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THERMAL SMEARING OF INFRARED PATTERN ON THE SURFACE OF A THIN FILM HTSC BOLOMETER

Purpose: *Composite superconducting bolometers of various cooling levels are widely used in astronomy for detecting radiation in the far IR, submillimeter and millimeter wavelength ranges. The inter-element thermal crosstalk is one of the basic issues in the development of composite HTSC bolometer arrays. The smearing of the temperature pattern formed on the surface of an HTSC thin film/substrate structure by incident IR radiation is studied. The purpose of the work is to measure the spatial and temporal parameters of thermal smearing of an IR image on the film surface.*

Design/methodology/approach: *The study exploits the method of scanning laser probe. The previously proposed approach to detect the spatial distribution of the intensity of external radiation using additional local thermal affect was also used. A laser beam focused on the surface heats a film area and brings it from superconducting to resistive state sensitive to external radiation. Scanning the entire structure with the laser probe is equivalent to moving the sensitive area thus providing the readout of the temperature pattern created by external radiation.*

Findings: *The temperature relief is smeared due to thermal diffusion along the surface of an HTSC structure, which absorbs radiation. Thus, for a structure composed of* $YBa_2Cu_3O_{7-x}$ *thin film with the thickness of 200 nm on a 500 μm thick* $SrTiO_3$ *substrate, the steady-state size of the thermal image is almost twice as large as the initial size of the IR image focused on the surface. The experimental data are consistent with the results of mathematical modeling of thermal processes during radiation absorption in the system. The thermal diffusion length and the characteristic time to achieve maximum heating of the film surface are studied as a function of the substrate thickness and the polling rate.*

Conclusions: *Thermal smearing of IR images along the surface of composite HTSC bolometers imposes limitations on their spatial resolution, speed, and other parameters. Reducing such smearing can be achieved by decreasing the polling time and optimizing the thermal design of the film/substrate system. Since it is the thermal diffusion length, which determines the size of sensitive elements and the optimal spacing between them, the results can be used for designing the composite HTSC bolometer arrays.*

Key words: *HTSC bolometer, IR pattern, thermal diffusion, laser probe*

1. Introduction

To date, large-format semiconductor focal plane arrays (FPA) of liquid nitrogen-cooled semiconductor photon detectors of infrared (IR) radiation operating in the BLIP (Background Limited Infrared Photodetector) mode have been created [1]. However, their spectral sensitivity has a cutoff wavelength of about 20 μm. So, the developers of photoelectronic equipment focus their interest on bolometric detectors with a fundamentally different, thermal detection mechanism, which makes their sensitivity independent of the spectral composition of incident radiation. Presently, superconducting bolometers of various cooling levels are among the major radiation sensors, which not only detect it, but can also get images in IR, submillimeter and millimeter wavelength ranges. The multi-element arrays of superconducting bolometers cooled down to ultra-low temperatures are successfully used for astronomical research in the millimeter-wave range [2]. Under the typical room-temperature background environment (300 K), the liquid nitrogen cooling is preferable to build the compact thermal imaging systems with an expanded spectral sensitivity range. From this point of view, high-T_c superconductors (HTSC) are considered as a promising material for creating high-sensitive arrays of bolometric radiation detectors, but their implementation is complicated by the issues of the element-by-element readout and the cross-element thermal interference [3].

