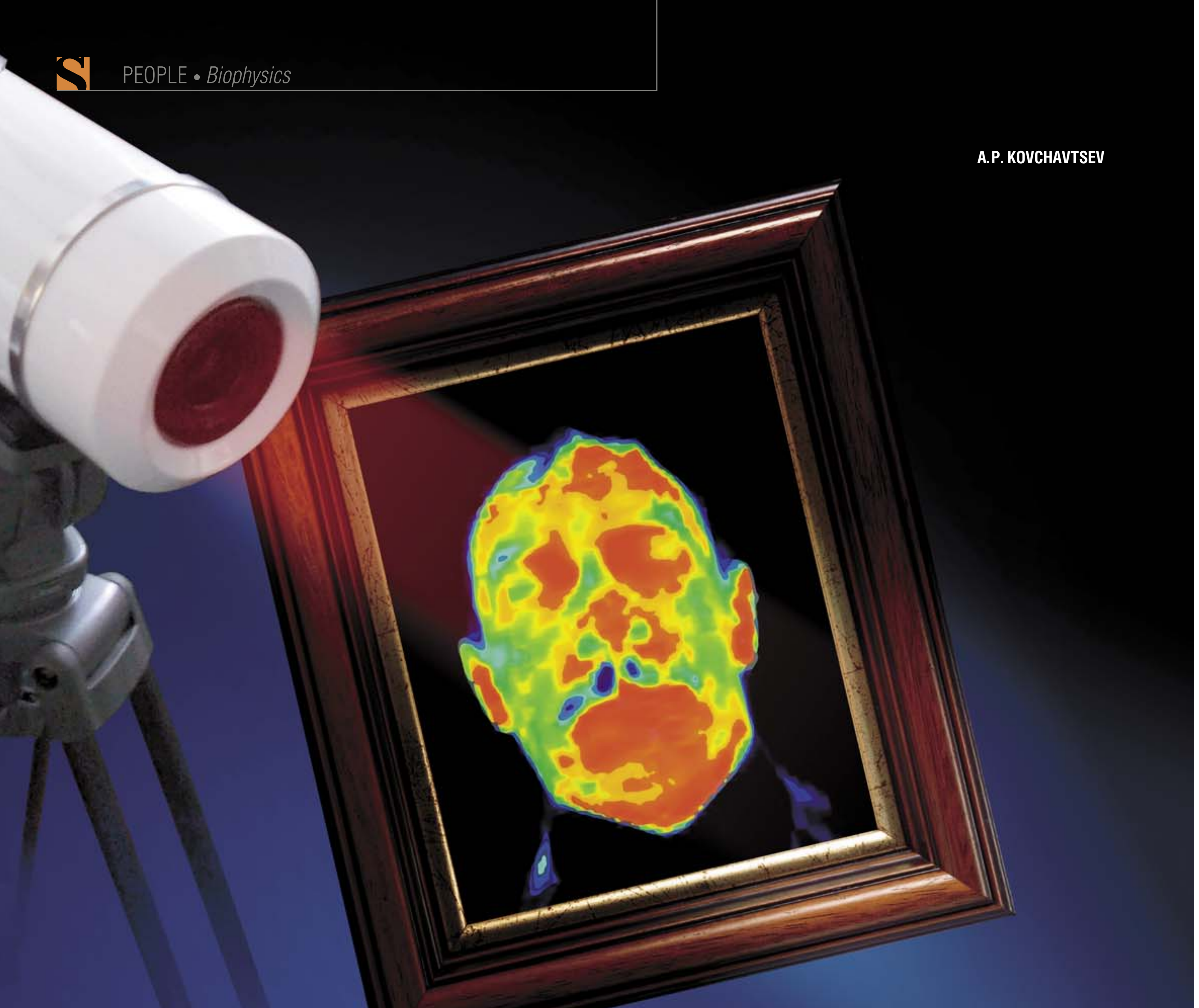
A. P. KOVCHAVTSEV



INFRARED IMAGER

it is better to see once

It is known that the human eye can capture electromagnetic radiation only in a narrow range of wavelengths referring to visible light. However, the spectrum of photons emitted by various objects is much wider. It is possible to see many useful and interesting details by considering living and dead objects in infrared (IR) light. Such IR images can be obtained by using special devices, i.e., IR imagers, which can clearly present the changes in the temperature of various bodies, accurately measure their temperature, and even be used for diagnosing various diseases at the early stages of development

Surprisingly, the first sensors responding to IR radiation were fabricated back in 1830. These sensors were based on thermocouples, which transformed heat to electric voltage. Half a century later, thermoresistive materials were discovered. The resistance of these materials is temperature-dependent, and they were used to develop radiation detectors (bolometers).

In 1920, there appeared photon radiation detectors (photoresistances and photodiodes) on the basis of semiconductor materials, where incident radiation quanta were directly transformed to the electrical signal. Such detectors ensured a higher sensitivity and performance. In 1944, photodetectors on the basis of lead sulphide were developed; the sensitivity of these photodetectors was focused in the spectral range from 1.5 to 3 μm.

By the middle of the last century, the spectral range of photodetector sensitivity was extended to the middle infrared (IR) range (3—5 μm) by using detectors based on indium antimonide; in the 1960s, it was further extended to the far IR range (8—14 μm) by using the mercury-cadmium-telluride alloys as a basis.

These semiconductor photon receivers are used in advanced IR imagers, which are widely used for the visualization of versatile objects in the IR range.

In the first devices, the IR image was obtained by one detector by scanning the examined object with rotating prisms in the vertical and horizontal directions. More recent devices are based on multielement radiation detectors (arrays and matrices).

Clear and accurate

The development of IR imagers opened up new prospects in studying thermal processes. These devices ensure visualization of the temperature distribution and provide clear and, importantly, precise information on the degree of heating of the various areas of the object being examined. Seeing an integral pattern of changes that occur in the object allows researchers to better and faster understand the physical meaning of the phenomenon.

