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Voltage-tunable YBCO Josephson mixer, operating in self-pumping mode at 750–970 GHz

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Abstract

Voltage-tunable response on noise signal from high-T_C Josephson device, operating in self-pumping mixing mode was experimental studied by Fourier transform spectroscopy technique at frequency band $f = 750$–970 GHz. Experimental device was bicrystal YBCO junction fabricated on sapphire substrate with a patterned log-periodic antenna in electrodes, exhibiting RSJ-like I–V curves with $I_C R_N$ product of order 1.8 mV at temperature $T = 12.5$ K. The intermediate frequency signal was amplified by a cooled low noise balanced 1–2 GHz HEMT amplifier. The clear double-side band mixer response at any of fixed bias voltage in the range 1.65–2.1 mV, strictly corresponded to Josephson frequency/voltage relation, was observed at Fourier transform spectrograms.

Keywords: YBCO; Josephson mixer; THz frequencies

1. Introduction

Due to specific nonlinearity of impedance of Josephson junction (JJ) [1] an effective frequency multiplication and mixing are expected for high-T_C superconducting (HTS) JJs, having large $I_C R_N$ products (I_C—critical current) and high values of normal state resistance R_N (see, e.g. [2,3]). It is well know that the power of the Josephson self-oscillations at frequency f_J may serve as a pumping source and down converted signal f_S at intermediate frequency $f_{IF} = \mp f_S \pm f_J$ should be registered. Josephson-effect self-pumped mixer, built on HTS bicrystal JJ may reach low enough noise temperature [1], defined in a simplified approach as $T_M \approx 10\alpha_{IN}\alpha_{OUT}T(f_S/f_C)^2$, where α_{IN} and α_{OUT} are impedance mismatch factors for input and output mixer ports, T—ambient temperature, $f_C = (2e/h)I_C R_N$—critical frequency of JJ. Starting from experimentally obtained values of product $I_C R_N \approx$ 1.6–2.2 mV, $R_N \approx 15$–$40\ \Omega$ at $T = 4.2$ K for YBaCuO JJ on sapphire substrates [2] an estimation for $f_S \approx 1$ THz gives $f_S/f_C \approx 1$, and taking optimistic $\alpha_{IN}\alpha_{OUT} = 2$ dB, yields in $T_M \approx 100$ K. For properly operating mixer the linewidth of pumping source (local oscillator LO in the case of heterodyne mixer) must be $\Delta f_{LO} \ll f_{IF}$. However, the HTS JJs exhibit linewidths Δf_J of Josephson self-oscillations larger than few GHz [3,4] and usually $\Delta f_J > f_{IF}$. That may result in crucial rise of T_M. From this point of view a heterodyne mixer seems

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preferable, but requires long term stable operating LO which is a problem remaining unsolved for THz frequencies. In this connection an experimental study of HTS self-pumped mixer, operating at THz frequencies becomes a subject of high interest.

2. Experimental

Experimental JJs coupled with the log-periodic antenna were fabricated by YBCO thin film deposition by dc sputtering at high oxygen pressure using bicrystal sapphire substrates with symmetric misorientation angle of 12°. The rf magnetron sputtering of a epitaxial CeO_2 buffer layer was used before deposition of YBCO film [2]. The YBCO thin film bridges 5 μm wide and 10 μm long, crossing the bicrystal boundary and electrodes with antenna, designed for frequency band $f = 100$–1500 GHz were patterned by rf plasma and Br_2-ethanol etching. Choosing samples with large enough values of $R_N = 15$–40 Ω for required impedance matching at the both input and output frequencies, the critical frequency f_C was kept to be not less than 1 THz. Measurements using modulator–demodulator technique were curried out in a optic cryostat with Mylar window at $T = 12.5$ in conditions when the sample was attached by its bottom side to a Silicon hyperhemispherical lens. A cooled balanced HEMT IF preamplifier of 1–2 GHz frequency band with noise temperature $T_N \cong$ 8 K at $T = 4.2$ K was connected to a JJ via a coplanar mounting, the output signal from quadratic detector, terminating the second stage "room" amplifier, was synchronously detected by selective low noise lock-in amplifier. For sample characterisation [4] the Hg-tube of the Michelson Fourier transform spectrometer (FTS) was used as a source of a input noise power of order of 2700–3000 K. The automatic resonator positioning of FTS and the data registration were made in PC-control regime.

3. Results and discussion

Fig. 1 demonstrates the spectrogram, obtained from detector response for the fixed bias voltage at

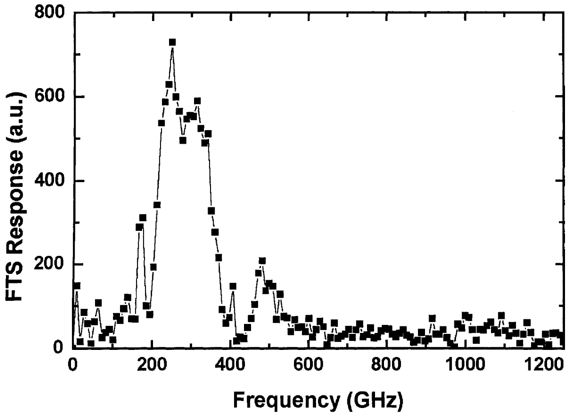

Fig. 1. FTS detector response from bicrystal JJ on sapphire substrate at $T = 12.5$ K for fixed $V = 1.15$ mV.

