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Microwave and Milliwave High Speed Phase Shifter Using Ferroelectric Liquid Crystal

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1. Introduction

Microwave and milliwave electrically tunable components, such as variable phase shifter, attenuator and filter, have attracted much attention for use in satellite broadcasting and intelligent transport systems (ITS). Liquid crystals have a large dielectric anisotropy in the microwave and millimeter wave regions, and therefore, microwave and millimeter wave applications using liquid crystals have been reported.[1-5] Among them, microwave phase shifters using nematic liquid crystals have mainly been studied using a microstrip line structure. In this case, there is a serious problem about the response time upon voltage removal.

On the other hand, a ferroelectric liquid crystals (FLCs) possess spontaneous polarization and exhibit high switching speed.[6] We have already reported a microwave variable phase shifter and have discussed the response time.[7] The response speed in this case is clearly higher than that obtained when a nematic liquid crystal is used. However, it is not sufficiently high because of the unwinding and winding of a helical structure in the FLC. In this study, we discuss a microwave and milliwave phase shifter of a coplanar waveguide with floating electrodes using FLC and discuss its fast switching response.

2. Experiments

Figure 1 shows a schematic of the device structure used in this study. A coplanar waveguide, whose center conductor is 250 μm in width and gaps between the central conductor and two ground planes are 20 μm in width, was constructed on a PTFE-glass dielectric substrate with a thickness of 80 μm for high-frequency circuits. Another PTFE-glass dielectric substrate with a thickness of 40 μm was fixed on the dielectric substrate of the coplanar waveguide with spacers, and a liquid crystal cell was prepared. Two floating electrodes for the application of dc voltage to the liquid crystal were constructed on the upper side of the

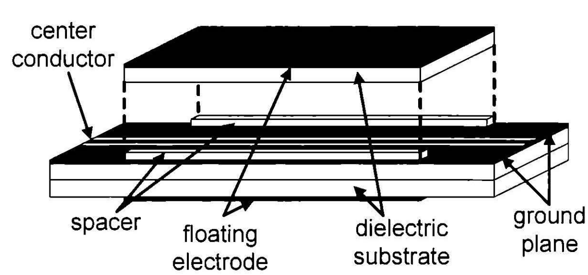

Fig. 1. Schematic of device structure used in this study.

upper dielectric substrate and the lower side of the lower dielectric substrate. The length of the coplanar waveguide of the FLC cell was 15 mm, and the thickness of the liquid crystal layer was 50 μm. Both surfaces of the PTFE substrates, which were in contact with FLC, were coated with polyimide (JSR, AL1254) and rubbed to achieve unidirectional alignment. The rubbing direction was at an angle of 45° from the propagation direction of microwaves. The FLC material used in this study was a commercial mixture (AZ Electronic Materials, FELIX-015/000), which has a tilt angle θ of 22° at 25 °C.

Figure 2 shows a schematic of the experimental setup used in this study. The dc voltage was applied to the liquid crystal using a function generator (Tektronix, AFG310) and a power amplifier (FLC, A400DI). The propagation phase shift and loss of the microwave and milliwave were measured using vector network analyzers (Agilent, N5230A) in the frequency range from 1 to 40 GHz. All measurements were performed at 25 °C, at which the liquid crystal shows the chiral

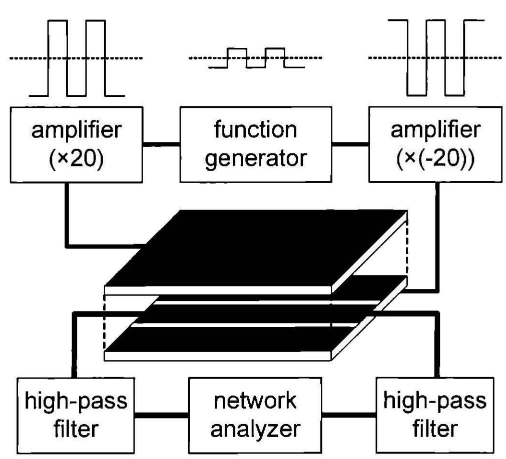

Fig. 2. Experimental setup used in this study.

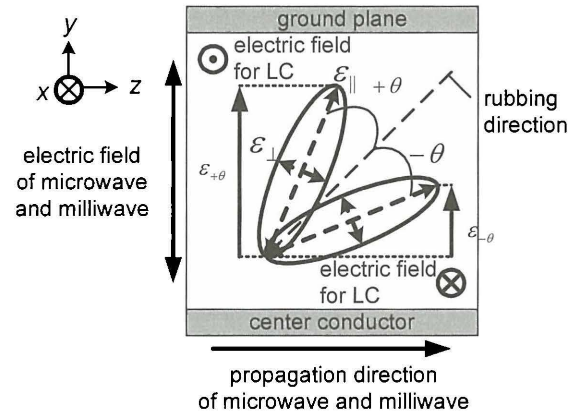

Fig. 3. Schematic molecular orientation of ferroelectric liquid crystal under application of dc voltage.

smectic C (Sm C*) phase.

