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Optical Constants of Two Typical Liquid Crystals 5CB and PCH5 in the THz Frequency Range

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Abstract. The complex refractive indices of two benchmark nematic liquid crystal, 4'-*n*-pentyl-4-cyanobiphenyl (5CB) and 4-(*trans*-4'pentylcyclohexyl)-benzonitrile (PCH5) have been determined in the frequency range from 0.2 to 0.8 THz. The technique of coherent THz time-domain spectroscopy (THz-TDS) was used. We show that the birefringence of 5CB is in the range of 0.15 to 0.21, while that of PCH is from 0.01 to 0.08. Both liquid crystals exhibit relatively small absorption in this frequency range. The large birefringence of 5CB indicates possible applications of liquid-crystal-based devices for modulation and polarization control of electromagnetic radiation in the THz frequency range.

Key words: 5CB, absorption, birefringence, liquid crystal, optical constants, PCH5, refractive index, THz, time-domain spectroscopy

1. Introduction

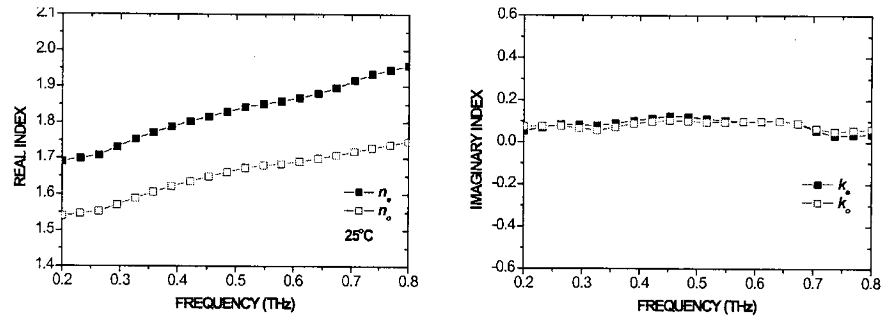
Many rod-like molecules, which can form liquid crystals or LCs, exist in biological systems [1]. In fact, the pioneering study in 1888 of cholesteryl benzoate by the Austrian Botanist, *Friedrich Reinitzer*, led to the discovery the liquid crystalline state of matter. The lyotropic LCs are of current interests because of their presence in biological membranes. More recent studies indicate that the biological rod-like molecules can also form the smectic and hexagonal columnar liquid crystal phase rather than that of the cholesteric. The various types of self-assembly observed in biological systems may be achieved by the stepwise transformation to the higher-order liquid crystal [2]. Knowledge of liquid crystals could thus be significant for the understanding of many biological systems and their applications. It would also help shed lights on the potential hazards of high-frequency electromagnetic radiation on humans. One of the key parameters of the LCs is its complex refractive indices or optical constants. In the visible range, the optical constants of LCs have been extensively investigated [3–4]. In the infrared range, the refractive indices and other optical properties of LCs have also been reported [5]. In the millimeter wave range, Lim et al. [6] first showed that many LCs have comparatively large birefringence with approximate values in the 0.1–0.18 range at 30 GHz. Further, the birefringence of LCs varied only slightly in the 15–94 GHz range. Nose et al. [7] reported the refractive indices and transmission losses for some nematic LCs, including 4'-*n*-pentyl-4-cyanobiphenyl (5CB), have been measured at three discrete wavelengths (118, 215, and 435 μm). The birefringence of 4-(*trans*-4'-pentylcyclohexyl)-benzonitrile (PCH5) in 0.1 to 0.8 THz range (~0.01) were found to be much smaller than those in the visible range (~0.12) [8]. In this work, we employ THz time-domain spectroscopy to measure the complex refractive indices of two technologically important liquid crystals, 5CB and PCH5, at room temperature. A direct comparison of optical constants of 5CB and PCH5 in the frequency range of 0.2 to 0.8 THz are reported, for the first time to our knowledge.

