

I.R. Zachek¹, R.R. Levitskii², A.S. Vdovych²

Hydrostatic Pressure Effect on Relaxation of Quasi-One-Dimensional GPI Ferroelectric

¹Lviv Polytechnic National University 12 Bandery Street, 79013, Lviv, Ukraine

²Institute for Condensed Matter Physics of the National Academy of Sciences of Ukraine
 1 Svientsitskii Street, 79011, Lviv, Ukraine

Dynamic model of deformed quasi-one-dimensional ferroelectrics with hydrogen bonds is proposed. On the basis of this model within the two-particle cluster approximation with taking into account short-range and long-range interactions and strains ε_i and ε_5 in the frames of Glauber method a dynamic dielectric permittivity of mechanically clamped crystal is calculated. Hydrostatic pressure effect on temperature and frequency dependences of the components of dynamic dielectric permittivity tensor of GPI ferroelectric is investigated.

Key words: ferroelectrics, cluster approximation, dynamic dielectric permittivity, hydrostatic pressure.

Article acted received 17.05.2017; accepted for publication 05.06.2017.

Introduction

Glycinium phosphite (GPI) belongs to the ferroelectrics with hydrogen bonds. Crystal structure in paraelectric phase is monoclinic (space group $P2_1/a$). Some changes in distances between ions in the tetrahedra HPO_3 and corresponding components of dipole moments of the hydrogen bonds in phosphate chains generate total dipole moment along Y-axis. At the temperature 225K crystal passes to the ferroelectric state (space group $P2_1$) with the spontaneous polarization, perpendicular to the chains of hydrogen bonds.

In [1] on the basis of the proposed model of deformed crystal within the two-particle cluster approximation a thermodynamic, piezoelectric, elastic and thermal characteristics of GPI ferroelectric are calculated and good quantitative description of the experimental data for these characteristics is obtained. Influence of electric fields on these characteristics of GPI crystal is studied in [2].

The aim of the present paper is study of hydrostatic pressure effect on the temperature and frequency dependences of the components of dynamic dielectric permittivity tensor of GPI crystal.

I. Relaxation of mechanically clamped GPI type crystal

We investigate dynamic properties of mechanically clamped GPI crystal in the presence of the electric fields E_i ($i = 1,2,3$) and hydrostatic pressure $p = -s_1 = -s_2 = -s_3$ on the basis of dynamic model, which is grounded on the ideas of stochastic Glauber model [3]. On the basis of methods, developed in [4, 5], we obtain such system of equations отримуюемо for time-dependent distribution functions of protons

$$-a \frac{d}{dt} \langle \Pi_{f' qf} \rangle = \sum_{f'} \left\{ \langle \Pi_{f' qf} \left[1 - s_{qf'} \text{th} \frac{1}{2} b e_{qf'}^z(t) \right] \right\}, \quad (2.1)$$

where $e_{qf'}^z(t)$ is local field, acting on f' -th proton in q -th cell. In order to obtain self-contained system of equations we use two-particle cluster approximation. Within this approximation the local fields $e_{qf'}^z(t)$ are coefficients at S_{qf} in two-particle $\hat{H}_q^{(2)}$ and one-particle $\hat{H}_{qf}^{(1)}$ hamiltonians, obtained in [1,2]:

$$\hat{H}_q^{(2)} = -2w \left(\frac{S_{q1} S_{q2}}{2} + \frac{S_{q3} S_{q4}}{2} \right) - \frac{y_1 S_{q1}}{b} - \frac{y_2 S_{q2}}{b} - \frac{y_3 S_{q3}}{b} - \frac{y_4 S_{q4}}{b}, \quad (2.2)$$

$$\hat{H}_{q^2}^{(1)1} = -\frac{\bar{y}}{b} \frac{S_{gf}^{(1)}}{2}, \quad \hat{H}_{q^2}^{(1)2} = -\frac{\bar{y}}{b} \frac{S_{gf}^{(2)}}{2},$$

$$\hat{H}_{gf}^{(1)} = -\frac{\bar{y}_f}{b} \frac{S_{gf}}{2}, \quad (2.3)$$

where such notations are used:

$$y_1 = b(\Delta_{13} + 2n_{11}h_1 + 2n_{12}h_2 + 2n_{13}h_3 + 2n_{14}h_4 +$$

$$+ m_{13}^x E_1 + m_{13}^y E_2 + m_{13}^z E_3), \quad h_f = \langle S_{gf} \rangle,$$

$$y_2 = b(\Delta_{24} + 2n_{12}h_1 + 2n_{22}h_2 + 2n_{14}h_3 + 2n_{24}h_4 +$$

$$- m_{24}^x E_1 - m_{24}^y E_2 + m_{24}^z E_3),$$

$$y_3 = b(\Delta_{13} + 2n_{13}h_1 + 2n_{14}h_2 + 2n_{11}h_3 + 2n_{12}h_4 +$$

$$- m_{13}^x E_1 + m_{13}^y E_2 - m_{13}^z E_3),$$

$$y_4 = b(\Delta_{24} + 2n_{14}h_1 + 2n_{24}h_2 + 2n_{12}h_3 + 2n_{22}h_4 +$$

$$+ m_{13}^x E_1 - m_{13}^y E_2 - m_{13}^z E_3),$$

$$\bar{y}_f = -b\Delta_f + y_f, \quad b = 1/k_B T,$$

Here $\Delta_{13,24}$ are effective fields, created by neighbour out of cluster bonds.

