Reactive ion beam etching of superconducting Bi2212 by Ta/PR and PR'/Ta/PR masks for the generation of THz waves

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Abstract: Generation of powerful THz radiation from intrinsic Josephson Junctions (IJJs) of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) may require mesas with large lateral dimension. However, there are difficulties in fabrication of perfect rectangular mesas. Mesa lateral angles should be close to 90 degrees to obtain IJJs with same planar dimensions for synchronization of IJJs. Since thick photoresist (PR) layer shades the lateral dimension of mesa during ion beam etching, we patterned Ta/PR and PR'/Ta/PR masks on Bi2212 and used selective ion etching to overcome this problem. The reactive ion beam etchings have done with ion beam of Ar, N_2 and O_2 and we have obtained mesas about 1 μm with lateral angle of approximately 50 to 75° which is better than the mesas fabricated with single layer mask.

Terahertz (THz) radiation is a part of the electromagnetic spectrum, lying between microwaves and the far-IR. This region has frequencies ranging from 0.1–10 THz and wavelengths from 3 mm to 0.03 mm. Recently, research community at science and technology are interested in the electromagnetic waves in terahertz frequency range because of their important application areas including physics, biology, chemistry, astronomy, medicine etc.[1]. Electromagnetic waves with frequency below and above the THz frequency range are widely generated by semiconducting electronics based on high-speed transistors and the photonics based on the semiconducting laser, respectively. However, in this frequency range there are still lacks of THz sources and difficulties in its generation although their functional advantages in many application areas entail the evolution of the THz sources in science [2].

Nowadays, the research on THz radiation sources with high power, low cost and portable has been increasing. Since they are planned to use in technological areas, they should be continuous, coherent and frequency tunable as well. Therefore the research has gone towards the novel THz sources which include technology of HTSs layered structure. One of the several reasons making HTSs suitable candidate for the generation of THz radiation is their layered structure which enables the propagation of electromagnetic wave by unique excitation called Josephson plasma oscillations and frequency of the Josephson plasma is between THz ranges [3].

High temperature superconducting $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystals have natural junctions called intrinsic Josephson Junctions (IJJs). They play an important role for generation of THz radiation when a static voltage is applied along the c-axis of Bi2212 (ac Josephson effect) [4]. Generation of powerful THz radiation requires mesas with large lateral dimension but there are difficulties in fabrication of perfect rectangular mesa. It should be close to 90 degrees to obtain IJJs with same planar dimensions for synchronization of IJJs [5].

Thick photoresist layer (single layer mask) shades the lateral dimension of mesa during ion beam etching. Therefore, we patterned multilayer mask on Bi2212 and used selective ion etching as in Nagai et al. works [6] overcome this problem. Therefore, in this study, to fabricate the smooth rectangular prism shape with large area, high thickness and high lateral angle THz emitting mesa, we used three different masks that are single layer mask and two different multilayer masks, which are Ta/PR and PR′/Ta/PR. In all three masks, all experimental steps are the same until the gold evaporation. After the gold evaporation, the experimental steps have different procedure. After the gold evaporation, for the Ta/PR multilayer mask, Ta metal was deposited by DC magnetron sputtering, and for the PR′/Ta/PR multilayer mask, firstly photoresist was coated onto the gold layer by using spin coater but for this photoresist layer (PR′) the spinner was rotated for 25 s giving a 750 nm layer of resist and then hard baked at the 200 °C for 40 minutes to get strongest photoresist layer, secondly as the same with Ta/PR multilayer, Ta metal was deposited onto the PR′ layer. The aim of the using Ta/PR and PR′/Ta/PR multilayer masks is that it was used to form mesa with another material, apart from the photoresist, which was used for the patterning the mesas. The thickness of photoresist is high and its edges are not smoothly perpendicular so during the etching, the edges of etched shape are like the curvature edges of mesa. Hence the smooth rectangular shape is not obtained. Furthermore, photoresist is etched with ions rapidly. The next step is optical photolithography in the mesa fabrication, which is used in micro fabrication to patterns photoresist layer on the gold layer and Ta layers of crystals.

