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The Electromechanical Properties of SEBS and SEBS-*g*-MA Dielectric Elastomer Gels

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*Electromechanical strain responses of a poly (styrene-*b*-ethylene-*co*-butylene-*b*-styrene) (SEBS) and a maleic anhydride grafted poly (styrene-*b*-ethylene-*co*-butylene-*b*-styrene) (SEBS-*g*-MA) dielectric elastomer gels have been investigated via an* in-situ *synchrotron SAXS. The gels had the periodic nanostructures where there was glassy styrene micelles acting as physical crosslink points in the oil swelled rubbery EB matrix. The electromechanical strain of the gel was evaluated from its nanostructure dimension change monitored by the synchrotron SAXS during the electromechanical actuation. The strain was increased with electric field strength. The SEBS-*g*-MA gel had the higher electromechanical strain response than the SEBS gel at the same electric field.*

Keywords Dielectric; electromechanical strain; SEBS; synchrotron SAXS

Introduction

Since last two decades there has been a fast growing interest in electroactive dielectric elastomers being capable of converting electrical energy to mechanical force or movement because they had a lot of advantages such as a high electromechanical strain ($>50\%$ strain), fast response (<1 msec), high elastic energy density ($\sim 1\,\mathrm{Jcm^{-3}}$), low cost, light weight, and facile processibility [1–4]. It has been considered as a candidate material for sensors, transducers, micro air vehicles, flat-panel speakers, haptic devices, and artificial muscles.

The operational principle of a dielectric elastomer is an electrostatic force between oppositely charged compliant electrodes, called the Maxwell stress [5,6]. The coulomb interaction causes the film compression in thickness direction and expands in literal direction. The electric field-induced strain along the thickness

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direction, s_z is calculated according to Eq. (1).

$$s_z = -\frac{\varepsilon_0 \varepsilon_r E^2}{Y} \tag{1}$$

where ε_0 and ε_r are the vacuum dielectric permittivity and the dielectric constant of the sample. E and Y are the electric field and a compressive modulus, respectively. Electromechanical response of a dielectric elastomer is significantly influenced by the dielectric constant and compressive modulus [2,6,7].

In recent, Shankar *et al.* reported that a poly (styrene-*b*-ethylene-*co*-butylene-*b*-styrene) (SEBS) triblock copolymer gel consisting of disordered hard styrene micelles and oil swollen EB block matrix, showed excellent electromechanical performance as well as a great tunability of their properties at the relatively low electric field. The performance enhancement was attributed to the strong surface polarization of styrene domain [2,4,8].

In this article, electromechanical strain responses of the SEBS and SEBS-*g*-MA gels are compared in order to investigate the effect of the dielectric constant of the matrix domain in the multiphase system. The SEBS-*g*-MA is a modified SEBS in which EB block is chemically grafted with maleic anhydride groups. A thickness strain of the gels is measured by using the *in-situ* synchrotron SAXS.

Experimental

Materials

A poly (styrene-*b*-ethylene-*co*-butylene-*b*-styrene) (Kraton G1650) (SEBS), and a poly (styrene-*b*-ethylene-*co*-butylene-*b*-styrene) triblock copolymer grafted with 1.7 wt% of maleic anhydride (Kraton FG1901X) (SEBS-*g*-MA) were purchased from Kraton Polymers LLC. Each triblock copolymer was including a 30 wt% S block. A paraffin oil (T150) obtained from Michang Oil Ind. Co. was used as a plasticizer. The SEBS and SEBS-*g*-MA gels were consisting of 20 wt% a triblock copolymer and 80 wt% a paraffin oil. The oil selectively swelled the EB midblock. The gels were prepared by using internal mixer at 100°C. After the mixing step, the film 0.5 mm thick was made by hot-pressing at 100°C. Circular compliant electrodes were spin-coated with carbon paste (FTU-20, ASAHI Chem. Research Lab. Co. Ltd.) on both sides of the film.

Characterization

The dielectric constant of the gel film was measured by HP1492A Impedance analyzer with Agilent dielectric test fixture 16451B at 1 kHz at room temperature. A compressive modulus was measured by using Instron 5883 according to ASTM D395. The electric voltage was delivered to the film by using a function generator, Agilent 33250A amplified by a factor of 1000 through a high voltage lock-in amplifier, Trek 10/10B. The synchrotron SAXS was performed at 4C1 SAXS beamline in Pohang Light Source for the electromechanical strain measurement of the dielectric elastomer. An incident x-ray beam was exposed perpendicular to the film surface. *In-situ* SAXS data were obtained via 20 seconds data accumulation under a predetermined external electric field.

