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Infrared blocking materials

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AlN thin films on the flexible polymeric Teflon and Mylar substrates show characteristics of efficient infrared (IR) blocking filters (IR "stealth"). They can suppress heat flows from the warm parts of objects ($T \sim 300 \div 500$ K) and block IR radiation from them, but are transparent in visible, microwave, and THz spectral regions in contrast to special paints that demonstrate a relatively high emissivity in the IR spectral range

Keywords: *IR blocking, AlN, filters, paints.*

Many modern optical imaging and detection systems operate not only in the visible, but in the infrared (IR), radio wave, and mm (sub-THz) spectral ranges. The rapid development of such systems requires the development of means of masking (suppression) of signals, for example, in the infrared region of the spectrum. Infrared blocking filters are also crucial for controlling the radiation load on cryogenic systems and optimizing the sensitivity of bolometric detectors in the far infrared region of the spectrum. In this case, the filters should minimize the radiation load on the cryogenic system, have a high thermal conductivity for heat sinks, avoid the reradiation, and be transparent in the THz spectrum.

In this work, a comparative analysis of the distribution of thermal fields of two types of masking coatings — special paint and composite structure based on aluminum nitride — is carried out. It is shown that the latter can be more efficient IR filter elements due to the AlN characteristic band of residual rays (Reststrahlen band, almost 100 % reflection) in the spectral range of 5—25 μm, where the main part of the radiation power of a black body at 300K is concentrated.

"Cover-blocking IR" paints. It is well known that any paint in IR spectral range has emissivity from $\varepsilon \approx 0.84$ (plastic, white) to $\varepsilon \approx 0.94$—0.97 (oil, various colors) [1]. Still, from time to time there are advanced offers proposing different kinds of paints that presumably can diminish an object visibility in the IR. Here a comparison of one of such paints with ordinary gray oil paint in the visible and IR spectral ranges was made. In visible, really, such experimental paint that covers a part of metallic sheet can reduce the visibility of object (see Fig. 1) but in the IR, contrary, its emissivity is growing substantially leading to large IR visibility by IR cameras compared to non-covered with paint metal surface and is equal to emissivity of ordinary gray oil paint (see Fig. 2). Images (Fig. 1 and Fig. 2) were obtained using a Mikron M7800 IR camera (λ = 7.5÷14 μm) with a temperature resolution of ΔT = 60 mK and simultaneously recording objects in the visible spectral range.

The visible images of investigated metallic sheet with paints at the temperatures $T \sim 20$ °C and $T \sim 60$ °C are not different. But, when using the IR camera, the distribution of thermal fields from the uncovered part of the metal plate and covered with paints differ. As can be seen from Fig. 2, when the plate is heated to the temperature T = 64,9 °C, the paint-covered parts of the metal plate have an effective thermal temperature of T = 62,2 °C, which is only 2,7 °C lower than the surface temperature of the heated plate.

IR blocking filters. The IR blocking filters based on AlN nanostructured thin films deposited on different polymeric substrates, particularly on the Teflon and Mylar films, by the low-temperature ion-plasma technique, are investigated. Due to the location of the residual band of AlN (Restrahlend band, almost 100 % reflection [2]), nanostructured surface morphology peculiari-

