Vol. 97 (2000) *ACTA PHYSICA POLONICA A* No. 2

BEHAVIOUR OF THE OPTICAL BIREFRINGENCE IN CONDITIONS OF THE "VISCOUS" INTERACTION

S.A. SVELEBA, V.S. ZHMURKO

Ferroics Physics Laboratory, Department of Unlinear Optics
Ivan Franko National University of Lviv, Dragomanova st. 19, Lviv, 79005, Ukraine

AND YU.I. PANKIVSKYI

Laboratory of Ecology, Department of Ecology, Ukrainian State University of Forestry and Wood Technology, O. Kobylyanskoyi st. 1, Lviv, 79005, Ukraine

(Received September 23, 1999)

The temperature dependences of optical birefringence $\delta(\Delta n)$ for the principal cuts of $[N(CH_3)_4]_2CuCl_4$ crystals are measured. On the basis of the obtained experimental and theoretical data the anomalous behavior of physical parameters in conditions of the "viscous" interaction of the modulated structure with mobile defects in the incommensurate phase is explained.

PACS numbers: 64.70.–p

1. Introduction

The anomalies on temperature dependences of optical birefringence [1] and dielectric permittivity [2] are observed in conditions of the "viscous" interaction. Their shape view has been discussed in different works [3, 4]. Moreover, the magnitude of $\delta(\Delta n)$ anomalies is considerably changed depending from the investigated crystal [5–7] and the sample of the same crystal [8]. In accordance with Refs. [3, 4] the "viscous" interaction is affected by the interaction of the movable defects with the soliton structure that causes the appearance of the region of the interaction of two commensurate phases. Such anomalous behaviour of the physical parameters in a transition region relates with the interaction of the space-modulated oscillations causing an appearance of the resulting oscillation. Temperature behaviour of the resulting oscillation should be affected by residual defects concentration around the soliton [8, 9]. At the first approach the residual concentration may be considered as an action of electric field intensity of definite value on the soliton structure [2].

A lot of scientific papers [2, 10–17] have been devoted to the investigations of the electric field influence on the incommensurate phase. In theoretical [11, 13, 15] and as well as in experimental papers [2, 10, 12] it has been noted that electric field affects the incommensurate structure deformation and also causes an appearance of the commensurate polar phase within the incommensurate phase. Otherwise, electric field influence on incommensurate structure accompanied by the change of the incommensurate structure period [8, 18], selection and widening of temperature region of incommensurate modulation vector localisation on commensurate values of higher order [19].

Under such circumstances it would be interesting to investigate in detail the behaviour of optical birefringence in condition of the "viscous" interaction, to discover internal field action created by residual defects concentration and as well as to study external electric field influence on the behaviour of the amplitude and phase of order parameter in the transition region. The $[N(CH_3)_4]_2CuCl_4$ crystal was chosen as an object of investigation, because it does not possess ferroelectric properties and also the anomalies of $\delta(\Delta n)$ in the form of "splashes" at "viscous" interaction [20] have been observed at a rather high rate of temperature change $\delta T/\delta t = 240$ mK/h [21].

2. Experiment and discussion

The crystals were grown at room temperature by a slow evaporation of an aqueous solution of $CuCl_2$ and $N(CH_3)_4Cl$ salts taken according to their molar ratios. The investigations of the birefringence increment were performed using Senarmount's method. The accuracy of temperature measurement and stabilization was ~ 0.005 K.

The temperature dependences of $\delta(\Delta n)$ for the principal cuts for $[N(CH_3)_4]_2CuCl_4$ crystal obtained in conditions of the "viscous" interaction at the rate of temperature change $\partial T/\partial t = 60$ mK/h are presented in Figs. 1 and 2. As one can see the anomalous temperature behaviours of $\delta(\Delta n_x)$ and $\delta(\Delta n_y)$ differ from the temperature behaviour of $\delta(\Delta n_z)$. The anomalies are significantly different both in their amplitude and the temperature region of their existence. When the anomalous change of $\delta(\Delta n_z)$ is equal to ~ 0.00005 (Figs. 2, 3), the anomalous changes of $\delta(\Delta n_x)$ and $\delta(\Delta n_y)$ are equal to 0.0013 and 0.0003, respectively. The last values are different from the value of $\delta(\Delta n_z)$ by one order. The temperature intervals of anomalies existence for x- and y-directions are equal to ~ 0.35 K and ~ 0.20 K for z-direction. The obtained data concerning the anomalous behaviour of $\delta(\Delta n)$ are analogous to formerly observed one for these $[N(CH_3)_4]_2CuCl_4$ crystals [22]. The difference in the anomalous behaviour of $\delta(\Delta n)$ between x-, y- and z-directions is obviously comprised with availability of the incommensurate modulation along the z-axis. Let us consider the thermodynamical potential in the form presented in Ref. [11]

