High Gap Nb-AlN-NbN SIS Junctions for Frequency Band 790-950 GHz

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Abstract— **We have designed, fabricated and tested superconductor-insulator-superconductor (SIS) mixers based on Nb/AlN/NbN twin tunnel junctions for waveguide receiver operating in frequency range of 790 - 950 GHz. The electromagnetic simulations and measurement results are presented. The junctions have high gap voltage of 3.2 mV and high current density of about 30 kA/cm^2 providing wide receiver band confirmed by FTS and noise temperature measurements. The corrected receiver noise temperature is varying from 250 K at low frequencies to 500 K at the high end of the band. We observed the junction heating caused by the Andreev reflection and studied the influence of it on the SIS junction characteristics.**

I. Introduction

In 2006 the CHAMP+ heterodyne array [1] was installed on the APEX telescope [2]. It is composed of 14 pixels, divided into two sub-arrays of 7-pixels each, arranged in a hexagonal configuration. The RF tuning range is 620-720 GHz for the 450 µm and 790-950 GHz for the 350 µm sub-array.

The low frequency band array was based on the state of the art SIS receivers developed for the ALMA Band 9 – a result of few years research and development. At the same time, for the high band mixers it was made only one design, without iterations.

Here we present our work on a new batch of SIS mixers for 790-950 GHz, which is dedicated to upgrade the existing CHAMP+ high band array.

II. Design and Fabrication

We have developed a SIS mixer based on high critical current density Nb/AlN/NbN junctions with the normal state resistance to area product RnA = 7 Ohm/µm^2, which corresponds to current density Jc = 30 kA/cm^2. Due to the high current density of produced AlN barrier a higher 1/RC ratio for the junctions is realised, providing a wider receiver band. The Nb layer of the junction is attached to the NbTiN bottom electrode of the microstrip line and the NbN layer is contacting the top electrode made of Al.

In order to make a wide band receiver, we have used a twin SIS junction (each single junction of the twin has area of 0.5 µm^2), which is coupled by an antenna to the field of rectangular waveguide 300x75 µm (see Fig.1).

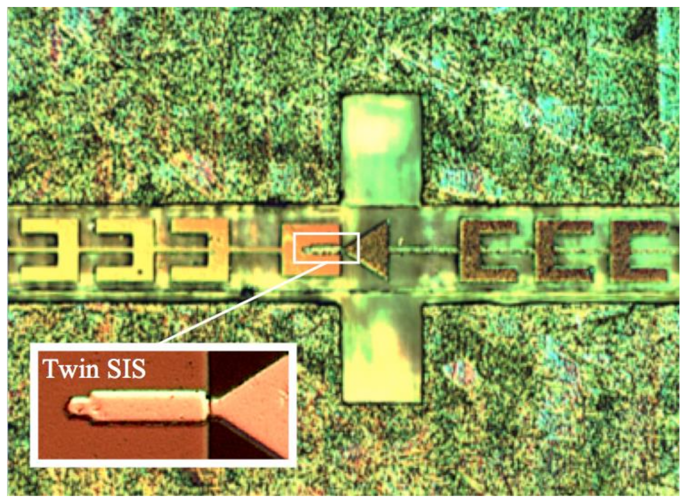

Fig. 1 Photo of the SIS mixer (including the antenna and the filter structure) installed in a waveguide. The central part with SIS twin junction is magnified.

III. Measurements

A. FTS results

Due to possible variations in microstrip dimensions and junctions parameters caused by production process, a set of design modifications were implemented. In addition, there was an uncertainty about specific capacitance Cs of the SIS junctions with the AlN barrier, which was assumed to be Cs = 60 fF/µm^2 in [3] for critical current Jc = 56 kA/cm^2 and was measured as Cs = 85 fF/cm^2 for Jc = 50 kA/cm^2 in [4] and, also, was estimated as Cs > 100 fF/cm^2 for Jc > 20 kA/cm^2 in [5] and [6].

