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**THERMOMETRIC NOISE AND
PERFORMANCE OF THERMOELECTRIC
THERMOMETERS**

Opportunities of thermoelectric thermometry are considered for the purpose of nanotechnology. Linear dimensions of thermometers have to be commensurable with those of the measured objects. The specific group of phenomena seems to become valid in nanopatterns due to the growing role of surface energy and its gradient. It changes the intensity of thermometric noise and forms the basis for sensor performance and their influence factors that affect measurement precision.

Key words: thermoelectric thermometer, nanotechnology, thermometric performance.

Introduction

Intensive development of microelectronics and nanotechnology involves significant improvement of the energy efficiency of chips which is impossible, first, without further progress in the field of thermoelectric conversion of scattered electrical power; second, without in-situ measuring the temperature of these very chips with the help of embedded sensors. The simplest of them are the thermoelectric sensors. Clearly, the size of the latter must comply with the size of measured objects, for instance wrap-around gate CNTFETs (CNT length ~ 100 nm and diameter ~ 20 nm) [1].

These measuring instruments of thermoelectric genesis are quite new and their operation in the size limits of nanoelectronics creates a series of problems, the most important of which are: a) the necessity to study the extent to which the concept of "temperature" can be described by common physical, thermodynamic and electrodynamic approaches [2]; b) further development at the nanoscale of thermoelectricity fundamentals and particularly the approach of eddy thermoelectric currents [3]; c) creating a new class of thermoelectric substances with nano distributed spatial heterogeneity [4]; d) establishment of standards of physical units based on the fundamental constants of matter [5]; e) update of thermodynamics towards consideration of surface tension forces and others that has led to the advent of nanothermodynamics [6].

1. Objective of the work

The objective of this work is studying the basic principles of high-precision thermoelectric thermometers development for nanotechnology purposes on the basis of researching influence factors caused by fluctuation-dissipation phenomena in thermometric substance that manifest thermometric noise (in the form of eddy thermoelectric currents).

2. Researches in thermoelectric thermometry: theory and experiment

We have proved the applicability of statistical-thermodynamic approach to the problem of thermo-EMF stability. A new thermodynamic force in the form of mechanical stress gradient $\nabla\sigma$ was considered in [7]. Then involvement of statistical thermodynamics of nonequilibrium processes shows the advisability of a

unifying approach in studying the influence functions caused by the complex processes of heat, charge, etc. transfer on the characteristics of thermometric substances of thermoelectric thermometers acting as numerous technological and operational factors, such as perturbation factors. For a prolonged use the thermometric substance is transferred to the thermodynamic state that is close to weakly unstable steady-state one. However, transfer processes in thermometric substance result in the fluctuations of electric genesis (i.e. thermometric noise) arising due to changes in thermodynamic state, thus, in a change of metrological characteristics and, therefore, in raising the instrumental component uncertainty of thermoelectric thermometer.

Specified noise provides the basis for forming a transformation function and its influence factors (Fig. 1). To avoid the correlation effects of different influence factors, which is important for assuring the accuracy in metrology, the metrologically stipulated system of selecting the non-related factors that are thermodynamic quantities is applied [8]. Fluctuation-dissipation theorem, related to reversible and irreversible thermodynamics, could be applied both to nanomaterials and thermosensitive substance. The Nyquist rate, combining the spectral density of energy of electric noises within certain frequency band and electric resistance, is treated as a particular case of this theorem.

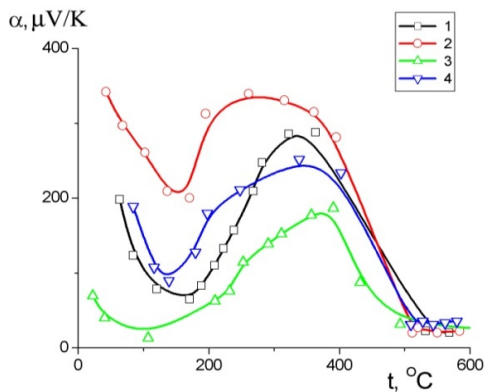


Fig.1. The Seebeck coefficient α of tellurium doped with 1.1% (1) and 1.5% (2) zinc and 1.1% (3) and 1.5% (4) of gallium and their changes at melting (higher 400°C).

