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Correlation between the temperature and elastic properties of the light guide plate in edge-lit light-emitting-diode backlights

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The correlation between the temporal and spatial variations of the elastic constant and temperature change was examined for a light guide plate (LGP) adopted in the edge-lit light-emitting-diode backlight for mobile applications, using the micro-Brillouin light scattering method. The velocity of sound and the elastic constant C_{11} of an LGP made from bisphenol-A polycarbonate (PC) were investigated as functions of temperature, time, and position on the LGP. The temporal variation of C_{11} exhibited an exponential decay, while the spatial variation of C_{11} reflected the temperature distribution on the LGP. The glass transition temperature of the PC LGP was found to be located at 155°C. The result showed that systematic transformation between the elastic property and the temperature is possible and that the temperature distribution on the bulk LGP can be accurately probed via the present experiment method, without using any special temperature measurement equipment.

Keywords: backlight unit; light guide plate; sound velocity; elastic constant; Brillouin scattering

1. Introduction

The backlight has become one of the most important components in liquid crystal displays (LCDs). The advent and rapid expansion of light-emitting-diode (LED) TV represent the important role of backlight technology in the evolution of the LCD TV. Edge-lit LED backlights are adopted in most LED TVs, by which superslim, low-power LCD TVs can be realized. The optical characteristics of edge-lit LED backlights, including the performances of optical films, have been shown to be superior to those of the conventional fluorescent-lamp-based backlights [1–3]. The light guide plate (LGP) is a key component of the edge-lit backlight for LCD applications. Light sources are attached to the sides of the LGP, which guides and spreads the incident light over the two-dimensional area under the LCD via total internal reflection (TIR). Microstructures such as white dots, microlens, and microprism arrays are incorporated on the bottom surface of the LGP to break the law of TIR and thus to emit the guided light towards the LCD.

Backlights should satisfy many criteria related to optical performance and reliability issues. Various tests have been standardized to ensure the reliability of backlights during long-term operation, for example, the high- or low-temperature hold test, high-temperature and high-humidity operation, temperature cycle test, and vibration and shock tests to name a few. Cold-cathode fluorescent lamps (CCFLs) and LEDs are generally used as light sources for edge-lit backlights. These light sources may have some side effects on the mechanical and thermal reliability of backlights during operation. For example, ultraviolet (UV) light leaked from CCFL may induce the degradation of the optical components, such as changing the transmission/absorption spectrum and/or mechanical properties, due mainly to the breakage of the chemical bonds of the polymers attacked by high-energy UV photons [4,5]. On the other hand, light sources cause local heating near the entrance surface of the LGP because the electrode temperature of CCFL or the junction temperature of LED is usually much higher than 100°C during operation. This may give rise to distortions and to the thermal degradation of the nearby optical components [6]. It is necessary to investigate the effect of temperature variation on the mechanical stability of the LGP under various conditions.

The elastic constant or modulus is one of the important mechanical properties of polymeric materials. It is related to the interatomic potential and is sensitive to thermodynamic variables such as temperature or pressure [7]. As such, probing the elastic constant is one of the effective ways of investigating the distribution of the thermodynamic properties of the optical components adopted in backlights. Moreover, the distribution of the elastic constant may be an useful information and may serve as basic data for analysis of the mechanical stability of the optical components of backlights. To these authors' knowledge, however, there has been no systematic study on the elastic properties of the

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optical components adopted in backlights. This study was thus devoted to the investigation of the correlation between the elastic properties of and the temperature variation in the LGP via Brillouin light scattering [8]. The temporal and spatial changes in the elastic properties of the LGP were examined and analyzed in detail. Although this study was focused on a small LGP for mobile applications, the adopted experimental method may easily be extended to large LGPs, such as those for LED TVs.

