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Characteristics of small-format matrix photodetectors

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Small-format matrix photodetectors of the 3÷5 μm spectral range based on matrices of indium antimonide photodiodes with minimal defects and uniform sensitivity are investigated. It is shown that the selection of plates from InSb ingots for the production of photosensitive element matrix in accordance with the analysis of statistical data and the use of group thinning and washing allowed to obtain 22 % defect-free of the total number of matrix photodetectors (MPDs) with a defect-free central region. It has been established that treatment of the viewing side of the photodiode matrix with argon ions significantly improves the homogeneity of the sensitivity distribution over the MPD area.

Keywords: matrix photodetectors (MPD); medium-wave spectral range; indium antimonide; defects; homogeneity of sensitivity; group thinning; ion etching; recombination.

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Introduction

Photodetectors (PDs) based on photodiode matrices made of indium antimonide (InSb) are widely used in modern thermal imaging and heat source direction finding systems for the mid-infrared spectral range [1]. Currently, small-format matrix PDs are most in demand for recognizing high-speed objects. The small photoelectric coupling of photosensitive elements (PEs) of small-format matrices allows obtaining thermal images with clear outlines, reducing the blurring of object boundaries. On thinned MPEs (matrix photosensitive elements), the short-range coupling in the region of element 3×3 does not exceed 5 % [2]. Good homogeneity of sensitivity over the area of the photodiode matrix and minimization of the number of photoelectric defects to zero allow for the recognition of objects with maximum accuracy [3, 6].

The structure of small-format MPDs (matrix photodetectors) based on InSb is a 64×64 matrix of photosensitive elements, hybridized with a LSI readout on a raster and a filter. To improve the quantum yield, an antireflective coating is applied to the illuminated side of the MPE. The thickness of the PE matrix of 10÷20 μm is determined by

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the balance between achieving the optimal quantum yield and the relationship caused by the lateral diffusion of minor charge carriers [4].

Defectiveness of the MPEs

Statistical processing and analysis of data on the defectiveness of the MPEs obtained from indium antimonide ingot plates showed that plates taken from the middle of the ingots are most suitable for the production of photodiode matrices with optimal characteristics. The selection of plates for the production of MPEs in accordance with the analysis of statistical data allowed us to increase the percentage of defect-free MPDs.

Figure 1 shows the integral distribution of defects of matrix photodetectors. Defect-free photodetectors accounted for 22 % of the total number of MPDs, and those with one photoelectric defect accounted for 48 % (with a defect-free central region) for group thinning. Evidently, the defectiveness of most MPDs does not exceed 10 elements. On average, there were ≈ 2 defects (368 MPDs measured).

Improving the homogeneity of the sensitivity distribution (current or volt) over the area of the matrix of photosensitive elements is determined by the homogeneity of the MPEs by thickness, since the number of absorbed photons and generated charge carriers is located in the volume of the semiconductor matrix and depends on its thickness. The most optimal method to obtain PE matrices with homogeneous thickness and implement mass production of photodetectors is to use group MPD thinning and washing [5]. Group chemical-dynamic polishing during thinning of photodiode matrices from the side of illumination allowed to reduce edge effects associated with over-thinning of matrices along the perimeter of the MPE, and therefore to reduce the areas of hypo sensitivity at the edges of the matrices. MPDs based on such matrices allowed to obtain more homogeneous images to improve the recognition of objects.

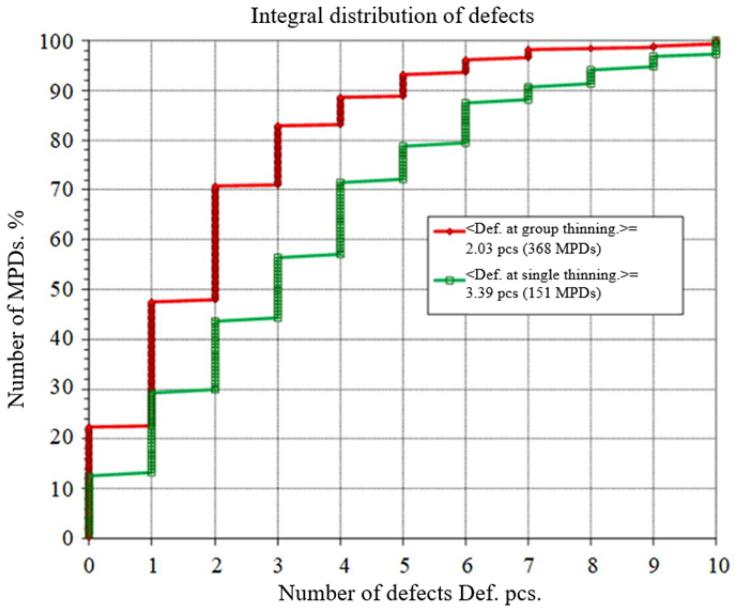

Fig. 1. Integral distributions of defects of matrix photodetectors

Homogeneity of sensitivity

Figure 2 shows the integral distributions of the spread in sensitivity of matrix photodetectors manufactured using single and group thinning of the PE matrices. On average, the spread of sensitivity for group processing methods decreased to 3.7 % (4.2 % for single thinning).

Another factor impacting the improvement of sensitivity homogeneity is

the maximum reduction of regions with an increased recombination rate of photogenerated current carriers, determined by the high density of additional energy levels in the restricted zone. When optical radiation falls from the side of the clarified surface of the MPE, some of the photocarriers can gather along the diffusion length at the interface between the PE matrix and the clarifying coating and recombine due to the high density of electron states.

