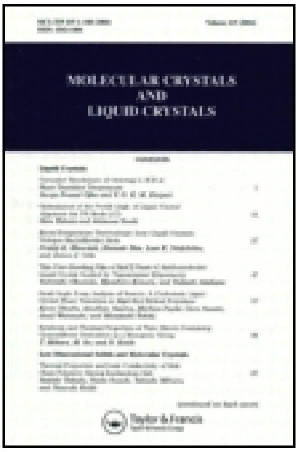

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

THz Nematic Liquid Crystal Devices Using Stacked Membrane Film Layers

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Version of record first published: 14 Jun 2011

To cite this article: R. Ito, T. Kumagai, H. Yoshida, K. Takeya, M. Ozaki, M. Tonouch & T. Nose (2011): THz Nematic Liquid Crystal Devices Using Stacked Membrane Film Layers, Molecular Crystals and Liquid Crystals, 543:1, 77/[843]-84/[850]

To link to this article: http://dx.doi.org/10.1080/15421406.2011.568334

Mol. Cryst. Liq. Cryst., Vol. 543: pp. 77/[843]–84/[850], 2011

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.568334

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THz Nematic Liquid Crystal Devices Using Stacked Membrane Film Layers

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Twisted nematic type THz polarization control devices using liquid crystal immersed membrane films were fabricated by using simple stacking process. First of all, we verify the liquid crystal alignment effect in various kinds of membrane films. From THz Time-Domain Spectroscopy measurements, apparent refractive index anisotropy was observed in liquid crystal immersed Polytetrafluoroethylene and Polyolefin membrane films. Furthermore, transmission properties of twisted nematic type THz device are in rough agreement with 4×4 matrix calculation data. We believe that primary characteristic of THz TN device can be obtained by optimizing the fabrication processes and measurement method.

Keywords Membrane immersed in LC; terahertz LC device; terahertz TDS; transmission properties; twisted nematic

1. Introduction

THz electromagnetic wave which is ranging from 0.1 to 10 THz has some unique properties such as penetration through various materials (paper, plastic, cloth etc.) and specific absorption band appears depending on materials (finger-print spectrum). There have been various studies for THz applications such as medical imaging, non-destructive testing and broadband communications [1–5]. For the next phase of THz application, high quality of THz optical elements will be important. Especially polarization control devices such as polarizer, wave plate and polarization modulator are necessary but there are few effective polarization control devices in THz region.

On the other hand, liquid crystal (LC) materials show relatively large refractive index anisotropy in THz region and they can have a potential application to some tunable devices with low drive voltage and low power consumption. Recently,

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birefringence and extinction coefficient of various LC materials have been investigated in THz region [6–13] and some kinds of THz LC devices have been investigated [14–17]. However, THz frequency is much lower than that in optical region so extremely thick LC layer is necessary in this frequency region because of the longer wavelength. This makes LC molecular alignment difficult and causes fatal disadvantage of response speed degradation. A simple solution is increase of wall effects and introduction of porous materials such as membrane films is effective method [18]. In our previous work, we studied relationship between microscopic structures of membrane films and LC molecular orientation by THz Time-Domain Spectroscopy (TDS) system and it is confirmed that the LC molecules tend to align along fiber aligning structure of membrane film [19].

In this study, we fabricate twisted nematic (TN) type THz polarization control devices using LC (5CB) immersed membrane films and their experimental results are discussed on calculation results using 4×4 matrix method. A possibility of the LC cell fabrication method utilizing the membrane films is investigated to attain various LC control devices in the THz region.

2. Experimental Methods

THz transmission properties of LC immersed membrane films and THz TN devices are measured by using THz TDS system as shown in Figure 1. THz emitter and detector are photoconductive switches fabricated on low-temperature grown InAs and GaAs, respectively. Femtosecond laser pulses are split into pump and probe beams. The emitted THz pluses are guided with parabolic mirrors through the sample and onto the detector. Scanning delay line allows the waveform of THz electric field to be recorded via photoconductive THz detector. In this study, we employ two wire-grid polarizes to examine the THz polarization condition. Transmittance and refractive indices are calculated from the measured data by using same calculation method in reference [19].