The measured FTS response of the receiver is presented on Fig.2 together with results of simulations. According to the best fit between the data and the simulations the specific capacitance is Cs = 80 fF/cm^2. The receiver response is shown to be more than 200 GHz wide, however it is clear that design should be corrected to shift the response to a higher frequencies for better coverage of desired 790-950 GHz range. One can see how the distribution of the energy between the junctions of the twin mixer (see dashed curves on Fig.2) helps to widen the bandwidth. The low frequency roll-off of the response is due to the waveguide cut-off.

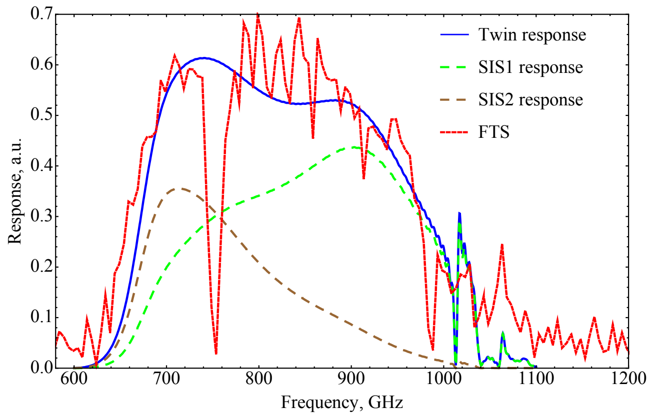

Fig. 2 Measured FTS response of the twin mixer – read dotted line; simulations of the response – blue solid line; simulated response of each single SIS mixer of the twin – dashed lines.

B. Noise Temperature

The noise temperature measurements are depicted on Fig.3. The data is already corrected for an LO injection beam splitter. For the best junction the Tn level is about 250 K at low frequency end and it goes up to 500 K at high frequencies. Since the receiver bandwidth was expected to be very wide, additional sensitivity measurements were done around 700 GHz, for one of the mixers. The results are in good agreement with the FTS data (see Fig. 2).

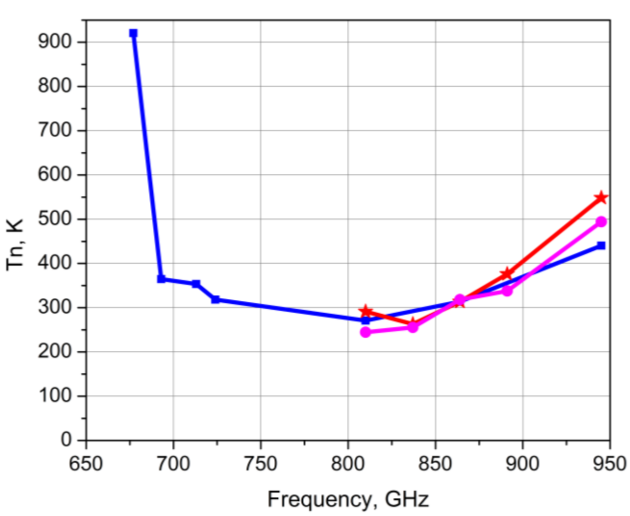

Fig. 3 Corrected DSB noise temperature. Data for three different mixers is presented. For one of the mixer there were measured additional points at lower frequencies (squares).

C. Heating due to Andreev reflection

While choosing the Nb/AlN/NbN technology for the SIS junction fabrication with the NbTiN/SiO_2/Al three-layer for the embedding microstrip circuit correspondingly, we expected an SIS heating effect [7] [8]. The thermal electrons in Nb layer are trapped between two higher-gap superconductors, and, as result, the electron gas is locally heated. The effect of heating is not visible on a single SIS IV curve (there is no negative resistance near the gap voltage), but the gap voltage Vg is sufficiently decreased when LO signal is applied to pump the SIS mixer (see Fig.4). Still, the Nb/AlN/NbN junction has high gap voltage and provides, as it was expected, a wide enough interval of bias voltages abound 2 mV, making is easy to operate the mixer.