On the basis of (2.1) we obtain such equations in two-particle approximation for time-dependent unary distribution functions:

$$a \frac{d}{dt} h_1 = -h_1 - P_1 h_2 + L_1, \quad a \frac{d}{dt} h_2 = P_2 h_1 - h_2 + L_2, \quad (2.4)$$

$$a \frac{d}{dt} h_3 = -h_3 - P_3 h_4 + L_3,$$

$$a \frac{d}{dt} h_4 = P_4 h_3 - h_4 + L_4,$$

where such notations are used:

$$P_f = \frac{1}{2} \left[\text{th} \left(\frac{bw}{2} + \frac{y_f}{2} \right) - \text{th} \left(-\frac{bw}{2} + \frac{y_f}{2} \right) \right],$$

$$L_f = \frac{1}{2} \left[\text{th} \left(\frac{bw}{2} + \frac{y_f}{2} \right) + \text{th} \left(-\frac{bw}{2} + \frac{y_f}{2} \right) \right]. \quad (2.6)$$

$$w = w^0 + \sum_{i=1}^3 d_{2i} e_i + d_5 e_5.$$

Similarly we can obtain corresponding equations in one-particle approximation:

$$a \frac{d}{dt} h_f = -h_f + \text{th} \frac{\bar{y}_f}{2}. \quad (2.5)$$

Let us limit oneself by the case of small deviations from equilibrium state for calculation of equations (2.4) and (2.5). For this case we write h_f and effective fields in the form of sum of equilibrium values and their deviations from equilibrium values:

$$h_{1,3} = \bar{h}_{13} + h_{1,3t}, \quad h_{2,4} = \bar{h}_{24} + h_{2,4t}, \quad E_i = E_{it} e^{i\omega t}$$

$$\Delta_{13} = \bar{\Delta}_{13} + \Delta_{13t}, \quad \Delta_{24} = \bar{\Delta}_{24} + \Delta_{24t} \quad (2.6)$$

$$y_{1,3} = \bar{y}_{13} + y_{1,3t}, \quad y_{2,4} = \bar{y}_{24} + y_{2,4t}.$$

We decompose the coefficients P_f and L_f in series

of $\frac{y_f t}{2}$, limiting by linear items:

$$P_f = P_f^{(0)} + \frac{y_f t}{2} P_f^{(1)}, \quad L_f = L_f^{(0)} + \frac{y_f t}{2} L_f^{(1)}, \quad (2.7)$$

where such notations are used:

$$P_{1,3}^{(0)} = \frac{1-a^2}{Z_{13}}, \quad L_{1,3}^{(0)} = \frac{2a \, sh \tilde{y}_{13}}{Z_{13}},$$

$$P_{2,4}^{(0)} = \frac{1-a^2}{Z_{24}}, \quad L_{2,4}^{(0)} = \frac{2a \, sh \tilde{y}_{24}}{Z_{24}},$$

$$P_{1,3}^{(1)} = -\frac{4a(1-a^2)sh \tilde{y}_{13}}{Z_{13}^2}, \quad L_{1,3}^{(1)} = \frac{4a[2a + (1+a^2)ch \tilde{y}_{13}]}{Z_{13}^2},$$

$$P_{2,4}^{(1)} = -\frac{4a(1-a^2)sh \tilde{y}_{24}}{Z_{24}^2}, \quad L_{2,4}^{(1)} = \frac{4a[2a + (1+a^2)ch \tilde{y}_{24}]}{Z_{24}^2},$$

$$Z_{13} = 1 + a^2 + 2ach \tilde{y}_{13}, \quad Z_{24} = 1 + a^2 + 2ach \tilde{y}_{24},$$

$$\tilde{y}_{13} = \frac{1}{2} \ln \frac{1 + \bar{h}_{13}}{1 - \bar{h}_{13}} + bn_1^+ \bar{h}_{13} + bn_2^+ \bar{h}_{24},$$

$$\tilde{y}_{24} = bn_2^+ \bar{h}_{13} + \frac{1}{2} \ln \frac{1 + \bar{h}_{24}}{1 - \bar{h}_{24}} + bn_3^+ \bar{h}_{24},$$

The order parameters \bar{h}_{13} , \bar{h}_{24} and the strains e_j are founded from the system of equations:

$$\bar{h}_{13} = \frac{1}{D} [sh(\tilde{y}_{13} + \tilde{y}_{24}) + a^2 sh(\tilde{y}_{13} - \tilde{y}_{24}) + 2ash \tilde{y}_{13}],$$

$$\bar{h}_{24} = \frac{1}{D} [sh(\tilde{y}_{13} + \tilde{y}_{24}) - a^2 sh(\tilde{y}_{13} - \tilde{y}_{24}) + 2ash \tilde{y}_{24}],$$

$$-p = c_{i1}^{E0} e_1 + c_{i2}^{E0} e_2 + c_{i3}^{E0} e_3 + c_{i5}^{E0} e_5 - \frac{2d_i}{u} + \frac{2d_i}{uD} M_e -$$

$$- \frac{1}{4u} (y_{1i}^+ \bar{h}_{13}^2 + 2y_{2i}^+ \bar{h}_{13} \bar{h}_{24} + y_{3i}^+ \bar{h}_{24}^2),$$

