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Anomalies of the temperature dependence of electrostriction in blue phases

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Abstract. — We investigated the field-induced shift of the blue phase diffraction bands. The temperature dependence of the electrostriction tensor components is determined for the first time. In the blue phase BPI at constant field strength $E \parallel [001]$, a change of the temperature leads to a change of both the unit cell volume and its shape. The deformation of the unit cell displays a pretransitional behaviour on approaching the BPI $\rightarrow$ BPII phase transition temperature.

1. Introduction.

In the liquid-crystalline blue phases BPI and BPII [1] the local ordering of molecular orientation forms a 3D periodic structure, having the symmetry of crystals. BPI exhibits a body centered cubic lattice $O^8$, while BPII is described by a simple cubic structure $O^2$. So far, essential progress has been achieved in the theoretical description and experimental study of blue phases. In the framework of the Landau theory on phase transitions and of the disclination model [2-4] it has been shown that for substances with a small cholesteric pitch the cubic structures, $O^8$ and $O^2$, can be thermodynamically stable between the isotropic liquid and the cholesteric phase. The structures have been determined experimentally and their optic characteristics have been examined in detail.

A series of electrooptic effects associated with the change of crystal orientation and local director in the lattice [5-9], electrostriction [9-11] and phase transitions [10-15] have been discovered in an electric field. Temperature dependences of the cell parameters, the scalar order parameter $\varepsilon$ [16, 17], and the optical activity, have been measured for the temperature range of blue phases. It should be noted that these alterations do not exhibit pretransitional behaviour for the BPI-BPII transition. For instance, $\varepsilon$ can be regarded as an order parameter only for the transition to the isotropic liquid, i.e. the temperature dependence for $\varepsilon$ has no singularities in the vicinity of the BPI-BPII transition. As yet, only few attention has been
devoted to the temperature dependence of the electrostriction tensor \( \gamma \). This tensor describes the dependence of a field-induced strain \( \tilde{u} \) of the blue phase lattice on the applied electric field \( \mathbf{E} \):

\[
\tilde{u}_{ij} = \gamma_{ijkl} E_k E_l .
\]  

From the function \( \gamma_{1111}(T) \) it has been concluded [18] that the BPI lattice is not stable near the BPI-BPII phase transition.

Here, we present for the first time the temperature dependence of all coefficients of the electrostriction tensor for BPI in two mixtures with negative dielectric anisotropy. Both mixtures give similar results. The temperature dependence of \( \gamma \) differs distinctly for the orientations \( \mathbf{E} \parallel [001] \) and \( \mathbf{E} \parallel [011] \). This indicates an essential change in the electrostriction anisotropy. For both mixtures the deformation of the unit cell at \( \mathbf{E} \parallel [001] \) displays a pretransitional behaviour upon reaching the BPI-BPII phase transition temperature.

2. Experimental.

Two separate mixtures, A and B, have been investigated. The first one (A) is a mixture of the chiral compound S811 (Merck, Germany, 30 % by weight) with the nematic mixture EN18 (Chisso Corp. Japan, 70 wt.-%). The second one (B) is a mixture analogous to that used earlier [18]: a chiral-nematic mixture with the chiral compound BNX-16 (Vilnius University, Lithuania (81 wt.-%)) and the nematic liquid crystal 1650D (18.9 wt.-%). Both mixtures have negative dielectric anisotropy. The mixture A forms the three blue phases BPI, BPII, and BPIII [19], showing the following temperature ranges. BPI : 41.80-42.12 °C, BPIII : 42.12-42.29 °C, BPII : 42.29-42.4 °C. The mixture B forms the blue phases BPI and BPII. The temperature ranges are for BPI : 37.64-38.025 °C, for BPII : 38.025-38.47 °C.

The sample was contained between two glass slides coated with a transparent conducting layer. Mylar spacers of 17 \( \mu \)m thickness were used. The temperature was controlled with an accuracy of \( \pm 0.005 \) °C. In order to investigate the behaviour of blue phases in an electric field, sinusoidal voltages with a frequency of 4 kHz were utilized. Diffraction lines were measured in the light transmission spectrum.

