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Measurements of anisotropic complex permittivity of liquid crystals at microwave frequencies

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Abstract

Recent interest in application of liquid crystals for tuning of microwave frequency range devices generated a need for better microwave characterization of these anisotropic and DC electric and magnetic fields sensitive materials. We report on measurements of the complex permittivity tensor of two liquid crystals and on determination of their DC electric field bias dependence. Measurements were carried out using a novel microwave cylindrical dielectric resonator technique which utilizes TE_{011} and TM_{011} modes. Liquid crystals are inserted into the inner hole in the dielectric resonator. Results of measurements have shown significant anisotropy in crystals dielectric properties and also allow estimates of tunability and tuning speed. The measurements showed some promises for liquid crystals to be used for tuning, but more characterization and technological work is needed.
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Keyword: Liquid crystals; Electrical properties; Functional applications

1. Introduction

While liquid crystals are most commonly used at optical frequencies, several papers have recently been published on their dielectric characterization at microwave frequencies, indicating the growing interest in applications of these anisotropic and DC electric and/or DC magnetic field sensitive crystals for electronically tunable devices.[1–7] In contrary to AC and optical frequency range, where the properties of these materials are sufficiently well known, the microwave properties were either not fully invesigated or understood yet. In this paper we descibe a dielectric resonator technique that has been employed for the measurements of the full complex permittivity tensor of such materials versus static electric field bias.

2. Measurements system

At a static electric bias, the complex permittivity of a liquid crystal can be described by permittivity tensor having the following components:

$$\overleftrightarrow{\varepsilon} = \begin{bmatrix} \varepsilon_\perp & 0 & 0 \\ 0 & \varepsilon_\perp & 0 \\ 0 & 0 & \varepsilon_{||} \end{bmatrix} \quad (1)$$

Measurements of the parallel and perpendicular components of permittivity tensor can be realized by employing two different modes in a microwave resonator. One of the modes should have electric energy concentrated predominantly in the direction perpendicular to the axis of static bias (z-axis), while the other focuses energy in the direction parallel to the axis of bias. One of the resonant structures having such properties is a cylindrical dielectric resonator operating on TE_{011} mode and TM_{011} mode (Fig. 1).

For the TE_{011} mode, the rf electric field has only the azimuthal component, which is perpendicular to z-axis, whereas for the TM_{011} mode, the rf electric field has two components: the axial and the radial. The axial component approaches maximum at the resonator axis while the radial component vanishes there. If the radius of the sample (radius of the inner hole) is relatively small, then the electric energy filling factor in the sample has a predominantly axial component. Measurements of the

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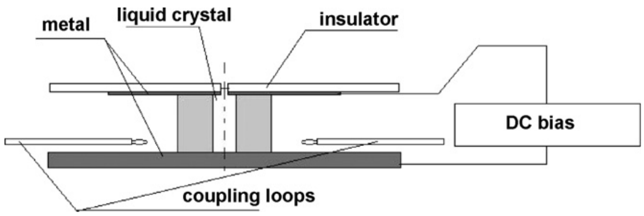

Fig. 1. A sketch of the dielectric resonator used for measurements of complex permittivity components of liquid crystals vs. external DC electric field.

resonant frequencies and the unloaded Q-factors of both modes for the same sample allow us to determine the two components of the complex permittivity tensor. The real part of the permittivity tensor can be found by solving characteristic transcendental equations for the specific modes with respect to the appropriate tensor components. The dielectric loss tangents are then determined from the following formula:

$$\tan\,\delta = p_{\mathrm{e}}^{-1}\left(\frac{1}{Q_{\mathrm{u}}} - \frac{1}{Q_0}\right), \qquad (2)$$

