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APPLICATION OF THERMOELECTRIC OSCILLATIONS IN A LITHIUM NIOBATE SINGLE CRYSTAL FOR PARTICLE GENERATION

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Abstract

Thermoelectric oscillations in lithium niobate single crystals include oscillations of temperature and pyroelectric current. The possibility of generating electrons and positive ions in vacuum conditions is shown. The results of the first experiments are presented. The possibilities and development prospects of the particle generation method are discussed.

INTRODUCTION

The absence of a centre of symmetry in certain materials, as lithium tantalate or lithium niobate, leads to the appearance of a constant dipole moment of each crystal cell [1]. In thermal equilibrium, an induced surface charge is completely screened. Presence of surface charge can be registered at changing of temperature of pyroelectric sample. It is called a pyroelectric effect. In standard atmosphere conditions this charge is screened very quickly, but in vacuum surroundings screening time can be about a few months.

This fact favours to collection of surface charge, which is enough to generate high electric field with strength of about 10^5 V/cm [2]. It is high enough to eject particles from the surface of the crystal and ionize residual gas molecules. Thus, electrons and positive ions can be generated and accelerated due to the pyroelectric effect [3-6].

In this paper, a method for generating electrons and positive ions based on thermoelectric oscillations at pyroelectric effect is presented and discussed. The frequency dependences of the amplitudes of the generated pyroelectric current and the current of the generated particles are also presented.

THERMOELECTRIC OSCILLATIONS

The generated pyroelectric current can be expressed as

$$i_{pyr} = pA\frac{dT}{dt} \qquad (1)$$

where p is the pyroelectric coefficient, A is the area of polar surface, $\frac{dT}{dt}$ is the time derivative of the temperature. If the temperature changes as

$$T(t) = T_0 + T_1 \sin \omega t \qquad (2)$$

where T_0 is an initial temperature of sample, ω is the frequency of oscillations, T_1 is an amplitude of temperature oscillation. In this case, the generated current could be rewritten in following form

$$i_{pyr} = pAT_1 \cos \omega t \qquad (3)$$

Such mode of current generation implies that there are oscillations of current on the polar surface induced by oscillation of the temperature. In vacuum condition the oscillating current is accumulated on the polar surface of pyroelectric sample. It leads to the oscillations of the amount of charge, and hence oscillations of the strength of the electric field. Thus, a stable mode of periodic generation of electric field can be achieved. Such conditions should provide stable generation of electrons or positive ions at each half-wave, which was previously unattainable for pyroelectric particle sources.

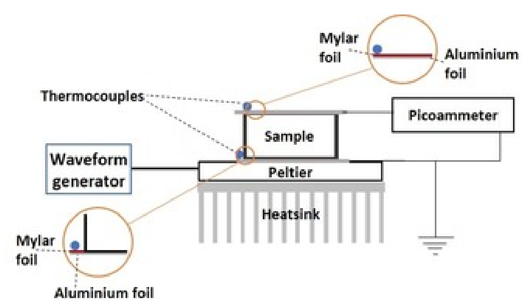

Figure 1: The scheme of experimental setup.

Analysis of literature shows that such oscillations in the bulk samples of lithium niobate are not investigated yet at all. The theory of sinusoidal temperature waves in the ferroelectrics as a way of determining pyroelectric coefficient of the sample, and also as a way of separation of the contribution of pyroelectric current from other currents stimulated by temperature, is being consistently developed in Garn and Sharp's works [7]. An experimental investigation of thermoelectric oscillations in a 50 µm thick LN sample shows that only pyroelectric current observed without any other contributions [8]. Due to the sinusoidal temperature change, it is possible to precisely determine the sample's pyroelectric coefficient [9] and its distribution [10] along

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the polar axis. However, no information was found on the study of thermoelectric properties in bulk samples of lithium niobate.

MEASUREMENT OF PYROELECTRIC CURRENT IN OSCILLATION MODE

The experimental setup is schematically presented in Figure 1.

The pyroelectric sample of lithium niobate (manufacturer is the Kola Science Center, Russia), the Peltier element and the heatsink were attached together in a single assembly using conductive epoxy glue. Polar surfaces of the pyroelectric crystal were covered by metallic foil for current measurements. Both thermocouples were placed on the mylar foil near the pyroelectric sample. The mylar foil is necessary to exclude the noise from temperature measurement circuit. On the other hand, the foil thickness was very small to make any significant changes in the temperature distribution.

