dielectric constant (ε') and dielectric loss (ε'') with the temperature range 30–250 °C, for pristine samples of Vectra-A at frequencies varying from 1 kHz to 1 MHz, have been studied. A dipolar peak which is expected ~ 30 °C in Vectra A due to the orientation of ester linkage at low temperature. This peak is not observed in dielectric constant (ε') *vs.* temperature (T) curve because the dielectric constant (ε') is almost independent of temperature as explained by the Kirkwood model.

The peak of dielectric loss around 110 °C ensures the glass transition temperature which arises due to the alignment of the main chain of Vectra-A. In the temperature region (150–220 °C), dielectric constant (ε') increases due to the space charge trapping phenomenon.

Hence, the conducting character of the polymer is revealed and can be utilized for micro-sized charge storing devices.

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