

UDC 53
EDN: GXTOCC

PACS: 07.07.Df, 07.57.-c,
81.05.Ea, 81.65.Rv

Testing array patterns for research dependence performance InSb FPA large-format from pixel topology

A. A. Lopukhin^{1,*}, E. V. Permikina¹, K. V. Barysheva¹ and V. V. Lopatin²

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

* E-mail: alexmatr0@mail.ru

² Foundation for Advanced Research, Moscow, 121059 Russia

Received 3.09.2025, revised 15.09.2025; accepted 20.10.2025

The topology of squares mesa and rounded mesa of testing array patterns with 10, 12, 15 and 20 μm pitch based on InSb intended for hybridization with 12 μm pitch 1280×1024 ROIC for research of basic photo-electric characteristics in single FPA large-format are developed. The structure of a complete set of photomasks with distribution over the area of testing array patterns for realization wedge-like thinning is presented in order to obtain ultra-thin structures with a controlled thickness over the area with to increase strength and minimize the crosstalk. Possibilities of realization of the offered testing array patterns are analysed.

Keywords: Focal Plane Array (FPA); indium antimonide; crosstalk; the scanning mask; topology; testing array patterns.

DOI: 10.51368/2949-561X-2025-5-19-26

Introduction

Modern medium-wave infrared array photodetectors with high resolution and wide field of view use photodiode arrays made of InSb for detection of thermal objects [1]. Optical radiation incident on the antireflective surface of the photosensor array generates the photocurrent within array photosensors. Some photocarriers with long diffusion length can be collected in adjacent elements, thus increasing the photoelectric interconnection. As the element pitch decreases, photoelectric interconnection becomes a critical parameter. Additionally, the perimeter-to-area ratio grows inevitably, and the impact of surface leakage currents on the characteristics intensifies. To handle the interconnection issue, structures with thin photosensitive regions are used, which requires stronger array photosensors [2, 3, 4] and finding a compromise between interconnection magnitude and photodetector's response. The homogeneity of photoelectric characteristics of array's elements (particularly of the large-size array) is

directly determined by the complexity of array fabrication process.

On the other hand, modern megapixel array photodetectors are based on a hybrid architecture, where the most complex and expensive component is the readout large-scale integrated (LSI) circuit, which requires lengthy development, design, testing, and debugging.

For this reason, it is proposed to use test array structures of array photosensors featuring various topologies and hybridized with a large-scale integrated circuit sized 1280×1024 with a 12 μm pitch to derive the most valid data on dependence of photoelectric characteristics of array photosensors (interconnection, detectivity, photoresponse, etc.) on the elements pitch, photosensitive structure thickness, topology of the photosensitive area (mesa, planar, mesa-planar), and shape of the photosensitive areas (square, circle). To minimize the impact of the wide process spread caused by material inhomogeneities across the wafer area, the test structures are located within a single array, and photoelectric characteristics between