$$0 = c_{15}^{E0} e_5 + c_{25}^{E0} e_5 + c_{35}^{E0} e_5 + c_{55}^{E0} e_{55} - \frac{2d_5}{u} + \frac{2d_5}{uD} M_e -$$

$$- \frac{1}{4u} (y_{15}^+ \bar{h}_{13}^2 + 2y_{25}^+ \bar{h}_{13} \bar{h}_{24} + y_{35}^+ \bar{h}_{24}^2),$$

$$0 = c_{44}^{E0} e_4 + c_{46}^{E0} e_{66} - \frac{2d_4}{u} + \frac{2d_4}{uD} M_e -$$

$$- \frac{1}{4u} (y_{14}^+ \bar{h}_{13}^2 + 2y_{24}^+ \bar{h}_{13} \bar{h}_{24} + y_{34}^+ \bar{h}_{24}^2),$$

$$0 = c_{46}^{E0} e_4 + c_{66}^{E0} e_6 - \frac{2d_6}{u} + \frac{2d_6}{uD} M_e -$$

$$- \frac{1}{4u} (y_{16}^+ \bar{h}_{13}^2 + 2y_{26}^+ \bar{h}_{13} \bar{h}_{24} + y_{36}^+ \bar{h}_{24}^2),$$

where such notations are used:

$$D = ch(\tilde{y}_{13} + \tilde{y}_{24}) + a^2 ch(\tilde{y}_{13} - \tilde{y}_{24}) +$$

$$+ 2ach \tilde{y}_{13} + 2ach \tilde{y}_{24} + a^2 + 1,$$

$$n_i^+ = n_i^0 + \sum_{j=1}^6 y_{ij}^+ e_j, \quad a = \exp \left\{ -b(w^0 + \sum_{j=1}^6 d_j e_j) \right\}.$$

$$M_e = 2a^2 ch(\tilde{y}_{13} - \tilde{y}_{24}) + 2a^2 + 2ach \tilde{y}_{13} + 2ach \tilde{y}_{24}.$$

Substituting (2.6) and (2.7) into equations (2.4) and (2.5) and excluding parameters $\Delta_{13t}, \Delta_{24t}$, we obtain the

differential equations for time-dependent GPI unary distribution functions of deuterons. Solving these equations we obtain the components of dynamic dielectric susceptibility:

$$c_{11,33}^e(w) = c_{11,33}^{e0} + \lim \frac{1}{u} [m_{13}^{x,z} \frac{d(h_{1t} - h_{3t})}{dE_{1,3t}} - m_{24}^{x,z} \frac{d(h_{2t} - h_{4t})}{dE_{1,3t}}] = c_{11,33}^{e0} + \sum_{i=1}^2 \frac{c_i^{x,z}}{1 + i\omega t_i^{x,z}},$$

$$c_{22}^e(w) = c_{22}^{e0} + \lim \frac{1}{u} [m_{13}^y \frac{d(h_{1t} + h_{3t})}{dE_{2t}} - m_{24}^y \frac{d(h_{2t} + h_{4t})}{dE_{2t}}] = c_{22}^{e0} + \sum_{i=1}^2 \frac{c_i^y}{1 + i\omega t_i^y}.$$

Here such notations are used:

$$c_{1,2}^{x,z} = \frac{b}{2u} \frac{t_1^{x,z} t_2^{x,z}}{t_2^{x,z} - t_1^{x,z}} \{ \pm [(m_{13}^{x,z})^2 m_1 + (m_{24}^{x,z})^2 m_2] \mathbf{m} \mathbf{m} t_{1,2}^{x,z} [(m_{13}^{x,z})^2 m_1 m_{22}^- + (m_{24}^{x,z})^2 m_2 m_{11}^- - m_{13}^{x,z} m_{24}^{x,z} (m_1 m_{21}^- + m_2 m_{12}^-)] \},$$

$$c_{1,2}^y = \frac{b}{2u} \frac{t_1^y t_2^y}{t_2^y - t_1^y} \{ \pm [(m_{13}^y)^2 m_1 + (m_{24}^y)^2 m_2] \mathbf{m} \mathbf{m} t_{1,2}^y [(m_{13}^y)^2 m_1 m_{22}^+ + (m_{24}^y)^2 m_2 m_{11}^+ - m_{13}^y m_{24}^y (m_1 m_{21}^+ + m_2 m_{12}^+)] \},$$

$$(t_{1,2}^{x,z})^{-1} = \frac{1}{2} [(m_{11} + m_{22}) \pm \sqrt{(m_{11}^- - m_{22}^-)^2 + 4m_{12}^- m_{21}^-}]$$

$$(t_{1,2}^y)^{-1} = \frac{1}{2} [(m_{11} + m_{22}) \pm \sqrt{(m_{11}^+ - m_{22}^+)^2 + 4m_{12}^+ m_{21}^+}]$$

$$m_{11}^\pm = \frac{1}{a} (1 - b n_1^\pm r_{13} K_{13}), m_{22}^\pm = \frac{1}{a} (1 - b n_3^\pm r_{24} K_{24}),$$

$$m_{12}^\pm = \frac{1}{a} [(1 + K_{13}) P_{13}^{(0)} + b n_2^\pm r_{13} K_{13}],$$

$$m_{21}^\pm = \frac{1}{a} [(1 + K_{24}) P_{24}^{(0)} + b n_2^\pm r_{24} K_{24}],$$

