Effect of Molecular Weight on Dielectric Properties of Polyvinyl Alcohol Films

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ABSTRACT: Impedance analysis is the best technique to reveal the microstructural details of the polymeric material. The dielectric polarization not only depends on physical and chemical properties, but also on the degree of polymerization (DP) of the polymeric material. In the present study, to understand the polarizing mechanism, two different molecular weights of polyvinyl alcohol (PVA) films were used for impedance analysis. Dielectric polarization of PVA film measured at normal temperature and pressure (NTP) condition by using LCR-4282A Impedance analyzer, within the frequency range 20 Hz to 1 MHz. The importance of investigation is to know the simultaneous application of DC bias potential from 0 to 40 V with AC signal for measurement of over all electrical parameters. The result shows higher magnitude of dielectric constant for low-molecular weight (LMW) of PVA film in comparison to higher molecular weight (HMW), which is based on Maxwell-Wagner (M–W) theory. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 102: 1014–1016, 2006

Key words: impedance analysis; DC bias potential

INTRODUCTION

The basic properties of PVA depend on its degree of polymerization and hydrolysis. Most common commercial grades are classified by the percentage of hydrolysis and degree of polymerization. With expansions of the commercial applications, many grades of PVA have been made available: (a) a fully hydrolyzed group with degree of hydrolysis above 98% and (b) a partly hydrolyzed group with 87–89% hydrolysis. Higher the degree of hydrolysis, higher is the molecular weight and vice versa.[1] Most of the workers reported the dielectric properties and relaxation mechanism of polymer PVA either in the pure or composite form.[2–6] By knowing the various grades of polymer PVA, and the degree of hydrolysis that related to the molecular weight (MW), it was thought interested to study the dielectric properties of HMW and LMW of PVA film as function of frequency for various DC bias potential from 0 to 40 V, at NTP condition. This investigation is rather new approach to study the dielectric polarization with help of clipped signal condition.

EXPERIMENTAL

Polymer PVA in the granular form of two different hydrolyzed grades 125,000 g/mol and 1700–1800 g/mol were supplied by S.D. Fine Chem., Mumbai, and is used for synthesis of PVA film by solution-casting method.

LCR-4282A impedance analyzer

The dielectric constant and loss were measured by using the Impedance analyzer make Aglient 4282A precision LCR meter. Guard electrode contact method was adopted with sample size 40 mm diameter PVA film, silver pasted from both sides. The relative dielectric constant confirmed by measuring the out plane capacitor (C_p) with the formula relative dielectric constant[7] (ε) = $C_p \times 9.96 \times 10.^9$ All the measurements were carried out at NTP condition within the frequency range 20 Hz to1 MHz for various DC bias potential from 0 to 40 V. The specialty of this Impedance analyzer is the inbuilt DC bias potential variation facilities, which enables to apply simultaneously DC potential along with AC signal for measuring over all the electrical parameters. The fixture assembly attached with this instrument designed to take observations at NTP condition only.

RESULTS AND DISCUSSION

Role of DC bias potential

The applications of DC bias potential (influence of direct field) from 0 to 40 V simultaneously along with AC signal clip the peaks of an AC.[8–9] The clipped

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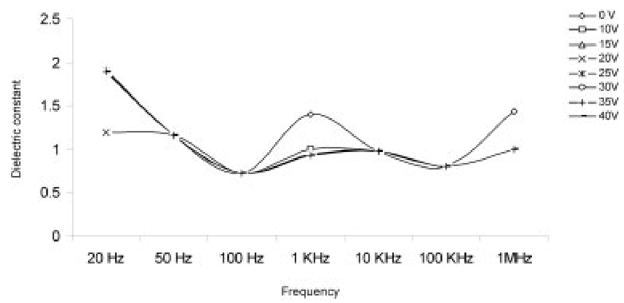

Figure 1 Dielectric constant as function of frequency-HMW of PVA film.

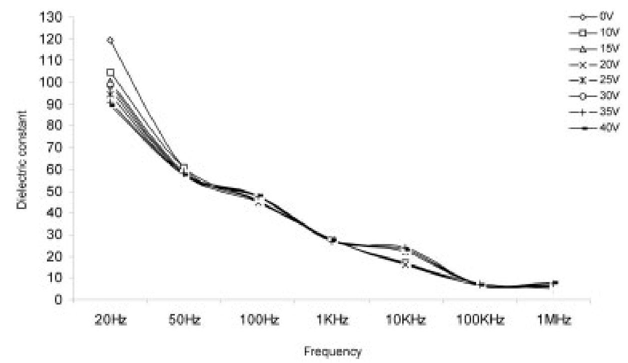

Figure 3 Dielectric constant as function of frequency-LMW of PVA film.

signal polarize the chain molecules of the polymer PVA, and the comparative electrical parameters recorded by LCR meter as function of frequency for various DC bias potential of PVA film at NTP condition.

