The study of the influence of physical fields of *Teslar ® technology* on the TGS crystal in the critical range

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Abstract. We have studied the temperature dependency of the permittivity and pyroelectric potential of the ferroelectric monocrystal triglycinsulphate (TGS) affected by the Teslar chip (the TC). It has been revealed that these responses are "frozen" when the crystal is affected by the TC radiation. The phenomenological theory proposed to describe the influence of the TC has shown that the TC's scalar field in fact is able to suppress the electric field and thermal waves induced in the crystal with temperature in the range from 20 to 65 ^{o}C.

Key words: Teslar technology, pyroelectric, permittivity, polarization

1. INTRODUCTION

The physical sense of our experiments is the investigation of the influence of physical fields generated by *the Teslar® technology* on ferroelectric crystals that feature the second kind of phase transitions related to the "order – disorder" species. Such physical objects have been chosen for the experimentation because in a temperature interval close to the phase transition, the dynamics of the crystal lattice are characterized by a degree of lability higher than usual and therefore, even a minute action by an external field may be able to elicit a response in the crystal object.

In the experiments, as a modelling object we have chosen a ferroelectric monocrystal triglycinsulphate (TGS), whose chemical formula is $(\mathrm{NH_2CH_2COOH})_3 \cdot \mathrm{H_2SO_4}$, with the organic additive L, i.e. α-alanine, whose chemical formula is $\mathrm{CH_3CH \cdot (NH_2)CO_2H}$. The latter was added to the crystal during its growth to enlarge the crystal unipolarity and to stabilize its domain structure.

Crystals used in these experiments represented a plate with the linear sizes 5×5 mm^2 and thickness 50 microns, which were cut out perpendicularly to the polar axis (the plane 010). Above the temperature of phase transition in the paraelectric phase the TGS crystal belongs to the centrosymmetrical point group *2/m* ($\mathrm{C_{2h}}$) of the monoclinic syngony. Below the temperature of phase transition the mirror plane *m* disappears and the crystal is transferred to the ferroelectric phase belonging to the point group 2 ($\mathrm{C_2}$) of the monoclinic syngony. This crystal has the second order axis of symmetry, the monoclinic axis *b* that is a peculiar polar axis.

2. EXPERIMENTAL

2.1. Experimental conditions

Our experiments have been conducted in a special room shielded from electromagnetic interference, in accordance with the National Standards of Ukraine on support of unity of measurements. Namely, at such conditions, measuring equipment yields results with accuracy up to 10 nV (nanovolts). This level of measurement is quite sufficient for obtaining trustworthy information in our experiments. The National Standards of Ukraine on support of unity of measurements corresponds to the defined norms of international standard IEC (International Electrotechnical Committee). Moreover, a grounded metal box covered the cuvette with samples studied; the box was cube-shaped with equal sides of approximately 12 cm.

In the room, the following common conditions were maintained:

- Barometric pressure was controlled between 750 to 770 mm of mercury column,
- Temperature was maintained between 18 to 22 °C,
- Relative humidity of air was maintained between 65 and 75 %.

The experiments were conducted during normal day working hours.

2.2. Measurements

Two kinds of experiments were performed:

a) The study of changes of the capacity of the TGS-plate with temperature. We examined the behavior of the capacity when 1) the TSG-plate has been affected by the Teslar chip radiation (TC-radiation) and 2) when the TC has not been used in the experimental scheme. The temperature ranged from 22 to 65 ^{o}C. For the TGS crystal, the phase transition from the ferroelectric phase to the paraelectric one occurs at 49 ^{o}C;

b) The study of changes of a signal of the pyroelectric response in the mode of measurement of the pyroelectric current of the TGS-plate irradiated by a modulated laser beam when 1) the TC affected the crystal and 2) when the TC has not been used in the experimental scheme. The measurements were recorded at temperatures from 22 to 65 ^{o}C.

The set-up used in the experiment of the kind (a) is shown in Figure 1.

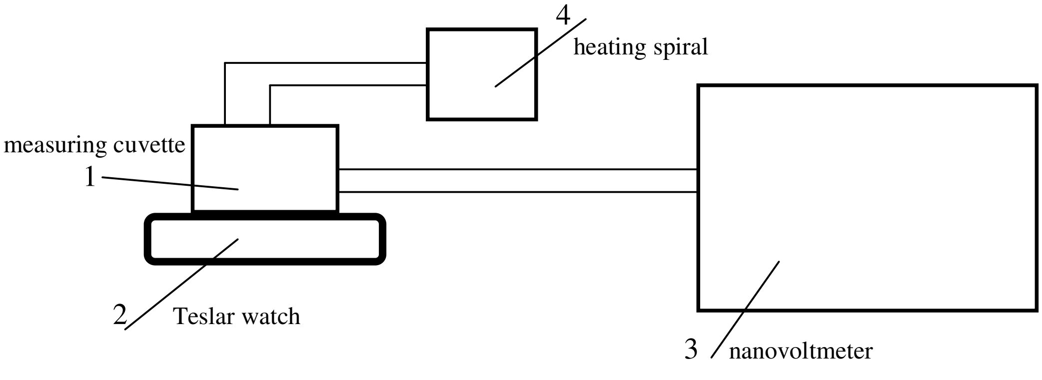

Figure 1. Scheme of set-up used to measure capacity of TGS crystal plate as a function of temp.

Experiments were carried out with the use of measuring cuvette "1", which is a chamber made of fluorine-containing plastic with size 50 × 50 × 40 mm^3. A capacitor has been fixed on a support inside the cuvette. The support made of a high-strength organic glass has plates made of high-quality nickel between which the TGS crystal plate has been settled down. The TGS crystal plate was covered by silver electrodes. Inside the chamber at its top heating element "2" has been mounted on a ceramic basis (the power of the element was 5 Watts; the power supply delivered by a source of direct current TEC 13). The capacity of the TGS crystal plate was measured with device "3", which is a measuring instrument of impedance E7 – 15. The value of the measuring field was $U_{meas} = 2$ V, the frequency of the measuring field took on values of $f_{meas} = 100$ Hz and $f_{meas} = 1$ kHz. The Teslar watch has been settled down as shown in Figure 1. The rate of heating was equal to 0.9 ^{o}C/minute in all the experiments.

