Repeatability and Reliability of the 640 GHz SIS Mixer for JEM/SMILES

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I. Introduction

The development of SIS mixers at 640 GHz band is a key issue of JEM/SMILES mission [1], which is an atmospheric observatory to be onboard the International Space Station. Through an early development phase, a good receiver noise performance less than 200 K (DSB) has been achieved with Nb-based Parallel-connected Twin-junction (PCTJ) SIS mixer as a breadboard model [2]. For use in a space experiment. not only to achieve a good noise performance, but also to establish a way to fabricate a reliable SIS mixer is critical. This presentation summarizes a recent investigation to understand and improve the controllability of SIS device parameters in our process. We also briefly reports the result of environmental tests, such as ion irradiation, to confirm the compatibility with the space environment.

II. SIS Device Fabrication

Our Nb/Al-AlOx/Nb junctions are being fabricated at the Nobeyama Radio Observatory. Typical junction area is $\sim 1 \times 1\ \mu\mathrm{m}^2$, and current density is 6–8 $\mathrm{kA\,cm^{-2}}$. Considering the space application, we adopted the PCTJ-type device to achieve a broad RF impedance matching without troublesome mechanical tuning.

Fig. 1 shows an example of cross-sectional image of junction portion observed using TEM. Since parameters such as the thickness of layers and the superconductivity of Nb films are directly related to the mixer performance, we should realize their characteristics and improve the controllability in our fabrication process. After several improvements. we attained moderately stable fabrication, and succeeded in increasing the yield of good junctions.

One of difficulties in fabrication is to control the junction size. As shown in Fig. 2, the deviation in size is sometimes up to 10 % even in the same wafer, which corresponding to a ~ 3 % shift in center frequency. Althouth some problems still remains to be solved, we obtained the SIS devices which show an excellent receiver noise performance with ~ 150 K.

III. Environmental Tests

The space environment is hostile to operating a sensitive measurement system in many ways. We carried out various tests with SIS mixers to confirm their compatibility with the space environments. Following describes some topics:

Cosmic Ray Particles : We performed a proton irradiation test with cooling the SIS device below 4 K. Although some changes in DC characteristics were observed after extremely high fluence irradiation, we confirmed the tolerance of SIS device against the cosmic ray was far higher than the total dose expected in the orbit.

Thermal Cycle : The SIS mixer is expected to experience some thermal $-30°C$ to $+60°C$ cycles in orbit during power-off period of mechanical cooler system. Moreover, baking of cryostat system is scheduled to reduce outgass before launch. In our test, an increase of normal resistance by ~ 10 % (corresponding to $\sim 1\ \Omega$) was observed after one week of 80°C load. It is probably due to the increase of tunnel barrier potential by the reaction of unbound oxygen with Al atoms.

Launch Vibration : The vibration load at 4 K stage of cryostat is estimated to $\sim 40\ G_{rms}$ for our launcher. We have performed a vibration test on the SIS mixer with the same level. As the result, no change in DC and RF performance was found.

References

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[2] Y. Fujii. K. Kikuchi. J. Inatani. Y. Irimajiri, M. Seta, S. Ochiai, T. Manabe, H. Masuko, T. Noguchi. K. Narasaki. S. Tsunematsu, and T. Shirota, "Space-borne 640-GHz SIS Receiver Based on 4-K Mechanical Cooler". *SPIE*, 4013, 90, 2000

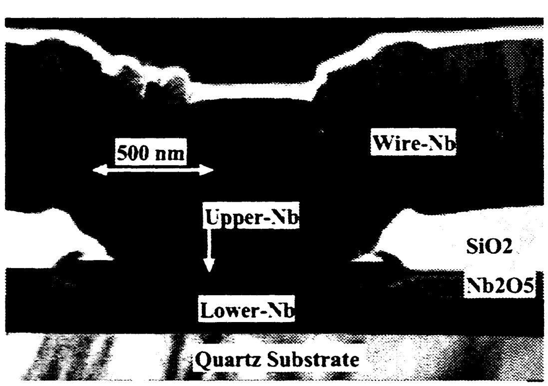

Figure 1: Cross-sectional image of SIS junction.