Dielectric polarization of PVA film

Dielectric properties of alcohol and diols have attracted the attention of many workers. There is great agreement that these molecules associate into various species. The precise nature of these species and parameters governing the various associative equilibrium are still very much interested and debatable; dielectric studies an alcohols and diols have revealed that dielectric dispersion is attributed to the OH-group reorientation, whereas the intermediate dispersion is suggested to be a contribution from molecular rotation due to an end group of liner polymer and or a smaller polymer reorientation. The low-frequency dispersion is a dominated process and is characterized by a simple Debye nature. Altogether, numerous studies have been carried out on various types of alcohols as pure liquid, in solution and even in the solid state.[10] Figure 1 shows the plot of dielectric constant (ε) as function of frequency for high molecular weight of PVA film. ε Values was maximum at 20 Hz frequency, $\varepsilon = 15.1$ at 0 V bias potential and $\varepsilon = 18.97$ at 40 V bias potential. The second dielectric polarization was observed at 1 KHz with $\varepsilon = 13.94$ to 9.26 for bias potential 0 to 40 V. It was observed that at 1 KHz frequency these ε values were inversely proportional to the applied bias voltage across the sample PVA film. This may be due to OH chain molecular polarization; then, the trend was found decreasing at 1 MHz frequency $\varepsilon = 14.31$; at higher frequency, the ε values shows the proportionality relation with applied bias voltage.[10] PVA film of higher molecular weight shows the dielectric polarization maximum at lower frequency. Figure 2 shows the dielectric loss of PVA film higher molecular weight; dielectric loss (ε') was found maximum at lower frequency with values $\varepsilon' = 0.725$ for all bias potentials. At 1 KHz, the loss trend was found with second maxima 0.55 to 0.042 for 0 to 40 V bias potential, respectively. At higher frequencies loss values were directly proportional to bias potential applied at 1 MHz. Dielectric constant as function of frequency for low-molecular weight PVA film is plotted in Figure 3. It was observed that at lower frequency 20 Hz dielectric polarization was maximum with values $\varepsilon = 119.221$ to 89.64 for bias potential 0 to 40 V respectively. As the bias voltage increases, dielectric constant peak decreases at 20 Hz frequency. In case of low molecular weight of polymer PVA film, ε value was inversely proportional to bias potential. Further in-

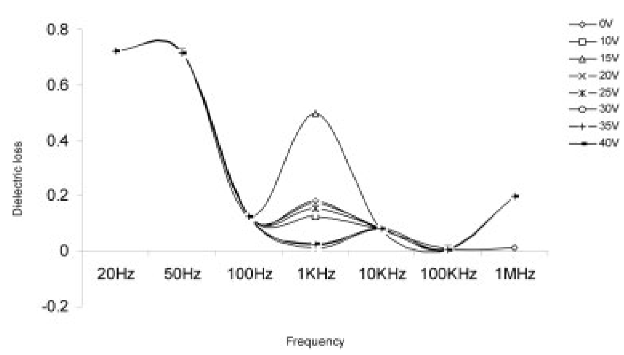

Figure 2 Dielectric loss as function of frequency-HMW of PVA film.

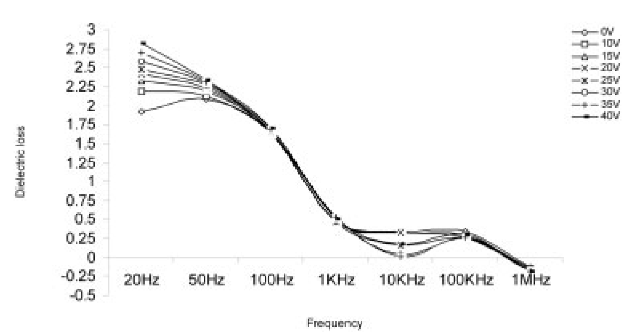

Figure 4 Dielectric loss as function of frequency-LMW of PVA film.

