

Peculiarities of light transmission at nematic – isotropic liquid and isotropic liquid – nematic phase transitions

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The optical transmission in thermotropic nematogens for a large temperature interval and in regions of direct and reverse phase transitions between the nematic mesophase and isotropic liquid has been investigated. The character of the optical transmission has been compared with that of the texture transformations of the nematogens. The thermal hysteresis effect for the optical transmission vs. temperature has been found. The shift of the isotropic liquid – nematic phase transition temperature and widening of the biphasic region of this phase transition have been observed.

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1. Introduction

As is well known, liquid crystalline materials have very sensitive structures to various external effects and the high sensitivity of these materials allows their application in different technical devices [1-7]. Liquid crystals have a rich variety of optical properties. Therefore many devices based on them work by using the optical properties of the materials. So far as the devices based on liquid crystals are generally used in different thermal regimes, in various temperature intervals and in different climatic conditions, investigations of the thermo-optical properties of these materials are very important from an application point of view. Also topics connected with studies of the optical (including thermo-optical, electro-optical and magneto-optical) properties are very important from fundamental points of view because such studies and investigations allow one to gain information about the structural and physical properties of liquid crystals, and to determine new fields for liquid crystal applications [8-11].

In this study we are interested in the temperature behaviour of the coherent optical transmission of thermotropic nematics over a large temperature interval and in regions of the direct and reverse phase transitions between the nematic mesophase and the isotropic liquid. We are also interested in the connection between the temperature dependences of the optical transmission and the temperature transformations of the specific textures of these nematics. Results of these investigations are presented in this work.

2. Experimental

2.1. Materials and samples

We have investigated the optical, thermo-optical and morphological properties of the Schiff based liquid

crystalline materials. These are N-(4-methoxybenzylidene)-4-butylaniline (MBBA) and the eutectic mixture of N-(4-methoxybenzylidene)-4-butylaniline with N-(4-ethoxybenzylidene)-4-butylaniline {MBBA+ EBBA (1:1)}. These liquid crystals are the monomorphic nematogens and exhibit only a nematic mesophase. The purity of the liquid crystals studies was examined by the chromatography technique and their purity was determined to be greater than 99.5%.

The samples used in this work were flat capillaries with glass optical reference surfaces. The thickness of the liquid crystals, placed between the reference surfaces of the flat capillary, was fixed by a Mylar thin film as 20 μm .

2.2. Methods

For investigations of the temperature dependences of the optical transmission of MBBA and MBBA+EBBA a special thermo-optical set-up was used. Our set-up consisted of a He-Ne laser light source ($\lambda = 632.8 \text{ nm}$ and 0.95 mW power), a heater-thermostat, heating system, temperature control system, flat capillary with the liquid crystal, differential Cu-Co thermocouples, multimeters, photodiode, polarizer, analyzer, relative transmission object and video camera.

Studies of the morphological and optical properties of the liquid crystals and their texture transformations were carried out by polarization optical microscopy (POM). In this work a trinocular Olympus polarizing microscope and an Olympus microphotographic system with optical filters and $\lambda -$ plates were used. The crystal-optics and crystal-physics methods also have been applied in these studies.

Investigations of the thermotropic properties of the liquid crystals were carried out by means of an original experimental method, i.e. a capillary temperature wedge (CTW). The CTW device consisted of a working element as the lengthy flat capillary, a temperature control system,

a heating and cooling system, and an observation and registration system. This method was previously presented in [12,13] and was used to study the thermal behaviour of thermotropic and lyotropic liquid crystals. This method allows one to obtain simultaneously in real time all of the thermal states of a liquid crystalline material, to investigate the morphologic and thermotropic properties of liquid crystalline mesophases and to calculate the phase transition temperatures and the linear and temperature widths of the biphasic regions of these transitions with an accuracy not better than 10^{-3} K [12-14].

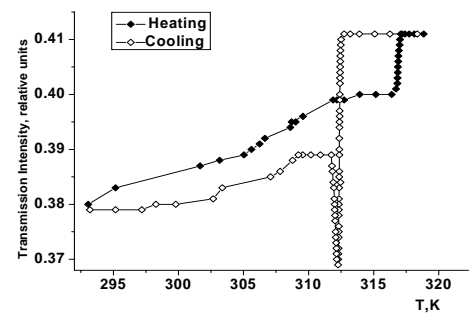
3. Results and discussions

MBBA and MBBA+EBBA liquid crystals exhibit the typical textures of non-oriented thermotropic nematics. The observed textures are specific and consist of thread-like formations, which are inversion walls, various singularities and separate oriented regions.