$V = 1.15$ mV which lays within the range of high differential resistance $R_D > 100$ Ω. Note, that our JJs exhibited transition (the discussed sample at $V = 1.65$ mV) to the almost linear slope of R_N asymptote. In general, applying wide band noise signal to a JJ, no selective detector response should be registered [1]. In the discussed case a relatively large Josephson linewidths Δf_J in comparison with the signal frequency band Δf_S of Hg-tube noise, filtered by Michelson resonator with high Q-factor resulted in the both: relatively intensive broad-band detection at $f = 200$–400 GHz and in a moderate response peak at $f = 400$–600 GHz which resulted from selective detection process. The broad-band detector FTS response peak demonstrates the frequency range, where signal losses in YBCO thin film antenna are small enough. Increasing the bias voltage and, correspondingly the frequency of selective detection, the losses in YBCO antenna also increased. That is why at voltage above the $V > 1.65$ mV no longer clear resolved detector FTS response have been registered for the discussed sample. At the same time we have registered self-pumping response at IF at any of biasing voltage in the range $V = 1.65$–2.1 mV. Due to our knowledge that is the first observation on tuneable by voltage self-pumped mixing of external noise signal on HTS JJ, operating at temperature $T = 12.5$ K. Fig. 2 demonstrates the spectrograms, obtained from frequency down converted IF response for three fixed voltage

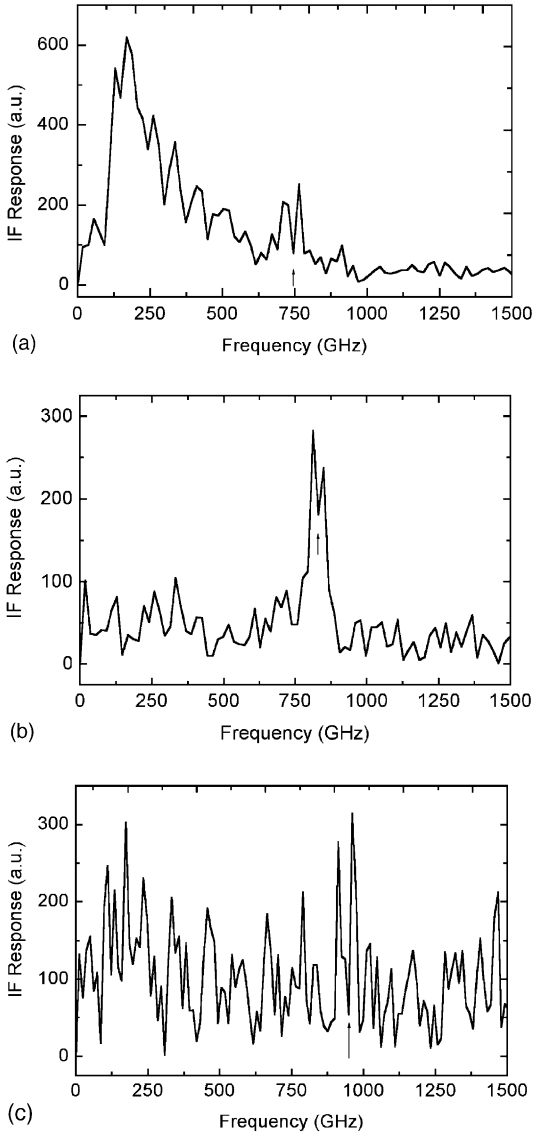

Fig. 2. FTS IF response in down conversion mixing self-pumping mode for JJ with $R_N = 23\ \Omega$, $I_C = 90\ \mu A$, $T = 12.5$ K. Bias voltages are corresponded to pump frequency: (a) 750 GHz, (b) 845 GHz and (c) 970 GHz. Arrows indicate the self-pumping frequency f_J.

biasing V, corresponding to self-pump frequency at 750, 845 and 970 GHz. The splitting of the response peak is caused by double-side band mixing regime. A "dark" IF interval was about 2 GHz wide. Arrows in the Fig. 2 indicate the dark case when $f_S = f_J$ for three different voltage bias. Plot (Fig. 2a) corresponds to bias $V \cong 1.65$ mV, demonstrating also the frequency dependent loss rise in YBCO antenna.

4. Conclusion

The YBCO JJs on sapphire substrates with $I_C R_N \approx 2$ mV and $R_N \approx 20\ \Omega$ at $T = 12$ K demonstrated frequency down conversion in self-pumping mode in THz range with frequency tuning by changing the bias voltage in the range 750–970 GHz. To increase the sensitivity at $f > 1$ THz the problem of frequency dependent loss rise in YBCO film and the other problem of reduction of Josephson self-oscillation linewidths of JJ should be solved.

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