Detection in the Contacts With Bismuth-Antimony Alloy: Numerical Modeling of the Contact Area Role

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***Abstract*: Diode detectors (DD) are widely used in electronic information and communication systems. The use of diodes with Schottky barrier gave a possibility to master radiowaves of high frequencies (above 1 GHz). These diodes use the quick-acting metal-semiconductor contacts.**

The further improvement of their parameters was achieved due to fall of the working temperature (T). This direction was named cryogenic electronics or briefly cryoelectronics, it allows to raise the nonlinearity of the current-voltage dependences (CVD) and current responsivity (CR).

In this paper the numerical modeling of the electrical potential distribution and current passing in the contacts of normal metal with semiconductor alloy bismuth-antimony (Bi-Sb) with different contact area was made. There were analyzed possibilities to create the diode detectors based on these contacts and working at liquid helium temperature 4.2 K. The dependences of the current responsivity, 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 (T= 4.2 K) 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 too. 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.

Therefore these DD are perspective for cryogenic electronics and there is an actual problem to elaborate them.

***Key words*- detection, Schottky diodes.**

I. INTRODUCTION

The diode detectors play an important role in radio technics 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/$\sqrt{Hz}$. 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 article there are discussed DD based on the contacts of normal metal with semiconductor solid solution Bi-Sb. We tried to analyze the contact area role in this DD.

II. RESULTS AND DISCUSSION

The contacts of semiconductor solid solution $Bi_{0.88}Sb_{0.12}$ with normal metal were considered. The normal metal may be aluminum at T ≥ 1.2 K and silver or gold at lower temperatures. Materials properties were taken from [9-11]. 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 3 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.

The round flat contacts with contact area 100, 10 and 1 μ^2 were studied. 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*, where *S* is the contact area, 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 (see curves 1, 2, 3 in fig. 1). 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).

For comparison our results [12] for contacts HTSC-semiconductor with contact area 100 μ^2 are presented in figs. 4, 5.

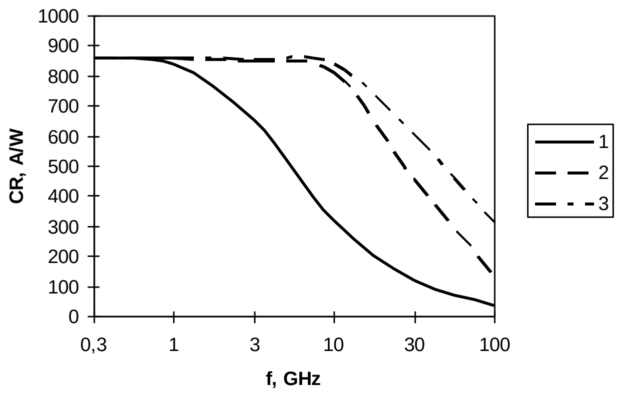

Fig. 1. The calculated current responsivity dependence on the signal frequency in the contacts with $Bi_{0.88}Sb_{0.12}$. The legend inscriptions 1, 2 and 3 correspond to the contact area 100, 10 and 1 μ^2.   T = 4.2 K.

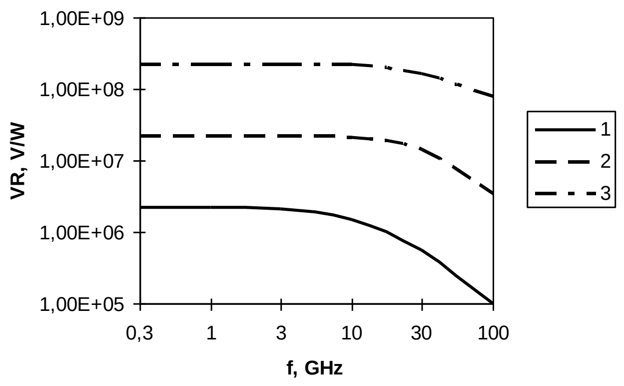

Fig. 2. The calculated voltage responsivity dependence on the signal frequency. The legend inscriptions and other data are similar to those in fig. 1. T = 4.2 K.

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.

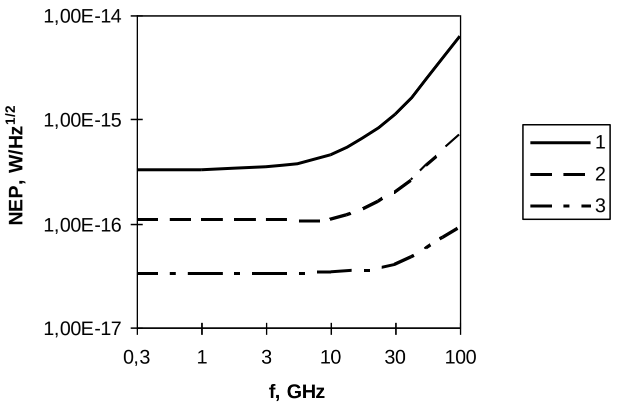

Fig. 3. The calculated noise equivalent power dependence on the signal frequency. The legend inscriptions and other data are similar to those in fig. 1. T = 4.2 K.

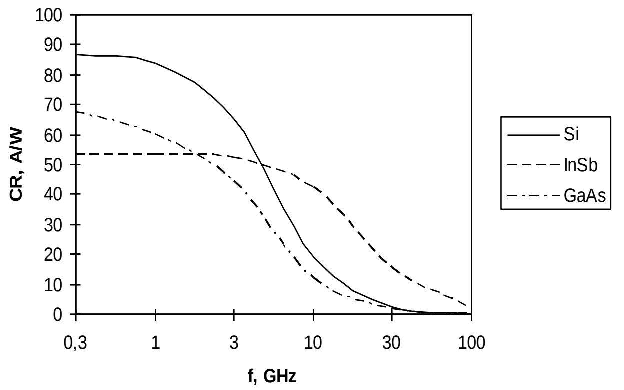

Fig. 4. The calculated current responsivity dependence on the signal frequency for contacts HTSC-semiconductor (the semiconductor substance is shown in legend inscriptions). T = 77.4 K.

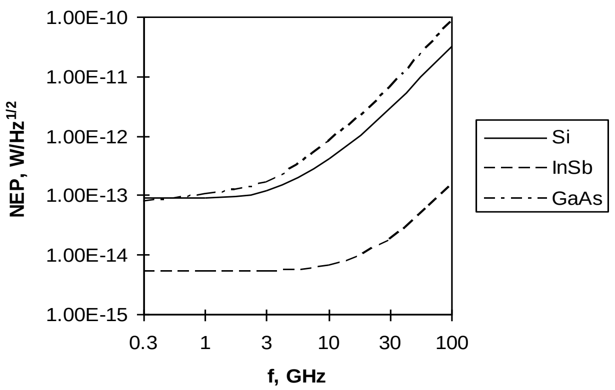

Fig. 5. The calculated noise equivalent power dependence on the signal frequency for contacts HTSC-semiconductor. The legend inscriptions and other data are similar to those in fig. 4. T = 77.4 K.

These 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.

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

III. CONCLUSION

The comparison with [3, 4] data shows that in the proposed DD current responsivity can be 2 times more and noise equivalent power can be 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.

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