DC and IF bandwidth measurements of superconducting diffusion-cooled hot electron bolometer mixers based on Nb/Au bilayer

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I. Introduction

Hot electron bolometer (HEB) mixers based on a superconductor-normal metal bilayer [1] are expected to improve the overall performance, in comparison with existing Nb or NbN mixers: lower mixer noise, larger intermediate frequency (IF) bandwidth, and in particular, lower LO power requirement. The bilayer takes advantage of the idea that one can engineer a superconducting layer with a required critical temperature and diffusion constant. We present measurements of IF bandwidth and DC resistance *vs* temperature using an Nb/Au bilayer HEB mixer, reporting the progress after work described previously (Ref. 1).

II. Nb/Au bilayer and mixer

The new concept is verified by using a combination of thin Nb and Au layers. Using a sputtered bilayer of a 5 nm Nb (bottom) and 5 nm Au (top), we obtain a T_c of 4.5 K and a sheet resistance of 10 Ω.

The IF bandwidth is measured with a mixer using a spiral antenna to couple the RF signal to the bridge. This design also allows a relatively simple fabrication process. We fabricate bilayer HEB mixers using a similar fabrication process as for Nb HEB's [2]. The process consists of: i) sputter deposition of a bilayer on a Si substrate, ii) thick Au cooling pads and antenna structure realized in the same step by evaporation and lift-off, patterned with e-beam lithography; iii) the narrow bridge defined by two etching steps using a thin Al strip as an etch-mask. The Au layer is etched with Ar RF sputtering, while the Nb is removed with a standard RIE etching using a gas mixture of CF_4/O_2. A SEM micrograph of a realized device is shown in Fig. 1.

The device used for IF measurements has a bridge length of 630 nm and a width of 200 nm, determined by SEM. The resistance *vs.* temperature of this device has been measured for temperatures down to 1.75 K (Fig.2). The T_c of the NbAu bridge is around 3.8 K, which is lower than an unprocessed bilayer, while the bilayer under the cooling pads does not become superconducting down to 1.75 K. The normal state resistance is 19

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Ω. The temperature dependence of the resistance below 3.8 K seems to behave in a similar way as the Nb devices[3]. However, an analysis using similar structures shows that a substantial part of the dissipation is due to the superconducting proximity effect[4], which, in contrast to the previously proposed charge-imbalance model[3], allows for dissipation due to quasi-particles with energies smaller than the energy gap.

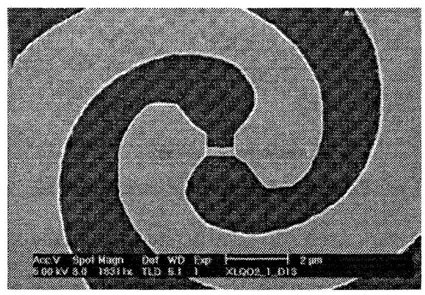

Fig. 1. SEM micrograph of an NbAu mixer. The NbAu bridge is located between the arms of the spiral antenna. The Au cooling pads are part of the antenna. The bar represents 2 μm.

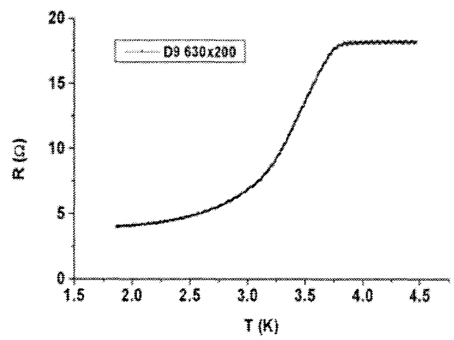

Fig. 2. The resistance as a function of temperature of the NbAu mixer used for the IF measurement. Bridge length: 630 nm and width 200 nm.

III IF bandwidth measurements

IF bandwidth measurements are done using a pair of submillimeter sources at frequencies around 650 GHz. A Miteq 0.1-8 GHz cryo-amplifier is used as the first stage amplification, followed by a room temperature amplifier and a spectrum analyzer.

