AlN Barrier SIS Junctions in Submm Heterodyne Receivers: Operational Aspects

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***Abstract*— The Atacama Large Millimeter Interferometer (ALMA) [1] site is an observatory which consists of more than fifty 12 meter diameter sub-mm telescopes, located at an altitude of 5000 m in the Atacama desert in Chile. It covers the 30-950 GHz frequency range which is divided into ten bands following the atmospheric transmission windows. ALMA front-ends will be using Superconductor-Insulator-Superconductor (SIS) heterodyne mixers as the key sensitive elements for all of its high frequency bands.**

The ALMA band 9 receiver which covers 600-720 GHz is being developed in the Netherlands. The first eight receivers have already been built based on AlO_x barrier SIS junctions mixers. These mixers have excellent noise temperature but show limited RF and IF bandwidth. Using new AlN barrier higher current density SIS junctions, it is possible to improve on the RF and IF bandwidth of SIS mixers thus making this technology significantly more attractive for the use in large series of SIS receivers. Currently, a good sensitivity and band coverage has already been achieved for AlN mixers [2]. However, performance of AlN mixers at higher frequencies depends highly on Josephson noise suppression and is only optimal if a precise magnetic field is applied on the barrier. Present routines for Josephson noise suppression in AlO_x barrier mixers were not sufficient. In this paper these routines will be discussed in detail and its adaptation to AlN barrier mixer operation will be reported.

I. Introduction

AlO_x barrier SIS junctions mixers developed for ALMA band 9 (600–720 GHz) [3], [4] have excellent noise temperature but show limited RF and IF bandwidth. Using a new AlN barrier higher current density SIS junctions [5], it is possible to improve on the RF and IF bandwidth of SIS mixers (see Figures 1 and 2), thus making this technology significantly more attractive for the use in large series of SIS receivers. As AlN junctions are relatively small and thin, a flux quantum at the barrier is already created if the bias voltage exceeds 3 mV. This does not disturb its operation as the bias voltage operation point lays at 2 mV.

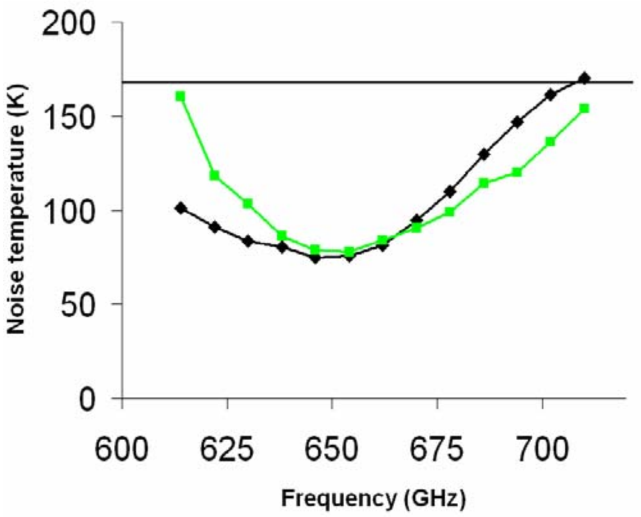

Fig. 9 Noise temperatures of present mixers based on AlO_x (green line) and AlN (black line) barriers. The AlO_x barrier mixer is one of the delivered junctions for ALMA. It has a size of 1 μm^2 and a resistance times area of 25 $\Omega\ \mu m^2$. The AlN barrier mixer has a size of 0.25 μm^2 and a resistance times area of 3.7 $\Omega\ \mu m^2$. The AlN mixer has a lower minimum noise temperature.