Samples with [001] and [011] directions normal to the glass plates were prepared. Samples of BPI with the cell plane parallel to the glass plates were obtained by applying sinusoidal voltage (\( \approx 45 \) V) to the sample. After a slow decrease of the field, a uniform [001] orientation was obtained. A [011] orientation in BPI samples was achieved by slow cooling from BPIII. The orientation [011] \( \parallel \mathbf{E} \) is not stable and eventually the sample may acquire the orientation [001] \( \parallel \mathbf{E} \). The time constant of reorientation depends on the applied field strength and on the temperature. At \( U < 40 \) V and \( T_c - T > 0.03 \) °C, the orientation [011] \( \parallel \mathbf{E} \) was stable for several hours. At a higher temperature, the reorientation time decreased drastically, and it was not possible to make measurements for the lattice orientation [011] \( \parallel \mathbf{E} \) in the close vicinity of the BPI-BPII phase transition temperature.

3. Results.

Beyond the sample absorption region the BPI transmission spectrum for the [001] faces parallel to the glass plates is presented by a single band \( \lambda_0 \). The band involves one reflection (002) and four reflections (011), coinciding in wavelengths for a body centered cubic lattice \( \Omega^8 \) (\( \lambda_{002} = d n \sin \theta, \ \theta = 90^\circ; \ \lambda_{011} = \sqrt{2} d n \sin \theta, \ \theta = 45^\circ; \ \lambda_{002} = \lambda_{011} \)). Without an electric field the spectral position of reflections shows a temperature dependence which is typical for blue phases (Figs. 1a, 2a): a short-wavelength shift of reflections (compression of the unit cell) is observed with increasing temperature. Deformation of the cubic structure of blue phases in an electric field (electrostriction) leads to splitting of the bands \( \lambda_{002} \) and
Fig. 1. — a) Temperature dependence of the diffraction band positions in the BPI transmission spectrum: (●) λ₀ = λ₀₀₂ = λ₀₁₁, U = 0; (■) λ₀₀₂, U = 39 V; (□) λ₀₁₁, U = 39 V; (+) (λ₀₀₂ + 2 λ₀₁₁)/3; b) Temperature dependence Δ₀₀₂ = λ₀₀₂ − λ₀(●), Δ₀₁₁ = λ₀₁₁ − λ₀(□), Δ₀₀₂ + 2 Δ₀₁₁(*), U = 39 V. Mixture A.

Fig. 2. — a) Temperature dependence of the diffraction band positions in the BPI transmission spectrum: (●) λ₀ = λ₀₀₂ = λ₀₁₁, U = 0; (●) λ₀₀₂, U = 45 V; (□) λ₀₁₁, U = 45 V; (+) (λ₀₀₂ + 2 λ₀₁₁)/3; b) Temperature dependence Δ₀₀₂ = λ₀₀₂ − λ₀(●), Δ₀₁₁ = λ₀₁₁ − λ₀(□), Δ₀₀₂ + 2 Δ₀₁₁(*), U = 45 V. Mixture B.

λ₀₁₁ (Figs. 1a, 2a). For the orientation [001] // E and Δε < 0 the lattice is extended along the field direction [20] and is compressed in the direction perpendicular to E. This deformation causes a long-wavelength shift of the (002) reflection and a short-wavelength shift of the (011) reflection in the transmission spectrum. The high-temperature limit in figure 1a corresponds to the temperature Tₑ⁻ of the BPI-BPII phase transition. In accordance with the T-E phase diagram [19], the temperature Tₑ⁻ is above the phase transition temperature Tₑ at zero field. Figure 3 shows the BPI transmission spectrum in an electric field. Splitting is observed only between the (002) and (011) reflections. The four reflections equivalent to (011) remain unsplitted.
Fig. 3. — Transmission spectrum in an electric field for the orientation $\mathbf{E}/[001]$. (1), (2), (3) : BPI. (1) $T = 41.99$ °C, (2) $T = 42.07$ °C, (3) $T = 42.12$ °C, (4) BPII. Mixture A.

