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Measurement Principle and Method for Liquid Crystal′s Rotational Viscosity Coefficient

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Abstract Rotational viscosity is one of important liquid crystal′s physical properties for display and telecommunication industries. The measurement method and principle of the temperature dependence of rotational viscosity coefficient of nematic liquid crystal were investigated on a personal computer-based optical system developed by us. Rotational viscosity coefficient was caculated from the phase decay time tested on the optical system. The data of the temperature dependence of rotational viscosity coefficient of a typical LC material — a Merck nematic E7 mixture were given, and experimental results agree with the theory well, which verifies the correction of the principle. The method is simple and automatic.

Keywords Liquid crystal; Rotational viscosity coefficient; Dielectric constant; Splay elastic constant; Measurement

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0 Introduction

Liquid crystals (LCs) have been widely used in flat panel displays and telecommunications. In a display device, its performance is heavily influenced by the physical properties of the employed liquid crystal[1,2]. For instance, dielectric constants influence the threshold voltage and viscosity (indirectly); elastic constants affect the threshold voltage and response time; and rotational viscosity affects the response time. Therefore, accurate and automatic evaluation processes of liquid crystal properties are essential to the display and telecommunication industries, which require the developments of measurement system and methods.

The rotational viscosity coefficient is particularly difficult to measure. Some experimental techniques have been developed for measuring rotational viscosity coefficient. These methods include electro-optics, ultrasound, rotating magnetic field, and light scattering[3~9]. Low rotational viscosity liquid crystals are highly desirable for liquid crystal display TV applications. Operating temperature plays important roles to rotational viscosity. Some theories about the temperature dependence of rotational viscosities of liquid crystal have been presented[10~12].

In this paper, a personal computer (PC)-based optical measurement system using a DAQ plug-in board was introduced and LabVIEW version 6. 0 was developed by us. The temperature dependence of rotational viscosity coefficient was also investigated, including test principle and method, related theories and results. A typical LC material — a Merck nematic E7 mixture was used as a test sample.

1 Experiment and theory

1.1 Experimental setup

Fig. 1 shows the schematic diagram of the experimental setup. A He-Ne laser ($\lambda = 632.8$ nm) was used as the light source. The linear polarizer was orientated at 45° with respect to the LC rubbing direction and the analyzer was crossed. The light transmittance was measured by a New Focus photodiode detector (Model 2031) and recorded digitally by a data acquisition system (DAQ, PCI 6110) using LabVIEW. The DAQ card can realize 5 MS/s, 12-bit, 4 analog input simultaneous samplings. An ac voltage with 1 kHz square waves was used to drive the LC cell whose inner sides were coated with ITO (indium-tin-oxide) electrodes. On top of the ITO, the substrate was covered with a thin polyimide alignment film. The buffing induced pretilt angle is about 3°. The cell was held in an oven (INSTEC

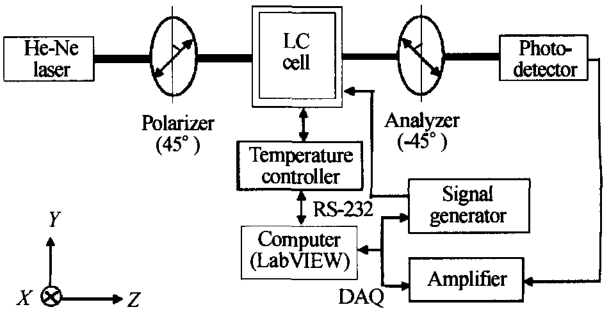

Fig. 1 Schematic diagram of the experimental setup for LC characterizations incorporating LabVIEW

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STC-200D) with a temperature stability of 0.2℃. The visual instruments programs were developed to generate LC driving signals and open a window for displaying experimental parameters. The LabVIEW system consists of three parts: function generator, voltage amplifier, and display window.

1.2 Theory

The measurement principle and method of rotational viscosity coefficient were described in this paper.

In the small angle approximation, the time-dependent phase decay of a homogeneous cell followed a simple exponential form[10]

$$\delta(t)=\delta_0 \exp(-2t/\tau) \qquad (1)$$

$$\tau=\frac{\gamma_1 d^2}{K_{11}\pi^2} \qquad (2)$$

In Eqs. (1) and (2), δ_0 is the initial phase retardation at a bias voltage which is not too far above threshold voltage, and τ is the decay time (free relaxation time). From the LabVIEW system, free relaxation time was measured firstly and then γ_1/K_{11} was calculated.

The voltage value (when the first transmission maximum occurs) was set as bias voltage in the LabVIEW system. When the bias voltage was removed instantaneously, the time-dependent transmittance change was recorded by oscilloscope. Its associated phase change can be calculated using the following relationship

$$I(t)=I_0\cos^2((\delta_0-\delta(t))/2) \qquad (3)$$

From Eqs. (1) and (3), and by taking into account the correlation of noise interference in the experiment, was obtained the time-dependent relaxation process

$$I(t)=I_0\cos^2\left(\frac{\delta_0\left(1-\exp\left(-\frac{2(t-t_0)}{\tau}\right)\right)}{2}\right) \qquad (4)$$

Using MATLAB to do the curve fitting by non-linear least squares method, τ was gotten. According to Eq. (2), to get the value of the rotational viscosity coefficient, the value of splay elastic constant K_{11} should be known.

