Some Aspects of Detection in the Low Temperatures Diode Detectors

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***Abstract*— Diode detectors (DD) are widely used in electronic information and communication systems. The numerical modeling of the electrical properties in the contacts of the high temperature superconductor (HTSC) with semiconductor indium antimonite (InSb) had been made. There were analyzed the possibilities to create DD based on these contacts and working at liquid nitrogen temperature 77.4 K. The influence of the contact potential difference on the DD parameters was analyzed.**

Also the numerical modeling of the electrical potential distribution and current passing in the contacts of normal metal or superconductor with semiconductor alloy bismuth-antimony (Bi-Sb) was made. There were analyzed possibilities to create DD based on these contacts and working at liquid helium temperature 4.2 K.

The comparison with existent literature data shows the proposed DD can be 10÷100 times better. Therefore these DD are perspective for cryogenic electronics and there is an actual problem to elaborate them.

***Key words* — Diode detectors, semiconductors, 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 (T). This direction was named cryoelectronics [2], it allows to raise the nonlinearity of the current-voltage dependences (CVD) and current responsivity (CR). 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 NEP ≈ 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 superconductivity the possibilities to use HTSC in cryoelectronics were studied too. At the liquid nitrogen temperature 77 K and signal frequency f = 37.5 GHz the corresponding structures revealed the voltage responsivity VR=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 results [8, 9] the diode detectors based on the contacts HTSC-InSb may have parameters: CR ≈ 40 A/W, VR ≈ 106 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 ≈ 3.5×105 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 temperature (T = 4.2 K). In this article there are discussed both DD based on HTSC-semiconductor contacts and DD based on the contacts of superconductor (or normal metal) with semiconductor solid solution Bi-Sb.

II. RESULTS AND DISCUSSION

The contact potential difference (CPD) seems to be an important parameter of the HTSC – InSb contacts. According to [1 ,2] we may write ΔA = A1 – A2, where is CPD, A1 and A2 are the work functions of HTSC and InSb accordingly.

Fig. 1 presents the calculated current responsivity on the signal frequency. In figures 1-3 the contacts HTSC-InSb are discussed, T = 77.4 K.

In all cases the current responsivity reduces at high frequencies, because the negative role of the barrier capacity is revealed and the contact capacity resistance becomes comparable with the ohmic resistance of the semiconductor volume. The redistribution of the applied voltage between contact resistance and volume resistance occurs, thus leading to the decrease of the rectified current and DD parameters become worse.

The calculated voltage responsivity dependency on the signal frequency is shown in fig. 2. The explanation of the frequency dependency is similar to one in fig. 1.

The calculated NEP dependency on the signal frequency is shown in fig. 3. The explanation of the frequency dependency is also similar to one in fig. 1.

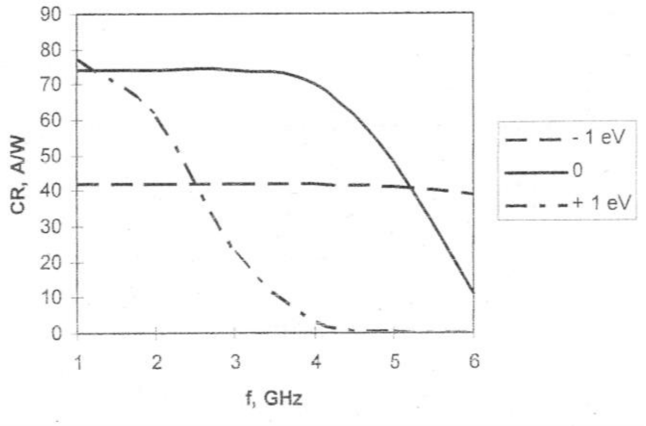

Fig. 1. Calculated dependence of the CR on the signal frequency for the HTSC–semiconductor contacts. The inscriptions show ΔA for corresponding curves. T = 77.4 K.

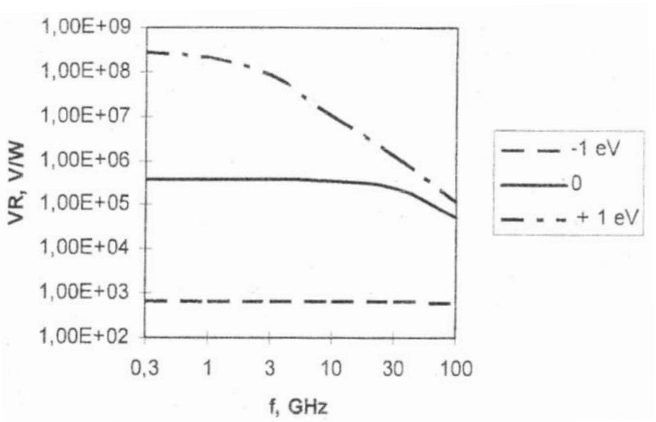

Fig. 2. Calculated dependence of the VR on the signal frequency for the HTSC–semiconductor contacts. The inscriptions and other data are similar to those in Fig. 1. T = 77.4 K.