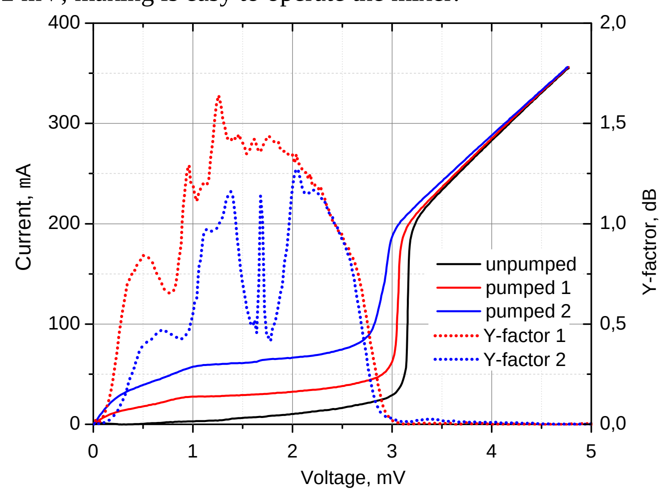

Fig. 4 IV-curves of a SIS twin junction: “unpumped” – no LO power is applied, “pumped 1” – LO power providing optimal Tn is applied, “pumped 2” over-pumped curve. LO frequency is 810 GHz. The measured Y-factor for 77 K/300 K loads is shown by dotted curves: “Y-factor 1” corresponds to “pumped 1” IV curve, “Y-factor 2” - to “pumped 2” one. Y-factors here should be corrected on 64% beam splitter to give a noise temperature point on Fig.3.

The gap voltage Vg is reduced by 0.1 mV for the LO power level giving the best noise temperature (curve “pumped 1” on Fig.4). It should be mentioned, that the optimal pumping level (ratio of the LO induced current to the gap current Ig) is only about 12%, which is about twice lower than for the regular single SIS mixers and can be explained by heating and by misbalance of power between the individual SIS junctions of the twin.

It was observed one more side effect of junction heating. Normally, the external magnetic field, required to suppress the SIS junction critical current, is independent on the LO power. Yet, in our measurements the required H-field level was changing drastically with the pumping level. The magnetic field is the same for both “Y-factor 1” and “Y-factor 2” curves on Fig.4, but there is strong deep on the second curve between 1.4 and 2.1 mV due to the critical current. This effect makes additional difficulties for the receiver operation.

To estimate the deterioration of the Tn due to heating of the junction, we have measured the mixer parameters at lower bath temperatures. By cooling down the mixer to the temperature of 2 K the Vg was increased by exactly 0.1 mV and compensated the Vg reduction caused by the LO power giving the 12% pumping level. In this case, the measured noise temperature is 10% less than at 4.2 K. However, we should keep in mind, that this measurement gives only estimation, because for 2 K bath temperature with applied LO power the NbN energy gap corresponds to 2 K (higher then for 4.2 K), but the Nb layer energy gap is lower than at 4.2 K due to LO signal heating, still, in combination they give the same Vg in both cases.

IV. Conclusions

The measured noise temperature is already 10% better than average of existing CHAMP+ high frequency mixers, installed on APEX telescope [1]. From other hand, the junction heating leads to increasing of the noise temperature by at least 10% and makes difficult the critical current suppression. Overcoming of a heating problem by replacing the NbN layer of the SIS junction by a pure Nb and correction of the design, or even switching to a single-junction option, it should give a reasonable improvement in sensitivity of the mixers, making it worth for the upgrade. The final goal is to reach the same, or even better, sensitivity as for the state of the art mixers for ALMA Band 10 made by a Japanese group [9], which perform 1.5 times better nose temperature at the moment.

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