2. Experimental Methods

The test cell was constructed as a double-cell with a liquid crystal cell and an empty reference cell side by side. Optical-quality fused silica windows were used as substrates. The thickness of the LCs were controlled by mylar spacers with a nominal cell thickness between 50 and 120 μm. Homogeneous alignment of the nematic LC was achieved by rubbing the polyimide coated substrate. The temperature of the sample cell was regulated within ± 0.1 °C. Our THz time-domain spectroscopy (THz-TDS) experimental setup is similar to the conventional THz system and has been described in detail elsewhere [9]. Briefly, the sub-50fs pulse train from a mode-locked Ti: Sapphire laser (Spectra Physics, Tsunami, $\lambda = 800$ nm) was divided into two beams, a pump and a probe. A large-aperture GaAs photoconductive antenna was used as the THz transmitter. The laser-excited THz wave was collimated and focused on the sample cell by a pair of off-axis paraboloidal mirrors. A 2-mm-thick (110) ZnTe crystal was used in an electro-optic sampling setup for coherent detection of the transmitted THz field in the time domain. The THz wave spectrum can be obtained by applying a Fast Fourier Transform (FFT) algorithm to the time-domain waveform. Dividing the FFT spectrum obtained with the LC cell by that of the vacant cell yields the magnitude and phase difference of the complex amplitude transmission function of the liquid crystal layer. The optical constants of 5CB and PCH5 for both the o-ray and e-ray are then calculated from the complex amplitude transmission function by the numerical method [10].

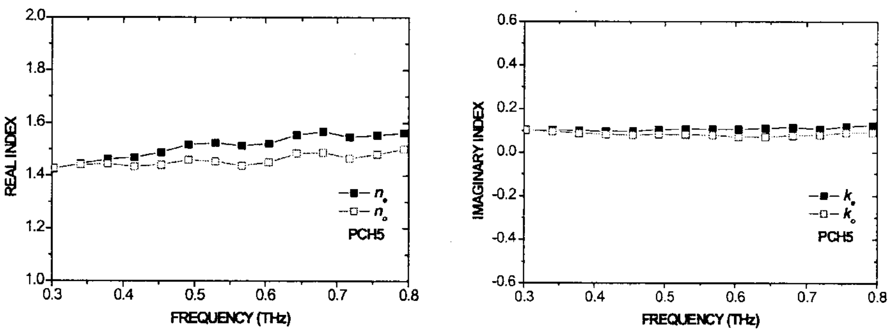
3. Results and Discussions

In Figure 1a, the THz-band extraordinary and ordinary indices of refraction of 5CB at 25 °C are shown. Clearly a slow and monotonic increasing trend are evident for both n_e and n_o. In the 0.2 to 0.8 THz range, n_e increases from 1.7 to 1.96, while n_o varies from 1.55 to 1.75. The birefringence of 5CB, $\Delta n = n_e - n_o$, is thus as high as 0.15 to 0.21. In comparison, the birefringence for 5CB in the visible region varied from 0.11 to 0.20 depending on the temperature and wavelength. Figure 1b illustrates the imaginary indices of refraction of 5CB, k_e and k_o, in the same



(a) (b)

Figure 1. (a) Extraordinary and ordinary indices of refraction of the LC, 5CB, is shown as a function of frequency between 0.2 to 0.8 THz. (b) Imaginary indices of refraction of 5CB in the same frequency range.



(a) (b)

Figure 2. (a) Extraordinary and ordinary indices of refraction of the LC, PCH5, is shown as a function of frequency between 0.2 to 0.8 THz. (b) Imaginary indices of refraction of PCH5 in the same frequency range.

frequency range. These are in general of the order of 0.1 or less. No resonance was detected.

The corresponding results for PCH5 at room temperature are shown in Figures 2(a) and (b). We also observed a slow and monotonic increasing trend for both n_e and n_o of PCH5. In the 0.2 to 0.8 THz range, n_e increases from 1.42 to 1.56, while n_o varies from 1.42 to 1.50. The birefringence of PCH5, $\Delta n = n_e - n_o$, is thus between 0.01 to 0.08. This is considerably smaller than the birefringence for PCH5 in the visible region, which varies from 0.12 to 0.135 depending on the temperature and wavelength. Figure 2(b) illustrates the imaginary indices of refraction of PCH5, k_e and k_o, in the same frequency range. These are in general of the order of 0.1 or less. Again, no resonance was detected.

4. Conclusions

We have investigated the far-infrared optical constants of two important liquid crystals, 5CB and PCH5, using THz time-domain spectroscopy for the first time to our knowledge. At 25 °C, the extraordinary refractive indices of 5CB vary from 1.70 to 1.96, while its ordinary indices of refraction slowly increases from 1.55 to 1.75. Positive birefringence, i.e., $n_e > n_o$ was observed, throughout this range and as high as 0.15 to 0.21. This is comparable to that of 5CB in the visible range. On the other hand, n_e of PCH5 varies from 1.42 to 1.56, while n_o varies from 1.42 to 1.50, with relatively small positive birefringence between 0.01 to 0.08. For both liquid crystals, the absorption in the frequency range of 0.2 to 0.8 THz range is negligible. Further studies are in progress to probe the origin of the significantly different THz properties of the two well-known LCs and its implications to biological physics.

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