

UDC 621.383.4/5
EDN: YKQGBS

PACS: 42.79.Pw, 85.60.Gz,
07.57.Kp, 85.60.Dw

Investigation of focal plane arrays based on CdHgTe barrier structures for medium-wavelength IR spectral range

© K. O. Boltar^{1,2}, I. D. Burlakov^{1,3}, N. I. Iakovleva^{1,*}, A. V. Trukhachev¹,
D. I. Gorn⁴, and N. N. Mikhailov⁵

¹ RD&P Center ORION, JSC, Moscow, 111538 Russia

* E-mail: niiakovleva@mail.ru

² Moscow Institute of Physics and Technology, Moscow Region, Dolgoprudny, 141701 Russia

³ MIREA – Russian Technological University, Moscow, 119454 Russia

⁴ National Research Tomsk State University, Tomsk, 634050 Russia

⁵ Rzhzanov Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences, Novosibirsk, 630090 Russia

Received 23.10.2025; revised 23.12.2025; accepted 20.02.2026

Using experimental technology, focal plane arrays (FPAs) for the medium-wavelength spectral range (MWIR) based on nBn-heterostructures with unipolar barriers and HgTe/CdHgTe superlattices barriers have been manufactured and investigated. The current-voltage, spectral characteristics and performance of photosensitive elements of experimental samples have been measured. The performance confirm the possibility of creating FPAs based on CdHgTe nBn-heterostructures with wide-band barriers and superlattices as barriers, and technical and constructive technological solutions for their manufacture.

Keywords: unipolar photodetector, nBn-heterostructure, MWIR, HgCdTe, MCT, Focal Plane Array (FPA), spectral response.

DOI: 10.51368/2949-561X-2026-1-11-17

1. Introduction

Hot operating temperature is the main goal for development of infrared (IR) Focal Plane Arrays (FPA) designed for thermal imaging and heat direction finding systems. The work at high operating temperature, as well as achieving high performance, is the choice of CdHgTe unipolar nBn heterostructures with wide-band barriers and superlattices as barriers, operating in MWIR (3–5 μm) and LWIR (8–12 μm) [1–4].

The nBn-heterostructure production is carried out using advanced methods of $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ epitaxial growth by molecular beam epitaxy [5], since MBE provides multilayer structures with a given doping level and type of conductivity.

Despite on the some advantages of barrier photodetectors, the FPA implementation is a

difficult task due to the presence of an undesirable VBO in the the band diagram at the absorbing/barrier boundary in the MCT structure. The propagation of the barrier layer into the valence band of the nBn-srtucture limits the non-primary charge carriers (holes) moving, which determine the useful component of the signal current in such devices. The gap in the valence band can be reduced if the barrier layer is replaced with an HgTe/CdHgTe superlattice, which was proposed in specialized papers [6, 7].

The main goal of this work is a study of MWIR photodetector devices based on nBn-architectures with CdHgTe unipolar barriers and HgTe/CdHgTe superlattice barriers to create a new FPAs generation.

2. Configuration of barrier nBn structures based on CdHgTe

MWIR nBn -structures with unipolar barriers and superlattices as barriers have been selected for the photosensitive arrays manufacture.

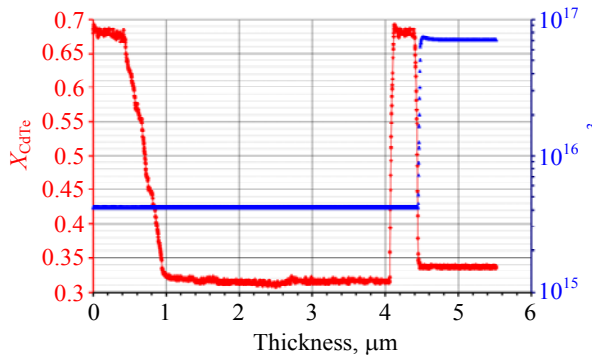
The composition distribution versus thickness in the CdHgTe unipolar barrier structures with the barrier (a) and the superlattice as a barrier (b) is shown in Figure 1.