The $YBa_2Cu_3O_{7-x}$ thin films with the superconducting transition temperature $T_c \approx 90$ K well suit for the HTSC bolometers. Studies show that these thin films deposited on the $SrTiO_3$ substrates are the best ones for their structural perfection, critical current density and long-term stability [4, 5]. It was also found that the $YBa_2Cu_3O_{7-x}$ epitaxial thin films on $SrTiO_3$ substrates have the lowest noise level [6, 7]. Since $YBa_2Cu_3O_{7-x}$ has low absorbance in the IR spectrum region (about 10 % at the wavelength of 10 μm and less than 2 % at wavelengths above 20 μm [8]), a composite bolometer is the preferred design for building IR detectors on the basis of such thin films. In this case, a substrate is used as an absorbing element, while the HTSC structure on it acts as a temperature-sensitive element (microthermometer). Such a design appears to be attractive to build also multi-element HTSC bolometric detectors. As an example, an HTSC 2×16 multi-element detector has been studied in [9]. Suppose that the substrate is initially in thermal contact with a cooling platform (heat sink) and has a uniform temperature T_0 in the receiving plane. Then, the incident thermal radiation from the detected object absorbed by the substrate will create a spatial temperature pattern $T = f(X,Y)$ on it, defined by the spatial distribution of the radiation intensity from this object. The temperature increment $\Delta T_{Xi\,Yi}$ in each elementary substrate area X_iY_i will generally be proportional to the incident power portion $P_{Xi\,Yi}$ and reciprocal to the thermal coupling strength of each of these areas to the heat sink $G_{Xi\,Yi}$. This temperature pattern is read out using an array of HTSC microthermosensors formed on each elementary substrate area X_iY_i and having a sharp temperature dependence of the resistance in the resistive state. Obviously, each elementary substrate area X_iY_i can be considered as a separate sensitive element of a multi-element detector, while its size determines the area occupied by this element. The heat removal from each X_iY_i area of the structure under consideration is of a complex nature since the heat flows both normally to the substrate to the heat sink and along the receiving elements plane. This leads to smearing of the temperature pattern $T = f(X,Y)$ that imposes a certain restriction on the spatial resolution of the composite bolometer.

The purpose of this work is to measure the amplitude and temporal parameters of the thermal smearing of an IR image on the surface of an HTSC thin film. These parameters are of practical interest for calculation and optimization of the composite multi-element HTSC IR image transducers. The studies were carried out using the scanning laser probe method [10].

2. Calculation Technique

To calculate thermal smearing of the temperature pattern on a bolometer surface, it is necessary to take into account heat flow both along the receiving areas of sensitive elements and in normal direction inward the multilayer system solving a non-stationary 3D heat transfer equation. To calculate an actual film/substrate system, the following assumptions are made. Firstly, the temperature variations in the receiving pad at operational liquid nitrogen temperatures are small enough even at maximum incident irradiation power, so the temperature dependence of thermal conductivity and heat capacity of the thin film and substrate can be neglected. Secondly, actually two-layer film/substrate system is considered as a single-layer one, since the thickness of the sensitive elements under study $(\approx 200$ nm$)$ is much smaller than that of the substrate $(h = 100-700$ μm$)$, while the film/substrate interface thermal resistance can be neglected [11]. In addition, thermal properties of the YBCO film and the STO substrate are almost the same: the thermal conductivity $\lambda = 4.5$ and 4.65 W/(m·K); the specific heat capacity $C_p = 176$ and 150 J/(kg·K) and the density $\rho = 6380$ and 6450 kg/m^3 for $YBa_2Cu_3O_{7-x}$ and $SrTiO_3$, respectively. We also believe that all incident power is completely absorbed by the receiver, and there is no back re-radiation. Then the non-stationary heat equation can be written as follows:

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right), \qquad (1)$$

where $\alpha = \lambda/(C_p\rho)$ is the thermal diffusivity.

Let us consider a situation where the external heat flux W_0 falls onto a sensitive element of $2m$ by $2l$ in size located on a bulk substrate of $2a$ in length, $2b$ in width and h in thickness (Fig. 1).