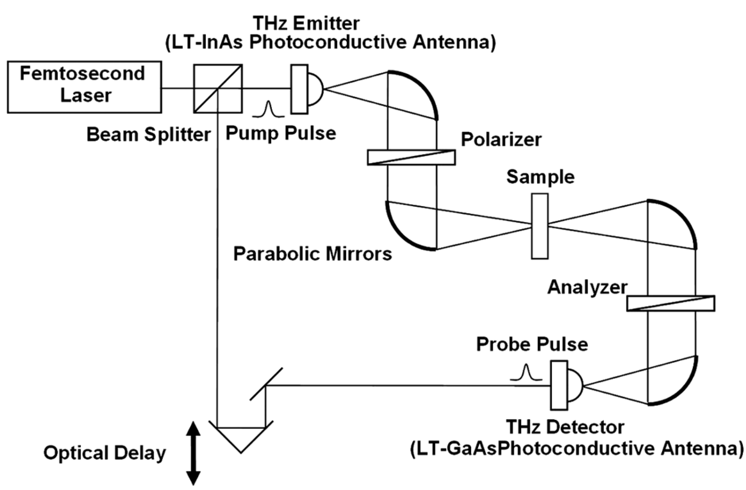

Figure 1. Experimental set up for THz TDS system.

3. Results and Discussion

3.1. *Refractive Indices of LC Immersed Membrane Films*

Membrane films are usually used for filtering acid/alkaline solution or microbe, and there are many commercially-available products. In our previous work, refractive indices of 5CB immersed Polytetrafluoroethylene (PTFE) membrane films were investigated in THz region and it is confirmed that the LC molecules tend to align along fiber aligning structure of membrane film [19]. In this study, we verify the LC alignment condition in various kinds of membrane films. Figure 2 shows the scanning electron microscope (SEM) images of the (a) PTFE, (b) Polyolefin, (c) Nylon and (d) Polyvinylidene Fluoride (PVDF) membrane films. In case of PTFE and Polyolefin, we confirm that there is anisotropy in fine structure. On the other hand, Nylon and PVDF have no anisotropic structure.

Table 1 shows the refractive indices of various membrane films at 1 THz evaluated from THz TDS measurement data. Thickness means membrane film thickness used in this measurement. In case of Polyolefin, we use the 8 stacked membrane films for the evaluation because it is difficult to evaluate the refractive indices of very thin sample. Perpendicular/Parallel means the relationship between THz pulse polarization direction and membrane film direction (defined as an arrowhead in Figure 1). Before immersing membrane films in LC, refractive index of perpendicular and parallel are almost the same value in Polyolefin, Nylon and PVDF membrane film. On the other hand, PTFE membrane film has refractive index anisotropy before introducing 5CB. This result was also observed in another pore size of PTFE membrane films [19] and we think that this refractive index anisotropy related to form birefringence.