The composition distributions in the barrier layer of two architectures: with the unipolar barrier and with the HgTe/CdHgTe superlattice barrier are shown in Figure 2 (a , b).

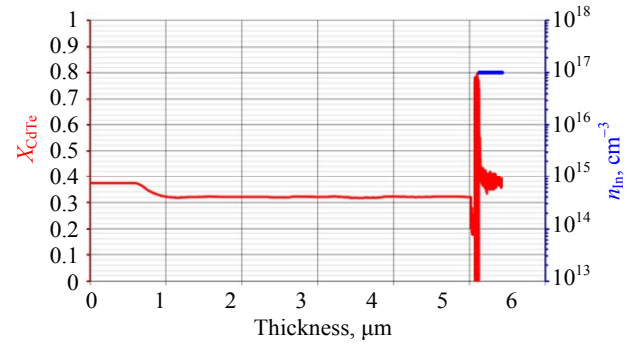
Figure 2a shows that from left to right of the substrate there is the barrier with a thickness

of about ~ 400 nm and $x = 0.7$. Presented in Figure 2b the barrier layer with a thickness of about 130 nm was formed by the superlattice consisting of 10 periods of HgTe/Cd_xHg_{1-x}Te, while the wideband layer was the Cd_xHg_{1-x}Te ternary alloy of $x = 0.7$, the second layer was formed by the semi-metallic HgTe. The thickness of the layers was approximately correlated as $\sim 2/5$.

Cd_xHg_{1-x}Te barrier structures were grown at the Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences by molecular beam epitaxy (MBE) on GaAs (013) substrates [8]. The parameters of the individual layers of the nBn structure are presented in Table 1.

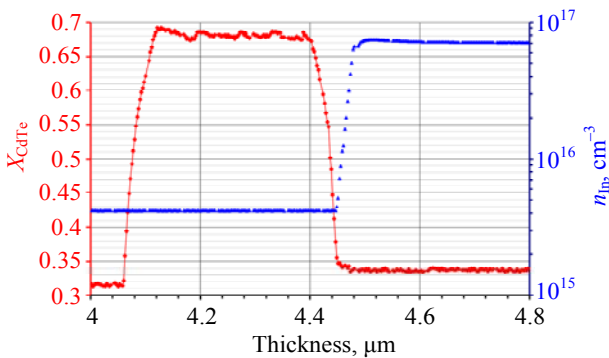


a) CdHgTe nBn -heterostructure with wideband unipolar barrier

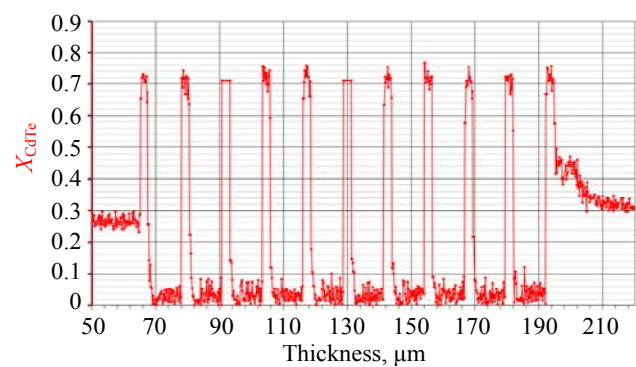


b) CdHgTe nBn -heterostructure with the superlattice as a barrier

Fig. 1. The composition and concentration distributions versus the doping impurity and thickness in CdHgTe nBn -heterostructures with an absorbing layer of $x = 0.3$



a) CdHgTe nBn -heterostructure with wideband unipolar barrier



b) CdHgTe nBn -heterostructure with the superlattice as a barrier

Fig. 2. The composition distribution the in the barrier layer of two architectures: with the unipolar barrier (a) and with the HgTe/CdHgTe superlattice barrier (b)