A simple way to determine K_{11} was to extract from the threshold voltage V_{th} if dielectric constants $\Delta\varepsilon$ was known[1]

$$V_{\mathrm{th}}=\pi\sqrt{\frac{K_{11}}{\varepsilon_0\Delta\varepsilon}} \qquad (5)$$

The threshold voltage was gotten by converting the voltage-dependent transmission curve into voltage-dependent phase retardation in the new system.

To measure dielectric constants, computer-controlled APT-Ⅲ manufactured by Displaytech was used. This technique has been published.

1.3 Results and discussion

The governing theories about the temperature dependence of dielectric constants, splay elastic constants, and rotational viscosity coefficient of liquid crystal were reviewed. The obtained data were then used to fit with these theories. The agreement between experiments and theories was quite satisfactory.

Fig. 2 shows the measured temperature-dependent dielectric anisotropy of E7 tested in computer-controlled APT-III. Dots in Fig. 2 represent the experimental data and the solid line is the curve fitting to the Mean Field theory. For a polar compound or mixture, Mean Field theory has a simplified form for $\Delta\varepsilon$

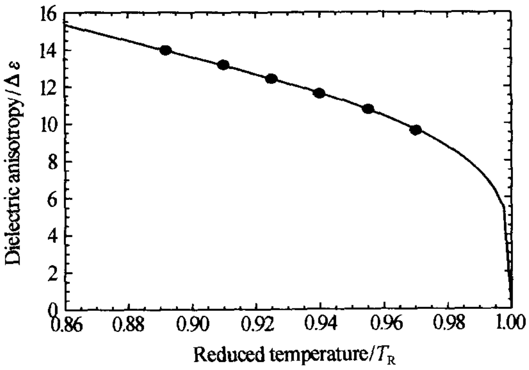

Fig. 2 Measured temperature-dependent dielectric anisotropy of E7 LC. T_c = 333 K. Dots are experimental data and solid lines are fittings using Eqs. (6) and (7). The two fitting parameters A and β_1 are listed in Table. 1 for comparison

$$\Delta\varepsilon=A\frac{S}{T} \qquad (6)$$

In Eq. (6), A is a proportionality constant, which is related to the dipole moment of the LC material. T is the absolute temperature, and S is the order parameter.

From Haller's empirical studies, the order parameter S can be approximated as[11]

$$S=(1-T/T_c)^{\beta_1}=(1-T_R)^{\beta_1} \qquad (7)$$

In Eq. (7), T_c is the clearing point of the LC mixture and β_1 is a constant. The ratio of T/T_c is the reduced temperature, T_R. For E7, T_c = 333 K. To fit experimental results, A and β_1 were treated as adjustable parameters. From fittings, A = 6895.9 and β_1 = 0.227 were obtained. These results were listed in Table. 1 for comparison to the new system's results.

Table. 1 The parameters obtained from fitting temperature-dependent dielectric anisotropy (A & β_1), splay elastic constant (B & β_2), and rotational viscosity coefficient (α E & β_3) data of the E7 LC cell

A(K)	β_1	B(pN)	β_2	E(meV)	α(Pa.S)	β_3
6895.9	0.227	30.8	0.224	439.0	1.30×10^{-8}	0.224

In the new system, the threshold voltage of liquid crystal cell was measured. Since the temperature-dependent dielectric constants of E7 as plotted in Fig. 2 have already been measured, the splay elastic constant can be calculated through Eq. (5). Results are depicted in Fig. 3.

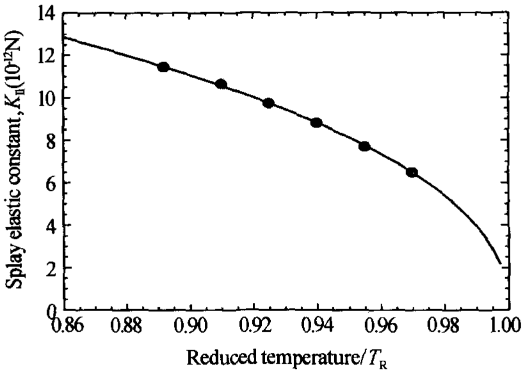

Fig. 3 The temperature-dependent splay elastic constant (K_{11}) of E7 LC cell. Dots are measured data and solid lines are fitting curves using Eq. (8). The fitting parameters B and β_2 are listed in Table. 1 for comparison

From the Maier-Saupe theory[11], the splay elastic constant was linearly proportional to S^2

$$K_{11} = BS^2 = B(1-T_R)^{2\beta_2} \qquad (8)$$

B and β_2 can be used as adjustable parameters to fit the experimental results and obtain $B = 30.8$ pN and $\beta_2 = 0.224$. As summarized in Table. 1, the two exponents (β_1, β_2) agreed with each other quite well, although the measurement techniques and systems were different.

