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THERMOELECTRIC PROPERTIES OF ASYMMETRICAL SANDWICH STRUCTURE METAL-LITHIUM NIOBATE-METAL

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Based on the model with internal EMF source the approximation of experimental dependences of thermostimulated EDS in doped crystal of lithium niobate with a pair of electrodes of different metals from crystal sizes, its temperature, dopant concentration has been carried out. Use of structure metal- lithium niobate-metal as a sensitive element of thermal radiation detector was shown.

In paper [1] the observation of thermostimulated EMF in a doped crystal of lithium niobate with two electrodes from different materials representing a sandwich structure of metal-ferroelectric-metal (MFM) is described. EMF sign is determined by position of electrodes coated in vacuum on crystal opposite faces and does not depend on orientation of sample crystallographic axes relative to electrodes. In comparison with classical pyroelectric effect thermostimulated EMF is proportional to the temperature of homogeneous heated crystal and does not depend on the rate of its change. The value of thermostimulated EMF has pronounced dependence on sample doping level, increases at decrease of crystal thickness and depends nonlinearly on electrode area [1]. Known thermoelectric phenomena (including dynamic pyroeffect in asymmetrical MFM-structure [2]) do not explain the obtained experimental results.

To describe the discovered phenomenon in [1] the model of asymmetrical MFM-structure with internal source of EMF (for example, of electrochemical origin) was proposed. The aim of this work is to approximate within this model the experimental dependences described in [1, 3].

In this model MFM-structure is considered as a source of EMF with internal resistance equal to crystal resistance. In this case thermostimulated EMF dependence on temperature is determined by temperature dependence of semiconductor crystal resistance R_{kp}.

Coefficient $P_{el}=(R_nS)^{-1}\partial U_n/\partial T$, [A·K^{-1}·sm^{-2}], was measured experimentally, where U_n is the loading voltage, T is the crystal temperature, R_n is the loading resistance, S is the crystal electrode area. We have from Ohm law:

$$U_n = E_0 R_n (R_k + R_n)^{-1}, \quad (1)$$

where E_0 is the EMF of internal source, R_k is the crystal resistance. Hence, we obtain for coefficient P_{el}:

$$P_{el} = E_0 L \rho' (R_n S + \rho L)^{-2}, \quad (2)$$

where ρ is the crystal resistivity, L is the crystal thickness, ρ' is the temperature derivative of crystal resistivity, $R_k=\rho LS^{-1}$.

Temperature dependence of resistivity of lithium niobate crystals iron-doped with concentration more than 0,3 wt. % (for which the main experimental results were obtained in [1, 3]) is described by Mott law [4, 5]:

$$\rho = \rho_0 \exp(T_0^{0,25} T^{-0,25}), \quad (3)$$

where ρ_0, T_0 are the empirical constants depending on dopant concentration [4]. We obtain from (3):

$$\rho' = -\rho T_0^{0,25} T^{-1,25}, \quad (4)$$

Finally we have for loading current and coefficient P_{el} from (1–4):

$$I = E_0 R_n (R_n + \rho_0 L S^{-1} \exp(T_0^{0,25} T^{-0,25}))^{-1}, \quad (5)$$

$$P_{el} = E_0 L \rho \cdot T_0^{0,25} T^{-1,25} (R_n S + \rho_0 \exp(T_0^{0,25} \cdot T^{-0,25}) L)^{-2}, \quad (6)$$

Comparison of the obtained analytical dependences with experimental ones allows checking the proposed model adequacy.

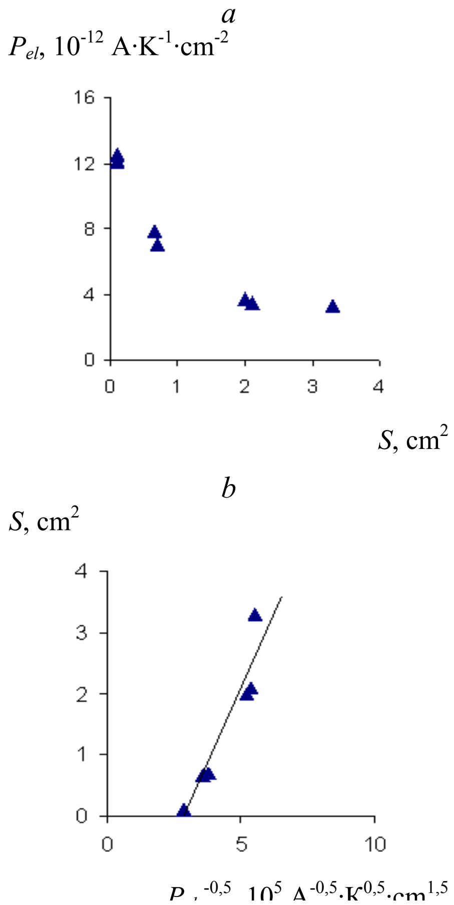

Fig. 1. *Experimental dependence of: a) coefficient P_{el} on electrode area S (L=1 mm; 0,3 wt. % Fe; electrodes Al-Cr) [1] and b) linear approximation according to the formula (7)*

To analyze the model the linear approximation of experimental dependences of value P_{el} on geometry and temperature of a crystal, dopant concentration was used.

