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Spectral measurements of THz radiation emitted from intrinsic Josephson junction stacks

V.P. Koshelets[1], N.V. Kinev[1], A.B. Ermakov[1], F. Rudau[2], R. Wieland[2], D. Koelle[2], R. Kleiner[2], and H.B. Wang[3]

[1] Kotel'nikov Institute of Radio Engineering and Electronics RAS, Moscow 125009, Russia; valery@hitech.cplire.ru
[2] Physikalisches Institut and Center for Collective Quantum Phenomena in LISA+, Universität Tübingen, D-72076 Tübingen, Germany;
[3] Research Institute of Superconductor Electronics, Nanjing University, Nanjing 210093, China.

A superconducting integrated receiver (SIR) comprises all of the elements needed for heterodyne detection on a single chip. Recently, the SIR was successfully implemented for the first spectral measurements of terahertz (THz) radiation emitted from intrinsic Josephson junction stacks (BSCCO mesa) at frequencies up to 750 GHz; a linewidth below 10 MHz has been recorded in the high bias regime. In this report the results of the spectral measurements of THz radiation emitted from intrinsic Josephson junction stacks are summarized; recent results of spectrometric gas detection using THz radiation from a BSCCO mesa are presented.

In recent years, coherent THz emission has been obtained from stacks of intrinsic Josephson junctions (IJJs), created naturally in the BSCCO unit cell with the CuO layers forming the superconducting electrodes and the BiO and SrO layers forming the barrier layer [1, 2]; a 1- µm-thick crystal consists of about 670 IJJs. Terahertz emission from BSCCO mesa has been obtained both at a low bias (where the temperature distribution in the stack is almost homogeneous) and a high bias regime (where an over-heated part and a cold part of the sample coexist) [3, 4].

Coherent emission above 1 THz by intrinsic Josephson BSCCO junction stacks with improved cooling has been demonstrated [5, 6]. Due to the variable size of the hot spot and the temperature rise caused by the self-heating, the emission frequency can be tuned over a wide range of up to 700 GHz [5]. So far, emitted by one device power up to 30 µW was obtained [7, 8]. These are very encouraging results, although for most practical application spectral properties of the novel oscillators are vitally important.

The spectral characteristics of the oscillator were studied using the high-sensitivity super-heterodyne SIR, which was developed at Kotel'nikov IREE [9 - 12]. Such a receiver is intended to perform spectral studies of the electromagnetic radiation in the frequency range 450–700 GHz and successfully used for measuring the profiles of the spectral lines of the gas-molecule radiation and absorption and for the spectral study of any external terahertz oscillator radiating in the operation frequency range of the receiver. The best noise temperature of the SIR is 120 K and its spectral resolution is better than 0.1 MHz, which exceeds the resolution of modern terahertz-range Fourier spectrometers by several orders of magnitude.

Two configurations for the oscillator and receiver location were used: in the first case the oscillator was located in a cryostat of the SIR in the vicinity of the mixing unit [11]; in the second case the oscillator and the receiver were located in independent cryostats with Mylar quasioptical windows. The SIR operates at temperature of about 4.5 K, whereas the optimal BSCCO-oscillator temperature is 20–50 K. The spectral lines of the oscillator radiation are recorded by the SIR and displayed on the spectrum-analyzer screen in the intermediate-frequency range 4–8 GHz. The spectrum analyzer allows one to average the signal, read it by a computer, and perform other necessary digital operations for the spectrum analysis and processing.

Application of the SIR has allowed to measure radiation emitted from intrinsic Josephson junction stacks in both regimes with spectral resolution better than 1 MHz [4].While at low bias we found that linewidth is not smaller than 500 MHz, at high bias, emission linewidth turned out to be in the range 10–100 MHz (see Fig. 1a). We attribute this to the hot spot acting as a synchronizing element; a linewidth as narrow as 7 MHz has been recorded at high bias [12], see Fig. 1b.