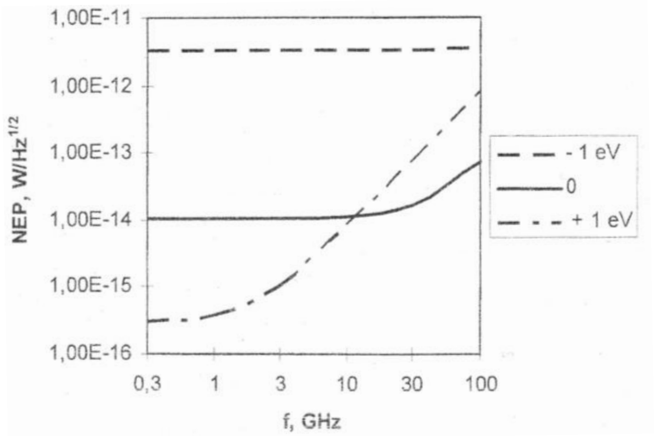

Fig. 3. Calculated dependence of the NEP on the signal frequency for the HTSC–semiconductor contacts. The inscriptions and other data are similar to those in Fig.1. T = 77.4 K.

When CPD is equal to – 1 eV the contact barrier height is minimal and the barrier permeability is maximal. In this case the working point current is big and the contact resistance is small. This situation provides the good frequencies characteristics due to small contact resistance, but the current responsivity is relatively small due to small nonlinearity of the current – voltage (I – V) curve, voltage responsivity is small due to small contact resistance and noise equivalent power is big due to big working point current.

The situation changes when CPD is equal to 0 and especially to + 1 eV. Then the contact barrier height increases and the barrier permeability decreases. In these cases the contact resistance becomes more and the working current becomes less. The current responsivity increases due to increasing of (I – V) curve nonlinearity, the voltage responsivity rises due to contact resistance rising and the noise equivalent power decreases due to working current decrease.

But in this situation the frequencies characteristics become worse due to contact resistance rising, because the shunting role of the barrier capacity becomes stronger.

Also contacts of semiconductor solid solution $Bi_{0.88}Sb_{0.12}$ with normal metal or superconductor were considered. The normal metal may be aluminum at T ≥ 1.2 K and silver or gold at lower temperatures. Niobium or niobium nitride (NbN) may be chosen as superconductors at liquid helium temperatures. Materials properties were taken from [10, 11]. Results of calculations are shown in figures 4 - 6. In all figures the logarithmic scale for X-axes is used.

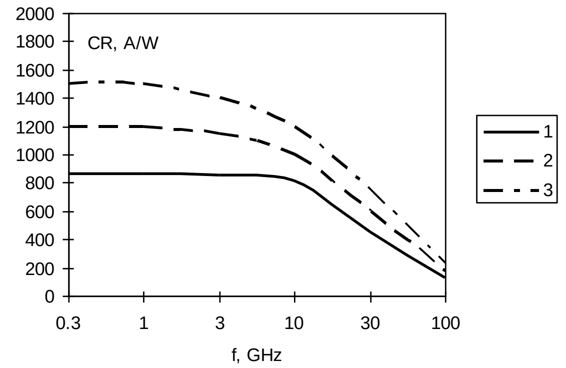

Fig. 4. The calculated current responsivity dependence on the signal frequency. The legend inscriptions 1, 2 and 3 correspond to the contacts of Bi0.88Sb0.12 with normal metal, niobium and niobium nitride accordingly. T = 4.2 K.

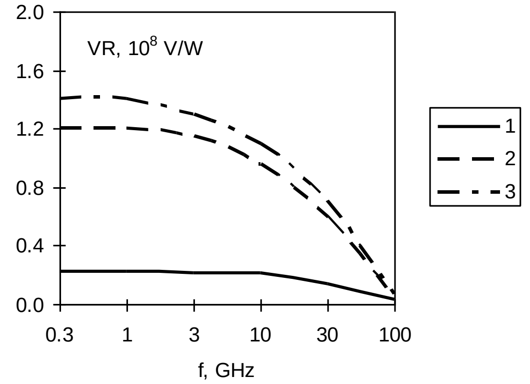

Fig. 5. The calculated voltage responsivity dependence on the signal frequency. The legend inscriptions are similar to those in fig. 4. T = 4.2 K.

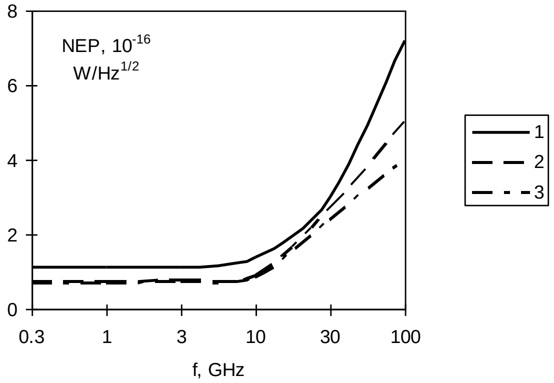

Fig. 6. The calculated noise equivalent power dependence on the signal frequency. The legend inscriptions are similar to those in fig. 4. T = 4.2 K.

Figures 4 - 6 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. The current redistribution occurs, it leads to reduction of the rectified current and DD parameters become worse.

If metal is replaced by superconductor the DD parameters are improved essentially. This effect increases when superconductor energy gap is more (see curves 2 and 3 in figs. 4-6). This fact points out the necessity to select superconductor with wide energy gap (for example NbN).

Taking into account results [3, 4, 6-8, 12] 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].

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.

III. CONCLUSION

According to obtained results the temperature decrease from 77.4 K to 4.2 K allows to improve the diode parameters by two orders.

On the other hand the working temperature 77.4 K may be applied too, if the correspondent parameters are acceptable.

The comparison with [3, 4, 6, 7] 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.

This fact draws the conclusion the studied contacts are perspective to elaborate them.

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