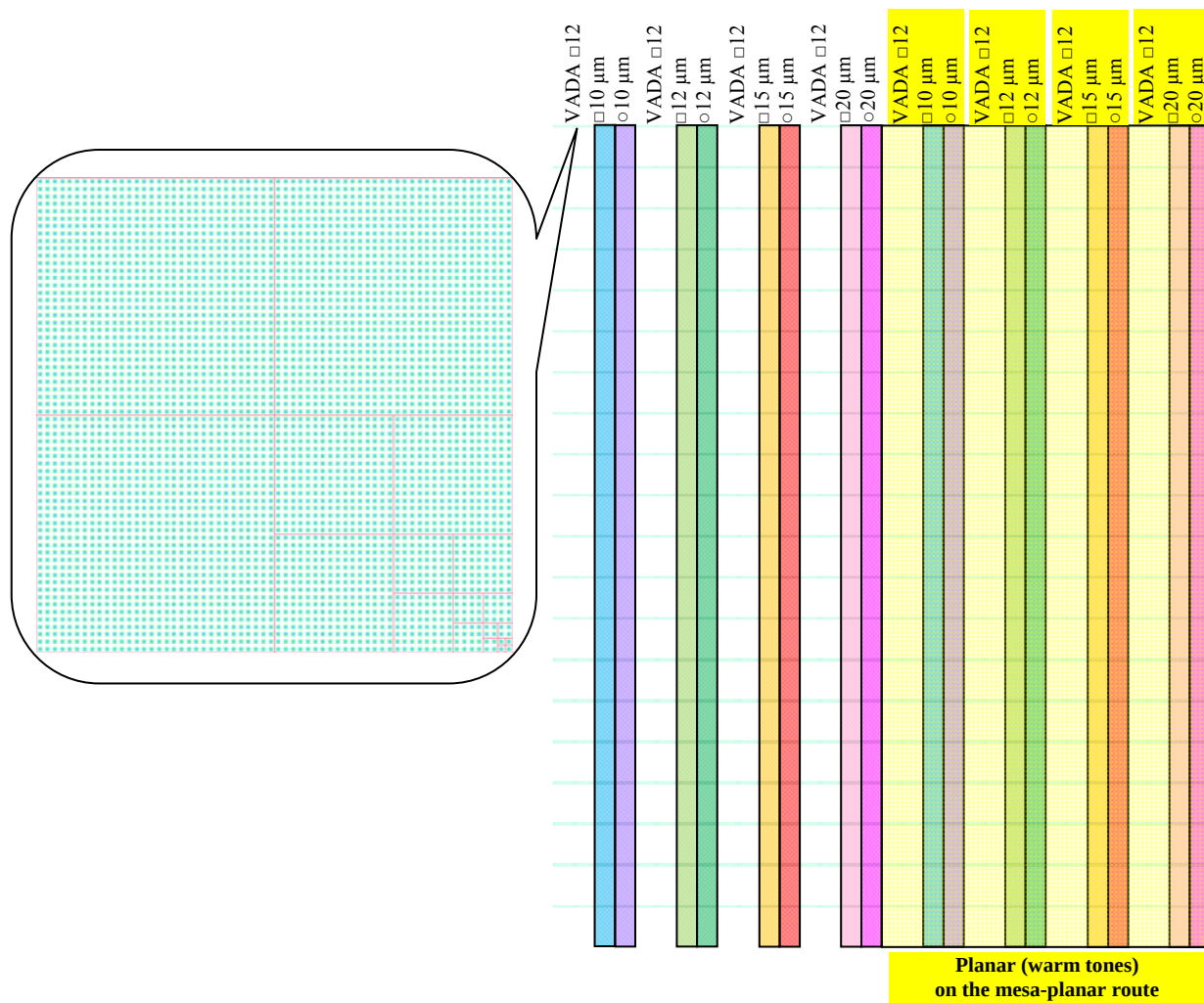


Fig. 2. Test structure versions of array photosensors within a single array: 1/2 of the array to the left – mesa (cold tones); 1/2 of the array to the right – planar (warm tones)

Six main mask works are required for fabrication of array photosensors. The table contains minimum sizes provided by each mask work, considering the photosensor pitch. It is recommended to use the mask work for generation of windows simultaneously for creating scanning masks and chromium-nickel mirrors on the periphery of 100 mm diameter silicon wafers

(Window+Si mask work). Scanning masks can be used to study the sensitivity distribution across the pixel area of the array photodetector [7, 8], while chromium-nickel mirrors can be utilized for dark current measurements to determine the passivation efficiency of large-size array photosensors [5, 6]. These test structures are marked in dark red in Figure 1.

Table

Minimum sizes	pitch = 20 μm	pitch = 15 μm	pitch = 12 μm	pitch = 10 μm
1. Mesa mask work	1 μm	1 μm	1 μm	1 μm
2. Planar mask work	2 μm	2 μm	2 μm	2 μm
3. Window+Si mask work	4 μm	4 μm	4 μm	3 μm
4. CrNi mask work	7 μm	7 μm	7 μm	6 μm
5. In mask work	7 μm	7 μm	7 μm	6 μm
6. Groove mask work	5 μm	5 μm	5 μm	5 μm

The main topological feature of array photosensors is square or circular shape of elements (Fig. 3). When good sensitivity and maximum photoresponse are to be achieved, both square and circular photosensitive area shapes have their advantages due to the element pitch in the array structure. As the pitch decreases, the circular shape becomes more optimal due to the growing influence of the perimeter, especially in the planar version where the lateral part of the p - n junction leads to the higher dark current compared to the mesa version. On the other hand, since elements are packed densely in the array, the circular shape gives rise to a significant area requiring surface passivation to reduce the surface recombination rate and increase the photoresponse. The selected series of pitches (10, 12, 15, and 20 μm) will allow identifying major trends in photoelectric parameters of array photosensors.