$$\Phi_l = \alpha\rho^2 + \beta\rho^4 - \alpha_l'\rho^{2l}\cos 2l\phi + a_1E_1\rho^l\cos l\phi + a_2E_2\rho^l\sin l\phi$$
$$-E_1^2/2\kappa_1 - E_2^2/2\kappa_2, \tag{1}$$

where E_1 and E_2 are the external actions, they are transformed according to

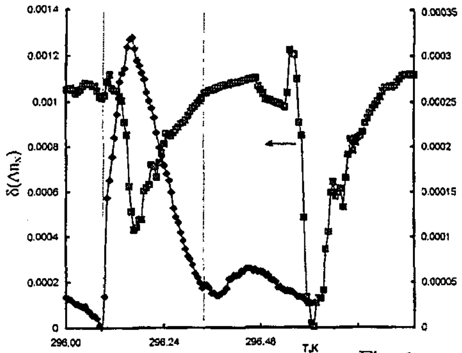

Fig. 1

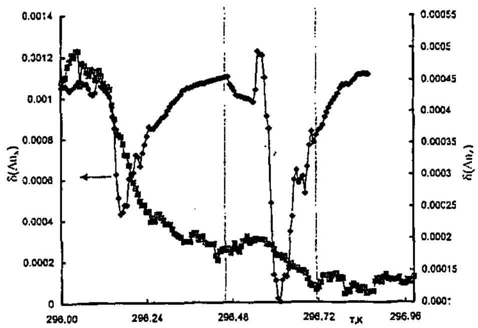

Fig. 2

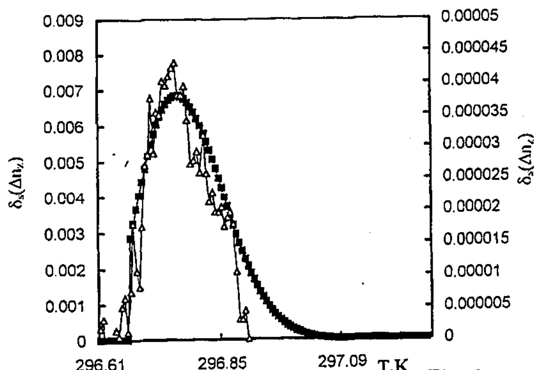

Fig. 3

Fig. 1. Temperature dependence of $\delta(\Delta n_x)$ and $\delta(\Delta n_y)$ for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h.
Fig. 2. Temperature dependence of $\delta(\Delta n_x)$ and $\delta(\Delta n_z)$ for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h.
Fig. 3. Temperature dependence of optical birefringence along the modulation axis for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h, ■ — theoretical curve, Δ — experimental curve.

the group of point symmetry of the initial phase and correspond to electric and mechanical fields intensities; the coefficients a_1, a_2, and α_l' have nonzero values only at discrete values of $k = k_l = m/l$; the coefficients κ_1, κ_2, α, β are continuous functions of k-vector [13].

Now let us consider the values of polarizational constants a_{ij} in conditions of existence of the incommensurate modulation. As it has been shown in Ref. [23], a_{ij} has the same functional dependence as σ_{ij}

$$a_{ij} = \sigma_{ij} = \partial\Phi/\partial u_{ij}, \tag{2}$$

because a_{ij} is the symmetric second rank tensor similarly as the mechanical stress tensor σ_{ij}. Analysing optical birefringence it is necessary to take into account higher order components of the thermodynamical potential [24]

$$\Delta a_i = \omega_i\rho^2 + R_{i2}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_i\rho^2(\partial\phi/\partial x) + \sum M_{ik}u_k^2, \quad i = 1,2,3,$$

$$\Delta a_k = \sum_{k=4}^{6} \omega_{k\rho}\rho^\lambda \sin\lambda\phi + \sum_{k=4}^{6} p_{kk}u_k + \sum_{k,j=4}^{6} R_{kj}P^2, \quad k = 4,5,6, \tag{3}$$

where R_{ij}, p_{ij}, M_{ij} are the coefficients of square electrooptic, linear elastooptic, and square elastooptic effects, respectively. Using the following relation between Δa_1 and Δn_1:

$$\Delta n_1 = \frac{n_1^2 n_2^2}{n_1 + n_2}\Delta a_1,$$

where $n_1^2 n_2^2/(n_1 + n_2) = \xi$ is a small changeable quantity and proceeding from symmetric reasons, the value of the optical birefringence for x-, y-, z-directions can be presented as

$$\Delta n_1 = \omega_1\rho^2 + R_{12}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_1\rho^2(\partial\phi/\partial x) + \sum M_{ik}u_k^2,$$

$$\Delta n_2 = \omega_2\rho^2 + R_{22}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_2\rho^2(\partial\phi/\partial y) + \sum M_{ik}u_k^2,$$

$$\Delta n_3 = \omega_3\rho^2 + R_{32}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_3\rho^2(\partial\phi/\partial z) + \sum M_{ik}u_k^2. \tag{4}$$

