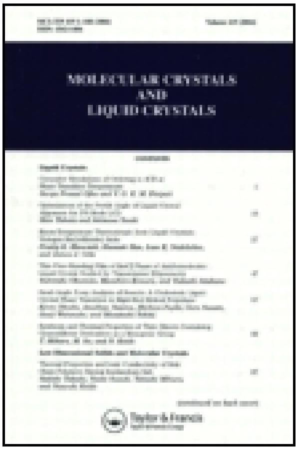
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Millimeter-Wave Propagation Properties of the Nematic Liquid Crystal Cell with a 1-D Periodic Structure Induced by Different Molecular Orientations

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A novel nematic liquid crystal (LC) cell with a one-dimensional (1-D) periodic structure prepared using homogeneous and homeotropic orientations alternately as the electrically controlled millimeter-wave devices is proposed. When an external voltage is applied across the LC layer, the LC molecules in the homogeneous orientation tend to align along the applied field direction and the periodicity of the molecular orientation vanishes. The millimeter-wave transmission properties of the LC cell are measured at 50 GHz. Changes in the phase and transmittance of the LC cell induced by applying the voltage to the cell are observed.

Keywords: electrically controlled LC device; millimeter-wave transmission; periodic structure of LC

1. INTRODUCTION

There has been a great interest in millimeter-wave (frequency range from 30 to 300 GHz) application systems due to the demand for wireless communication systems at higher frequencies. In the millimeter-wave frequencies, small-size and low-weight devices are promising compared to radio wave frequencies. Considering modulation effects, nematic liquid crystal (LC) materials with relatively large dielectric anisotropy in the microwave and millimeter-wave region are attractive in applications to millimeter-wave devices [1–3].

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Previously, we proposed an LC prism [4] and LC lens [5] with stack-layered structure as the quasi-optical millimeter-wave devices, which was composed of wedge-shaped and lens-shaped metal substrates and nematic LC. Electrically controlled deflection and focusing effects were observed for the LC prism and LC lens, respectively. In this work, we propose a novel planar waveguide with a one-dimensional (1-D) periodic structure induced by different molecular orientations. The properties of the LC cell with a periodic structure prepared using the homeotropic and homogeneous LC molecular orientations and the influence of the voltage application on the millimeter-wave transmission are discussed.

2. LC CELL STRUCTURE WITH 1-D PERIODIC STRUCTURE

The nematic LC cell with the periodic structure was prepared using the different molecular orientations as shown in Figure 1, where indium-tin-oxide (ITO) coated glass substrates were used as a parallel-plate waveguide and an electrode to drive the LC molecules. The nematic LC (E-44) with a positive dielectric anisotropy was sandwiched between a pair of ITO coated glass substrates, which were coated with a polyimide (PI) to achieve the homeotropic orientation. Then the rubbed photoresist film to obtain the homogeneous orientation was formed into the grating by the photolithographic method on the PI film.

Figures 2(a) and 2(b) show the typical micrographs of the LC cell at the off state and the on state, respectively. The cell thickness was 130 μm and the period of the grating was about 2 mm. The cell is observed under crossed polarizers, where the angle between the polarization direction of the polarizer and the grating vector (rubbing direction) is set at 45°. In the absence of the applied voltage, the area of the homeotropic orientation becomes not so dark compared to the conventional LC cell with the thin LC layer of 10 μm because of the large thickness of LC layers. Figure 3 shows the transmission light intensity versus the applied voltage in the homeotropic orientation ($\lambda = 632.8$ nm). The transmission level easily decreases with increasing the applied voltage and the threshold does not appear. It seems that the LC molecules in the middle part of the LC layer might not take the perfect homeotropic alignment and slightly fluctuate as the LC layer becomes thicker.

3. EXPERIMENT AT MILLIMETER-WAVE REGION

The millimeter-wave transmission properties of the LC cell with the 1-D periodic structure are measured by using an interferometer at

50 GHz. The experimental system for measuring the millimeter-wave transmission properties is schematically shown in Figure 4. The interferometric technique is utilized and the attenuation and phase shift of the transmitted wave through the LC cell are measured. It constitutes an interferometric circuit, by which both the attenuation and the phase shift due to the presence of the LC cell are determined by the diode detector. The millimeter wave supplied by a Gunn diode is divided into two arms by the splitter. The two waves are recombined with a magic tee, and then the interferometric output is obtained by the diode detector. Thus, the relative variations of the phase shift and the attenuation can be directly measured. The millimeter wave with the polarization direction perpendicular to the glass substrates can