As an illustration, let us consider the dynamics of the falling of a heated (up to 38 °C) water drop onto the water surface at room temperature. It is difficult to image any other method (except for IR imaging) that would provide such a detailed image of this rather complicated and fast process, which lasts less than 0.2 s.

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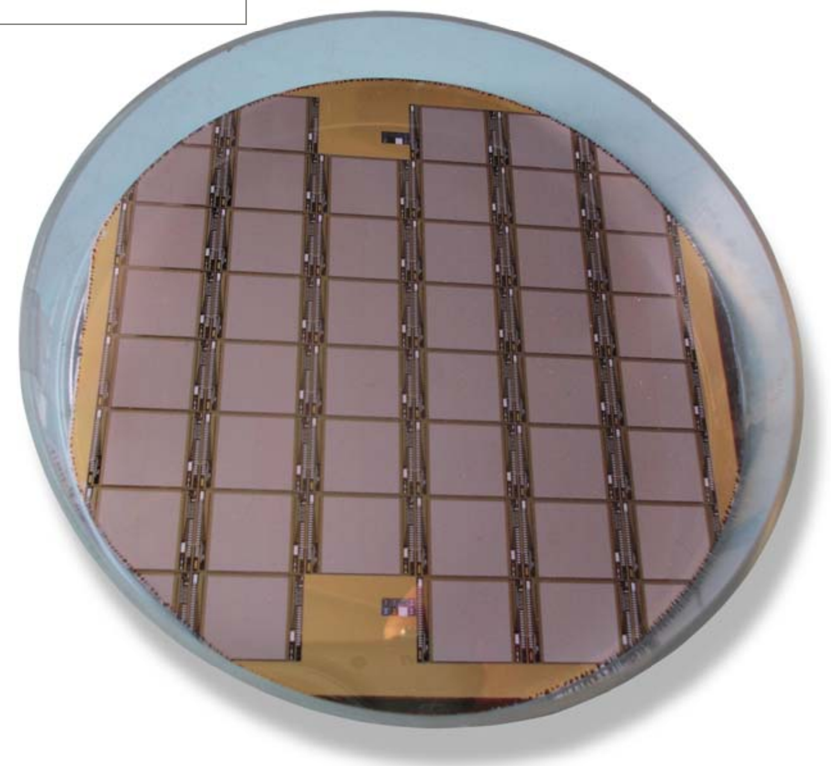
Key words: microelectronics, temperature measurement, integral circuit, medical testing

The SVIT infrared imager was developed under the supervision of Professor G. L. Kuryshev, Doctor of Physics and Mathematics, head of the Laboratory of Microelectronics of the Rzhanov Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences (1945 — 2012).
Since the 1990s, he intensely worked in the field of photoelectronics, namely, he was involved in the development of multielement photodetectors for the near and middle IR ranges. In addition to SVIT, it is necessary to mention the IR scanning microscope of high spatial resolution and the spectrometer based on line photodetectors.



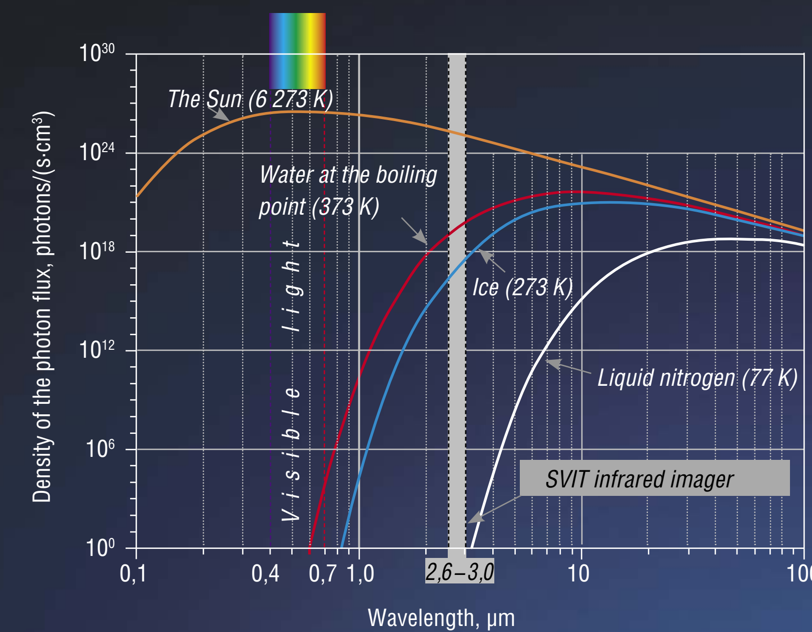
Silicon multiplexors are important elements of the matrix of the SVIT infrared imager, which is sensitive to IR radiation. They are integral circuits assembled on one crystal, which are designed for the detection, amplification, and preliminary processing of signals of the array of sensors sensitive to IR radiation.
In the course of assembling, the multiplexors are mounted on the matrix by means of cold welding. The figure shows a commercial array of multiplexors assembled on a single technological plate

Thus, a warm spherical drop surrounded by a colder thin water shell separates from the end of the dropper. As the drop falls down, the drop surface is cooled. Approximately in 0.1 s, the drop hits cold water; the cold shell of the drop is destroyed, but the interior of the drop remains heated. Further, a water plume is formed above some part of the drop that has fallen into water; a small droplet separates from the plume, moves upward, and also cools down. At a certain time instant, this “daughter” drop hovers, and its surface is heated owing to water thermal conductivity because the droplet remains warm inside. Falling down, the droplet cools down, but the IR imager “sees” the heated interior of the droplet even when the latter falls onto the water surface. Investigation of the behavior of a heated drop is a good model problem, which is extremely useful for studying thermophysics and hydrodynamics of jet flows and emulsion formation.