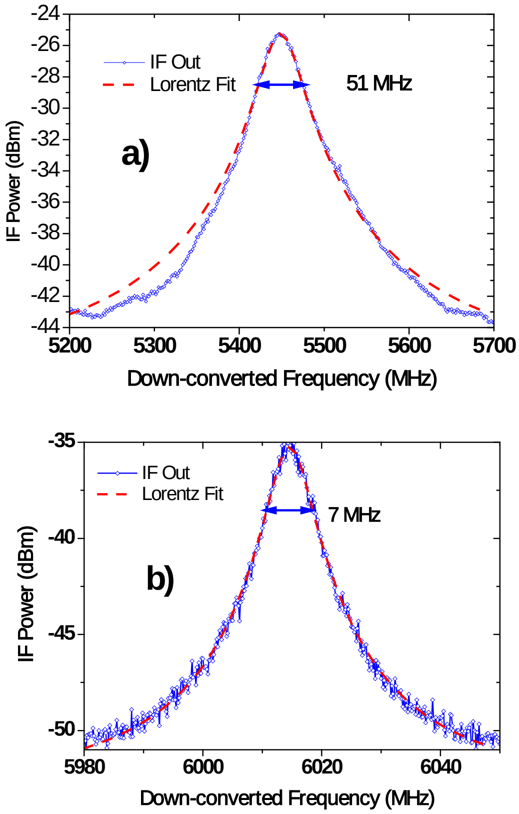

Fig. 1. Down-converted spectrum of the BSCCO at 527 (a) 476 GHz (b) in the high bias regime; dashed line is a Lorenzian fit with full linewidth 51 and 7 MHz respectively.

Typical dependencies of the linewidth on the BSCCO frequency both in the low-bias and high-bias regimes that were measured by the SIR are presented in the Fig. 2. Important to note that the tuning of the BSCCO oscillator frequency is continuous over the range; that was confirmed by fine tuning of the SIR LO frequency. Actually for the presented data the lowest measured frequency of about 550 GHz was limited by the BSCCO mesa, while losses in the Nb interconnection lines of the SIR restrict the measurements at frequencies higher than 730 GHz.

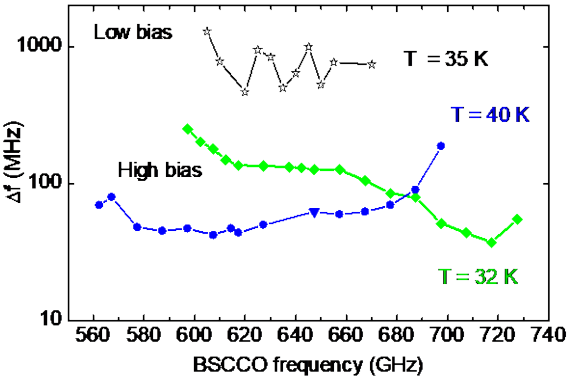

Fig. 2. Typical dependence of the BSCCO linewidth on the frequency (measured for the different sample temperatures — solid (open) symbols are for high (low) bias regime.

A combination of the BSCCO mesa and the SIR was used to accurately measure the terahertz absorption spectra of ammonia and water vapor [13]. In this experiment, the bias current through the BSCCO emitter is kept at a constant value, tuned to the respective gas-line frequency, and intermediate-frequency (IF) spectra are taken using the SIR.

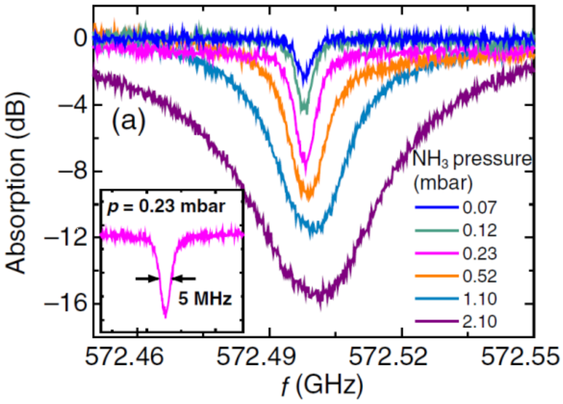

Fig. 3. Terahertz absorption spectra of ammonia (mixed with water; 10% solution) at different pressures by a BSCCO emitter and a SIR terahertz detector. The emitter and the SIR are operated at T_b = 4.2 K. The empty cell curve is subtracted from the data. Spectrum of ammonia vapor at p = 0.23 mbar, with an absorption linewidth of 5 MHz is presented as an inset.

Measurements are done at T_b = 4.2 K, where the linewidth of radiation of the emitter is 60 MHz at 572.5 GHz (NH_3). With this setup, high resolution THz absorption spectra of ammonia achieved in a narrow frequency band lower than the linewidth of the BSCCO emitter; see Fig. 3 [13]. The emitter, operated in a free-running mode, is stable enough to permit this kind of measurement. The absorption lines of ammonia are highly broadened at large gas pressures, with the linewidth decreasing with decreasing pressure. For ammonia, at p = 0.23 mbar, which is the order of the concentration of trace gases, a clear absorption dip with an absorption linewidth of about 5 MHz is observed, as shown in the inset of Fig. 3. At p = 0.07 mbar, the measured linewidth is 4 MHz (although affected by Doppler broadening). The observed rotation frequencies of ammonia (572.498 GHz) coincide with literature values. Further improvement of the lowest resolvable linewidth is possible by using proper feedback techniques for the oscillator [10].

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