Coherent and Continuous Terahertz Emitters from High-Tc Superconductor Mesa structures

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Abstract

After the discovery of high temperature Superconductor YBa2Cu3O7-δ with the superconducting transition temperature $T_c=92$ K, which is well above 77 K, the boiling point of liquid nitrogen, this year has become a celebrative and a commemorative 30th anniversary in the history of superconductivity research. In addition to this memorable occasion, this years is another important anniversary that ten years have passed after the discovery of terahertz electromagnetic wave emission from the mesa structure of Bi2212 single crystals [1]. The important ingredients here is that the superconducting CuO double layers are built in a unit cell of the Bi2212 crystal as it is grown and are sandwiched by the insulating Bi2201 layers, forming a stack of intrinsic Josephson junctions (IJJs). Since the electronic structure as a result of this layered structure the superconducting as well as even normal state is highly two dimensional, the superconducting coupling becomes Josephson-junction like, extremely weak as measured by the c-axis critical current $J_{c}^{c} = 10^{5} - 10^{6}$ A/cm² compared with $J_{c}^{ab} = 10^{8} - 10^{9}$ A/cm², resulting in the reduction of the superconducting plasma frequency to the level of $f_{p} \sim 10^{11}$ c/s (0.2 ~ 1 meV), which is well below the superconducting gap $\Delta \sim 30$ meV. This Josephson plasma mode can be excited by the $dc$-current through the nonlinear Josephson coupling effect by the $dc$-Josephson effect and the coherent THz emission is generated due to the $ac$-Josephson oscillation with the frequency $f_{1} = (2e/h)v_{f}$, where $e$ is the elementary charge of electron, $h$ Planck constant, and $v_{f}$ the voltage per intrinsic Josephson junctions, when it matches well the cavity mode frequency. Although the understanding of this phenomenon has already been well established by various experiments and theoretical works [2], the practical limitation of the device is not well understood yet. For example, the most important issue is on what determines the maximum power extracted from one intrinsic Josephson junction, and how much power can be generated from the actual mesa structure with $N$-intrinsic Josephson junctions, where $N$ is the number of intrinsic Josephson junctions in a mesa. The next issue is on what limits the maximum frequency.

The essential parameter related to two issues has evidently been thought the thermal effect due to the Joule heating by the $dc$-current (10 - 50 mW), which produces heat of $\sim$MW/cm² and naturally causes a serious temperature increase and inhomogeneity, which is often called as a hot-spot. It has been disclosed by the dc-current (10 - 50 mW), which produces heat of $\sim$MW/cm², that the formation of the hot-spot gives only a detrimental effect on the THz radiation phenomena so that it is better to avoid it or control it to make the influence minimum on the THz emission. The heating issue has recently been studied intensively [3]. As a result, we have achieved a frequency of 2.4 THz with a power of 30 μW [4] quite reproducibly.

Recently, we have done a systematic case study on the rectangular, square, circular, triangular mesas, etc. and found an interesting fact. That is concerning the missing modes, which are expected to be as the strong emission modes but systematically disappear or are missing, perhaps, due to very weak intensities. This seems to occur especially in the degenerated symmetric cases such as in square and circular mesas. We argue this effect as a mode cancellation in the degenerated cavity modes in a symmetric mesa.

References

[4] Takananri Kashiwagi; Kazuki Sakamoto; Hirokyuki Kubo; Yuuki Shibano; Takuma Enomoto; Takeo Kitamura; Kentaro Asanuma; Takaki Yasui; Chiharu Watanabe; Kurama Nakade; Yoshihiko Saiwai; Takuya Katsuragawa; Manabu Tsujimoto; Ryozo Yoshizaki; Takashi Yamamoto; Hidetoshi Minami; Richard A. Klemm; Kazuo Kadowaki, A high-Tc intrinsic Josephson junction emitter tunable from 0.5 to 2.4 terahertz. Applied Physics Letters. 107, 082601 (2015). doi:10.1063/1.4929715

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