(short-wavelength band in Fig. 3), which is in agreement with the tetragonal symmetry of the cell [19] in an electric field $\mathbf{E}/[001]$. The temperature dependences for $\lambda_{002}(T)$ and $\lambda_{011}(T)$ differ considerably (Figs. 1a, 2a). To separate the effects related to electrostriction and temperature variation we have plotted the shifts of the (002) and (011) reflections relative to their positions without a field in figures 1b, 2b ($\Delta_{002} = \lambda_{002}(E) - \lambda_0$; $\Delta_{011} = \lambda_{011}(E) - \lambda_0$). To calculate $\Delta_{002}$ and $\Delta_{011}$ for $T > T_c$ (Fig. 4) the value of $\lambda_0$ was determined by linear extrapolation of the temperature dependence $\lambda_0(T)$. The lattice constants of the deformed lattice are given by $d_{001}(E) = d + a$, $d_{100}(E) = d + b$, where $d$ is the lattice constant of the undisturbed cubic lattice; $d_{001}$ and $d_{100}$ are the lattice constants parallel and perpendicular to the field direction. The shift of the (002) reflection is caused by a change of the interplanar spacing $d_{001}$.

$$\lambda_{002} = (d + a) n.$$  (2)

The shift of the (011) reflections occurs due to variations of both the lattice constant $d_{011}$ and the diffraction angle $\theta_{011}$.

$$d_{011} \approx \frac{d}{\sqrt{2}} \left( 1 + a + b \right)$$  (3)

$$\sin \theta_{011} \approx \frac{1}{\sqrt{2}} \left( 1 - a - b \right)$$  (4)

$$\lambda_{011} = 2 d_{011} n \sin \theta_{011} = (d + b) n = d_{100} n.$$  (5)

For the field direction $[001]$ the shift of the (002) reflection is proportional to the change of the lattice parameter parallel to the field direction, the shift of $\lambda_{011}$ is proportional to the change of the lattice parameter normal to the field direction. If the volume of the unit cell is preserved ($a = -2 b$) we get from equations (2) and (5):

$$\Delta_{002} = -2 \Delta_{011}.$$  (6)

In this case, the sum $(\lambda_{002} + 2 \lambda_{011})/3$ should be constant ($= \lambda_0$), i.e. $\Delta_{002} + 2 \Delta_{011} = 0$. Figures 1 and 2 present the values of $(\lambda_{002} + 2 \lambda_{011})/3$ and $\Delta_{002} + 2 \Delta_{011}$ obtained from the experimental values of $\lambda_{002}$ and $\lambda_{011}$. Proceeding from the data of figures 1 and 2, we conclude that within the experimental accuracy of our measurements the deformation of the unit cell does not affect its volume.
Turning to the electrostriction coefficients, our experimental observation of the functions \( \lambda_{hk\ell}(E) = \tilde{\gamma}_{[hk\ell]} E^2 \) yields effective coefficients \( \tilde{\gamma}_{[hk\ell]} \) which are linear combinations of the components \( \gamma_{ijmn} \) defined in equation (1). \( \gamma_{1111} = \tilde{\gamma}_{[001]} \) can be calculated either from the shift of the (002) reflection, \( \tilde{\gamma}_{[001]} = \Delta_{002}/\lambda_0 E^2 \), or (due to the constant volume of the unit cell) from the splitting between the reflection bands \( \Delta = \lambda_{002} - \lambda_{011}, \tilde{\gamma}_{[001]} = \frac{2 \Delta}{3 \lambda_0 E^2} \) (Figs. 5, 6). The

![Fig. 4. — Temperature dependence of the splitting \( \Delta \) between the two reflections (002) and (011), in BPI: (O) \( U = 42 \text{ V} \), (□) \( U = 39 \text{ V} \), (△) \( U = 30 \text{ V} \). Mixture A.

![Fig. 5. — Temperature dependence of the electrostriction coefficients in BPI: \( \gamma_{1111} = \tilde{\gamma}_{[001]} \), (O) \( U = 42 \text{ V} \), (□) \( U = 39 \text{ V} \), (△) \( U = 30 \text{ V} \); (●) \( \tilde{\gamma}_{[011]} \), (+) \( \tilde{\gamma}_{[011]} \), \( U = 39 \text{ V} \); (*) \( \gamma_{2323} \). BPII: (●) \( \gamma_{1111} \), \( U = 39 \text{ V} \), mixture A.

