

# Division of Multidisciplinary Chemistry – Polymer Materials Science –

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## Scope of Research

The structure and molecular motion of polymer substances are studied, mainly using scattering methods such as neutron, X-ray, and light with intent to solve fundamentally important problems in polymer science. The main projects are studies on 1) the mechanism of structural development in crystalline polymers from glassy or molten state to spherulites, 2) the dynamics in disordered polymer materials including low-energy excitation, 3) glass transition and local segmental motions, 4) formation processes and structure of polymer gels, and 5) the structure and molecular motion of polyelectrolyte solutions.

### KEYWORDS

Polymer Physics  
Polymer Properties  
Scattering  
Neutron Scattering  
Synchrotron X-ray Scattering



## Selected Publications

Kanaya, T.; Ogawa, H.; Kishimoto, M.; Inoue, R.; Suter, A.; Prokscha, T., Distribution of Glass Transition Temperatures  $T_g$  in Polystyrene Thin Films as Revealed by Low-energy Muon Spin Relaxation: A Comparison with Neutron Reflectivity Results, *Phys. Rev. E*, **92**, 022604-1-022604-7 (2015).

Nishida, K.; Zhuravlev, E.; Yang, B.; Schick, C.; Shiraishi, Y.; Kanaya, T., Vitrification and Crystallization of Poly(butylene-2,6-naphthalate), *Thermochim. Acta*, **603**, 110-115 (2015).

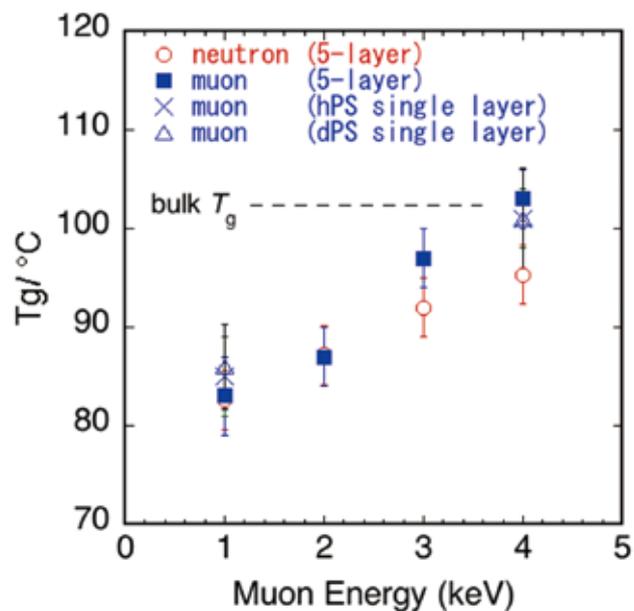
Ogawa, H.; Nishikawa, Y.; Fujiwara, A.; Takenaka, M.; Wang, Y.-C.; Kanaya, T.; Takata, M., Visualizing Patterned Thin Films by Grazing-incidence Small Angle X-ray Scattering (GISAXS) Coupled with Computed Tomography (CT), *J. Appl. Cryst.*, **48**, 1645-1650 (2015).

Matsuura, T.; Murakami, M.; Inoue, R.; Nishida, K.; Ogawa, H.; Ohta, N.; Kanaya, T., Microbeam Wide-Angle X-ray Scattering Study on Precursor of Shish Kebab. Effects of Shear Rate and Annealing on Inner Structure, *Macromolecules*, **48**, 3337-3343 (2015).

Osaka, O.; Bente, H.; Ohkita, H.; Ito, S.; Ogawa, H.; Kanaya, T., Nanostructures for Efficient Hole Transport in Poly(3-hexylthiophene) Film: A Study by Conductive Atomic Force Microscopy, *J. Phys. Chem. C*, **43**, 24307-24314 (2015).