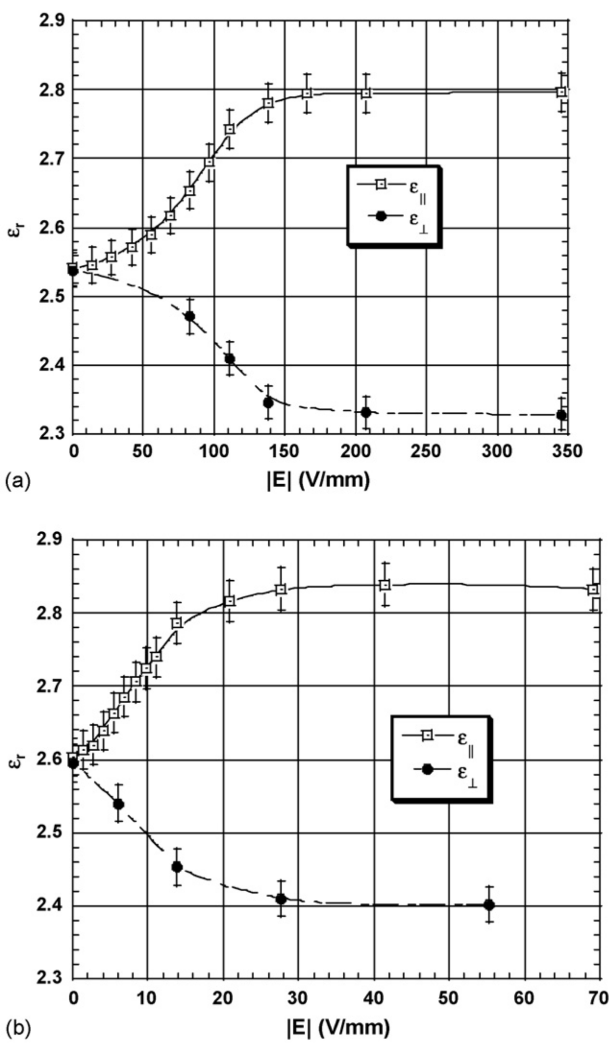

Fig. 2. Anisotropy of the real part of complex permittivity vs. DC external electric field bias measured for the 784-2 (a) and 6HCBT (b) liquid crystals, respectively.

where Q_{u} denotes the measured value of the unloaded Q-factor of the appropriate mode containing the sample under test, Q_0 denotes the Q-factor due to parasitic losses (resonator without liquid crystal) and p_{e} denotes the electric energy filling factor in the sample.

3. Results of measurements

Measurements have been performed using a cylindrical dielectric resonator operating on TE_{011} and TM_{011} modes. The dielectric resonator has been made of single crystal quartz (Table 1).

Results of measurements of complex permitivity DC bias for two liquid crystals are shown in Figs. 2 and 3. One can observe that the permittivity component parallel to the biasing electric field increases while the component perpendicular to the biasing field decreases with the DC electric field strength. Such behavior is consistent with an increased alignment of long molecules of liquid crystals along DC electric field lines.

Dielectric loss tangent components behave in the opposite way. The dielectric loss tangent parallel to the biasing field dielectric decreases while the dielectric loss tangent perpendic-