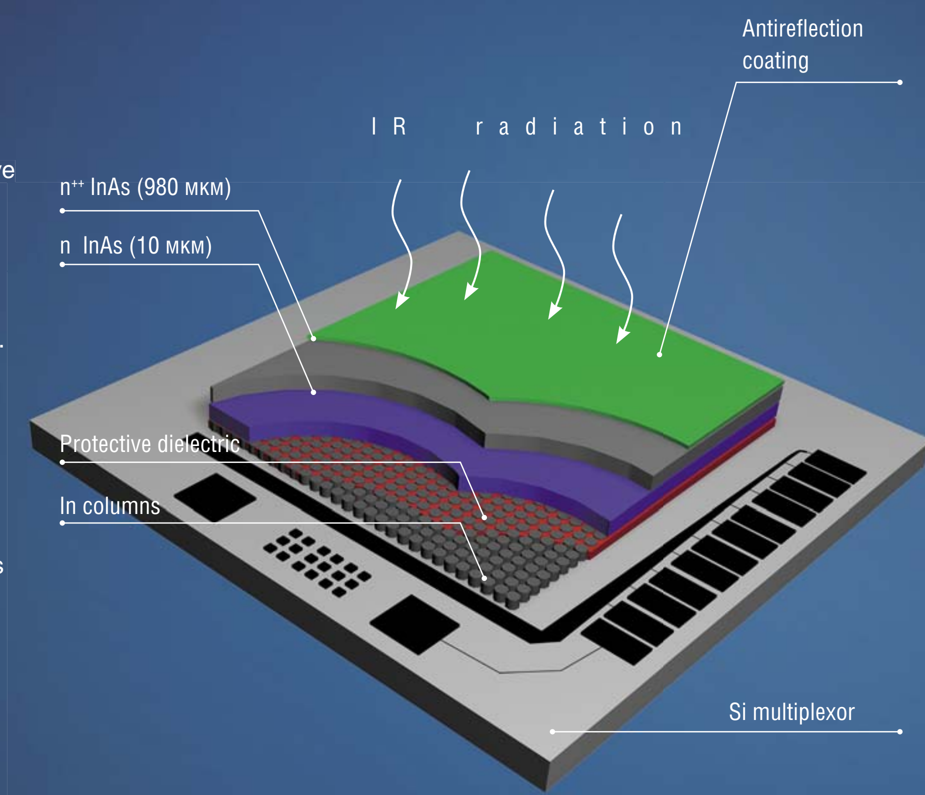
Another interesting effect can be observed when a water drop at room temperature is absorbed by a dry fabric. At the outset, only the uniformly heated smooth surface of the fabric is seen. Later on, a temperature halo (a red ring) appears around the drop; the temperature in this ring is 6 °C higher than the temperature at the middle of the drop. The halo moves over the fabric together with the front of absorbed water and exists only for a short time.

The observed heating is related to the release of absorption heat in fabric capillaries. The greater the absorption capability of the fabric, the more pronounced this effect: for instance, it is weakly expressed or even absent in synthetic fabrics.

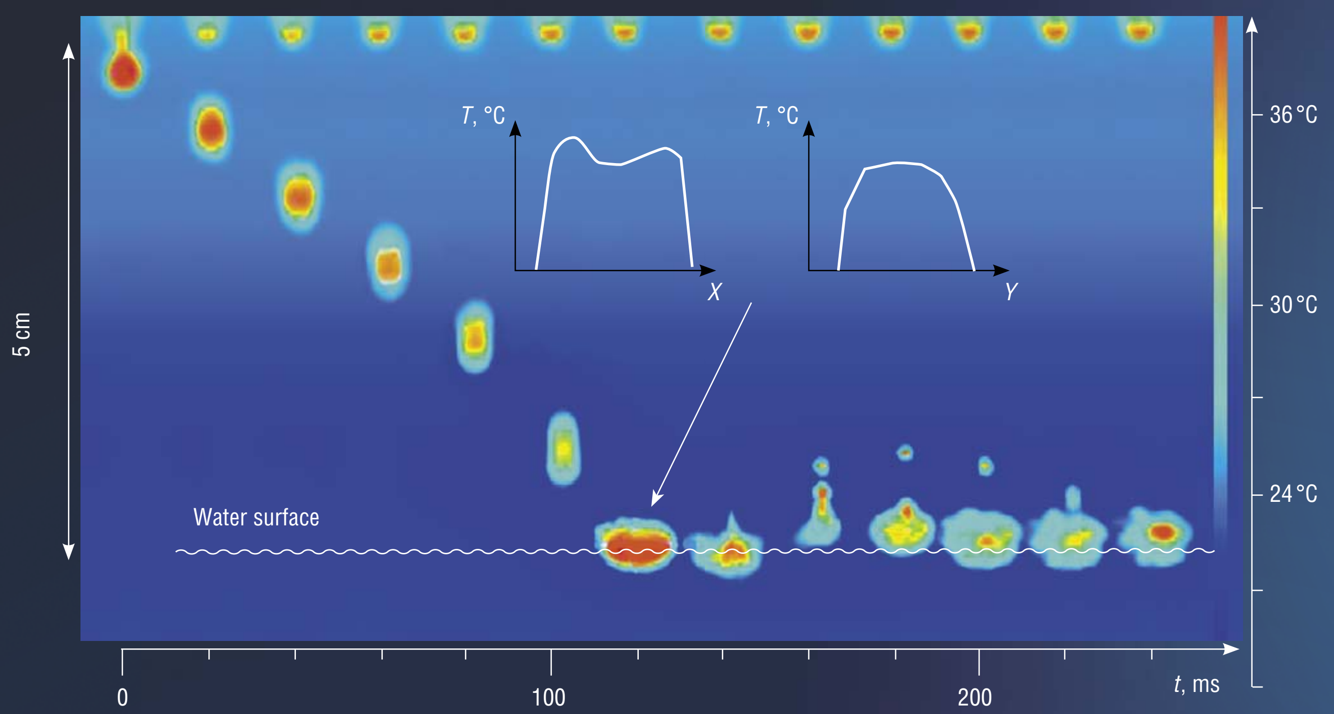
Spectra of radiation of bodies having different temperatures



