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MICROWAVE DETECTION AT METAL–HIGH-T_c SUPERCONDUCTING CERAMICS POINT CONTACT

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Experimental results of observed microwave detection at a point contact of metal–high-temperature superconducting $YBa_2Cu_3O_{7-x}$ (YBCO) ceramics at room and liquid nitrogen temperatures are presented. The use of ceramics instead of a thin film allowed for a better heat removal from the point contact and reduction of output resistance down to 50 ohms. It is demonstrated that the observed detection is non-bolometric. The possibility to use YBCO ceramics-based detectors with properties comparable to those of semiconducting analogues is discussed.

Keywords: microwave, microwave detection, point contact

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1. Introduction

It is established experimentally [1–4] that the high-temperature superconducting materials such as $YBa_2Cu_3O_{7-x}$ (YBCO) and $Bi_2CaSr_2Cu_2O_{8+\delta}$ (BCSCO) produce a wide microwave range response when placed in a microwave electric field. The response mechanism may be either thermal (bolometric) or non-thermal.

Investigating the detection of millimetre waves in a point-like metal–superconducting BCSCO layer contact, it has been obtained (see earlier works [4, 5]) that contact response in the 25–30 GHz range is thermal. The contact has the sensitivity similar to that of semiconducting detectors as well as a linear voltage–power characteristic. The sensitivity of such a contact was equal to about 2 V/W for a 0.2 mA stationary current. Without a biasing voltage the detection signal was 20 times lower. At the liquid nitrogen temperature the detected signal was several times higher. Despite the advantages of such a contact, its practical use may be difficult because the response is primarily related to the manifestation of a highly resistive degraded surface of high-temperature superconductor (the resistance of contact was as high as hundred kΩ) which determines its inertness due to thermal effect. This obscures observation and measurement of short pulses of microwave radiation. To obtain a better contact the metallic probe should be pressed more firmly to the thin superconducting layer, but such a pressure on the probe may destroy the layer itself. To reduce this negative effect one should use the high-temperature ceramics.

2. Measurement methods

The experiments were carried out on a usual superconducting YBCO ceramics with $T_c = 90.7$ K and density of 5.7 g/cm^3 prepared by the standard technology of solid state synthesis. The choice of YBCO ceramics was motivated by its attractive properties: (i) using the ceramics a better heat transfer may be obtained because the heat-resistance effect of the base-superconducting layer junction is avoided; (ii) ceramics is much more resistant to the mechanical pressure of a probe, which due to the dependence of surface resistance on the material density [6] allows one to assume that the surface resistance of ceramics could be changed by the probe pressure and thus the detector's resistance could be diminished. All of this permitted us to anticipate that the characteristics of such detectors could be made close to the characteristics of the best semiconductor detectors. In Fig. 1 a 10 GHz frequency waveguide head *G* is shown schematically, with its waveguide window cross-section being 23×5 mm^2. A cylindrical 6 mm radius and 4 mm high sample *B* of YBCO superconducting ceramics with a burned-in silver contact on the bottom side was located onto a screw *V* in the bottom wall of the head *G*. The upper face of sample *B* treated

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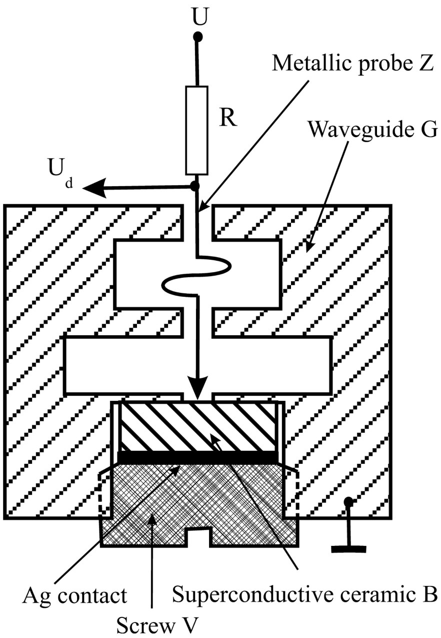