Taking into account the increase in the incommensurate modulation along z-axis, the increment of optical birefringence with temperature may be expressed as

$$\delta(\Delta n_1) = \omega_1\rho^2 + R_{12}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_1\rho^2(\partial\phi/\partial z) + \sum M_{ik}u_k^2,$$

$$\delta(\Delta n_2) = \omega_2\rho^2 + R_{22}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_2\rho^2(\partial\phi/\partial z) + \sum M_{ik}u_k^2,$$

$$\delta(\Delta n_3) = \omega_3\rho^2 + R_{32}P^2 + \sum_{m=1}^{3} p_{im}u_m + \nu_3\rho^2 \int(\partial\phi/\partial z)\mathrm{d}z + \sum M_{ik}u_k^2. \tag{5}$$

Equation (5) has been obtained because the phase difference caused by a temperature change for x-direction of light propagation may be written in the following form:

$$\Delta\psi = \frac{2\pi}{\lambda_0}(n_2 - n_3)\mathrm{d}x = \left(\frac{\partial\phi_y}{\partial y} - \frac{\partial\phi_z}{\partial z}\right)\mathrm{d}x. \tag{6}$$

On the basis of expression (5) one can explain the difference between observed anomalous changes of $\partial(\Delta n)$. The phase difference of the order parameter $(\partial\phi/\partial z)$ contributes into the increment of optical birefringence with temperature for x- and y-directions of light propagation. For z-direction according to Eq. (5) the expression $\nu_3\rho^2\int(\partial\phi/\partial z)\mathrm{d}z$ causes the anomalous behaviour of $\delta(\Delta n)$. This expression contains information about the behaviour of the incommensurate modulation vector. Therefore, the change of the phase of the order parameter causes the appearance of $\delta(\Delta n)$ anomalies in conditions of the "viscous" interaction when light does not propagate along the modulation axis. Hence, the change of the phase of the order parameter as a result of interaction of the modulation wave with defects will be observed in a considerable temperature interval [19] that was obtained in the experiment. The expression, which contains information about the behaviour of the wave vector of the incommensurate modulation, explains its contribution into $\delta(\Delta n)$ for light propagation along the modulation axis. It has been found [25] that the incommensurability wave vector manifests a sharp change at a transition from one commensurate value to another. Hence, the temperature interval of the anomalous behaviour of $\delta(\Delta n_z)$ should be smaller in comparison with the period of the anomalous changes of $\delta(\Delta n_x)$ and $\delta(\Delta n_y)$. Therefore, the change of the incommensurability wave vector in $[N(CH_3)_4]_2CuCl_4$ crystals causes the anomalous changes of the optical birefringence along the modulation axis at the rate of temperature change $\partial T/\partial t = 60$ mK/h (Fig. 3). Let us consider the theoretical description of anomalous changes of birefringence in conditions of the "viscous" interaction to prove the above-mentioned conclusions. In accordance with Ref. [19] the change of $\delta(\Delta n_z)$ in direction of the modulation axis may be written as

$$\delta(\Delta n_z) = \frac{\Delta T \nu_1 \rho^{*2}}{d} \int_0^d \Bigg| \frac{\rho_0}{2} \Big[(T_2 - T)^{\frac{n_1-2}{2}} + (T - T_1)^{\frac{n_2-2}{2}} - (T_2 - T_1)^{\frac{n_1-2}{2}}$$

$$-(T_2 - T_1)^{\frac{n_2-2}{2}} \Big] \cos \Big\{ n_1 \mathrm{ctg} \Big[\exp \Big(-(\alpha/\beta)(T_2 - T)^{1/2} x \Big) \Big]$$

$$-n_2 \mathrm{ctg} \Big[\exp \Big(-(\alpha/\beta)(T - T_1)^{1/2} x \Big) \Big] \Big\} \Bigg|^{1/2} \mathrm{d}z. \tag{7}$$

This expression describes the model of interaction of two close oscillations (harmonics of the incommensurate modulation) in a transitional region. As a sequence of this interaction the resulting oscillation appears, which causes the anomalous change of birefringence with temperature. The analogous dependences (experimental and theoretical) for investigated crystal for direction of the modulation axis are presented in Fig. 3. In this case the theoretical curve quite well fits the experimental data.