Results and Discussions

Figure 1 presents a schematic of thickness strain measurement for the dielectric elastomer gels by using an *in-situ* synchrotron SAXS during electromechanical actuation. The gel has the periodic nanostructure. Incident x-ray beam goes through the sample film surface and is parallel to the applied electric field. Synchrotron SAXS monitors the nanostructure dimension change in elastomer gels. The triblock copolymer based thermoplastic elastomers like the SEBS and SEBS-g-MA gels have been well known as a material satisfying an affine deformation [9,10]. If the sample is incompressible and follows symmetric planar extension under external electric field, The thickness strain, s_z can be evaluated by using the nanostructure dimension change (d/d_0) in the sample according to Eq. (3) [11].

$$\frac{\lambda_z}{\lambda_{z_0}} = \frac{1}{\left(\frac{\lambda_x}{\lambda_{x_0}}\right)^2} \approx \frac{1}{\left(\frac{d}{d_0}\right)^2} \tag{2}$$

$$s_z = \frac{1}{\left(\frac{d}{d_0}\right)^2} - 1 \tag{3}$$

where d_0 and λ_0 are a mean domain spacing of the nanostructure and a bulk dimension of the sample without an external electric field, respectively. d and λ are the dimensions with an applied electric field. The domain spacing, d is simply calculated by Bragg's law.

Figure 2 shows synchrotron SAXS patterns of the SEBS gel during actuation. Without electric field, the SEBS gel had one broad reflection peak, indicating it had disordered micelle structure. As the electric field was applied, the reflection maximum position got shifted to the low q with the electric field. It means that the average-inter micelle spacing in micro-phase increased with the electric field. A SEBS-*g*-MA gel shows the almost same electric field dependency in the SAXS pattern as the SEBS.

The thickness strain of elastomer gel as a function of various applied electric field is presented in Figure 3. The measured strain is quadratically increased with

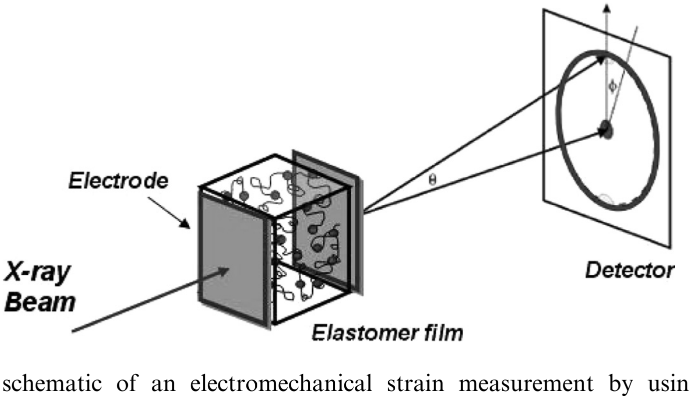

Figure 1. A schematic of an electromechanical strain measurement by using an *in-situ* synchrotron SAXS.

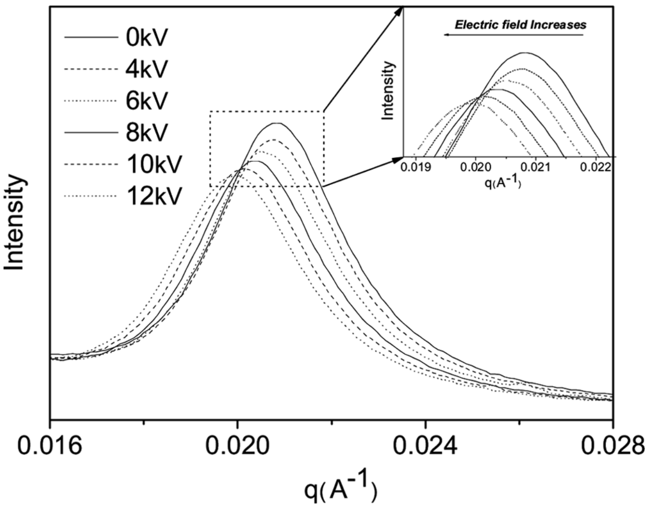

Figure 2. SAXS patterns of the SEBS gel as a function of the applied electric field.

the electric field as expected from Eq. (1). The SEBS-*g*-MA gel had higher electromechanical thickness strain than the SEBS gel at the same electric field strength. It must be caused by introduction of maleic anhydride groups to the SEBS. Dielectric constants of the SEBS and SEBS-*g*-MA gels were 2.36 and 2.65, respectively. The higher dielectric constant of the SEBS-*g*-MA gave a favorable influence on true thickness strain of elastomer gels. However, the SEBS and the SEBS-*g*-MA had similar compressive modulus of 0.415 and 0.406 MPa, respectively. The dielectric constant difference between the SEBS and the SEBS-*g*-MA was less than 13%, while the measured strain difference was more than 50%. It means that there was another