The distances between parts of the set-up shown in Figure 1 are the following: The distance from the cuvette "1" to the heating spiral "4" was 4 cm; the Teslar watch "2" was separated by 1 mm from the cuvette "1"; the nanovoltmeter "3" was separated by 30 cm from the cuvette "1".

Data obtained in the experiments of the kind (a) are shown in Figures 2 to 5.

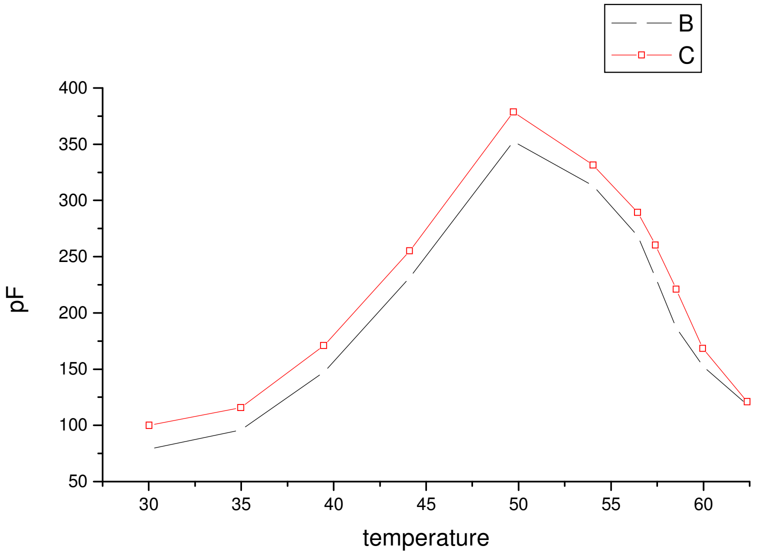

Figure 2. Temperature dependence of the capacity (in picoFarads) of the TGS crystal that is found in the external (measuring) electric field with the frequency $f_{meas} = 100$ Hz without the TC, but in the presence of its imitator (a conventional electric quartz watch was used as an imitator, which allowed us to exclude the influence of the metal case of the Teslar watch and its quartz generator on the distribution of the intensity of measuring field in the cuvette). The black curve represents the heating of the crystal; the red curve depicts cooling of the crystal. The temperature is measured in Celsius.

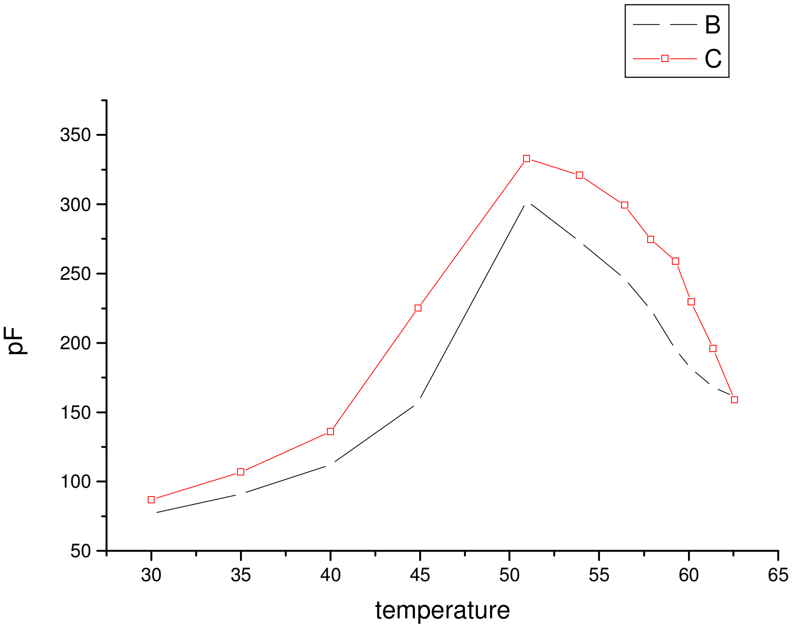

Figure 3. Temperature dependence of the capacity of the TGS crystal affected by the TC, which is found in the external (measuring) electric field with the frequency f_{meas} = 100 Hz. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

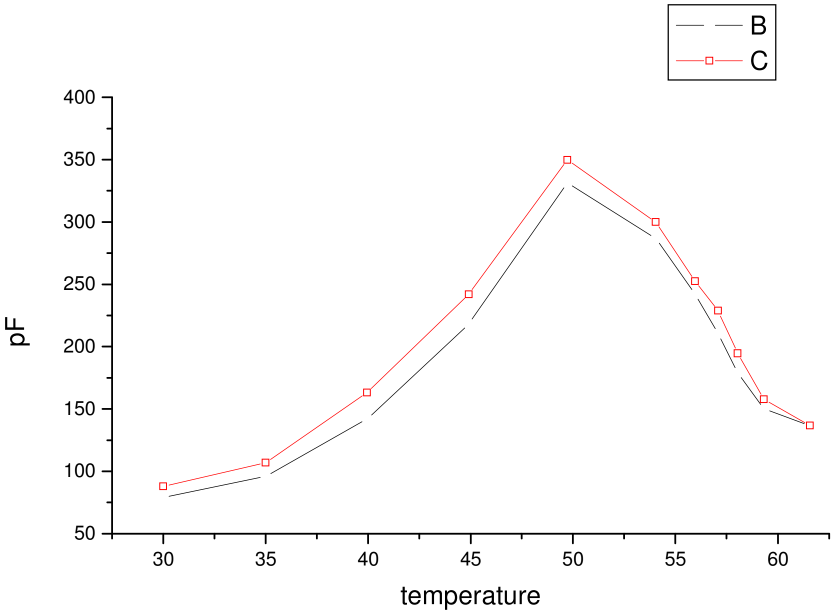

Figure 4. Temperature dependence of the capacity of the TGS crystal that is found in the external (measuring) electric field with the frequency f_{meas} = 1 kHz without the TC, but in the presence of its imitator. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