Then involvement of statistical thermodynamics of nonequilibrium processes emphasizes the advisability of a unifying approach to studying the influence functions caused by the complex transfer processes as regards the effect on thermoelectric thermometers thermometric substance of numerous technological and operational factors such as perturbation factors. However, in thermometric substance transfer processes the fluctuations of electric genesis (i.e. **thermometric noise**) arising due to changes in thermodynamic state, result in changing the metrological characteristics and therefore in raising the uncertainty of thermoelectric thermometer readings.

Considering the classical electro thermal phenomena in conducting medium, which set the basis for thermoelectric phenomena, we obtain a system of three equations with three unknowns in the presence of electric and heat transfer, and their related mass transfer in thermodynamic system of thermometric substance under consideration. Namely thermopower (or its equivalent value) emerges in a rather long and thin conductor which is located in thermally inhomogeneous medium. Three components of three equations given below that describe the fluxes of heat I_h , charge I_e and mass I_m , are derived:

$$\begin{cases} I_e = -L_{11}\nabla\varphi - \frac{L_{12}}{T}\nabla T - L_{13}\nabla\left(\frac{\mu}{T}\right) \\ I_h = -L_{21}\nabla\varphi - \frac{L_{22}}{T}\nabla T - L_{23}\nabla\left(\frac{\mu}{T}\right), \\ I_m = -L_{31}\nabla\varphi - \frac{L_{32}}{T}\nabla T - L_{33}\nabla\left(\frac{\mu}{T}\right) \end{cases} \quad (1)$$

where thermal diffusion is described by coefficients $L_{23} = L_{32}$. Coefficients $L_{13} = L_{31}$ concern the electro diffusion that is absent at measuring thermopower with the help of compensating method when $I_e = 0$. Electrical transfer applies when it is necessary to minimize the error of thermoelectric thermometers, for example in nuclear power plants where essentially the possibility of their metrological verification is impossible. In general, the solution of electrical flux transfer equation of thermometer is obtained as transformation function:

$$I_e = k_1 \left[e^2 E_l - eT \nabla \left(\frac{\mu}{T} \right) \right] - \frac{e}{T} k_2 \nabla T = 0 \quad (2)$$

Here $k_1; k_2; k_3$ are the kinetic coefficients. With the obtained intensity of electric field along thermoelectrodes the intensity of electric field E_l :

$$E_l = \frac{k_2 - k_1 \mu}{ek_1 T} \nabla T + \frac{1}{e} \nabla \mu = \alpha \nabla T + \frac{1}{e} \nabla \mu, \quad (3)$$

is integrated over the length of electrodes, hence of a thermocouple located in the temperature gradient area. We obtain thermopower or in a wide temperature range the transformation function of thermoelectric thermometer:

$$U(T, \dots) = U(T) + \Delta U [T(x); \mu(x)] = \int_x \alpha [T(x)] \nabla_x T dx + \frac{1}{e} \int_x \nabla_x \mu [T(x)] dx. \quad (4)$$

Here α is the Seebeck coefficient; 1st summand determines the transformation function; 2nd summand defines the influence function. In this case, thermoelectrodes are considered to be heterogeneous, and there may be a gradient of chemical potential ($\nabla \mu = 0$) along their length. Radially heterogeneous medium is successfully simulated [10] by parallel connected conductors of different materials. The studies explain the reasons for the appearance and mechanisms of occurrence of thermoelectric effects in thermoelectric materials with smoothly distributed properties. Thus, the equivalent thermopower U_E of a multifilament wire drawn up by different wires of particular thermopower U_i and electrical conductivity γ_i is computed as:

$$U_\Sigma = \frac{\sum_i U_i \gamma_i}{\sum_i \gamma_i}. \quad (5)$$

A similar formula is obtained [11] by using thermodynamic foundations. In that case various temperature dependences of conductivity can be considered.