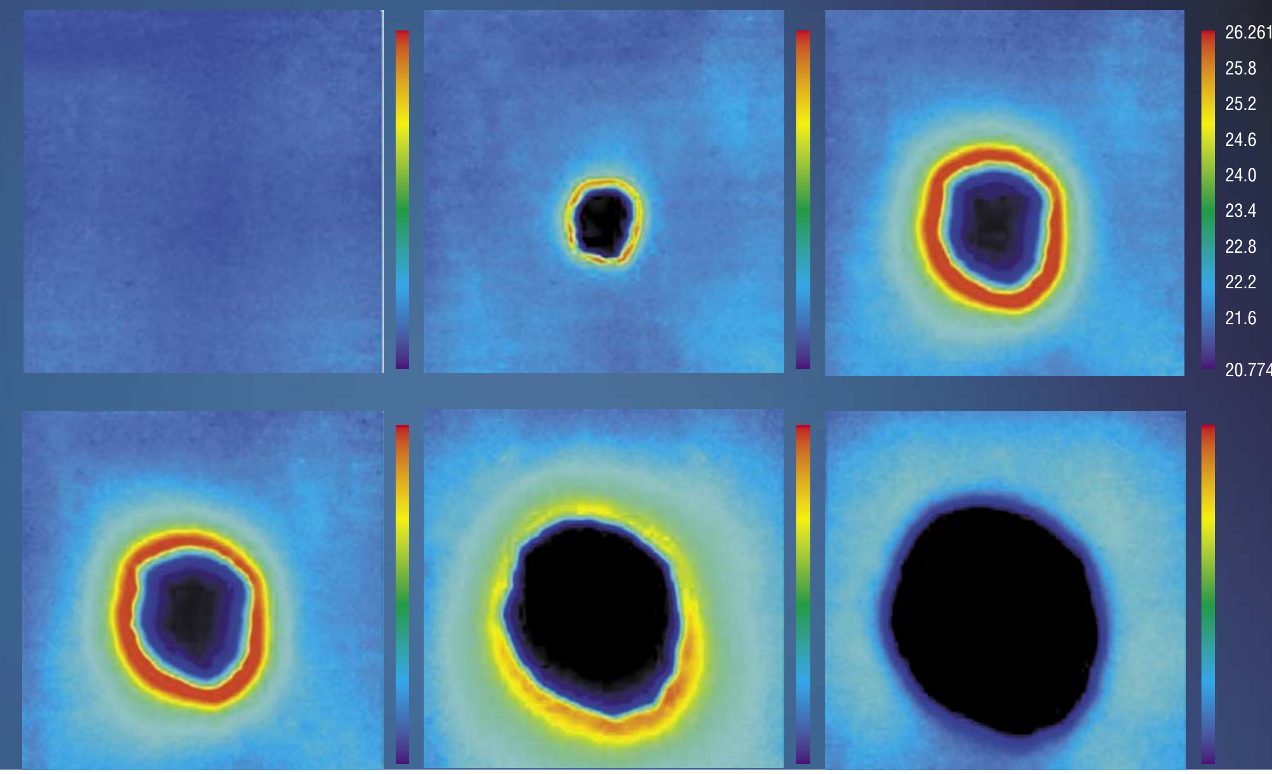
The character of the spectrum of IR radiation of various bodies, i.e., the intensity of radiation in a certain range of wavelengths, depends on their temperature. The SVIT infrared imager is capable of detecting IR radiation in a comparatively narrow range of wavelengths. The value of the IR imager signal can be correlated with the body temperature by using Planck’s law, which describes the dependence of the radiative capability of a blackbody on the temperature and wavelength. *Drawing by I. V. Mzhel’skii (Rzhanov Institute of Semiconductor Physics SB RAS)*



The hybrid photosensitive circuit consists of an array of photosensitive MIS capacitors (16,384 pieces) and a silicon multiplexor with individual readout cells for signals from each capacitor. The antireflection coating reduces spurious reflection from the nonplanar polished n^{++} InAs surface. Absorption of quanta occurs in the epitaxial n InAs layer. The indium columns ensure mechanical and electrical connection of the focal matrix elements with the readout cells of the Si multiplexor after alignment and compression of the crystals. In this case, the In columns become flattened and welded to each other (cold welding). The size of the photosensitive elements is 40×40 μm, and the step between them is 50 μm.
Drawing by I. V. Mzhel’skii (Rzhanov Institute of Semiconductor Physics SB RAS)



Using the IR imager, it is possible to obtain the time evolution of falling of a heated water drop onto the water surface at room temperature. The behavior of such a drop is a good model that can be used for studying thermophysics and hydrodynamics of jet flows and emulsion formation.
The insets show the temperature profiles over the drop cross section at the instant of its submerging into water.
Experiment performed by V.M. Bazovkin (Rzhanov Institute of Semiconductor Physics SB RAS)



When a water drop is absorbed by a dry fabric (in the case considered, coarse calico), an interesting phenomenon is observed: a halo is formed around the drop, and the halo temperature is higher by almost 6 °C. This effect has to be studied and should be taken into account for the development of clothes and underwear to be used in sport and medicine.
Photo by A.E. Nastov'yak (Rzhanov Institute of Semiconductor Physics SB RAS)

This phenomenon has applications in the studies of various absorbents, such as zeolites, or in development of fabrics for sport and medicine.

A clear example of IR imager applications is visualization of the so-called Benard cells, which are dissipative self-organizing structures formed in nonuniformly heated fluids during the origination of turbulent flows. The device provides an almost instantaneous pattern of the temperature distribution and allows one to detect the shape of convective cells being formed and to estimate their scale.

The IR imager can be effectively used in searching for the defects of printed boards, based on the overheating of electron components. By adding a special IR microscopic objective to the IR imager, it is possible to fabricate an IR scanning microscope of high spatial resolution. Such a device can be used, for instance, for studying radiation nonuniformity in IR light-emitting diodes.

"Thermal portrait" of a disease

The IR imager can be successfully applied to study numerous thermal processes where the surface temperature is nonuniform and changes rapidly. Obviously, the class of such objects includes human beings as well. A thermographic team of researchers headed by V.Ya. Belen'kii, V.V. Ivlyushkin (LLC Health Service), V.V. Stupak, Doctor of Medicine, and S.V. Pushkarev, Doctor of Medicine, (now deceased) develops new IR imaging methods to diagnose the initial stages of some diseases.

