Keynote

INTENSE CONTINUOUS THZ EMISSION FROM HIGH TEMPERATURE SUPERCONDUCTOR $Bi_2Sr_2CaCu_2O_{8+\delta}$ SINGLE CRYSTAL MESA STRUCTURES

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It is well-known that there is a missing frequency region in the electromagnetic spectrum near the THz frequency, where no compact source exists with sufficiently strong emission (≥mW) in spite of a great interest in a variety of applications including not only physical and chemical spectroscopies, but also medical diagnosing, pharmaceutical applications, a variety of imaging applications, environmental studies, security issues, ultrafast communications, quantum computations, *etc*. The mising frequency domain is called the “THz gap”, which has been desired for filling in for a long time.

Here, we show an experimental evidence for such a possibility by a generation of intense THz radiation being sufficient for filling the “THz gap”. This is realized by utilizing a mesa made of a piece of high temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal. This material is known to be superconducting at T_c □ 90 K and is comprised of multi-stacked intrinsic Josephson junctions: the superconducting CuO_2 layers being inherently separated by Bi_2O_2 insulating layers only by □1.5 nm, where the unsurpassed packing density of the Josephson junctions are naturally realized in a crystal. In Fig. 1 the crystal structure of $Bi_2Sr_2CaCu_2O_{8+\delta}$ is shown schematically.

When the crystal is a perfect single crystal, no defects would be expected. However, in actual single crystals defect layers and intergrowth of structurally similar phases such as $Bi_2Sr_2CuO_{6+\delta}$ and $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ are often found to intervene easily, for instance, in high resolution transmission electron microscopy (TEM) study. This evidence is not so clear by X-ray diffraction technique as usually used for inspecting the phase purity of material, but can very easily be detected in the resistivity measurement in the CuO_2 plane, *i.e.*, the *ab*-plane resistivity. Similarly, a careful measurement of the Meissner diamagnetism can also reveal the contamination of $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ phase at around 108 K quite easily. From our experience it is known that our good quality single crystals contain impurities of only about 0.01% including structural defects such as low angle grain boundaries, *etc*. This high quality ensures in our crystals that there would be no defect layers even in a few micrometer thick sample and therefore can sustain surprisingly high static voltages of □50-300 kV/cm across the junctions. The typical *I-V* characteristic curve is shown in Fig. 2.

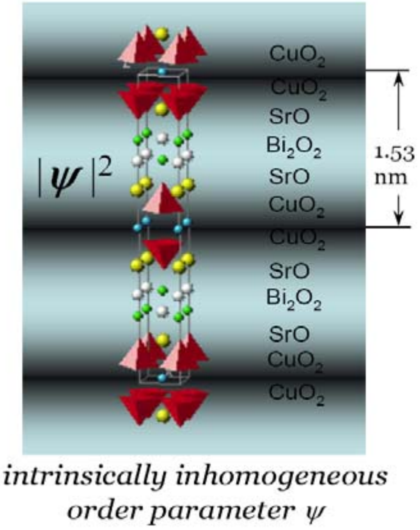


Fig. 1. The schematic crystal structure of $Bi_2Sr_2CaCu_2O_{8+\delta}$. The superconducting CuO_2 layer are sandwitched by the insulating Bi_2O_2 layers.

We fabricated rectangular mesas with dimensions of 300-400 μm in length, 40-100 μm in width, 1-2 μm in thickness from our single crystals by a standard photolithography technique. The example of the optical and the AFM images are shown in Fig. 3. Note that the mesa has not a regular rectangular shape but has a rather trapezoidal shape due to the ion milling effect. This could give a bad effect on the emission of THz radiation.