Figure 3 shows corner fragments of combined top-layer topologies of readout LSI circuits sized 1280×1024 and featuring the 12 μm pitch, including 4 rows of common contacts and at least two unscanned rows serving as "guard rings" to suppress edge effects caused by lateral diffusion of minority charge carriers and topologies of array photosensors for pitches of 10 μm (a), 12 μm (b), 15 μm (c), and 20 μm (d) with square and circular shapes of photosensitive elements. It can be seen that periods consisting of 6, 5, 4, and 3 array photosensors correspond to the pitches of 10, 12, 15, and 20 μm and are equal to the period of 5 LSI circuit elements with the 12 μm pitch. Figure 3a shows the most optimal combination for square and circular areas of In

micro-contacts sized 5×5 elements, within which the primary photoelectric parameters of array photodetectors for the 10 μm pitch can be obtained. Here, every sixth array photodetector shall be fabricated without In micro-contacts and be connected via CrNi traces to the common contact on the periphery, thus forming a grid of closed p - n junctions to prevent edge effects caused by lateral diffusion of minority charge carriers. To ensure the most optimal contact and avoid closing for the 15 μm pitch of array photosensors (Fig. 3c), a 1 μm offset from the mesa center diagonally towards the center of each element in the group of 4×4 array photosensors has been defined. Similarly, for the 20 μm pitch of array photosensors (Fig. 3d), a 2 μm offset from the mesa center away from the center of each edge element in the group of 3×3 array photosensors has been defined.

The variable topological parameters of elements (square, circle, pitch) within a single array were implemented as strips along longer sides of chips to enable wedge-type thinning along these strips after hybridization with the readout LSI circuit for measuring the dependencies of photoelectric characteristics on thickness. These dependencies allow deriving such parameters as the volume diffusion length, identifying dark current generation mechanisms, and gaining the information about recombination at the interface of the epitaxial growth/substrate, etc. To ensure precise thickness measurement via interference in each element, element-based measurement of spectral characteristics is proposed [9].