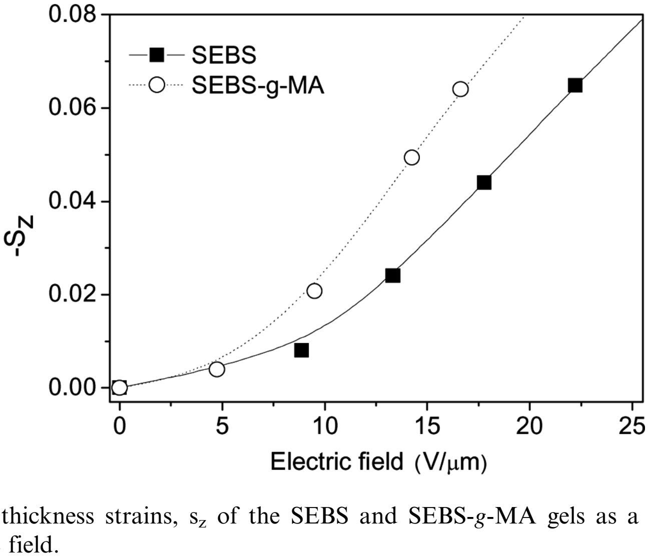

Figure 3. The thickness strains, s_z of the SEBS and SEBS-*g*-MA gels as a function of an applied electric field.

factor more significant than Maxwell stress contribution in the SEBS and SEBS-*g*-MA gels. One reason might be the development of an inhomogeneous electric field across the film thickness [4,8,11,12]. The SEBS and SEBS-*g*-MA are typical nanostructured multiphase systems. Polystyrene domains have a relatively higher permittivity than EB matrix. An inhomogeneous electric field can be developed across the film thickness because of interfaces between dielectric mismatched nanoscale domains in the SEBS and SEBS-*g*-MA. The nonuniform electric field can enhance the strain response, because the relationship between the strain and electric field in a dielectric elastomer is described by a quadratic relationship presented in Eq. (1). Therefore, the SEBS and SEBS-*g*-MA show larger strain response at relatively low electric field strength than conventional dielectric elastomers such as a polyurethane and a silicone rubber. Especially, SEBS-*g*-MA seems to be more strongly enhanced by the nonhomogeneity of the electric field than SEBS.

Conclusion

Electromechanical strain responses of the SEBS and SEBS-*g*-MA dielectric elastomer gel films have been measured by using an *in-situ* synchrotron SAXS. The thickness strain of the gels were successfully measured by the nanostructure dimension change monitored by synchrotron SAXS. Reflection peak was shifted to low q ranges indicating the average d-spacing in nanostructure dimension reduced as an external electric field increased. The thickness strain increased with the electric field. The SEBS-*g*-MA had higher thickness strain than the SEBS gel.

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References

[1] Pelrine, R., Kornbluh, R., Pei, Q., & Joseph, J. (2000). *Science*, *287*, 836.

[2] Shankar, R., Ghosh, T. K., & Spontak, R. J. (2007). *Soft Matter*, *3*, 1116.

[3] Zhang, Q. M., Bharti, V., & Zhao, X. (1998). *Science*, *280*, 2101.

[4] Shankar, R., Ghosh, T. K., & Spontak, R. J. (2007). *Adv. Mater.*, *19*, 2218.

[5] Zhang, Q. M., Su, J., Kim, C. H., Ting, R. Y., & Capps, R. (1997). *J. Appl. Phys.*, *81*, 2270.

[6] Pelrine, R. E., Kornbluh, R. D., & Joseph, J. P. (1998). *Sens. Actuators A*, *64*, 77.

[7] Zhang, Q. M., Li, H., Poh, M., Cheng, Z.-Y., Xu, H., Xia, F., & Huang, C. (2005). *Adv. Mater.*, *17*, 1153.

[8] Shankar, R., Krishnan, A. K., Ghosh, T. K., & Spontak, R. J. (2008). *Macromolecules*, *41*, 6100.

[9] Daniel, C., Hamley, I. W., & Mortensen, K. (2000). *Polymer*, *41*, 9239.

[10] Koo, C. M., Hillmyer, M. A., & Bates, F. S. (2006). *Macromolecules*, *39*, 667.

[11] Kim, B., Park, Y. D., Kim, J., Hong, S. M., & Koo, J. M. Submitted to *Sens. Actuators A*.

[12] Su, J., Ting, R. Y., & Zhang, Q. M. (1997). *Appl. Phys. Letter.*, *71*, 386.