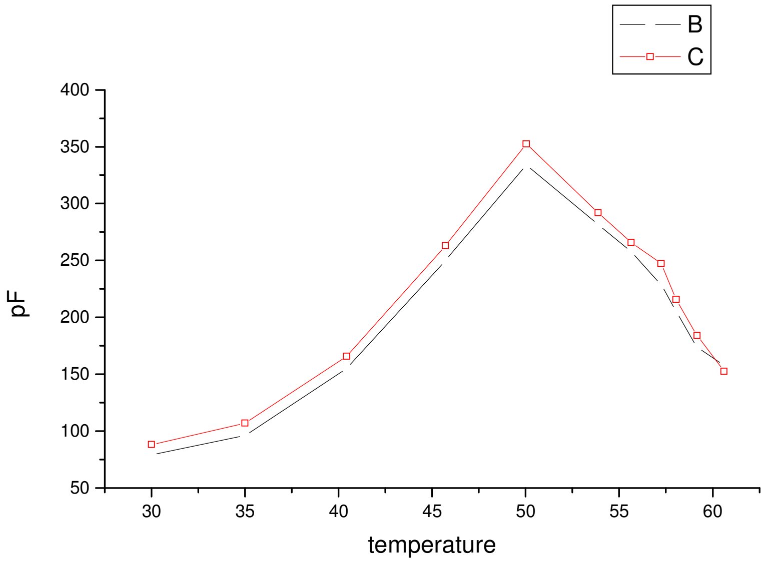

Figure 5. Temperature dependence of the capacity of the TGS crystal affected by the TC, which is found in the external (measuring) electric field with the frequency f_{meas} = 100 Hz. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

In the experiments of the kind (b) we used the set-up shown in the Figure 6.

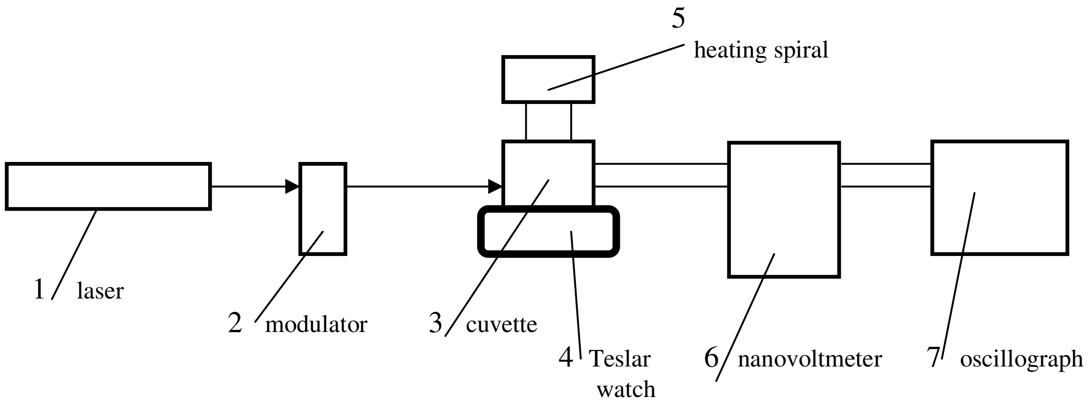

Figure 6. Scheme of the setup to measure the temperature dependence of the pyroelectric response in the mode of pyroelectric current of the TGS monocrystal in the range from room temperature to 65 °C.

The source of continuous radiation "1" was the gaseous He-Ne laser ЛГН-113 whose power parameters were controlled by the pyroelectric tester of power ПВЦ-2, developed in the Institute of Physics of the National Academy of Sciences of Ukraine. This device is certified in Ukraine and is able to measure power in the range 10^{-7} to 1 Watt in the wavelength spectral range $\lambda = 0.3$ to 15 microns. In the given experiments the laser power was P = 8 milliWatt. The flow of laser radiation was modulated by mechanical modulator "2", which enters the makeup of the power tester ПВЦ-2. The frequency of modulation was varied from 7 to 20 Hz.

The measuring cell "3" is a cuvette with sizes indicated above. The incident beam with the wavelength $\lambda = 0.632$ micrometers entered the cuvette through a special window.

The heating spiral "6" was located above the cuvette; the Teslar watch "4" was placed below the cuvette, as shown in Figure 6.

It should be particularly emphasized the significance of such kind of experimentation: It allows us to act upon the solution in question in the frequency range close to 7 to 9 Hz, which as presupposed is distinctive for the non-specific radiation of the TC.

A signal of the pyroelectric response in the mode of pyroelectric current was measured by the selective nano-voltmeter "5" of the 'Model 124A Lock-in Amplifier' class (manufactured by Princeton Applied Research) in a wide frequency range, 25 deciBell, and controlled by the oscillograph "7" of the 'Tektronix 2445A' class (manufactured by Tektronix Inc.). The rate of heating was equal to 0.9 ^{o}C /minute in all the experiments.

The distances between parts of the set-up shown in Figure 6 are the following. The distance from the exit window of laser "1" to the modulator "2" was about 30 cm; the cuvette "3" was separated from the modulator "2" by 50 cm; the Teslar watch "4" was separated by 1 mm from the cuvette "3"; the heating spiral was separated from the cuvette by 5 cm; the nanovoltmeter "6" was separated by 50 cm from the cuvette "3"; the oscillograph "7" was seperated from the nanovoltmeter "6" by 20 cm.

In the experiments we have investigated how the capacity of the solution varies with time both with TC influence and without TC influence.

Data obtained in the experiments of the kind (b) are shown in Figures 7 to 10.

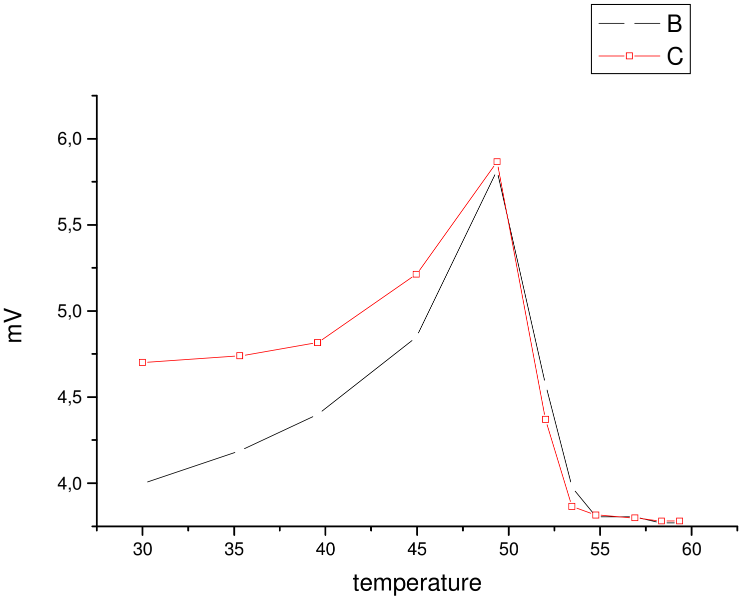

Figure 7. Temperature dependence of the signal of pyroelectric response (in milliVolts) of the TGS crystal measured at the modulating frequency $f_{mod} = 7.8$ Hz of the laser beam without the TC, but in the presence of its imitator. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