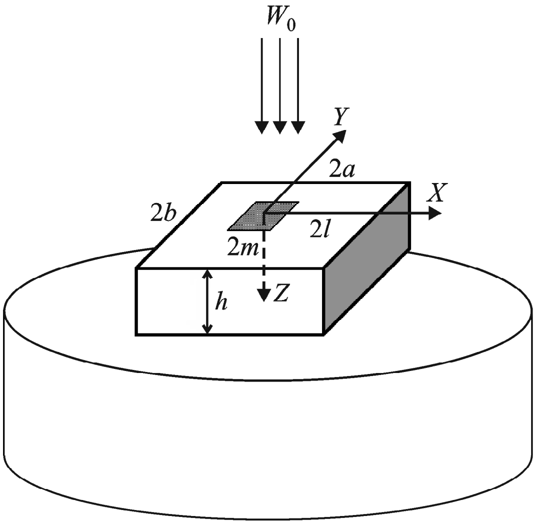

Fig. 1. Receiving $2m \times 2l$ element on a $2a \times 2b$ bulk substrate with thickness h contacting with heat sink. W_0 is incident IR radiation flux

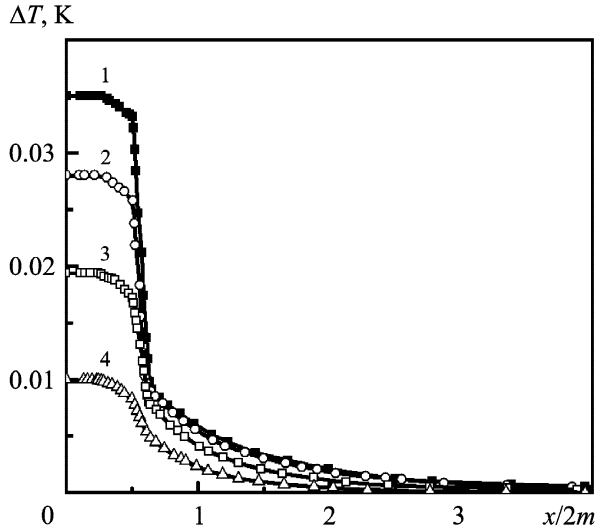

Fig. 2. Stationary overheating distribution in the surface of an IR-illuminated receiving element along the X axis with origin at the receiving pad center at various substrate thickness h: 1 – 700 μm, 2 – 500 μm, 3 – 300 μm, 4 – 100 μm

3. Calculation of the Temperature Pattern on the Surface of a Thin-Film HTSC Bolometer

Equation (1) with corresponding boundary conditions was solved by numerical methods. Since modern optical lens systems have the least circle of confusion $d_{\text{opt}} \approx 25-50$ μm in the spectral range of $8-14$ μm [14], we consider a sensitive HTSC element of 50×50 μm^2 in size, which receives incident IR radiation power of 10^{-5} W per element with the same 50×50 μm^2 beam cross section. The size of the substrate (3000×3000 μm^2) used in calculations is much greater than that of the sensitive element. As a result of absorption of a constant-flux radiation, the temperature on the sensitive element surface starts to grow, and after a characteristic time $t = t_{\max}$ comes to a steady-state temperature $T_{\max}$ when the system reaches thermodynamic equilibrium.

Fig. 2 shows the calculated steady-state distribution of the temperature on the heated surface $(Z = 0)$ of the structure under consideration along the X axis with origin in the center of the receiving pad, for various substrate thicknesses. One can see a sharp temperature drop in the receiving plane at the interface between the illuminated and dark areas. Notably, both the maximum heating temperature $\Delta T_{\max}$ in the center lowers and the smearing of thermal boundary of the receiving area increases with reducing the substrate thickness. The longitudinal heat flow in receiving element plane in addition to the transverse flow towards the heat sink causes a temperature gradient beyond the area adsorbing incident radiation. For example, the temperature decreases approximately by a factor of 5.5 from its maximum value 50 μm apart from the center of the receiving pad regardless of the substrate thickness. Since it is the change in the sensitive element temperature that leads to generation of an electrical signal, it can be concluded that the substrate thickness should be large to increase the temperature sensitivity. At the same time, the increase in the substrate thickness does not significantly affect smearing of the temperature pattern. This means that the sensitivity can be enhanced with no degradation of the spatial resolution. However, the larger the substrate thickness, the longer the steady temperature time for the system and, consequently, the thermal processes become slower.