Table 1

Layer parameters of *nBn*-heterostructures based on CdHgTe

Name of the layer in the structure	MCT HES with a unipolar barrier			MCT HES with a superlattice HgTe/Cd _x Hg _{1-x} Te		
	Concentration, cm ⁻³	Composition	Thickness, μm	Concentration, cm ⁻³	Composition	Thickness, μm
<i>n</i> -Cd _x Hg _{1-x} Te contact layer	$n \sim (3-8) \times 10^{16}$	0.34	0.2	$n \sim (3-8) \times 10^{16}$	0.32	0.5
<i>n</i> -Cd _x Hg _{1-x} Te barrier layer	—	0.7 (barrier)	0.35	—	0.72 (barrier) / 0.03 (well)	0.004 (barrier) / 0.010 (well); 10 periods 0.140 (total)
Cd _x Hg _{1-x} Te absorbing <i>n</i> -layer	$n \sim (3-5) \times 10^{15}$	0.32	3.0–4.0	$n \sim (3-5) \times 10^{15}$	0.30	3.0–4.0
Graded-gap base CdHgTe	—	1.0–0.32	1.0	—	1.0–0.30	1.0
CdTe buffer layer	—	—	5.5	—	—	5.5
ZnTe buffer layer	—	—	0.03	—	—	0.03
Optically transparent GaAs (013) substrate, Ø 50.8 mm			600			600

During the MBE growth process a ZnTe buffer layer (~ 30 nm thick), then a CdTe buffer layer (~ 5.5 μm thick), and a Cd_xHg_{1-x}Te gradient layer (~ 1 μm thick) were formed on the GaAs substrate. The *nBn*-architecture included *n*-Cd_xHg_{1-x}Te absorbing, barrier and contact layers, the concentration in the absorbing and barrier layers was $n \sim (3-5) \times 10^{15} \text{ cm}^{-3}$, the concentration in the contact layer exceeded $n > 3 \times 10^{16} \text{ cm}^{-3}$. The Cd_xHg_{1-x}Te absorbing layer had 3–4 μm thickness, the CdTe composition in the barrier layer and the composition in the contact layer with a thickness of ~ 1 μm were depending on the operating spectral range. During the growing process, the doping donor impurity was indium.

3. Manufacturing and research FPAs on the basis of CdHgTe *nBn*-architectures

The properties of CdHgTe barrier *NBn*-architectures in which the barrier layer (B) effectively suppressed the current component of the main charge carriers (electrons) have been considered in the works [9, 10]. The same type of doping in the barrier and absorbing layers causes a low dark current limited by the diffusion mechanism [11].

Focal plane arrays based on CdHgTe *nBn*-heterostructures were manufactured using mesa

technology. The size of the photosensitive elements and the step between them were guaranteed by the topological dimensions and the manufacturing accuracy of the photomasks. The separation of the matrix elements was carried out by ion plasma etching through a photoresist mask forward to a barrier or buffer *n*-layer with finishing liquid etching in order to obtain smooth profile of lateral surfaces and the bottom of the groove without additional inhomogeneities. The crystal of the 64×64 matrix with a step of 40 μm between the elements had overall dimensions of ~ 2.74×2.74 mm. The local sizes of the *n*-area collector were 0.02×0.02 mm, an ohmic contact was made to each matrix element by the technological operation of photolithography, and common indium microcontacts were formed to the base region of the crystal.

The matrix structure after the mesa etching operation with photosensitive elements separated by mesa grooves with indium microcontacts on the top surface is shown in Figure 3 (*a*, *b*).

The distance between the sensitive elements was ~ 11–13 microns. The anisotropic nature of the etching process in the vertical direction concerning to the surface is revealed. Small surface irregularities were observed on the surface of the dividing groove after etching.