Functionally graded thermocouples are realized on the basis of thermoelectric materials with smoothly distributed properties (or with the gradient of chemical potential along the electrodes) [12]. It is due to imposing the temperatures drop on the latter during the thermoelectric thermometers operation. As a result, the transformation function becomes more precise, just as the thermoelectric thermometer readings.

It can be shown that other thermodynamic fluxes excluding the above mentioned heat, charge and mass fluxes, are especially significant in micro- and nano-volumes. These are exactly the mechanical flux connected with volume gradient (∇V) and the flux caused by the available surface area gradient of nanosamples (∇M), which give rise to amendments in equations (1):

$$E_l = \alpha \nabla T + \frac{1}{e} \nabla \mu + c \nabla V + d \nabla M \quad (6)$$

changing by integration the integral thermopower to:

$$\begin{aligned}
 U(T, \dots) &= U(T) + \Delta U [T(x); \mu(x); V(x); M(x)] = \\
 &= \int_x \alpha [T(x)] \nabla_x T dx + \frac{1}{e} \int_x \nabla_x \mu [T(x)] dx + c \int_x \nabla_x V [T(x)] dx + d \int_x \nabla_x M [T(x)] dx.
 \end{aligned}
 \tag{7}$$

It should be taken into account that “mechanical” thermodynamic flux is the flux generated due to mechanical stress gradient along the X -axis of thermoelectrode. This one-dimensional task ignores the possibility of thermodynamic forces and fluxes action in other two coordinates, in contrast to [9].

3. Nanothermometry features

3.1. Nanothermocouples

Nanotechnology requires temperature measurement and control of very small volumes of material with the microsecond time response. Such measurement instruments seem to be thin-film thermocouples. Unfortunately, they do not offer a reasonable level of performance reproducibility.

In reality, these metrological characteristics do not exceed millisecond value with the smallest sizes of the available thermoelectric thermometers. The latter can be considered to be thin-film thermocouples with the Seebeck coefficient proportional to the thickness of films; with the thickness of 100 nm the sensors response time makes about 1 μ s. Known are [10] also electrodeposited thermocouples in the form of silver-nickel nanowires as electrodes with sufficiently linear performance within the range of 20-100 °C. Unfortunately, these sensors are not produced yet with proper reproducibility, interchangeability etc.

The reasons could consist in technological peculiarities that cause the differences between thermocouples in certain lots and between thermocouples within the lots; they change their characteristics over time. We have studied the effect of thermo structural mechanical stress on thermoelectric output and, hence, on thermocouple readings. When studying the impact of thermal shocks there were observed deviations from equilibrium values (Fig.2). The latter increased with a rise in temperature jump ΔT . This process became more intensive when the jump was done in two phases ($\Delta T = 600 + 600$ K). These changes can be related to the emergence and relaxation of mechanical stresses that correlate with thermopower drift and occur in the neighborhood of defects.

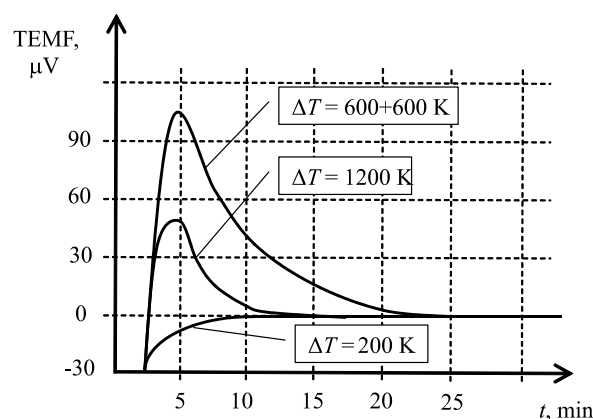


Fig. 2. Effect of thermal shocks demonstrated according to readings of two differentially connected thermocouples at different values of temperature drop ΔT .