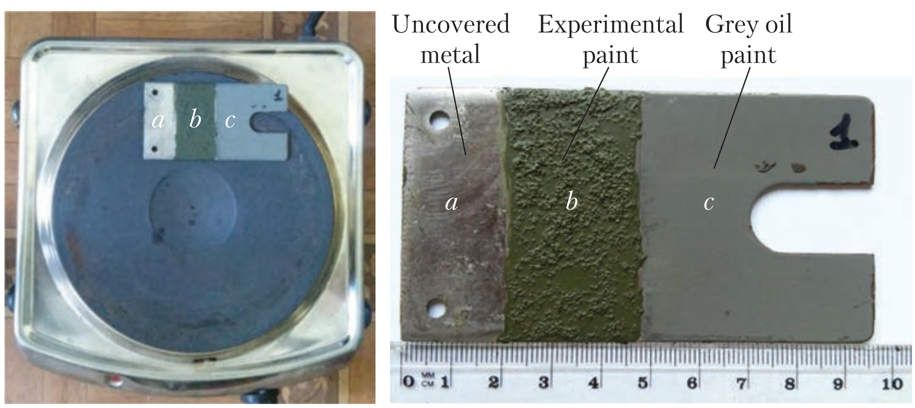
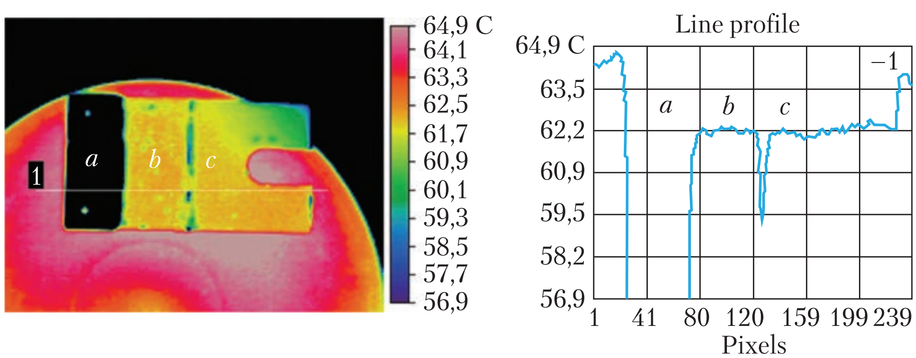
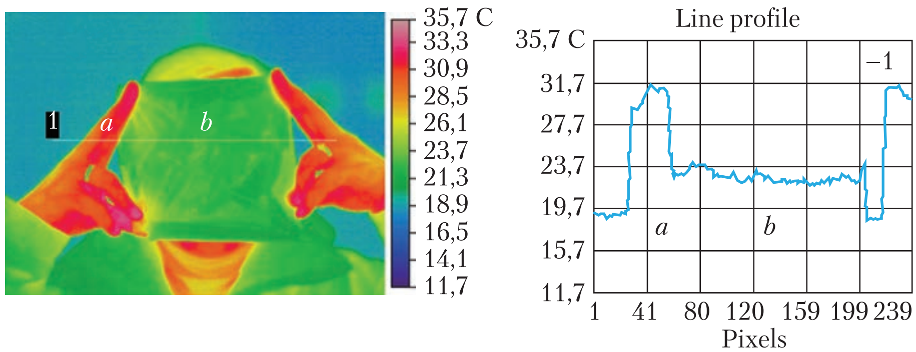


Fig. 1. A metallic sheet with uncovered polished part (a), experimental paint (b), and ordinary gray oil paint (c) on the top of a hot plate, visible photos



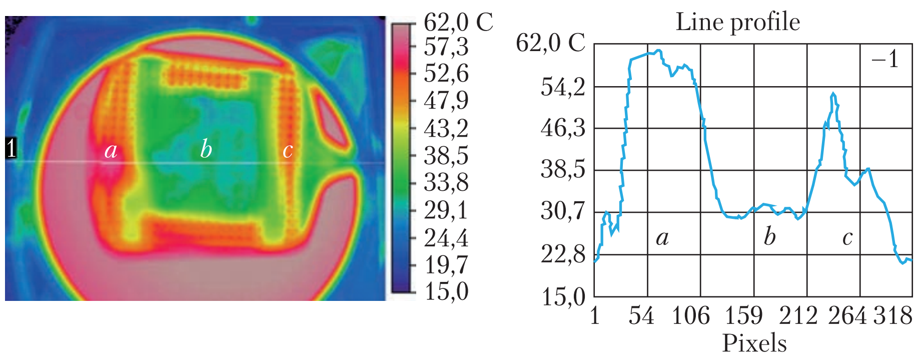
1 *2*

Fig. 2. IR image of a metallic sheet with uncovered polished part (a), experimental paint (b), and ordinary gray oil paint (c) on the top of a hot plate heated to the temperature T = 64.9 °C (1) and distribution of the effective temperature along line “1” (2) obtained with a Mikron M7800 IR camera



a *b*

Fig. 3. IR image of woman's face behind the AlN/Mylar filter (*a*) and distribution of the effective temperature along line "1" (*b*) obtained with a Mikron M7800 IR camera (temperature resolution is $\Delta T = 60$ mK)



a *b*

Fig. 4. IR image of the hot plate heated to $T = 61.8$ °C with using an AlN / Mylar filter and a plastic mesh (*a*) and distribution of the effective temperature along line "1" (*b*) obtained with a Mikron M7800 IR camera (temperature resolution is $\Delta T =$ $= 60$ mK).

ties, and the high thermal conductivity ($\gamma \approx 134 \div 180$ W/m · K), such thin films composite structures effectively block an IR radiation from the wavelengths 10.3 microns up to almost 20 microns [3]. Fig. 3 demonstrates the IR image of woman's face behind the AlN/Mylar filter. As it can see from Fig. 3, *a*, this blocking filter has well masking characteristics in the IR spectral range. From the analysis of the curve (Fig. 3, *b*),we obtain the reduction in the temperature along line "1" from 31.7 °C (on the hand) to 22.4 °C (at the center of the filter). However, the temperature distribution along line "1" (Fig. 3, *b*) on the segment lying in the filter plane is characterized by a slight temperature gradient. This can be explained by the insignificant nonuniformity of the thickness of the AlN coating, when synthesized on polymeric substrates of a larger area.