Let us consider the dependence of P_{el} on area of electrodes coated on crystal opposite faces, Fig. 1. Reducing (2) to linear function we obtain:

$$S = P_{el}^{-0,5}(E_0\rho' L)^{0,5}R_n^{-1} - \rho_k L R_n^{-1}, \qquad (7)$$

Experimental data (Fig. 1, *a*) in linearized coordinates according to the formula (7) are shown in Fig. 1, *b*. A straight line corresponds to numerical approximation of the expression (7) by the least-square technique.

Similarly, linearizing dependence P_{el} on crystal thickness (Fig. 2, *a*), we obtain:

$$L = L^{0,5}P_{el}^{-0,5}(E_0\rho_k')^{0,5}\rho_k^{-1} - R_n S\rho_k^{-1}, \qquad (8)$$

The diagram corresponding to (8) is given in Fig. 2, *b*.

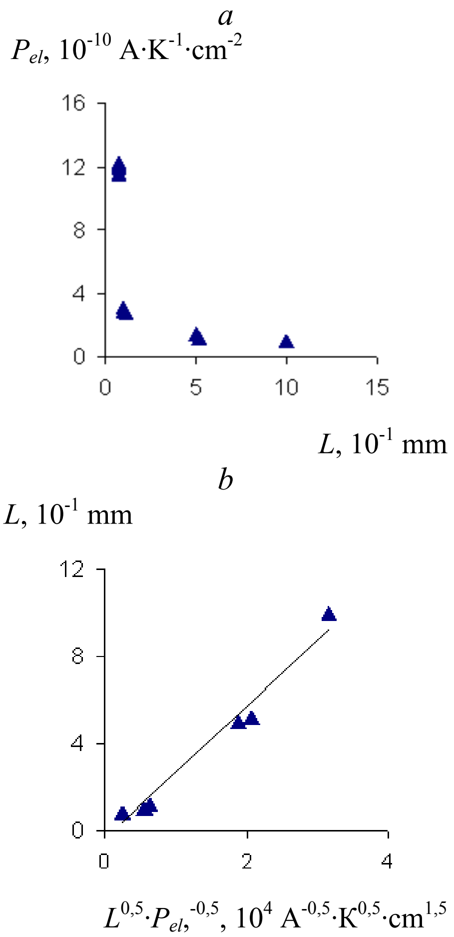

Fig. 2. *Experimental dependence of: a) coefficient P_{el} on thickness L of a crystal (S =5 mm²; 0,3 wt. % Fe; electrodes Al-Cr) [1] and b) linear approximation according to the formula (8)*

Experimental dependence of thermostimulated current density on crystal temperature is given in Fig. 3, *a*. This dependence may be also approximated by linearized function obtained from the formula (5):

$$T^{0,25} = -T_0^{0,25}\ln J + T_0^{0,25}\ln(E_0 R_n S^{-1}), \qquad (9)$$

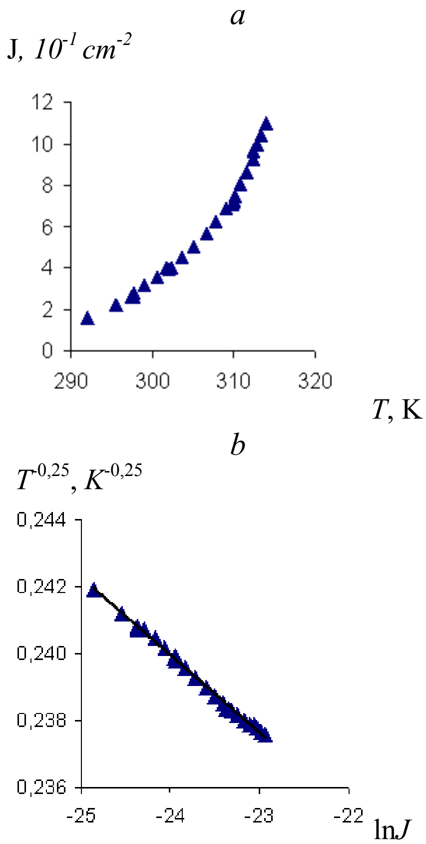

Fig. 3. *Experimental dependence of: a) current density on crystal temperature ($LiNbO_3$:Fe – 0,43 wt. %, 10×5×1 mm³, Y-cut; Al-Cr) [3] and b) its linear approximation according to the formula (9)*

Concentration dependence of coefficient P_{el} (Fig. 4, *a*) may be conditioned as well by the dependence of ρ' and ρ on dopant percentage. Linear approximation of this dependence is shown in Fig. 4, *b*, values ρ' and ρ are taken from the work [4].