What is the first thing you do if you suddenly feel sick? Take your temperature, of course! The thermographic diagnostics is based on the fact that temperature is one of the main features that characterize the state of the human health. The temperature palette of the human body reveals its ability to adapt to changes in the ambient medium and stresses and reflects the current physiological state of the body.

The temperature on the human body surface changes because of the activity of the autonomic nervous system, which controls the blood content in the subcutaneous vascular tree in reflexogenic zones corresponding to this or that viscus. Observing these zones, we detect not the structural features of viscera, as it is done by ultrasonic, X-ray, and other methods of active beam diagnostics but functional changes, which bear information about the normal and pathological processes in the organism.

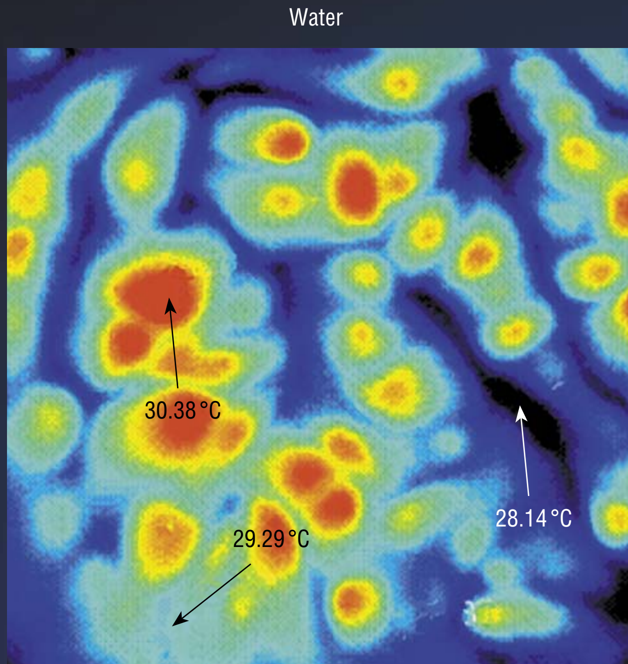
Based on this approach, the early diagnostics of various diseases - from oncology to dentistry - was developed. IR imaging diagnostics is eversafe. Actually, it does not differ from usual video recording, but it can be used to monitor the state of the human body and to estimate the efficiency of medical treatment. The thermogram yields the "thermal portrait" of the disease almost instantaneously. Based on this information, an experienced physician can easily diagnose and estimate the stage of the disease development.

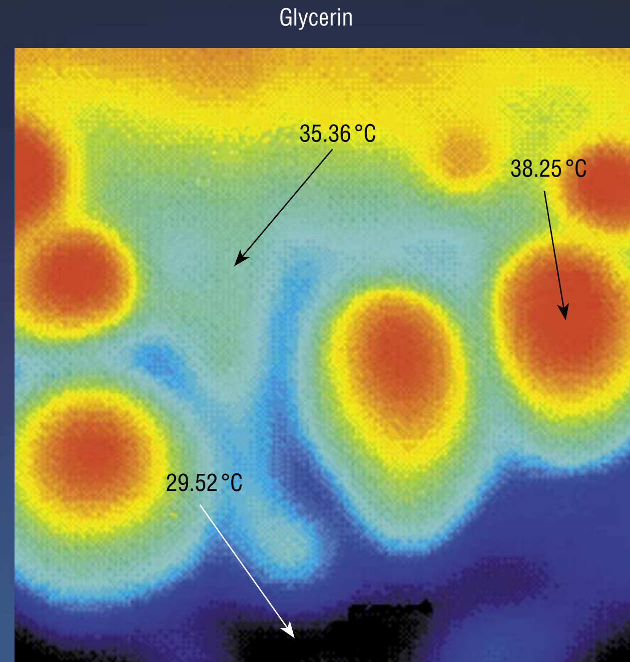
SVIT's infrared eye

The matrix IR imager called SVIT, which allows real-time recording of the IR images of various objects with the ultimate temperature resolution of 7 mK, was developed at the Laboratory of Microelectronics of the Rzhanov Institute of Semiconductor Physics SB RAS. This unique tool is designed for the measurements of temperature fields and visual analysis of static and time-dependent patterns of the thermal state of various objects to be used in the area of medical and scientific thermography.

The main advantages of SVIT over its foreign analogs (there are no Russian analogs of this device) are its availability and a lower (by a factor of 3-4) cost. Moreover, it was certified as a medical instrument in Russia (Ross Ru.AYa79.R15452) and in Europe (EC CERTIFICATE N110176QS/NB).

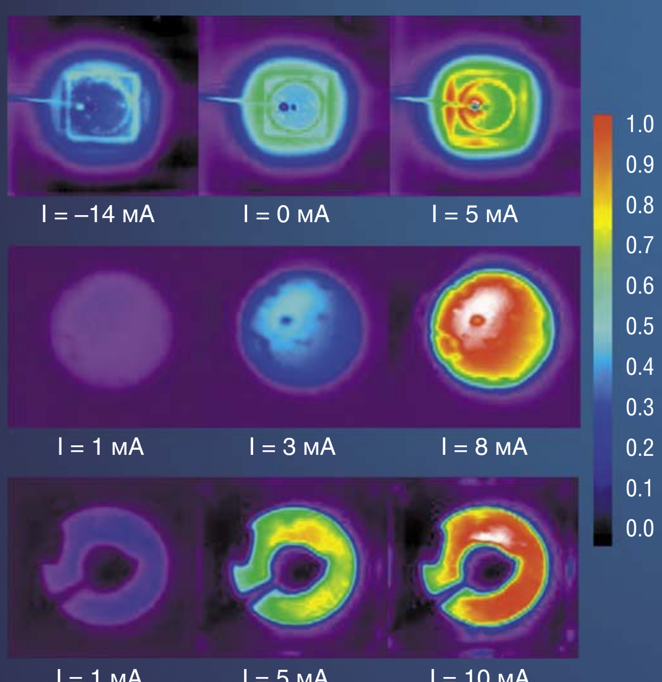
The object image is formed in SVIT by a special IR objective and is detected by a matrix radiation detector mounted in the focal plane of the objective. As the magnitude of the