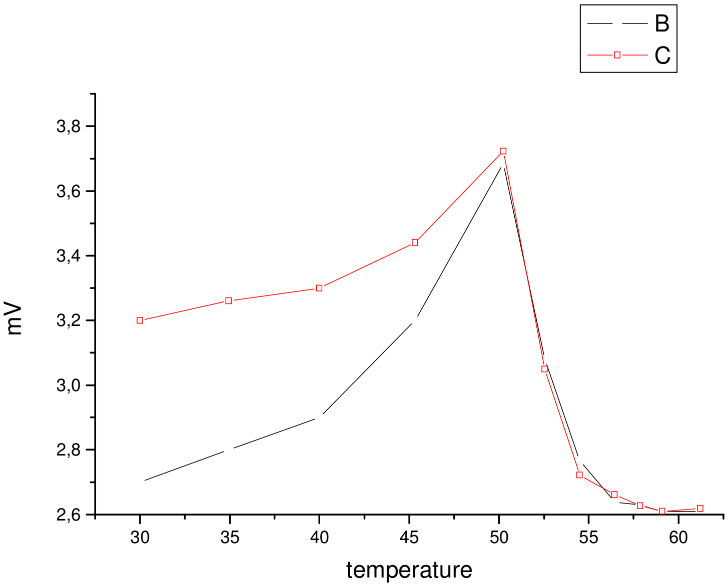

Figure 8. Temperature dependence of the signal of pyroelectric response of the TGS crystal affected by the TC, which is measured at the modulating frequency $f_{mod} = 7.8$ Hz of the laser beam. Black curve is heating, red curve is cooling. The temperature in Celsius.

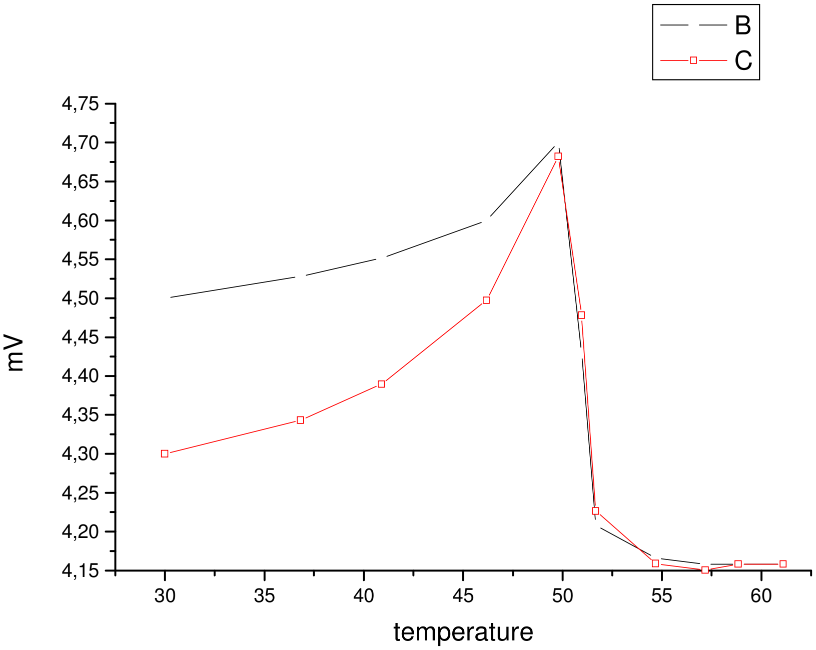

Figure 9. Temperature dependence of the signal of pyroelectric response of the TGS crystal measured at the modulating frequency $f_{mod} = 20$ Hz of the laser beam without the TC, but in the presence of its imitator. Black curve is heating, red curve is cooling. The temperature in Celsius.

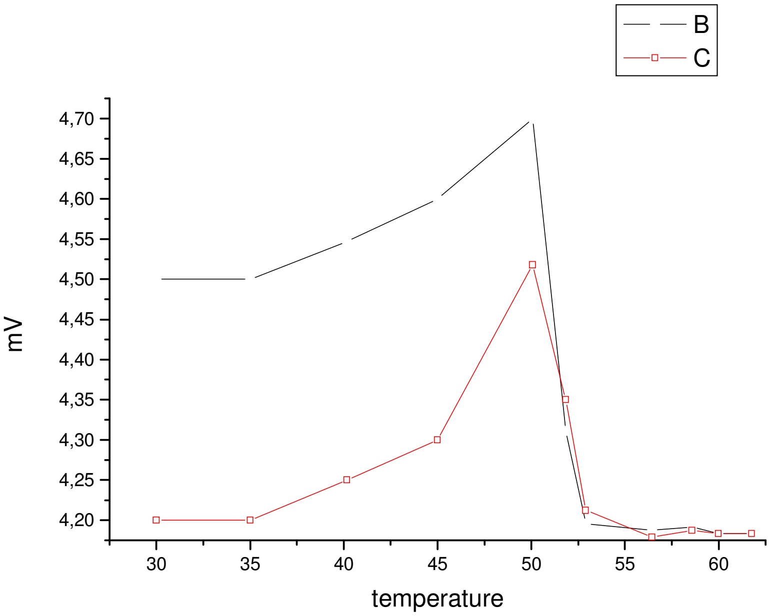

Figure 10. Temperature dependence of the signal of pyroelectric response of the TGS crystal affected by the TC, which is measured at the modulating frequency f_{mod} = 20 Hz of the laser beam. Black curve is heating, red curve is cooling. The temperature in Celsius.