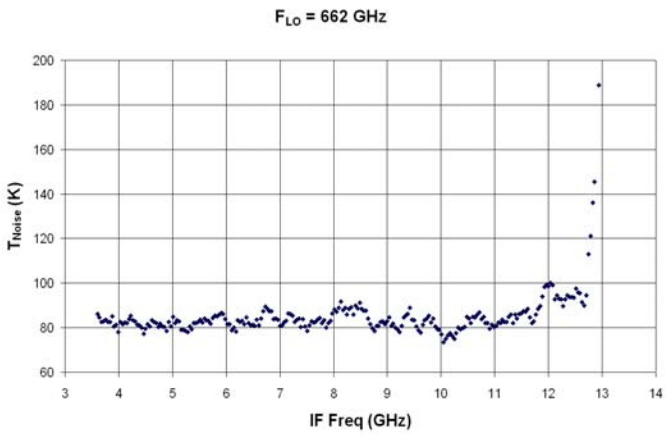

Fig. 2 IF coverage for the AlN mixer using an LO frequency of 662 GHz. For obtaining data over the whole 600 - 720 GHz range, the LO frequency

can be altered in steps of 8 GHz as the IF coverage is nicely flat over an 8 GHz range (from 4 to 12 GHz).

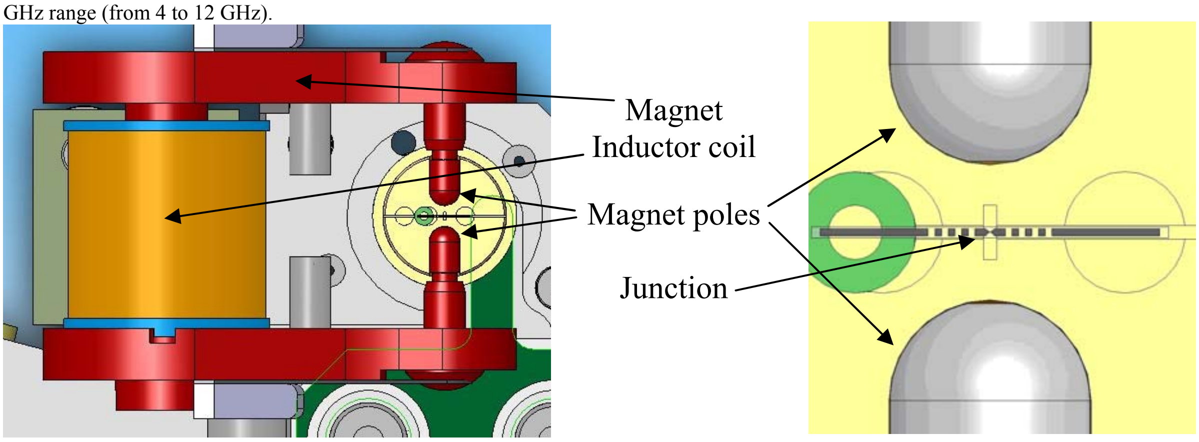

Fig. 3 Overview and detail of the Vacoflux 50 ferromagnetic construction for generating a magnetic field at the junction. Within the overview picture the ferromagnetic material is shown in red. Tuning and demagnetizing it is done using the inductor (coil made of 4600 turns of 30µm NbTi wire), shown in orange. The junction is positioned in between the two poles as shown in the detail picture. At the junction, the magnetic field can be considered uniform and the field lines are in the same plane as the barrier (Figures by Gerrit Gerlofsma).

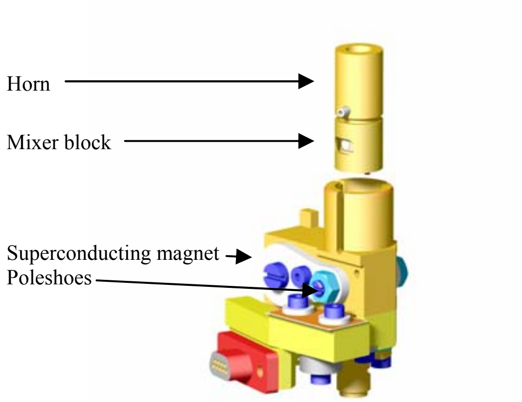

Fig. 4 Mixer holder with superconducting magnet, poleshoes, heater contact, thermometer and IF connector. To operate an AlN barrier mixer the remanent field inside the magnet and the flux inside the superconducting material should be removed. After this, the right magnetic field can be set to suppress the Josephson effect (Figure by Gerrit Gerlofsma).