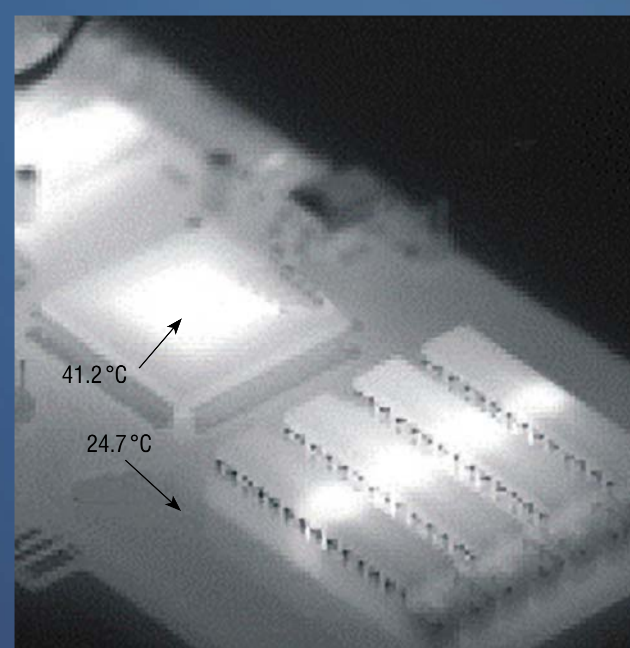


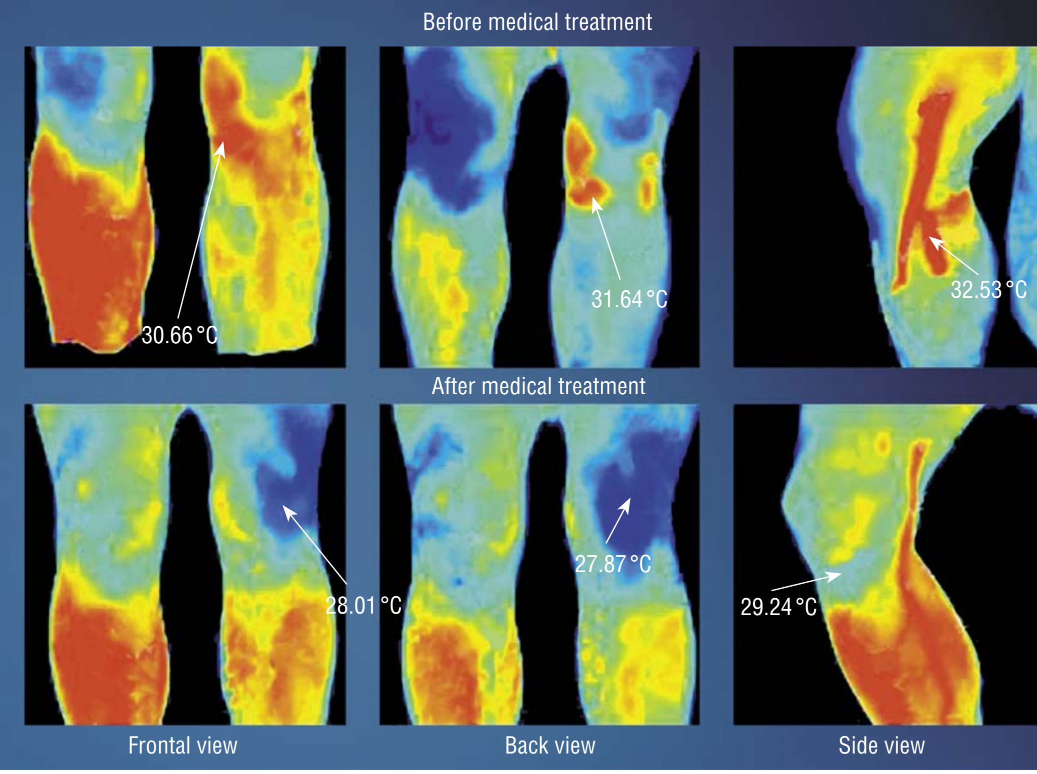


Clear and useful information can be obtained by studying convective phenomena (the so-called Benard cells arising in the case of slow heating of a liquid from below) by means of IR imaging. The thermogram allows accurate measurements of the spatial distribution of the temperature field

In fabrication of IR diodes, it is important to ensure uniform radiation (the figure in the middle row on the left). The IR microscope ensures monitoring of the equality of light-emitting diodes with different configurations: the figure shows three types of diodes; the upper row of the samples demonstrates significant nonuniformityof radiation. *Ioffe Physical Technical Institute of the Russian Academy of Sciences. Photo by I. V. Mzhel'skii and S.M. Kozhevnikov (Rzhanov Institute of Semiconductor Physics SB RAS, Novosibirsk)*







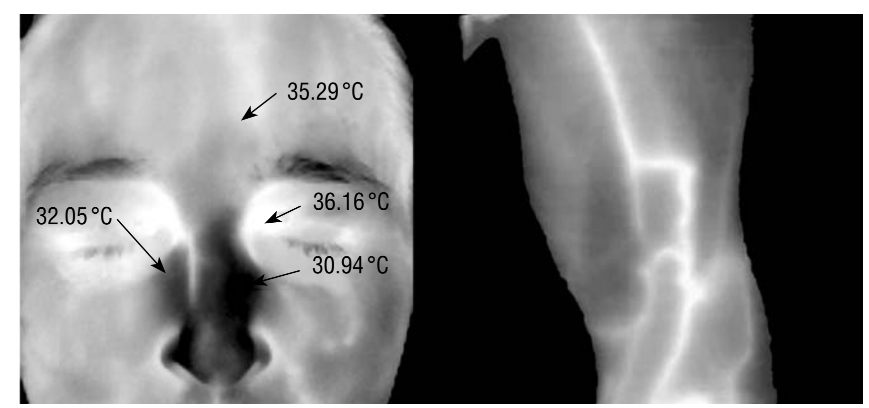
The thermogram helps the physician to control the process of healing of the injury of the left knee

Thermogram of a board with ADC and memory microchips (standard operation mode). If there are malfunctions of some microchips, their positions can be diagnosed by an increase in temperature. *Photo by V.M. Bazovkin (Rzhanov Institute of Semiconductor Physics SB RAS)*

output signal from the photosensitive elements of the detector is proportional to the object temperature, the image can be visualized as a black-and-white or colored thermogram.

