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INFRARED THERMOGRAPHY AS AN EFFECTIVE TOOL FOR RESEARCH AND INDUSTRIAL APPLICATION

Introduction. *Improving the informativeness and efficiency of research through the use of infrared thermography is a vital task of modern science and industry.*

Problem Statement. *In recent years, infrared thermography has gained significant importance in physical research, medicine, industry, and others. The use of high-precision and high-speed thermographs with high resolution has opened up new opportunities for thermography application. The widespread introduction of the thermographic research method and its practical use are constrained by the lack of completed scholarly research works on the interpretation of thermographic images and by understudied capabilities of the method. The introduction of remote infrared thermography is a topical issue of scientific importance.*

Purpose. *The purpose of this research is to demonstrate the capabilities of the method in various fields of human activity and to analyze thermographic images in detail.*

Materials and Methods. *A thermograph with a matrix photodetector of domestic production has been used. A few studies have been performed with the use of the FLIR Systems (USA) thermograph.*

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Results. *It has been shown that thermography is a modern, high-precision quantitative research method that significantly expands the instrumental base for scholarly research. On specific examples, the capabilities of thermography in terms of increasing the information content for both scholarly research and practical application have been considered.*

Conclusions. *The obtained new research and practical results of the use of infrared thermography have demonstrated the effectiveness of the method, which allows introducing thermography as a powerful tool for modern scientific research in a wide range. The introduction of this method expands the instrumental base of modern scholarly and practical research.*

Keywords: thermography, science, scientific research, biological object, and temperature.

Infrared thermography (IRT) has been widely used in various fields of human activity in recent decades. This is because of the fact that thermography combines the method and technical means for remote express temperature measurement and allows obtaining data in monochrome and color digital images.

The software is constantly improved, which increases the informativeness and simplifies the decoding of the obtained thermographic images [1—4].

The military industry is among the first fields of practical application of thermal diagnostics technology. Thermography has found its use in biology, forensics, ecology, energy, mining, agriculture, and so on.

Despite a variety of technical means and measurement techniques used in research, the creation of new measuring systems still remains an important area for developing scholarly research. The design of new and the improvement of existing physical research tools continues growing.

IRT is one of the advanced simple and easy to use measuring instruments for physical experiments.

Medical thermal diagnostics has proved its effectiveness as a method for radiological diagnosis of human diseases; numerous thermographic researches in the world clinical practice and in medical institutions of Ukraine have been carried out.

The advanced matrix thermal imaging systems and their software have transformed this method from a qualitative to a quantitative research method. The use of thermal imaging research methods in various fields of human activity has become possible due to modern technologies for the production of infrared receivers, including a new generation of thermal imagers that are light, compact, have a high resolution and modern software [5—7].

New results of basic researches on combined ultrasonic and induction IRT have been received. These methods act as an alternative to conventional techniques with the use of active optical heating [8, 9].

Thermography has been successfully used for the diagnosis of silicon ingots [10], thermographic control of solar panels [11, 12]. The use of IRT in open and underground enterprises has shown a high efficiency for the study of thermophysical and geomechanical processes occurring in rocks with various technologies of field development [13—16]. In the electronics industry, thermography is used for thermal control of operating modes of electronic equipment [17]. A system for thermal non-contact inspection of metal rolling integrity and quality of materials of fuel-producing objects has been developed [18]. Numerous studies that gave a positive result and demonstrated good prospects for using thermography to determine the condition of metal in the pipelines have been carried out [19]. A method for thermal non-destructive testing of products has been developed [20].

IR imaging technologies have found application in forensics. The authors [21, 22] have identified the most promising areas of application of thermographic capabilities in the process of detection and investigation of crimes.

The IRT method in combination with the mathematical apparatus of digital software analysis of images of dynamic processes may be used for remote control of human psychophysiological parameters [23].

The authors [24] have made a comparative review of algorithms for segmentation of information areas on human thermal images. The results of the simulation have allowed identifying several key algorithms that are most suitable for solving problems of analysis and monitoring of blood circulation in the facial arteries. The results of this research may be used to develop a software package for processing and analyzing thermal images while solving problems of medical thermography.

Several studies on the application of IRT in medical practice have been performed [25—29].

This paper presents the results of long-term use of IRT in biomedicine, ecology, physical research, and agro-industry as well as new scholarly research results.

The research has shown a high efficiency of the use of IRT, which significantly increases the research informativeness.

Let us consider the results obtained.

Thermography in Scholarly Research of Biological Objects

The following examples show the possibilities of practical application of thermography in biomedical research.

One of the important problems studied in biology, medicine, and related sciences is electromagnetic radiation (EMR) of a biological object (BO) [30, 31]. The aspects of electromagnetic fields, which are associated with the signal characteristics of human organism, i.e. with information that is coded in the corresponding fields and radiation and is significant for the biological system, are of the greatest interest for research.

One of the methods for radiological diagnostics is magnetic resonance imaging (MRI) that has been widely used in many fields of diagnostic medicine in recent decades [32, 33].