Let us consider the theoretical description of the anomalous temperature dependence of birefringence for another direction of light propagation. To achieve this behaviour of $\delta(\Delta n_i)$ $(i = 1, 2)$ it has been assumed that the temperature region of anomaly existence corresponds to the transition one (i.e. regions of transition from one long-periodic phase to another) — the region of existence and interaction of two close by temperature space modulated oscillations [26]. To obtain such theoretical curve, which should describe analogous experimental dependence, in this case (Fig. 1) the transition region should be located in a temperature interval from $T_1 = 296.648$ K to $T_2 = 296.924$ K. As one can see on the experimental curve (Fig. 4, it was shown by the arrows) this region was located between two anomalous changes of $\delta(\Delta n_x)$. Concerning the theoretical curve, the anomalous change of $\delta(\Delta n_x)$ was observed only at T_1 (see Fig. 4).Taking into account Eqs. (1) and (5) the anomalous change of the birefringence may be expressed as

$$\delta(\Delta n_x) = \Delta T \nu_1 \rho^{*2} \Bigg| \frac{\rho_0}{2} \Big[(T_2 - T)^{\frac{n_1-2}{2}} + (T - T_1)^{\frac{n_2-2}{2}} - (T_2 - T_1)^{\frac{n_1-2}{2}} - (T_2 - T_1)^{\frac{n_2-2}{2}} \Big] \cos \Big\{ n_1 \mathrm{ctg} \Big[\exp \Big(-(\alpha/\beta)(T_2 - T)^{1/2} x \Big) \Big] - n_2 \mathrm{ctg} \Big[\exp \Big(-(\alpha/\beta)(T - T_1)^{1/2} x \Big) \Big] \Big\} \Bigg|^{1/2} . \quad (8)$$

The corresponding dependence is presented in Fig. 4. Similarly to the previous case the theoretic curve fairly well fits the experimental one.

Therefore, the anomalous behaviour of the optical birefringence at light propagation along the modulation axis significantly differs from the behaviour for perpendicular direction. This difference is caused by different contributions of the incommensurability wave vector and the phase of the order parameter for direction of the modulation axis and two perpendicular other directions. It is necessary to note that for both cases the same values of n_1 and n_2 are taken. But the anomalous changes of $\delta(\Delta n_x)$, calculated on the basis of expression (8), do not describe in detail the experimental changes. To our mind, this is caused by the influence of the defects network field on the temperature behaviour of the phase of the order parameter [25]. This defects network arises as a result of the interaction of the defects with a modulation structure [27].

As it has been noted above the residual defects concentration around soliton may be considered as an action of the electric field intensity of definite value on soliton structure. To prove this let us rewrite the first motion integral using Eq. (1) at the condition of the applied field E by analogy with Ref. [9]

$$\frac{1}{2}\left(\frac{\mathrm{d}\phi}{\mathrm{d}z}\right)^{-2} - \frac{\alpha_l' \rho^{2l-2}}{2\gamma} \cos 2l\phi + \frac{a_l}{\gamma} E_i \rho^l \cos l\phi = \Xi, \quad (9)$$

where ρ and ϕ denote the amplitude and phase of the two-component order parameter $\eta_1 = \rho\cos\phi$ and $\eta_2 = \rho\sin\phi$, respectively; α_l', a_l, γ are the expansion coefficients; ρ^l comes from Fourier's transformation of the thermodynamical potential; Ξ is the integration constant. Hence,

$$\frac{\mathrm{d}\phi}{\mathrm{d}z} = \left(\Xi + \frac{\alpha_l' \rho^{2l-2}}{\gamma} \cos 2l\phi - \frac{2 a_l E_i \rho^l}{\gamma} \cos l\phi \right)^{1/2} . \quad (10)$$

The expression for $\delta(\Delta n_i)$ may be written as

$$\delta(\Delta n_i) \sim \nu_{ij} \frac{1}{d} \rho^2 \int_0^d \left(\Xi + \frac{\alpha_l' \rho^{2l-2}}{\gamma} \cos 2l\phi - \frac{2 a_l E_i \rho^l}{\gamma} \cos l\phi \right)^{1/2} \mathrm{d}z, \quad (11)$$

where ν_{ij} is the expansion coefficient; d denotes the sample thickness.

In accordance with the data of Ref. [28] the change of the phase of the order parameter may be expressed as

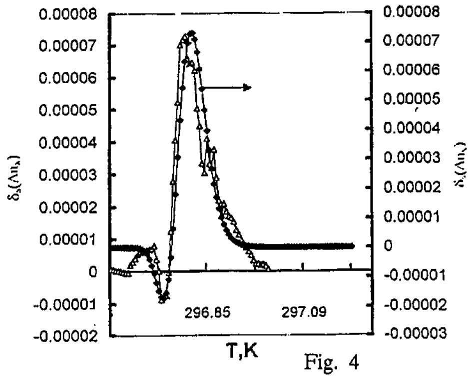

Fig. 4

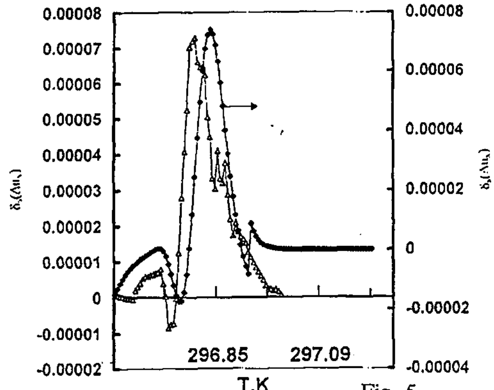

Fig. 5

Fig. 4. Temperature dependence of optical birefringence along x-axis for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h, Δ — experimental curve, ■ — theoretical curve.

