Physica C 372–376 (2002) 347–350

PHYSICA C

www.elsevier.com/locate/physc

Submillimeter-wave quasioptical integrated tester based on bicrystal Josephson junctions

M. Tarasov [a,d,*], E. Stepantsov [a,c], T. Lindström [a], A. Lohmus [b], Z. Ivanov [a]

[a] MINA, Department of Physics, Chalmers University of Technology and Göteborg University, Gothenburg S41296, Sweden
[b] Institute of Physics, University of Tartu, Riia 142, Tartu 51014, Estonia
[c] Institute of Crystallography, Lenensky Prosp. 59, Moscow 117333, Russia
[d] Institute of Radio Engineering and Electronics, Mokhovaya 11, Moscow 101999, Russia

Abstract

YBCO integrated structures consisting of a planar antenna and a Josephson junction were designed and fabricated on bicrystal sapphire substrates. By combining two such structures in an oscillator-receiver arrangement a submillimeter-wavelength tester was realised. Two types of relatively narrow-band double-slot and double-dipole antennas, a broadband complementary log-periodic antenna and an array of dipole antennas were investigated.

Keywords: Josephson oscillators; Josephson detectors; Quasioptics; Submillimeter-wave spectrometers

1. Introduction

Microwave spectrometers are powerful tools for environment control, material science and microwave-device design and evaluation. The two main types of millimeter and submillimeter-wavelength (submm) spectrometers are Fourier transform spectrometers and backward wave oscillator spectrometers. Spectrometers operating in this frequency range can for example detect absorption lines from gases and measure dielectric properties and they are also needed in the development of new submm-wavelength techniques and for the evaluation of different components such as antennas, filters, detectors and submm-wavelength spectrometers. Commercially available spectrometers are big, expensive and difficult to use in the evaluation of small cryogenic components. We propose a novel type of mm and submm-wavelength spectrometer that can be designed as an on-chip device and is a few millimeters in size. The low price of such an on-chip device will bring new possibilities compared to its competitors. We suggest that our tester could be a first step towards the development of such a spectrometer.

The source of the signal in our tester is a high critical temperature (HTS) Josephson junction (JJ) emitting radiation at frequencies up to few terahertz. By tuning the bias voltage is possible to sweep the source from around a hundred gigahertz up to several terahertz. Conventional

* Corresponding author. Address: MINA, Department of Physics, Chalmers University of Technology and Göteborg University, Gothenburg S41296, Sweden. Fax: +46-31-7723-224.

E-mail addresses: tarasov@fy.chalmers.se (M. Tarasov), tobiasl@fy.chalmers.se (T. Lindström).

0921-4534/02/$ - see front matter
PII: S0921-4534(02)00666-4

superconducting junctions based on traditional Nb technology can only be used below 700 GHz whereas a HTS JJ allows us to increase the frequency to several THz. The line width of such an oscillator is theoretically [1] of the order

$$\Delta F\ (\mathrm{MHz}) = 40R\ (\Omega) \times T\ (\mathrm{K}) \quad (1)$$

which at 4 K is about 1 GHz. By using a low-inductance resistive shunt it is possible to further reduce the line width. The characteristic frequency of our junctions exceeds 2 THz; the normal resistance is about 10 Ω and they therefore fit the requirements for spectrometers. Another advantage of JJs is that it is possible to analyze the spectra of the incoming radiation using Hilbert spectroscopy. The designs described here should be very suitable for this purpose [2–5].

2. Experimental setup

We have designed and fabricated quasioptical integrated structures comprising a planar antenna and a bicrystal JJ. Three types of antennas were studied: a broad-band log-periodic and a relatively narrow-band double-slot and double-dipole antennae made of 200 nm thick Au film. The JJs were fabricated on 14°, 18° and 24° symmetrical grain boundaries of welded bicrystal sapphire substrates. The structures were attached to MgO, Al_2O_3 or Si lenses separated by a distance of about 30 mm. One of the structures serves as a oscillator, and the other as a receiver of the emitted radiation. The experimental setup is very simple: The sample under test is placed between the JJ source and the JJ sensor (see Fig. 1). By varying the bias voltage from about 0.1 to 4 mV one can get an output frequency variation from 50 GHz to 2 THz. The detected signal dependence on the JJ bias voltage will have a frequency period that corresponds to the electric length of the path and corresponds to the real part of the dielectric constant. The decay in amplitude corresponds to losses or the imaginary part of the dielectric constant. If the structure under test has any specific response at some frequency, e.g. if we study a filter structure, this will result in a corresponding maximum or minimum in the detected signal. With this type of spectrometer it is possible to evaluate the transparency of submm-wavelength components, e.g. bandpass and neutral density filters.