It should be noted that recently there has been growing interest in the potential risks that MRI may cause in the long run, especially in light of the conflicting research findings on the further detection of human DNA damage, homeostasis, and oxidative stress abnormalities (physiological stress or disorders resulting from oxidative reactions not specific for organism's metabolism and changes in the initial frequency of DNA endogenesis).

We have conducted research on the use of IRT effects of MRI on the temperature state of BO (on the rats with Guerin's carcinoma, from vivarium of the National Cancer Institute).

While doing the research we have used: stationary thermograph designed by the Lashkarev Institute of Semiconductor Physics and operating in the range of 3—5 μm with a temperature measurement accuracy of 0.07 °C [25]) and a portable thermograph manufactured by *FLIR Systems* (USA) with an uncooled matrix of chromium-vanadium microbolometers measuring 320×240 pixels with a temperature sensitivity of 0.1 °C within the spectral range of 8—14 μm.

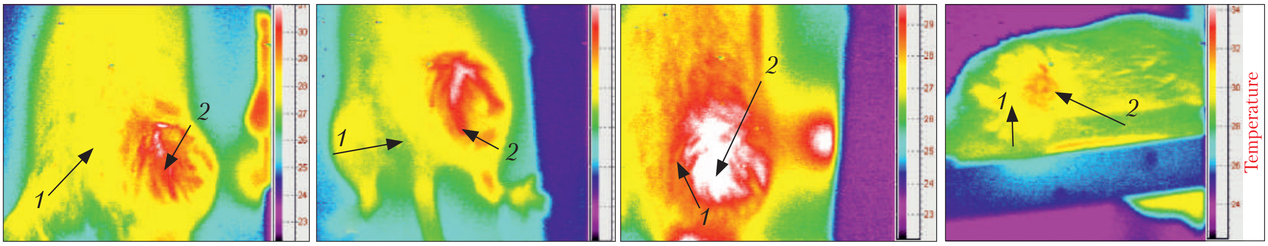
It is almost impossible to measure the temperature of biological object in any part of skin by other methods.

It has been shown that MRI does not lead to an increase in the temperature of biological object instead, the temperature decreases by (0.9—1.3) °C.

Thermographic Visualization of EMR Effect on Neoplasms in Biological Object and on the Efficacy of Antitumor Therapy

Changes in the heterogeneity of EMR and its effect on the antitumor efficacy of the antibiotic therapy administered to animals (female rats) have been studied jointly with the National Cancer Institute of the Ministry of Healthcare of Ukraine, with the use of materials prepared by its staff [26].

The beginning of the formation of a malignant neoplasm is presented in Fig. 1, *a*. The temperature gradient is defined as the temperature difference in the tumor area (2) and the adjacent areas (1), which is shown in Fig. 1 with the arrow. The temperature gradient is: ΔT_{2-1} = + 1.5 °C. There is observed forming network of blood vessels to feed the tumor and to supply it with O_2. The development of malignant neoplasms over time is featured in Fig. 1, *b*. The temperature gradient is: ΔT_{2-1} = +2.9 °C. After heating the tumor with high-frequency radiation, the temperature gradient is:



a *b* *c* *d*

Fig. 1. Thermograms at the early tumor formation (*a*), in the course of the tumor development (*b*), after irradiation (*c*) and after the end of irradiation (*d*)

$\Delta T_{2\text{-}1}$ = +4.1 °C (Fig. 1, *c*). Having been exposed to high-frequency radiation, the tumor decreases and so does the temperature gradient, down to $\Delta T_{2\text{-}1}$ = +2.2 °C (Fig. 1, *d*).

In order to select the most favorable conditions of electromagnetic irradiation (EMI) of human malignant tumors, the effects of EMI on various biological substances have been studied [34]. The thermographic representation of biological substances (*a* — flesh meat, *b* — lard) under the influence of EMI is shown in Fig. 2.

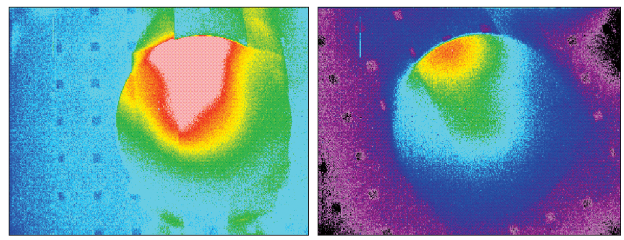
The given examples of using the IRT procedure for diagnostic purposes have demonstrated the effectiveness of the method and the possibility of obtaining experimental results to solve biomedical problems related to the processes of heat release, which is an important for researchers and practical users.

The study of heat distribution and rise in temperature makes it possible to establish the most favorable conditions of irradiation in the cancer treatment.

Thermographic Visualization of Human Pathologies

Modern IRT allows identifying the anatomical area of pathological changes long before the manifestation of clinical symptoms and determining the activity and the nature of the processes occurring in the human body [35—37].

Usually, the distribution of temperature areas of symmetrical parts of the body is uniform. The only method that enables obtaining the most reliable temperature distribution and detecting the areas with abnormal temperature is IRT [38].



