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Microwave Heterodyne Mixing by Step-Edge Microbridge Josephson Junctions Using YBaCuO Thin Films

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Microwave heterodyne mixing by Step-Edge microbridge Josephson Junctions (SEJJs) using YBaCuO thin films was systematically investigated. The step-edge was formed on the surface of MgO(100) substrate employing the common photolithograph and wet-etching technique. After the deposition of YBaCuO films, the microbridge junctions were fabricated so as to cross the step-edge. The SEJJ showed typical DC and AC Josephson characteristics, which obey the Resistively Shunted Junction (RSJ) model qualitatively. Mixing experiments were carried out using the RF signal with frequency (f_{RF}) of 23.87~25.85GHz and Lo signal with frequency (f_{Lo}) of 23.85GHz. An IF output with the frequency range of 20MHz~2.0GHz was successfully obtained.

1.Introduction

For the electronic application of the high Tc superconductors, such as microwave detectors, SQUIDs and digital devices, there has been an urgent need for the development of fabricating technique for a Josephson junction. Both the tunnel type and the bridge type junctions have been under investigation [1-5]. The tunnel type junction has some difficulties in fabrication due to the extremely short coherent length and the atomic interdiffusion between the layers. The bridge type junction was first realized as the Grain Boundary Josephson Junction (GBJJ) using the natural grain boundaries in polycrystalline films [3]. Microwave or millimeter-wave detection and magnetic field sensing have been reported employing the GBJJs [6,7]. However several problems have been pointed out in the GBJJs, such as an anomaly in the I-V characteristic and poor reproducibility. The large 1/f noise of the DC SQUIDs made by the GBJJs also has been considered to be caused by the flux flow through the weak-links of excessive grain boundaries. Therefore, Josephson junctions which show single-junction-like characteristics with a good reproducibility have been required.

In this paper we report on the achievement of the microwave mixing using newly developed Step-Edge microbridge Josephson Junctions (SEJJs) with excellent characteristics and reproducibility.

2.Experimental Procedure

The fabrication process of the SEJJ is shown in Fig.1. First, a step-edge 200nm high was formed on the surfaces of MgO(100) substrates employing the common photolithography and wet-etching technique (Fig.1(a)). The photoresist was OFPR800 and the etchant was 3.0 volume% phosphoric acid solution. YBaCuO thin films of 150~200nm thick were deposited on the substrates by the off-axially-arranged-sputtering method, in which the substrate was set vertically above the stoichiometric $Y_1Ba_2Cu_3O_y$ powder target. The films were c-axis oriented except near the step edge (Fig1(b)). Details of the sputtering conditions are described elsewhere [8,9]. Next, microbridges of 5μm wide and 30μm long were patterned out so as to cross the step-edge using the same process mentioned above (Fig.1(c)). Four junctions were arranged parallel to each other on each MgO substrate. Figure 2 shows a SEM photograph of one junction of the array.

The I-V characteristics of the junctions under the microwave irradiation were measured, introducing microwaves with the frequency of 10~25GHz through the coaxial-line fed dipole antenna. The microwave mixing experiments were carried out according to the block diagram shown in Fig.3. RF signals with a frequency (f_{RF})of 23.87~25.85GHz and an Lo signal with frequency (f_{Lo}) of 23.85GHz were fed to the junction through a chip capacitor. The RF signal was then frequency modulated by a sine-wave of DC~2MHz. The IF output signals were observed using the spectrum analyzer through the voltage detection terminals.

3.Results and Discussions

The I-V characteristics under microwave irradiation are shown in Fig.4. The microwave frequency was 24GHz and the sample temperature is 10K. The numbers in the figure show the relative irradiation power. In the dark condition (-∞), the critical current was 230μA. Abnormal structures such as kink structures which have often appeared in the GBJJs were not observed. The SEJJ behaved like the well-known point contact Josephson junction treated as the RSJ model. In the microwave characteristics, typical constant voltage steps are clearly observed at V=nhf/2e, where h is the Plank constant, f is the microwave frequency, e is the electron charge and n is an integer.

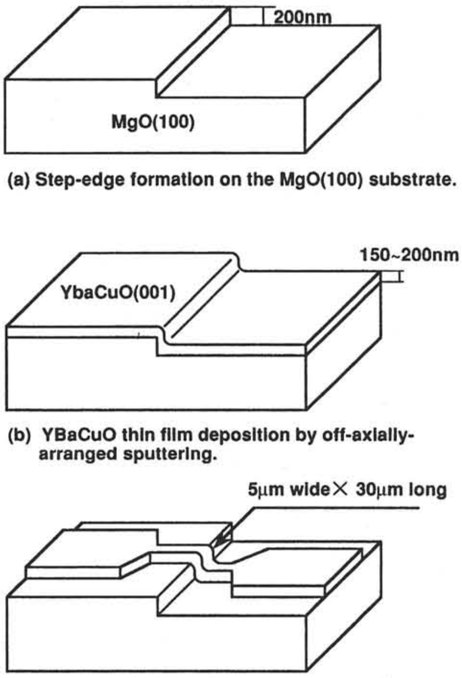

Fig.1.The flow of fabricating the SEJJ.