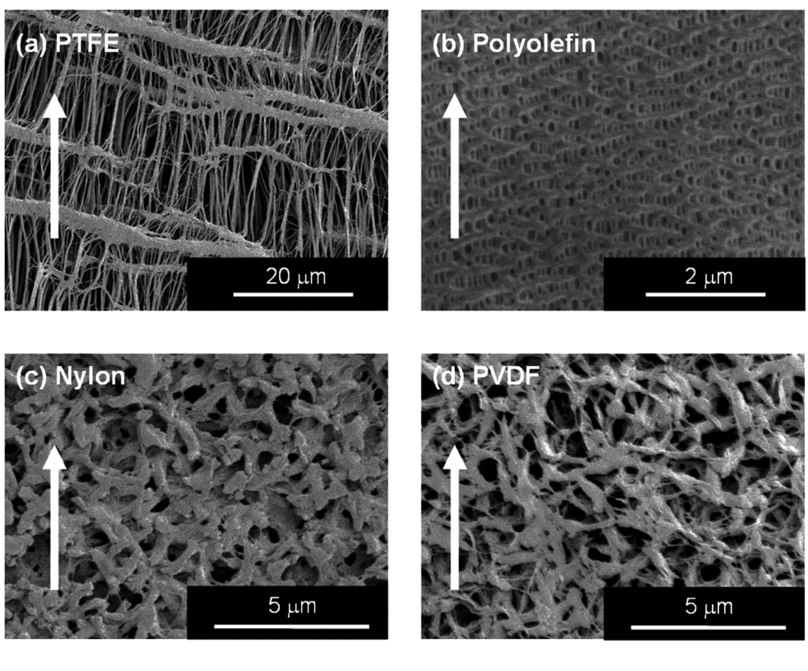

Figure 2. SEM images of the (a) PTFE, (b) Polyolefin, (c) Nylon and (d) PVDF membrane films.

Table 1. Refractive indices of various membrane films at 1 THz evaluated from THz TDS measurement data

Materials	Thicknes (μm)	Pore Size (μm)	Δn (without 5CB)		n (with 5CB)		n (with 5CB)
			Perpendicular	Parallel	Perpendicular	Parallel	
PTFE	85	1	1.07	1.03	1.80	1.93	0.13
Polyolefin	※200	0.1	1.30	1.32	1.66	1.78	0.12
Nylon	150	0.2	1.27	1.26	1.90	1.87	−0.03
PVDF	140	0.2	1.09	1.09	1.57	1.55	−0.02

※25 μm × sheets.

After immersing membrane films in LC, apparent refractive index anisotropy was observed in PTFE and Polyolefin membrane films. These results show that LC molecular tends to align along the arrowhead direction as shown in Figure 1. On the other hand, Nylon and PVDF membrane films show no refractive index anisotropy. In this study, we adopt PTFE and Polyolefin membrane films for constructing THz TN device.

3.2. *Fabrication of THz TN Devices*

Figure 3 shows the schematic diagram of THz TN device using LC immersed membrane films. LC immersed membrane films were stacked by rotating the orientation direction from 0 to 90 degrees. To prevent leakage of LC materials from the membrane films, we introduce the Teflon sheets (50 μm) to the surfaces (both side of the device). Finally, we set THz TN device in the metal holder to keep the thickness and orientation direction (not shown in Fig. 3).

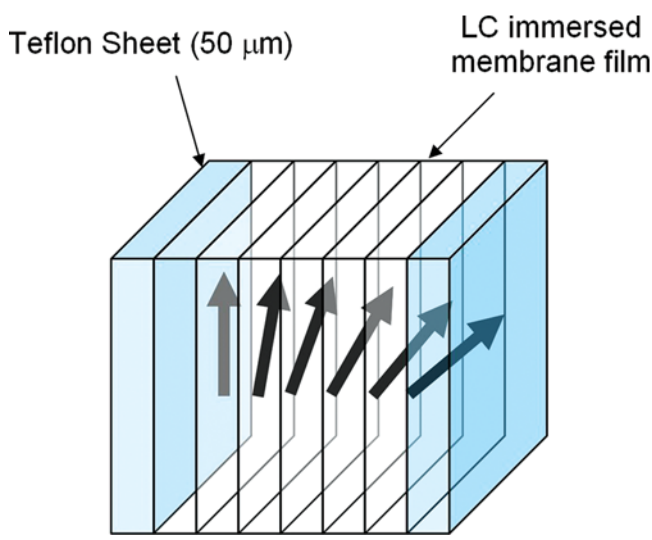

Figure 3. Schematic diagram of THz TN device using LC immersed membrane films. (Figure appears in color online.)

