ELSEVIER

October 2002

Materials Letters 56 (2002) 248–251

MATERIALS LETTERS

www.elsevier.com/locate/matlet

Dielectric properties of ionomers at microwave frequencies

K.T. Mathew [a,*], S. Biju Kumar [a], Anil Lonappan [a], Joe Jacob [a], Jacob Samuel [b], Thommachan Xavier [b], Thomas Kurian [b]

[a] *Department of Electronics, Cochin University of Science and Technology, Kochi-682 022, India*
[b] *Department of Polymer Science and Rubber Technology, Cochin University of Science and Technology, Kochi-682 022, India*

Received 7 October 2001; accepted 15 November 2001

Abstract

Ionic polymers (ionomers) with interesting characteristics are emerging as important commercial polymers. Ionomers have the unique ability to behave as cross-linked materials at ambient temperatures and to melt and flow at elevated temperatures like thermoplastics. The complex permittivity and conductivity of a class of ionomers at microwave frequencies are determined using the cavity perturbation technique and the results are presented.

Keywords: Ionomers; Complex permittivity; Microwaves; Cavity perturbation technique

1. Introduction

Ionic polymers or ionomers basically contain a small percentage of ionic groups attached to a hydrocarbon backbone. The ionic interaction between the groups results to significant changes in polymer properties [1–3]. The ionomer has an intermediate position between purely organic and purely inorganic structures. Considering the thermally reversible behaviour and enhanced mechanical properties, it seems to be an ideal material for many applications.

Very little is known about the microwave properties of ionomers. Microwave study on the dielectric properties of these materials reveals some interesting observations. A detailed study on the complex permittivity, loss tangent and conductivity at four different frequencies in S band (2–4 GHz) for the different ionomer samples is presented.

2. Principle

Cavity perturbation technique [4] is employed for the study. Closed section of a waveguide constitutes a waveguide cavity resonator. The cavity resonator can be of transmission or reflection type. Electromagnetic energy is coupled to the cavity through coupling holes at the ends of the cavity. A nonradiating slot is provided at the broad wall of the cavity for the introduction of the sample. The cavity resonates at different frequencies depending on its dimensions. The schematic diagram of the transmission type cavity is shown in Fig. 1.

The basic principle involved in the technique is that the field within the cavity resonator is perturbed by the introduction of the dielectric sample through the non-

* Corresponding author. Tel.: +91-484-532161; fax: +91-484-532800.
E-mail address: mathew@doe.cusat.edu (K.T. Mathew).

0167-577X/02/$ - see front matter
PII: S0167-577X(02)00450-0

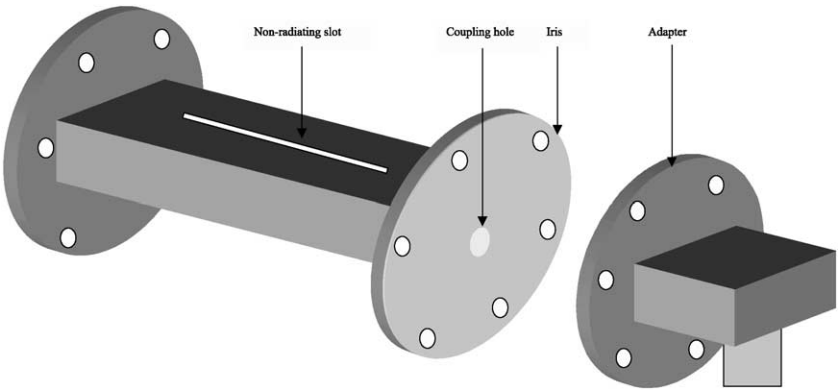

Fig. 1. Schematic diagram of the cavity resonator.

radiating slot. The resonant frequency and the quality factor of the cavity get shifted by the perturbation. The shift in the frequency is a measure of dielectric constant and that in quality factor gives the loss factor. The conductivity of the sample can be found out from the loss factor.

3. Sample preparation

Samples were prepared by sulphonation of high-styrene resin (HSR) using the sulphonating agent, acetyl sulphate, generated in situ, from acetic anhydride and concentrated sulphuric acid. The HSR sulphonic acid produced was neutralised by a solution of zinc acetate in methanol. The zinc-sulphonated HSR was washed several times with water and then it was vacuum-dried at 50 °C. This ionic polymer is hereafter represented as *xy* ZnS–HSR, where *xy* shows the number of milliequivalents of sulphonic acid per 100 g of HSR. Five samples were considered, they are I_0, I_{10}, I_{20}, I_{30} and I_{40}. I_0 represents the pure HSR. I_{10}, I_{20}, I_{30} and I_{40} indicate 10.6, 20.4, 34.38 and 42.7 milliequivalents of sulphonate per 100 g of HSR. Quantity of sulphonate is analysed using X-ray fluorescence (XRF) method.

