DETECTION IN THE CONTACTS WITH BISMUTH-ANTIMONY ALLOY WHEN THE SURFACE STATES HAVE THE BIG DENSITY

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Abstract. *Diode detectors (DD) are widely used in electronic information and communication systems. In this paper the numerical modeling of the electrical potential distribution and current passing in the contacts of niobium nitride (NbN) with semiconductor alloy bismuth-antimony (Bi-Sb) was made.*

Earlier we studied situation when the surface states had a little density. In this article an opposite situation is studied, when the surface states have a big density. There were analyzed possibilities to create the diode detectors based on these contacts and working at temperatures (T) of liquid helium 4.2 K and 1 K. The dependences of the current responsivity (CR), the voltage responsivity (VR) and the noise equivalent power (NEP) on the signal frequency (f) were analyzed. The obtained results were compared with literature data. Both DD working at temperature of liquid nitrogen (T = 77.4 K) and liquid helium were considered.

The comparison with existent literature data shows the proposed DD can be 10¸100 times better. The physical reasons of these advantages were discussed. It is shown that unique properties of Bi-Sb alloys and especially of $Bi_{0.88}Sb_{0.12}$ alloy make these alloys to be the very perspective materials for cryoelectronics.

Keywords: *diode detectors, superconductors*

I. Introduction

The diode detectors play an important role in radio technique and electronics. The use of high frequencies (above 1 GHz) stimulated the careful study of diodes with Schottky barrier. These diodes use the quick-acting metal-semiconductor contacts [1].

The further improvement of their parameters was achieved due to fall of the working temperature. This direction was named cryoelectronics [2], it allows to raise the nonlinearity of the current-voltage dependences and current responsivity. The thermal noise power decreases too. For example there were elaborated DD based on the contacts Pb-pGaAs [3, 4]. At the signal frequency f = 9 GHz and T= 4.2 K these diodes had CR ≈ 500 A/W and noise equivalent power 5×10^{-15} W/$\sqrt{Hz}$. At the same frequency and T= 1 K there parameters were: CR ≈ 2500 A/W and noise equivalent power 5.4×10^{-16} W/$\sqrt{Hz}$. Also the deep cooling allows using the materials with little energy gap width but high mobility of electrons, such as solid solutions Bi-Sb [2, 5].

After the discovery of the high temperature superconductors (HTSC) the possibilities to use HTSC in cryoelectronics were studied too. At the liquid nitrogen temperature T = 77 K and signal frequency f = 37.5 GHz the corresponding structures revealed the voltage responsivity 3000 V/W [6]. The further studies [7] allowed to create the structures with VR=5000 V/W and noise equivalent power NEP = 2×10^{-12} W/$\sqrt{Hz}$ at the signal frequency f=31 GHz and temperature T = 77 K. According to our publication [8] the diode detectors based on the contacts HTSC-InSb may have CR ≈ 40 A/W, VR ≈ 10^6 V/W and NEP ≈ 8×10^{-15} W/$\sqrt{Hz}$ at T = 77.4 K and f = 10 GHz At the same temperature and f = 30 GHz these DD may have CR ≈ 15 A/W, VR ≈ 3.5×10^5 V/W and NEP ≈ 2×10^{-14} W/$\sqrt{Hz}$.

On the other hand often there is an oxidation of semiconductor in HTSC-semiconductor contacts, because oxygen is an integral part of HTSC. Also cooling to the liquid nitrogen temperature 77.4 K may be insufficient to obtain the good DD parameters. In this situation, taking into account the rapid development of cryogenics, the study of DD based on the contacts traditional superconductor – semiconductor seems to be actual problem. Usually these DD work at liquid helium temperatures (T ≤ 4.2 K). In this paper the numerical modeling of the electrical potential distribution and current passing in the contacts of niobium nitride with semiconductor alloy bismuth-antimony was made for situation when the surface states have a big density.