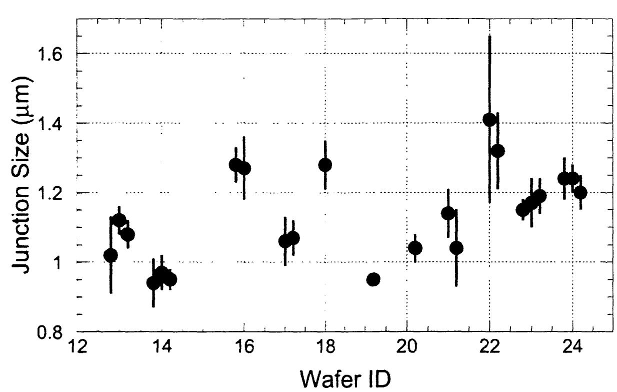

Figure 2: Mean junction size with 1-σ deviation in a wafer.

Observation of an anomalous IF peak at high bias voltage in 660-GHz SIS Mixers

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Abstract

We have designed and fabricated 660GHz parallel-connected-twin-junction mixer for SMA. The receiver noise temperature, T_{rx}, is around 200K with a wire grid of 80% signal coupling. However, some mixers have poor performance when an anomalous IF peak beyond the junction's gap voltage is observed. In this paper, we will discuss the origin and influence of this IF peak.

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We have designed and fabricated parallel-connected-twin-junction 660GHz SIS mixers. Typically the receiver noise of these mixers is near 200K[1]. However, some junctions have poor performance although their junction's parameters are similar. The LO pumping of these mixers are difficult and the receiver noise temperature can be worse than 1000 K. It is important issue to understand the reason causing the poor performance for future design and fabrication.

Since the junction parameters are similar for good and poor performance mixers. Some important effects might be missing in regular measurement. Thus, we measured the junction's I-V curve and mixer's IF response to high bias voltage, up to 17mV, as shown in Figure 1(a). Anomalous IF peaks are observed, an indication of the non-linearity in junction's I-V curve. The peak position shifts to higher voltage as the temperature decreases. Figure 1(b) shows the temperature dependence of corresponding current of IF peak. The data (solid square) can be fitted by a formula of $I_C \sim 1-(T/T_C)^{\alpha}$, where T_C is 9.2 K and α is 4.6. In addition, not shown here, the IF peak position is modulated by an external magnetic field. Both temperature and magnetic field dependence indicate the existence of unintentional weak-link junctions in series with the SIS junctions.

To understand the origin of this unintentional junction, the cross section structure of junction with good and poor performance is studied by TEM. A regular contact between top and wiring Nb is observed in the junction with good performance, as shown in Figure 2(a). On the contrary, the contact area is small in the junction with poor performance, Figure 2(b). Most area on the top Nb seems filled by the fragments of insulating oxide. The contact area is estimated to be 0.15μm in diameter. This small contact behaves as an unintentional weak-link junction. The oxide fragments might fall into the contact hole during the oxide lift-off process.

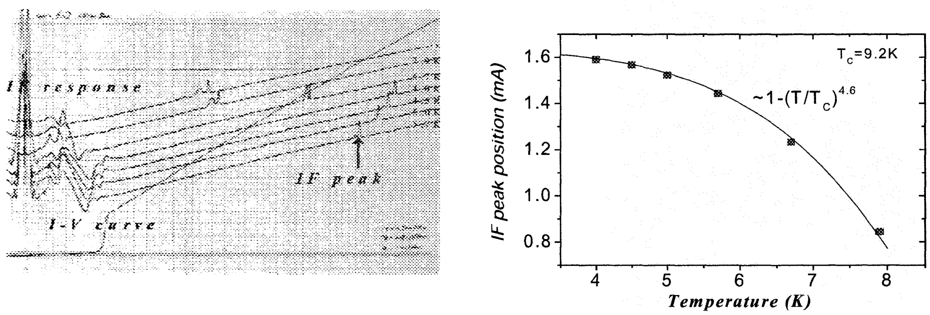

Figure 1 The anomalous IF peak beyond junction's gap voltage, (a) IF peak at different temperature and (b) temperature dependence of corresponding current of IF peak.