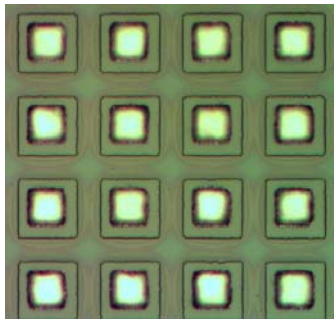
Etching to a considerable depth was accompanied by a masking coating decrease

during etching, which led to an increase of separating groove size and a decrease in the area of the sensitive element. Elements with a groove depth exceeding the thickness of the barrier layer had a small sensitivity variation among themselves. There are a number of technological problems in the mesa etching process, one of which is the need for passivation of the mesa elements lateral surface in order to protect their surface and to reduce the processes of generation-recombination on the surface after the mesa etching operation.

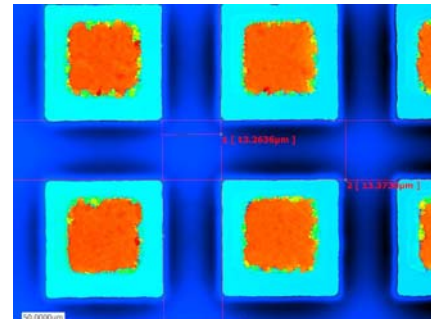
The silicon integrated circuit designed for reading, pre-analog processing and output of photosignals from each element of the 64×64

matrix, has been provided the photocurrent accumulation on integration capacitors, amplification and multiplexing into 2 analog outputs.

The hybridization of CdHgTe FPA and silicon ROIC was carried out using indium microcontacts by pressure diffusion welding, which made it possible to obtain a reliable electrical connection of the assembled crystals. The hybrid crystals were placed in vacuum cryostats. The electrical outputs from the silicon ROIC contact pads were welded onto a sapphire raster with mounted thin gold wires, and then from the raster onto the external outputs of cryostat (fig. 4 *a, b*).

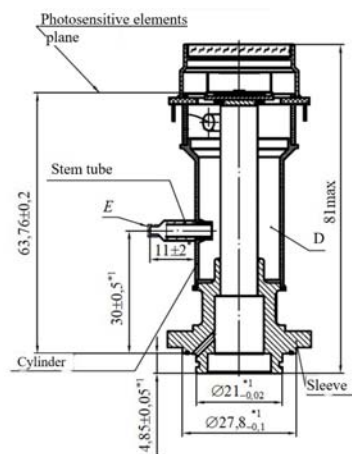


a) a fragment of the matrix structure with In microcontacts



b) measuring the gap between the photosensitive elements

Fig. 3. Fragment of the matrix structure after the mesa etching operation



a) cryostat design



b) photo of the cryostat

Fig. 4. CdHgTe 64×64 FPA with the $40 \mu\text{m}$ step in the vacuum cryostat

The volt-ampere characteristics of the two test matrices FPA-01 and FPA-02 based on CdHgTe *nBn*-heterostructures at $T = 300 \text{ K}$ are shown in Figure 5 *a, b*.

The spectral response characteristics of the two test FPAs based on CdHgTe *nBn*-heterostructures

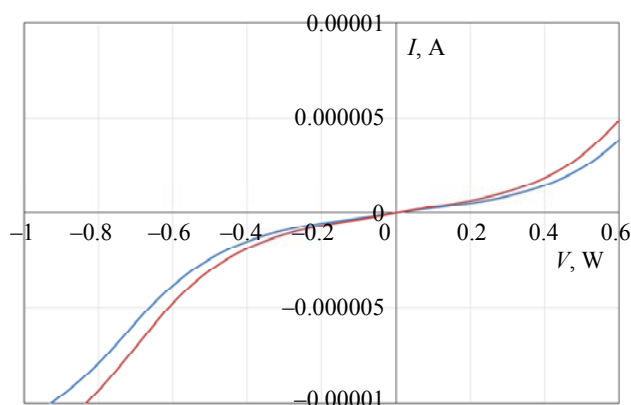
with the wide-band barrier and with the superlattice as the barrier have been measured at $T = 300 \text{ K}$. The measuring spectral responses of the test FPAs are shown in Figure 6 (*a, b*).