Fig. 3 shows the surface thermal pattern smearing curves (temperature distribution along the X direction) in a thin film on a 500 μm thick substrate taken at different time lapses since illumination start. It illustrates the dynamics of the heat propagation outside the irradiated sensitive element. One can see that the temperature rises with time not only in the receiving pad center but also in the thermal “tails”. If at time $t = 0.036$ s after starting the external illumination, the temperature pattern is only slightly smeared

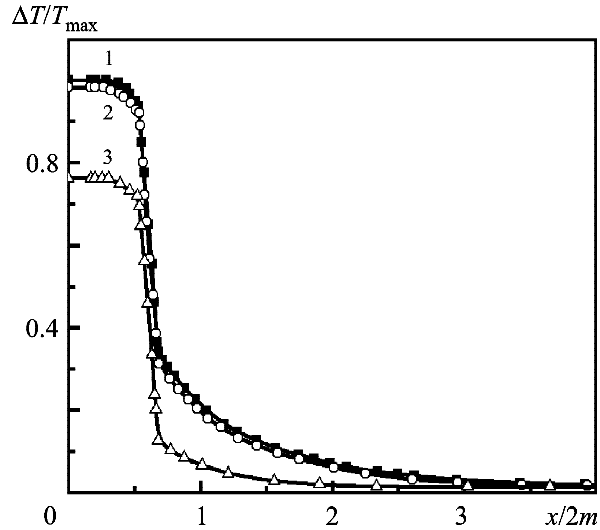

Fig. 3. Temperature distribution in an IR-illuminated receiving element plane along the X axis taken at various times t after starting external illumination: 1 – 0.046 s ($t = t_{max}$), 2 – 0.042 s, 3 – 0.036 s. The substrate thickness $h = 500$ μm

(while the temperature at the pad center is about $2/3$ of its maximum value), then upon reaching the steady state at $t = t_{max} = 0.046$ s, the length of the thermal "tail" essentially exceeds the IR beam cross section.

The length of the thermal "tail" (or the length of thermal diffusion) l_T will be fixed at the level of 0.37 $(1/e)$ of the maximum temperature increment in the receiving element center. Consequently, for a receiving pad of 50×50 μm^2 in size on a substrate with a thickness of 500 μm, the thermal diffusion length in the temperature steady state is $l_T \approx 35$ μm for unmodulated external heat power.

At a fixed stabilized temperature $T_0 = \text{const}$ and constant thermal characteristics of the system in the considered temperature range $(78-95$ K), the temperature increment ΔT_{max} at the pad center is proportional to the incident radiation power. Mathematically, the temperature distribution law $\Delta T(x, y, t)$ in the surface does not depend on the absorbed power, so the thermal diffusion length determined by the criterion above remains unchanged.

Obviously, the smearing of the temperature pattern in the receiving plane of the detector considered limits its the spatial resolution, which in this case is determined both by the aberrations and diffraction of the optical system, and by the thermal diffusion length l_T. In other words, the limitation of spatial sensitivity is determined by a common circle of confusion γ, which size can be obtained from the expression [12]:

$$\gamma = (d_{opt}^2 + 4l_T^2)^{1/2}. \quad (2)$$

An extended thermal object to detect which is focused on the receiving plane and creates a spatial temperature pattern can be considered as a set of point sources. If the sources images in the image plane are spaced by γ or more, then they are fairly distinguishable in the thermogram. Obviously, the sensitive elements should also be spaced by no less than γ. Thus, as follows from expression (2), the acceptable inter-element spacing (between the centers of the sensing elements) L should be $L \geq \gamma \approx 85$ μm in our particular case with an unmodulated incident radiation.

4. Experimental Study of the Surface Temperature Pattern in a Thin Film HTSC Bolometer: Experimental Technique and Results

For an experimental study of the temperature pattern smearing in the sensitive element plane, a structure was used consisting of an epitaxial 200 nm thick $YBa_2Cu_3O_{7-x}$ thin film deposited by laser evaporation on a 3000×3000 μm^2, 500 μm thick $SrTiO_3$ substrate. The sample geometry was a superconducting 50 μm-wide strip forming a meander with an area of 1.5×1.5 mm^2 patterned using electron beam lithography and chemical etching. The meander consisted of 23 HTSC strips with 1500 μm in length spaced by 10 μm gap. On each side, the meander was supplied with electrical contacts coated with 1 μm thick gold using magnetron sputtering through a mask. As was shown in [13–15], such a structure can be considered as a multi-element detector of IR radiation.