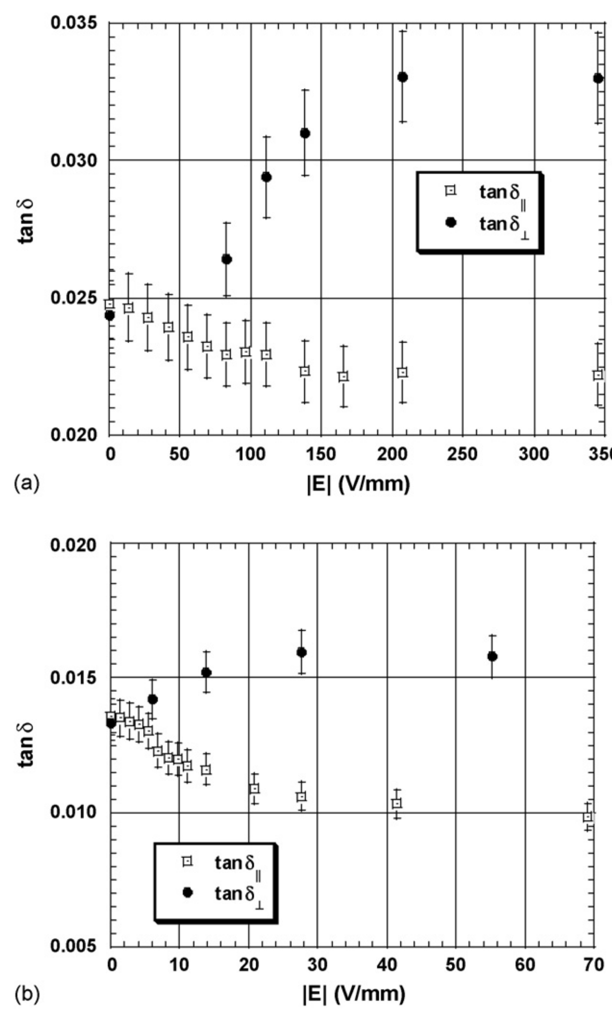

Fig. 3. Anisotropy of the dielectric loss tangent vs. DC electric field bias measured for the 784-2 (a) and 6HCBT (b) liquid crystals, respectively.

Table 1
Parameters of the dielectric resonator used in measurements

Parameter	Value
Disk hole diameter, *d* (mm)	2.18
Disc outer diameter, *D* (mm)	13.86
Disc height, *L* (mm)	7.24
f_0 (TE_{011})	13.712 GHz
f_0 (TM_{011})	15.125 GHz
Q_0 (TE_{011})	8100
Q_0 (TM_{011})	3450

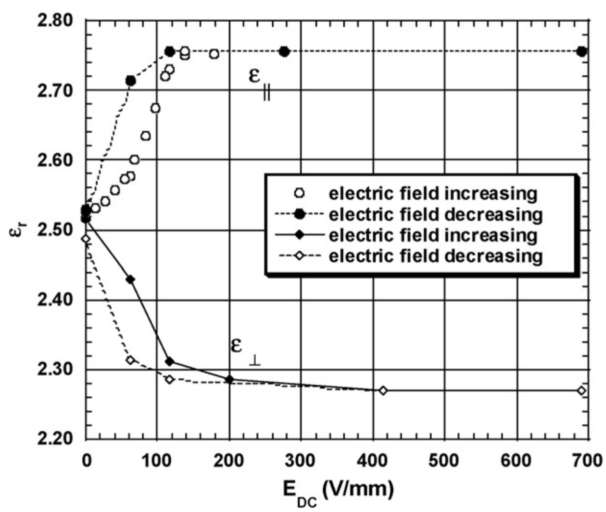

Fig. 4. Hysteresis of the real part of complex permittivity ε_r of the liquid crystal 784-2 as a function of incresing and decreasing DC electric field bias. Parallel and perpendicular components of ε_r were measured.

ular to the biasing field increases with applied bias. For frequncy range 13–15 GHz permittivity values and dielectric loss tangents of both measured crystals are in the range of 2 and 3 and 0.01–0.05, respectively. Relative changes of dielectric constant and loss tangent versus DC electric field bias are of the order of 10%.

One of the apparent drawbacks of measured liquid crystals in practical applications in tunable microwave devices is the presence of hysteresis in the dielectric constant on DC electric field dependence and low tuning speed. In Fig. 4, such measured hysteresis, which depend on the speed rate of the bias field change, is shown.

4. Conclusions

A new microwave dielectric resonator based technique for characterization of dielectric properties of anisotropic liquid crystals has been presented. This technique allows the determination of parallel and perpendicular components of real and imaginary parts of complex permittivity of two liquid crystals in the presence of the applied DC electric bias. The measurements confirmed high anisotropy of the investigated crystals, which resulted in 0.45 (∼20%) of the maximum change of the dielectric constant at 100 V/mm obtained for both crystals. Measured loss tangent was 0.015 and 0.035 at 0 V/mm and maximum anisotropy was measured as 0.1 and 0.06 at 100 V/mm for crystals 744-2 and 6HCBT, respectively.

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