The results obtained in this sequence of experiments point to the following:

- the temperature dependence of the capacity has shown a noticeable temperature hysteresis in the 'heating – cooling' process near the Curie temperature (the critical temperature that separates the ferroelectric phase, below 49^o C, and the paraphase, above 49^o C) at the frequency f_{meas} = 100 Hz of the measuring field; the phenomenon of hysteresis is feebly marked at f_{meas} = 1 kHz. When the TGS crystal is affected by the TC the temperature hysteresis is weakly observed in both cases, f_{meas} = 100 Hz and f_{meas} = 1 kHz;
- the insertion of the TC creates a noticeable difference in the temperature dependence of the processes of heating and cooling of the TGS crystal in comparison with the results measured without the TC. The TC radiation essentially inhibits temperature changes of the pyroelectric response of the TGS crystal. The effect of oppression of changes of the pyroelectric response is especially obvious at the heating of the ordered ferroelectric phase of TGS, i.e. from the room temperature up to the Curie temperature (49^o C). In sort, the influence of the TC leads to a less appreciable difference in the temperature hysteresis, i.e. the heating and cooling curves.

3. FURTHER EXPERIMETATION

At this stage of research we have studied the behavior of the capacity of the plate TGS under the condition of the influence of the TC and without the TC at the additional irradiation of the sample by a modulated laser radiation in a temperature range from room temperature up to 65 ^{o}C.

In these next experiments the setup represented in Figure 11 was used. The source of continuous radiation was gas laser ЛГН - 113 whose power parameters were inspected by the pyroelectric meter of power of laser radiation ПВЦ – 2, which measures power from 10^{-7} to 1 W and in a spectral range 0.3 to 15 microns (this instrument and the laser were used in the previous experiments). In the given experiments power of laser "1" made P = 8 mW.

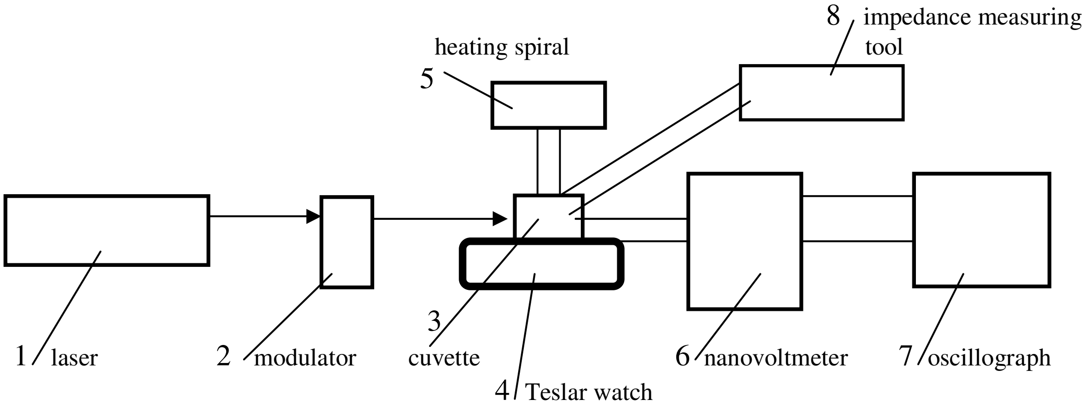

Figure 11. Scheme of the setup used to measure the temperature dependence of the capacity of the TGS crystal irradiated by a laser beam.

The laser beam was modulated by mechanical modulator "2", which is a part of the device ПВЦ-2. The modulation frequency f_{mod} was stable; three values of f_{mod} were chosen: 7.8, 10 and 15 Hz. The sense of these frequencies is to approach parameters of the probing modulated laser radiation to the hypothetical frequency of the TC, namely, 7.83 Hz [1, 2]. If in fact the TC radiates at the frequency 7.8 Hz, the resonance should be revealed at the simultaneous action of two fields: the TC's field and the thermal field generated at the absorption of laser radiation by the TGS crystal plate.

The experiments were carried out using measuring cuvette "3", representing a camera with sizes described in the previous experiments. The camera had a window for the laser beam, which was characterized by the wavelength λ = 0,632 microns. Inside the cuvette heat was supplied by means of the heating spiral "5", which operated on the basis of direct current (the device TEC 13).

The center focusing of laser beam incident on the TGS crystal plate was controlled by the value of signal of the pyroelectric response in the regime of pyroelectric current. A signal of the pyroelectric response in the mode of pyroelectric current was measured by selective nanovoltmeter "6" of the 'Model 124A Lock-in Amplifier' class (manufactured by the Princeton Applied Research) in a wide frequency range and controlled by oscillograph "7" of the 'Tektronix 2445A' class (manufactured by Tektronix Inc.).

A new element in the scheme presented in Figure 11 is device "8" , the impedance tester E7-15 (Ukraine). It is this device that was used to measure the capacity of the TGS crystal plate. The value of measuring field was equal to U_{meas} = 2 V and the frequency of measuring field, 1 kHz.

The experiments were performed in the temperature range from 20 to 65 ^{o}C; the rate of heating/cooling was equal to 1 ^{o}C/minute.

Distances between parts of the set-up were the same as in the previous section and in addition the impedance measuring tool "8" was seperated from the cuvette "3" by 60 cm.

Data obtained in the experiments are shown in Figures 12 to 17.

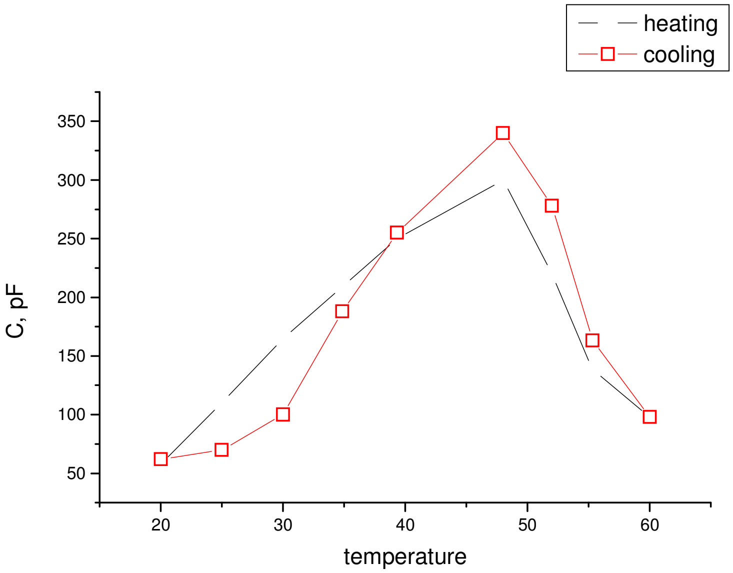

Figure 12. Temperature dependence of the capacity (in picoFarads) of the TGS crystal that is measured at the modulation frequency of laser beam f_{mod} = 10 Hz, without the TC, but in the presence of its imitator. The black curve represents the heating of the crystal; the red curve depicts cooling of the crystal. The temperature is measured in Celsius.