The study was performed by the scanning laser probe method. The spatially inhomogeneous incident IR radiation is absorbed by a film/substrate system and forms a characteristic temperature pattern on its surface. To read this pattern out, we used a laser probe (laser beam focused to a spot) moving along the HTSC strip, which was in superconducting state near the critical temperature T_c. In this case, local overheating ΔT_{loc} of a small region of the strip above its critical temperature caused by the laser beam brings this area into resistive state with dramatically sharp temperature dependence of the resistance. Since such areas can be formed in any part of the superconducting strip, scanning the structure with a laser probe provides read-out of the spatial temperature pattern. Indeed, scanning laser radiation of constant power causes the same heating of all local regions of the HTSC strip by ΔT_{loc}, "raising" the temperature pattern by the same amount and providing one-by-one transition of these regions into resistive state. The laser beam movement along the HTSC strip thus translates the sensitive region. When the sample is biased with a dc current, a voltage drop over the sample arises proportional to the resistance of each illuminated spot that is equivalent to sequential polling of the individual sensitive elements.

It will be noted that the laser probe causes a substantially greater overheating of the illuminated region as compared with that of the radiation to detect. In this regard, the thermal gradients arising during the polling should be minimized. In the ideal case, the mutual thermal influence during polling neighboring elements should not exceed the level of natural temperature fluctuations of the receiving surface. Obviously, at a sufficiently high polling rate, the system will not have time enough to go to a stationary temperature state, and the heat propagation aside the sensitive element formed by the laser probe will be insignificant. Earlier, we found that equivalent temperature fluctuations corresponding to the excess noise, which makes the main contribution to the total noise voltage of the used HTSC thin films, is about $K_T \approx 3\cdot 10^{-8}$ K [9]. The polling rate should be chosen so that the resulting temperature gradients at the distance $L \approx 85$ μm estimated from expression (2) apart from a selected sensitive element would not exceed K_T. Taking into account this fact, the temperature patterns smearing we obtained and the required laser probe radiation power ($W_{loc} \approx 10^{-3}$ W), we get 20 kHz as the lower estimation for the polling rate. In this case, the condition is met:

$$\frac{\Delta T_L(f_{r/out})}{\Delta T'_{\max}(f_{r/out})}\Delta T_{loc} \le K_T, \qquad (3)$$

where $\Delta T'_{\max}(f_{r/out})$ and $\Delta T_L(f_{r/out})$ are the temperature increments in the center of a sensitive element and at a distance L apart vs. the polling rate at a fixed laser probe radiation power.

The experimental setup block diagram can be found in [14]. A HTSC structure was mounted on a platform cooled down to about 80 K in the vacuum part of an optical liquid nitrogen cryostat. The platform heater and the temperature controller provided a stable (± 0.005 K) working point for the sample in its superconducting state near the critical temperature. The optical window of the cryostat made of ZnS was transparent for both the IR radiation from a heat source and the laser probe radiation in visible range. The IR radiation was focused using a 3-lens Ge objective with a focal length of 50 mm and a relative aperture of 1:0.85. The laser probe, a semiconductor LED with radiation wavelength of 0.63 μm and fixed power of 5 mW, was mounted on a moving platform. The laser beam was put into the cryostat through the ZnS window and was precisely focused on the HTSC structure surface. The beam was moved in two mutually perpendicular directions by two stepper motors, which were controlled from an electronic unit based on a digital signal processor (DSP). Such a design enabled flexible programming of any law to scan the HTSC structure with the laser probe. The amplification channel of the photoresponse signal consisted of a low-noise ($U_{noise} \le 1$ nV/Hz$^{1/2}$) preamplifier and a lock-in detector. After analog-to-digital convertor, the signal was processed and put by the DSP via the interface into PC. Further signal processing was carried out with specially developed PC software.