$$m_1 = \frac{1}{a} K_{13} r_{13}, m_2 = \frac{1}{a} K_{24} r_{24},$$

$$K_{13} = \frac{P_{13}^{(1)} \tilde{h}_{13} + L_{13}^{(1)}}{2r_{13} - (P_{13}^{(1)} h_{13} + L_{13}^{(1)})}, K_{24} = \frac{P_{24}^{(1)} \tilde{h}_{24} + L_{24}^{(1)}}{2r_{24} - (P_{24}^{(1)} h_{24} + L_{24}^{(1)})},$$

$$r_{13} = 1 - (\tilde{h}_{13})^2, r_{24} = 1 - (\tilde{h}_{24})^2.$$

The components of dynamic dielectric permittivity of the clamped GPI crystal are as follow:

$$e_{ii}^{e'}(w) = e_{ii}^{e0} + \sum_{i=1}^2 \frac{4pc_i^a}{1 + (\omega t_i^a)^2}, (a = x, y, z)$$

$$e_{ii}^{e''}(w) = \sum_{i=1}^2 \frac{4p\omega t_i^a c_i^a}{1 + (\omega t_i^a)^2}.$$

II. Comparison of numerical calculations with experimental data

For quantitative estimation of the temperature and frequency dependences of corresponding physical characteristics of GPI crystal, obtained within the proposed theory, we need to set the values of the following parameters:

- parameter of the short-range interactions w^0 ;
- parameters of the long-range interactions $n_1^\pm, n_2^\pm, n_3^\pm$;
- effective dipole moments $m_{13,24}^a$;
- deformational potentials δ_i, y_{ji}^\pm ;
- "seed" dielectric susceptibilities c_{ii}^{e0} ;
- "seed" coefficients of piezoelectric stress e_{2i}^0, e_{25}^0 ;
- "seed" elastic constants $c_{ii}^{E0}, c_{i5}^{E0}, c_{jj}^{E0}, c_{46}^{E0}$;
- parameter a , that determine time scale of relaxation processes.

The values of given theory parameters are determined studying of the static properties of GPI [1]. For the crystal of [6], where the phase transition temperature $T_c = 225K$ these parameters are as follow:

$$w^0 / k_B = 820K; \quad \tilde{n}_1^{0+} = \tilde{n}_2^{0+} = \tilde{n}_3^{0+} = 2,643K,$$

$$\tilde{n}_1^{0-} = \tilde{n}_2^{0-} = \tilde{n}_3^{0-} = 0,2K, \quad \tilde{n}_i^{0\pm} = n_i^{0\pm} / k_B;$$

$$\tilde{d}_1 = 500K, \tilde{d}_2 = 600K, \tilde{d}_3 = 500K, \tilde{d}_4 = 150K,$$

$$\tilde{d}_5 = 100K, \tilde{d}_6 = 150K, \tilde{d}_l = d_l / k_B;$$

$$\tilde{y}_{il}^+ = 87,9K; \tilde{y}_{i2}^+ = 237,0K; \tilde{y}_{i3}^+ = 103,8K; \tilde{y}_{i4}^+ = 149K;$$

$$\tilde{y}_{i5}^+ = 21,3K; \tilde{y}_{i6}^+ = 143,8K; \tilde{y}_{il}^+ = y_{il}^+ / k_B.$$

The effective dipole moments in the paraelectric phase are equal to $\mathbf{m}_{13}^{\mathbf{r}} = (0,5; 4,02; 4,3) \cdot 10^{-18} esu \cdot cm$, $\mathbf{m}_{24}^{\mathbf{r}} = (2,5; 3,0; 2,2) \cdot 10^{-18} esu \cdot cm$. In the ferroelectric phase $m_{13}^y = 3,82 \cdot 10^{-18} esu \cdot cm$.

In [7] the transition temperature is $T_c = 223.6K$ and the parameters $w^0, n_1^\pm, n_2^\pm, n_3^\pm, \delta_i, y_{ji}^\pm, m_{13,24}^a$ one should multiply on the coefficient 0.994.

Parameter a is determined from the condition of agreement of theoretically calculated and experimentally obtained frequency dependences of $e_{22}(w)$. At that we consider, that parameter a slightly changes with temperature:

$$a = [1,6 - 0,011(\Delta T)] \cdot 10^{-14} c^{-1}, \quad \Delta T = T - T_c.$$

The volume of primitive cell of GPI is the $u = 0,601 \cdot 10^{-21} cm^3$.

The "seed" parameters:

$$e_{21}^0 = e_{22}^0 = e_{23}^0 = e_{25}^0 = 0 esu/cm^2,$$

$$c_{11}^{e0} = 0,1; \quad c_{22}^{e0} = 0,403; \quad c_{33}^{e0} = 0,5;$$

$$c_{11}^{0E} = 26,91 \cdot 10^{10} dyn/cm^2, \quad c_{12}^{E0} = 14,5 \cdot 10^{10} dyn/cm^2,$$

$$c_{13}^{E0} = 11,64 \cdot 10^{10} dyn/cm^2, \quad c_{23}^{E0} = 20,38 \cdot 10^{10} dyn/cm^2$$