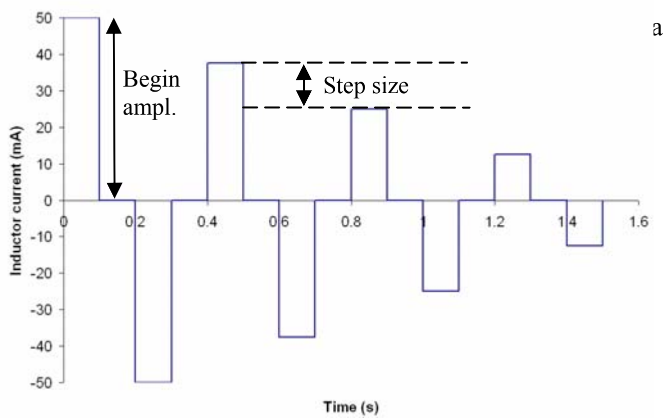

Fig. 5 Block shaped current function with decreasing amplitude used for demagnetizing the magnet. The step size is the amplitude decrease between two succeeding current pulses of the same sign. Each negative current pulse has the same amplitude as the previous positive pulse.

To get a small and repeatable noise temperature and stable operation for AlN SIS mixers operating at 600–720 GHz, the Josephson effect should be properly suppressed by applying a specific magnetic field over the junction. An external magnet consisting of a superconducting coil and a ferromagnetic core is in our mixer. Here, the coil is made of 4600 turns of 30µm NbTi wire and the ferromagnetic core is made of Vacoflux 50 (49% cobalt and 49% iron, having a high saturation induction) and its poles are positioned near the junction (see Figure 3, 4). At the junction the magnetic field can be considered uniform and the field lines are in the same plane as the barrier.

Due to hysteresis a magnet can produce a remanent field. This remanent field can be removed by demagnetization of the magnet. Only after demagnetization a current through the inductor will result in a predictable magnetic field delivered by the magnet. Also flux quanta trapped in the superconducting material in or around the SIS junction will able to set the right magnetic field for maximum Josephson effect suppression.

Demagnetizing a magnet core is ordinary done by putting a block shaped current with decreasing amplitude through the inductor surrounding the magnet (see Figure 5). With each current pulse a magnetization is created inside the magnet which will be replaced by a magnetization of opposite direction during the preceding current pulse of opposite sign. This magnetization will be replaced by a magnetization of opposite sign and smaller magnitude during the next pulse which has a smaller magnitude.

Defluxing superconducting material is done by temporarily taking it out of superconducting state by heating it up. Once it is out of superconducting state the flux will vanish due to resistance of the film. If there is no magnetic field during the proceeding cooling down (proper demagnetized required) no new flux will be trapped and the defluxing procedure was successful.

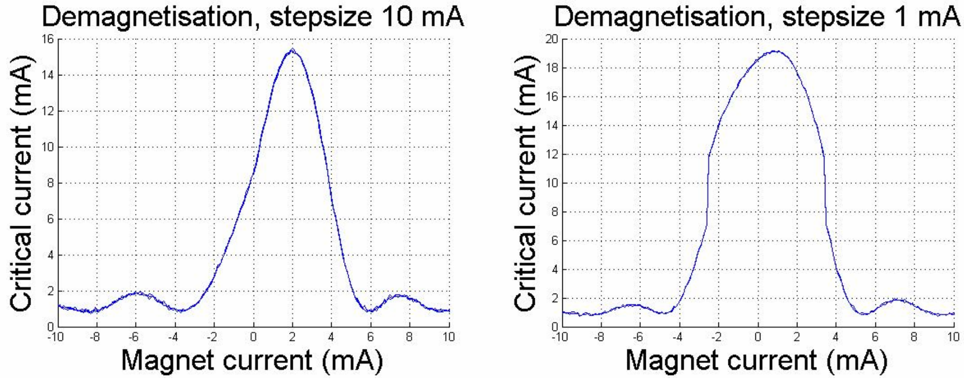

Figure 6: Demagnetization with a step size of 10 mA (common for ALMA AlO_x mixers) results in a asymmetric curve (left hand side). Demagnetization with a step size of 1 mA results in an almost symmetric curve (right hand side). Both curves were obtained using an AlO_x barrier and a starting amplitude of 40 mA. Demagnetizing was always followed by defluxing.