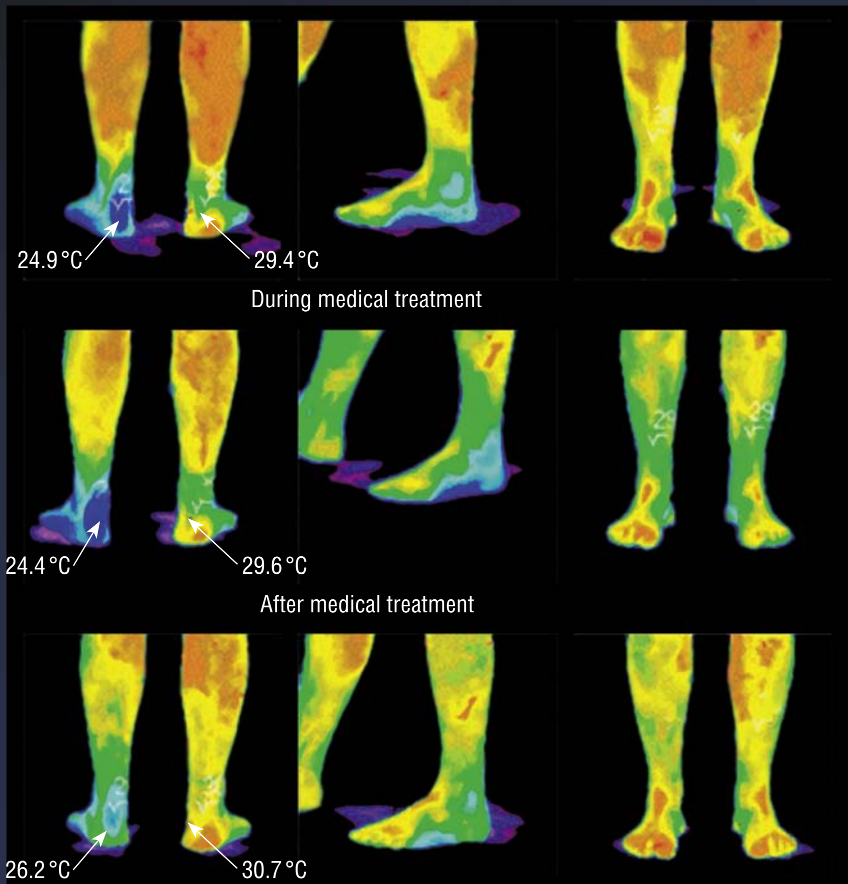
The IR radiation detector is a hybrid integral circuit consisting of InAs-based semiconductor capacitors mounted on a cooled pedestal of a cryostat. The photosensitive elements of the semiconductor matrix transform light quanta into electric charges, which are read out by another integral circuit (Si multiplexor), amplified, transformed, and fed to a computer.

Black or violet color can be assigned to the minimum signal intensity, white or red color can be assigned to the maximum signal intensity, and the intermediate signal intensities can be uniformly distributed over 256 grades of gray or color shades. As a result, the monitor shows a color or black-and-white IR image of the object, i.e., a thermogram, which allows the object to be observed "in IR beams."



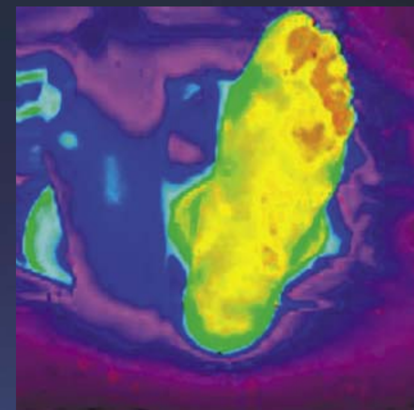
The thermogram can be used for diagnostic purposes: the inflammatory process in the Highmore antrum is evidenced by the temperature asymmetry in the nose region *(left)*; the varicose disease is evidenced by the varicose veins of the lower limb, which are "marked" by high temperature *(right)*

Before medical treatment

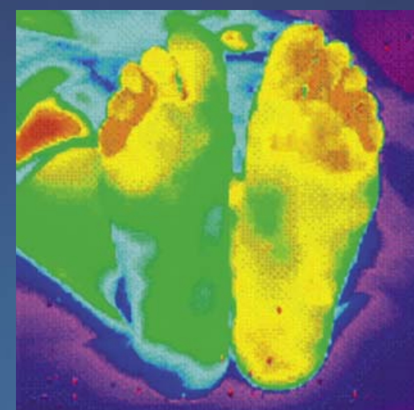


Diabetic foot: the affected foot has a lower temperature than the healthy foot. The increase in temperature after medical treatment testifies to the recovery of blood circulation in damaged areas and to medical treatment effectiveness

