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Thermal radiation shielding by nanoporous membranes based on anodic alumina

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Thermal radiation shielding by nanoporous membranes based on anodic alumina

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Abstract. The paper is devoted to infrared thermography studies of nanoporous alumina membranes with various geometric parameters of the porous layer: its thickness and average pore diameter. Thermal radiation shielding by anodic alumina membranes is presented. The result obtained showed that nanoporous alumina membranes can be used as heat shields to smooth contrast of thermal radiation of the object and the surrounding background.

1. Introduction

Investigation of the optical properties of nanomaterials is an important task in modern solid state physics. This is because nanocomposite media are the basis on which to base development and create new materials with specified physical and optical properties, the parameters of which are determined by the size, shape, and density of nanoscale objects.

The properties of porous dielectrics are important in research. For example, the structure of nanoporous anodic aluminum oxide is formed by creating a uniformly distributed network of nano-sized channels in a bulk material. Therefore, the physical and optical properties of such nanoporous materials can be very different from those of the whole material. The procedure for obtaining nanoporous anodic aluminum oxide is simple. The properties of the porous structure can be controlled by changing the formation regimes [1, 2]. Technology features make alumina a very convenient object for studying physical phenomena in nanostructures. It is possible to note such important properties of porous anodic aluminum oxide as lower than in bulk aluminum oxide, the refractive index and the dielectric constant, as well as the ordered structure of nanosized pores.

In our previous works [3–5] we studied transmission spectra of thin alumina membranes in a wide range of wavelengths and analyzed spectral regions that characterized certain membrane properties. It was shown that porous alumina membranes significantly blocked infrared radiation in the range of 8–14 μm. This funding is a good agreement with [6]. Within the above limits, there is a maximum of thermal radiation from bio-objects at a wavelength of ≈10 μm (figure 1).

2. Experiment

In this paper, the processes of shielding the heat flux by porous anodic aluminum oxide with a nanosized structure using thermal imaging measurements were studied.

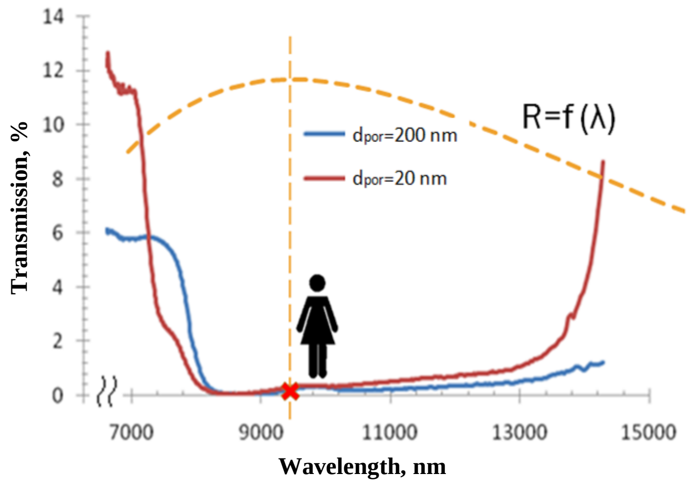

Figure 1. The IR transmission spectra of porous alumina membranes thickness of 10 μm and spectral distribution of blackbody radiation with temperature of 36.6 °C ($R = f(\lambda)$) [7].

The investigations were carried out using two thermal imagers: RGK TL-160 (temperature range –20…+350 °C) and uncooled infrared imaging camera system MobIR M4 (–20…+250 °C). The aluminum foil of 99.99 % purity, 100 μm thickness was used in the experiments. The specimens were etched in 1 M solution of NaOH and then in acetone. Then they were air-dried and thoroughly rinsed with distilled water and air-dried.

To prepare nanoporous anodic alumina with the highly ordered nanoporous structure the two-step anodizing process was used. At the first stage aluminum was anodized in 0.3 M aqueous solution of oxalic acid in the two-electrode cell equipped with Pt cathode at (15.0 ± 0.1) °C. The anodizing voltage was linearly increased from 0 to 40 V with the rate of 0.5 $V \cdot s^{-1}$, and then the anodizing process was carried out at a potentiostatic mode. The oxide layer was subsequently treated with chemical etching in the solutions of phosphoric and chromic acids. At the second stage the aluminum was iteratively anodized potentiostatically at 40 V. To form nanoporous anodic alumina films of different thicknesses (2–60 μm) the process was carried out during different periods of time. After anodizing the samples were rinsed and dried in hot air. Then from the opposite site to the anodic oxide the remaining aluminum layer was selectively etching. After complete metal dissolution the impermeable membrane was formed.

Anodic alumina membranes had ordered porous structure with a pore size of about 21 nm and the distance between them was 84 nm. The pores were oriented parallel to each other and arranged perpendicular to the growth surface, and possessed the same cylindrical shape.