II. Results and discussion

The contacts of semiconductor solid solution $Bi_{0.88}Sb_{0.12}$ with NbN were considered, because according to our results [9] these contacts seem to have the best parameters. The round flat contacts with contact area (S) 10 μ^2 and 1 μ^2 were studied. Earlier we studied situation when the surface states had a little density 1.6×10^{12} cm $^{-2}$ [9, 10]. In this article an opposite situation is studied, when the surface states have a big density 1.6×10^{14} cm $^{-2}$ (according to [11] this situation may take place too). Materials properties were taken from [12, 13]. Results of calculations are shown in figures (figs.) 1-3. In all figures the logarithmic scale for X-axes is used. An exponential form is often used for numbers of axes.

Figs. 1 - 3 show that current and voltage responsivities decrease and NEP increases at the frequencies more 10 GHz. At these frequencies the negative role of the barrier capacity is revealed and it begins to shunt the nonlinear contact resistance. On the other hand at high frequencies the contact capacity resistance becomes compared with ohm spreading resistance. The current redistribution occurs, it leads to reduction of the rectified current and DD parameters become worse.

According to figs. 1 -3 the reduction of the contact area may sufficiently improve these parameters (compare curves 1 and 2, 3 and 4 in these figs.). Taking into account the little surface area, these contacts may be considered as point contacts [1]. In this case the barrier capacity is proportional to S and ohm spreading resistance is proportional to $S^{-1/2}$ [1]. In this situation, when the contact area decreases, the capacity resistance rises faster then the ohm spreading resistance. Therefore the redistribution of applied variable voltage occurs, the contact voltage grows and DD parameters become well. When the contact area reduces the contact differential resistance rises and voltage responsivity rises too. On the other hand noise current falls and noise equivalent power falls too (see figs. 2 and 3).

Also the reduction of the working temperature from 4.2 K to 1 K may sufficiently improve these parameters. On one hand nonlinearity of the current – voltage characteristic rises sufficiently, that leads to increase of the current responsivity, voltage responsivity and noise equivalent power [1 - 3]. On the other hand noise current falls and this effect provides with additional reduction of noise equivalent power [1 - 4].

The comparison with our data [10] shows that also in situation, when the surface states have a big density, DD based on Bi-Sb may have the very good parameters.

For comparison our results [14] for contacts HTSC-semiconductor are presented in figs. 4 - 6.

Taking into account results [3, 4, 6-8] we may conclude that contacts with Bi-Sb allow improving considerably DD parameters. They are much more effective than contacts HTSC-superconductor [6 – 8, 14]. Also they are better than contacts with GaAs [3, 4] working at liquid helium temperature.

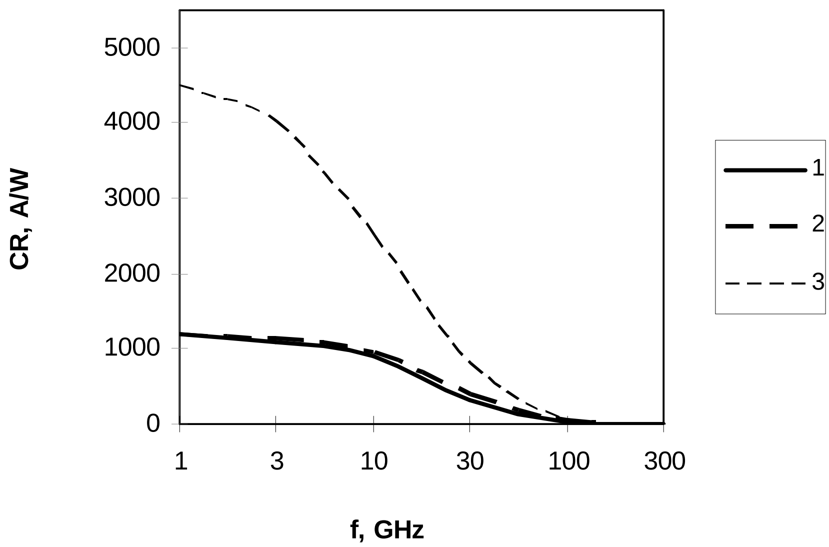

Fig. 1. The calculated current responsivity dependence on the signal frequency in the contacts with $Bi_{0.88}Sb_{0.12}$. The legend inscriptions correspond to the next data:
1 – T = 4.2 K, S = 10 μ^2 , **2** – T = 4.2 K, S = 1 μ^2 and 3 – T = 1 K, S = 1 μ^2.