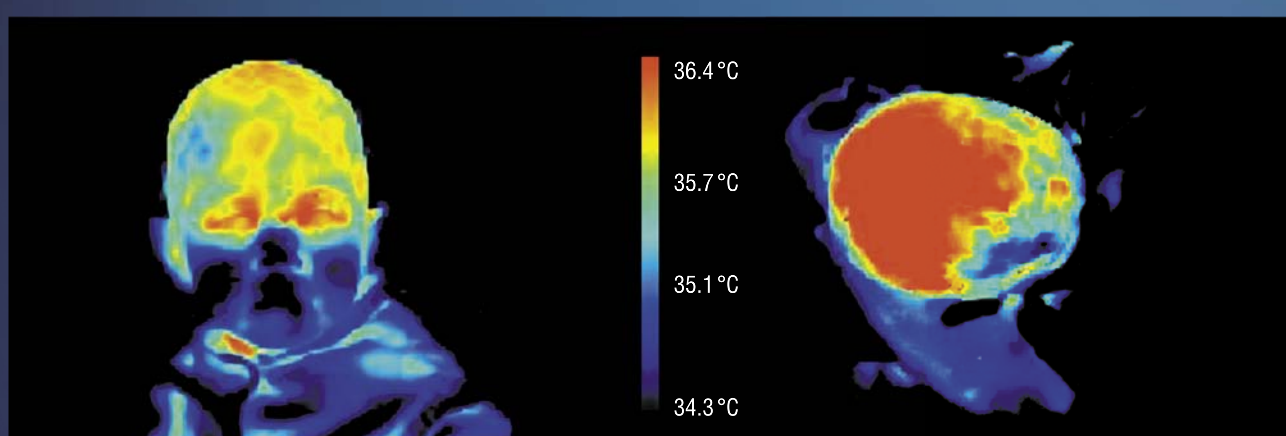
Before medical treatment



After medical treatment

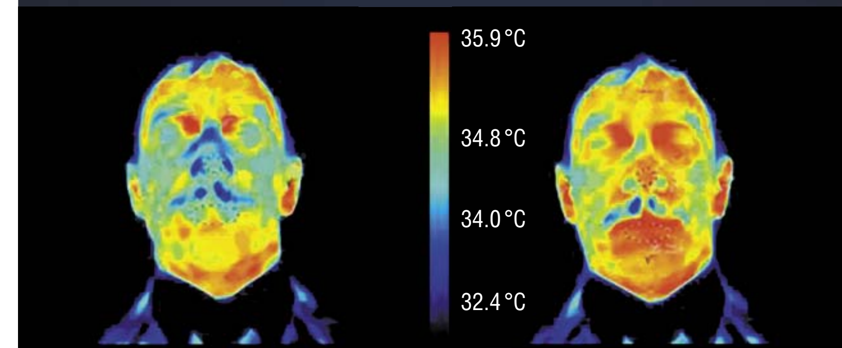


Diabetic foot (the right foot is injured). The increase in temperature, which testifies to the recovery of blood circulation, is clearly visible

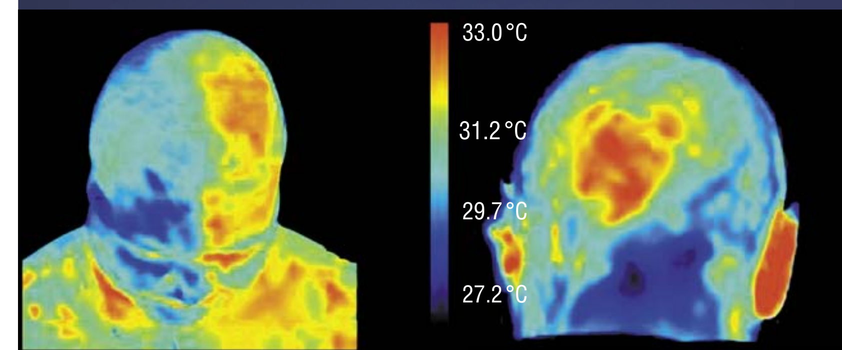


Being hit on his head from the left side, this patient had an injury on the right side. The bruise is seen in the thermograms of two projections of the patient's head as lower temperature area. In this way, the injured area to be operated was determined

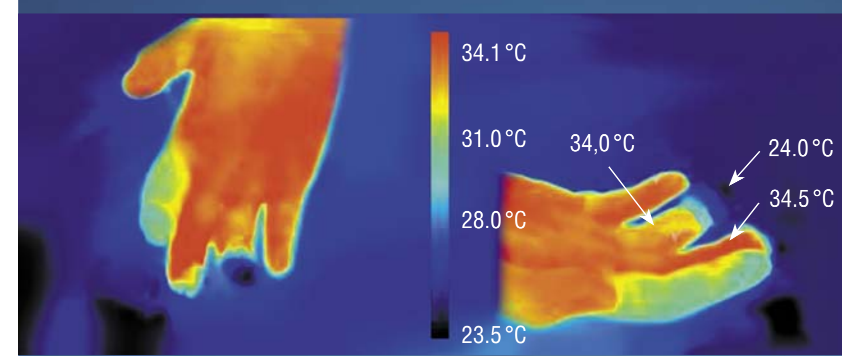
The increase in the temperature of the face of a healthy test person in five minutes after swallowing the "Yantar antitoks" (Amber antitox) biologically active additive *(right)* occurs owing to improvement of blood circulation



Malignant neoplasms are characterized by an elevated temperature; therefore, the face thermogram ensures localization of tumors in the cases of the Hodgkin's disease *(left)* and meningioma *(right)*



The necrosis of the ring-finger phalanx is evidenced by a lower temperature of the affected finger



Photos by V. Belen'kii, S. V. Pushkarev, V. V. Ivlyushin (Health Service Joint-Stock Company), and V. V. Stupak (Tsev'yan Institute of Trauma Surgery and Orthopedics, Novosibirsk)

Modern technologies make it possible to visualize things that cannot be detected by the human eye, thus appreciably extending the capabilities of science, industry, and medicine. For instance, by using the "infrared eye" of the IR imager, it is possible to detect the disease at an extremely early stage, avoiding the use of other (more complicated and painful) diagnostic procedures.

A particular advantage of the IR imager is its ability to give a clear pattern of the temperature field of the object being examined rather than a mere list of numbers. As a result, it is possible to see the relationships between various phenomena and to catch the general trends of the occurring processes. At the same time, the IR imager provides extremely accurate data on the object temperature. Owing to such a unique combination of clear visualization and accuracy, IR imagers have very promising applications in various areas of human activities.

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