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Double sided fabrication process of $Bi_2Sr_2CaCu_2O_{8+x}$ THz oscillator stack on-chip coupled to THz detector by dilute acid solution

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Abstract

We fabricated $Bi_2Sr_2CaCu_2O_{8+\delta}$ intrinsic Josephson junctions with oscillator and detector stack by using photolithography and dilute acid solution (pH=1.65). These stacks were formed in a same crystal, which were isolated by an acid-treated product of BiOCl. For the oscillator IJJ stack, various lateral dimensions 45×8 μm^2 was made, while detector stack were about 15×8 μm^2 in their lateral dimensions. Also, these stacks have 180 junctions. At 77 K, zero voltage current for the detector stack was measured while sweeping a bias voltage of the oscillator stack. The zero voltage current of the detector stack was a strong suppressed when the step structure in current-voltage curve of the oscillator stacks were appeared. This indicates that the oscillator stack emits a radiation at this voltage. From the Josephson voltage-frequency relation, it is found that the voltage correspond 0.86 THz.

1. Introduction

Recently, coherent THz emission from $Bi_2Si_2CaCu_2O_{8+\delta}$ intrinsic Josephson junction (Bi-2212 IJJ) with a large mesa type structure was observed by L. Ozyuzer *et al.* firstly[1]. Numerous experimental studies for the THz emission of Bi-2212 IJJ have been performed using a surface mesa structure on Bi-2212 single crystal, which was fabricated using an Ar ion milling or FIB method [1-4], except for a stack with all-superconducting electrodes by a double side patterning (DSP) process [5]. The mesa structure fabricated on the crystal surface frequently exhibited irregular IJJ characteristics, in which the Josephson critical currents (I_c) indicate inhomogeneous [6]. Irregular IJJ characteristics might make it difficult to achieve complete a phase lock in the Bi-2212 IJJ. We deduce that the irregular characteristics could be responsible for a reproducibility of the THz emission between different Bi-2212 IJJs. Since the main reason for such irregular IJJ characteristics could be surface degradation due to the formation of a metal electrode on the Bi-2212 cleaved crystal surface [7], we could use the DSP process developed by Wang *et al*. [5] to avoid a surface degradation of Bi-2212 IJJs. A stack fabricated by the DSP process does not have the surface degradation of IJJs, because the stack is formed inside the Bi-2212 crystal.

In this paper, we report the DSP process that employs a dilute acid solution [8] for the fabrication of the Bi-2212 IJJ oscillator on-chip coupled to a Bi-2212 IJJ detector and experimental results for THz wave emission at 77 K.

2. General Instructions

In this experiment, the Bi-2212 single crystals were grown by a self-flux method. Details of DSP process for fabrication of the Bi-2212 IJJ stacks have been outlined elsewhere [8]. The Bi-2212 THz oscillator stacks on-chip coupled to THz detector of the samples were fabricated by the following DSP process.

(A): Firstly, an approximately 1.0 mm^2 Bi-2212 crystal is adhered onto a glass substrate using an optical adhesive (NOA-61). Two lines with width of 50 μm and 20 μm are then patterned on the cleaved surface by photolithography. (B): After patterning, the sample is immersed in dilute hydrochloric acid (pH=1.65) for 5 min in order to form insulating BiOCl crystal around the photoresist patterns. Next, the photoresist was removed from the surface of the Bi-2212 crystal and then (C): the photoresist was patterned to form trench in Bi-2212 lines made by step (A). (D): The trench structure was formed in a manner completely analogous to that using dilute hydrochloric acid. The dipping time into the dilute hydrochloric acid was 2 min. (E): In order to form the stacks into the Bi-2212 crystal, the first acid-treated crystal surface was glued onto another glass substrate using the NOA-61 and the surface of the Bi-2212 crystal was then cleaved until two Bi-2212 lines were appeared on the surface. (F): Next, the photoresist for the trench structure in Bi-2212 lines was patterned. After the patterning process, the crystal was immersed into dilute hydrochloric acid of pH=1.65 to fabricate the two stacks into the single crystal. Then, the photoresist was removed.

Figure 1 shows an optical photograph and schematic illustration of the stacks. An optical photograph with back-side illumination was possible, because a transparent substrate and optical adhesive were employed. The lateral size of the oscillator and detector stack was 45×8 μm^2 and

15×8 μm^2, respectively. The oscillator-to-detector distance was 20μm and the two stacks were isolated by BiOCl.

