Terahertz Radiation above 1 THz from $Bi_2Sr_2CaCu_2O_8$ Intrinsic Josephson Junctions

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September 26, 2014 (STH27, HP91). In recent years, high temperature superconductor (HTC) $Bi_2Sr_2CaCu_2O_8$ (BSCCO) devices have become indispensable for generating electromagnetic coherent terahertz (THz) radiation. Great efforts have been paid to optimize the power, frequency and tunability of terahertz emission since it was first observed in 2007 [1-4]. To get higher frequencies, it is essential to solve the problem of the self-heating, which is caused by the relatively high input DC power and the poor *c*-axis thermal conductivity of BSCCO [2, 3, 5]. For a conventional mesa structure, the stack of intrinsic Josephson junctions (IJJs) stands on a thick pedestal of the BSCCO single crystal, through which the heat diffuses from the mesa to the substrate. In our previous work, we developed a gold-BSCCO-gold structure (GBG) to improve the cooling condition as shown in Fig. 1 (left). It has been reported that the GBG can emit THz emission with a directly detected power as high as ~25 μW [6].

In our recent experiments, we started from fabricating a GBG structure with a BSCCO stack embedded between two gold layers. When mounted onto a single substrate the stack emitted in the frequency range of 0.43-0.82 THz. We then glued a second, thermally anchored substrate onto the sample surface with Polyimide (see Fig. 1 (right)), forming a sandwich structure (SWS) with the BSCCO stack embedded between two substrates. The transport and emission experiments were carried out again like for the pristine GBG and emission of up to1.05 THz from the SWS stack at T_b = 20 K was observed, being considerably higher than that of GBG [7].

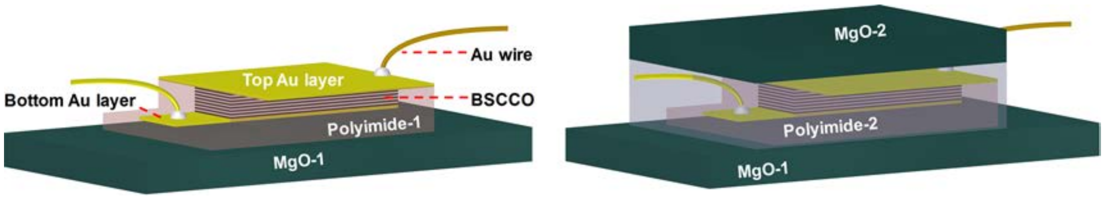

Fig. 1. Schematic views of (left) a GBG and (right) a SWS structure. The BSCCO stack with the dimension of 230×50×1.5 μm^3 was fabricated by photolithography and ion milling technology, involving ~1000 junctions.

The IVCs of GBG and SWS in the high-bias regime both exhibit negative differential resistance on the outmost branch in the voltage state. However, the highest voltage of the SWS reaches ~ 2.5 V, 25% larger than that of the GBG. One can see that at a fixed temperature, the frequency can be continuously tuned by the junction voltage V_0, according to the Josephson relation $f_e = 2eV_0/h$, and thus the SWS yields a broader frequency range.

Fig. 2 shows the temperature-dependent frequency at high and low current bias. Both structures exhibit the similar tendency below T_c ~ 88 K, namely, the emission frequencies gradually increase with decreasing T_b. The GBG was found to radiate for bath temperatures below 65 K, while the emission of SWS can be detected over a broader temperature range below 80 K. Particularly, the emission frequencies of the SWS cover a considerably larger range than the GBG at a fixed T_b = 20 K, e.g., 0.76-1.05 THz for SWS and 0.62-0.82 THz for GBG. For the entire temperature range the SWS exhibits a much broader emission frequency range (0.34-1.05 THz) than the GBG (0.43-0.82 THz). We emphasize that the corresponding spectrum of the highest emission frequency is up to 1.05 THz, being the highest frequency within the THz radiation spectrum emitted by intrinsic BSCCO JJs until present.

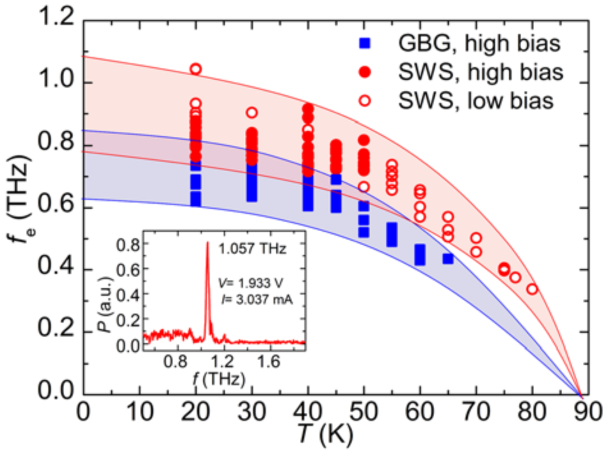

Fig. 2. Emission frequency vs. the bath temperature. The inset shows the spectrum of THz emission at T_b = 20 K and I =3.037 mA.

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References

[1] L. Ozyuzer et al., Science **318**, 1291 (2007).

[2] H. B. Wang et al., Phys. Rev. Lett. **102**, 017006 (2009).

[3] H. B. Wang et al., Phys. Rev. Lett. **105**, 057002 (2010).

[4] T. Kashiwagi et al., J. J. Appl. Phys. **51**, 010113 (2012).

[5] A. Yurgens, Phys. Rev. B **83**, 184501 (2011).

[6] D. Y. An et al., Appl. Phys. Lett. **102**, 092601 (2013).

[7] M. Ji et al., Appl. Phys. Lett. 105, 122602 (2014).