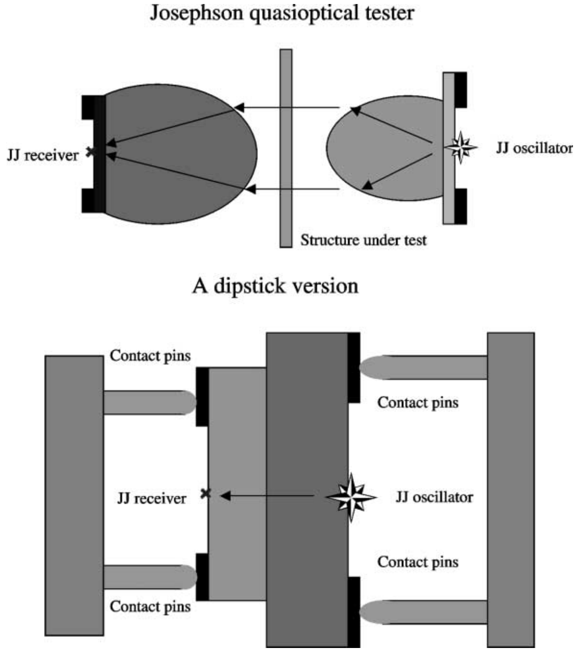

Fig. 1. Schematic layout of the developed quasioptical cryogenic microwave spectrometer. *Top*: with two elliptical lenses, *bottom*: a back-to-back arrangement.

The first version of our JJ tester is simple, small and easy to assemble (see Fig. 2). It consists of source chip with a JJ oscillator integrated in a planar log-periodic antenna, two quasielliptical lenses and a receiver chip with a JJ sensor and a similar planar log-periodic antenna. The sample under test is placed between the lenses and the whole construction is a few centimetres in size.

The second version of the tester is intended for fast microwave tests in a dipstick and consists of two sample holders containing two substrates attached back-to-back (see Fig. 3). The main lobe of both the Josephson oscillator and the detector antennas are directed into the dielectric which means that they will be matched if the antennas are placed in front of each other. Such simple quasioptical matching gives us the possibility to study oscillation spectra in a wide frequency range and avoid losses in lenses, material boundaries, and long beamguides. In this construction the dielectric

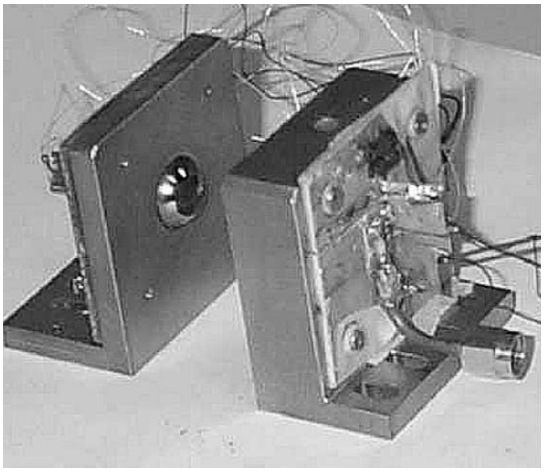

Fig. 2. Photo of a practical realization of the schematics from Fig. 1. Comprising a quasioptical source and detector, both with extended hyper-hemi-spherical lenses.

Fig. 3. Photo of a dipstick version of the back-to-back attached receiver and oscillator chips forming a submm-wavelength tester for cryogenic radiating and receiving structures.

constants are equal and no reflection occurs at the boundary of the substrates. This tester allows us to estimate the wavelength of the radiation from different planar superconducting oscillators or to test planar detector microwave response. The use of this tester is straightforward and can be used to evaluate fabricated structures using available JJ oscillators and detectors.

By placing something in between the oscillator and detector, e.g. a substrate, it is possible to evaluate for example the transmission and absorption in very quick, simple and cheap experiment.

3. Experimental results

With the above spectrometers we measured the response of a detector junction when it was irradiated with another junction. The dependencies on detector bias voltage and oscillator bias voltage (see Fig. 4) are due to differences in the spectral characteristics of different antennas used in oscillator and detector chips. The dependence of the detector response on the source and detector junction bias voltage shows the frequency dependence of the double-slot antenna radiation efficiency and matching to JJ. The so-called selective detector response with polarity changing at the resonant frequency shows three resonances at voltages 0.3, 0.9, 2.2 mV which corresponds to resonant frequencies of about 150 GHz, 450 GHz and 1.1 THz for the structure with a double-slot antenna.