The main advantages of Bi-Sb are next:

(i) Little barriers heights due to narrow energy gap. This fact provides a big CVD nonlinearity and big current responsivity.

(ii) High mobility of electrons, which reduces ohm resistance and improves frequencies properties.

(iii) Little barrier capacity, due to little barriers heights and small effective masses of electrons, which also improves frequencies properties.

These unique properties of Bi-Sb alloys and especially of $Bi_{0.88}Sb_{0.12}$ alloy make these alloys to bethe very perspective materials for cryoelectronics.

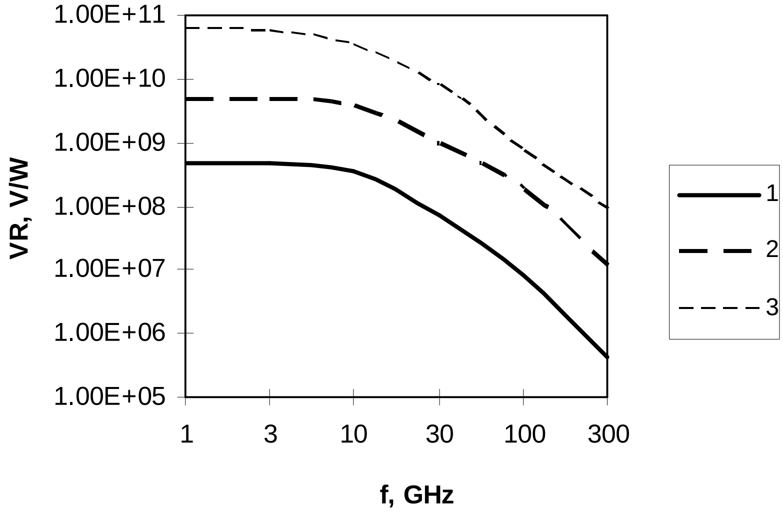

Fig. 2. The calculated voltage responsivity dependence on the signal frequency.
The legend inscriptions and other data are similar to those in fig. 1.

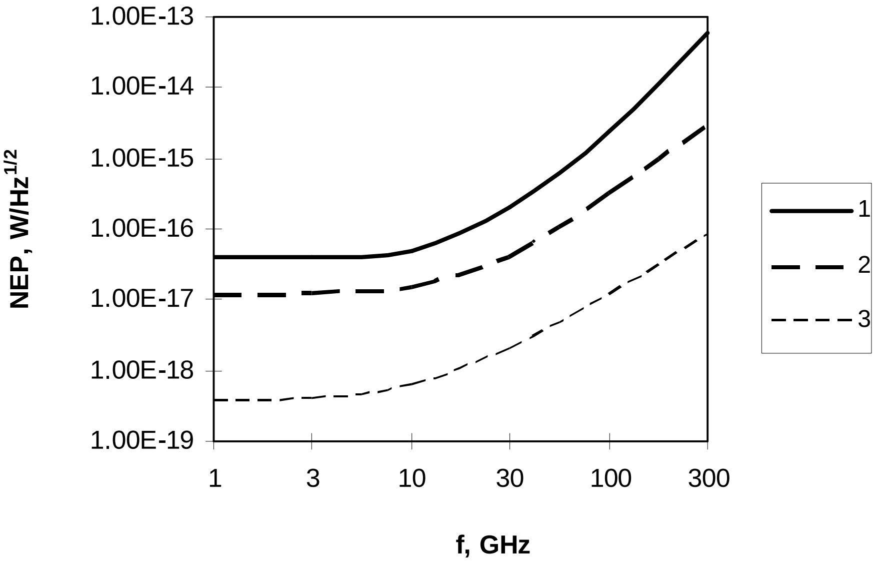

Fig. 3. The calculated noise equivalent power dependence on the signal frequency. The legend inscriptions and other data are similar to those in fig. 1.