The dimensions the pyroelectric sample are 20×20×10 mm. An arbitrary waveform generator TGA12104 was used for supply Peltier element by sinusoidal power wave with amplitude I_{RMS} = 0.2 A, V_{RMS} = 10 V. The frequency range was varied from 2 to 50 mHz. The temperature of a pyroelectric sample was measured from two different positions, as seen in Fig 1, using thermocouples and a thermocontroller ATEC302. Generated pyroelectric current was measured using a picoammeter Keithley 6485.

Typical picture current oscillations and temperature oscillations from top surface of pyroelectric sample at frequency of 14 mHz is shown on Figure 2.

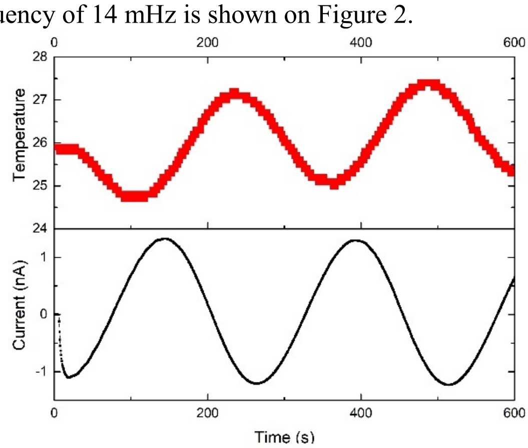

Figure 2: Typical picture of observed oscillations of current and temperature from top surface of pyroelectric sample at frequency 14 mHz.

The observed oscillations are stable, but immediately fade out after stopping the powering wave. The observed oscillations have the same frequency as the initial oscillations of power wave. Of particular interest there is the dependence of the amplitude of the oscillations on the frequency. The dependence of peak-to-peak amplitude of temperature oscillations on the frequency is shown in Figure 3. The temperature oscillation amplitude decreases with increasing the frequency. This fact is explained quite simply,

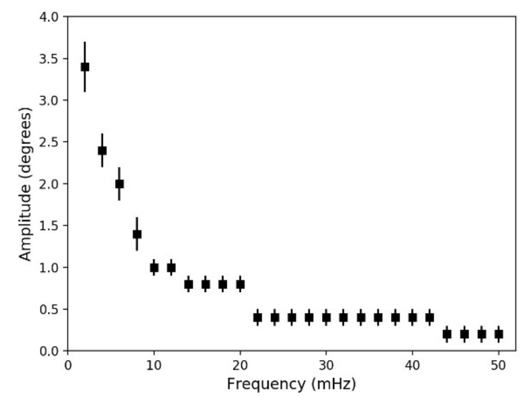

Figure 3: The dependence of peak-to-peak amplitude of temperature oscillations on the frequency.

so that with increasing the frequency, the amount of heat transferred to the pyroelectric sample decreases.

The dependence of amplitude of current oscillations on the frequency is shown in Figure 4. The behaviour of the current amplitude is very different from the temperature amplitude. It can be seen that the amplitude monotonically rises with the frequency until 10 mHz.. After that, amplitude decreases with the frequency rise. The presence of some optimal range of frequency with maximal current oscillation amplitude is clearly shown. At higher frequency, amplitude decreases because of the amount of heat transferred to the pyroelectric sample is reduced, at low frequency thermal wave inside sample has time to relax and attenuate.

From the point of view of generation of a high electric field, the presence of an optimum frequency suggests that the generation of electrons and ions in this frequency range should be especially productive. The next stage of the work was the study of particle generation during thermoelectric oscillations in lithium niobate sample.

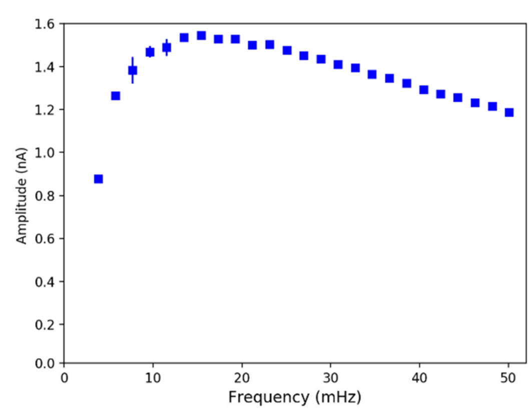

Figure 4: The dependence of amplitude of current oscillations on the frequency.