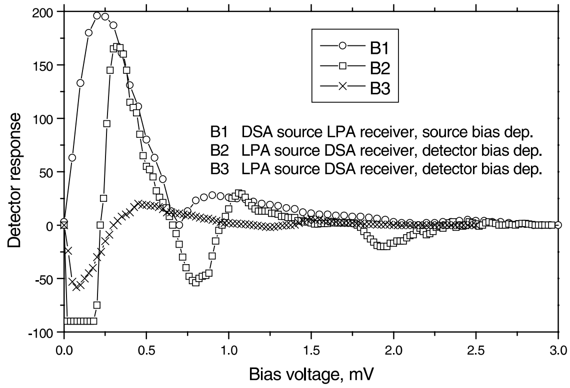

Fig. 4. The response of the detector junction on the emitted radiation from the oscillator chip. Curve B1: source with double-slot antenna biased at 0.63 mV, receiver with log-periodic antenna, dependence on source bias voltage. Curves B2 and B3: source with log-periodic antenna biased at 1 mV, receiver with double-slot antenna, dependencies on detector bias voltage.

With the back-to-back arrangement in the dipstick we measured radiation from a JJ array of parallel dipole antennas. The selective detector response (see Fig. 5) with changing polarity at the resonant frequency at voltages 0.7 and 3 mV corresponds to resonant frequencies of 350 GHz and 1.5 THz. The high detector response at voltages over 4 mV corresponds to oscillations at frequencies over 2 THz. For details see [6]. Using Hilbert transform spectroscopy technique [2–4] it is possible to extract the spectrum of incoming radiation from the selective Josephson detector response.

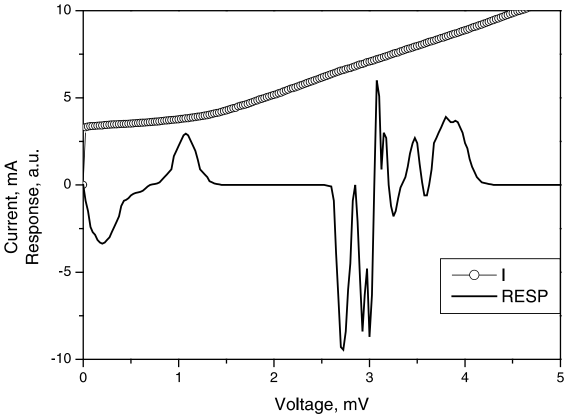

Fig. 5. Radiation from a Josephson junction array measured in the dipstick version of the tester. The response curve is changing polarity from negative to positive at voltages 0.7 and 3 mV. A response is observed even when the oscillator is biased over 4 mV. The detector was biased at 0.4 mV.

4. Conclusion

We have designed and fabricated quasioptical integrated structures that use planar antennas and bicrystal Josephson junctions. The structures have been used to build two types of submm-testers. We have shown that these designs can be used in a wide frequency range, 150 GHz–2 THz.

We expect that these devices can be developed further and compete with existing technology. By using Hilbert spectroscopy it is also be possible to extract information about the spectra of the radiation emitted by Josephson oscillator.

Acknowledgements

Authors acknowledge the financial support from KVA, SI, INTAS-01-686, INTAS-00-384, ISTC-1239, Estonian Scientific Foundation grant 5015 and the SSF program "OXIDE".

References

[1] K. Likharev, Dynamics of Josephson junctions and circuits, Gordon and Breach Science Publications, NY, 1986.
[2] M. Tarasov et al., JETP Lett. 70 (5) (1999) 340–345; See also M. Tarasov et al., in: EUCAS'99, Sitges, September 13–17, 1999.
[3] M. Tarasov et al., in: Superconducting Electronics Conference, ISEC'97, Berlin, Germany, vol. 1, June 25–28, 1997, pp. 83–85.
[4] Y.Y. Divin et al., Appl. Phys. Lett. 68 (1996) 1561–1563.
[5] E. Kume, I. Iguchi, H. Takahashi, Appl. Phys. Lett. 75 (18) (1999) 2809–2811.
[6] M. Tarasov, E. Stepantsov, T. Lindström, A. Kalabukhov, Z. Ivanov, T. Claeson, Physica C 372–376, these Proceedings.