Currently, the structures of FET CNT type are of particular interest for thermoelectric phenomena research due to their nanodimensions as well as to the presence of two junctions (inlet

wire –source; outlet wire - drain) that are in immediate vicinity to each other, that is, the points where the heat could be released or absorbed.

3.2. Liquid-in-nanotube and solid-in-nanotube thermometers of volumetric expansion

Examination [11] showed that surface and bulk transfer processes together form the calibration characteristics of liquid-in-glass thermometer. Moreover, intensity ratio of these processes cardinally changes with thermometer dimensions reduction down to nanosizes. Eventually, it changes to the opposite flux responsible for formation of thermometer influence function.

Thus, in the considered case we deal with the thermodynamic forces that correspond to mechanical, surface and heat freedom degrees and define the system of transfer equations for thermosensitive substance:

$$\begin{cases} I_m = -L_{11}\nabla V - L_{12}\nabla M - L_{13}\nabla T \\ I_n = -L_{21}\nabla V - L_{22}\nabla M - L_{23}\nabla T \\ I_T = -L_{31}\nabla V - L_{32}\nabla M - L_{33}\nabla T \end{cases} \quad (8)$$

Here, $I_e; I_n; I_m$ are the transfer fluxes caused by electrical charges, surface tension and heat transfer, respectively; L_{ij} are the transfer coefficients. Equations of calibration characteristics of mentioned thermometers for macroworld and micro(nano)world are derived below from this system.

In the macroworld it is deemed necessary to minimize an error caused by surface tension and the temperature gradient. The latter is negligibly small ($I_T=0$) because liquid-in-glass thermometers measure the temperature at small space temperature gradient. Then system (8) is reduced to:

$$\begin{cases} I_m = -L_{11}\nabla V - L_{12}\nabla M \\ I_n = -L_{21}\nabla V - L_{22}\nabla M \end{cases} \quad (9)$$

The 1st equation concerns the flux of displacement of thermosensitive liquid column under the action of forces caused by the gradients of volume and surface area. The 2nd equation concerns the surface tension force gradient leading to decrease/increase of column height under the action of said thermodynamic forces. In so doing, the force caused by surface effects becomes important on drawing near to nanosize and becomes determinative in nanoworld. So, in case of liquid-in-nanotube thermometer we deal with displacement of column due to a change in surface tension forces caused by temperature change. The effect of mechanical freedom degree becomes responsible for the deviations from the nominal calibration characteristics, which determines measurement error of nanothermometer.

In other words, consideration of a liquid-in-glass thermometer in macroworld with neglect of surface tension forces could bring us to interrelation of liquid volume ΔV and controlled temperature changes:

$$\Delta V = V_0 \alpha_V \Delta T \quad (10)$$

Here, V_0 is the initial liquid volume; α_V is the coefficient of thermal expansion of liquid. With a spherical container of diameter D for liquid it gives the possibility to estimate changes in the column height Δh (diameter d) of a thermometer as a function of temperature ΔT by the proportionality (when $\alpha_V = 10^{-4}$ 1/K and $D = 10d$) describing the equation of thermometer calibration characteristic:

$$\Delta h = 0.067d\Delta T = A\Delta T, \text{ mm.} \quad (11)$$

Indeed, thermometer sensitivity is reduced with a decrease in thermometer tube diameter. The temperature dependence of surface tension forces could be depicted for all liquids, so that the data are placed along one common curve. If V is the molar volume and T_c is the critical liquid temperature, then surface tension coefficient σ is defined as:

$$\sigma V^{2/3} = k(T_c - 6 - T). \quad (12)$$

Here, k is a constant for all liquids (Eötvös constant makes 2.1×10^{-7} Joule/K mole^{-2/3}). Then, equation of calibration characteristic of a liquid-in-nanotube thermometer takes on the form:

$$\Delta h = \frac{4k'}{\gamma d} \left(\frac{N_A}{V} \right)^{2/3} (T_c - 6 - T) = C(T_c - 6 - T), \quad (13)$$

where C is a constant.