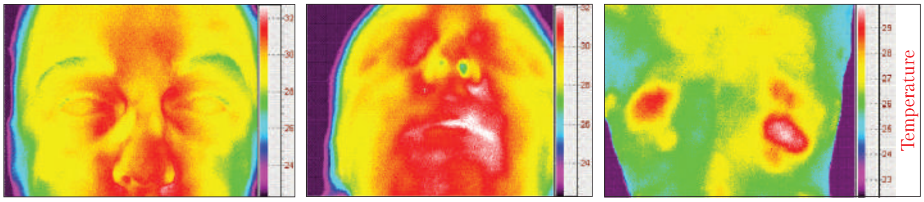
a *b*

Fig. 2. Thermographic images of biological substances (*a* — flesh meat, *b* — lard) under the action of EMI

The thermographic method in otorhinolaryngology has been successfully used to diagnose diseases of the maxillary and frontal cavities with simultaneous detection of respiratory disorders [39]. It is quite difficult to qualitatively and quantitatively evaluate the function of respiration through the nasal cavities because there are have been no simple methods for the above surveys so far. This problem has been effectively solved by the authors with the use of the thermography method by determining the cross-sectional area of the air inhaled through the nasal cavities; appropriate software has been developed.

Below, there are shown the thermogram of a patient with bilateral sinusitis (Fig. 3, *a*) and the curvature of the nasal septum (Fig. 3, *b*). The temperature gradient in the area of the left maxillary sinus is +0.89 °C, that in the area of the right sinus is +1.57 °C. The respiratory function through the right nasal cavity is disordered (Fig. 3, *b*). There is established hyperthermia of the frontal sinuses with a temperature gradient of +1.55 °C.

The use of IRT in urology significantly expands and complements the complex diagnostic instru-



a *b* *c*

Fig. 3. Hyperthermia of the paranasal sinuses in bilateral sinusitis (*a*); curvature of the nasal septum (*b*); acute bilateral pyelonephritis (*c*).

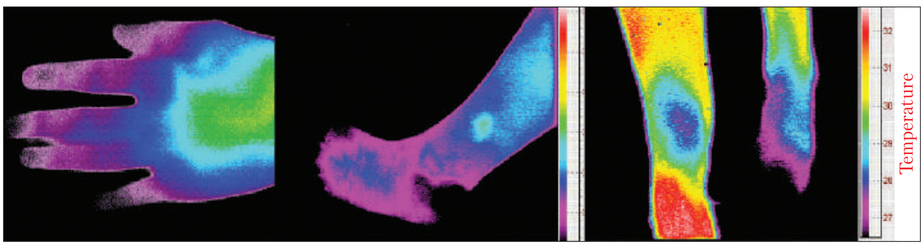


Fig. 4. Thermographic visualization of blood circulation disorder of the distal regions of extremities with varying degrees of injury

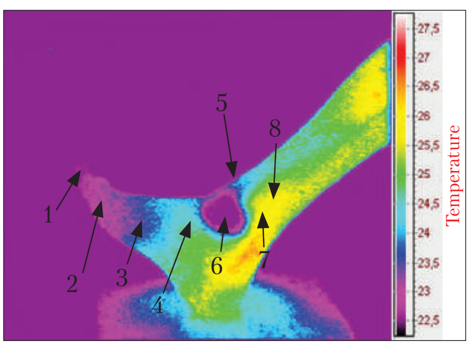


Fig. 5. Thermographic visualization of type 1 diabetes, trophic ulcer

mentation for the early detection of pathology of the urinary system [40]. Promptly and without radiation exposure to the patient, IRT enables dynamic monitoring of disease, identification of possible complications, and timely correction of the prescribed treatment.

The thermogram of a patient with acute bilateral pyelonephritis is presented in Fig. 3, *c*. The thermoasymmetry of the lumbar region with a hyperthermia of the inflammation site in the area of projection of the kidneys is visualized.

The IRT method is among quite informative non-invasive diagnostic methods for detecting spasm of the large arteries of the distal extremities [41]. The use of IRT allows detecting the early stage and monitoring the course of the disease.

Fig. 4 shows the obtained thermograms with varying degrees of manifestation of insufficient distal blood circulation in the upper and lower extremities, which may be a manifestation of Raynaud's disease. The temperature gradient varies from -1.4 °C to -12 °C.

Diabetes mellitus (DM) is an urgent medical and social problem [42]. Diabetic foot disease (DFD) is the most severe complication of diabetes as a manifestation of purulonecrotic injury in the lower extremities, which is observed in 30—60% of patients.

The thermographic methods enable diagnosing complications of diabetes in time, in particular DFD, which significantly increases the effectiveness of treatment and the quality of life. The degree of blood supply to the lower extremities is one of the most important criteria for the likelihood of healing ulcers and wounds in the case of DFD.