Table 2. Structural parameters of fabricated THz TN devices

Name	Material	Number of Sheets	Rotation Angle (degree/sheet)	Total Thickness (μm)
PTFE 10	PTFE	10	10	850
PTFE 21		21	4.5	1785
Polyolefin 46	Polyolefin	46	2	1150

Table 2 shows the fabrication parameters of THz TN devices and figure 4 shows the calculated transmission properties of these devices under parallel nicols condition by using 4×4 matrix method. In this study, we design the three types of devices PTFE 10, PTFE 21 and Polyolefin 46 as shown in Table 2. Rotation angle in Table 2 means the membrane film rotation angle during the stacking process. Total thicknesses of PTFE 10, PTFE 21 and Polyolefin 46 are 850 μm, 1785 μm and 1150 μm, respectively. From Figure 4, first minimum condition is satisfied at 1.2 THz (PTFE 21), 1.9 THz (Polyolefin 46) and 2.6 THz (PTFE 10). Futhermore, second minimum condition is satisfied at 2.6 THz in PTFE 21 device.

3.2. *Transmittance of THz TN Devices*

Figure 5 shows transmittance of PTFE 10 and PTFE 21 measured by using THz TDS system under (a) parallel nicols and (b) crossed nicols condition. In Figure 5, 4×4 matrix calculation data are also plotted with solid line. In case of parallel nicols condition, measured transmittance of PTFE 10 and PTFE 21 decrease with increasing frequency and they are in rough agreement with 4×4 matrix calculation data. But we can not observe increase tendency of PTFE 21 in 1.2 THz to 2.0 THz region.

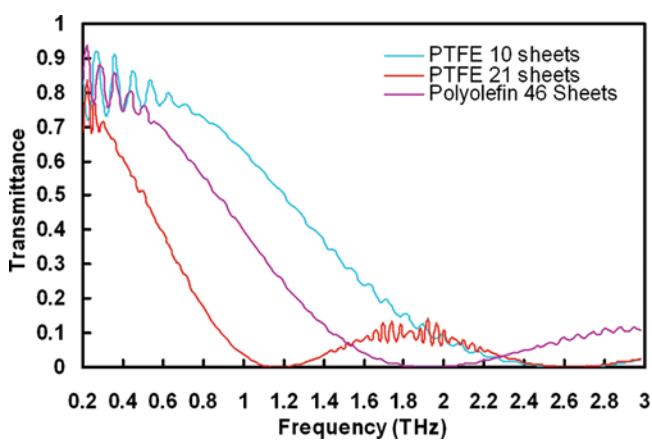

Figure 4. Transmission properties of THz TN devices under parallel nicols condition calculated by using 4×4 matrix method.

Furthermore, in case of crossed nicols condition, we can not observe any transmission signals as shown in Figure 5(b). From these results, ideal polarization rotation of THz wave may not occur in PTFE TN devices by some influence of defects in our PTFE TN devices.

Figure 6 shows transmittance of Polyolefin 46 measured by using THz TDS system under (a) parallel nicols and (b) crossed nicols condition. In Figure 6, 4×4 matrix calculation data are also plotted with solid line. In case of parallel nicols condition, measured transmittance decreases with increasing frequency and they are in rough agreement with 4×4 matrix calculation data. Moreover, in crossed nicols condition, we can observe that the transmitted THz signals and they increase with increasing frequency in 0.2 to 1.0 THz region. These results imply that THz wave polarization rotation occurs in Polyolefin TN devices. But we can not observe the perfect transmission properties of TN devices so further improvements of our device is necessary. We believe that primary characteristic of THz TN device can be obtained by optimizing the fabrication processes and measurement method.