$$\begin{aligned}
 c_{33}^{E0} &= 624,41 \cdot 10^{10} \text{ dyn/cm}^2, c_{15}^{E0} = 3,91 \cdot 10^{10} \text{ dyn/cm}^2 \\
 c_{25}^{E0} &= 5,64 \cdot 10^{10} \text{ dyn/cm}^2, c_{35}^{E0} = -2,84 \cdot 10^{10} \text{ dyn/cm}^2, \\
 c_{55}^{E0} &= 8,54 \cdot 10^{10} \text{ dyn/cm}^2, c_{44}^{E0} = 15,31 \cdot 10^{10} \text{ dyn/cm}^2, \\
 c_{46}^{E0} &= -1,1 \cdot 10^{10} \text{ dyn/cm}^2, c_{66}^{E0} = 11,88 \cdot 10^{10} \text{ dyn/cm}^2. \\
 c_{22}^{E0} &= (65 - 0,04\Delta T) \cdot 10^{10} \text{ dyn/cm}^2
 \end{aligned}$$

different ΔT , at that the smaller ΔT the stronger this increasing. At the frequencies close to ν_r the value of e'_{22} decreases with pressure, but the value of e''_{22} increases to some maximum value with further decreasing. At the frequencies higher then ν_r increasing of hydrostatic pressure leads to decreasing of e'_{22} and e''_{22} . As we can see from the frequency dependences of permittivity,

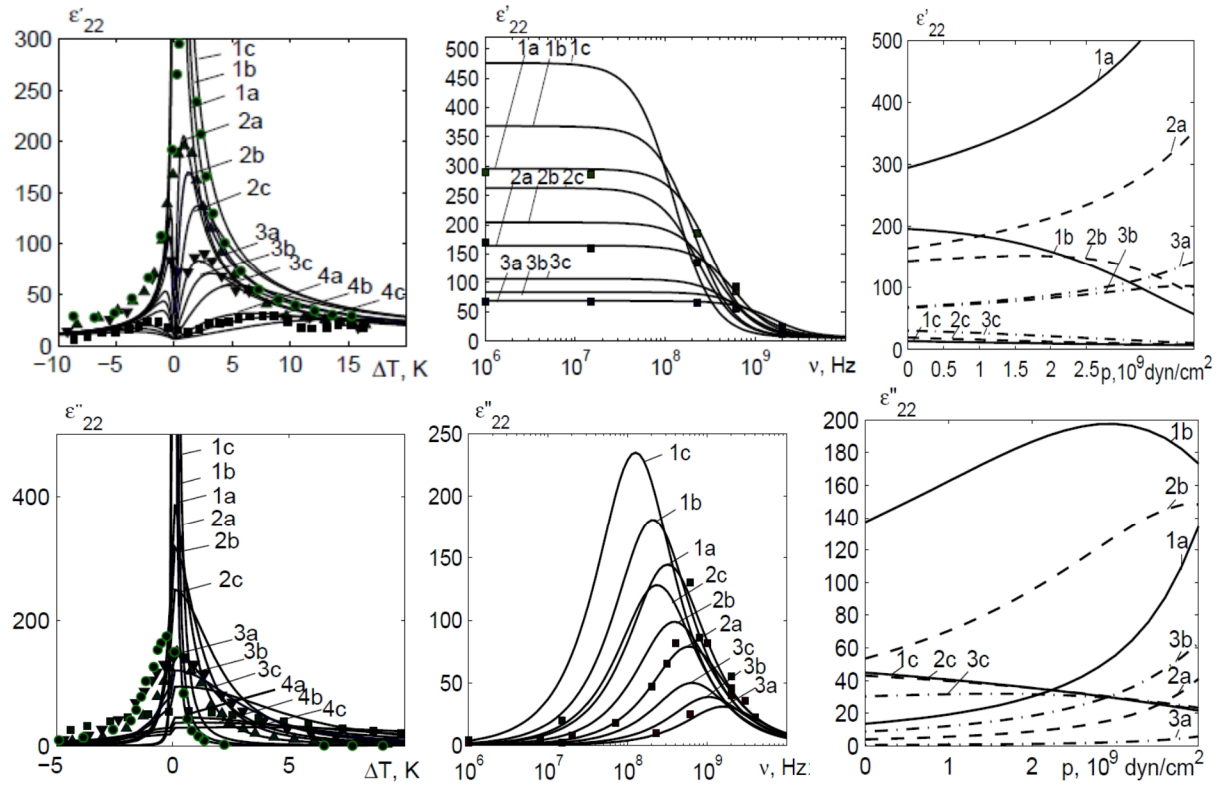


Fig. 1. The dependences on ΔT of real e'_{22} and imaginary e''_{22} parts of dynamic dielectric permittivity of GPI at different frequencies ν (GHz): 0.015 – 1, ● [7]; 0.23 – 2, ▲ [7]; 0.61 – 3, ▼ [7]; 2.0 – 4, ■ [7] and at different values of hydrostatic pressure p (10^9 dyn/cm^2): 0.0 – a; 1.7 – b; 3 – c; frequency dependences of e'_{22} and e''_{22} at different ΔT (K): 1.0 – 1; 2.0 – 2; 5.0 – 3; ■ [17] and at different values of hydrostatic pressure p (10^9 dyn/cm^2): 0.0 – a; 1.7 – b; 3 – c; pressure dependences of e'_{22} and e''_{22} at different ΔT (K): 1.0 – 1; 2.0 – 2; 5.0 – 3 and at different frequencies ν (GHz): 0.015 – a; 0.23 – b; 2.0 – c.