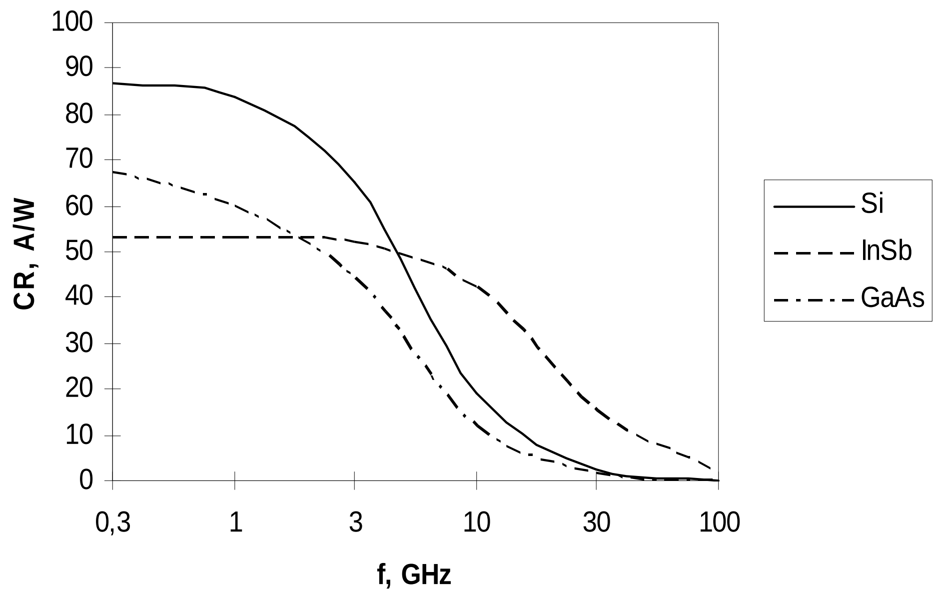

Fig. 4. The calculated current responsivity dependence on the signal frequency for contacts HTSC-semiconductor (the semiconductor substance is shown in legend inscriptions). T = 77.4 K.

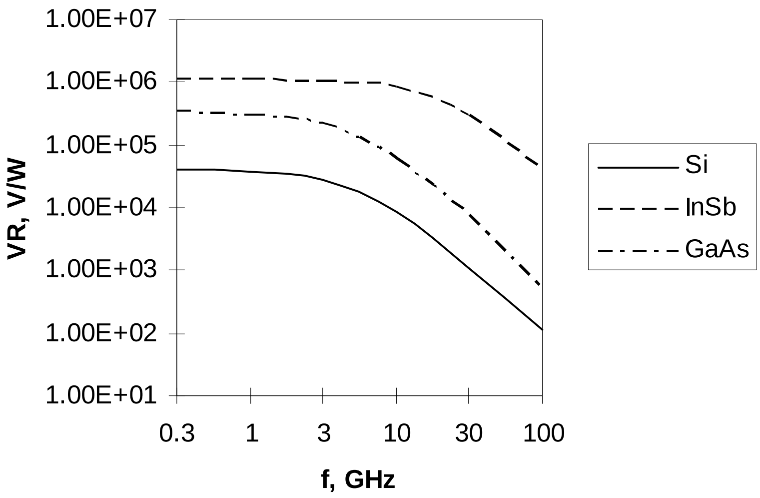

Fig. 5. The calculated voltage responsivity dependence on the signal frequency for contacts HTSC-semiconductor.
The legend inscriptions and other data are similar to those in fig. 4. T = 77.4 K.

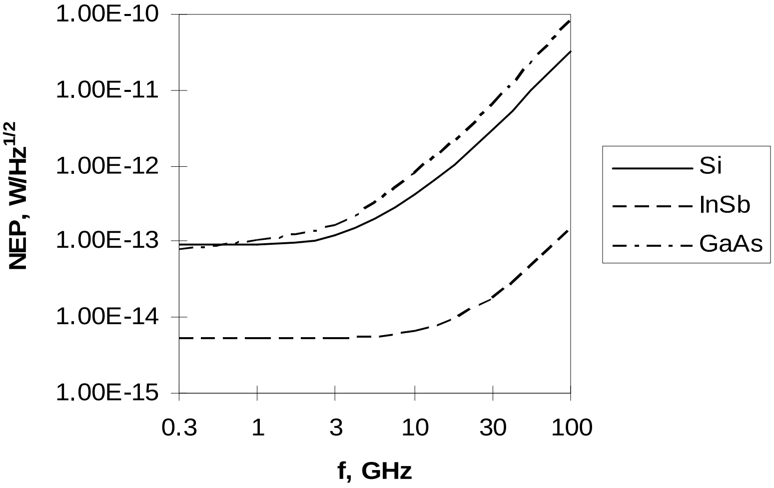

Fig. 6. The calculated noise equivalent power dependence on the signal frequency for contacts HTSC-semiconductor.
The legend inscriptions and other data are similar to those in fig. 4. T = 77.4 K.