2. Experiment

Inelastic Brillouin light scattering is a powerful tool for investigating the elastic properties of condensed matters [9,10]. Brillouin scattering is brought about by the inelastic scattering events between the incident photons and the acoustic phonons. The velocity of sound and the elastic constants can easily be obtained from the measured spectrum. A Sandercock-type tandem Fabry–Perot interferometer combined with a photomultiplier tube was used to measure the Brillouin spectra of the LGP. A schematic diagram of the Brillouin scattering equipment is shown in Figure 1(a). A diode-pumped solid-state laser (Monopower-532-100-SM, Alphalas) at a wavelength of $\lambda = 532$ nm was incident on the surface of the sample at a backscattering geometry. The backscattered light from the sample was guided into the interferometer via lenses and mirrors. The input light was made to pass through two Fabry–Perot etalons (FP1 and FP2 in Figure 1(a)) six times and was then guided into the photomultiplier tube. The detected signal was analyzed using a multichannel analyzer (1024 channels). A free spectral range of 25 GHz was adopted, and a scan range of ± 15 GHz was used to analyze the spectrum of the scattered light. An optical microscope (BH-2, Olympus) was modified for the backscattering geometry, by which the laser beam was incident on each local micro-area of the LGP. Due to the short focal length (-10 mm) of the objective lens, the beam width at the focal point was only a few micrometers, indicating that the spatial resolution was less than 10 μm. This is a favorable condition for the investigation of the microheterogeneity of the elastic properties of condensed matters.

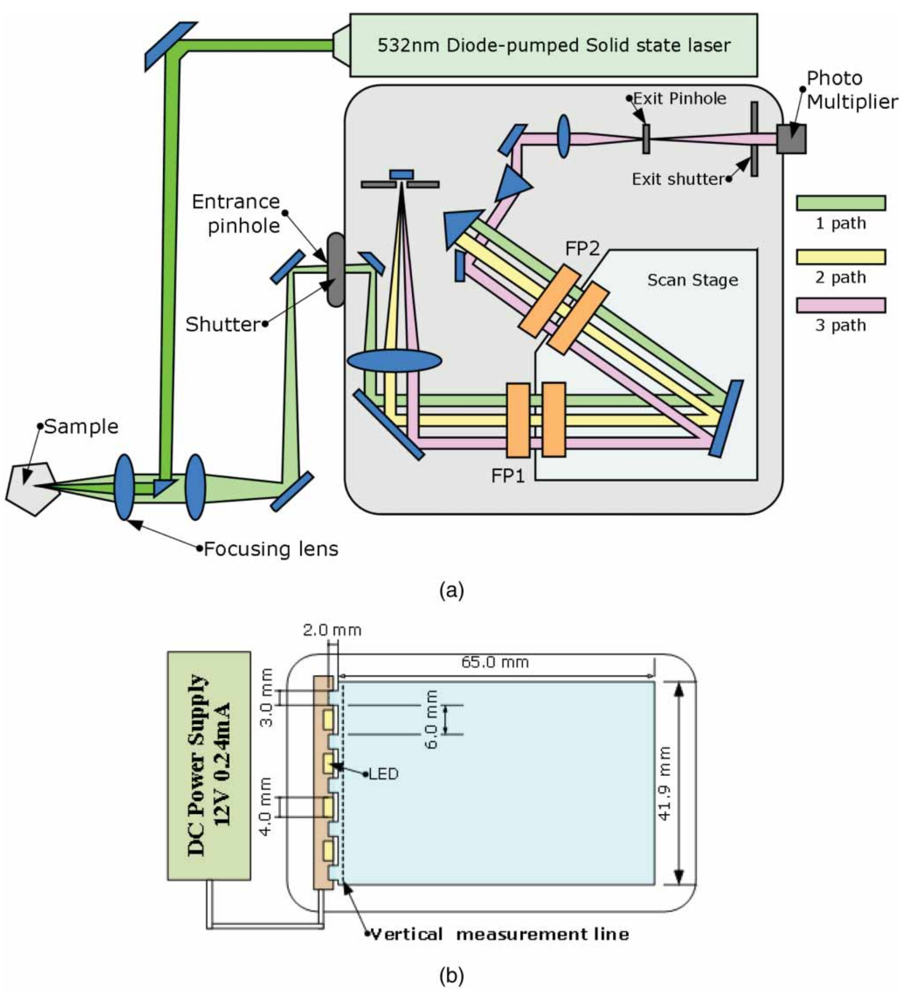

Figure 1. (a) A schematic diagram of the Brillouin scattering system. (b) A schematic diagram of the experimental setup for the edge-lit LED backlight.