Experiments were performed in liquid N_2. A schematic diagram of our experimental setup for detection is shown in Fig. 2. Characteristic of emission and detection using the integrated stacks were performed by another bias circuit. In this experiment, the *I-V* characteristic of the oscillator stack was measured with a source measure unit (National Instruments, PXI-4132) as constant voltage power supply. On the other hand acquisition of the *I-V* cure for the detector stack was done by pre-amplifiers, a function generator and an analog-to-digital converter (National Instruments, PXI-4462). These were performed concurrently by a PC-based LabVIEW measurement program. In this system, the radiation of electromagnetic from the oscillator stack can be detected by the suppression of the zero voltage current (I_{c0}) of the detector stack. The I_{c0}^{det} was the result of the average determined after measurement of several hundred switching events from the superconducting to the resistive state in order to reduce ambiguity caused by thermal fluctuations.

Figure 3 (a) shows *I-V* curve of the oscillator stack with lateral dimension of 45×8 μm^2. Figures 3(b) and 3(c) show the I_{c0}^{det} of the detector stack as a function of, respectively, current and voltage. The V_{osc} dependence of the I_{c0}^{det} shows a dip around the hump structure at V_{osc}=320 mV.

There are possible factors contributing to suppression effect of the I_{c0}^{det} in the detector stack. The first is the Joule heating from the oscillator stack, which is caused by the suppression of the I_{c0}^{det}. However, after founding the most significant suppression of the I_{c0}^{det}, it changes nearly the same as for the I_{c0}^{det} without the bias to the oscillator stack. Thus, we can deny the possible existence of the effect of the Joule heating. Another is magnetic field caused by the biased current to the oscillator stack, which can be reduced to the I_{c0}^{det} of the detector stack. If the suppression of the

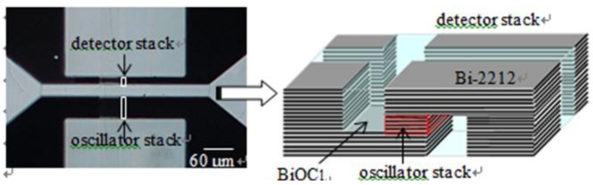

Fig. 1. Optical photograph and schematic illustration of the fabricated stack

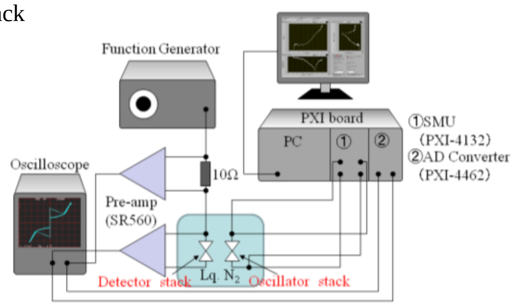

Fig. 2. Schematic diagram of the experimental setup for THz radiation and detection

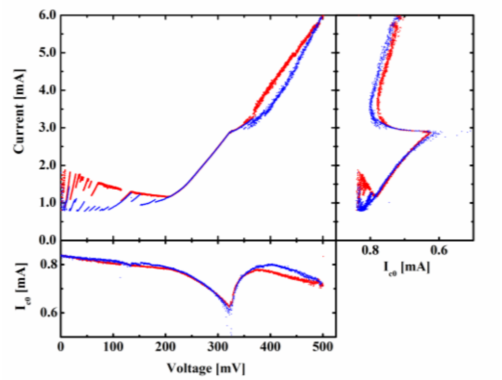

Fig. 3. (a) *I-V* curve of the oscillator stack at 77 K (b) Emission detected by the variation of the I_{c0}^{det} of the detector stack vs bias current and (c) bias voltage to oscillator stack.

I_{c0}^{det} is Fraunhofer modulation due to the field penetrated in interlayer, periodicity is one flux quantum Φ_0. Therefore, in this experiment, the period is 0.17 T as expected from formula of $H=\Phi_0/Ws$, where s=1.5 nm is the interlayer spacing and W=8 μm is the short side length of the detector stack. When the bias current of 3 mA seen in most suppression of the I_{c0}^{det}, if we assume homogeneous current flow through the bias line, the estimated magnetic field is 2.8×10^{-5} T around 20 μm from current pathway. However the magnetic field of 2.8×10^{-5} T is quite low to suppress the I_{c0}^{det}.

From these reasons, we think that the observed suppression of the I_{c0}^{det} results from the detection of an electromagnetic wave emission from the oscillator stack. From the Josephson voltage-frequency relation of $f_J=V_{osc}/N\Phi_0$, where the V_{osc} is 320 mV and N is 180 junctions, it is found that the voltage correspond 0.86 THz.

3. Conclusions

The Bi-2212 THz oscillator sack coupled the detector stack were fabricated using the developed DSP process with a dilute acid solution. The *I-V* characteristic measured by the pulse current method showed that the critical currents from the zero voltage current (I_{c0}) to last resistive branch (I_{cl}) were almost identical, which indicates that the stack has no surface degradation as observed in surface stack IJJs. The Josephson frequency is good agreement with the cavity mode in the oscillator stack. The DSP process allows fabrication of oscillator stack coupled a superconducting antenna, which will be a significant advantage for control of the radiation pattern.

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