The temperature pattern smearing due to thermal diffusion along the receiving plane was studied by measuring spatial distribution of the photoresponse voltage when detecting IR radiation of 800-K blackbody with the known size of optical imprint of the radiation incident on the sample surface. The size of the blackbody output diaphragm and the distance to the lens was chosen so that the optical image of the diaphragm focused on the sample surface did not exceed 50 μm accounting for the lens circle of confusion. To make a preliminary calibration measurement, a 50 μm wide sliding shutter was placed in the blackbody diaphragm image plane, which could gradually obscure the image by means of a translating microscrew. An additional IR sensor located behind the image plane measured the photoresponse signal amplitude as a function of the shutter position. The distance between the input lens aperture and the blackbody diaphragm was chosen so that the diaphragm image was completely covered by the shutter. Then, an HTSC structure to test was placed instead of the shutter. In this case, the blackbody diaphragm image focused onto the structure surface can be assumed not more than the shutter width thus being 50 μm.

Thermal radiation was modulated at a low frequency of 20 Hz using a mechanical chopper placed directly in front of the blackbody. We assumed that, according to the above calculations (see Fig. 3), the modulation frequency of the incident IR radiation is low enough to let the structure under study to go into the stationary temperature state ($f_{mod} \approx 1/t_{max}$), so the experimental results for the thermal diffusion along the receiving plane can be matched with mathematical modeling data.

The image of the blackbody diaphragm was focused on an arbitrary part of one of the strips composing the HTSC meander. To read out the resulting temperature pattern, the HTSC structure was scanned by the laser probe with a step of 10 μm. The laser probe spot size on the HTSC thin film surface was $10 \times 50\ \mu m^2$ and completely covered the meander strip width. To minimize the thermal gradients on the structure surface caused by the readout beam, the laser probe radiation intensity was modulated with the high frequency of 20 kHz in accordance with the above calculations. The photoresponse signal was measured with a lock-in amplifier at the blackbody modulation frequency of 20 Hz.

In Fig. 4(*a*) and 4(*b*) one can clearly see smearing of the temperature pattern on receiving plane of the considered HTSC structure (meander fragment) upon absorption of radiation from an external heat source. The size of the visualized IR image of the blackbody diaphragm exceeds its true size due to thermal diffusion. The heat spot size γ in the receiving plane can be determined from a cross section drawn along the HTSC strip of the meander (Fig. 4(*b*)); it is 0.95 μm at the level of 0.37. Taking into account the spot size of the laser probe, the obtained result agrees well with the results of mathematical modeling of thermal processes in the HTSC thin film/substrate system discussed above.