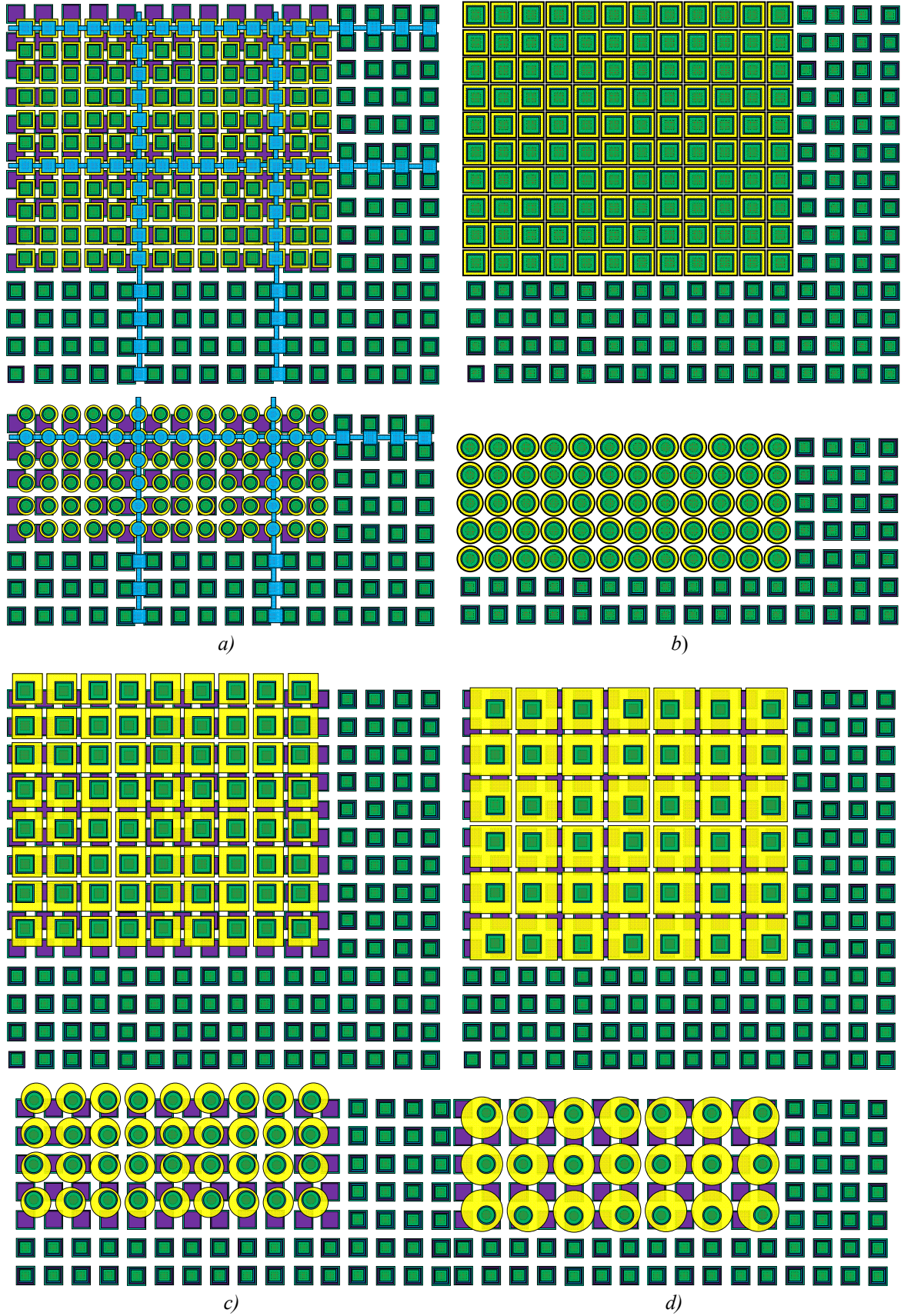


Fig. 3. Images of angular fragments of combined top-layer topologies of the readout LSI circuit sized 1280×1024 elements and featuring the $12 \mu\text{m}$ pitch (CrNi – $\blacksquare$, In – $\blacksquare$) and topologies of array photosensors sized 1536×1228 elements and featuring the $10 \mu\text{m}$ pitch (a), 1280×1024 elements and $12 \mu\text{m}$ pitch (b), 1024×819 elements and $15 \mu\text{m}$ pitch (c), and 768×614 elements and $20 \mu\text{m}$ pitch (d) for square (top) and circular (bottom) topologies

Wedge Test

Study of the interconnection between photoelectric elements and detector photoresponse as a function of photosensitive region thickness is of particular significance. The photoelectric interconnection between elements is known to decrease as the photosensitive region thickness is reduced, but the reduction in photocarrier numbers leads to lower photoresponse and, consequently, reduced sensitivity of the photodetector. It is possible to determine the optimal ratio between thickness and interconnection of the elements by studying the distribution of photosensors' sensitivity across

arrays thinned in the wedge-like manner using silicon scanning masks [7, 8]. The front side of the photosensor array featuring variable thickness and not provided with antireflection coating shall be pre-treated with argon ions to eliminate surface recombination [3, 4]. Figure 4 shows example images of an output signal of an epitaxial pattern with a 4- μm thick absorbing layer grown on a heavily doped indium antimonide substrate with orientation (100), with implanted p - n junctions sized 640×512 and featuring the 15 μm pitch, before and after left-to-right thinning in wedge-like manner from ~ 0 to ~ 14 μm , without antireflection coating and after being treated with Ar^+ ions.