It is seen from Fig. 1–4 that experimental dependences are rather close to linear ones that supports the examined model. The value of resistivity determined from Fig. 1–3, amounts to $7\cdot10^9$ and 10^{10} Ohm·cm respectively that is close by order of magnitude to the values obtained in works [4, 5]. Magnitude E_0 average value of which is 1,2±0,5 mV may be obtained from the same diagrams.

The upper deviations of calculated and experimental data are observed in the region of small thickness of MFM-structure that may be connected with contact phenomena influence and requires more detailed examination.

The described effect may be used for recording electromagnetic emission in wide spectral range. Iron-doped crystal $LiNbO_3$:Fe (2×2,5×0,13 mm³; 0,3 wt. % Fe, Y-cut) on opposite faces of which a pair of electrodes aluminum-cromium (Al-Cr) was coated in vacuum was used in detector pilot sample. Absorbing electrode (Al) was shaded for excluding the influence of photogalvanic effect. Incident radiation heats the crystal that results in increasing quasisteady current to loading resistance owing to increasing crystal electroconductivity. Experimentally

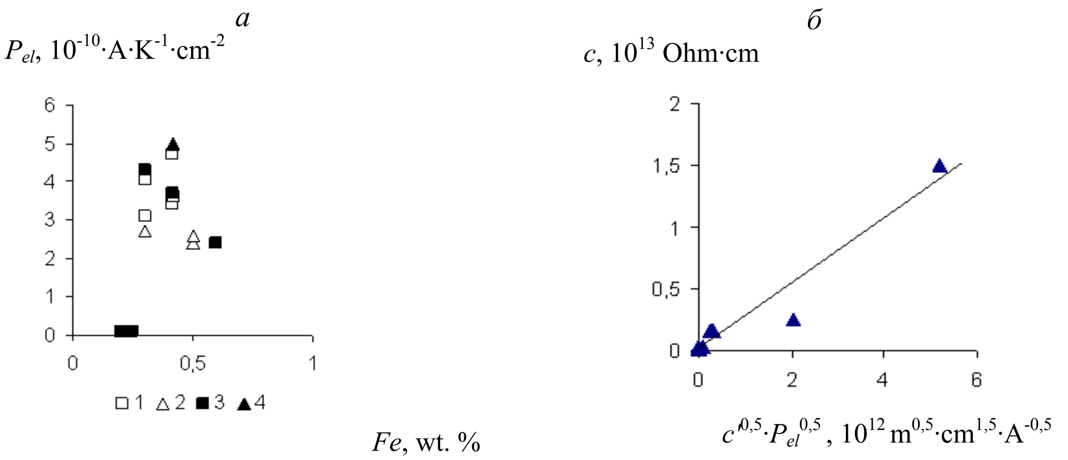

Fig. 4. *Experimental dependence of: a) coefficient P_{el}, on concentration of iron impurity in lithium niobate crystal for different cuts and materials of contacts (1 – Al-Cr, Z-cut; 2 – In-Cr, Z-cut; 3 – Al-Cr, Y-cut; 4 – In-Cr, Y-cut) [1] and б) its linear approximation[5] by the formula (6)*

measured volt-watt sensitivity of this detector ($H=\Delta U/P$, where: ΔU is the change of voltage by loading resistance, P is the incident radiation power) on modulation frequency 1 Hz amounts to 6 V/W (at gain coefficient of electron preamplifier K_y=20) and with error not more than 20 % is uniform in spectral range 0,4...1,5 mkm. Detectability of detector amounts to value $8\cdot10^4$ cm·Hz$^{1/2}$W. Detector, in comparison with traditional pyroelectric detectors of radiation [7] possesses higher sensitivity on subsonic frequencies of radiation modulation.

Use of more efficient blackening of radiation absorbing electrode, crystal geometry optimization (its thickness decrease [1]) allow increasing more than order the detector detectability up to 10^6 cm·Hz$^{1/2}$·W that is comparable with characteristics of widely spread thermal radiation detectors.

Thus, the carried out comparison of experimental data and numerical calculations on the basis of the examined model shows quite good qualitative and quantitative fit. The obtained data may be used for determining nature of EMF occurrence in MFM-structure. The preliminary experimental results showed that temperature dependent EMF in MFM-structure may be used for recording electromagnetic radiation in wide spectral range.

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