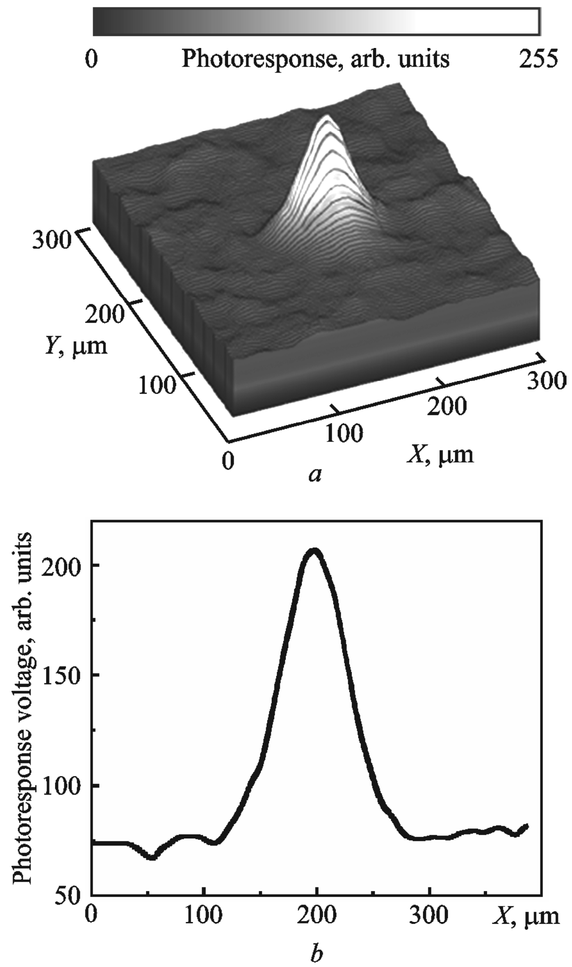

Fig. 4. Smearing of the temperature pattern created by a heat source on the surface of a fragment of a meander-shaped HTSC structure: spatial distribution of the photoresponse taken by scanning the HTSC structure with a laser probe (*a*) and 1D photoresponse distribution in a cross section at $Y = 210$ μm along the *X* axis (*b*)

5. Conclusions

In the composite design concept, the receiving element is the substrate which serves as a "sample and hold" unit. It has to both effectively absorb the incident radiation ("sample") and "hold" the surface temperature pattern, which is an imprint of the spatial distribution of the radiation intensity, for further readout. Such a design provides high sensitivity when creating single HTSC bolometers but faces certain limitations in the case of building multi-element HTSC detectors. In the latter case, the pattern can be read out either by a two-dimensional array of superconducting microthermosensors formed on the substrate, or by an extended meander-shaped structure in which thermosensitive areas of micron size are formed using additional local thermal effects like a laser beam probe.

The studies carried out by the laser probing method showed that the spatial temperature pattern smears due to thermal diffusion along the HTSC structure surface that absorbs IR radiation. Thus, for a structure composed of a 200 nm thick $YBa_2Cu_3O_{7-x}$ thin film on a 500 μm thick $SrTiO_3$ substrate, the steady-state size of the diffused heat spot is almost twice as large as the optical size of the IR radiation source image. The experimental data are in good agreement with the results of mathematical modeling of thermal processes associated with radiation absorption in such a system.

Reducing the temperature pattern smearing can be achieved primarily by reducing the polling time of each element, optimizing the modulation frequency of the incident radiation, as well as optimizing the thermal design of the thin film/substrate system. Since it is the thermal diffusion length that determines the sizes of individual sensitive elements and the optimal spacing between them, the obtained results can be used in designing composite HTSC array IR detectors of the bolometric type.

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ТЕПЛОВЕ РОЗМИТТЯ ІНФРАЧЕРВОНОГО ЗОБРАЖЕННЯ НА ПОВЕРХНІ ТОНКОПЛІВКОВОГО ВТНП БОЛОМЕТРА

Предмет і мета роботи: Композитні надпровідникові болометри різного рівня охолоджування широко використовуються в астрономії для детектування випромінювання в довгохвильовому інфрачервоному (ІЧ), субміліметровому і міліметровому діапазонах довжин хвиль. Наявність міжелементних теплових перешкод – одна з основних проблем при розробці матриць композитних високотемпературних надпроводникових (ВТНП) болометрів. У роботі досліджується розмиття температурного рельєфу, утвореного на поверхні тонкоплівкової ВТНП структури падаючим ІЧ випромінюванням. Мета роботи – вимірювання просторових і часових параметрів теплового розмиття ІЧ зображення на поверхні плівки.
Методи і методологія: Дослідження виконано методом скануючого лазерного зонда. Використано запропонований раніше підхід до реєстрації просторового розподілу інтенсивності зовнішнього випромінювання за допомогою додаткової локальної теплової дії. Сфокусований на поверхні лазерний промінь перегріває ділянку плівки і переводить її з надпровідного стану в резистивний, чутливий до зовнішнього випромінювання. Сканування всієї структури лазерним зондом є еквівалентним переміщенню чутливої ділянки і забезпечує зчитування температурного рельєфу, створеного зовнішнім випромінюванням.
Результати: Внаслідок теплової дифузії температурний рельєф розмивається уздовж поверхні ВТНП структури, що поглинає випромінювання. Так, для структури на основі плівки $YBa_2Cu_3O_{7-x}$ товщиною 200 нм на підкладці $SrTiO_3$ товщиною 500 мкм сталий розмір теплового зображення майже вдвічі перевищує початкові розміри сфокусованого на поверхні ІЧ зображення. Експериментальні дані узгоджуються з результатами математичного моделювання теплових процесів при поглинанні випромінювання в такій системі. Вивчено залежність довжини теплової дифузії і характерного часу досягнення максимального розігрівання поверхні плівки від товщини підкладки і частоти опиту.
Висновок: Теплове розмиття ІЧ зображення уздовж поверхні композитних ВТНП болометрів накладає обмеження на їх просторове розрізнення, швидкодію та інші параметри. Зменшення такого розмиття може бути досягнуте за рахунок скорочення часу опиту і оптимізації теплового дизайну системи "плівка/підкладка". Оскільки саме довжина теплової дифузії визначає розміри чутливих елементів і оптимальну відстань між ними, отримані результати можуть бути використані у проектуванні матриць композитних ВТНП болометрів.