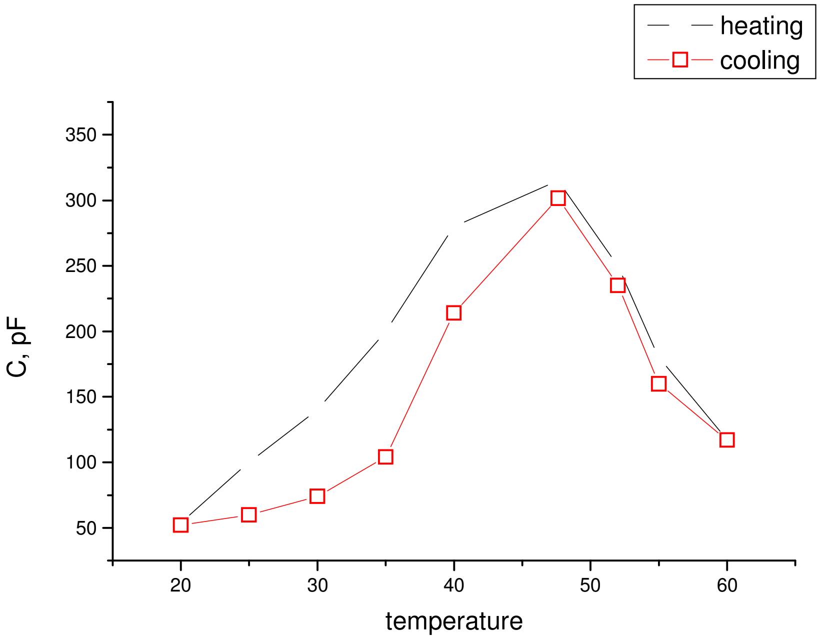

Figure 13. Temperature dependence of the capacity of the TGS crystal affected by the TC measured at the modulation frequency of laser beam f_{mod} = 10 Hz. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

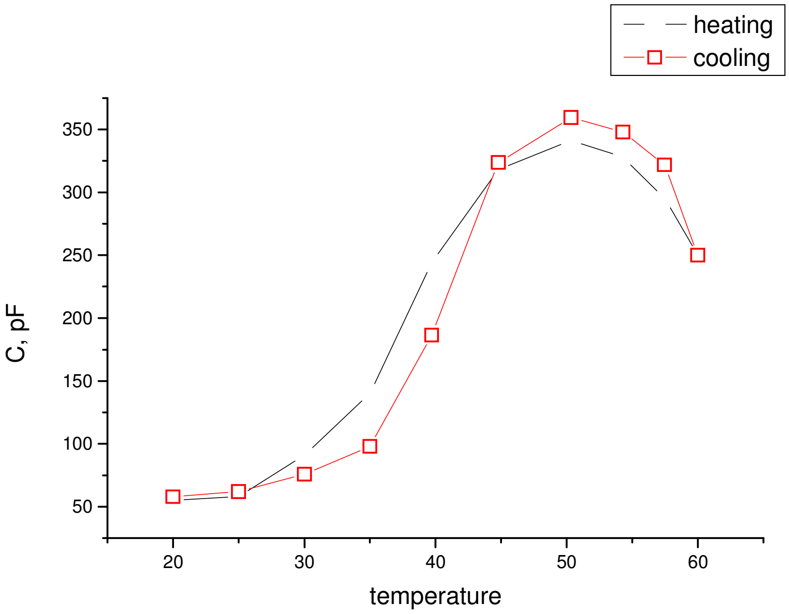

Figure 14. Temperature dependence of the capacity of the TGS crystal measured at the modulation frequency of laser beam f_{mod} = 7.8 Hz, without the TC, but in the presence of its imitator. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

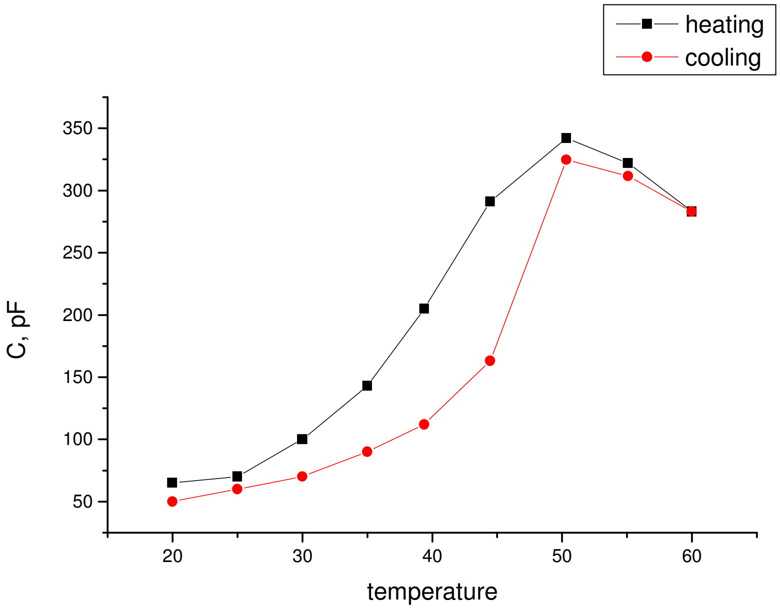

Figure 15. Temperature dependence of the capacity of the TGS crystal affected by the TC measured at the modulation frequency of laser beam f_{mod} = 7.8 Hz. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