Fig. 1. Schematic view of a waveguide head with metal–YBCO ceramics point contact.

with a M-20 abrasive was pressed against the 1 mm diameter hole in the middle of the wide bottom wall of the waveguide window, on its outer side. A probe made of a 0.2 mm thick tungsten wire, with its end electrochemically sharpened to a 20 micron diameter, through a hole at the upper side of a waveguide window was pressed to the surface of sample *B*. The head *G* was connected to the waveguide tract. Voltage–power characteristic measurements were performed using the microwaves modulated by a 680 Hz frequency meander, with their wavelengths in the waveguide being 4.4 cm. The power P incident onto the head could be varied from 0 to 600 mW, with the average power measured using a standard wattmeter with an accuracy of $\pm 6\%$. The bias voltage U_p needed for detection was created by applying voltage U to a divider shown in Fig. 1, consisting of resistance R (5 kΩ) and probe resistance R_z. The voltage of detected signal U_D was measured by a selective voltmeter and recorded by an autorecorder.

When measurements were performed at the liquid nitrogen temperature, a part of the waveguide tract with the head *G* was enclosed in a vessel with liquid nitrogen as described in [7], to ensure the stable temperature of head *G* and sample *B*. The temperature of the liquid nitrogen was measured by a differential copper–constantan thermocouple.

To determine the microwave detection capabilities of point-like metal–superconducting YBCO ceramics contacts, their voltage–current characteristics at stationary electric current were measured as well.

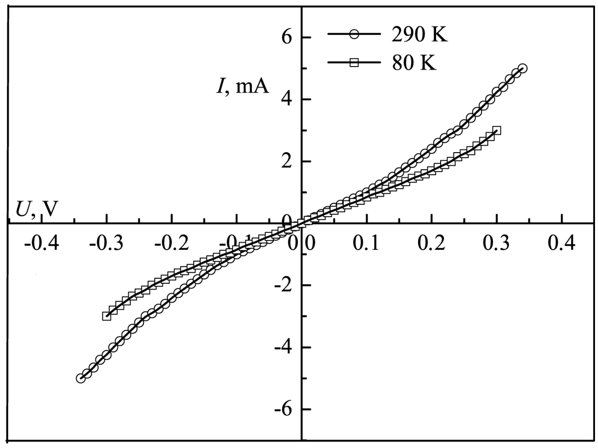

Fig. 2. Voltage–current characteristics of a metal–superconducting YBCO ceramics point contact at temperatures T = 290 K and T = 80 K.

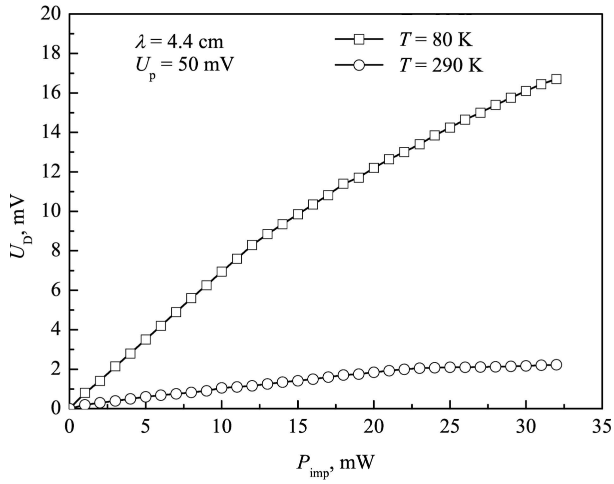

Fig. 3. Voltage–power characteristics of the detector presented for T = 80 K and T = 290 K.

3. Experimental results and discussion

Voltage–current characteristics of a point-like metal–superconducting YBCO ceramics contact at 290 K and 80 K are presented in Fig. 2. It is seen that in both cases the curves are symmetric with respect to the voltage sign inversion. This means that the barrier is also symmetric and different from p–n and n–n^+ barriers. Therefore it should not detect electromagnetic waves without a stationary bias voltage U_p.

