A Tunable 350-780 GHz CW Solid State Oscillator of Intrinsic Josephson Junctions in a high-T_c Superconductor

H. B. Wang[#,*], M. Y. Li[#,*], J. Yuan[#], N. Kinev[†], J. Li[#], B. Gross[‡], S. Guenon[‡], A. Ishii[#], T. Hatano[#], D. Koelle[‡], R. Kleiner[‡] V. P. Koshelets[†], P. H. Wu[*]

[#]National Institute for Materials Science, Tsukuba 3050047, Japan

[*]Research Institute of Superconductor Electronics, Nanjing University, Nanjing 210093, China

[†]Kotel'nikov Institute of Radio Engineering and Electronics, Moscow 125009, Russia

[‡]Physikalisches Institut and Center for Collective Quantum Phenomena in LISA+, Universitaet Tuebingen, D-72076 Tuebingen, Germany

Email: hbwang1000@gmail.com

***Abstract*—We report on THz emission measurements and low temperature scanning laser imaging of $Bi_2Sr_2CaCu_2O_8$ intrinsic Josephson junction stacks. Coherent emission is observed at large dc input power, where a hot spot and a standing wave, formed in the "cold" part of the stack, coexist. By changing bias current and bath temperature the emission frequency can be varied over a wide range of 350-780 GHz; the variation matches the well-known Josephson-frequency relation. The linewidth of radiation, recently measured with an integrated superconductor-insulator-superconductor (SIS) receiver, is as narrow as 6 MHz, much smaller than expected from a purely cavity-induced synchronization. Thus, an additional mechanism seems to play a role. Some scenarios, related to the presence of the hot spot, are discussed.**

I. Introduction And Background

Phase synchronization is one of the prerequisites to use Josephson junction arrays as tunable high frequency sources. While Nb based junctions are limited to frequencies below 1 THz—with applications up to 600 GHz—intrinsic Josephson junctions (IJJs) in $Bi_2Sr_2CaCu_2O_8$ are, at least in principle, able to operate up to several THz [1]. Stacks of many junctions can be made, e.g., by patterning mesa structures on top of single crystals. For many years, investigations focused on small structures consisting of some 10 IJJs, with lateral sizes of a few μm. Here, with few exceptions, the IJJs in the stack tended to oscillate out-of-phase or were not synchronized at all.

Recently, coherent off-chip THz radiation with an extrapolated output power of some μW was observed from stacks of more than 600 IJJs, with lateral dimensions in the 100 μm range. Phase synchronization involved a cavity resonance oscillating along the short side of the mesa [2]. This radiation was studied theoretically in a series of recent papers, either based on vortex-type or plasmonic excitations, coupled to cavity modes, or on nonequilibrium effects caused by quasiparticle injection.

II. Results

While THz emission was obtained at relatively low bias currents and moderate dc power input [2], using low temperature scanning laser microscopy (LTSLM) we have shown that standing wave patterns, associated with THz radiation, can be obtained at high input power where, in addition, a hot spot (i.e., a region heated to above the critical temperature T_c) forms within the mesa structure [3, 4]. The radiation has been further measured with a superconducting integrated receiver. The linewidth at hot-spot regime is at least two orders narrower than that with absence of the hot-spot.

To conclude, a novel terahertz oscillator has been successfully fabricated from IJJs of high-T_c superconductors, with a wide tunable range of 350-780 GHz, a narrow linewidth down to 6 MHz at free-running state, and a wide operation temperature up to 60 K. In the near future, a phase-locked oscillator may find itself many applications in bridging the so-called THz gap, e.g., as a tunable local oscillator of a superconducting THz receiver.

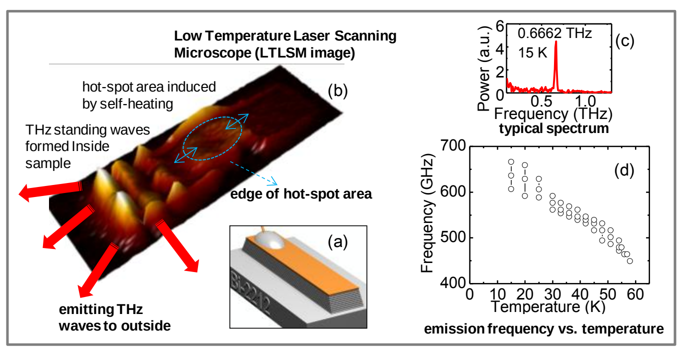

Fig. 1. (a) Schematic view of a stack of intrinsic Josephson junctions standing on its pedestal of the same $Bi_2Sr_2CaCu_2O_8$ superconductor, (b) standing waves and a hot-spot observed with a low temperature laser scanning microscope, (c) typical spectrum measured with an interferometer with a resolution of 12 GHz, and (d) a wide tunable frequency ranged can be obtained by varying temperature or bias current. The linewidth measured with an integrated superconducting receiver is not shown here.

References

[1] R. Kleiner et al., "Intrinsic Josephson effects in $Bi_2Sr_2CaCu_2O_8$ single crystals", *Phys. Rev. Lett.* 68, 2394, 1992.

[2] L. Ozyuzer et al., "Emission of coherent THz radiation from superconductors", *Science* 318, 1291, 2007.

[3] H. B. Wang et al., "Hot Spots and Waves in $Bi_2Sr_2CaCu_2O_8$ Intrinsic Josephson Junction Stacks: A Study by Low Temperature Scanning Laser Microscopy", *Phys. Rev. Lett.* 102, 017006, 2009.

[4] H. B. Wang et al., "Coherent Terahertz Emission of Intrinsic Josephson Junction Stacks in the Hot Spot Regime", *Phys. Rev. Lett.* 105, 057002, 2010.