4. Experimental set-up

The experimental set-up consists of a transmission type S-band rectangular cavity resonator, HP 8714 ET network analyser and an interfacing computer as shown in Fig. 2. The cavity resonator is excited in the TE_{10p} mode. A typical resonant frequency spectrum of the cavity resonator is shown in Fig. 3. Initially, the resonant frequency f_o and the corresponding quality factor Q_o of each resonant peak of the empty cavity are

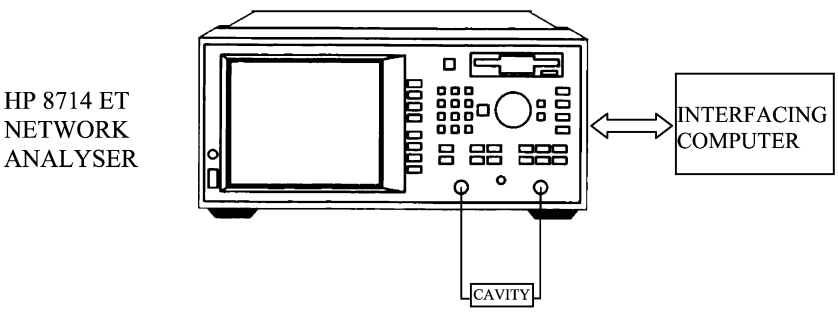

Fig. 2. Experimental set-up.

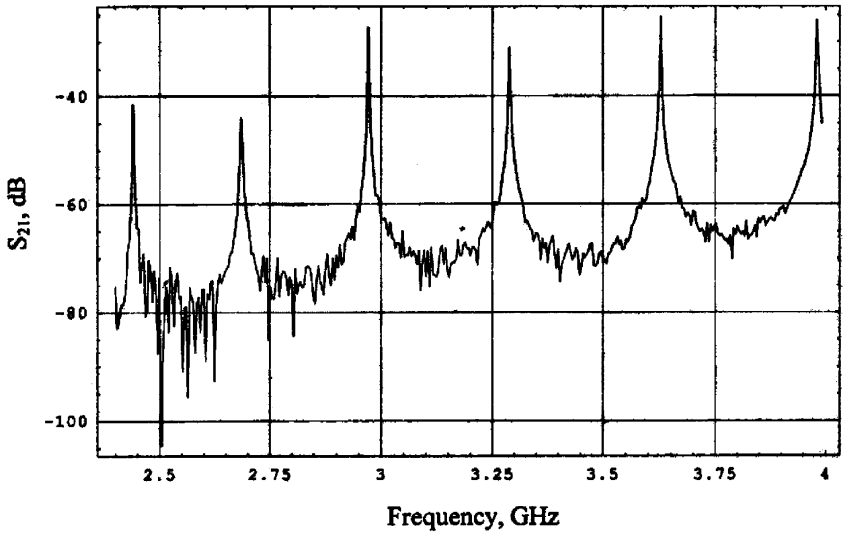

Fig. 3. Resonant frequency spectrum of cavity resonator.

determined. Samples prepared in the form of thin strip are introduced into the cavity resonator through the nonradiating slot. One of the resonant frequencies of the loaded cavity is selected and the position of the sample is adjusted for maximum perturbation (i.e. maximum shift of resonant frequency with minimum amplitude for the peak). The new resonant frequency f_s and 3-dB bandwidth and hence, the quality factor Q_s are determined. The procedure is repeated for other resonant frequencies.

Table 1
Dielectric properties of ionomer samples at different microwave frequencies

Frequency (GHz)	Sample	$\varepsilon'_r - 1$	ε''_r
2.246	I_0	1.426	0.0026
	I_{10}	0.347	0.0281
	I_{20}	1.465	0.0576
	I_{30}	1.718	0.0594
	I_{40}	1.853	0.1281
2.438	I_0	1.393	0.0084
	I_{10}	1.533	0.0369
	I_{20}	1.623	0.0624
	I_{30}	1.732	0.0694
	I_{40}	1.889	0.0980
2.683	I_0	1.427	0.0129
	I_{10}	1.689	0.0394
	I_{20}	1.620	0.0657
	I_{30}	1.747	0.0704
	I_{40}	1.891	0.1007
2.970	I_0	1.378	0.0084
	I_{10}	1.538	0.0384
	I_{20}	1.582	0.0637
	I_{30}	1.718	0.0714
	I_{40}	1.875	0.0962