In fig. 1 are presented dependences on ΔT of real $e'_{22}(n, T)$ and imaginary $e''_{22}(n, T)$ parts of dynamic dielectric permittivity of GPI at different frequencies and at different values of hydrostatic pressure, and experimental data [7]; frequency dependences of e'_{22} and e''_{22} at different ΔT and at different values of hydrostatic pressure; and pressure dependences of e'_{22} and e''_{22} at different ΔT and at different frequencies.

Maximum values of real e'_{22} part of dielectric permittivity of GPI decrease and shift to the higher temperatures with increasing of hydrostatic pressure. At the frequencies less than relaxation frequency ($\nu_r \approx 8 \cdot 10^7 \text{ GHz}$) increasing of hydrostatic pressure, applied to the crystal, leads to increasing of real e'_{22} and imaginary e''_{22} parts of dielectric permittivity of GPI at

hydrostatic pressure shifts region of dispersion to lower frequencies.

In fig. 2 are presented dependences on ΔT of real $e'_{11}(n, T)$ and imaginary $e''_{11}(n, T)$ parts of dynamic dielectric permittivity of GPI at different frequencies and at different values of hydrostatic pressure; frequency dependences of e'_{11} and e''_{11} at different ΔT and at different values of hydrostatic pressure; and pressure dependences of e'_{11} and e''_{11} at different ΔT and at different frequencies. Analogous dependences of real e'_{33} and imaginary e''_{33} parts of dynamic dielectric permittivity of GPI are presented in fig. 3.

Character of the pressure dependence of real e'_{33} and imaginary e''_{33} parts of dielectric permittivity of GPI is similar to the pressure dependence of e'_{11} and e''_{11} , but

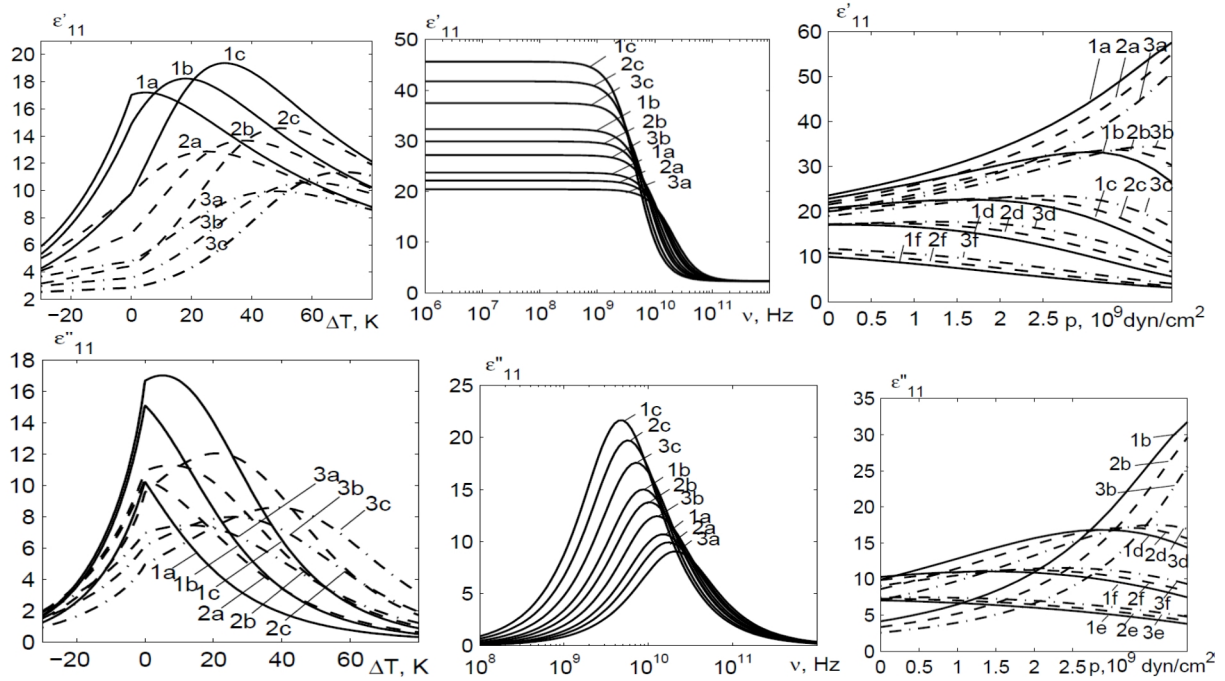


Fig. 2. The dependences on ΔT of real ϵ'_{11} and imaginary ϵ''_{11} parts of dynamic dielectric permittivity of GPI at different frequencies ν (GHz): 10.0 – 1; 20.0 – 2; 40.0 – 3 and at different values of hydrostatic pressure p (10^9 dyn/cm^2): 0 – a; 1.7 – b; 3 – c; frequency dependences of ϵ'_{11} and ϵ''_{11} at different ΔT (K): 1.0 – 1; 5.0 – 2; 10.0 – 3 and at different values of hydrostatic pressure p , (10^9 dyn/cm^2): 0 – a; 1.7 – b; 3 – c; pressure dependences of ϵ'_{11} and ϵ''_{11} at different ΔT (K): 1.0 – 1; 5.0 – 2; 10.0 – 3 and at different frequencies ν (GHz): 1.0 – a; 3.0 – b; 6.0 – c, 10 – d; 20 – f; 40 – e.