The relative conversion gain *vs.* the IF (the frequency difference between two coherent sources) has been measured for a few DC bias voltages varying from 0.4 to 0.7 mV and at a bath temperature of 2.5 K. The IF bandwidth measurements together with the (un)pumped IV curves are given in Fig. 3. The one-pole Lorentzian fit to the data gives the $IF_{roll\text{-}off}$ (IF bandwidth) value varying from 0.4 GHz (0.4 mV) to 1.9 GHz (0.7 mV). Why the IF bandwidth increases by a factor of 5 for increasing bias voltage is not fully analyzed. Assuming for the highest bias voltage that the measured value is intrinsic, without the influence of electro-thermal feedback, and that the superconducting bridge becomes fully normal, it should follow the out-diffusion model[5],

$$IF_{roll\text{-}off} = \pi D/2L^2$$

where D denotes the diffusion constant and L the length of the bridge. Having known the measured $IF_{roll\text{-}off}$ and L, we obtain a diffusion constant of 5 cm^2/s for this device, which is at least a factor of 3 higher than what we obtained in Nb HEB devices (1-1.5 cm^2/s). The higher diffusivity in the Nb/Au bilayer suggests the potential to improve the bandwidth obtained so far in Nb HEB devices.

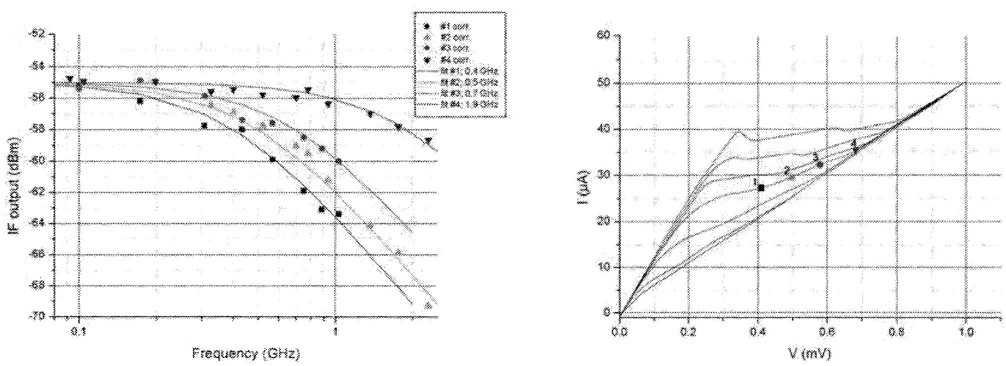

Fig. 3. Relative conversion gain as a function of IF frequency (difference between two coherent RF sources) for 4 different bias voltages (in the left-hand side). The unpumped and pumped IV curves of the same device with indications of the 4 bias points (in the right-hand side). The LO frequency in this case is about 650 GHz. The measurements are done at 2.5 K.

By simply assuming that the highly conductive Au layer dominates the sheet resistance (~10 Ω) of the bilayer, one would expect to have a much higher diffusivity value than observed. At this moment, it is not yet clear how to derive a reasonable value for the diffusivity from the resistance of a bilayer or to measure it directly, to compare to the value from the IF bandwidth measurement.

IV Sensitivity measurements

The IV curves pumped with different LO powers at 700 GHz have been measured at temperatures down to 500 mK using a ^3He cooler. No Y-factor could be measured with our current devices. We largely attribute this to the impedance mismatch between the low impedance bridge and the spiral antenna. To measure the Y-factor, we have to change the antenna design to a more suitable twin-slot antenna. A twin-slot antenna can also limit the RF bandwidth, reducing the direct detection effect in the Y-factor measurement. Another possible reason is that at the low bias voltages (see Fig. 3), the IF bandwidth is too low for the standard IF chain (1.5 GHz). It is worthwhile to mention that the recent measurement[6] of a mixer using a similar bilayer at 30 GHz gives a maximum mixer conversion gain of an order of –10 dB, suggesting that Nb/Au mixers are indeed promising.

We also notice that the NbAu devices are more robust against electro-static discharge (ESD) in comparison with Nb HEB mixers studied in our labs. Several devices have been measured in both DC and RF setup, showing so far no change of the characteristics. This feature is important for real application.

V Summary

We succeeded in fabricating spiral antenna-coupled NbAu bilayer mixers. The largest IF bandwidth measured from a mixer with a 630 nm long bridge is 1.9 GHz, giving a diffusion constant of 5 cm^2/s for the bilayer. The IF bandwidth also shows a strong dependence on DC bias voltage.

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