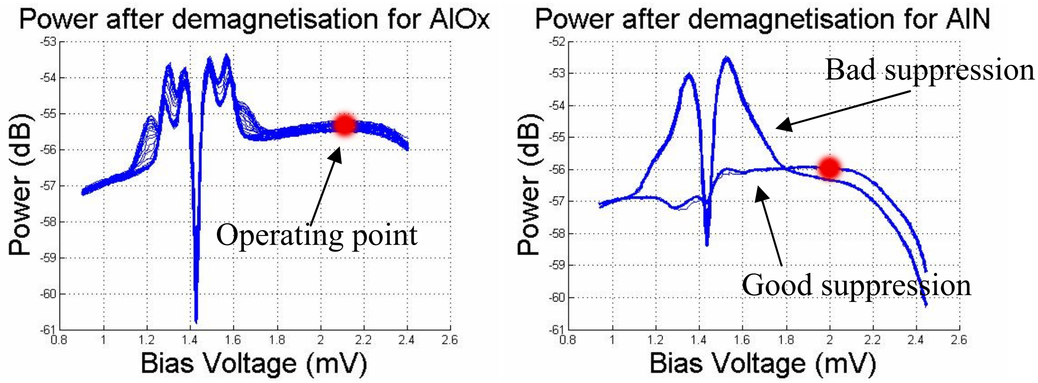

Figure 7: Measured power v.s. bias voltage profile after demagnetization and defluxing for an AlO_x and the AlN mixer. The operation procedure was repeated 40 times for each mixer. For AlO_x all attempts did result in a good operating point (the red dot). For AlN in 21 cases the Josephson effect was insufficiently suppressed. The starting amplitude of demagnetization was 40 mA and the step size was 1 mA.

II. Used methods & results

The quality of the defluxing and demagnetizing procedure can be studied by measuring the critical current as a function of the magnet current afterwards. If this function is symmetrical around zero, there was no flux or remanent field. As this involves applying magnet currents of opposite signs a remanent field will be introduced somewhere and influence part of the measurement. To overcome this problem, the measurement is done in two parts: first magnet currents from zero to a negative minimum value are applied (and critical currents are measured), then the defluxing and demagnetizing procedure is repeated and finally magnet currents from zero to a positive maximum value are applied. The whole measurement was done twice to show its repeatability.

Demagnetization AlO_x mixers for ALMA is currently done using a step size of 10 mA. Using this step size did result in an asymmetric curve. Decreasing the step size to 1 mA did result in a more symmetric curve, showing a better quality demagnetization.

If the demagnetizing and defluxing was performed correctly, a specific magnetic field can be obtained by putting a specific current through the inductor. The Josephson effect then gets properly suppressed and the measured power gets predictable for a given bias voltage (an operating point, see Figure 7). If the Josephson is not suppressed properly, the measured power will differ which will result in a bad noise temperature.

The repeatability of demagnetizing and defluxing can be tested by retrieving the power v.s. bias voltage profile afterwards for a specified magnet current and repeat the whole procedure many times. This was done 40 times for both the AlO_x and the AlN mixer (see Figure 7). For AlO_x all attempts did result in a good operating point (indicated in the Figure). For AlN in 21 cases the Josephson effect was insufficiently suppressed, because the AlN junction is more sensitive to small deviations from the optimal magnetic field. This is due to the small dimensions of the AlN junction: it is small and thin when compared with AlO_x junctions. So for the AlO_x mixer one can assume that the Josephson effect is properly suppressed, while for AlN one has to test this and repeat the demagnetizing and defluxing procedure in case the