Transmission of thermal energy to the object due to thermal radiation, accompanied by the processes of reflection or absorption of heat in the object, leads to the fact that its temperature varies on the environment. The main contribution to the observed thermal contrast is made by the object and background radiation. To visualize the thermal image of objects, two types of thermal imagers are used: cooled thermal imagers operating in the short-wave range (3–5 μm), and uncooled thermal imagers in the medium-wave range (8–14 μm). To detect and identify thermal objects, such as a person whose spectral wavelength of thermal radiation is 9.3 μm, uncooled thermal imagers are used.

As a source of heat radiation, the human palm was chosen. A Teflon plate (5 mm thickness) was applied as a heat shield. The plate had two 14 mm-diameter holes: the first one was used to arrange the samples and study the characteristics of the thermal shielding, and through the second one the thermal radiation passed without obstacles. Teflon plate (heat shield) was located above human palm (heat source), blocking the main heat radiation and passing it only through the described holes. The heat shield was located at the distance of 4 mm from the heat source.

3. Results and discussion

As a result of the studies, data on the temperature change of the object for various membranes were obtained (figure 2) and the temperature profile was constructed (figure 3).

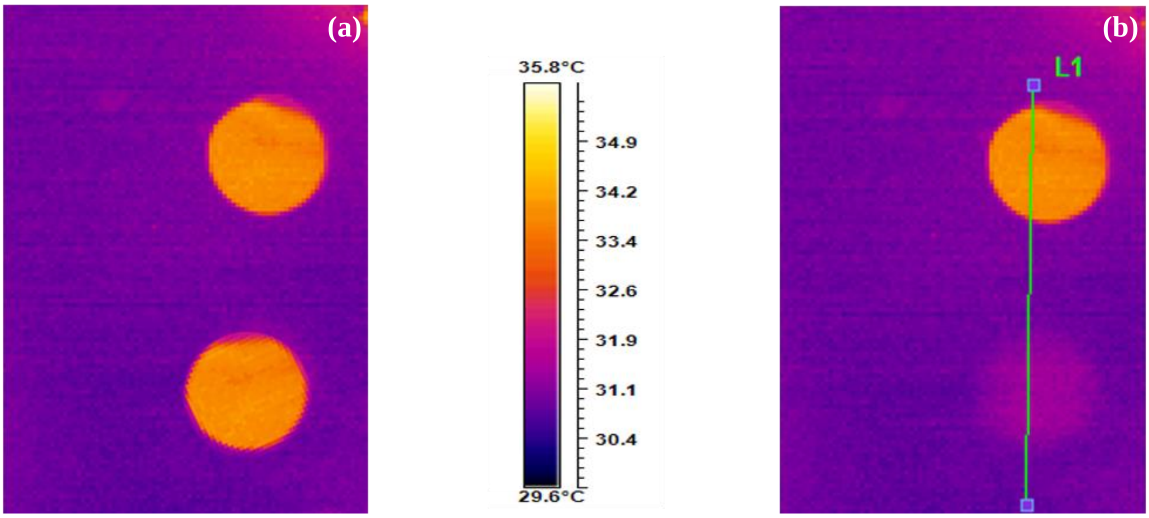

Figure 2. The results of thermal studies: an appearance of the bio-object through the lens of the thermal imaging camera for the case of **(a)** the passage of heat flow through the control and operation hole and **(b)** masking the operation hole with nanoporous anodic alumina.

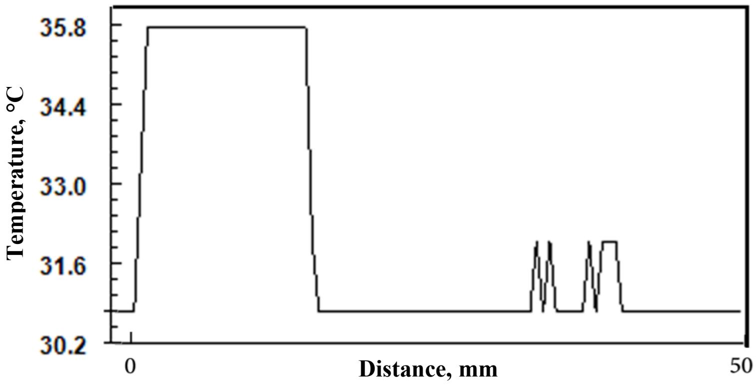

Figure 3. The temperature profile for the line passing through the control and operation holes.

In addition, the dependence of the change in the thermal temperature of the object on the thickness of the nanoporous alumina film was revealed (figure 4).