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MEASUREMENT OF CURRENT OF GENERATED PARTICLES UNDER OSCILLATION MODE IN VACUUM

The experimental setup for recording the current is shown in Figure 5. The experiments used the same sample of lithium niobate as in the previous section. To register the current of generated particles, a target, an iron foil, was used. The foil had a thickness of 100 μm and a size of 50×50 mm2. This made it possible to collect the whole particle flux generated near the pyroelectric. The current of particles collected on the target was measured using a picoammeter Keithley 6485. The generation of the power wave was also carried out using the arbitrary waveform generator TGA 12104, with the following parameters: IRMS = 1.35 A, VRMS = 2 V. The frequency range was varied from 1 to 14 mHz. The residual gas pressure was maintained in the range from 0.5–1.3 mTorr during the experiment. The temperature of pyroelectric was recorded using a FLIR E30 infrared camera focused on the side surface of the pyroelectric sample.

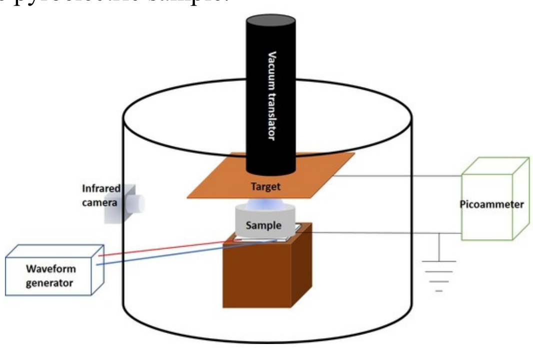

Figure 5: The scheme of experimental setup.

Typical picture of observed oscillations of particle current and temperature from top surface of pyroelectric sample at frequency 8 mHz is shown in Figure 6. There is a positive half-wave (generated positive ions) and a negative half-wave (generated electrons). Both half-waves have approximately the same amplitude and duration.

It should be noted that the generation of particles in a vacuum begins almost immediately after the initiation of a power wave, since the thresholds for ferroelectric electron emission and ionization of molecules are quite small [11,12]. Nevertheless, particle acceleration does not occur immediately, but when a certain electric field is reached, but the issue of the energy of the generated flow is not discussed in this paper.

The dependences of the peak-to-peak amplitude of temperature (for the top surface of the pyroelectric) and the oscillation amplitudes for the current of generated particles as a function of frequency are shown in Figure 7 and Figure 8.

The peak-to-peak amplitude of temperature oscillation monotonically decreases with arising of frequency, as it has been established in the previous section. The dependence for the current of the generated particles shows some optimum in the region of 6 - 8 mHz and at 12 mHz. It is the question how the optimal frequencies are correlated for generating the pyroelectric current and the particles current generated by the pyroelectric effect. However, the fact of a nonmonotonic dependence of the current of particles generated by the pyroelectric effect on frequency during thermoelectric oscillations is very curious and has not been detected before.

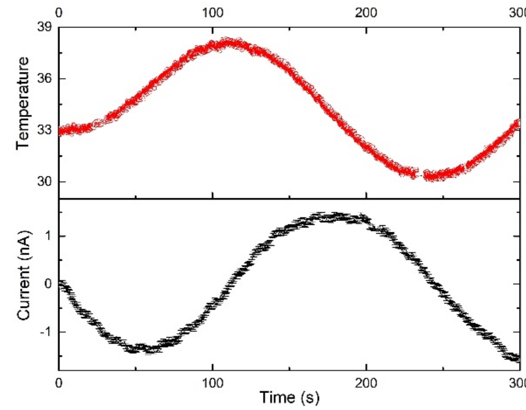

Figure 6: Typical picture of observed oscillations of particle current and temperature from top surface of pyroelectric sample at frequency 8 mHz.

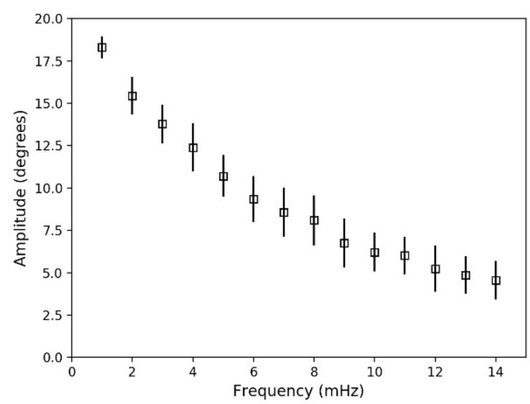

Figure 7: The dependence of peak-to-peak amplitude of temperature oscillations on the top surface of pyroelectric on the frequency.