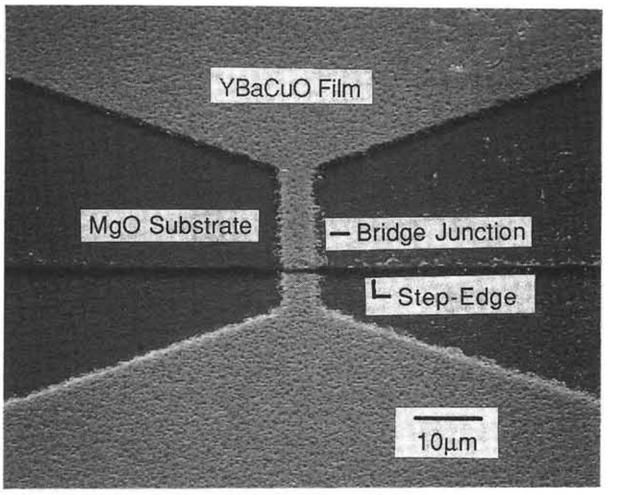

Fig.2 SEM photograph of the SEJJ.

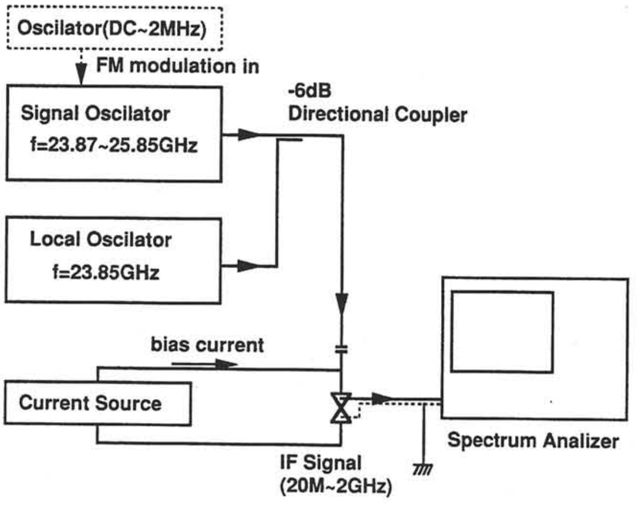

Fig.3 Block diagram of the mixing experiment.

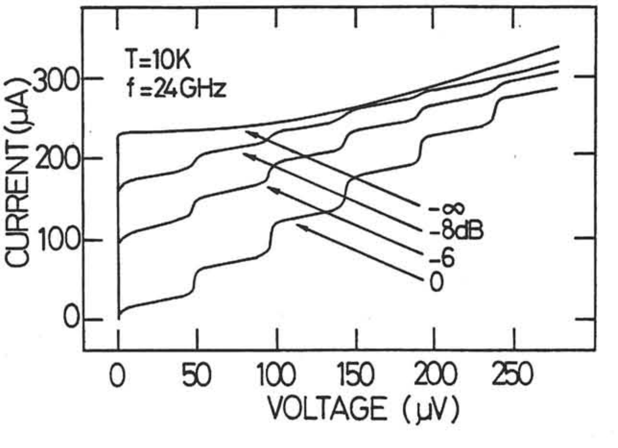

Fig.4 I-V characteristics of the SEJJ under microwave irradiation of 24GHz at 10K.

The critical current (0th step) was reduced and further steps appeared with the increase of the irradiation power. The 15th step (V~310μV) corresponding to over 300GHz was observed under larger irradiation power. In Fig 5, the heights of the n'th step (I_n, n=0~3) are plotted as a function of the RF current i.e. $(\text{RF power})^{0.5}$, where In is normalized by the critical current of the dark condition. The normalized In (I_n/I_c) vibrated against the RF current like the Bessel function. The 0th step was completely suppressed by the adequate RF current. This shows that all the current flowing through the junction consisted of Josephson current. These characteristics qualitatively agree well with the current activated RSJ model [10]. Although the microwave induced steps lost its sharpness as the temperature was increased, they could be observed up to 69K. Similar microwave characteristics were observed under irradiation of the microwaves with a frequency of 10~25GHz. The critical currents of the four junctions on the same substrate was 100~230μA and all the junctions showed almost the same microwave response.

These results show that the SEJJ operates as a single Josephson junction and has high reproducibility. Near the step-edge, the film is thought to be locally polycrystalline and one of the grain boundaries showed the Josephson effect similar to the ordinary GBJJs. However, the numbers of the weakly coupled grain boundaries were expected to be less than the GBJJs, because the other regions apart from the step-edge were c-axis oriented with few grain boundaries in the SEJJs. This is the reason why the SEJJs have exhibited excellent characteristics with high reproducibility. Moreover the SEJJ has a great advantage in that it can be fabricated at any place on the substrate as the step-edge is artificially made on the surface of the substrate by the common photolithography technique, which is not realized by JJ using bicrystals.