The thermogram (Fig. 5) shows complications of diabetes: trophic ulcer and impaired blood supply to the right lower extremity, which manifest themselves as hypothermia in the area of finger phalanges, feet, and legs. The temperature distri-

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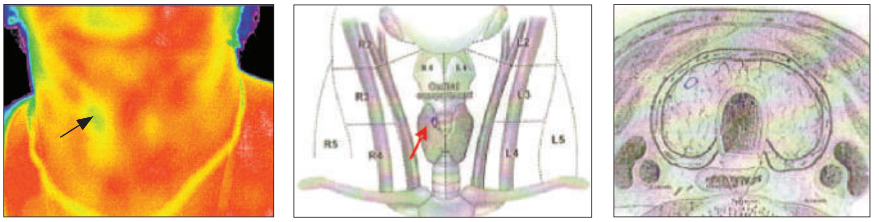


Fig. 6. Thermogram of thyroid projection with hypothermic formation of the right lobe (*a*) and ultrasound survey results (*b, c*)

bution by sections 1-2-3-4-5-6-7-8 is 22.45 °C —23.07 °C —23.57 °C —24.56 °C —22.4 °C —22.93 °C —24.83 °C —26.0 °C, respectively.

The obtained results of thermographic studies of patients with diabetes have given an insight into the problem and its negative effects on the body, acute and chronic complications.

The detection of thyroid diseases by simple thermographic method, especially given the negative consequences of the Chornobyl accident, is of great research and practical interest. The results of IRT and ultrasound surveys have been compared. Research [43] has shown a high correlation of these methods.

The thermogram of a patient with hypothermic formation in the right lobe of the thyroid gland is shown in Fig. 6, *a*. The temperature gradient in the area indicated by the arrow is —1.04 °C. To verify the hypothermic formation, an ultrasound survey has been made, the results of which are shown in Fig. 6 (*b, c*) and the level of thyroid hormones in the blood has been measured.

The scope of medical applications of the IRT method is rather broad, the number of publications on this subject has been constantly growing, which tesfifies to relevance and importance of this diagnosis method.

Thermography in Agricultural Production

Innovative development of crop production aims at increasing the profitability of production and sales of agricultural products requires constant monitoring of the quality and ripeness of fruits and vegetables at all stages, from harvesting to the counter [44—45]. It is also important to study the condition of plants, timely detect damages that lead to disruption of the hydration process and affect their development [46—47]. Thermography is important for assessing the quality and storage conditions of fruits and vegetables. In world practice, thermal imaging methods in agro-industrial production have become widespread [48—52].

The authors have made several researches to study the possibility of using IRT in assessing the conditions of fruit and vegetable products during their storage.

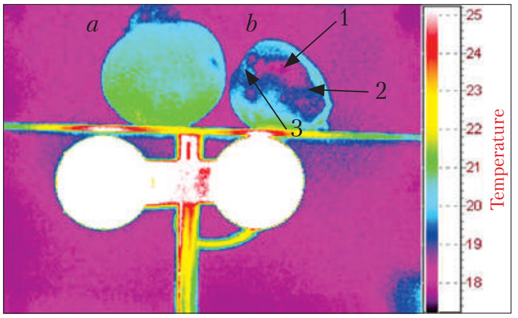


Fig. 7. Thermogram of potato tubers without lesion (*a*) and with the initial lesion process (*b*); (the affected areas are shown by arrows 1—3)

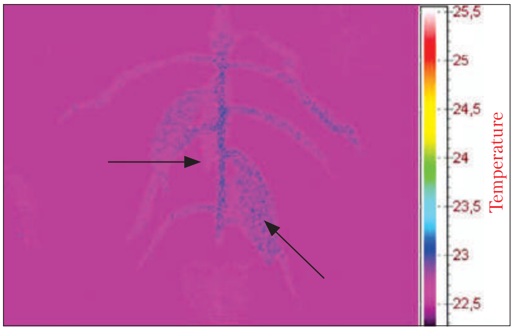


Fig. 8. Distribution of liquid in the trunk and leaves of the plant

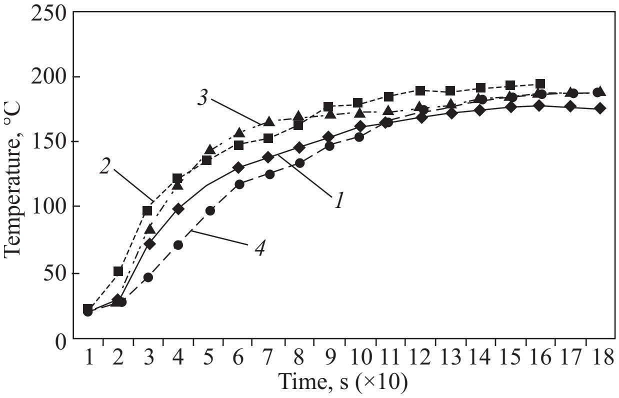


Fig. 9. Kinetics of heating of ceramic samples from 20 °C to 200 °C (*1* — sample No.1; *2* — sample No.2; *3* — sample No. 3; *4* — sample No.4)

The thermograms of potato tubers without lesions (*a*) and with the initial lesion process (*b*) are presented in Fig. 7. The temperature gradients with respect to the unaffected areas in the areas shown by arrows 1-2-3 are: ΔT_1 = —0.3 °C; ΔT_2 = = —0.29 °C; and ΔT_3 = —2.07 °C, respectively.