Fig. 5. Temperature dependence of optical birefringence along y-axis for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h, Δ — experimental curve, ■ — theoretical curve, calculated according to Eq. (9).

$$\phi = \phi_0 + \phi_1, \qquad \text{where} \qquad \phi_1 = \frac{\mathrm{d}\phi_0}{\mathrm{d}z} \int_0^x \frac{aE_z \rho^l \sin l\phi_0 + C}{2\gamma(\mathrm{d}\phi_0/\mathrm{d}x)^2 d} z, \tag{12}$$

C denotes the integrating constant; ϕ_0 does not depend on E_1.

At the first approximation it is possible to assume that $\phi_1 \approx b_1 E_z$, where b_1 is the expansion coefficient [28]. Therefore, the expression for $\delta(\Delta n_i)$ can be written in the following form:

$$\delta(\Delta n_i) \sim \nu_{ij} \frac{1}{d} \rho^2$$

$$\times \int_0^d \left\{ \Xi + \frac{\alpha_l' \rho^{2l-2}}{\gamma} \cos\left[2l(\phi_0 + b_i E_i)\right] - \frac{2a_l E_i \rho^l}{\gamma} \cos\left[l(\phi_0 + b_i E_i)\right] \right\}^{1/2} \mathrm{d}z. \tag{13}$$

In the case of light extending along y-axis the expression (11) for $\delta(\Delta n_i)$ in accordance with Ref. [26] may be rewritten as

$$\delta(\Delta n_y) \sim \nu_{ij} \frac{1}{d} \rho^2$$

$$\times \left\{ \Xi + \frac{\alpha_l' \rho^{2l-2}}{\gamma} \cos\left[2l(\phi_0 + b_2 E_y)\right] - \frac{2a_l E_y \rho^l}{\gamma} \cos\left[l(\phi_0 + b_2 E_y)\right] \right\}^{1/2}. \tag{14}$$

Taking into account that in conditions of the "viscous" interaction of defects with solitons, the anomalous behaviour of $\delta(\Delta n_i)$ according to Ref. [26] is caused by the interaction of two close by temperature space-modulated oscillations, the expression (14) can be written in the following form:

$$\delta(\Delta n_y) = \Delta T \nu_l \rho^{*2} \Bigg| \frac{\rho_0}{2}\Big[(T_2 - T)^{\frac{n_1-2}{2}} + (T - T_1)^{\frac{n_2-2}{2}} - (T_2 - T_1)^{\frac{n_1-2}{2}}$$
$$-(T_2 - T_1)^{\frac{n_2-2}{2}}\Big]\Big\{\cos\Big\{2n_1 \mathrm{ctg}\Big[\exp\Big(-(\alpha/\beta)(T_2 - T)^{1/2}x\Big)\Big]$$
$$-2n_2 \mathrm{ctg}\Big[\exp\Big(-(\alpha/\beta)(T - T_1)^{1/2}x\Big)\Big] - 2n_2\lambda E_y\Big\}$$
$$-(2a_{n2}\rho^{n2}E_y/\gamma)\cos\Big\{n_1 \mathrm{ctg}\Big[\exp\Big(-(\alpha/\beta)(T_2 - T)^{1/2}x\Big)\Big]$$
$$-n_2 \mathrm{ctg}\Big[\exp\Big(-(\alpha/\beta)(T - T_1)^{1/2}x\Big)\Big] - n_2\lambda E_y\Big\}\Big\}\Bigg|^{-1/2}. \quad (15)$$

The $\delta(\Delta n_y) \sim f(T)$ dependence calculated according to the expression (15), is plotted in Fig. 5. As it is clearly seen in the figure the theoretical curve correlates well with the corresponding experimental dependence. Therefore, the residual defects concentration around the soliton in conditions of the "viscous" interaction of modulated structure with moving defects causes an increase in the defects field. The intensity of this field affects the anomalous behaviour of $\delta(\Delta n_i)$ at T_2. Hence, the transitional region is in the temperature interval of $T_1 \div T_2$ (in this case it is 296.648 ÷ 296.924 K). An analogous picture is observed for $\delta(\Delta n_x) \sim f(T)$ dependence.