Figure 3 shows a schematic of the molecular orientation of FLC under the application of the dc voltage to the liquid crystal. In this study, the rubbing direction is at 45° from the propagation direction, and therefore, the angle between the molecular direction of FLC and the electric field direction of the microwave is $45°+\theta$ or $45°-\theta$. The dielectric permittivities perpendicular to the substrate (x-axis) and along the electric field direction of the microwave (y-axis) are given by

$$\varepsilon_{FLC\_x} = \varepsilon_{\perp},$$

$$\varepsilon_{FLC\_y,\pm} = \frac{\varepsilon_{\parallel}\varepsilon_{\perp}}{\varepsilon_{\parallel}\cos^2(45°\pm\theta)+\varepsilon_{\perp}\sin^2(45°\pm\theta)},$$

where $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are the dielectric permittivities along the long and short axes of the FLC molecule in the microwave region, respectively.

3. Results and Discussion

Figure 4 shows the microwave frequency dependences of the phase shifts of the microwave and milliwave under the application of the square voltages of 100 and 200 V. The phase shifts are proportional to the frequency of the microwave and milliwave, and the proportional coefficient of the phase shifts increases with increasing voltage in the liquid crystal layer.

The phase shift ΔP is given by

$$\Delta P = \frac{2\pi f l}{c}\left(\sqrt{\varepsilon_{eff,+}} - \sqrt{\varepsilon_{eff,-}}\right),$$

where l is the length of the coplanar waveguide with the FLC cell, f is the frequency of the microwave and milliwave, c is the speed of light in vacuum, and $\varepsilon_{eff,+}$ and $\varepsilon_{eff,-}$ are the effective dielectric permittivities of the coplanar waveguide under the application of positive and negative voltages, respectively. This equation indicates that the phase shift ΔP is proportional to the microwave frequency when the dielectric anisotropy is constant. It was confirmed from Fig. 4 that the dielectric anisotropy is almost constant in the measured frequency range.

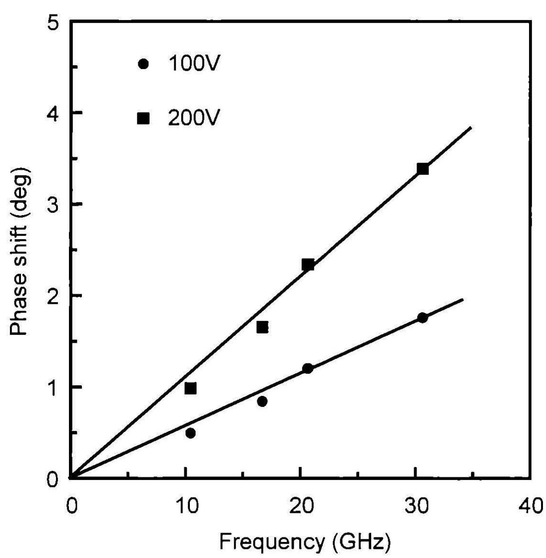

Fig. 4. Frequency dependence of measured phase shift of microwave and milliwave.

Figure 5 shows the measured phase waveforms under the application of various voltages form an offset voltage of -200 V at the frequency of 30 GHz. It was confirmed that the phase changes from a certain value to other values, depending on the applied voltage. The microwave and milliwave variable phase shifter is expected to change the phase from a certain value to other values. Thus, the phase response under the

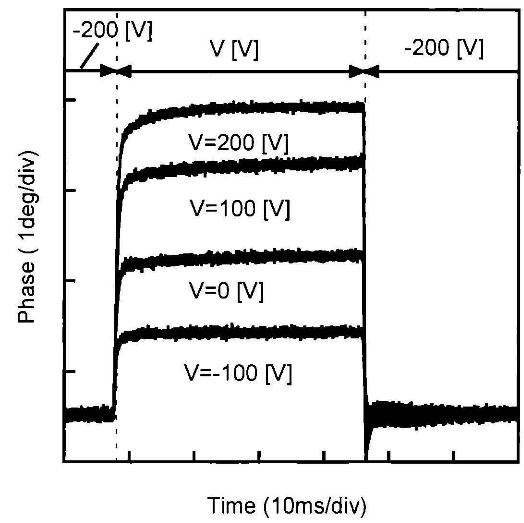

Fig. 5. Measured phase waveforms of microwave and milliwave under application of various voltages from offset voltage of -200 V at frequency of 30 GHz.