We show a direct spectroscopic evidence of THz emission of these mesas in Fig. 4, where the return branch of the *I-V* curve is shown simultaneously with the detecter signal as a function of voltage. As soon as the detector sensed intense EM waves while the voltage is scanned down slowly, the scan stopped at the peak voltage (the top pannel), then the FTIR spectroscopy was done (the bottom pannel) as indicated by red line. A sharp peak at about 12 cm^{-1} was clearly detected. The line width is very sharp and is within the resolution limit of the spectrometer of 0.25 cm^{-1}. It is noted that the emission continues at least more than 1.5 hours without noticeable fluctuations as long as the voltage is kept constant. The frequency of EM radiation obeys a relation

$$\nu = \frac{c}{\lambda\sqrt{\varepsilon}} = \frac{c}{2w\sqrt{\varepsilon}} = \frac{2e}{h}\frac{V}{N},$$

where ν and λ are the frequency and the wave length of the EM wave, respectively, w the width of the mesa, V the voltage applied to the mesa, N the number of the intrinsic Josephson junctions, ε the dielectric constant in mesa, e the electric charge, h the Planck constant.

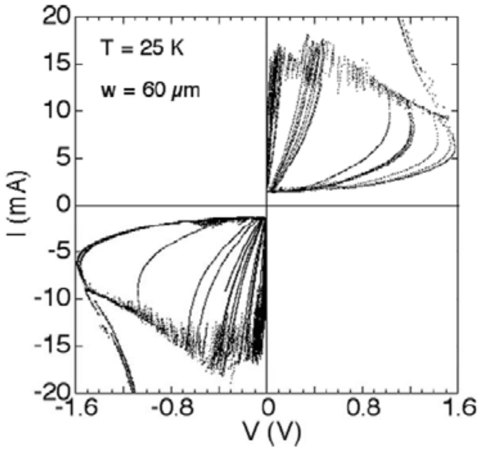
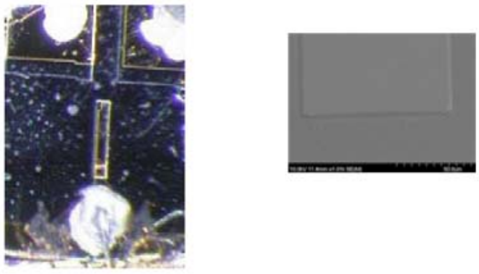


Fig.2 The *I-V* characteristic curves of a 1 μm thick mesa sample at *T*=25 K with 60 μm width.



(a) (b)

Fig. 3. Photographs of the mesa structure with dimensions of 60 μm in width, 400 μm in length and 1 μm in thickness. (a) A rectangular mesa is seen at the center with three electrodes. (b) AFM image of the mesa structure.

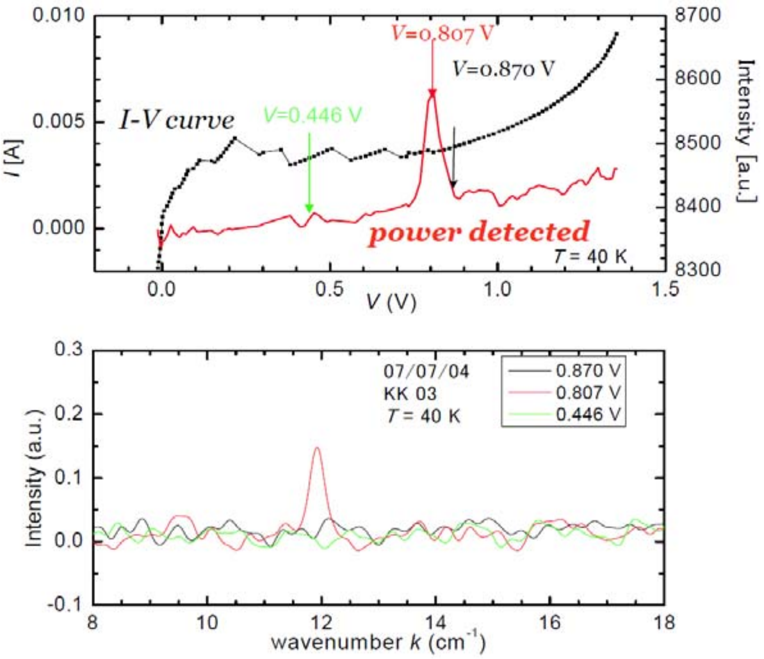


Fig. 4. The *I-V* return branch (black line) was shown simultaneously with the detector signal (red line) as a function of voltage (upper pannel). The detector signal was analyzed by the FTIR spectrometer (bottom pannel).

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