Figure 1(b) shows a schematic diagram of the experimental setup that was used in this study. Commercially available backlights for mobile applications were chosen for the investigation. An LGP made from bisphenol-A polycarbonate (PC) with a thickness of 0.8 mm was inserted into a 92 mm (width) × 51 mm (depth) × 20 m (height) acrylic box. Four SMT (surface mount) white LEDs were attached to one of the four sides of the LGP, with 6-mm intervals. The total power consumption of these LEDs was 2.88 W. This experimental setup was used to simulate the LGP in an edge-lit backlight. The optical films were removed from the backlight because the purpose of this study was to find a correlation between the elastic properties and the temperature of the LGP itself. Three experiments were sequentially carried out, as follows:

(1) A piece of PC block was cut from the LGP and was inserted into a temperature cell (THMS600, Linkam) for the microscope. The elastic properties were investigated as a function of temperature (T), from 25 to 190°C.
(2) A micro-area located at the center of the measurement line shown in Figure 1 was selected, and the elastic properties were examined as a function of time, from the cold start to 100 min.
(3) The LGP was attached to an X–Y translator, and the positional dependence of the elastic properties was investigated along a line parallel to the side along which the four LEDs were attached. The distance between the measurement line shown in Figure 1 and the edge of the LGP was 1 mm. This experiment was carried out after the backlight was aged for 2 h.

3. Results and discussion

Figure 2 shows a Brillouin spectrum of the PC measured at 25°C. The Brillouin spectrum consisted of one doublet due to the propagating longitudinal-acoustic (LA) waves. The transverse acoustic mode is forbidden at this backward scattering geometry. The Stokes and anti-Stokes Brillouin peaks correspond to the phonon creation and annihilation event, respectively. The Brillouin doublet is usually modeled by the response function of the damped harmonic oscillator, which is again approximated by the Lorentzian functions convoluted by the Gaussian instrumental function of the interferometer [11]. The Brillouin frequency shift (ν_B) can be obtained from this fitting procedure, and the sound velocity (V) can be calculated based on the refractive index ($n = 1.592$ for the PC), the scattering angle ($\theta = 180°$), and the laser wavelength ($\lambda = 532$ nm), according to Equation (1), where ω is the angular frequency and q the scattering wavevector:

$$V = \frac{\omega}{q} = \frac{2\pi \nu_B}{4\pi n \sin(\theta/2)/\lambda} = \frac{\lambda \nu_B}{2n \sin(\theta/2)}. \quad (1)$$

The elastic constant C_{11} can be obtained via $C_{11} = \rho V^2$, where ρ is the density of the PC (1.2 g/cm^3). Figure 3 shows the temperature dependence of the elastic constant C_{11}. It shows a linearly decreasing behavior at low temperatures and then exhibits a sudden change in the slope at 155°C. This temperature is almost the same as the reported glass transition temperature of the PC [12], which suggests that the sudden softening at 155°C is a clear indication of the occurrence of glass transition in the PC LGP. The calculated elastic constant at room temperature was 6.98 GPa, which is consistent with the previous reports [13]. The linearly decreasing part of $C_{11}(T)$ in the glassy phase of the PC was fitted using a linear function, and the best-fitted result is as follows:

$$C_{11}(T) = 7.38 - 0.0153T\ (°\mathrm{C}) \quad \text{or}$$
$$C_{11}(T) = 11.56 - 0.0153T\ (\mathrm{K}). \quad (2)$$

The aforementioned result is almost the same as that reported in [13]. The elastic constant C_{11} at 0 K was 11.56 GPa, and the temperature coefficient 0.153 GPa/K