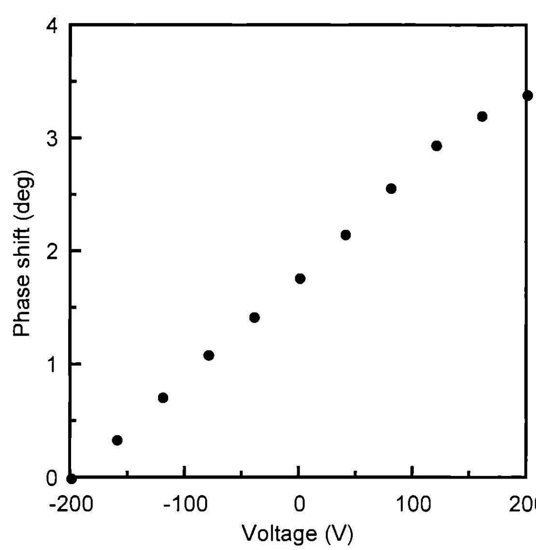

Fig. 6. Voltage dependence of measured phase shift at frequency of 30 GHz.

application of various voltages form the offset voltage is important. Figure 6 shows the measured phase shift as a function of the applied voltage from the offset voltage of -200 V at the frequency of 30 GHz. The phase shift increased with the applied voltage and did not saturate under the application of a voltage below 200 V. This indicates that the liquid crystal molecule did not completely reorient. Figure 7 shows the applied voltage dependences of the measured response times at the frequency of 30 GHz. In this measurement, the rise and decay times are defined as the response times for the phase change from 10% to 90% and that from 90% to 10%, respectively. Both response times were below 1.6 ms in the entire applied voltage range including low voltages. From this result, it was confirmed that a high-speed microwave and milliwave variable phase shifter is realized and that the coplanar waveguide with floating electrodes using FLC can be adopted for high-speed phase shifters.

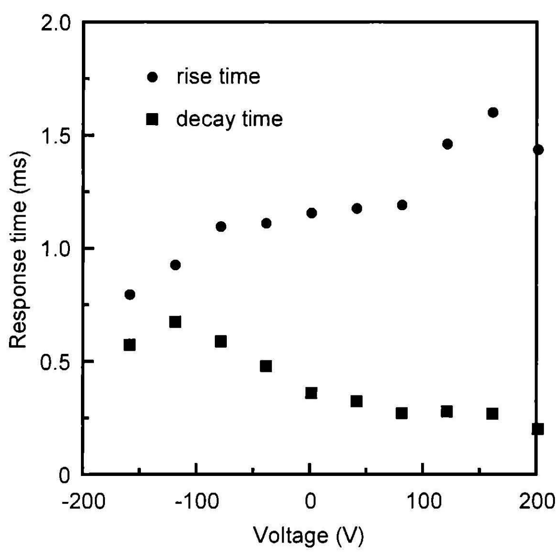

Fig. 7. Voltage dependences of rise and decay times at frequency of 30 GHz.

4. Conclusions

A microwave and milliwave variable phase shifter of a coplanar waveguide with floating electrodes using FLC was constructed. The measured phase shift was proportional to the frequency of the microwave and milliwave. The measured phase shift increased with increasing voltage under the application of various voltages from an offset voltage. The response time was less than 1.6 ms in the entire voltage range, and a high-speed microwave and milliwave variable phase shifter was realized. The coplanar waveguide with floating electrodes using FLC is promising for high-speed microwave and milliwave phase shifter application.

References

[1] K. C. Lim, J. D. Margerum, and A. M. Lackner: *Appl. Phys. Lett.* **62** (1993) 1065.

[2] F. Yang and J. R. Sambles: *Appl. Phys. Lett.* **79** (2001) 3717.

[3] D. Dolfi, M. Labeyrie, P. Joffre, and J.P. Huignad: *Electron. Lett.* **29** (1993) 926.

[4] T. Kuki, H. Fujikake, T. Nomoto, and Y. Utsumi: *Trans. IEICE Electron.* **J84-C** (2001) 4409 [in Japanese].

[5] C. Well, St. Muller, P. Scheele, P. Best, G. Lussem, and R. Jakoby: *Electron. Lett.* **39** (2003) 1732.

[6] N. A. Clark and S. T. Lagerwall: *Appl. Phys. Lett.* **36** (1980) 899.

[7] H. Moritake, K. Toda, T. Kamei, Y. Utsumi, and W. Haase: *Mol. Cryst. Liq. Cryst.* **434** (2005) 52.

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