III. Conclusion

The comparison with [3, 4, 9, 10] data shows that also in situation, when the surface states have a big density, the proposed DD may have the current responsivity 2 times more and noise equivalent power 100 times less than the ones in existing DD (at the same temperature and signal frequency). Also they may have very high voltage responsivity.

The contact area reduction may sufficiently improve the frequencies properties, noise equivalent power and especially voltage responsivity.

This fact draws the conclusion the contacts with Bi-Sb are perspective to elaborate them.

IV. References

1. Striha V.I., Buzaneva E.V., Radzievsky I.A. Semiconductor devices with Schotttky barrier. Physics, technology, application [in Russian]. – M.: Sov. Radio. 1974, -248 p.

2. Alfeev V.N. Superconductors, semiconductors and paraelectrics in cryoelectronics [in Russian]. – M.: Sov. Radio, 1979. - 408 p.

3. Mc Call M., Millea M.F., Silver A.H.The superconductor-semiconductor Schottky barrier diode detectors. Applied Physics Letters, Volume 23, Issue 5, Sept 1973, pp. 263-264.

4. Mc Call M., Millea M.F., Silver A.H. et al.The super Schottky microwave mixer. IEEE Transactions on Magnetics, Volume MAG-13, Issue 1, Jan 1977, pp. 221-227.

5. Alekseeva V.G., T.M. Lifshits T.M., Chirkova E.G., Shul'man A.Ia.Bi1-xSbx is a new semiconductor material. Radio technique and Electronics (in Russian), Volume 23, Issue 9, Sept 1978, pp.1926-1938.

6. Kulikov V.A., Matveets L.V., Serebryakov A.Iu. et al. The detecting properties of the superconducting thin film micro bridges from YBa2Cu3O7-x. Pis'ma v JTF (Letters in Journal of Technical Physics – in Russian), Volume 15, Issue 20, Oct 1989, pp. 74-77.

7. Kuz`min L.S., Ohrimenko V. N., Soldatov E. S., Tavhelidze A. N. The detecting properties of the YBaCuO films micro bridges. Sverhprovodimost` (Superconductivity– in Russian), Volume 3, Issue 11, Nov 1990, pp. 2650-2660 .

8. Kerner Ia.I. HTSC-Si and HTSC-InSb contacts for diode detectors: comparison of characteristics. Moldavian Journal of the Physical Sciences, Volume 5, Issue 3-4, Dec 2006, pp. 360 – 365.

9. Shik A. Ia. Carrier concentration in the non-uniform samples and films of semimetals. Fizica tverdogo tela (Solid State Physics – in Russian), Volume 16, Issue 9, Sept 1974, pp. 2801 – 2803.

10. Kerner Ia. I. Detection in the contacts with bismuth-antimony alloy when the surface states are in dynamic regime. Proceedings of the 7th International Conference on "Microelectronics and Computer Science", September 22-24, 2011, Chişinău, Moldova, U.T.M., Chişinău, Sept 2011, pp. 37 - 40.

11. Sze S. M. Physics of semiconductor devices. Volume 1. – N. Y.: A Willy – Interscience Publication, 1981.- 455 p.

12. Gitsu D.V., Holban I.M., Kantser V.G., Munteanu F.M. Transport phenomena in bismuth and its alloys [in Russian]. – Kishinev: Stiinta , 1983. - 266 p.

13. Tables of the physical values. Reference book [in Russian]. Ed. by acad. Kikoin I.K. – M.: Atomizdat, 1976. - 1006 p.

14. Kerner Ia.I. Contacts of HTSC with different semiconductors for diode detectors: comparison of characteristics. Proceeding of the 3-rd International Conference "Telecommunications, Electronics and Informatics", Chisinau, Moldova, May 20-23, 2010, UTM, Chisinau, Volume 1, May 2010, pp. 268 - 273.