Glass Transition in Fructose-Water Mixture Studied by Broadband Dielectric Spectroscopy

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Sugar is one of a main energy source of a creature, and it is the important material which is indispensable to the activity. In addition, it is widely used as food additives, and on this account glass transition of a sugar aqueous solution is an important subject to be concerned with preservation of drying /frozen food directly.

Fructose is a monosaccharide with six carbons and the ketone group, and it is easy to dissolve in water. In addition, it is included in fruit and honey, and its sweetness is greatest in all the saccharides.

In order to make clear the dynamics of water and saccharide molecules in a water-saccharide mixture in the liquid to the glassy states, broadband dielectric measurements of fructose-water mixture with 94.6wt%, 88.2wt% and 86.5wt% fructose were carried out in the frequency range of 2mHz-20GHz in the temperature range of -30℃ to 45℃.

The fructose purchased from Wako pure Chemical industries was used for all the fructose-water mixtures. Broadband dielectric measurements were performed in the frequency range of 2mHz to 20GHz using a time domain reflectometry (TDR) (100MHz-20GHz), an impedance/material analyzer (Hewlett Packard 4291A) (1MHz-1.8GHz), a precision impedance analyzer (Agilent Technologies 4294A) (40Hz-110MHz), an LCR meter (Hewlett Packard 4284A) (20Hz-1MHz), and an AC phase analysis (ACPA) method (2mHz-1kHz) in the temperature range of -30℃ to 45℃.

Figure 1 shows dielectric constant and loss for fructose-water mixture with 94.6wt% fructose at various temperatures by way of an example of the temperature dependence of the fructose-water mixture. The frequency dependence of the dielectric constant and loss for the fructose-water mixtures can be described well by assuming two relaxation processes and contribution of dc conductivity. The high-frequency process (β-process) observed in a frequency range between 10kHz and 1GHz. The low-frequency process (α-process) observed in a frequency range between 100mHz and 10MHz. In the frequency range below 1kHz for the dielectric constant and below 1MHz for the dielectric loss, huge electrode polarization (l-process) and dc conductivity are recognized.

The temperature dependence of the relaxation time of the α-process obeys the Vogel-Fulcher law [1,2]. On the other hand, the temperature dependence of the relaxation time of the β-process is the Arrhenius type. The relaxation time of the α-process increases with increasing fructose concentration. On the other hand, the relaxation time of the β-process is independent of the fructose concentration. Generally, it has been shown that the relaxation time of the primary process is 100-1000seconds at the glass transition temperature, T_g, by dynamical observation. According to our experimental results for all the fructose-water mixtures, the relaxation time of α-process is 100-1000seconds around the glass transition temperature. The α-process is related to the glass transition. On the other hand, the β-process is caused by the local motion with smaller length scale than that of the α-process.

In the higher temperature range, the relaxation strength of the α-process is smaller than that of the β-process. On the other hand, in the lower temperature range, the relaxation strength of the α-process is larger than that of the β-process. The relaxation strength of the α-process increases with increasing fructose concentration. On the other hand, the relaxation strength of the β-process decreases with increasing fructose concentration. More detailed discussions of the contributions of fructose and water to the relaxation processes will be presented in the meeting.

References

[1] H. Vogel, Phys. Z. **22**, 645 (1921).
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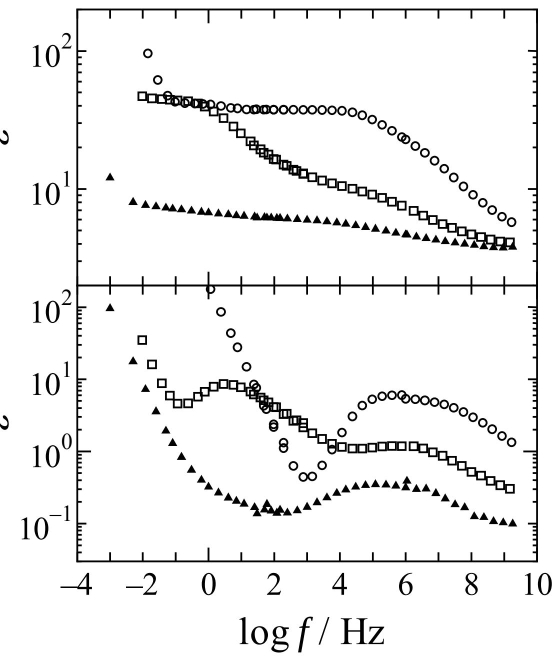

Fig. 1. Dielectric constant and loss for fructose-water mixtures with 94.6wt% fructose at various temperatures. The symbols in the figure indicate the temperature of the fructose-water mixtures at 45℃; ○, 10℃; □, -15℃; ▲.