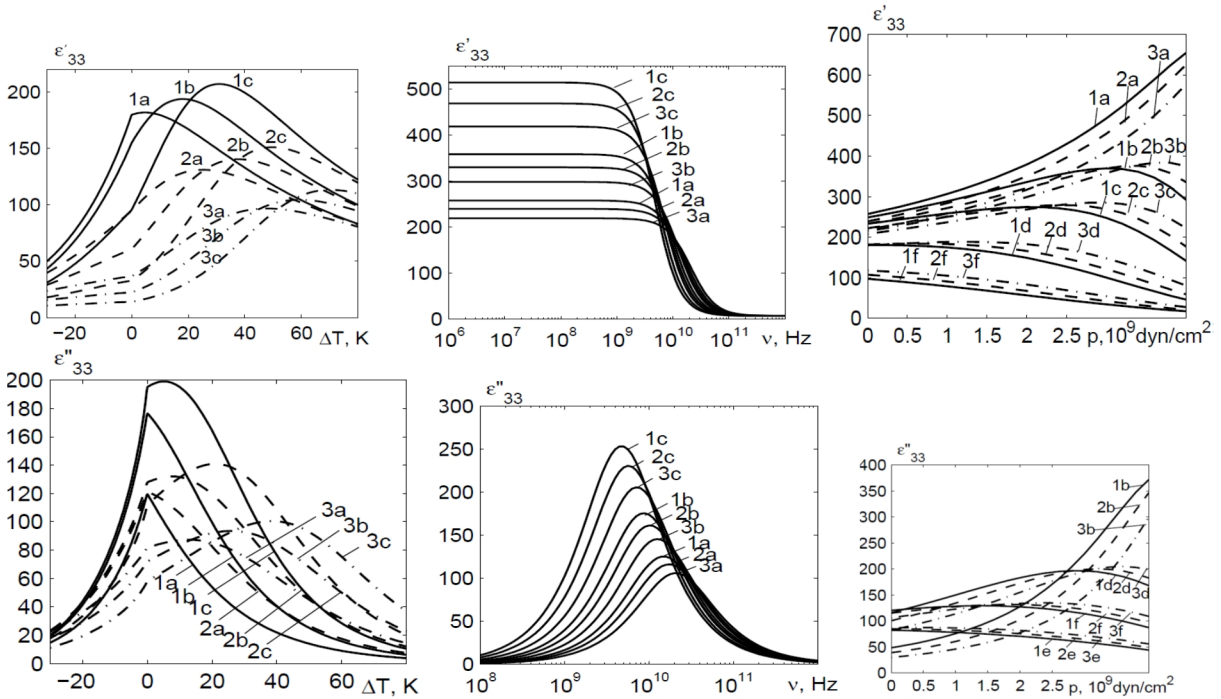


Fig. 3. The dependences on ΔT of real ϵ'_{33} and imaginary ϵ''_{33} parts of dynamic dielectric permittivity of GPI at different frequencies ν (GHz): 10.0 – 1; 20.0 – 2; 40.0 – 3 and at different values of hydrostatic pressure p (10^9 dyn/cm^2): 0 – a; 1.7 – b; 3 – c; frequency dependences of ϵ'_{33} and ϵ''_{33} at different ΔT (K): 1.0 – 1; 5.0 – 2; 10.0 – 3 and at different values of hydrostatic pressure p , (10^9 dyn/cm^2): 0 – a; 1.7 – b; 3 – c; pressure dependences of ϵ'_{33} and ϵ''_{33} at different ΔT (K): 1.0 – 1; 5.0 – 2; 10.0 – 3 and at different frequencies ν (GHz): 1.0 – a; 3.0 – b; 6.0 – c, 10 – d; 20 – f; 40 – e

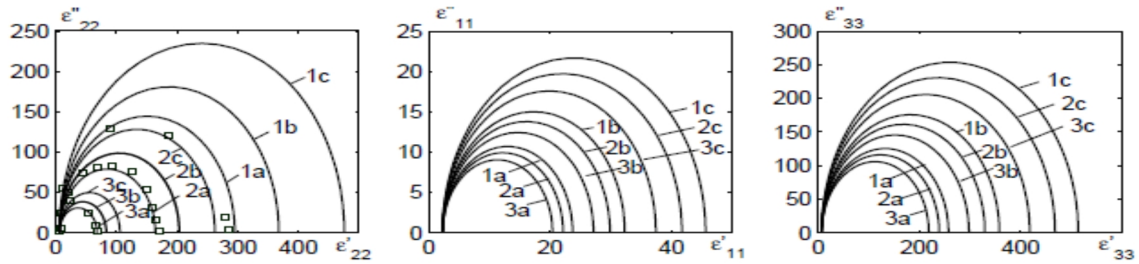


Fig. 4. The Cole-Cole curves at different ΔT (K): 1.0 – 1, \square [7]; 2.0 – 2, \square [7]; 5.0 – 3, \square [7] and at different values of hydrostatic pressure p , (10^9 dyn/cm^2): 0 – a; 1.7 – b; 3 – c.