![Fig. 6. — Temperature dependence of the electrostriction coefficients in BPI: \( \gamma_{1111} = \tilde{\gamma}_{[001]} \), (O) \( U = 45 \text{ V} \), (□) \( U = 39 \text{ V} \), (●) \( \gamma_{1111} \), (+) \( \tilde{\gamma}_{[011]} \), \( U = 39 \text{ V} \); (*) \( \gamma_{2323} \). BPII: (●) \( \gamma_{1111} \), \( U = 39 \text{ V} \), mixture B.}
electrostriction coefficient $\tilde{\gamma}_{[001]}$, characterizing the variation of the interplanar spacing $d_{011}$ for the orientation $E // [011]$, was determined in BPI from the shift of the diffraction band $\lambda_{011}$ in the transmission spectrum: $\gamma_{[001]} = \Delta \lambda_{011}/\lambda_{011} E^2$ (Figs. 5, 6). The electrostriction coefficient $\tilde{\gamma}_{[001]}$ in BPI was found from the shift of the diffraction band $\lambda_{001}$ in samples with the orientation $[001] // E$ (Figs. 5, 6).

4. Discussion.

The most remarkable feature of the data obtained is a drastic increase in the splitting $\Delta$ (Fig. 4) and in $\gamma_{1111}$ (Figs. 5, 6) on approaching the phase transition temperature. There is an essential difference in the behaviour of $\tilde{\gamma}_{[001]}$ and $\tilde{\gamma}_{[011]}$. The electrostriction coefficient $\tilde{\gamma}_{[001]}$ diverges close to the transition temperature, while $\tilde{\gamma}_{[011]}$ depends only slightly on temperature. Since the volume of the unit cell is preserved ($\gamma_{1122} = -\frac{1}{2} \gamma_{1111}$), only two of the three electrostriction tensor components (in cubic structures $\gamma_{1111}$, $\gamma_{1122}$ and $\gamma_{2323}$) are independent: $\gamma_{1111} = \tilde{\gamma}_{[001]}$, $\gamma_{2323} = \tilde{\gamma}_{[011]} - \frac{1}{4} \tilde{\gamma}_{[001]}$ [20]. An anomalously drastic increase of $\gamma_{1111}(T)$ occurs only in BPI. At the phase transition BPI-BPII, the sign of $\gamma_{1111}$ changes and its absolute value above the transition temperature is smaller. For BPII, $\gamma_{1111}$ does not depend on the temperature. The shift of the diffraction bands in a substance with a large cholesteric pitch, observed in paper [21], is likely to be associated with the change of electrostriction. The values of $\gamma_{2323}$ presented in figures 5, 6 were obtained from the relation $\gamma_{2323} = \tilde{\gamma}_{[011]} - \frac{1}{4} \tilde{\gamma}_{[001]}$. In contrast to $\gamma_{1111}$, $\gamma_{2323}$ does not exhibit a critical behaviour close to the BPI-BPII transition. This result indicates that the lattice becomes soft with respect to field-induced deformations along the axes of the cubic lattice (which are described by $\gamma_{1111}$), but remains stable as far as shear deformations are concerned (which are described by the off-diagonal elements of $\tilde{u}$). The difference in the behaviour of $\gamma_{1111}$ and $\gamma_{2323}$ (Figs. 5, 6) results in a strong change of the electrostriction anisotropy $\eta = (\gamma_{1111} - \gamma_{1122})/2 \gamma_{2323}$ in BPI (Figs. 7, 8). The absolute value of $\eta$ increases on approaching the phase transition temperature.

![Fig. 7](image7.png)

**Fig. 7.** — Temperature dependence of the electrostriction anisotropy $(\gamma_{1111} \gamma_{1122})/2 \gamma_{2323}$ in BPI. Mixture A.

![Fig. 8](image8.png)

**Fig. 8.** — Temperature dependence of the electrostriction anisotropy $(\gamma_{1111} - \gamma_{1122})/2 \gamma_{2323}$ in BPI. Mixture B.
For both mixtures the dependence $\gamma_{1111}(T)$ can be described by the function $\gamma_{1111}(T) = A(T^* - T)^{-1}$. The temperature $T^*$ is in close vicinity of the phase transition temperature $T^* - T_c = 0.05-0.08^\circ C$, which is by an order of magnitude less than the corresponding value for the phase transition from a nematic or cholesteric phase to the isotropic liquid. Note that $T^*$ determined in this way indicates the high-temperature limit of divergence for $\gamma_{1111}$, since the latter may have a temperature-independent part. In this case, the difference $T^* - T_c$ will be of a smaller value. Therefore, the temperature variation of $\gamma_{1111}$ indicates a pretransitional behaviour for the BPI-BPII transition in both mixtures.