The intensity of spectral distributions in the IR range is known to be determined by oscillating molecules involved in CH, OH, and NH bonds. Stress and infection lead to changes in the surface temperature through affecting the metabolic processes. The spectral bands of water absorption are in the near IR range, which allows contactless survey of individual plants by the thermography method due to its versatility, accuracy, and high resolution. The conventional methods for determining the vegetative parameters of plants are reliable, but cost-intensive. The thermogram (Fig. 8) shows the plant hydration process and clearly visualizes the internal defects that lead to uneven absorption of liquid, which affects the yield.

Thermography in Physical Research, Industry

a) Study of some thermophysical properties of radiolucent ceramics

The study of ceramics thermophysical parameters by the laser flash method has been widely used [53], but it requires expensive equipment.

This research proposes to use IRT for studying the kinetics of heating and cooling of ceramic samples, as well as for detecting structural defects, which is important given the special purpose of this ceramics. The prototypes have been made by slip casting of different chemical composition (samples No.1, 2, 3, and 4). The samples are heated with the use of a thermal platform that provides heating to a temperature of 200 °C.

At the initial stage of heating the samples, the lowest rate is observed in sample No. 4 (Fig. 9).

It should be noted that sample No.4 shows the lowest heating rate and the lowest cooling rate.

The thermographic images of one of the studied samples during heating have been obtained. The uneven temperature distribution at the initial stage of heating may indicate structural heterogeneity; after heating for 200 s, we have observed the temperature equalization over the entire surface of the sample.

b) Thermographic modeling of the process of water pollution by heavy components

Thermography, as a method of remote measurement of temperature field, enables physical modeling of the pollution process, and, in particular, stratification of contaminated water [54]. Heavy components of pollution have a higher density than water, so they are precipitated and accumulate in the bottom zone of the reservoir. If there is no flow in the reservoir, and the contaminants have a higher temperature than the water in the reservoir, the contaminants are transferred by the three mechanisms:

- the process of gravitational mass transfer (precipitation);
- the process of diffusion through the interface of contaminants and water of the reservoir;
- the process of conductive heat transfer via the interface (no convection).

The process of water pollution by sewage containing anti-icing salts has been studied and simulated (with an aquarium with fresh water as a closed reservoir).

Fig. 11, *a, b* features that the saline solution is deposited in the bottom layers, where the con-

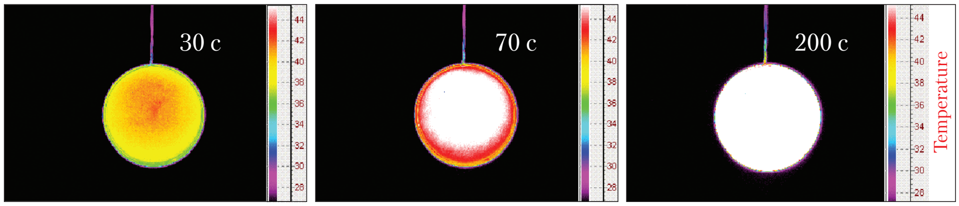


Fig. 10. Thermographic visualization of a ceramic sample in the course of its heating

taminants are concentrated. The thermograms provide information about the distribution of the temperature field, the changes in which differ from the mass transfer process.

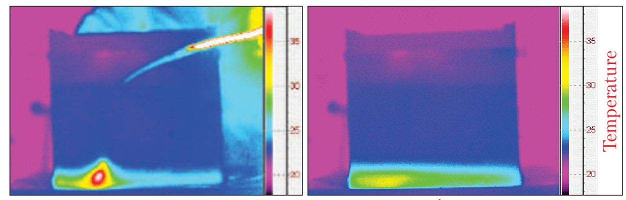
c) Control of photovoltaic solar cell (PSC) defects while heated by dark current

The IRT method [11,12] with the use of the author's technique [55, 56] has proven itself as effective method for studying defects in solar cells (SC).

The thermogram a flawless PSC and the pixel-by-pixel temperature distribution are shown in Fig. 12, *a, b*. Detecting SC defects by direct dark current heating is very useful for diagnosing solar panels that are built on a parallel connection. When PSC is heated by direct dark current, a defective SC act as a shunt for all its neighbors connected in parallel with it and heat up more than all other cells. The type of defects controlled in this case is parasitic Schottky diodes. The required voltage for this method depends on the number of in the PSC and is approximately 0.6V for one and 22V for a section of 36 series-connected SCs. (Fig. 12, *c*). However, with a series connection of SCs, which is typical for most low- and medium-power solar panels, it is important to diagnose the presence of defects that are formed because of electrical breakdown and have a resistive nature.

The use of the method based on the flow of reverse dark current allows controlling defects of additional shunt resistance type [12]. When a SC is heated, the defect area has an elevated temperature (72 °C), which is shown in the thermogram (Fig. 12, *d*).