We have found that the 660-GHz SIS junctions showing the IF-peak structure are usually difficult to be pumped by LO signals, thereby giving high receiver noise temperature. Obviously, such additional weak-link junctions might absorb a fraction of RF/LO signal power and result in poor mixer matching. As exhibited in Fig. 3(a), the

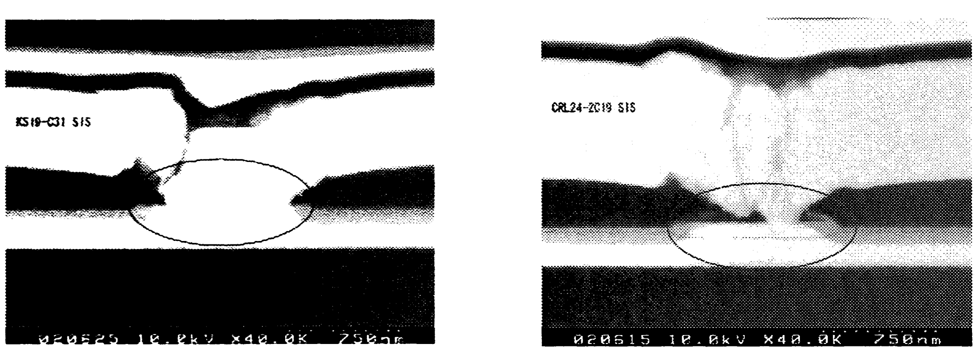

Fig. 2 Cross-sectional views of (a) good contacting junction and (b) poor contacting junctions

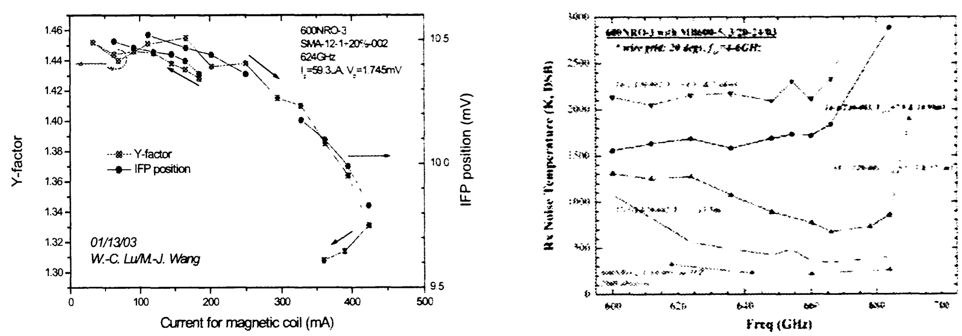

Fig. 3 Measured Y-factor as a function of magnetic filed (a) and Measured receiver noise temperature for five different junction samples of different IF peak positions (b).

testing result for a mixer demonstrates that the mixer performance (Y-factor) is dependent upon the magnetic field applied to the SIS junction, which changes the position of the IF peak correspondingly. Fig. 3 shows the receiver noise temperature of five mixer samples, which have different IF peak positions. Obviously, the receiver noise temperature is strongly dependent upon the position of the IF peak, differing from ~200K to >2000K. The higher voltage the IF peak occurs at, the lower receiver noise temperature the junction demonstrates.

In summary, an anomalous IF peak at high bias voltage region is observed in our 660-GHz SIS mixers when their performance is poor. The cross section structure of junction shows that some insulating oxide fragments might fall on the top Nb layer because of imperfect lift-off process. It reduces the contacting area between top and wiring Nb and an unintentional weak-link junction is formed. The existence of this unintentional weak-link junction will result in (1) the absorption of RF signal, and (2) the change of the mixer RF impedance. We have demonstrated the correlation between junction's IF peak position and mixer's performance. The performance becomes better when the IF peak is observed at higher bias voltage. In practical operation, the mixers with IF peak can be screened by checking the linearity of junction's I-V curve at high bias voltage.

References:

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