The measuring results of the spectral cutoffs of test FPAs based on CdHgTe *nBn*-

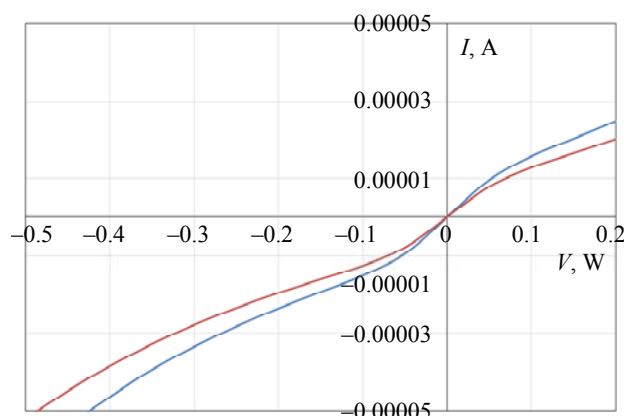
heterostructures with the wideband barrier (FPA-01) and with a superlattice as the barrier (FPA-02) are presented in Table 2.

The long-wavelength cutoff of the spectral sensitivity response for the elements of the test FPA-01 and FPA-02 are: $\lambda_{L0.5} = 5.13 \mu\text{m}$ and

$\lambda_{L0.5} = 4.84 \mu\text{m}$, they were formed by $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ composition choosing, and the short-wavelength cutoff are $\lambda_{S0.5} = 2.74 \mu\text{m}$ and $\lambda_{S0.5} = 2.70 \mu\text{m}$, they were determined by the absorption in the gradient layer of the $n\text{Bn}$ -heterostructure with a thickness of $1 \mu\text{m}$.

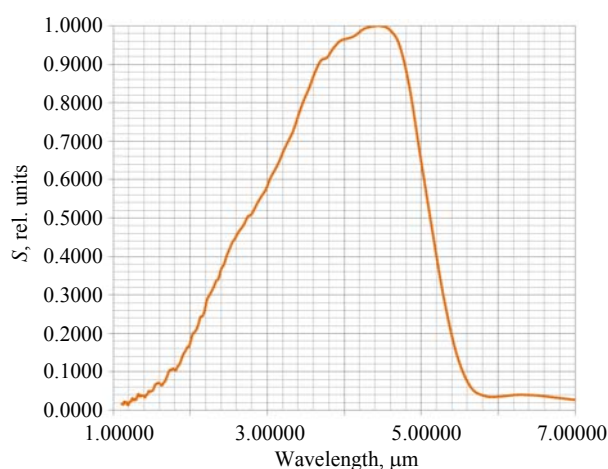


a) FPA-01 with wideband barrier

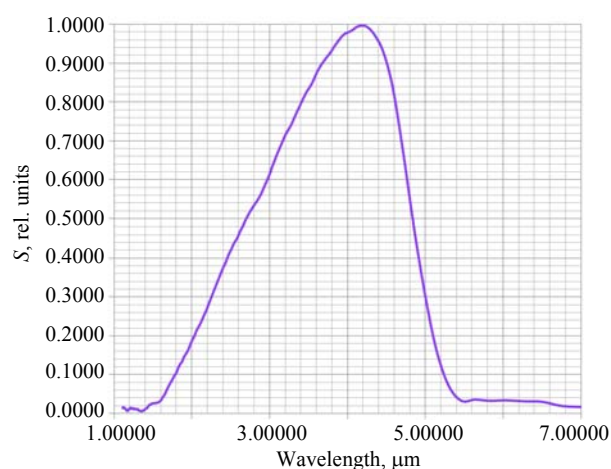


b) FPA-02 with the superlattice as a barrier

Fig. 5. The volt-ampere characteristics of the two test matrices FPA-01 and FPA-02 based on CdHgTe $n\text{Bn}$ -heterostructures with wideband barrier (a) and with the superlattice as a barrier (b)



a) FPA-01 with wideband barrier



b) FPA-02 with the superlattice as a barrier

Fig. 6. The measuring spectral responses of the test FPAs: (a) – with wideband barrier and (b) – with the superlattice as a barrier