Investigations of influence of the electric field of intensities E_1 and E_2 on birefringent properties of $[N(CH_3)_4]_2CuCl_4$ crystals have been performed to prove that in the crystal the internal field caused by the residual defects concentration around the soliton exists at normal conditions. In Fig. 6 the $\delta(\Delta n_y) \sim f(T)$

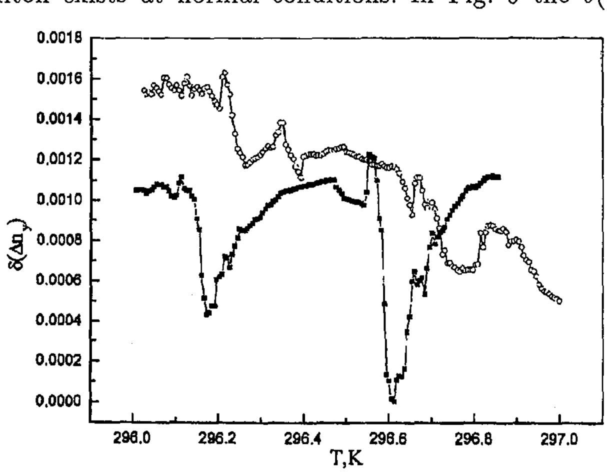

Fig. 6. Temperature dependences of optical birefringence along y-axis for $[N(CH_3)_4]_2CuCl_4$ crystal in conditions of "viscous" interaction ($\partial T/\partial t$ = 60 mK/h) at $E_2 = 0$ (■) and $E_2 = 10^4$ V/m (o).

dependence under influence of electric field of intensity $E_2 = 10^4$ V/m has been plotted. As a result of the field applied the form $\delta(\Delta n_y)$ of anomaly behaviour changes and the temperature interval of its existence shifts to a region of higher temperatures.

A spontaneous increase in $\delta(\Delta n_y)$ in the transition region at $E_1 = 0$ and 10^4 V/m has been shown in Fig. 7. One can see in the figure that the electric field influence causes an increase in temperature interval of transition region existence and postpones the centre of the greatest anomalous change of $\delta(\Delta n_y)$ to a region of higher temperatures.

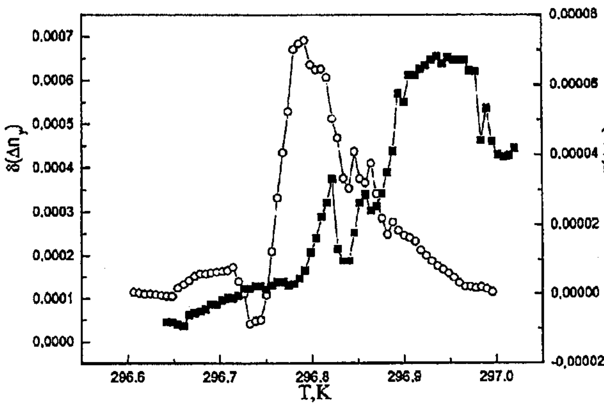

Fig. 7. Spontaneous increment of $\delta(\Delta n_y)$ with temperature in the transitional region for $[N(CH_3)_4]_2CuCl_4$ crystal at $E_2 = 0$ (o) and $E_2 = 10^4$ V/m (■).

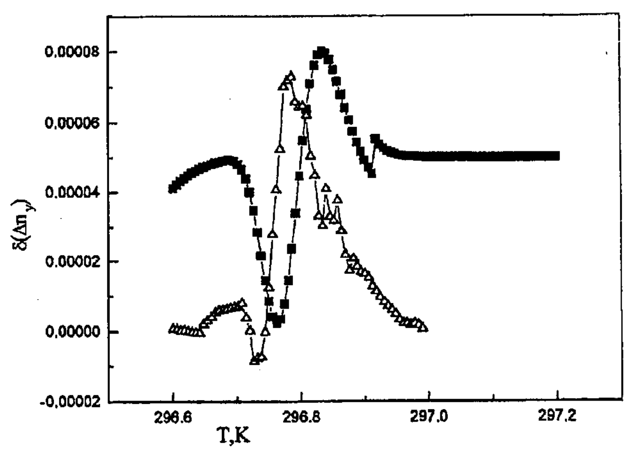

Fig. 8. Temperature dependence of optical birefringence along y-axis for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h, Δ — experimental curve, ■ — theoretical curve, calculated according to expression (9) at the influence of external electric field E_2 on the phase of the order parameter.

Let us consider Eq. (15) at some bigger values of the electric field intensity to describe the $\delta(\Delta n_y)$ behaviour at $E_2 \neq 0$. Such $\delta(\Delta n_y) \sim f(T)$ dependence obtained from Eq. (15) has been shown in Fig. 8. On the basis of the above-presented results one can conclude that the change of the phase of the order parameter under field influence due to Eq. (15) causes only the change of the shape of anomalous $\delta(\Delta n_y)$ behaviour. However, the anomalies shifts under field influence are caused rather by the change of the order parameter.