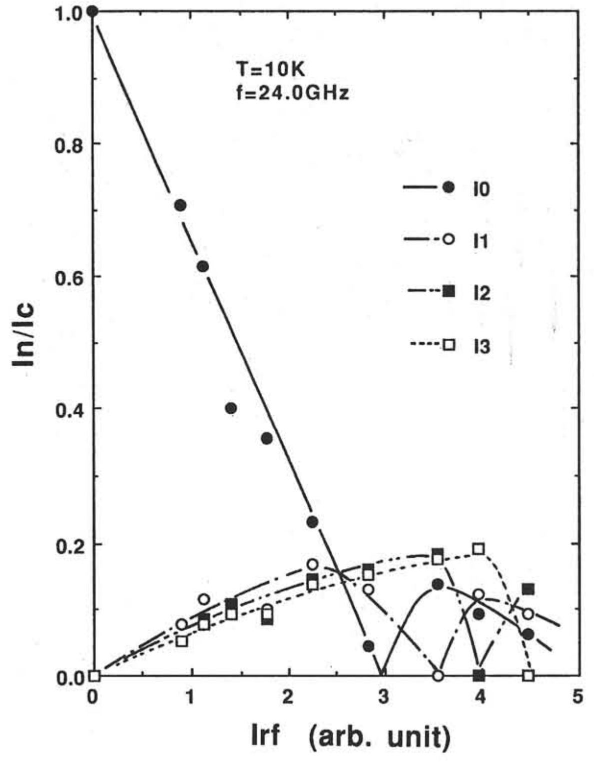

Fig.5 The heights of microwave induced steps vs RF current.

The frequency spectrum of the IF output of the SEJJ mixer is shown in Fig.6. The f_{Lo} was 23.85GHz and the f_{RF} was 24GHz. In Fig.6(a), the IF signal with frequency of $|f_{RF}-f_{Lo}|$=150MHz can be seen clearly. The IF output was obtained from the frequency range from 20MHz up to 2GHz corresponding to the difference between the RF and Lo frequency. The upper limit of the IF frequency might be caused by the reflection loss of the signal at some point between the sample and the analyzer. Figure 6(b) also shows the frequency spectrum when the RF signal was frequency modulated by a sine wave with a frequency of 2MHz. Signals at $f_{IF}\pm$2MHz and $\pm$4MHz corresponding to the side-bands of the frequency modulated signal appeared, which indicates that the modulated RF signal was successfully converted by the SEJJ mixer. The basic characteristics of the mixer such as the noise figure or conversion efficiency are now under investigation.

4.Conclusions

The I-V characteristics of the Step-Edge type Josephson Junction (SEJJ) and its microwave heterodyne mixing were systematically investigated. The SEJJ showed the typical microwave induced voltage steps and the step heights vibrated against the RF current, which obeyed the current activated RSJ model qualitatively. The microwave mixing was successfully made by the SEJJ, and an IF output with the frequency of 20MHz~2GHz was obtained.

Acknowledgements

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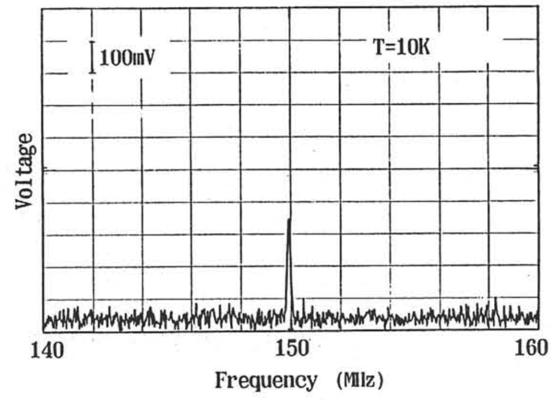
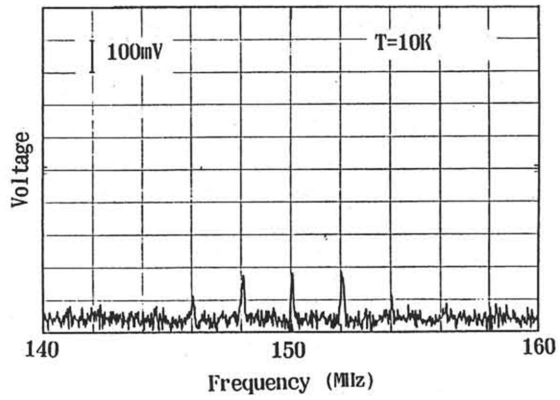


(a)



(b)

Fig.6 Frequency spectrum of the IF output.
(a) f_{RF}=24GHz
(b) f_{RF}=24GHz and frequency modulated by 2MHz.

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