## Distribution of Glass Transition Temperature $T_g$ in Polystyrene Thin Films as Revealed by Low-energy Muon Spin Relaxation ( $\mu$ SR)

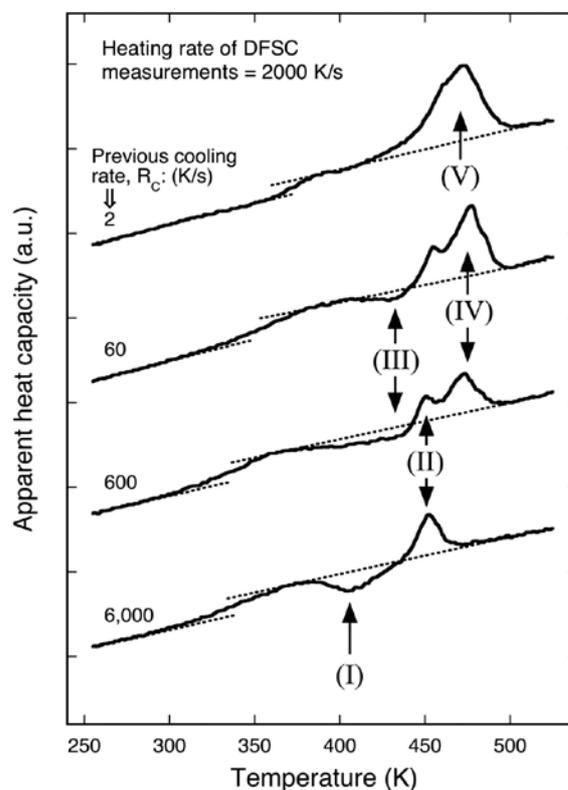
Information on  $T_g$  distribution is very useful for understanding the interesting but unusual properties of polymer thin films. However, one problem that we have to clarify is whether there are effects of deuterium labeling on  $T_g$  or not. To tackle the problem, we performed low-energy muon spin relaxation ( $\mu$ SR) measurements on the aforementioned deuterium-labeled 5-layer PS thin film as well as dPS and hPS single layer thin films  $\sim 100$  nm thick as a function of muon implantation energy. It was found that deuterium labeling had no significant effect on  $T_g$  distribution, guaranteeing that we can safely discuss the unusual thin-film properties based on the  $T_g$  distribution revealed by neutron reflectivity on the deuterium-labeled thin films. In addition, the  $\mu$ SR result suggested that the higher  $T_g$  near the Si substrate is due to the strong orientation of phenyl rings.



**Figure 1.** Distributions of the average neutron  $\langle T_g \rangle_{ME}$  (○), the muon  $T_g$  evaluated (■) for the 5-layer dPS/hPS/dPS/hPS/dPS thin film, and the muon  $T_g$  for the single layer hPS (×) and dPS (△) thin films, as a function of muon implantation energy.

## Perfect Vitrification, Mesophase Formation, and Crystallization of Poly (butylene-2,6-naphthalate)

It was very difficult to obtain the glassy state of poly(butylene-2,6-naphthalate) (PBN), because PBN crystallizes very quickly on cooling from the molten state. The differential fast scanning calorimetry (DFSC) technique has been successfully applied to study the vitrification of PBN and crystallization from the glassy state. A cooling rate of more than 6000 K/s could prevent PBN from crystallizing and more than 30000 K/s effectively reduced the development of active nuclei. A heating rate faster than 7000 K/s could prevent cold crystallization from the proper glassy state. In cooling and heating rates less severe than 30000 K/s and 7000 K/s, respectively, a variety of structure formations, such as nucleation, mesophase formation, crystallization, and their multiple melting behaviors, have been observed (Figure 2). The present work has been performed through the collaborative research with Professor Schick's laboratory at Rostock University in Germany and supported by Researcher Exchange Program between Japan Society for the Promotion of Science (JSPS) and Deutscher Akademischer Austausch Dienst (DAAD) awarded to K.N.



**Figure 2.** Representative DFSC curves illustrating five categories of exo- and endothermic peaks. (I) Mesophase formation from (devitrified) amorphous, (II) melting of mesophase, (III) cold crystallization on heating, (IV) melting of crystal formed on heating, and (V) melting of the original crystal that formed on previous cooling.