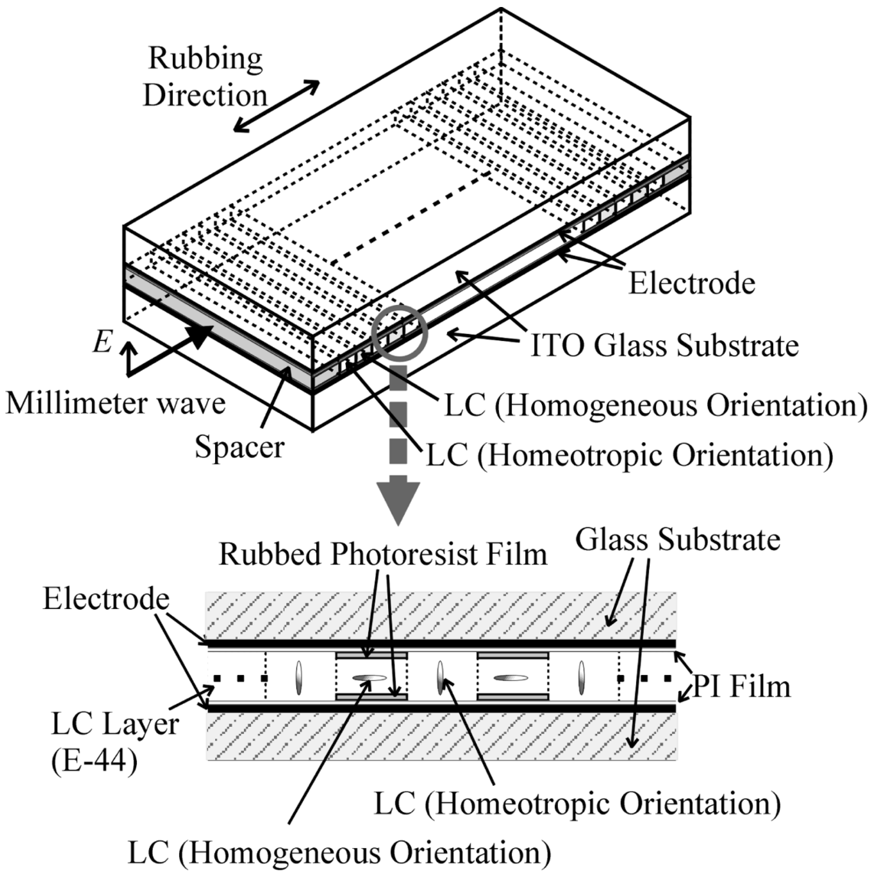

FIGURE 1 Typical layout of the LC cell.

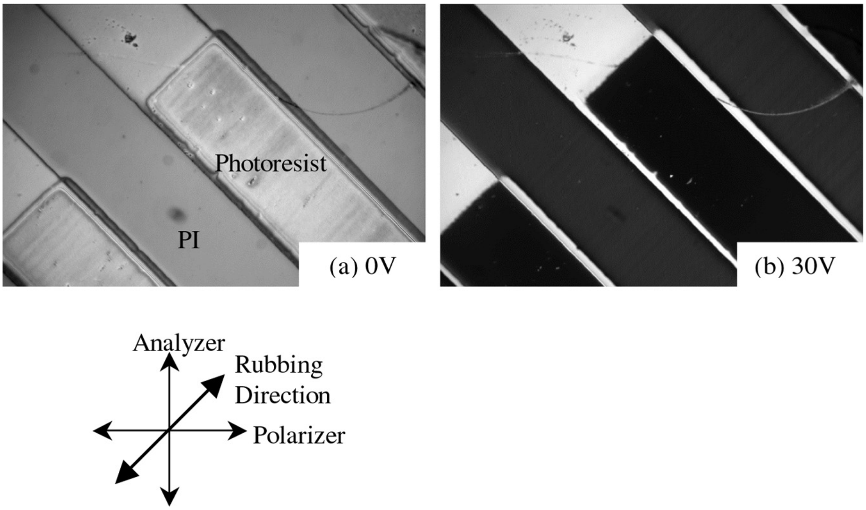

FIGURE 2 Micrographs of the LC cells observed with a polarizing microscope, P and A are the directions of the polarizer and analyzer, respectively.