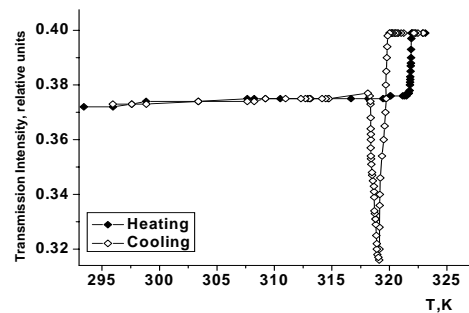
Samples with these textures exhibit interesting thermo-optical behaviour, namely interesting dependences of the $I = I(T)$ at heating and cooling of the flat capillary. These dependences, both for MBBA and MBBA+EBBA, upon heating of the sandwich-cell can be considered in three stages. In the first by heating the sample, a slow change of the I for both MBBA and MBBA+EBBA has been observed (Figs. 1a,b). In the second stage a temperature increase led in definite temperature intervals to the abrupt increase, fluctuations and abrupt jump of the I , both for MBBA and MBBA+EBBA (Figs. 1a,b). In the third stage, any changes in I have not been observed by a temperature increase of the flat capillaries. In this stage, the disappearance of the $I = I(T)$ dependences in the saturation state took place for both MBBA and MBBA+EBBA.

The $I = I(T)$ dependences upon cooling of the flat capillaries with MBBA and MBBA+EBBA can be also considered in three stages. In the first, no changes in I have been observed in a sufficiently large temperature interval for these liquid crystals. In the second stage, abrupt changes of I have been observed for MBBA and MBBA+EBBA. In the third stage, a slow decrease in I with decreasing temperature took place for the liquid crystals under investigation.

In this work, we were also interested in character of the thermo-morphological properties of non-oriented textures of MBBA and MBBA+EBBA at the direct *nematic – isotropic liquid* and the reverse *isotropic liquid – nematic* phase transitions, and the connection of these properties to the temperature dependences of I at these transitions. Therefore we also investigated the character of texture transformations vs. temperature for these liquid crystals.



a



b

Fig.1. Temperature dependences of the optical transmission vs. temperature for MBBA (a) and MBBA+EBBA (b). These dependences were obtained without polarizers.

Investigations showed that by heating the liquid crystals over sufficiently large temperature intervals, which were different for MBBA and MBBA+EBBA, texture transformations which were smooth and unremitting for MBBA and imperceptible for MBBA+EBBA took place. The temperature intervals corresponded to a gradual change in I in the first stage of the $I = I(T)$ dependences for MBBA and MBBA+EBBA. Then, in definite temperature intervals the appearance of the biphasic region of the *nematic – isotropic liquid* phase transition was observed for these liquid crystals. As an example, in Fig. 2a a microphotograph of the biphasic region for MBBA is presented. In the biphasic region simultaneous coexistence of nematic mesophase and isotropic liquid took place. Investigations showed that the temperature intervals of these regions are equal to those of the abrupt changes in I for MBBA and MBBA+EBBA. And finally, at temperatures higher than the high temperature limit of the biphasic region, MBBA and MBBA+EBBA were in an isotropic liquid state. Here by following heating of the samples only an isotropic background was observed. This case corresponds to the third stage of the temperature dependences of I .

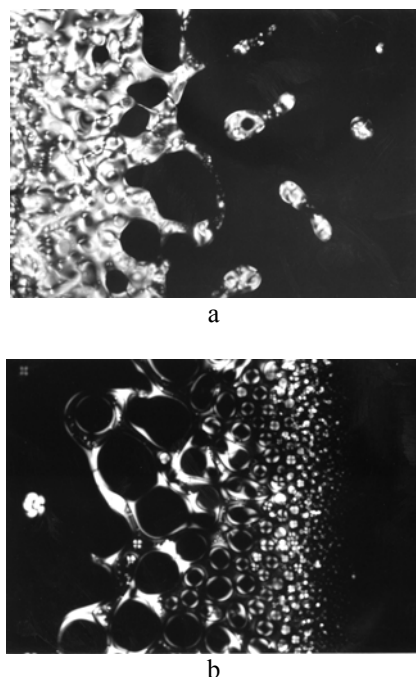


Fig. 2. Heterophase regions of the nematic – isotropic liquid (a) and isotropic liquid – nematic (b) phase transitions for MBBA.