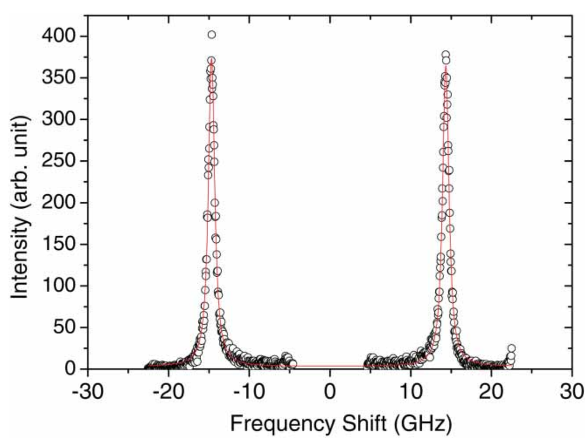

Figure 2. A Brillouin spectrum of the PC LGP at 25°C (open circles) along with a fitting line using Voigt functions.

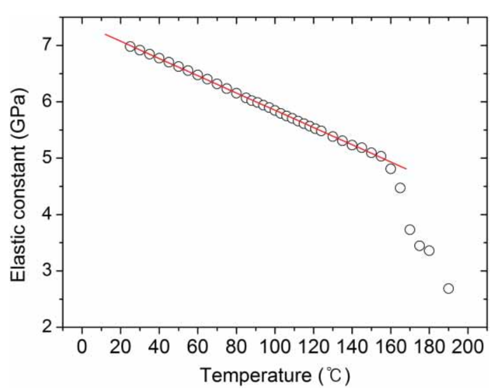

Figure 3. The temperature dependence of the elastic constant C_{11} (open symbols) and the best-fitted result (red solid line) obtained using a linear function.

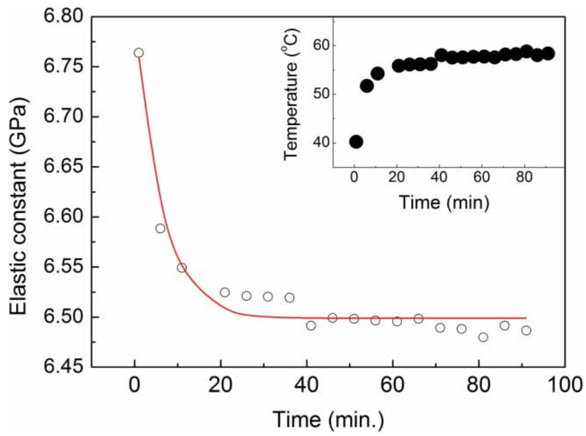

Figure 4. The temperature dependence of the elastic constant C_{11} (open symbols) and the best-fitted result (red solid line) obtained using Equation (3). The inset shows the corresponding change in temperature.

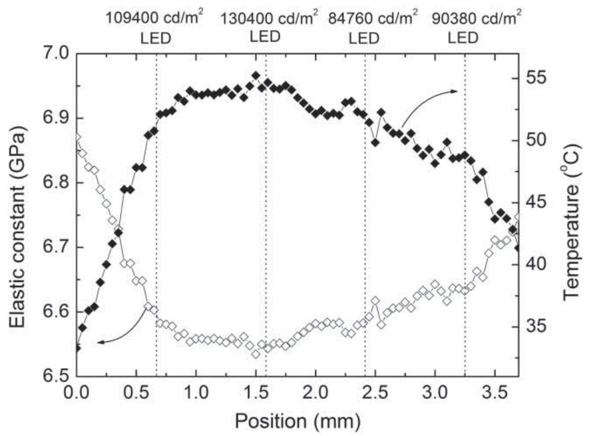

Figure 5. The positional dependence of the elastic constant C_{11} (open symbols) and the temperature (filled symbols) calculated using Equation (2). The locations of the four LEDs are indicated by dotted lines.

is interpreted as the change in C_{11} with respect to a temperature variation of 1 K.