After the preparation of the mesa shaped PR pattern, sample is mounted in to the ion beam etching system that produces ion beam accelerated through the surface of sample to etch down some area unprotected by PR layer on crystal. For the all three mask the etching procedure is different, but technique and the parameters are same. **For the single layer mask (PR)**, reactive ion beam etching process was applied to the mounted sample (Bi2212/Au/PR) with Ar plasma until the PR layer onto the Au

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layer of mesa was removed. **For the Ta/PR multilayer mask**, reactive ion beam etching process was applied to the mounted sample (Bi2212/Au/Ta/PR) with Ar plasma until the Ta and Au layers out of the mesa was removed, then by using N_2 plasma, etching of Bi2212 was continue to get the Bi2212 mesa until the Ta layer onto the Au layer of mesa was removed. We used N_2 plasma for the etching of Bi2212, because the etching rates of Ta is smaller than Bi2212. This provides us to fabricate taller (≈1 μm) and high lateral angle mesas. **For the PR′/Ta/PR multilayer mask**, reactive ion beam etching process was applied to the mounted sample (Bi2212/Au/PR′/Ta/PR) with Ar plasma until the Ta and Au layers out of the mesa was removed then with Ar+O_2 plasma the PR′ layer onto the out of mesa was removed and then etching of Bi2212 with N_2 plasma was continue to get the Bi2212 mesa until the Ta layer onto the PR′ layer of mesa was removed. After the Ta layer was etched, the sample has taller mesa with high lateral angle and at the top of the mesa, there are PR′ layer. To etch the PR′ layer, etching was ended with Ar+O_2 plasma until the PR′ layer onto the Au layer of mesa was etched.

After the mesa fabrication, in order to establish electrical contact to the gold layer on top of the mesa, CaF_2 layer was evaporated through a shadow mask onto the top part of the crystal including a small section of the mesa for the electrical isolation purpose. Subsequently, a gold stripe was evaporated through a shadow mask onto the mesa and the CaF_2. Finally, a gold wire was attached to the strip over the CaF_2 and 2 pads with silver epoxy for the electrical connection of the mesa and two contact pads. After the mesa fabrication and the contacted the mesa, the surface (lateral dimensions) and electrical characterizations of the mesas was measured.

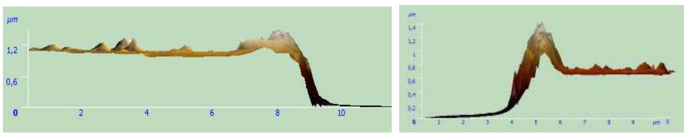

Fig. 1. AFM measurement of HC06 (Bi2212/Au/PR/Ta)

Table 1. AFM analysis results of fabricated mesas

Mesa height and lateral angle	Edge 1	Edge 3
HC09 (Bi2212/Au)	570 nm - 12°	650 nm - 13°
HC06 (Bi2212/Au/PR/Ta)	860 nm - 75°	770 nm - 35°
HC07 (Bi2212/Au/PR/Ta)	930 nm – 50°	820 nm - 42°
SG12–1 (Bi2212/Au/Ta)	860 nm - 51°	870nm - 52°

AFM image of one of the mesa edges can be seen in Fig. 1. Table 1 shows AFM analysis results of the fabricated mesas. The results indicate that mesas with thickness of about 1 μm can be fabricated. Using multilayer instead of single layer, a distinctive increase of the lateral angle of approximately 50 to 75°, which is better than the previous studies, was obtained. This is most important achievement of this study.

In electrical characterizations of mesas, R-T and I-V measurements were done to get information about superconducting and temperature dependence of tunneling behaviors in IJJs. THz cryostat system was used to examine electrical properties of mesas. R-T measurements of the Bi2212 single crystals were obtained between 300 and 10 K and sharp phase transitions to superconducting state were observed. I-V measurements was obtained, and hysterical tunneling behavior of the Bi2212 mesas and many number of quasiparticle branches such a voltage jumps were observed as seen Fig. 2. During I-V measurements, the bolometric measurements were done to detect emission from the Bi2212 superconducting mesas.

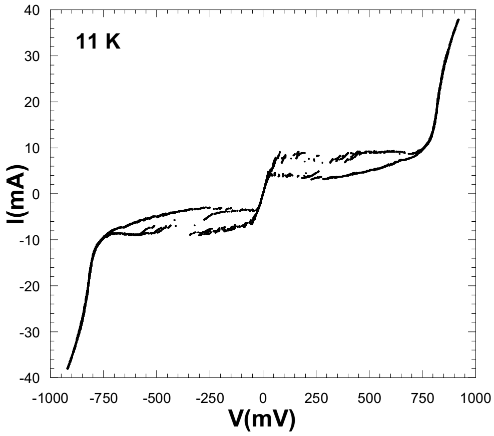

Fig. 2. Current-Voltage (I-V) curve of HC09

Acknowledgments

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