3.3. Resistance thermometers made of nanostructured thermosensitive substance

Metal glasses (MG) with an amorphous structure are subject to investigations as novel materials with a high resistivity ρ and a small value of temperature coefficient α . The particular efforts are made in the endeavour to bind the electrical MG properties with the peculiarities of their manufacturing technology which could be beneficial in the manufacture of special electrotechnical materials, spintronics etc. The study of nanostructured materials confirms the existence of fields of considerable mechanical microstresses whose influence is equal to doping with admixtures. In the approximation of a MG model, i.e., assuming that there are precipitations of other phases in a matrix, e.g. pseudo-phases which could be represented by the microvolumes of different densities, to obtain experimental results, we have considered the equation of the third order for the resistivity of two-phase material: $\rho_a (\Delta\rho)^2 = (1-q)\rho_1 (\Delta\rho)^2 + (\Delta\rho)^3 - q\rho_1^2$. Here, $q = \Delta S/S$ is the effective intersection area of precipitations, $\rho_1 = a + bT$ is the resistivity of a matrix, $\Delta\rho$ is the change of the specific electrical resistance due to precipitations. Explanation roots in the dependence of the specific volume on the speed of chilling, determined in connection with the above temperature. The increment in the MG volume reaches several percent and has a considerable impact on transmission processes with a rise in temperature.

3.4. Ultrasonic thermometers with a sensitive element made of nanostructured thermosensitive substance

Such thermometer could be applied to measuring ultrahigh temperatures with a minimal methodical error component. To provide the stability of thermometer transformation function, we should consider process peculiarities, particularly electron-phonon interaction with tensile defects, occurring in thermometric substance. The porous thermometric materials of real, lower than ideal, density are characterized by smaller changes of thermometer transformation function as compared to ideally dense materials due to deformation influence. Relaxation of the above-mentioned stresses with time acquires a form of resilient plastic structural shifting, diffusive micropores drifting (potassium mechanism) or initiates other phases as in the case of silicium and aluminium oxides that also could encourage the renewal of a transformation function [12].

3.5. Noise thermometers

Thermometric noise can be studied most efficiently with the aid of this kind of thermometers, since their calibration characteristics are calibrated in noise power unit; these thermometers are intended for measurement and have been specially calibrated for this purpose as measuring instruments. Thus, at rapid heating of noise thermometers we have recorded the noise transition process caused by thermodynamic disequilibrium in the sensitive element. It is due to internal changes of defects density in thermosensitive material. As result of imposition of uneven temperature gradient on the thermometer, the changes in calibration characteristics increase (Fig.3).

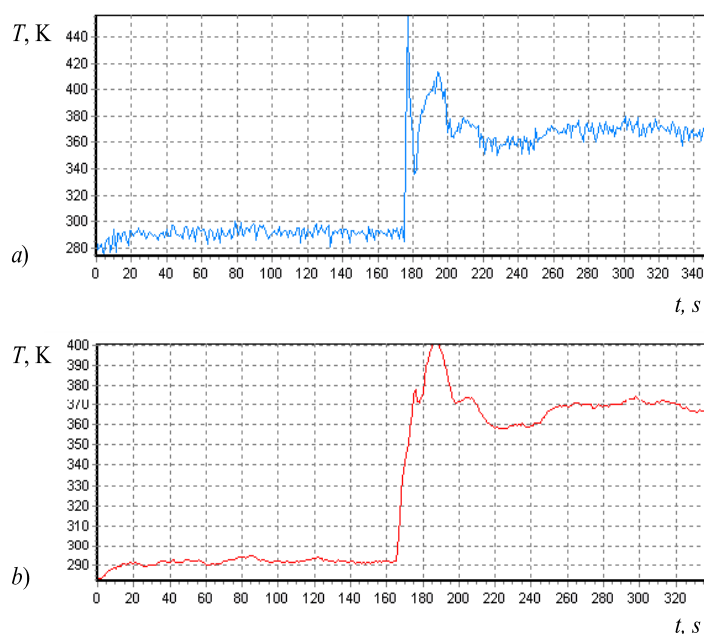


Fig. 3. Process of changing the readings of noise thermometer due to temperature jump from 288 K to 368 K (frequency band of noise signal: 10 - 110 kHz, time of averaging: a) 1s.; b) 10s.