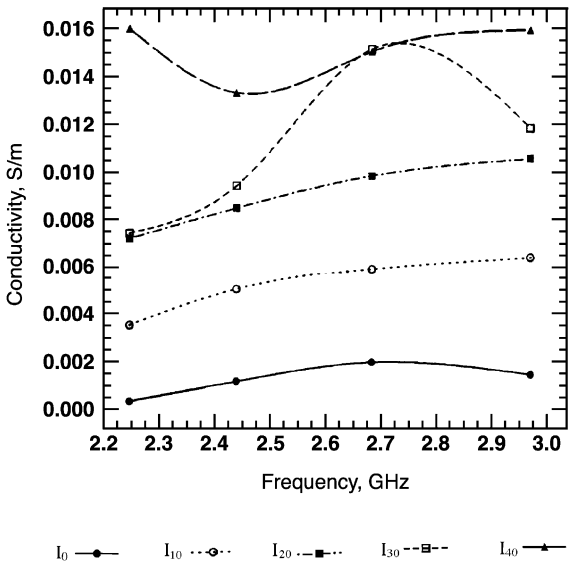

Fig. 4. Variation of conductivity of ionomers with frequency.

5. Theory

According to the theory of cavity perturbation, the complex frequency shift is related as [5]:

$$-\frac{d\Omega}{\Omega} \approx \frac{(\overline{\varepsilon_r}-1)\int_{V_s} EE_0^* dV}{2\int_{V_c}|E_0|^2 dV}. \quad (1)$$

But,

$$\frac{d\Omega}{\Omega} \approx \frac{d\omega}{\omega} + \frac{j}{2}\left[\frac{1}{Q_s} - \frac{1}{Q_0}\right]. \quad (2)$$

Equating (1) and (2) and separating real and imaginary parts, we get:

$$\varepsilon_r' 1 = \frac{f_o - f_s}{2f_s}\left(\frac{V_c}{V_s}\right) \quad (3)$$

$$\varepsilon_r'' = \frac{V_c}{4V_s}\left(\frac{Q_o - Q_s}{Q_o Q_s}\right) \quad (4)$$

Here, $\overline{\varepsilon_r} = \varepsilon_r' - j\varepsilon_r''$; $\overline{\varepsilon_r}$ is the relative complex permittivity of the sample, ε_r' is the real part of the relative complex permittivity, which is usually known as dielectric constant, and ε_r'' is the imaginary part of the relative complex permittivity, which is associated with the dielectric loss of the material. V_s and V_c are the volumes of the sample and the cavity resonator, respectively.

The conductivity can be related to the imaginary part of the relative dielectric constant as:

$$\sigma_e = \omega\varepsilon'' = 2\Pi f \varepsilon_0 \varepsilon_r'' \quad (5)$$

6. Results and discussion

The dielectric properties of ionomers at microwave frequencies are determined and tabulated in Table 1. It is found that as the zinc content in the HSR increases, the dielectric constant remains nearly the same but the imaginary part of the complex permittivity increases drastically. The variation of conductivity of the sample with frequency is shown in Fig. 4. Ionic polymer has numerous potential applications in plastic industry, package industry[6], electrophotography [7,8] and dentistry [9]. Because of its high thermal stability, mechanical strength and high conductivity, it is superior to conducting polymer [3]. The microwave applications of ionomers are yet to be explored. The possibilities of using ionomers in microwave monolithic integrated circuits (MMIC) and microwave devices can be investigated.

References

[1] D.Y. Chao, J. Kuo, N.H. Wang, C.L. Lee, K.H. Yang, J. Appl. Polym. Sci. 67 (1998) 19.
[2] J.-W. Lee, C.-H. Kim, J.-K. Park, T.-S. Hwang, Polym. Int. 45 (1998) 47.
[3] J. Samuel, T. Xavier, T. Kurian, Prog. Rubber Plast. Technol. 16 (2000) 1.
[4] K.T. Mathew, U. Raveendrannath, Sensors Update (Ger.) 7 (1999) 185.
[5] U. Raveendranath, K.T. Mathew, J. Mol. Liq. 68 (1996) 145.
[6] W.J. MacKnight, R.D. Lundberg, Thermoplastic Elastomers (Munich), 1987.
[7] J.S. Tan, NATO ASI Series C: Mathematical and Physical Sciences, vol. 198, Reidel, Dordrecht, 1987, p. 439.
[8] A. Diaz, D. Fenzel-Alexander, D.C. Miller, D. Wollmann, A. Eisenberg, J. Polym. Sci., Part C: Polym. Lett. 28 (1990) 75.
[9] L. Stanislawski, E. Soheili-Majd, A. Perianin, M. Goldberg, J. Biomed. Mater. Res. 51 (2000) 469.