Investigations showed that by cooling of the liquid crystals over sufficiently large temperature intervals no texture transformations were observed for MBBA and MBBA+EBBA. These temperature intervals were different for MBBA and MBBA+EBBA. In these temperature intervals, the liquid crystals were in an isotropic liquid state. This case corresponds to a first stage of the $I = I(T)$ dependences for the cooling of the samples. Then by subsequent cooling of the samples, the appearance of the biphasic region of the *isotropic liquid – nematic* phase transition has been observed for MBBA and MBBA+EBBA. As an example, in Fig. 2b a microphotograph of the biphasic region for MBBA is presented. In this region, also as in the biphasic region of the *nematic – isotropic liquid* phase transition, the simultaneous coexistence of a nematic mesophase and an isotropic liquid took place. The appearance of this region was accompanied by abrupt changes in the $I = I(T)$ dependences (Fig. 1). And finally, at temperatures lower than the low temperature limit of the biphasic region smooth and unremitting for MBBA and imperceptible for MBBA+EBBA texture transformations have been observed. This case corresponds to the third stage of the $I = I(T)$ dependences for the cooling of the samples.

As the investigation results showed, the character of the changes in the thermo-optical properties of MBBA and MBBA + EBBA for the direct and reverse phase transitions between the nematic mesophase and the isotropic liquid totally correspond to the character of the changes in their thermo-morphologic properties for these phase transitions. Also, the nonlinear behaviour of the $I = I(T)$ dependences takes place in the biphasic regions of

the *nematic – isotropic liquid* and *isotropic liquid – nematic* phase transitions for these liquid crystals.

Table 1. Features of phase transitions in MBBA and MBBA+EBBA liquid crystals.

Samples	Temperatures of the phase transitions, K		Temperature widths of the heterophase regions, K	
	Heating	Cooling	Heating	Cooling
MBBA	316.63	312.35	0.526	0.956
MBBA+EBBA	321.07	319.11	0.669	1.030

As seen in Fig. 1, the temperatures of the direct and reverse phase transitions in both MBBA and MBBA+EBBA do not coincide. Besides, the linear and temperature widths of the biphasic region for the *isotropic liquid – nematic* phase transitions are larger than the widths for the *nematic – isotropic liquid* phase transition (Fig. 2). The temperatures of the phase transitions and also the temperature widths of the biphasic regions are presented in Table 1. Thus, in MBBA and MBBA+EBBA the thermal hysteresis for the phase transitions between the nematic mesophase and the isotropic liquid takes place. As is known, these are the first order phase transitions and the availability of the thermal hysteresis for them has been predicted theoretically [15-20] and also observed experimentally [15,21-26].

4. Conclusions

In this work the character of temperature dependences of the optical transmission of MBBA and MBBA+EBBA in a large temperature interval and the connection between this character with the temperature transformations of non-oriented textures of these liquid crystals have been investigated. The conformity between the macroscopic thermo-optical properties and the microscopic thermo-morphological properties has been found for the non-oriented nematic mesophase of MBBA and MBBA+EBBA over a large temperature interval and in the regions of the direct and reverse phase transitions between the nematic mesophase and the isotropic liquid.

The *nematic – isotropic liquid* and *isotropic liquid – nematic* phase transitions are characterized by the biphasic regions with temperature widths as $\Delta T = T_{NI}^{**} - T_{NI}^*$ and $\Delta T = T_{IN}^{**} - T_{IN}^*$, accordingly (Table 1). Abrupt changes in the optical transmission take place in the biphasic regions of these phase transitions (Figs. 1 and 2).

The differences in the temperatures of the direct and reverse phase transitions between the nematic and isotropic liquid and the widening of the temperature and linear widths of the biphasic regions for the reverse phase transitions have been found for both MBBA and MBBA+EBBA. These differences are clearly identified by

the temperature dependences of the optical transmission for MBBA and MBBA+EBBA (Fig. 1a,b).

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