The use of the IRT method in the study of SC allows detecting defects in individual SCs or in solar panels.



a *b*

Fig. 11. Thermographic image of the distribution of saline solution at the beginning (*a*) and after 30 min of the experiment (*b*)

d) Thermographic diagnostics to control the uniformity of the film coating thickness

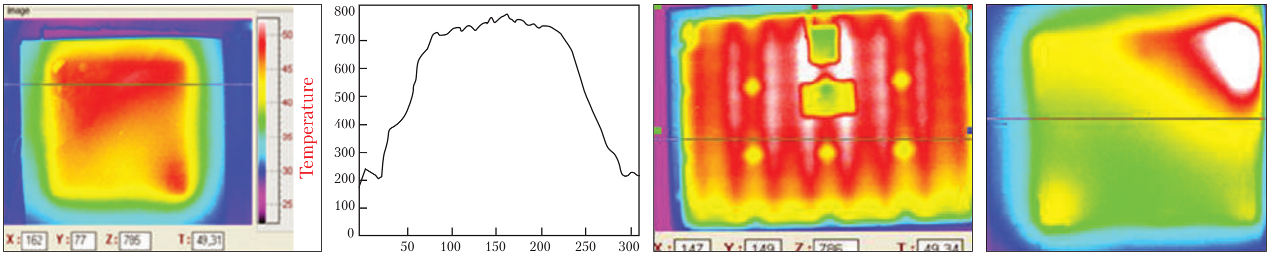
Transparent electrically conductive coatings based on tin oxide and indium on a glass substrate have been studied. Such structures are used in microelectronics and in SCs. The IRT method has been used to study the topological non-uniformity of the coating thickness.

During visual analysis of thermographic images, it has been found that at a voltage from 5 to 15V the heating is uniform, while at a voltage from 15 to 35V, there appear temperature singularities (Fig. 13) in the form of vertical hotter areas of the sample, where the temperature reaches 60—90 °C, whereas the middle part is heated up to 30—40 °C, and does not exceed 30 °C at the ends with electrodes.

The nonuniform temperature distribution may be associated with changes in the composition of the coating, as well as with the topological non-uniform distribution of its thickness.

e) Study of the elasto-optical effect in quartz glass samples

The elasto-optical effect in a quartz glass sample in which mechanical stresses σ (y, t) and optical anisotropy are induced in time and space by heat flux has been studied theoretically and experi-



a *b* *c* *d*

Fig. 12. Thermogram of SC without defects (*a*); pixel-by-pixel temperature distribution of SC without defects along the OX axis (*b*); thermogram of the backside of a PSC with a power of 30 W in the flow of direct dark current (*c*); thermogram of SC under reverse dark current with a temperature in the defect zone of 72 °C (*d*)

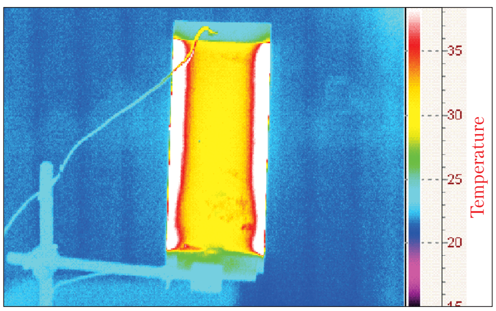
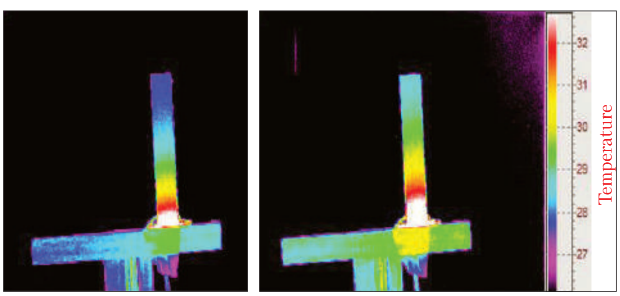


Fig. 13. Thermogram of nonuniform heating of the manufactured sample at a voltage of 30V, AC



a *b*

Fig. 14. Thermographic visualization of quartz glass samples at different points in time ($t_a < t_b$) in contact with the lower end of the heater

mentally with the use of the technique of modulation polarimetry and the IRT method. The problem of thermoelasticity induced by thermal radiation has been thoroughly covered in monograph [57].

The thermograms of quartz glass samples used for studying the elasto-optical effect are shown in Fig. 14.

The optical scheme of the experiment is shown in Fig. 15. The improved photoelastic method with the use of a polarization modulator (pos. 5) enables increasing its ability to detect the value of thermoelasticity sufficient for its reliable registration in conditions of a temperature difference of few fractions of a degree at the sample ends.

From the experimental thermographic images, there have been obtained the temperature kinetics data at certain points of the *y*-coordinate (Fig. 16, *a*) in a sample of quartz glass in the direction of the heat flux of the contact origin from a heater with a power of ~ 1 W at different times of thermal stresses $\sigma_y(t)$.

The experimental curves presented in Fig. 16, *b* is the result of the thermally stressed state of the sample during its contact heating, given the heat release in the sample caused by absorption and emission of thermal energy. A qualitative coincidence of the temperature function ΔT (*t*) that is obtained by integrating the experimental function σ (*t*) and the color temperatures shown in Fig. 14 has been established.