A bias voltage $V = 1.21$ V_{rms} was set in the new system, and the time-dependent relaxation process curve was obtained in Fig. 4, and τ was algo gotten. Knowing the cell gap (the LC cell we used for experiment was a homogeneous cell with uniform gap $d = 15.07$ μm), and the temperature-dependent splay elastic constant K_{11} of E7 as plotted in Fig. 3, rotational viscosity coefficient γ_1 was calculated from Eq. (2). The results of the temperature-dependent rotational viscosity coefficient of E7 were plotted in Fig. 5 where dots represented the experimental data and solid lines were fittings to the following equation[11]

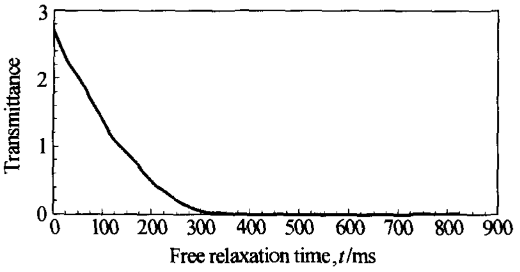

Fig. 4 The time-dependent relaxation curve of the $d=15.07$ μm E7 LC cell at 24℃. The bias voltage $V_b = 1.21$ V_{rms}

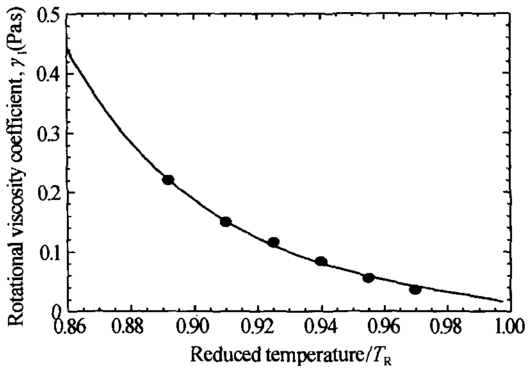

Fig. 5 The temperature-dependent rotational viscosity coefficient of E7 LC. Dots are experimental data and solid lines are fitting using Eq. (9). Two adjustable parameters α and E are listed in Table. 1 for comparison

$$\gamma_1 = \alpha S\exp(E/kT) = \alpha(1-T_R)^{\beta_3} S\exp(E/kT) \qquad (9)$$

In Eq. (9), α is a proportionality constant, E is the activation energy, and k is the Boltzmann constant. In order to fit experimental data with minimal variables, $\beta_3 = \beta_2 = 0.224$ was chosen for the order parameter (S) and leave α and E as two adjustable parameters. From curve fittings, we find $\alpha = 1.3\times10^{-8}$ Pa · s and $E = 439$ meV.

2 Conclusion

A personal computer-based optical system for characterizing the physical properties of nematic liquid crystals was developed. And the measurement methods and principles of the temperature dependence of rotational viscosity coefficient of liquid crystal were investigated on this system. The data of a typical LC material — a Merck nematic E7 mixture were given. The fitting values of the order parameter $S = (1-T_R)^{\beta}$ (the exponents β_1 for dielectric constants $\Delta\varepsilon$, β_2 for splay elastic constants K_{11}) abtained from the measured data and related theories agree with each other quite well, although the measurement techniques and systems were different — dielectric constants $\Delta\varepsilon$ tested by computer-controlled APT-Ⅲ manufactured by Displaytech; splay elastic constant K_{11} tested by our system and methods. When the data of rotational viscosity coefficient measured on the new system and the value β_2 of the order parameter from splay elastic constant were used to fit the theoretical equation of rotational viscosity coefficient, experimental results agreed with theory well, which verified the correction of the principle and method for the measurement of rotational viscosity coefficient. The research will benefit display and telecommunication industries in characterizing the liquid crystal' s important property — rotational viscosity.

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液晶的转动粘质系数的测试原理与方法

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摘 要 液晶的转动粘质度是液晶用于显示和通讯的重要物理参量.本文设计开发了基于微机的液晶参数测试光学系统,在该系统上研究了液晶的转动粘质系数的测试原理与方法:通过测试液晶盒在偏置电压下相位驰预时间,推导出转动粘质系数的值.测试 Merck 公司的 E7 液晶的转动粘质系数随温度变化的曲线,进行了理论拟合,测试结果与理论符合得很好.通过分析另一系统对液晶介质常数随温度变化的曲线的测试结果,验证了该测试原理与方法的正确性.该测试方法具有简单、自动化的特点.

关键词 液晶;转动粘质系数;介质常数;展曲弹性系数;测试

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