For comparison with the experimental paint (Fig. 2), the thermal image of a hot plate heated to $T = 61.8$ °C in vertical position with using an AlN / Mylar filter and a plastic mesh to form an air gap between the heated object and the filter is presented in Fig. 4.

Fig. 4 shows the efficiency of an AlN / Mylar filter that significantly reduces the effective temperature of the heated object from $T = 61.8$ °C to $T = 30.7$ °C.

The use of polymeric films of Mylar and Teflon as substrates made it possible to evaluate the potential of an AlN / Mylar (Teflon) film structures to obtain filters that block IR radiation and transmit sub-THz/THz radiation, for example, for highly sensitive cooled detectors. To estimate the transmittance of the radiation intensity with a frequency of 140 GHz, we use a simplified model. We will assume that plane waves interfere. Let the incident wave that falls on the detector for the first time have the amplitude of the electrical component E_1. Let the amplitude of a wave reflected from the surface of the detector, reflected from the source, and again falling on the detector have the amplitude E_2. The following many multiple reflections will be neglected to facilitate the consideration. We will also assume that, at small displacements along the optical axis, the amplitudes E_1 and E_2 do not change, only the phase of these waves changes. Then the maximum of the power will be observed, if these two waves are in the phase $P_{max} = \alpha\,(E_1 + E_2)^2$, respectively, the minimum — when in the antiphase $P_{min} = \alpha\,(E_1 - E_2)^2$, where α is the dimension coefficient. When the investigated structure overlaps the output of the horn antenna of the source, the maximum and minimum conditions can be written as

$$P^{T}_{max} = \alpha\,(\eta^{1/2}E_1 + \mu^{1/2}\,\eta^{3/2}\,E_2)^2, \tag{1}$$

$$P^{T}_{min} = \alpha\,(\eta^{1/2}E_1 - \mu^{1/2}\,\eta^{3/2}\,E_2)^2, \tag{2}$$

where η is the transmittance of the radiation through the structure, and μ is the reflectance of the radiation from the detector and the source. We define η from Eqs. (1) and (2):

$$\eta = \left(\frac{\sqrt{P^{T}_{min}} + \sqrt{P^{T}_{max}}}{\sqrt{P_{min}} + \sqrt{P_{max}}} \right)^2 . \tag{3}$$

The calculations of the transmittance coefficient according to formula (3) showed that, for an AlN / Mylar samples $\eta \approx 85 \div 90$ % in sub-THz spectral range (140—280 GHz).

Conclusions. The distribution of thermal fields in structures based on layers with different coefficients of thermal conductivity (AlN / Mylar) in the spectral range of 8—14 μm with a resolution of 60 mK is experimentally investigated and compared with the experimental "Cover-blocking IR" paint. An analysis of obtained thermal images and their temperature distributions with the use of AlN / Mylar filters demonstrates an effective temperature reduction by ≈ 9.3 °C for living objects at room temperature. The effectiveness of the suppression of infrared radiation by such filters and paints in the application to heated objects has been studied. It is shown that the AlN/Mylar filters demonstrate the better masking characteristics in the IR spectrum (the temperature contrast is ~ 30 °C with using an air gap) in contrast to experimental paint, where the temperature contrast is only 2.7 °C (and much smaller compared to the unpainted metal surface, $\Delta T \approx 40$ °C).

AlN / Mylar filters showed a good transparency in the sub-THz spectral region. They can improve the performance of THz low-temperature detectors by supressing the parasitic background IR radiation.

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МАТЕРІАЛИ, ЯКІ БЛОКУЮТЬ ІНФРАЧЕРВОНЕ ВИПРОМІНЮВАННЯ

Тонкі плівки AlN на гнучких полімерних підкладках тефлону та майлару характеризуються властивостями ефективних інфрачервоних (ІЧ) блокуючих фільтрів. Вони можуть придушувати теплові потоки від гарячих частин об'єктів (T ~ 300÷500 K) і блокувати ІЧ випромінювання від них, але є прозорими у видимому, мікрохвильовому та ТГц спектральних діапазонах на відміну від спеціальних фарб, що демонструють відносно високу випромінювальну здатність в ІЧ області спектра.

Ключові слова: *ІЧ блокуючий, AlN, фільтри, фарби.*

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МАТЕРИАЛЫ, БЛОКИРУЮЩИЕ ИНФРАКРАСНОЕ ИЗЛУЧЕНИЕ

Тонкие пленки AlN на гибких полимерных подложках тефлона и майлара характеризуются свойствами эффективных инфракрасных (ИК) блокирующих фильтров. Они могут подавлять тепловые потоки от нагретых частей объектов (T ~ 300÷500 K) и блокировать ИК излучение от них, но являются прозрачными в видимом, микроволновом и ТГц спектральных диапазонах в отличии от специальных красок, которые демонстрируют относительно высокую излучательную способность в ИК области спектра.

Ключевые слова: *ИК блокирующий, AlN, фильтры, краски.*