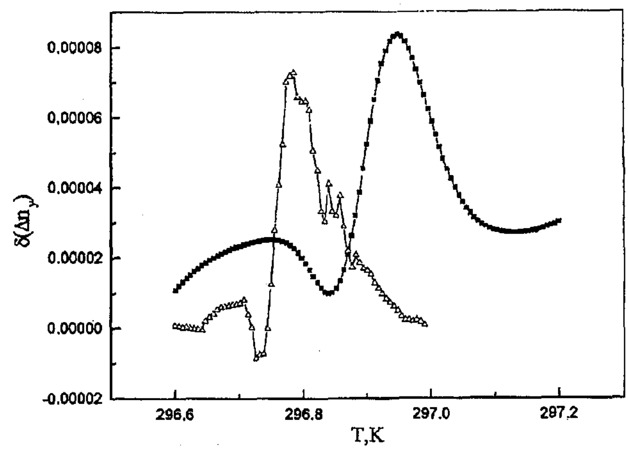

Fig. 9. Temperature dependence of optical birefringence along y-axis for $[N(CH_3)_4]_2CuCl_4$ crystal at the rate of temperature change $\partial T/\partial t = 60$ mK/h, Δ — experimental curve, ■ — theoretical curve, calculated according toexpression (9) at the action of external electric field E_2, which causes the change of the amplitude of the order parameter.

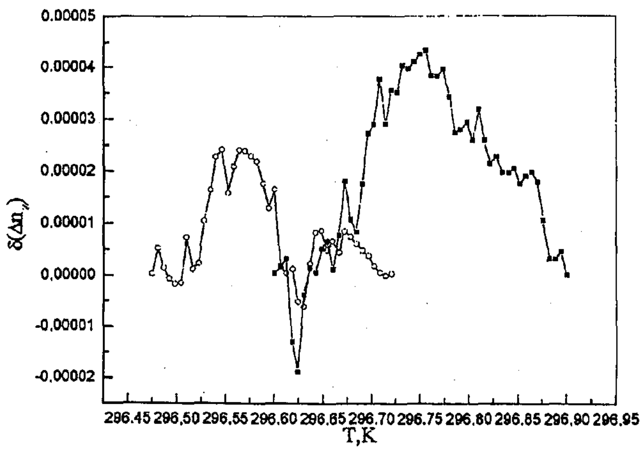

Fig. 10. Temperature dependences of optical birefringence along z-axis for $[N(CH_3)_4]_2CuCl_4$ crystal in conditions of "viscous" interaction ($\partial T/\partial t = 60$ mK/h) at $E_3 = 0$ (o) and $E_3 = 10^4$ V/m (■).

In such a case the $\delta(\Delta n_y)$ anomalies under field influence could be shifted by two causes: the first, erosion of temperature motion of P_s in the vicinity of phase transition; the second, only a shift of the transition temperature (T_1 and T_2) occurs. In this crystal at normal conditions spontaneous polarisation has not been observed. Consequently, the shift of $\delta(\Delta n_y)$ anomalies is possibly caused by a shift of transition temperature under field influence. As one can see from Fig. 9, the action of electric field relates to the shift of transition at T_1 and as well as at T_2. On the basis of the above-presented explanation the dependence $\delta(\Delta n_y) \sim f(T,E)$ according to Eq. (15) has been plotted in Fig. 9. Due to these data the shift of the $\delta(\Delta n_y)$ anomaly in conditions of viscous interaction under field influence has been caused by the shift of the transition temperatures T_1 and T_2 in the region of higher temperatures ($\mathrm{d}T_1/\mathrm{d}E_2 \sim 3.4\times10^{-6}$ mK/V; $\mathrm{d}T_2/\mathrm{d}E_1 \sim 5\times10^{-6}$ mK/V). It is necessary to note that electric field causes an increase in the transition region and consequently the temperature interval of interaction of space modulated oscillations ($\mathrm{d}(\Delta T)/\mathrm{d}E_1 \sim 1.6\times10^{-6}$ mK/V).

Let us consider how the intensity of electric field changes the conditions of viscous interaction along the modulation axis (see Fig. 10). As one can see, the applying of the field of intensity E_2 causes a change of the wave vector behaviour of the resulting space modulated oscillation and the widening of the temperature region of its existence.

3. Conclusions

On the basis of the above-mentioned experimental and theoretical data one can draw the following conclusions:

(1) the anomalous behaviour of the optical birefringence at light propagation along the modulation axis differs from other perpendicular directions;

(2) it has been shown that along the modulation axis the anomalous behaviour of the incommensurability wave vector affects the anomalous temperature behaviour of $\delta(\Delta n)$; in other directions such behaviour of $\delta(\Delta n)$ is caused by the change of the phase of the order parameter;

(3) in the crystal around the soliton in the condition of "viscous" interaction there arises the residual defects concentration. It may be considered as some electric field intensity that is related to the interaction of the space-modulated waves in the transition region;

(4) it has been found that electric field applied to the crystal in the direction perpendicular to the modulation axis causes the change of the phase of the order parameter of the resulting oscillation as well as temperature region of its existence.