Table 2

The spectral cutoffs of test FPAs based on CdHgTe $n\text{Bn}$ -heterostructures with the wideband barrier (FPA-01) and with a superlattice as the barrier (FPA-02)

Parameter name	Measurement results for FPA-01	Measurement results for FPA-02
1 Long-wave cutoff of the spectral sensitivity range, μm	5.13	4.84
2 Short-wave cutoff of the spectral sensitivity range, μm	2.74	2.70

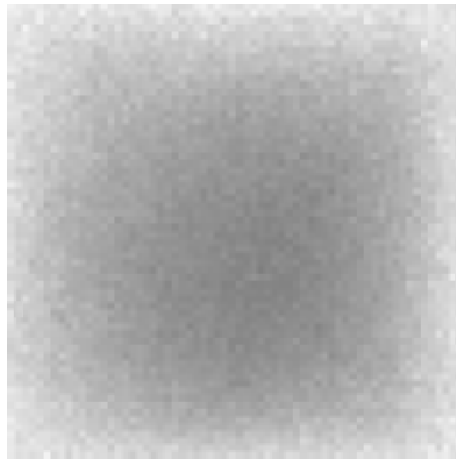
The performance of FPAs based on CdHgTe *nBn*-heterostructures were determined by the photosignal and noise measurements. A flexible automated information processing system operating in automatic mode was used to carry out the measurements. The measuring system consisted of the following main components:

- an optical signal source based on a blackbody;
- control electronics (analog processing and control unit, analog-digital processing unit, interface unit);
- measuring system, which included a computing unit and interface boards.

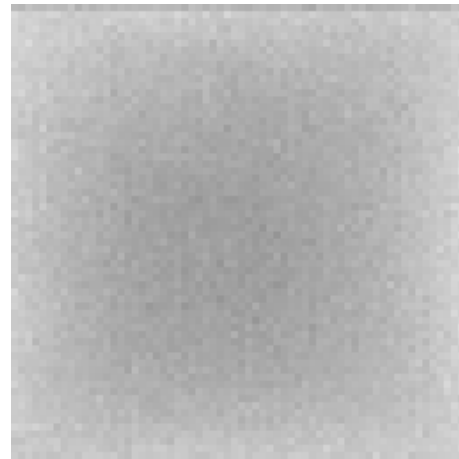
Measurements of current, photosignal and noise of MWIR test devices FPA-01 and FPA-02 have been carried out (current diagrams for the arrays elements are shown in Figures 7 *a*, *b*).

The achievement of high performance of barrier FPAs is guaranteed both by the quality of the original CdHgTe heterostructures and by the manufacturing FPA technology, ROIC and hybrid assemblies based on them according to the developed technological process. The performance of MWIR barrier 64×64 FPAs with the 40 μm pitch based on CdHgTe *nBn*-heterostructures is presented in Table 3.