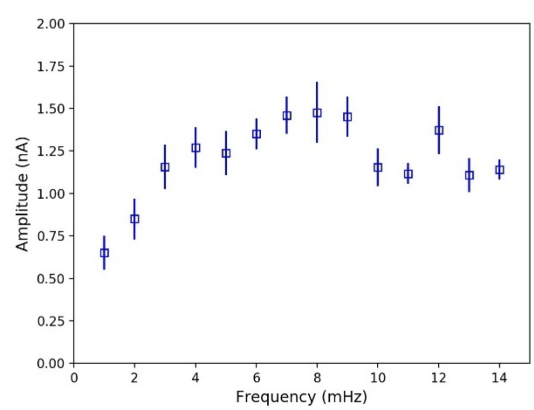

Figure 8: The dependence of amplitude of particle current oscillations on the frequency.

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CONCLUSION

The fundamental possibility of generating a flow of electrons and positive ions during thermoelectric oscillations in a lithium niobate single crystal was shown. The frequency dependence of the oscillations of the pyroelectric current and the flow of generated particles is investigated. It has been established that there is a frequency range in which particle generation has the largest amplitude.

The results require interpretation and deeper understanding. It is necessary to establish the energy of particles in the generated flow and also to determine a correlation between the oscillations of the pyroelectric current and oscillations of the flow of generated particles. Nevertheless, the obtained facts are very promising for the development of alternative energy-efficient tuneable particle sources.

REFERENCES

[1] K. K Wong, "Properties of lithium niobate", London: INSPEC [Orig.-Prod.], 2002.

[2] B. Rosenblum, *et. al.*, "Thermally Stimulated Field Emission from Pyroelectric $LiNbO_3$", *Appl. Phys. Lett.*, 1974, pp. 17 -22.
doi:10.1063/1.1655260

[3] J. D. Brownridge, *et. al.*, "Observation of multiple nearly monoenergetic electron production by pyroelectric crystals in ambient gas." *Appl. Phys. Lett.*, 2001, pp. 1158-1159.
doi: 10.1063/1.1342209

[4] J. D. Brownridge and S. M. Shafroth, "Electron beam production by pyroelectric crystals", in *Proc. Int. Conf. on High-Power Electron Beam Tech. [EBEAM 2002],* Hilton Head, SC, October 27 – 29, 2002, pp 30-34.

[5] J. A. Geuther and Y. Danon, "Electron and positive ion acceleration with pyroelectric crystals", *J. Appl. Phys.*, 2005, pp. 074109 – 074115.
doi: 10.1063/1.1884252

[6] V.I. Nagaichenko, *et. al.*, "Electron energy increase in the pyroelectric accelerator", *Prob. of At. Sci. and Tech.*, 2008. pp.72-76.

[7] L.E. Garn and E.J Sharp. "Use of low-frequency sinusoidal temperature waves to separate pyroelectric currents from nonpyroelectric currents. Part I. Theory", *J. App. Phys.*, 1982, pp. 8974-8980.
doi:10.1063/1.330454

[8] L.E. Garn and E.J Sharp. "Use of low-frequency sinusoidal temperature waves to separate pyroelectric currents from nonpyroelectric currents. Part I. Experiment", *J. App. Phys.*, 1982, pp. 8980-8988.
doi:10.1063/1.330455

[9] H. Khanbareh *et. al.,* "A temperature oscillation instrument to determine pyroelectric properties of materials at low frequencies: Towards elimination of lock-in methods", *Rev. Sci. Instrum.*, 2015, pp. 105111 – 105118.
doi:10.1063/1.4932678

[10] G. Gerlach *et. al.,* "Non-destructive testing of ferroelectrics by thermal wave methods", Proc. *of SPIE*, 2007, pp. 65300-65308.

[11] G. Rosenman *et. al.,* "Electron emission from ferroelectrics ", *J. Appl. Phys*., 2000, pp. 6109-6163.
doi: 10.1063/1.1319378

[12] E. L. Murphy and R. H. Good, "Thermionic emission, field emission, and the transition region" *Phys. Rev.,* 1956, pp. 1464-1473.
doi:/10.1103/PhysRev.102.1464