Investigation of noise signal behavior is conducted in dynamic temperature mode by the method of rapid transfer of sensitive element from one medium to another of higher temperature (Fig.3). At the instant of 170th second from measurement beginning, the temperature varies abruptly (from 288 K to 368 K). The recorded temperature defined by noise power exceeds the temperature of gauged medium almost twice.

4. New formalism of nanothermodynamics and peculiarities of thermometer operation

4.1. Fundamental approaches, appropriate for extension of thermodynamics to nanolevel

Up to date, two fundamental approaches are known for extension of thermodynamics to nanoscale; they are based on the microscopic and macroscopic viewpoints, respectively. The first one would refer to the fundamental theorem of macroscopic thermodynamics and establish the new formalism of nanothermodynamics by introducing a new function(s) presenting the fluctuations or reflecting the surface effects in nanopatterns. Another one could directly modify the equations of the macroscopic thermodynamics and establish a new model of thermodynamics on nanoscale by introducing after the Laplace–Young equation additional pressure $\Delta P = \sigma \left(\frac{1}{R_x} + \frac{1}{R_y} \right)$, where $R_x; R_y$ are 2 local radii of surface curvature, or the Gibbs–Thomson relation concerning the fluctuation density of nanosystems in the corresponding thermodynamic expressions [7]. We used both approaches to address the behavior and metrological characteristics of thermosensitive elements made of nanoscaled and nanostructured substances.

4.2. Additional freedom degrees of the fundamental equation of thermodynamics

In order to explain MG electro kinetic and some other defining properties, the nanothermodynamics [7] involves introduction of two additional freedom degrees in the fundamental equation of thermodynamics (Fig.4).

They are: σdM (M is the surface area), caused by the surface tension σ , and $\square dV$ (V is the volume of 2nd phase precipitations), caused by the expenses of the specific energy \square for the formation of these precipitations in the matrix of original substance.

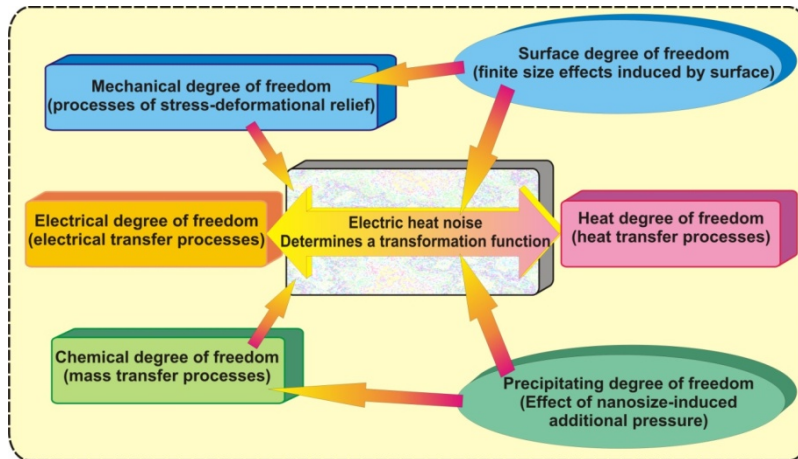


Fig.4. Formation of different noise types and transformation functions of (nano) thermometers in relation to appropriate freedom degrees of the fundamental equation of nanothermodynamics.

We try to consider the influence of the latter by the example of polycrystalline structure of barium-strontium ferrite studies conducted in [16]. Contact overcooling of thin layer occurs at the final stage of pressed powder sintering due to grains interaction through this very layer being in liquid state. Contact temperature difference (up to ten kelvins) for a number of material compositions decreases rapidly with increasing the size of crystallites. The same applies to considerable temperature (tens of kelvins per cm) gradient and, hence, concentration gradient. At the grain size more than 6 μm contact temperature difference becomes negligible.

