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Relation between Molecular Structure of Nematic Liquid Crystal and Dielectric Loss in Microwave Frequency

○Yoichi Murakami, Yosei Shibata, Hiroyasu Sato, Takahiro Ishinabe, Qiang Chen, Hideo Fujikake

Tohoku University

1. Introduction

In order to handle the massive growth of communication traffic with the progress of the Internet of Things (IoT) society, the development of next-generation communication technology using microwave or millimeter-wave band has been urgently required in recent years. As the candidates of antenna technology for their wave bands, phased array antennas using nematic-phase liquid crystal (LC) for phase shifters have been proposed [1]. The advantages of phased array antenna using nematic LC is continuous beam steering toward any direction because molecular alignment of LC is freely controlled by low-frequency alternating current (AC) voltage. However, the optimal structural design of LC molecules was not clear for suppression of dielectric loss in radio frequency.

To overcome this issue, we focused on the basic skeleton of LC molecules. The LC is generally composed of main chain, hydrocarbon group and polar group. They determine the optical characteristics of LC and molecular interaction among liquid crystal molecules.

In this study, we report on the relation between structural factors of LC and the dielectric loss evaluated with coaxial line.

2. Evaluation method of dielectric loss

Fig.1 shows the coaxial line composed of polytetrafluoroethylene (PTFE) and injected LC materials for evaluation of dielectric loss in radio frequency. The applied voltage of square wave to the coaxial line plays a role of alignment control of LC molecules. The coaxial line was connected with a vector network analyzer, and transmission coefficient S_{21} through LC was obtained. The dielectric constant (aligned state ($\varepsilon_r(\parallel)$) and randomly-aligned state ($\varepsilon_r(av)$)) at 12 GHz was calculated by numerical fitting for S_{21}. The dielectric loss was defined as $\tan\delta(\parallel)$ *and* $\tan\delta(av)$. Assuming that a LC molecule has elongated uniaxial rotating body, the dielectric constant along short axis ($\varepsilon_r(\perp)$) of the LC molecule is expressed as following equation (1).

$$\varepsilon_r(\perp) = \frac{3\varepsilon_r(av) - \varepsilon_r(\parallel)}{2} \quad (1)$$

The $\tan\delta(\perp)$ value was calculated from equation (2).

$$\tan\delta(\perp) = \frac{3\varepsilon_r(av)\cdot\tan\delta(av) - \varepsilon_r(\parallel)\cdot\tan\delta(\parallel)}{2\varepsilon_r(\perp)} \quad (2)$$

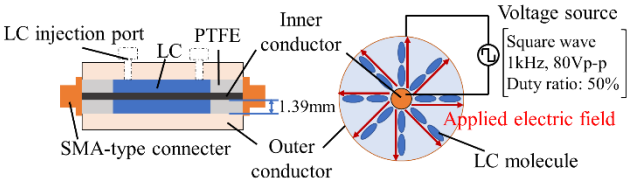


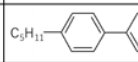
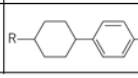
Fig.1 Cross-sectional schematic diagram of dielectric-loss measurement system based on coaxial cable structure frequency.

3. Results and discussion

Prior to discussion, we investigated the effect of chain length in hydrocarbon on the dielectric loss using cyano-biphenyl LC materials. From the results, we confirmed that the value of $\tan\delta$ was not affected by chain length. For the reason, the effect of main chain structure and polar groups is discussed on following.

The evaluated dielectric loss and chemical structure of LC were summarized in Table 1. The structural difference between LC mixtures of 5CB and TD-1018XX is skeleton of main chain. The structural change from cyclohexane to phenyl group contributes to loss reduction. These results are attributed to more stable phenyl group due to the rigid ring structure. The dielectric loss might be suppressed by rigid molecular structure. Then, we evaluated LC mixture of TD-1017XX composed of biphenyl and terminally-modified fluorine as a polar group. As a result, improvement of $\tan\delta$ can be observed. Other terminally-modified LC with fluorine also exhibited low dielectric loss (data are not shown here). Since the fluorocarbon group has high electronegativity due to fluorine atom, C-F bonding energy is relatively high. In addition, molecular rotation was suppressed by steric interactions between adjacent fluorocarbon [2]. Therefore, we considered that the fluorocarbon group has role of suppression of molecular vibration loss by radio frequency.

Table 1. Evaluated dielectric loss at 12GHz and chemical structure of LC molecules

LC (manufacturer)	Chemical structure	ε_r		tan δ	
		$\parallel$	$\perp$	$\parallel$	$\perp$
5CB (LCC corp.)		3.32	3.00	0.024	0.052
TD-1018XX (JNC corp.)		2.53	2.44	0.027	0.070
TD-1017XX (JNC corp.)		2.67	2.35	0.016	0.028

4. Conclusions

In this study, we investigated the structural factor of nematic-phase liquid crystal in the dielectric loss at radio frequency. As the results, we found that that the dielectric loss was affected by rigidity of main chain and terminally-modified polar groups in the nematic liquid crystals.

References

[1] Yu. Garbovskiy, V. Zagorodnii, P. Krivosik, J. Lovejoy, R. E. Camley, Z. Celinski, A. Glushchenko, J. Dziaduszek, and R. Da˛browski, "Liquid crystal phase shifters at millimeter wave frequencies," *J. Appl. Phys.* **111**, 054504 (2012)

[2] Michael Hird, "Fluorinated liquid crystals – properties and applications," *Chem. Soc. Rev.*, **36**, 2070-2095 (2007).