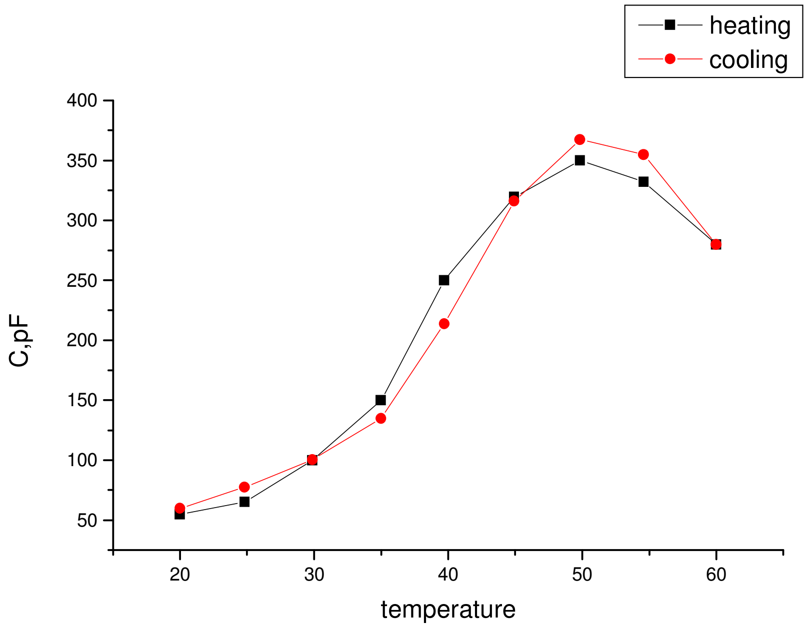

Figure 16. Temperature dependence of the capacity of the TGS crystal measured at the modulation frequency of laser beam f_{mod} = 15 Hz, without the TC, but in the presence of its imitator. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

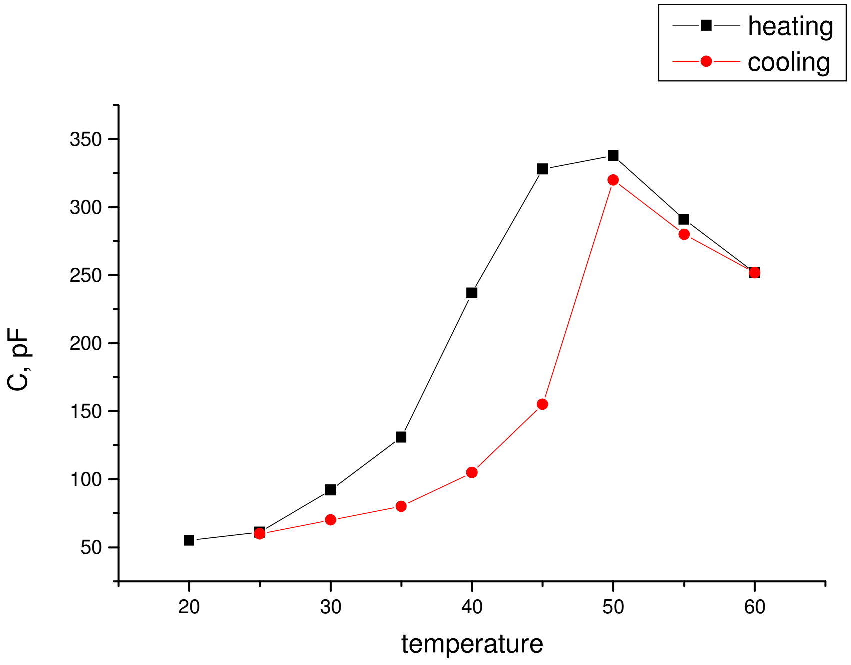

Figure 17. Temperature dependence of the capacity of the TGS crystal affected by the TC measured at the modulation frequency of laser beam f_{mod} = 15 Hz. Black curve is heating, red curve is cooling. The temperature is measured in Celsius.

The results obtained in this sequence of experiments lead to the following conclusions:

- in the case of an additional influence of thermal waves generated in the TGS crystal at the absorption of modulated laser radiation, the temperature dependence of the capacity has shown a temperature hysteresis at the transition from the ferrophase to the paraphase, i.e. in the course of the 'heating – cooling' process near the Curie temperature, 49° C. The hysteresis is observed both with and without the TC. However, when the TC affects the crystal, a noticeable reduction of the capacity C is observed, which is stipulated by the decrease in the permittivity ε in the regime of crystal cooling.
- the effect is caused by the influence of the TC on the vibratory dynamics of polar active ions of the TGS crystal lattice. The decrease of the capacity C manifests itself only in a long-run influence (several minutes) of the TC's field on phonons of the TGS crystal and does not appear in the beginning of the 'heating-cooling' process. The effect is unavailable far from the Curie temperature, namely in the range where the crystal lattice is less mobile.
- any anomaly in the behavior of temperature dependency of the capacity C of the crystal TGS affected by the TC has not been revealed with the variation of the incident laser radiation's modulation frequency.

4. THEORY

The effect of the influence of the TC field on parameters of the crystal TGS, which have been examined in the present project, can be accounted for on the basis of the following phenomenological model.

The dependency of the spontaneous polarization P as a function of the electric field E is defined from the minimum of the free energy F,

$$\left[F(P,\, E,\, T)-F_0(T)\right]_{V_c}=\tfrac{1}{2}a(T)P^2+\tfrac{1}{4}b(T)P^4+\tfrac{1}{6}d(T)P^6-PE \qquad (1)$$

where $F(P, E, T)$ is the free energy ascribed to one cell of the crystal lattice; V_c is the volume of a cell; a, b and d are coefficients of the phenomenological expansion of Ginzburg-Devonshire [3]. The minimum condition has the form

$$\frac{\partial F}{\partial P}=0\,, \qquad (2)$$

or

$$a+bP^3+dP^5=E\,. \qquad (3)$$

Expression (3) can be utilized for the description of low frequency dynamics of a ferroelectric crystal [3]. For this purpose in the case of the second kind of phase transition, which occurs in the ferroelectric crystal TGS (the order-disorder transition), when fields change slowly one can retain only two lower members in the expansion of P in terms of degrees of frequencies, i.e. degrees of the operator of the time derivative d/dt. This procedure results in the following equation of motion for the polarization P

$$\mu \frac{d^2P}{dt^2} + 2\mu\gamma \frac{dP}{dt} + aP + bP^3 = E\,. \tag{4}$$

Here phenomenological constants μ and γ respective have a sense of a mass coefficient and a decay coefficient for vibrations of the polarization *P*.

