Nano-Micro Conference

Promoting Science

Abstract View Online

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

K. Kadowaki,[1,2]* T. Yuasa,[1] T. Tanaka,[1] Y. Komori,[1] R. Ota,[1] G. Kuwano,[1] Y. Tanabe,[1] K. Nakamura,[1] M. Tsujimoto,[1,2] H. Minami,[1,2] T. Kashiwagi,[1,2] Richard A. Klemm[3]*

[1]*Graduate School of Pure & Applied Science, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki 205-8573, Japan*
[2]*Division of Materials Science, Faculty of Pure & Applied Sciences, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki 305-8573, Japan*
[3]*Department of Physics, University of Central Florida, Orlando, Florida 32816-2385, USA*
Corresponding Author. Email: K. Kadowaki, kadowaki@ims.tsukuba.ac.jp; Richard A. Klemm, Richard.Klemm@ucf.edu

Received: 04 June 2017, Accepted: 18 June 2017, Published Online: 07 October 2017

Citation Information: K. Kadowaki, T. Yuasa, T. Tanaka, Y. Komori, R. Ota, G. Kuwano, Y. Tanabe, K. Nakamura, M. Tsujimoto, H. Minami, T. Kashiwagi, Richard A. Klemm, Nano-Micro Conference, 2017, 1, 01013 doi: 10.11605/cp.nmc2017.01013

Abstract

After the discovery of high temperature Superconductor $YBa_2Cu_3O_{7-\delta}$ 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_2 double layers are built in a unit cell of the Bi2212 crystal as it is grown and are sandwiched by the insulating Bi_2O_2 layers, forming a stack of intrinsic Josephson junctions (IJJs). Since the electronic structure as a result of this layered crystal 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 $J_c^c = 10^2$ - 10^3 A/cm^2 compared with $J_{ab}^c = 10^6$ - 10^7 A/cm^2, resulting in the reduction of the superconducting plasma frequency to the level of $f_J \sim 10^{11}$ 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 $f_J = (2e/h)v_J$, where e is the elementary charge of electron, h Planck constant, and v_J 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 ~MW/cm^3 and naturally causes a serious temperature increase and inhomogeneity, which is often called as a hot-spot. It has been disclosed by us 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 reproduciblly.

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

[1] L. Ozyuzer; A. E. Koshelev; C. Kurter; N. Gopalsami; Q. Li; M. Tachiki; K. Kadowaki; T. Yamamoto; H. Minami; H. Yamaguchi; T. Tachiki; K. E. Gray; W.-K. Kwok; U. Welp, Emission of Coherent THz Radiation from Superconductors. Science. 318, 1291 (2007). doi:10.1126/science.1149802

[2] Ulrich Welp; Kazuo Kadowaki; Reinhold Kleiner, Superconducting emitters of THz radiation. Nature Photonics. 7, 702–710 (2013). doi:10.1038/nphoton.2013.216

[3] T. Kashiwagi et al., to be published in Supercond. Sci. Technol.

[4] Takanari Kashiwagi; Kazuki Sakamoto; Hiroyuki 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

Open Access