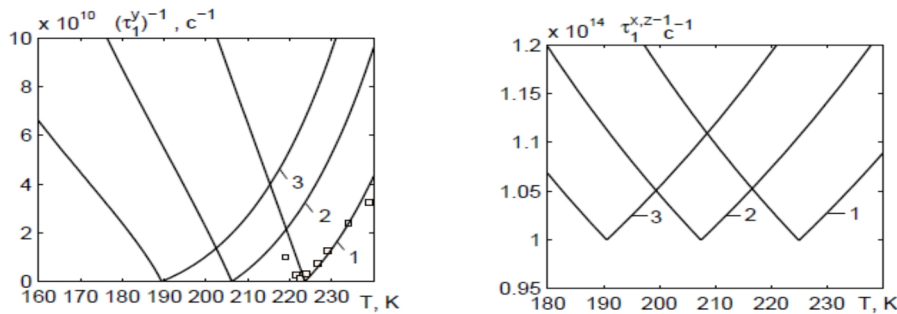


Fig. 5. The temperature dependences of inverse relaxation times $(t_1^y)^{-1}$ and $(t_1^{x,z})^{-1}$ at different values of hydrostatic pressure p , (10^9 dyn/cm^2): 0 – 1; 1.7 – 2; 3.0 – 3

the values of $e_{33}(n, T)$ is ≈ 10 times larger than $e_{11}(n, T)$. Behaviour of real e'_{11} and imaginary e''_{11} parts of dielectric permittivity of GPI in the presence of hydrostatic pressure depends on deviation of temperature from phase transition temperature ΔT and on frequency n of external electric field. At small values ΔT and pre-relaxation frequencies increasing of pressure leads to nonlinear increasing of e'_{11} and e''_{11} , at that increasing of ΔT leads to decreasing of permittivity. In the region of relaxation frequencies permittivity increases at first and then decreases; and maximums of permittivity on the pressure dependence shift to the lower pressures with increasing of frequency. At the over-relaxation frequencies increasing of pressure leads to decreasing of permittivities e'_{11} and e''_{11} , but increasing of ΔT leads to increasing of permittivities.

In fig. 4 are presented Cole-Cole at different ΔT and at different values of hydrostatic pressure. In all cases radii of Cole-Cole semicircles increase with increasing of pressure and decrease with increasing of ΔT .

Temperature dependences of inverse relaxation times $(t_1^y)^{-1}$ and $(t_1^{x,z})^{-1}$ at different values of hydrostatic pressure are presented in fig.5. Their minimum values shift to lower temperatures with increasing of hydrostatic pressure; magnitudes of $(t_1^y)^{-1}$ decrease with pressure,

but $(t_1^{x,z})^{-1}$ do not change.

Conclusions

In the present paper within modified proton ordering model of quasi-one-dimensional GPI type ferroelectrics with hydrogen bonds with taking into account of piezoelectric coupling with strains ε_i , ε_j in ferroelectric phase within the two-particle cluster approximation we have studied hydrostatic pressure effect on the temperature and frequency dependences of the components of dynamic dielectric permittivity tensor of GPI ferroelectric. We have determined that hydrostatic pressure increases relaxation time t_1^y , in consequence of which the frequency dependence of dielectric permittivity shifts to the lower frequencies.

Zachek I.R. – Doctor of Sciences (Physics and Mathematics), Professor of the Department of Physics
Levitskii R.R. – Professor, Doctor of Sciences (Physics and Mathematics), Senior Research Fellow
Vdovych A.S. – Ph.D (Physics and Mathematics Science), researcher.

- [1] I.R. Zachek, Ya. Shchur, R.R. Levitskii, A.S. Vdovych, *Physica B* 520, 164 (2017).
- [2] I.R. Zachek, R.R. Levitskii, A.S. Vdovych, I.V. Stasyuk, *Condens. Matt. Phys.* 20(2), 23706 (2017).
- [3] J. Glauber, *J. Math. Phys.* 4(2), 294 (1963).
- [4] P.P. Левицький, I.P. Зачек, А.С. Вдович, *ФХТТ* 10(2), 377 (2009).
- [5] R.R. Levitskii, I.R. Zachek, A.S. Vdovych, *Condens. Matt. Phys.* 15(3), 33705(2012).

- [6] S. Dacko, Z. Czapla, J. Baran, M. Drozd, Phys.Lett. A 223, 217 (1996).
[7] R. Tchukvinskyi, Z. Czapla, R. Sobiestianskas, A. Brilingas, J. Grigas, J. Baran, Acta Phys. Polonica A 92, 1191 (1997).

І.Р. Зачек¹, Р.Р. Левицький², А.С. Вдович²

Вплив гідростатичного тиску на релаксацію квазіодновимірного сегнетоелектрика GPI

¹Національний університет "Львівська політехніка" вул. С. Бандери 12, 79013, Львів, Україна
²Інститут фізики конденсованих систем НАН України, вул. Свенціцького, 1, Львів, 79011, Україна

Запропонована динамічна модель деформованих квазіодновимірних сегнетоелектриків з водневими зв'язками типу GPI. На основі цієї моделі в наближенні двочастинкового кластера з врахуванням короткосяжних і далекосяжних взаємодій та деформацій ε_i і ε_5 в рамках методу Глаубера розраховано динамічні діелектричні проникності механічно затиснутого кристалу. Досліджено вплив гідростатичного тиску на температурні і частотні залежності компонент тензора динамічної діелектричної проникності сегнетоелектрика GPI.

Ключові слова: сегнетоелектрики, кластерне наближення, динамічна діелектрична проникність, гідростатичний тиск.