In the presence of the TC's scalar field the behavior of the decay constant is very specific. An analogy with the behavior of a mechanical system suggests itself: A mechanical system vibrating under the influence of two elastic forces that are equal in absolute value but have opposite directions is characterized by the doublet decay constant $2\gamma_0$ as compared with the action of only one force when the decay constant is γ_0.

The inclusion of the temperature dependency in the ferrophase of the spontaneous polarization P, which has the form [3]

$$P \propto (T_c - T)^{1/2} \tag{5}$$

and also the linear temperature dependency of the parameter *a*

$$a = a(T_c - T) \tag{6}$$

where T_c is the Curie temperature, allows us to modify Eq. (4) to the following approximate equation

$$\frac{d^2P}{dt^2} + 2\gamma \frac{dP}{dt} + \omega_0 P = E/\mu \tag{7}$$

where $\omega_0^2 = 2a(T_c - T)/\mu$ is the renormalized constant that determines the square of the frequency of oscillations of the spontaneous polarization caused by the influence of the TC's scalar field. The spontaneous polarization P_s is determined by expression (3) in the stationary state when the external electric field (the measuring field in our case) $E = 0$, i.e.

$$P_s = a(T_c - T)/b \tag{8}$$

The solution to heterogeneous differential equation (7) in which the right hand side is harmonic

$$E = E_0 \cos\omega t \tag{9}$$

we will seek in the form

$$P = P_0 \cos(\omega t + \varphi) \tag{10}$$

where P_0 and φ respective are the amplitude and the initial phase of constrained vibrations of the polarization.

Substituting expression (10) to Eq. (7), we get

$$P_0\left[\left(\omega_0^2-\omega^2\right)\cos\left(\omega t+\varphi\right)-2\gamma\omega\sin\left(\omega t+\varphi\right)\right]=\left(E_0/\mu\right)\cos\omega t, \tag{11}$$

or in the other form

$$\begin{aligned}&\cos\omega t\left\{P_0\left[\left(\omega_0^2-\omega^2\right)\cos\varphi-2\gamma\omega\right]\;-\;E_0/\mu\right\}\\&\quad+\;P_0\sin\omega t\left[\left(\omega_0^2-\omega^2\right)\sin\varphi-2\gamma\omega\cos\varphi\right]=0.\end{aligned} \tag{12}$$

This expression represents the sum of two harmonic terms

$$A\cos\omega t+B\sin\omega t \tag{13}$$

where A and B are time-independent functions. Expression (12) is equitable if the coefficients A and B at the harmonic functions are equal to zero [4], i.e.

$$P_0\left[\left(\omega_0^2-\omega^2\right)\cos\varphi-2\gamma\omega\right]\;=\;E_0/\mu, \tag{14}$$

$$\left[\left(\omega_0^2-\omega^2\right)\sin\varphi-2\gamma\omega\cos\varphi\right]=0. \tag{15}$$

Expression (15) allows one to determine the phase

$$\varphi=\arctan\left[\frac{2\gamma\omega}{\omega_0^2-\omega^2}\right]. \tag{16}$$

Then expression (14) enables one to obtain the amplitude of oscillations of the polarization

$$P_0=\frac{E_0}{\mu}\frac{1}{\sqrt{\left(\omega_0^2-\omega^2\right)^2+4\gamma^2\omega^2}}. \tag{17}$$

It should be noted that in the case of ferroelectrics that are characterized by the order-disorder phase transition, such as the TGS crystal, the following conditions are held

$$\omega<<\omega_0 \tag{18}$$

and

$$\gamma>>\omega_0. \tag{19}$$

In ferroelectrics typical frequencies of soft modes of optical phonons $\omega_0\sim10^{10}$ to 10^{11} s^{-1}, i,e. ω_0 significantly exceed measuring frequencies ω that in our experiments have been equal to $2\pi\times100$ and $2\pi\times1000$ s^{-1}. Thus in our experiments inequality (18) strongly held.

Inequality (19) means that the decay of the amplitude of polarization P heavily decreases and therefore the response of the crystal to the external electric field E severely diminishes.

By this means expression (17) becomes

$$P_0 = \frac{E_0}{\mu} \frac{1}{\sqrt{\omega_0^4 + 4\gamma^2 \omega^2}} . \tag{20}$$

This expression qualitatively describes the behavior of the polarization of the crystal affected by the TC, namely, the corresponding information is contained in the introduction of the parameter γ that is able strongly to suppress the value of spontaneous polarization P_0 of the crystal.

4. DISCUSSIONS AND CONCLUSION

Thus the theory allows us to describe the influence of the TC on the TGS crystal in terms of a phenomenological scalar field. The shifting of temperature dependency of the permittivity and pyroelectric potential indicates that the crystal response to an external influence (the electric field at the dielectric measurements and thermal waves at the pyroelectric measurements) is suppressed in the case when the TC affects the crystal. As it follows from expression (20), the availability of the parameter γ results in a "freezing" of the polarization *P*, i.e., the response of the crystal becomes smaller due to the fact that $\gamma \neq 0$.

We did not record any resonance effects in the pyroelectric experiments near the frequency of about 8 Hz. Expression (20) also does not show any anomaly of the polarization *P* in the vicinity of this frequency. The response of the liquid system affected by the TC to thermal waves generated in the system by the mechanical modulator, which was studied in our previous sub-project [2], was associated with a peculiar proper dynamics of the liquid system, namely, the availability of reductive-oxidative reactions in aqueous solutions. Such kinds of reactions are not typical for crystals and therefore a pyroelectric crystal cannot show any anomaly in a low frequency range.

A more detailed theory of the phenomenon of suppression of the response of the TGS crystal affected by the Teslar technology requires rather a submicroscopic theory similar to that that has been developed in Ref. [2].

References

[1] B. Reeves, *Electromagnetic Fields: The Problem and the Solution.* Teslar Inside Corporation, 2003.

[2] V. Krasnoholovets, S. Skliarenko and O. Strokach, *The study of the influence of physical fields of Teslar® technology on liquids in a critical range*, Final report written for the Teslar Inside Corporation.

[3] V. G. Vaks, *Introduction to the microscopic theory of ferroelectrics* (Nauka, Moscow, 1973); in Russian.

[4] C. E. Khaikin, *Physical principles of mechanics* (Fiziko Matematicheskoe Izdastelstvo, Moscow, 1963); in Russian.