Using this approach, a vast field of various influence factors producing effect on the thermometric substance, hence on thermometer transformation function, can be reduced to a small number of independent factors, whose effect on the specified function is uncorrelated. Thus, the accuracy of thermoelectric thermometers is considerably increased, which is of minor importance for thermoelectric energy sources.

In the linear thermodynamics, when the system is not too distant from equilibrium, thermodynamic forces X and fluxes J are bound by the Onsager reciprocity relation:

$$J_i = \sum_j \beta_{ij} X_j \dots (i, j = 1 \dots l), \text{ where } \beta_{ij} = \beta_{ji} \dots (i, j = 1 \dots l) \text{ received with expansion of the complex}$$

function $J = J(X_1; X_2; \dots X_6)$ in a Taylor series:

$$J_i(X_1, \dots, X_6) = J_i(0) + \sum_j \left. \frac{\partial J_i}{\partial X_j} \right|_{(0)} (X_j - 0) + \sum_j \sum_n \left. \frac{\partial^2 J_i}{\partial X_j \partial X_n} \right|_{(0)} (X_j - 0)(X_n - 0) + \dots \quad (14)$$

The sources due to the influence of thermodynamic forces and fluxes for thermosensitive substance of thermoelectric thermometers are considered and analyzed below while reducing their linear sizes to micro- and nano-sizes. The processes of electric, thermal and partly mass transfer form the thermoelectric thermometer transformation function, and other transfer processes are responsible for forming the influence functions. So, for these thermometers the transformation function

$F(T, p, \dots)$, that is defined by three thermodynamic forces (electrical, chemical, heat) and caused by the effect of other thermodynamic forces on total influence function $F_I(T, p, \dots)$, are represented in connection with a normalized value of transformation function $F(T, 0, 0, \dots)$:

$$\begin{aligned}
 F(T, p, \dots) &= F(T, 0, 0, \dots) + F_I(T, p, \dots), \\
 \text{where } F_I(T, p, \dots) &= \sum_{I=3..6} F_I(X_I), \\
 F(T, p, \dots) &= F(T, 0, 0, \dots) \left[1 + \frac{F_I(T, p, \dots)}{F(T, 0, 0, \dots)} \right] = F(T, 0, 0, \dots) [1 + K_\Sigma(T, p, \dots)].
 \end{aligned}
 \tag{15}$$

Here $K_\Sigma(T, p, \dots) = K_X + K_M + \dots$ is the relative total influence function due to complex action of mass transfer K_X , deformation K_M etc.

4.3. Coherence effect as extra mechanism of eddy currents emergence in nanomaterials

In the classical theory of heat conductivity it is considered that the only reason for heat flux in solids is the temperature gradient different from the zero. However, the thermal deformation of the body, in the case of a significant rate of heat flux, results in the so-called coherence effect. It consists in the interaction of deformation and temperature fields. This is already a ground for a transition to the thermodynamics of nonequilibrium processes and even to thermodynamics of nonlinear processes. Numerical evaluation of the impact of the specified effect was performed on the glass and steel samples characterized by about the same thermal diffusivity a . Glasses and ceramics are characterized by large values of coherence parameters $\varepsilon'/a_T T' \ll 400$; whereas the similar parameter of steel is far less and makes 20. This means the following. For ceramics and nanostructured materials the assessment of temperature field effect necessitates a solution of related linear dynamic thermo elasticity problem. Especially it concerns ceramics, where small changes in temperature over time lead to significant deformation impacts.

5. Further development of fundamental principles of eddy currents formation in the absence of temperature gradient imposed on material

One of the real cases of any thermoelectric material application is the absence of marked temperature gradient imposed thereon. Then, the conception of eddy currents can work properly, because according to the fluctuation-dissipation principles of thermodynamic parameters fluctuation, including temperature, they still exist in this substance. Such fluctuations are inevitably manifested by eddy thermoelectric currents. The latter results in the appearance on sample surface of charge fluctuations that can be identified by the method of passive noise spectroscopy [13]. As an example, let us give the results of electrical fluctuations/noise studies as compared with the thermoelectric phenomenology research.