Since the electrostriction is the result of a competition between electric and elastic forces, let us consider the connection between these properties in more detail in the following paragraph. In general, the dependence of the free energy on an external field $E$ and on deformations $u$ of the blue phase lattice is described by [22]

$$\Delta F = \frac{1}{2} \lambda_{ijkl} u_{ij} u_{kl} - \frac{1}{16} \chi_{ijkl} E_i E_j E_k E_l - \frac{1}{8} p_{ijkl} E_i E_j u_{kl}.$$  

(7)

Here, the elastic constant tensor $\lambda$ characterizes the stiffness of the lattice, $\chi$ is the non-linear dielectric susceptibility tensor, and the elasto-optic tensor $p$ describes a coupling term which connects the free energy to both $u$ and $E$. The electrostriction tensor $\gamma$ which is investigated in our paper is connected to these macroscopic properties by [22]

$$\gamma_{ijkl} = \frac{1}{8} S_{ijmn} P_{nmkl}.$$  

(8)

where $S$ is the tensor of elasticity or compliance coefficients, i.e. the reciprocal tensor to $\lambda$. Physically, equation (8) means that the magnitude of the electrostrictive effect is large if the lattice is mechanically soft and/or if the coupling between the electric field and the strain in the free energy expansion (i.e. the third term in Eq. (7)) is large. In order to explore these relations in more detail, we have to express the individual components of the electrostriction tensor by the components of the elasto-optic tensor and the elastic constant tensor. For cubic structures, the tensors $S$ and $\lambda$ have three independent components, which can be used for expressing $\gamma_{1111}$, $\gamma_{1122}$, and $\gamma_{2323}$.

$$\gamma_{1111} = \frac{1}{8} (S_{1111} P_{1111} + 2 S_{1122} P_{1122}),$$  

(9)

$$\gamma_{1122} = \frac{1}{8} (S_{1111} P_{1122} + 2 S_{1122} P_{1111} + S_{1222} P_{1122}),$$  

(10)

$$\gamma_{2323} = \frac{1}{2} S_{2323} P_{2323}.$$  

(11)

The splitting between the reflections, $\Delta = \lambda_{002} - \lambda_{011} = (a - b)n$, depends on the difference between the electrostriction components $\Delta = (\gamma_{1111} - \gamma_{1122}) E^2 \lambda_0$. For $\gamma_{1111} - \gamma_{1122}$ we obtain the simple relation:

$$\gamma_{1111} - \gamma_{1122} = \frac{1}{8} (P_{1111} - P_{1122})(S_{1111} - S_{1122}).$$  

(12)

The tensor $S$ is reciprocal to the elastic constant tensor $\lambda$. Thus, for a cubic structure the relation between the independent components of the tensors $S$ and $\lambda$ has the form:

$$S_{1111} = \frac{\lambda_{1111} + \lambda_{1122}}{(\lambda_{1111} - \lambda_{1122})(\lambda_{1111} + 2 \lambda_{1122})}$$  

(13)
From (12)-(14) the following relation must be fulfilled:

\[
\gamma_{1111} - \gamma_{1122} = -\frac{1}{8\pi} \frac{P_{1111} - P_{1122}}{\lambda_{1111} - \lambda_{1122}}.
\]

(16)

The relation \(\gamma_{1111} = -2\gamma_{1122}\) imposes limitations on the components of the elasto-optic tensor \(\tilde{P}\). It follows from equations (9), (10) and from the relation \(\gamma_{1111} = -2\gamma_{1122}\), that \(P_{1111} = -2P_{1122}\). This relation leads to the electrostriction coefficients:

\[
\gamma_{1111} = \frac{1}{8\pi} P_{1111}(S_{1111} - S_{1122})
\]

(17)

\[
\gamma_{1122} = -\frac{1}{16\pi} P_{1111}(S_{1111} - S_{1122}).
\]

(18)

From equations (11), (13)-(15), (17) and (18) we can obtain the components of the electrostriction tensor:

\[
\gamma_{1111} = \frac{P_{1111}}{8\pi(\lambda_{1111} - \lambda_{1122})}
\]

(19)

\[
\gamma_{1122} = -\frac{P_{1111}}{16\pi(\lambda_{1111} - \lambda_{1122})}
\]

(20)

\[
\gamma_{2323} = \frac{P_{2323}}{8\pi\lambda_{2323}}
\]

(21)

Equations similar to (19)-(21) have been obtained previously by Stark and Trebin [23] using the assumption that an electric field causes only a change of the orientational order \((P_{1111} = -2P_{1122})\). However, in the present paper the equations (17)-(21) have been derived from the condition of conservation of the unit cell volume under its deformation in an electric field. It should be noted that the relation (16) is valid without the condition of constant unit cell volume, whereas the relations (19), (20) are valid only under the condition \(\gamma_{1111} = -2\gamma_{1122}\), or \(P_{1111} = -2P_{1122}\).