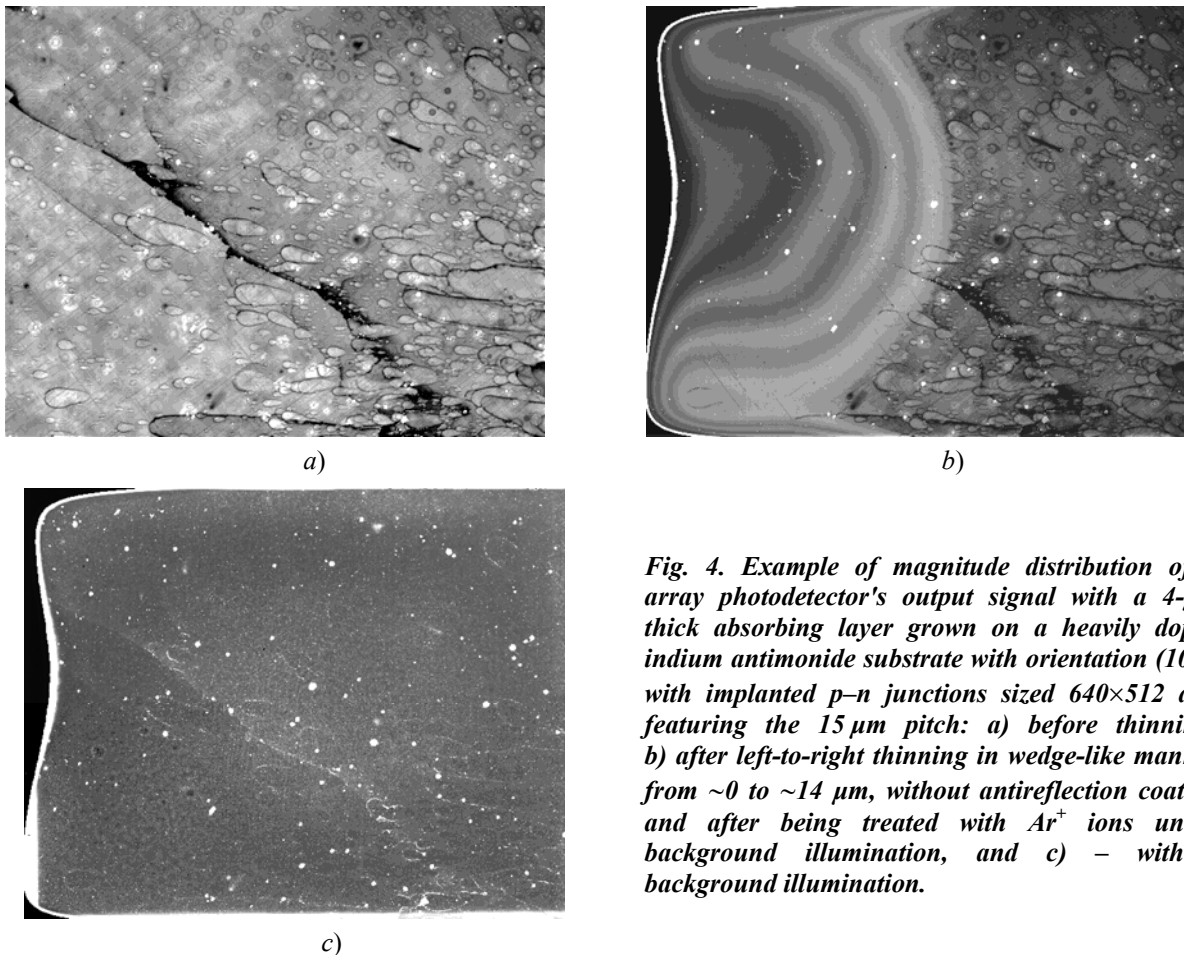


Fig. 4. Example of magnitude distribution of an array photodetector's output signal with a 4- μm thick absorbing layer grown on a heavily doped indium antimonide substrate with orientation (100), with implanted p - n junctions sized 640×512 and featuring the 15 μm pitch: a) before thinning; b) after left-to-right thinning in wedge-like manner from ~ 0 to ~ 14 μm , without antireflection coating and after being treated with Ar^+ ions under background illumination, and c) – without background illumination.

Figure 4a shows magnitude distribution of an output signal of the epitaxial pattern before thinning under background illumination. Bright areas correspond to p - n junction leakage, while dark areas correspond to recombination in the n -region. After thinning in the wedge-like manner from the substrate side, the epitaxial growth

interface can be clearly seen in the photoelectric image obtained in background mode (Fig. 4b), with thickness resolution of ~ 20 nm limited by the 15 μm array pitch and the wedge angle. Four interference bands can be distinctly seen in the left part of the image, these bands corresponding to the wedge-shaped epitaxial layer thickness

from 0 to 4 μm after thinning after at the array photodetector's absorption wavelength of 3.6–5 μm and complete removal of the substrate. Dark areas remain in the right part of the image and correspond primarily to recombination at the substrate/epitaxial layer interface. Thus, we can observe a sharp substrate/epitaxial layer interface. Interestingly, some recombination areas extend through the epitaxial layer growth depth down to $\sim 1 \mu\text{m}$. At the same time, most recombination areas cannot be observed in the grown epitaxial layer, that is defective areas occurring at the growth interface are “healed”. On the contrary, in the dark current image (Fig. 4b), not only the growth interface cannot be seen, but also the dark current does not depend on the epitaxial layer thickness. This indicates the predominance of the generation-recombination mechanism of dark current formation in the space charge area directly within the p – n junction over the diffusion mechanism of dark current generation in the epitaxial structure [10].

Conclusions

InSb-based test array structures based have been developed for hybridization with readout LSI circuit sized 1280×1024 and featuring the

12 μm pitch in order to study the topology of array photosensors of the array photodetector's primary photoelectric characteristics within a single large-size array.