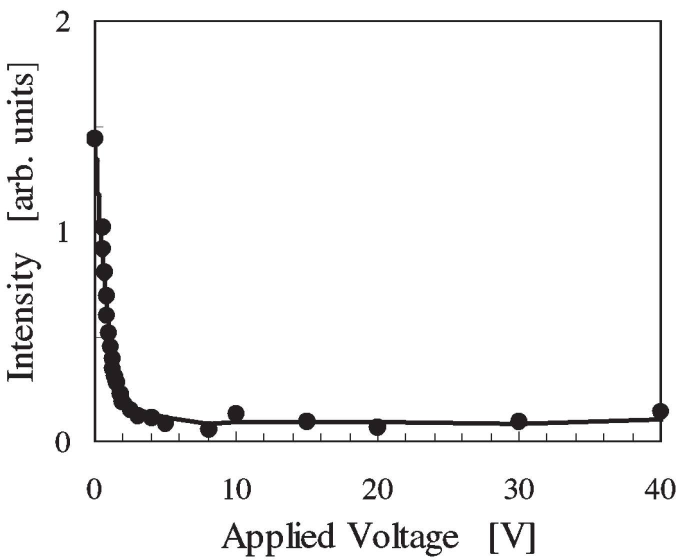

FIGURE 3 Transmission light intensity versus the applied voltage in the homeotropic orientation.

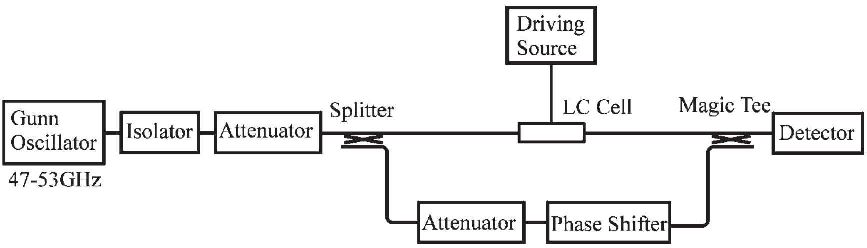

FIGURE 4 Schematic diagram of the measuring system.

transmit the LC cell, on the other hand the wave with the parallel polarization can not transmit the call because the propagating wavelength is longer than the cutoff wavelength determined by the electrode spacing.

Table 1 shows the relative phase shift of the LC cells at 47 GHz for various period of the grating, where the path length of the LC layer is about 30 mm. The phase shifts of the LC cells decrease with increasing the applied voltage and become about -30° at 30 V. The half parts of the LC layer, that is, the molecules in the homogeneous orientation mainly contribute to the transmission changes. Thus, the phase shifts of the LC cells are estimated to be about -20°/cm. The attenuation of the LC cells at the on state that is different from the transmission level at off state is shown in Table 2. The transmission levels increase at the on state because of the absorption anisotropy, that is, the absorption of the LC for the ordinary wave is larger than that for the extraordinary wave at the millimeter-wave region [6]. At 50 GHz and 53 GHz, the detected transmission waves can not interfere since the transmission level through the LC cell is very small compared with the reference wave. It is possible that the transmitted wave through the LC cells is affected by the periodic structure. The more distinct analysis, that is, the relationship between the wavelength and the periodicity of the LC cell will be published elsewhere.

TABLE 1 The Phase Shift of the LC Cells ($f = 47$ GHz, Reference Level = 0 V)

	Phase shift [deg.]	
Grating period [mm]	Applied voltage = 3 V	Applied voltage = 30 V
1.78	−21	−27
1.90	−27	−29
2.09	−26	−31

TABLE 2 The Attenuation of the LC Cells (Reference Level = 0 V)

Grating period [mm]	Attenuation [dB] 47 GHz	50 GHz	53 GHz
1.78	+1.25	+2.56**	*
1.90	+1.65	+2.17**	*
2.09	+1.34	*	+0.93

*The signal through the LC cell is very small compared with the reference signal.
**The signal through the LC cell is smaller than the reference signal.

4. CONCLUSIONS

The nematic LC cell with a 1-D periodic structure induced by the alternately aligned homeotropic and homogeneous orientations is prepared and the millimeter-wave transmission properties are investigated. The transmission loss and phase shift of the LC cell with the periodic structure are measured at 50 GHz bands. The phase delay is observed and the transmission loss becomes small when the voltage is applied to the LC cell.

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