Figure 4 shows the elastic constant measured as a function of time (t) from the cold start. It usually takes about 2 min to measure one Brillouin spectrum, and the elastic constant shown in this figure should be considered the average value within this time interval, during which the Brillouin data were recorded. The elastic constant first decreases substantially within 10 min and then becomes saturated. This change was fitted using the following empirical equation, similar to the approach in [3]:

$$C_{11}(t) = A \exp\left(-\frac{t}{\tau}\right) + C_{11}^{0}. \qquad (3)$$

The parameters that were obtained were $A = 0.31 \pm 0.01$ GPa, $\tau = 5.5 \pm 0.7$ min, and $C_{11}^{0} = 6.50 \pm 0.01$ GPa. As can be seen in Figure 3, the change in the elastic constant is directly related to the temperature of the PC LGP, which means that the change that can be seen in Figure 4 reflects the change in the temperature of the PC over time. Equation (2), obtained from the elastic constants in the glassy state of the PC, can be used to estimate the temperature change corresponding to the change in C_{11} within 90 min, and the result is shown in the inset of Figure 4. The temperature rise in the first 10 min amounted to 14°C, and the overall change in T within 90 min was 18°C.

Figure 5 shows the positional dependence of the elastic constant C_{11} along the measurement line shown in Figure 1. The locations of the four LEDs are indicated as four dotted lines in the same figure. C_{11} becomes high on both ends and becomes smallest near the center of the measurement line. This reflects the temperature distribution on the LGP and indicates that the temperature is highest near the center of the measurement line and becomes lower toward the side surfaces of the LGP, through which the generated heat can be released effectively. By using the temperature variation of C_{11} shown in Figure 1 and Equation (2), the spatial distribution of C_{11} shown in Figure 5 can easily be transformed into that of the temperature. The temperature distribution calculated using Equation (2) is also plotted in Figure 5. The temperature of the central region is within the range 50–55°C over 2 mm, and the temperature decreases rapidly upon approaching the two side ends of the LGP. The weak local humps shown in Figure 5 are approximately correlated to the locations of the LEDs, indicating that the local heating effect is not very substantial. The asymmetry of the distribution of C_{11} and the temperature seems to be due to the difference in the electric and optical performances of the four LEDs. To confirm this, the luminance values of the four LEDs were measured using a conventional spectroradiometer when the backlight was aged for 2 h. The luminance values are shown in Figure 5. As can be seen, two LEDs are brighter than the other two, which means that the dissipated heat from these LEDs is not symmetrically distributed in the LGP. This might be the origin of the asymmetry of the elastic constant that was observed in this study.

The above results show that the micro-Brillouin scattering method may be a powerful tool for investigating the temporal and spatial changes in the elastic and temperature properties of condensed matters. First, compared to the conventional ultrasonic method, micro-Brillouin scattering can be used to measure the elastic properties at a spatial resolution of a few micrometers. The changes in the elastic properties can be monitored and analyzed at this microscopic scale. Second, the present micro-Brillouin technique is a non-contact method, which means that the temperature from some micro-regions in the bulk can be read out without any contact with the thermocouple, for instance. Infrared thermometry is another conventional, non-contact method for temperature measurement, but its spatial resolution may be worse than that of the present method due to the long wavelength of the infrared light.

4. Summary

The elastic properties of the PC LGP were investigated as functions of temperature, time, and location. The temperature variation of C_{11} clearly showed that glass transition occurs at 155°C in PC, which is consistent with the previous reports. The temporal and spatial variations of C_{11} were measured and were found to reflect the temperature change or distribution on the LGP. Based on the temperature dependence of C_{11} in the glassy state of PC, the temperature change was correctly estimated as a function of time and position. The present study showed that micro-Brillouin scattering can be a powerful, non-contact method for investigating the elastic properties of the optical components adopted in backlights as well as of the correlated temperature distribution. In addition, the distribution of the elastic constant in the various components adopted in backlights may serve as basic data for thermoelastic analysis, which may be important in the study of the long-time stability of display components.

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