Transfer processes are significantly complicated with a considerable rate of temperature change. For instance, thermoelectric substance is annealed at one temperature and rapidly is moved to a medium with a higher temperature, where due to the formation of dislocation ensembles the mechanical stresses arise that are capable of accumulating the internal energy. Their length can be significantly larger than the lattice constant. In a dynamic temperature mode the availability of structural defects can lead to changes in characteristics of noise. Noise phenomenology is clearly explained by involving the mechanism of energy accumulation-dissipation on local tensile quasi

defects of vacancy origin at their interaction with phonons. With or without current flow, phonons are generated in thermosensitive substance; they are accumulated in quasi defects and then are relaxed in reversible or irreversible manner, causing respectively $1/f$ or thermal noise.

The Raman method gives opportunity of electron-phonon interaction study. The wave number of optical phonon of the Stokes component is strongly dependent on temperature. For example, for silicon monocrystal this dependence in the temperature range 300...400 K is linear: $\nu_0 (cm^{-1}) = 0,025\Delta T$, where ΔT is a change in monocrystal temperature [14]. It enables to obtain more precise temperature readout at known temperature dependence of the Raman shift ν_0 . With a rise in temperature, the wavelength of scattered light approaches the wavelength of the laser. It is caused by the elimination of tensile micro stresses acting in studied substance due to increased mobility of defects, especially vacancies.

While capturing the phonons by a tensile defect, its local temperature is rising. Considerable thermo-extension takes place, which at some moment could cause the rupture of inter-atomic bonds and thus microcrack emergence. By using the intensity of the Stokes and anti-Stokes bands in the Raman spectrum, the phonon value n was defined and their capture by tensile defects was ascertained. Local temperature of the above mentioned defects (with linear size till 10 atoms) is determined as

$$T_d = \frac{h\nu}{k[\ln(n+1) - \ln n]}.$$

It is obvious how important for thermosensitive substance is a rise in temperature of these dots, that is, on these defects. On the other hand, focusing attention on tensile defects as physically elementary nanosized structure subsystems enables to motivate the introduction of thermodynamic values i.e. the application of nanothermodynamics to the objects under study.

It is important to consider such common factor of influence on calibration characteristics as a deformation factor that tends to increase at a combined action of temperature and strains (structural, resilient, ductile or others) in thermosensitive substance during measurement. This factor is manifested in local distortion of temperature of these materials as a result of applying stresses of tensile micro concentrators that are considered as quasi local nanosized defects of thermo-fluctuation origin. These distortions greatly reduce the real durability of thermometric substance due to noise, which at the same time strengthen deviations of thermoelectric thermometer calibration characteristics, degrading its precision.

Conclusions

1. Reducing the sizes and diminishing the thermometric substance dispersion lead to emergence of the influence factors on the thermoelectric thermometer performance that can be considered by nanothermodynamics. In nanoworld, while decreasing dimensions of thermosensitive substance, surface tension forces and forces of second phase precipitations formation become more effective and can lead not only to drift, but also to changing the character of calibration characteristics.

2. Nanothermometry (including the thermoelectric nanothermometry) considers the action of: a) surface tension thermodynamic force; b) thermodynamic force caused by formation of second phase precipitations in the matrix of original substance.

3. By changing the power of foregoing sources, the thermosensitive substance state permanently drifts producing thermometric noise in thermoelectric thermometry or elementary eddy currents in thermoelectric energetics. Control of this charge deviations enables us to produce new quasi-nonequilibrium materials with high-stable calibrating characteristics for thermoelectric

thermometers; to create functionally graded thermocouples that are a bright example of smoothly distributed structures [15]; and to develop new types of unique thermoelectric thermometer on the industrial base of such devices as CNTFETs the linear dimensions of which are less than thermocouple hot-junction sizes (it is possible to measure in-situ FET's temperature regime with the aid of thermoelectricity).

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Submitted 24.04.2015