It is known that mechanical stresses σ (*y*, *t*) in solids are caused by the nonlinearity of the temperature function, which is expressed by equation div (grad *T*) ≠ 0. Therefore, with the help of functions σ (*y*, *t*) measured at certain points in time and at certain coordinates in the direction of heat flow, the dependences T (y, t) may be obtained by the graphical integration method.

The reason for this action is Poisson's law $\frac{\sigma^2 T}{\sigma y^2} = \frac{\sigma}{\tau}$, which connects the temperature nonuniformity with stress values, which are satisfactorily consistent with the experimental data.

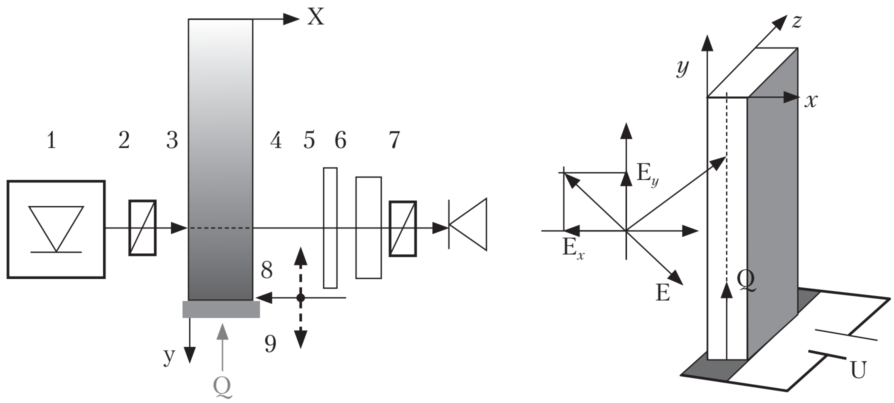


Fig. 15. Optical scheme of the experiment (*a*): 1 — laser diode; 2, 6 — polarizer; 3 — sample; 4 — compensation phase plate; 5 — polarization modulator; 7 — photodetector; 8 — device for moving the sample along the *y*-axis; geometry of the experiment (*b*): *E* is electric field of the radiation wave; *Q* is the direction of heat flow from contact heating; *U* is power supply source of the heater

The obtained results have been analyzed given, first of all, the fact that the amplitudes of the dependences in Fig. 16 are determined by relation div (grad *T*) ~ σ (y). This means that the strain of elastic solid, which is induced by nonuniform temperature gradient, is described by the Poisson equation

$$\frac{\sigma^2 T}{\sigma y^2} = -\frac{\sigma}{\eta}, \tag{1}$$

where σ is the normal component of mechanical stress relative to one of the coordinates; 1/η is the coefficient of proportionality.

In this case, the operation of double graphical integration of experimental function σ (*y*) has made it possible to obtain the coordinate dependence of temperature T (*y*) thereby supporting the definite integral condition by appropriate actions.

The first of them is to establish the constant component of the temperature function, which is determined by the smaller temperature at the end of the sample and is lost during differentiation. The second condition is to establish the relationship between the absolute second derivatives of function ΔT (*y*) and function σ (*y*) as the boundaries of the integral. The results of the mechanical stress distribution are shown in Fig.17 in absolute values, with the use of the calibration of the measuring system sensitivity.

Conclusion. The authors of the research have studied several important applications of the modern

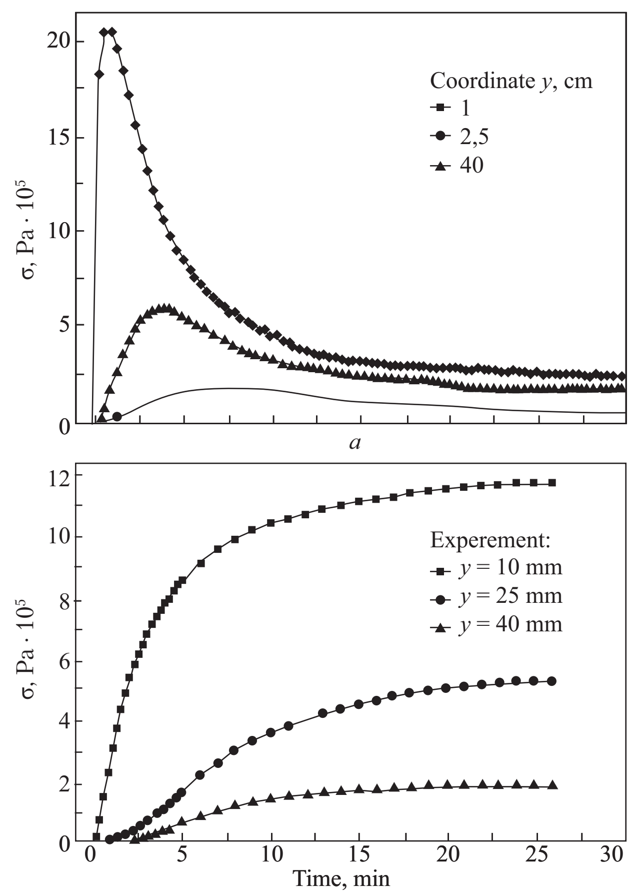


Fig. 16. The kinetics of thermal stress σ(*t*) at three points of the *y*-coordinate (*a*); the kinetics of temperature values obtained by integrating functions σ (*t*) (*b*) based on the data presented in Fig. *a*