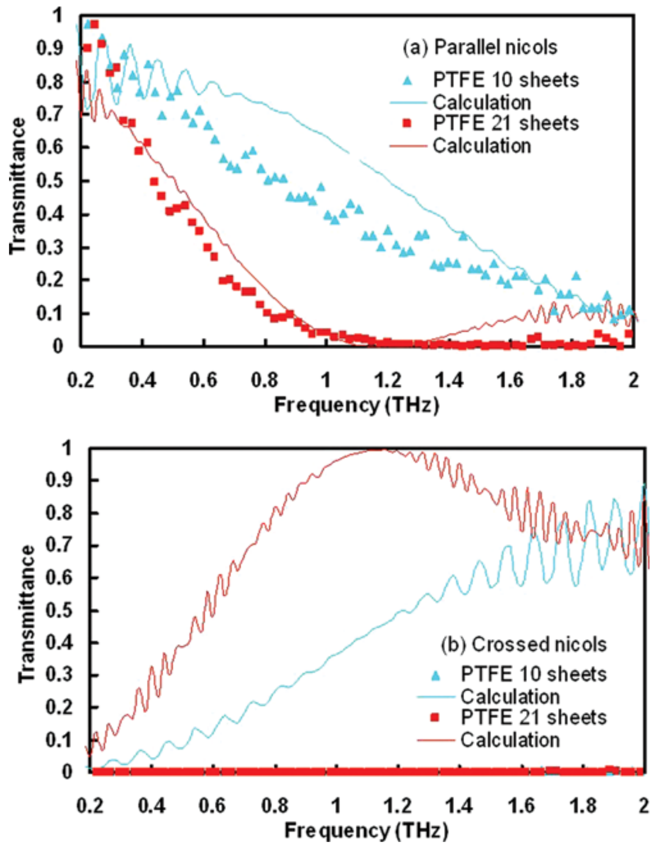

Figure 5. Transmission properties of THz device with PTFE 10 and PTFE 21 measured by using THz TDS system under (a) parallel nicols and (b) crossed nicols condition.

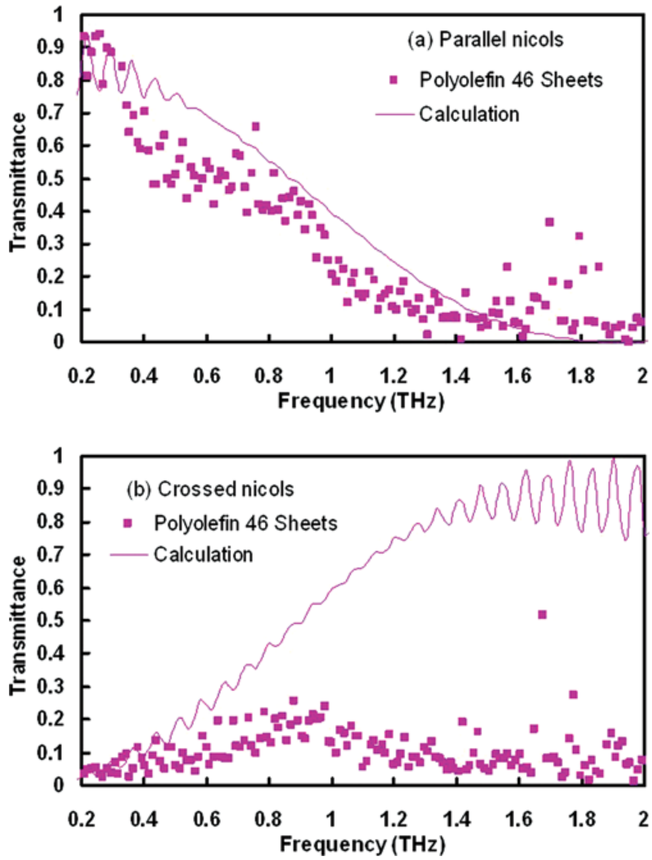

Figure 6. Transmission properties of THz device with Polyolefin 46 measured by using THz TDS system under (a) parallel nicols and (b) crossed nicols condition.

4. Conclusions

Twisted nematic type THz polarization control devices using 5CB immersed membrane films were fabricated. From THz TDS measurements, the transmittance of parallel nicoles condition decreases with increasing frequency and they are in rough agreement with 4×4 matrix calculation data. Furthermore, we can observe that the transmittance of crossed nicols condition increases with increasing frequency in 0.2 to 1.0 THz region. We believe that primary characteristic of THz TN device can be obtained by optimizing the fabrication processes and measurement method, and the stacking membrane method is useful for constructing very thick LC layer of various LC THz control devices.

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