TABLE I
Comparative Electrical Parameters Recorded by LCR Meter as a Function of Frequency for Various DC Bias Potential of PVA Film at NTP Condition

Parameters	HMW PVA film	LMW PVA film
Out plane capacitor C_p	235 nF, 0 V, 20 Hz	11.97 nF, 0 V, 20 Hz
In plane capacitor C_s	290 nF at, 0 V 20 Hz	81 nF, 40 V, 20 Hz
Dielectric constant ε	900 at 20Hz	119.221, 0 V, 20 Hz
Dielectric loss ε'	0.774, 40V at 50Hz	2.82, 40V, 20Hz
Out plane Resistance R_p	78 M-Ω, 35 V, 1 KHz	388 KΩ, 20 V, 20 Hz
In plane Resistance R_s	304 M-Ω, 0 V, 20 Hz	284 KΩ, 30 V, 20 Hz
Impedance Z	33.79 M-Ω, 40 V, 20 KHz	311.13 KΩ, 20 V, 20 Hz
Reactance X	9.76 M-Ω, 10 V, 50 Hz	−140 K-Ω, 0 V, 20 Hz
Conductance G	138 μs, 15 V, 1 MHz	156 μs, 0 V, 100 KHz
Sucepetance B	1.31 m-s, 1 MHz	463 μs, 0 V, 100 KHz
Admittance Y	147 μs, 0 V, 100 Hz	24.1, 40 V, 10 KHz
Phase angle θ	136°, 0–10 V, 20–50 Hz	100° , 0–40 V, 1 MHz
Quality factor Q	11.3, 30 V, 1 MHz	24.1, 40 V, 10 KHz

crease in frequency ε trend was found decreasing at higher frequency. ε Values are directly proportional to bias potential, i.e., at 1 MHz frequency, $\varepsilon = 5.08$ to 7.65 for 0 to 40 V bias potential respectively. Figure 4 shows the plotted dielectric loss as function of frequency for low molecular weight PVA film;[11,12] maximum dielectric loss (ε) was observed at lower frequency. The magnitudes of dielectric loss values are directly proportional to bias voltage applied across the sample with values $\varepsilon' = 1.92$ to 2.28, for 0 to 40 V respectively, at 20 Hz frequency, and at higher frequency 1 MHz, the dielectric loss trend was found negative.

CONCLUSIONS

From the present investigation, it was clear that the electric properties of polymer PVA film not only depend on the MW but also on the DC bias potential applied across it at lower frequency (Table I).

1. The comparative magnitude of dielectric constant was directly proportional to applied DC bias potential in case of LMW of PVA film whereas inversely proportional to the HMW at lower frequency.
2. The comparative magnitude of dielectric loss trend was found directly proportional to applied DC bias potential for LMW of PVA film whereas inversely proportional to the HMW of PVA film at lower frequency.
3. The magnitudes of conductance, admittance, susceptance, and out-plane resistance trend were inversely proportional to the applied DC bias potential, and no significant impact was observed over impedance trend of HMW of PVA film, whereas these parameters for LMW admittance and conductance trend are directly proportional to the applied DC bias potential at higher frequency.
4. The magnitude of in-plane resistance was found directly proportional to the applied DC bias potential at lower frequency.
5. Basically, the quality (Q)-factor is a measure of a resonant system. Resonant system responds to frequencies close to their natural frequency much more strongly than it responds to other frequencies. The Q-factor indicates the amount of resistance to resonance system. Q-factor magnitude is directly proportional to the applied DC bias potential for both LMW and HMW of the PVA film at higher frequency.

The splitting magnitude of the various electrical parameters under the clipped signal is the major achievement of this work, hence may be utilized not only for sensing application but also as biocompatible material.

References

1. Flinch, C. A. Polyvinyl Alcohol Properties and Applications, Wiley: New York; 1971, p 18.
2. Sengwa, R. J.; Kaur, K. Indian J Eng Mater Sci 2003, 492.
3. Abed Al-Kedar, F. H. J Appl Polym Sci 2001, 39, 1471.
4. Zone, C. D.; Lopez, A. A.; Carmen, M. J Ploym Sci Part B: Ploym Phys 2001, 39, 1968.
5. Hodge, R. H.; Dastow, T. J.; Edward, G. H.; Simon, G. P.; Hill, A. J. Macromolecules 1996, 29, 8137.
6. Khalaed, M. A.; Elwy, A.; Hussein, A. M.; Abdullah, K. Egypt J Sol 2003, 26, 83.
7. Riande, E.; Diaz-Calleja, R. Electrical properties of polymers; Marcel Dekker: New York, 2004.
8. Taylor. Physics of Dielectric Materials; Mir Publication: Moscow, 1971.
9. Vijaya, S. M.; Rangarajan, G. Material Science; Tata Mc. Hill Publishing Company: New Delhi, 2003.
10. Abed-Messien, S. L.; Mohamed, M. G.; Mazrouaa, A. M.; Soliman, A. J Appl Polym Sci 2002, 85, 271.
11. Joshi, G. Proceedings of National Conference on Ferroelectrics and Dielectric (NSFD-XIII); Allied Publisher Pvt. Ltd: New Delhi, 2004; pp 343–346.
12. Available at www.geocities.com/nsfd13/abstract.