The average value of detectivity for FPA-01 was of $D^* = 0.52 \times 10^{11} \text{ cmHz}^{1/2} \text{ W}^{-1}$; the average value of volt sensitivity for FPA-01 was $S_u = 0.3 \times 10^8 \text{ V/W}$. The average value of detectivity for FPA-02 was of $D^* = 0.61 \times 10^{11} \text{ cmHz}^{1/2} \text{ W}^{-1}$; the average value of volt sensitivity for FPA-02 was $S_u = 0.55 \times 10^8 \text{ V/W}$.



a) FPA-01



b) FPA-02

Fig. 7. Current distribution for FPAs format of 64×64 elements with the step of 40 μm based on CdHgTe MWIR barrier *nBn*-heterostructures

Table 3

*The performance of MWIR barrier 64x64 FPAs with the 40 μm pitch based on CdHgTe *nBn*-heterostructures*

FPA No.	Performance (800 K, $T_{int} = 0.3 \text{ ms}$)		
	Volt sensitivity, S_u , V/W	Noise N , μV	Detectivity D^* , $\text{cm} \cdot \text{Hz}^{1/2} \cdot \text{W}^{-1}$
FPA-01	0.3×10^8	0.35	0.52×10^{11}
FPA-02	0.55×10^8	0.30	0.61×10^{11}

The obtained values of the performances confirm the possibility of creating FPAs based on CdHgTe *nBn*-heterostructures with wide-band barriers and superlattices as barriers, as well as the correctness of technical and constructive technological solutions for their manufacture. The further improvement of the FPA performance, it is necessary to optimize the photosensitive element architectures and refine

the manufacturing technology of FPAs based on CdHgTe *nBn*-heterostructures with wide-band barriers and with superlattices as barriers.

4. Conclusion

The paper presents promising CdHgTe *nBn*-architectures with unipolar barriers and superlattices as barriers, and experimentally

investigated performance and spectral responses for FPAs manufactured on their basis.

The following results were obtained:

The long-wavelength cutoff of the spectral sensitivity response for the elements of the test FPA-01 and FPA-02 are: $\lambda_{L0.5} = 5.13 \mu\text{m}$ and $\lambda_{L0.5} = 4.84 \mu\text{m}$, they were formed by $\text{Cd}_x\text{Hg}_{1-x}\text{Te}$ composition choosing, and the short-wavelength cutoff are $\lambda_{S0.5} = 2.74 \mu\text{m}$ and $\lambda_{S0.5} = 2.70 \mu\text{m}$, they were determined by the absorption in the gradient layer of the $n\text{Bn}$ -heterostructure with a thickness of $1 \mu\text{m}$. The detectivity was of $\sim 10^{11} \text{cmHz}^{1/2}\text{W}^{-1}$; the average value of volt sensitivity was of $\sim 10^8 \text{V/W}$. The obtained values of the performances confirm the possibility of creating FPAs based on CdHgTe

$n\text{Bn}$ -heterostructures with wide-band barriers and superlattices as barriers, as well as the correctness of technical and constructive technological solutions for their manufacture. The further improvement of the FPA performance, it is necessary to optimize the photosensitive element architectures and refine the manufacturing technology of FPAs based on CdHgTe $n\text{Bn}$ -heterostructures with wide-band barriers and with superlattices as barriers, as well as optimizing ROIC for this photosensitive element.

The research was carried out at the expense of a grant from the Russian Science Foundation No. 23-62-10021, <https://rscf.ru/project/23-62-10021/>.