Figure 3 shows voltage–power characteristics of the investigated point-like contact at T = 80 K and T = 290 K. It is seen that at T = 290 K the sensitivity is more than one order in magnitude less than at T = 80 K. The slopes of these voltage–power characteristics also differ.

Figure 4 demonstrates how the detected signal U_D depends on the biasing voltage U_p when the meander-modulated microwave pulse power P_imp incident onto

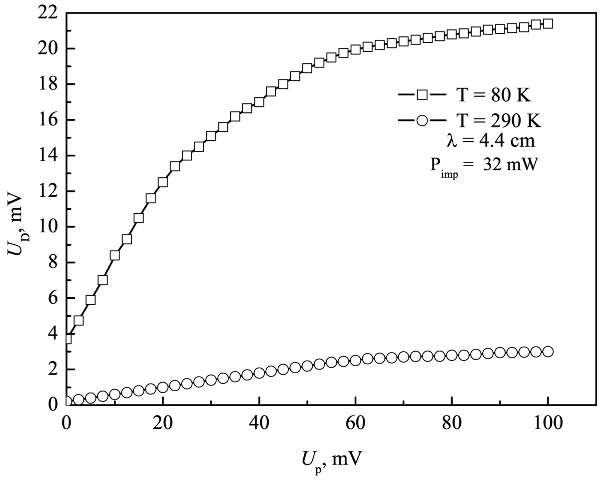

Fig. 4. Dependences of detected signal U_D on the biasing voltage U_p when the microwave pulse power P_imp incident onto the measuring head is 32 mW, at temperatures $T = 80$ K and $T = 290$ K.

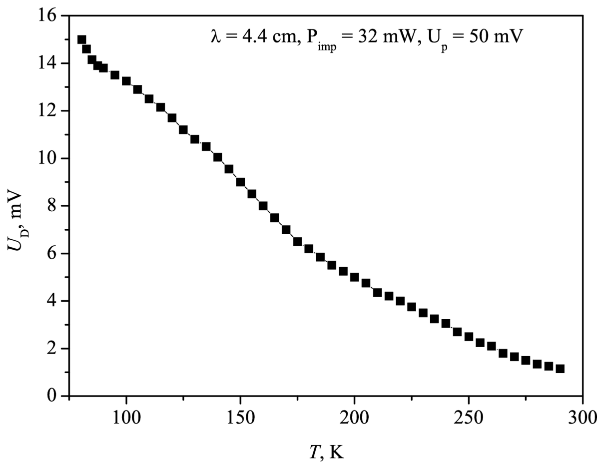

Fig. 5. Dependence of detected signal U_D on temperature T, $U_\mathrm{D} = f(T)$.

the measuring head is 32 mW, at $T = 80$ K and $T = 290$ K temperatures. It is seen from the figure that the curves $U_\mathrm{D} = f(U_p)$ saturate in the region where U_p approaches the 100 mV value.

Dependence of detected signal U_D on temperature T presented in Fig. 5 is obtained experimentally at natural evaporation of the liquid nitrogen by measuring the temperature of head *G* and specimen *B* with a differential copper–constantan thermocouple. The curve indicates that with the change of the point-like contact temperature the detected signal changes by more than one order in magnitude.

The presented results allow one to presume that the microwave detection is determined by non-thermal properties of the point-like metal–superconducting YBCO ceramics contact. The voltage–current characteristic of symmetric shape may allow detection due to

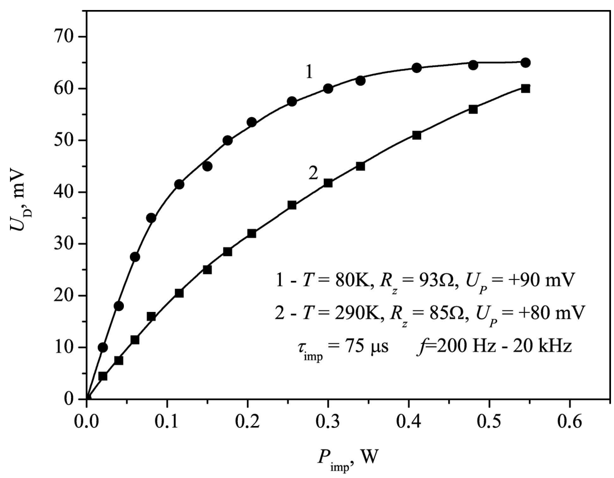

Fig. 6. Dependences of detected signal U_D on pulsed power P_imp (pulse duration $t = 75$ μs) when the average value of every pulsed power was changed by changing the pulse frequency from 200 Hz to 20 kHz.