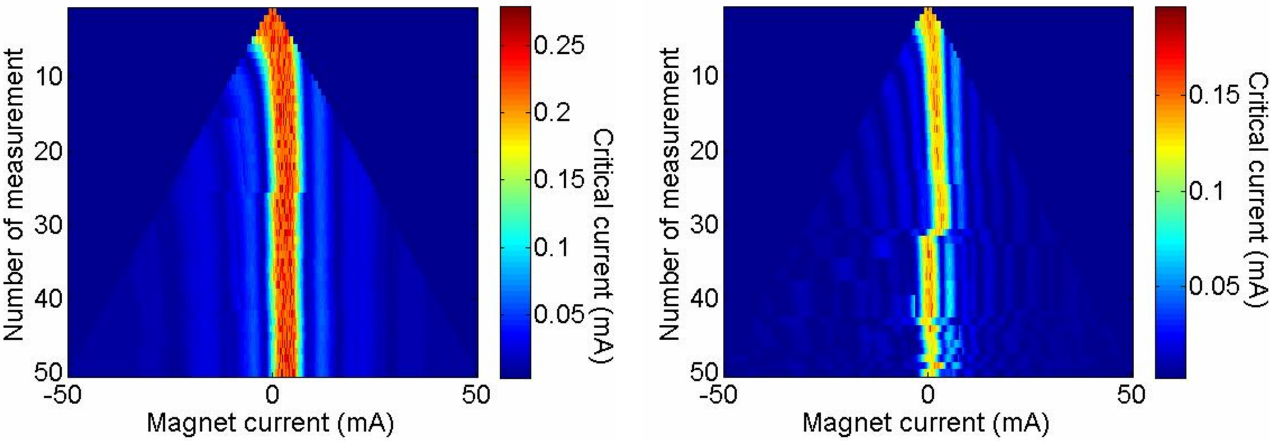

Figure 8: 50 measurements (measurement number on the vertical axis) of the critical current (intensity) as a function of magnet current (in mA, horizontal axis). Data for 0.25 μm^2 AlN barrier junction is presented on the left hand side and data for 1 μm^2 AlO_x is on the right hand side. For each measurement the magnet current was varied between a negative and a positive value with increasing magnitude. The junction was demagnetized and defluxed before doing these measurements. The measurements show the critical current response to different magnet current extrema. With increasing magnet current extrema the intensity patterns first start to look similar as the magnet will move towards its saturation level. If the magnitude of the extrema gets above 20 mA the patterns can get shifted. This is not explained yet. One possibility can be that a flux in the film can be generated relatively far from the junction location that shifts the curve, but does not decrease the maximum critical current.

Josephson effect was not properly suppressed. This is a big drawback for AlN mixers right now and requires further investigation.

The response to high magnet currents and the saturation level of the magnet was studied. This was done by doing 50 measurements of the critical current as a function of magnet current (see Figure 8). For each measurement the magnet current was varied between a negative and a positive value with increasing magnitude. The junction was demagnetized and defluxed before doing these measurements and both AlN and AlO_x barriers were used. The measurements show the critical current response to different magnet current extrema. With increasing magnet current extrema the intensity patterns first start to look similar as the magnet will move towards its saturation level. If the magnitude of the extrema gets above 20 mA the patterns can get shifted. One possibility can be that a flux in the film has been created that shifts the curve but does not decrease the maximum critical current. This effect does not prevent operation of the ALMA detectors, but it does occur during the demagnetization procedure now used on the ALMA mixer.

Conclusions

We succeeded in operating an AlN barrier SIS junction. This junction is the result of very recent developments and shows a top sensitivity. AlN barrier junctions do have some drawbacks. It is relatively difficult to suppress the Josephson noise. Also, bias voltages of over 3 mV will introduce flux in the junction. Finally, to properly deflux the junction, AlN barrier junctions should also be symmetrically shaped. This puts lower limits on the sizes of fabricated junctions.

We developed an automatic operating procedure for the junction which includes demagnetizing and defluxing. Executing this procedure statistically results in about 50% chance of success. When attempts are unsuccessful, subsequent attempts also have 50% chance of success.

Acknowledgment

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