The Influence of Anomalous IF Peaks on the Performance of 660GHz Mixers

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Abstract

We have designed and fabricated 660GHz Nb-based SIS mixers for SMA. The receiver noise temperature, $T_{\text{rx}}$, of 200K has been achieved with a wire grid of 80% signal coupling. However, we observed an anomalous IF peak beyond the junction’s gap voltage in some mixers with poor performance. This IF peak position is dependent on temperature, external magnetic field and applied LO power. The existence of this IF peak affects the mixer’s performance even its position is far away beyond the gap voltage.

To reduce the junction’s parasitic capacitance and retain a reasonable bandwidth, high current density and small area become essential for SIS junctions applied to sub-mm wave mixers. For example, the typical current density is 10 kA/cm² and junction area is about 1.1 µm² in our 660GHz mixer. Because of small area, the contact quality between the top electrode of junction and the wiring layer becomes important. Planarization of dielectric layer is a standard technique in semiconductor industry to deal with a small contact via [1]. However, most of groups in the world, including us, use a self-aligned process, instead of the planarization technique, to fabricate micron- and sub-micron-sized Nb SIS junctions. Therefore, the SiO₂ lift-off process becomes a crucial step in fabricating SIS junctions for sub-mm applications.

We have designed and fabricated 660GHz Nb-based SIS mixers. Typically the receiver noise of these mixers is near 200K [2]. However, some mixers have poor performance although their junction’s I-V curves are similar in the low bias region (up to $2V_g$). We measured the junction’s I-V curve and mixer’s IF response to high bias voltages in the absence of LO power, as shown in Figure 1(a). The IF response should not have any sharp structures in the normal state regime because of a resistor-like characteristic. However, we observe anomalous peaks in the IF response of those mixers with poor performance. The peak

![Figure 1](image-url)
position shifts to higher voltage as the temperature decreases. In Figure 1(b), the data (solid squares) can be fitted by a formula of $I \sim 1 - (T/T_C)^{\alpha}$, where $T_C$ is set at 9.2 K and $\alpha$ is 4.6 which is close to the prediction of two-fluid model. This result indicates that the IF peak is related to the superconducting switch. From the cross-section image of TEM, most area on the top Nb layer seems filled by the fragments of the insulating oxide due to imperfect lift-off process. The contact area is estimated to be 0.15 $\mu$m in diameter. This small contact behaves as an unintentional superconducting weak-link.

The magnetic field dependences of the IF peak position and the mixer’s Y-factor are consistent, as shown in Figure 2. The data are obtained at a bias voltage of 1.745mV and a pumped current of 59.3 $\mu$A under 624GHz LO pumping. When the IF peak is shifted to a lower bias voltage by magnetic field, the Y-factor becomes smaller correspondingly. The noise temperature can be varied from 400K ($Y \sim 1.46$) to 640K ($Y \sim 1.3$) by changing the IF peak position in this particular device.

The existence of this unintentional weak-link might result in (1) the change of the mixer RF impedance, and (2) the absorption of RF signal. Thus the LO pumping of mixer becomes difficult. Usually, the LO pumping level is too low for optimum operation. In addition, the RF signal might be rejected and the coupling coefficient is degraded. Part of RF signal might be absorbed by this superconducting weak-link due to the reverse Josephson effect.

Fig. 3 shows the receiver noise temperature of five mixer samples, which have different IF peak positions. The bias peak position varies from 4.52mV to 13mV for the first four samples and no IF peak is observed in the fifth sample (the one with the lowest $Tr_x$). The data are obtained at a bias voltage of 1.745mV and a pumped current of 59.3 $\mu$A under 624GHz LO pumping. When the IF peak is shifted to a lower bias voltage by magnetic field, the Y-factor becomes smaller correspondingly. The noise temperature can be varied from 400K ($Y \sim 1.46$) to 640K ($Y \sim 1.3$) by changing the IF peak position in this particular device.

In summary, an anomalous IF peak in the high bias voltage region is observed in our 660-GHz SIS mixers when their performance is poor. This anomalous IF peak is due to the bad contact between the top Nb layer of junction and the wiring Nb. It results in an unintentional superconducting weak-link. 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. One important thing, we want to emphasize, is that mixer’s performance can be affected remarkably by the bad contact between the top Nb layer of junction and the wiring layer even the $I_C$ of this bad contact is much higher than junction’s $I_C$.

References:
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