Recombination of charge carriers which occurs due to non-uniform thickness and composition of oxide films on the surface of the PE matrices and other defects formed during technological processing, suggests the appearance of additional states in the restricted zone, resulting in an increase in the recombination rate in localized areas of the matrix, which contributes to an increase of sensitivity range.

The use of ion treatment of the surface of the MPE with a low-energy flow of positively charged argon ions (high-frequency cathode sputtering with argon ions with an energy of less than 0.25 keV removes a damaged layer up to 0.5 μm) allows to remove mechanically damaged, and partially or completely (depending on the number of ion treatments) damaged layer of the material, changing the magnitude of the surface charge, preventing the flow of mobile charge carriers into the near-surface region and their subsequent recombination [6, 7]. Treatment with argon ions before clarification forms a positive built-in charge on the surface of the back side of the matrix, providing a significant bending of the semiconductor's restricted zone, but not exceeding the width of the restricted zone, which forms a repulsive field for minor charge carriers. That is why the amorphous surface layer formed during the process of exposure to a low-energy flow of positively charged ions, which is less than 50 Å thick [8] and has a high value of surface recombination, does not impact significantly on the effective recombination rate and does not create additional dark currents of the photodiodes.

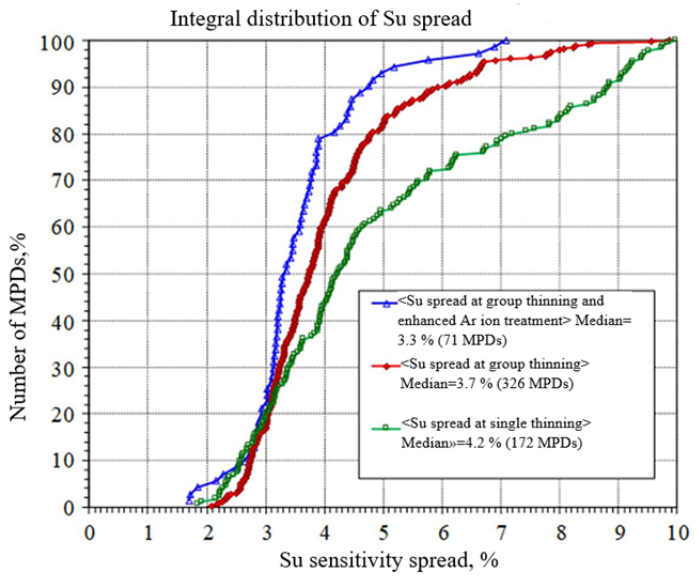

Fig. 2. Integral distributions of the spread of sensitivity of matrix photodetectors

The homogeneity of sensitivity over the area of the MPD was improved during group thinning due to enhanced ion treatment of the back surface [6, 7] (see Fig. 2). Ion treatment removed a significant portion of the damaged surface material and initiated a large positive built-in charge at the interface on the incident radiation side. The increase of surface potential formed a repulsive field for minor charge carriers and inhibited the

recombination of photocarriers on the surface, due to which the sensitivity range (current or volt) over the area of the MPE decreased several times.

Conclusion

1. It is shown that the selection of plates from InSb ingots for the production of small-format MPE in accordance with the analysis of statistical data and the use of group thinning and washing made it possible to obtain 22 % defect-free of the total number of matrix photodetectors with a defect-free central region.

2. It has been established that treatment of the viewing side of the photodiode matrix with argon ions significantly improves the homogeneity of the sensitivity distribution over the MPD area.

REFERENCES

1. Boltar K. O., Burlakov I. D., Iakovleva N. I., Vlasov P. V. and Lazarev P. S., Usp. Prikl. Fiz. (Advances in Applied Physics) **10** (2), 170–182 (2022) [in Russian].

2. Boltar K. O., Vlasov P. V., Lazarev P. S., Lopukhin A. A. and Chishko V. F., Applied Physics, No. 1, 18–24 (2020) [in Russian].

3. 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].

4. Lopukhin A. A., Boltar K. O., Vlasov P. V., Eroshenko V. V., Chishko V. F., Koshchavtsev N. F. and Larionov N. A., Usp. Prikl. Fiz. (Advances in Applied Physics) **8** (5), 334–340 (2020) [in Russian].

5. Lopukhin A. A., Eroshenkov V. V., Irodov N. A., Savostin A. V., Barysheva K. V., Vlasov P. V., Permikina E. V. and Grishina A. N. Method of group fabrication of a thinned hybridized assembly for a matrix photodetector. Patent No. 2811380 (RF). 2023.

6. Lopukhin A. A., Permikina E. V., Boltar K. O. and Grishina A. N., Usp. Prikl. Fiz. (Advances in Applied Physics) **11** (5), 421–431 (2023) [in Russian].

7. Vlasov P. V., Grishina A. N., Lopukhin A. A., Permikina E. V. and Shishigin S. E. A method for manufacturing a thinned multi-element photodetector based on indium antimonide with improved uniformity and increased mechanical strength. Patent No. 2811379 (RF). 2023.

8. Chulkyun Seok, Minkyung Choi, Sehun Park, Jinwook Jung, Yongjo Park, In-Sang Yang and Euijoon Yoona, ECS Solid State Letters **3** (3), P27–P29 (2014).