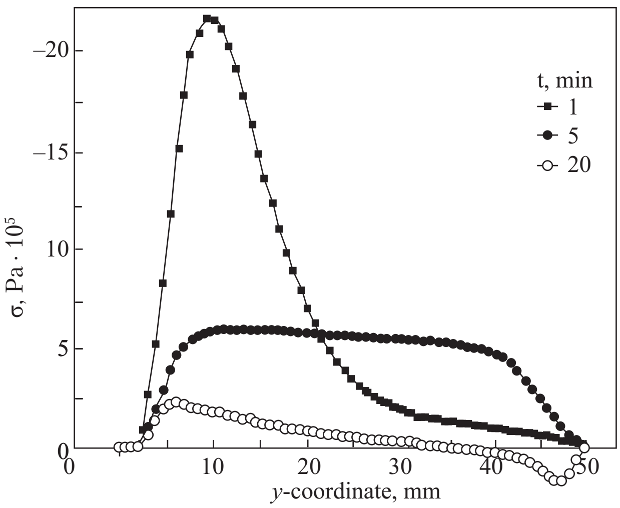


Fig. 17. Coordinate distribution of thermal stress σ (y) caused by a heat flux of the contact origin from a 1 W heater, at different time

IRT method in scholarly research, engineering, and biomedical fields. New results with the use of the IRT method have been obtained. The effectiveness of this method in solving problems during research has been demonstrated by specific examples.

In medical practice, the IRT method allows detecting the initial process of pathological changes in the body of BO at the early preclinical stages and starting the treatment in a timely manner. In addition, the medical IRT method is an effective and completely safe diagnostic tool for mass screening of the population to identify patients during pandemics.

The studies of the effect of EMR on the state of BO, with the use of thermography, have demonstrated versatile capabilities of the method, which enable not only making qualitative studies in the IR spectrum, selecting the essential features, and classifying the object of study, but also measuring temperature in the area of interest.

The IRT method allows obtaining additional research results during clinical trials of drugs, which increases their efficacy and safety for the BO organism.

In agro-industrial sector, it is important to develop methods for the timely detection of product damage and the study of plant hydration processes, which has become especially important in recent years, as a result of a sharp decline in water resources of Ukraine.

In terms of conducting research, the IRT method simplifies the experimental work and allows obtaining results that are not available by other methods.

It has been shown that the use of the IRT method enables detecting defects of solar cells, determining the degree of uniformity of thin film coating, studying the elasto-optical effect with the help of modulation polarimetry, measuring temperature in certain areas with a high accuracy, and applying IRT for environmental needs.

Hence, the IRT method is an effective and promising tool in modern scholarly research and engineering applications.

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ІНФРАЧЕРВОНА ТЕРМОГРАФІЯ — ЕФЕКТИВНИЙ ІНСТРУМЕНТ СУЧАСНОГО НАУКОВО-ТЕХНІЧНОГО ЗАСТОСУВАННЯ

Вступ. Підвищення інформативності та ефективності наукових досліджень шляхом застосування інфрачервоної термографії є важливим завданням сучасної науки та промисловості.

Проблематика. Інфрачервона термографія в останні роки набула суттєвого значення у проведенні досліджень у фізиці, медицині, промисловості тощо. Застосування високоточних та швидкодіючих термографів з високою роздільною здатністю відкриває нові можливості термографії. Широке впровадження зазначеного методу досліджень та його практичне застосування стримується у зв'язку із недостатньою кількістю наукових праць щодо інтерпретації термографічних зображень, відсутністю комплексних робіт, які всебічно розкривають можливості методу. Впровадження дистанційної інфрачервоної термографії є актуальним питанням науково-прикладного значення.

Мета. Показати можливості та доступність методу термографії в різних галузях діяльності людини. Детально проаналізувати термографічні зображення.

Матеріали та методи. Використано термограф з матричним фотоприймачем вітчизняного виробництва. Деякі дослідження виконано з використанням термографа фірми FLIR Systems (США).

Результати. Показано, що термографія є сучасним, високоточним, кількісним методом досліджень, що значно розширює інструментальну базу під час виконання наукових досліджень. На конкретних прикладах показано можливості термографії у підвищенні інформативності під час виконання як наукових досліджень, так і у практичному застосуванні.

Висновки. Отримано нові наукові та практичні результати використання інфрачервоної термографії, які показали ефективність методу, що дозволяє внести термографію в потужний інструмент сучасних наукових досліджень широкого спектру. Впровадження методу суттєво розширює інструментальну базу сучасних науково-практичних досліджень.

Ключові слова: термографія, наука, дослідження, біологічний об'єкт, температура.