Ключові слова: ВТНП болометр, ІЧ зображення, теплова дифузія, лазерний зонд

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ТЕПЛОВОЕ РАЗМЫТИЕ ИНФРАКРАСНОГО ИЗОБРАЖЕНИЯ НА ПОВЕРХНОСТИ ТОНКОПЛЕНОЧНОГО ВТСП БОЛОМЕТРА

Предмет и цель работы: Композитные сверхпроводниковые болометры различного уровня охлаждения широко используются в астрономии для детектирования излучения в длинноволновом инфракрасном (ИК), субмиллиметровом и миллиметровом диапазонах длин волн. Наличие межэлементных тепловых помех – одна из основных проблем при разработке матриц композитных высокотемпературных сверхпроводниковых (ВТСП) болометров. В работе исследуется размытие температурного рельефа, образованного на поверхности пленочной ВТСП структуры падающим ИК излучением. Цель работы – измерение пространственных и временных параметров теплового размытия ИК изображения на поверхности пленки.
Методы и методология: Исследования проведены методом сканирующего лазерного зонда. Использован предложенный ранее подход к регистрации пространственного распределения интенсивности внешнего излучения при помощи дополнительного локального теплового воздействия. Сфокусированный на поверхности лазерный луч перегревает участок пленки и переводит его из сверхпроводящего состояния в резистивное, чувствительное к внешнему излучению. Сканирование всей структуры лазерным зондом эквивалентно перемещению чувствительного участка и обеспечивает считывание температурного рельефа, созданного внешним излучением.
Результаты: Вследствие тепловой диффузии температурный рельеф размывается вдоль поверхности ВТСП структуры, поглощающей излучение. Так, для структуры на основе пленки $YBa_2Cu_3O_{7-x}$ толщиной 200 нм на подложке $SrTiO_3$ толщиной 500 мкм установившийся размер теплового изображения почти в 2 раза превышает начальные размеры сфокусированного на поверхности ИК изображения. Экспериментальные данные согласуются с результатами математического моделирования тепловых процессов при поглощении излучения в такой системе. Изучена зависимость длины тепловой диффузии и характерного времени достижения максимального разогрева поверхности пленки от толщины подложки и частоты опроса.
Заключение: Тепловое размытие ИК изображения вдоль поверхности композитных ВТСП болометров накладывает ограничения на их пространственное разрешение, быстродействие и другие параметры. Уменьшение такого размытия может быть достигнуто за счет сокращения времени опроса и оптимизации теплового дизайна системы "пленка/подложка". Так как именно длина тепловой диффузии определяет размеры чувствительных элементов и оптимальное расстояние между ними, полученные результаты могут быть использованы при проектировании матриц композитных ВТСП болометров.

Ключевые слова: ВТСП болометр, ИК изображение, тепловая диффузия, лазерный зонд

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