its nonlinearity when the bias voltage is provided. To prove the validity of assumption that thermal effects do not determine the microwave detection in this case, experimental investigations of two types were conducted.

The first study to heat up the point-like contact by the microwave radiation modulated with 75 μs-long pulses has been performed at $T = 80$ K and $T = 290$ K. Its pulsed power was changed up to 0.5 W and the average power tuned by changing the pulse repetition rate from 200 Hz to 20 kHz.

It was obtained (see Fig. 6) that for every value of pulsed power, when the average power was varied via the pulse repetition rate, the magnitude of detected signal was constant within the accuracy of $\pm 2\%$. This indicates that the point-like contact does not heat up and

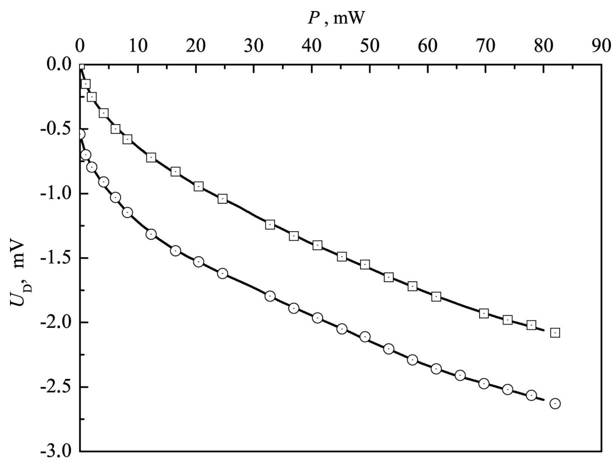

Fig. 7. Dependences of detected signals on the incident power P of the constant generation microwave radiation when a non-heating stationary bias voltage was (circles) and was not (squares) applied to the ceramics at temperature $T = 290$ K.

therefore we may conclude that the observed detection is non-bolometric.

The second study was carried out as in Ref. [4]. The detected signal was measured at 290 K by changing the power of the constant generation microwave radiation, when a small non-heating stationary bias voltage (-0.5 mV) was or was not ($U_p = 0$ mV) applied to the specimen (Fig. 7). Earlier results [4] had shown that due to a small internal electric field in the barrier a weak detection was observed for zero bias voltage U_p. Comparing the obtained curves it is possible to see that the given magnitude of the bias voltage does not change in the whole range of power P, leading to the conclusion that the microwave radiation does not heat up the point-like contact. Therefore this investigation also confirms the non-bolometric nature of the observed detection.

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MIKROBANGŲ DETEKTAVIMAS TAŠKINIAME METALO IR AUKŠTATEMPERATŪRĖS SUPERLAIDŽIOSIOS KERAMIKOS KONTAKTE

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Santrauka

Pateikiami kambario ir skysto azoto temperatūrose stebėto mikrobangų detektavimo eksperimentiniai rezultatai taškiniame metalo ir $YBa_2Cu_3O_{7-x}$ (YBCO) aukštatemperatūrės superlaidžiosios keramikos kontakte. Keramikos panaudojimas vietoje plono sluoksnio leido pagerinti šilumos nuvedimą iš taškinio kontakto ir sumažinti išėjimo varžą iki 50 omų. Nustatyta, kad stebimas detektavimas yra nebolometrinis. Pademonstruota galimybė panaudoti YBCO keramiką detektoriams, kurių savybės būtų palyginamos su puslaidininkiniais analogais.