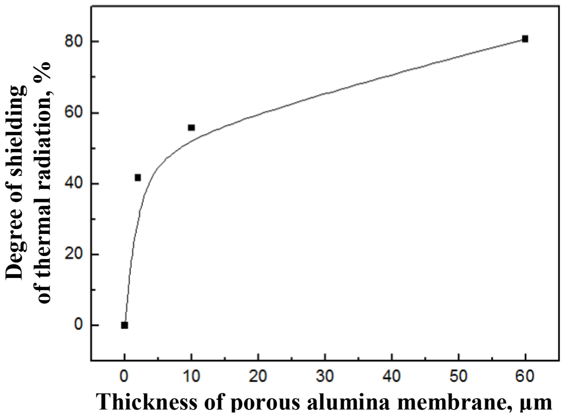

Figure 4. The curve of the degree of shielding vs. thickness of alumina membrane.

The degree of heat radiation shielding (D) for the anodic alumina membrane with thickness 10 μm has reached 56 %. To compute the degree of shielding the following equation was used

$$D = \frac{T_s - T_m}{T_s - T_{sh}} \cdot 100\,\%,$$

where T_s – temperature of heat source; T_m – temperature of membrane; T_{sh} – temperature of shield. This can be explained by the diffusive scattering of the optically inhomogeneous media [1], where the sources of inhomogeneity are small diameter pores.

The results showed that the use of porous anodic alumina films for shielding significantly reduced the passage of thermal radiation from heat sources and reduced the temperature of the heat spot emitted by the bioobject (human palm) from 37.1 to 32.0 °C (figure 2).

In addition, the studies of shielding radiation using a membrane thickness of 100 μm from a thermal source with a temperature of 68 °C were carried out (figure 5).

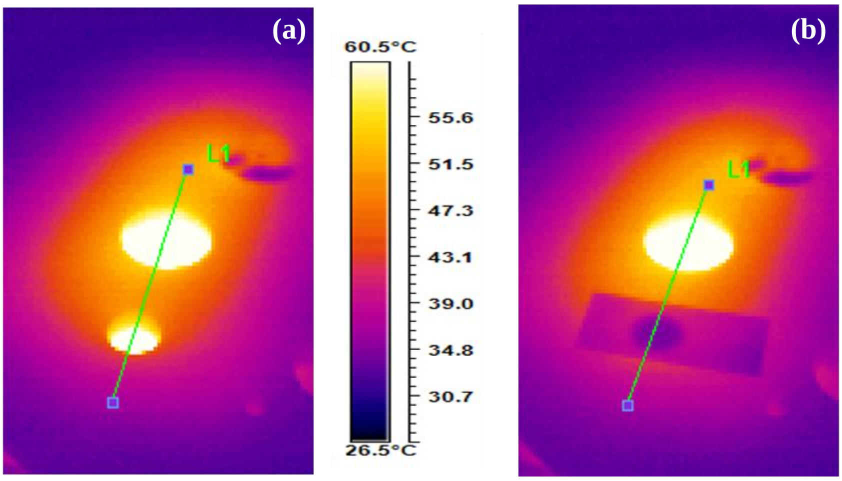

Figure 5. The results of thermal studies: an appearance of a thermal source through the lens of the thermal imaging camera for the case of **(a)** the passage of heat flow through the control and operation hole and **(b)** masking the operation hole with nanoporous anodic alumina thickness of 100 μm.

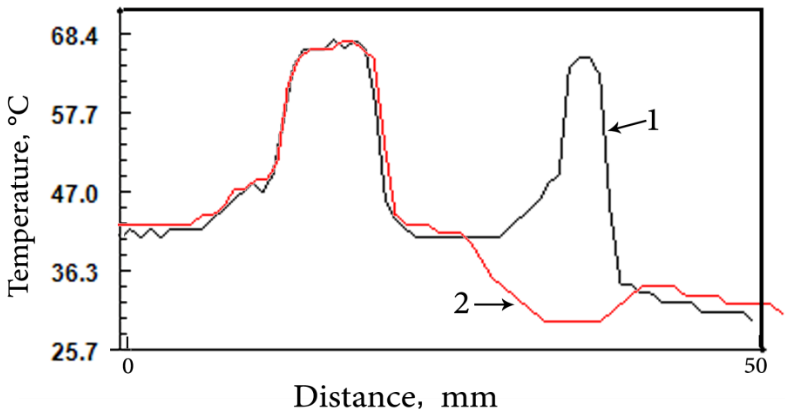

Figure 6. The temperature profiles for the line passing through the control and operation holes: 1 – without a membrane; 2 – with a membrane.

As it can be seen from the results obtained (figure 6), the use of a porous anodic alumina membrane with a thickness of 100 μm allows completely blocking thermal radiation and smoothing out the thermal profile for the radiation source relative to the background.

4. Conclusions

Based on the conducted studies, the temperature profiles of the bio-object in the holes of the Teflon plate for the case without a mask and using a mask from a porous anodic alumina film were obtained. It was found that the porous anodic alumina did not absorb the heat radiation in the wavelength region 8–14 μm and its properties could be controlled by choice of the appropriate geometric parameters. Therefore, such membranes can be used as heat shields to smooth contrast in the infrared range thermal radiation of the object and the surrounding background.

Acknowledgments

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