References

[1] I.I. Polovinko, S.A. Sveleba, O.G. Vlokh, V.S. Zhmurko, *Acta Phys. Pol. A* **81**, 409 (1992).

[2] S. Sveleba, I. Polovinko, V. Zhmurko, Z. Trybula, W. Kempinski, T. Zuk, *Physica B* **183**, 183 (1993).

[3] O.G. Vlokh, V.S. Zhmurko, I.I. Polovinko, S.A. Sveleba, *Ukrainian Phys. J* **35**, 1493 (1990).

[4] G. Dolino, F. Mogeon, V. Soula, *Phase Transitions* **36**, 129 (1991).

[5] O.G. Vlokh, V.S. Zhmurko, I.I. Polovinko, V.I. Mokryi, S.A. Sveleba, *Kristallografiya* **36**, 769 (1991).

[6] O.G. Vlokh, I.I. Polovinko, S.A. Sveleba, *Fiz. Tverd. Tela* **31**, 277 (1989).

[7] I. Polovinko, S. Sveleba, V. Kapustianik, V. Zhmurko, *Phys. Status Solidi A* **135**, 143 (1993).

[8] S.A. Sveleba, V.S. Zhmurko, V.B. Kapustianik, I.I. Polovinko, Z. Trybula, *Phys. Status Solidi A* **133**, 481 (1992).

[9] Yu.A. Izyumov, V.M. Syromyatnikov, *Phase Transitions and Crystal Symmetry*, Nauka, Moscow 1984, p. 284.

[10] I. Polovinko, S. Sveleba, V. Zhmurko, Z. Trybula, W. Kempinski, J. Stankowski, *Phys. Status Solidi A* **135**, 527 (1993).

[11] D.G. Sannikov, V.A. Golovko, in: *IV All-Union School-Seminar on Ferroelastics, Dnepropetrovsk 19-24 of September 1988*, p. 40.

[12] J.P. Janet, *J. Phys. Lett.* **42**, L123 (1981).

[13] D.G. Sannikov, *Zh. Eksp. Teor. Fiz.* **96**, 2198 (1989).

[14] P. Lederer, J. Jamet, G. Montambaux, *Ferroelectrics* **66**, 25 (1986).

[15] N. Barretto, P. Lederer, J. Jamet, *Phys. Rev. B* **28**, 3994 (1983).

[16] K. Saito, I. Kunishima, J. Kobayashi, Y. Uesu, *Ferroelectrics* **64**, 137 (1985).

[17] S. Sveleba, V. Kapustianik, I. Polovinko, M. Bublyk, Z. Czapla, R. Strykowec, *Phys, Status Solidi A* **147**, 257 (1995).

[18] S.A. Sveleba, I.I. Polovinko, Yu.I. Pankivskyi, V.B. Kapustianik, V.S. Zhmurko, V.I. Mokryi, Z. Trybula, *Phys. Status Solidi* **140**, 573 (1993).

[19] S. Sveleba, I. Polovinko, V. Zhmurko, V. Kapustianik, Z. Trybula, *Phys. Status Solidi A* **133**, 481 (1992).

[20] O.G. Vlokh, I. Polovinko, S. Sveleba, V. Zhmurko, V. Kapustianik, *Ferroelectrics* **131**, 137 (1991).

[21] O.G. Vlokh, V.S. Zhmurko, I.I. Polovinko, S.A. Sveleba, *Pis'ma Zh. Exp. Teor. Fiz.* **16**, 39 (1990).

[22] I.I. Polovinko, S.A. Sveleba, V.B. Kapustianik, V.S. Zhmurko, *Phys. Status Solidi A* **131**, K13 (1992).

[23] J. Fousek, C. Konak, *Czech. J. Phys. B* **22**, 995 (1972).

[24] C. Konak, *Phys. Status Solidi A* **54**, 99 (1979).

[25] M. Bziouet, R. Almairac, P. Saint Cregoire, *J. Phys. C, Solid State Phys.* **20**, 2635 (1987).

[26] S.A. Sveleba, I.I. Polovinko, Yu.I. Pankivskyi, V.A. Sergatyuk, M.I. Bublyk, V.I. Mokryi, *Ukrainian Phys. J.* **42**, 294 (1997).

[27] S. Sveleba, I. Polovinko, M. Bublyk, V. Kapustianik, in: 3rd *Intern. Semp. on Domain Structure of Ferroelectrics and Related Materials, Zakopane, Sept. 6–9, 1994, Wrocław*, Wrocław University, Wrocław 1994, p. 4.

[28] V.A. Golovko, D.G. Sannikov, *J. Phys., Condens. Matter* **1**, 5497 (1989).