Using the equations (19)-(21), we can now discuss how the electrostriction coefficients are affected by the components of \(\tilde{P}\) and \(\lambda\). The relation \(\gamma_{1111} = -2\gamma_{1122}\) leads to a relationship between the elasto-optic coefficients \((P_{1111} = -2P_{1122})\), but it does not lead to a relationship between the elasticity tensor components. Signs and values \(\lambda_{ijkl}\) are only limited by the crystal stability condition. The crystal deformation energy \(\frac{1}{2} \sum_{ijkl} \lambda_{ijkl} u_{ij} u_{kl}\) should be positive at any values of \(u_{ij}\). This imposes certain restrictions on \(\lambda_{ijkl}\):

\[
\lambda_{2323} > 0 ; \quad \lambda_{1111} \pm \lambda_{1122} > 0 ; \quad \lambda_{1111} + 2\lambda_{1122} > 0.
\]

(22)

Electrostriction tensor components have been calculated numerically by means of the Landau-de Gennes theory [23, 24]. However, a numerical comparison of absolute values of \(\lambda_{ijkl}\) with the experimental values cannot be done, since the final results obtained in [23, 24] involve Landau coefficients, for which no exact data are available at present. The theoretical
calculations neither predict the sign of the temperature dependence of $\gamma$ nor yield in quantitative values for the temperature coefficients of $\gamma$. A decrease of $\gamma$ with increasing temperature [24], or an increase of $\gamma$ with temperature [23] have been predicted in BPI and BPII. In conclusion, the theoretical considerations available as yet give no hints how to explain the unusual temperature dependence of the electrostriction tensor observed in our experiments; especially, it has not been discussed whether $\gamma_{1111}$ may grow anomalously in vicinity of the BPI-BPII phase transition temperature.

However, in previously published experimental works [25-27] the temperature dependence of the shear modulus has been measured for blue phases [25-27]. The variation of the shear modulus in BPI near the BPI $\rightarrow$ BPII phase transition temperature amounts approximately $30 \%$ ($T_c - T \approx 0.15$ °C) [27]. $\gamma_{2323}$ (Figs. 5, 6) is changed by about the same magnitude. One may thus suppose that the basic contribution to the temperature dependence of $\gamma$ comes from the temperature dependence $\lambda(T)$. According to equation (19), an increase of $\gamma_{1111}$, while approaching the phase transition temperature (Figs. 5, 6), can be associated with a decreasing value of the difference $\lambda_{1111} - \lambda_{1122}$. It is important to note that this difference is involved in the conditions for elastic stability of the crystal (see relations (22)). As $\lambda_{1111} - \lambda_{1122}$ tends to zero, the O$^8$ (BPI) lattice becomes unstable relative to spontaneous deformations. Estimates of the mean-square fluctuation values of the cubic lattice near the BPI-BPII transition temperature [18] are in agreement with such an interpretation of the cause for the BPI $\rightarrow$ BPII phase transition. There are other evidences of temperature dependent dynamical processes in BPII [28, 29] as the transition to BPIII is approached.

5. Conclusion.

We have determined the temperature dependence for all the three independent components of the electrostriction tensor, $\gamma_{ijkl}$, for two mixtures with the negative dielectric anisotropy. The temperature dependences for $\gamma_{1111}$ and $\gamma_{2323}$ in BPI differ essentially which leads to deformation of the unit cell with varying temperature. The coefficient $\gamma_{1111}$ and the electrostriction anisotropy $\eta$ display a pretransitional behavior, when approaching the BPI-BPII phase transition temperature. Such a behaviour may be explained by the temperature behaviour of the elasticity module, and, as a result, the BPI lattice may become unstable relative to spontaneous deformations. In this case, the BPI $\rightarrow$ BPII phase transition and pretransitional behaviour can be described using the components of the elastic constant tensor $\lambda$ as an order parameter.

References