Some versions of test structures for array photosensors and topologies for silicon scanning masks with a universal pitch exceeding the diffusion length of minority charge carriers in InSb have been proposed for the purpose of measuring the interconnection.

A structure for a mask work set has been developed that features the area distribution of array test structures to enable wedge-like thinning in order to produce ultra-thin structures with controlled thickness across the area for better strength and minimum interconnection. The feasibility of implementing the proposed test structures has been analyzed.

The change in the output signal distribution characteristics was studied in the image after wedge-like thinning of an epitaxial sample grown on a heavily doped indium antimonide substrate (sized 640×512, 15 μm pitch):

- defective areas (with enhanced recombination) formed at the growth interface were proved to be “healing” experimentally;
- the penetration depth of defective areas into the epitaxial layer was approximately 1 μm .

REFERENCES

1. Gershon G., Albo A., Eylon M., Cohen O., Calahorra Z., Brumer M., Nitzani M., Avnon E., Aghion Y., Kogan I., Ilan E., Tuito A., Ben Ezra M. and Shkedy L., SemiConductor Devices (SCD), Israel. «Large Format InSb Infrared Detector with 10 μm Pixels», OPTRO-2014-2931891.
2. Lopukhin A. A., Boltar K. O., Grishina A. N. and Shishigin S. E., Usp. Prikl. Fiz. (Advances in Applied Physics) **10** (1), 14–22 (2022) [in Russian].
3. Lopukhin A. A., Permikina E. V., Boltar K. O. and Grishina A. N., Usp. Prikl. Fiz. (Advances in Applied Physics) **11** (5), 421–432 (2023) [in Russian].
4. Lopukhin A. A., Vlasov P. V., Grishina A. N., Permikina E. V. and Shishigin S. E. Method for manufacturing thinned multi-element photodetector based on indium antimonide with improved uniformity and increased mechanical strength. Patent No. RU 2811379 C1 (RF). 2024.
5. Lopukhin A. A., Permikina E. V., Taubes E. V., Shishigin S. E., Mirofyanchenko A. E. and Mirofyanchenko E. V., Usp. Prikl. Fiz. (Advances in Applied Physics) **13** (1), 21–29 (2025) [in Russian].
6. Lopukhin A. A., Permikina E. V., Lavrentev N. A., Taubes E. V., Shishigin S. E., Mirofyanchenko A. E. and Mirofyanchenko E. V. Method of measuring dark current on test matrix structures with variable topology for determining passivation efficiency of large-format matrix photodetectors with small pitch. Patent No. RU 2841177 C1 (RF). 2025.
7. Lopukhin A. A., Boltar K. O., Akimov V. M. and Arbuzov M. A., Applied Physics, No. 5, 44–52 (2021) [in Russian].
8. Boltar K. O., Akimov V. M., Arbuzov M. A. and Lopukhin A. A. Method for obtaining the sensitivity distribution over the matrix photodetector pixel area. Patent No. RU 2783220 C1 (RF). 2022.
9. Davletshin R. V., Lazarev P. S., Nikonov A. V. and Korneeva M. D., Applied Physics, No. 4, 63–66 (2016) [in Russian].
10. Chishko V. F., Kasatkin I. L., Burlakov I. D., Lopukhin A. A., Ponomarenko V. P., Filachev A. M., Borodin D. V., Osipov Yu. V., Karpov V. V. and Kroshin A. M., Applied Physics, No. 2, 64–68 (2007) [in Russian].

About authors

Lopukhin Alexey Alekseyevich, Cand. Sci. (Eng.), Head of Laboratory, RD&P Center ORION, JSC (111538, Russia, Moscow, 9 Kosinskaya st.). E-mail: alexmatr0@mail.ru SPIN code: 7352-7713, AuthorID: 221931

Permikina Elena Vyacheslavovna, Lead Engineer, RD&P Center ORION, JSC (111538, Russia, Moscow, 9 Kosinskaya st.). SPIN code: 4231-5554, AuthorID: 780646

Barysheva Ksenia Vladimirovna, Engineer 1st Category, RD&P Center ORION, JSC (111538, Russia, Moscow, 9 Kosinskaya st.).

Lopatin Vadim Vladimirovich, Dr. Sci. (Eng.), Project Manager Foundation for Advanced Research (121059, Russia, Moscow, 22/3 Berezhkovskaya Emb.). AuthorID: 370192