REFERENCES

1. Boltar K. O., Burlakov I. D., Iakovleva N. I., Sednev M. V., Trukhachev A. V., Irodov N. A., Lopukhin A. A., Permikina E. V., Voitsekhovskiy A. V., Gorn D. I., and Mikhailov N. N., Applied Physics, № 1, 38–44 (2025) [in Russian].
2. Voitsekhovskiy A. V. and Gorn D. I., Applied Physics, № 4, 83–86 (2016) [in Russian].
3. Kopytko M. et al., J. Electron. Mater. **44** (1), 158–166 (2015).
4. Rogalski A., Martyniuk P., Kopytko M., and Hu W., Appl. Sci. **11**, 501 (2021).
5. Varavin V. S., Dvoretzky S. A., Mikhailov N. N., Remesnik V. G., Sabinina I. V., Sidorov Yu. G., Shvets V. A., Yakushev M. V., and Latyshev A. V., Autometry **56** (5), 12–26 (2020).
6. Akhavan N. D., Umana-Membreno G. A., Jolley G., Antoszewski J., and Faraone L., Appl. Phys. Lett. **105** (12), (2014).
7. Voitsekhovskiy A. V., Dzyadukh S. M., Gorn D. I., Dvoretzky S. A., Mikhailov N. N., Sidorov G. Yu., and Yakushev M. V., Applied Physics, № 3, 37–42 (2022) [in Russian].
8. Varavin V. S., Sabinina I. V., Sidorov G. Yu., Marin D. V., Remesnik V. G., Predein A. V., Dvoretzky S. A., Vasilyev V. V., Sidorov Yu. G., Yakushev M. V., and Latyshev A. V., Infrared Phys. Technol. **105**, 103182 (2020). <https://doi.org/10.1016/j.infrared.2019.103182>.
9. Voitsekhovskii A. V., Nesmelov S. N., Dzyadukh S. M., Dvoretzky S. A., Mikhailov N. N., Sidorov G. Yu., and Yakushev M. V., Infr. Phys. and Techn. **102**, 103035 (1–4) (2019).
10. Jiale He, Peng Wang, Qing Li, Fang Wang, Yue Gu, Chuan Shen, Lu Chen, Piotr Martyniuk, Antoni Rogalski, Xiaoshuang Chen, Wei Lu, and Weida Hu, IEEE Trans. Electron Devices **67** (5), (2020).
11. Voitsekhovskiy A. V., Dzyadukh S. M., Gorn D. I., Dvoretzky S. A., et al., Journal of Communications Technology and Electronics **69** (4–6), 231–235 (2024). <https://doi.org/10.1134/S1064226924700372>.

About authors

Boltar Konstantin Olegovich, Doctor of Physical and Mathematical Sciences, Director of Applied Development, RD&P Center ORION, JSC (9 Kosinskaya st., Moscow, 111538, Russia); Moscow Institute of Physics and Technology (9 Institutskiy per., Moscow Region, Dolgoprudny, 141701, Russia). E-mail: boltarko@yandex.ru SPIN-code: 9249-2720, AuthorID: 171355

Burlakov Igor Dmitrievich, Doctor of Technical Sciences, Professor, Deputy General Director for Innovation and Science, RD&P Center ORION, JSC (9 Kosinskaya st., Moscow, 111538, Russia); MIREA – Russian Technological University (78 Vernadsky Ave., Moscow, 119454, Russia). E-mail: idbur@orion-ir.ru SPIN-code: 6042-3634, AuthorID: 171368

Iakovleva Natalya Ivanovna, Doctor of Technical Sciences, Chief Scientific Officer of the STS MFE, RD&P Center ORION, JSC (9 Kosinskaya st., Moscow, 111538, Russia). E-mail: niakovleva@mail.ru SPIN-code: 1077-9113, AuthorID: 602076

Trukhachev Anton Vladimirovich, Lead Engineer, RD&P Center ORION, JSC (9 Kosinskaya st., Moscow, 111538, Russia). E-mail: orionmoscow@mail.ru

Gorn Dmitry Igorevich, Candidate of Physical and Mathematical Sciences, Senior Research Associate, National Research Tomsk State University (36 Lenin Ave., Tomsk, 634050, Russia). E-mail: gorn_dim@sibmail.com SPIN-code: 4514-3163, AuthorID: 724442

Mikhailov Nikolay Nikolaevich, Candidate of Physical and Mathematical Sciences, Senior Research Associate, Rzhanov Institute of Semiconductor Physics of the Siberian Branch of the Russian Academy of Sciences (13 Lavrentiev Ave., Novosibirsk, 630090, Russia). E-mail: mikhailov@isp.nsc.ru SPIN-code: 3449-3155, AuthorID: 107682