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Investigation and Application of Ultrafast Photoresponse of $YBa_2Cu_3O_{7-\delta}$ Microbridges Excited by High Fluence Optical Pulses

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Ultrafast photoresponse of dc-biased optically-thick $YBa_2Cu_3O_{7-\delta}$ microbridges at $T < T_c$ triggered with 100 fs optical pulses of high fluence was investigated by means of sampling oscilloscope and approach of a S-(1.5–4 GHz) & C-(4–7 GHz) frequency-band antenna radiation, excited by the photoresponse. A superposition of ultrafast- (photokinetic) and slow- (bolometric) components of the photoresponse caused a quadratic rise of Fourier amplitude of the radiation with a laser fluence increase. The maximum of the radiation amplitude was obtained at $T = T_c - 9.2$ K and a repetition rate of the transmitting-antenna decreased from 180 to 20 MHz, when laser fluence was increased from 5 to 40 mJ cm^{-2}/pulse. A method for optically-thick photoswitches triggering with high fluence optical pulses is demonstrated and discussed.

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1. Introduction

The operating frequency band (OFB), determining the resolving capacity and the sounding depth, is one of the main characteristics of antenna of the ground penetrating (S- & C-band) radar, operating in the 1.6–6 GHz frequency range. Since many real media (e.g. soil, buildings, etc.) have an appreciable dispersion, the choice of the OFB is based on a compromise between the resolving capacity, limited by the OFB and “jitter” (random delay of the transmitting pulses) and the sounding depth, limited by the radiation power.

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Recent ultrafast sampling measurements using femtosecond-optical-pulses (FOP) demonstrated that the photoresponse (PR) of high-T_c superconducting films consists of "photokinetic" (single picosecond timescale modulation of the kinetic inductance [1]) and "bolometric" (nanosecond timescale thermalization of photocarriers [2]) components. Transient dynamics in the $YBa_2Cu_3O_{7-\delta}$ (YBCO) film, biased with the supercritical ($I \geq I_c$) current, showed that light absorption can modulate the flux-flow regime and generate a ~ 10 mV amplitude PR with a risetime less than 100 ps, giving the maximal repetition rate of transients in the range of GHz [3].

The main purpose of this work was to investigate ultrafast PR of the YBCO superconducting microbridges at $T < T_c$ biased with low ($I < I_c$) current (to minimize heating) and shined with high fluence (tens of mJ cm^{-2}/pulse) FOP. The approach of PR driven transmitting-antenna radiation [4] and ultrafast oscilloscope for measurements of PR waveforms were used in our experiments.

2. Samples and experimental setup

Epitaxial 0.2 μm thick YBCO films deposited onto MgO substrates were patterned into 8 mm long and 150 μm wide 50 Ω coplanar transmission-lines (CTLs) with a single 50 μm long and 25 μm wide microbridge shunting the CTL. Microbridges were characterised by the zero-resistance transition temperature $T_c =$ 86.8 K ($\Delta T_c \sim 0.8$ K) and the critical current density $J_c(78\text{ K}) = 1.6$ MA cm^{-2}. The substrate was glued with a silver paste to a cold finger of a temperature controlled He-cryostat. Then, the superconducting CTL was wire-bonded to the 2.2×1.3 cm^2 rectangular-contour of a transmitting-antenna (see Fig. 1).

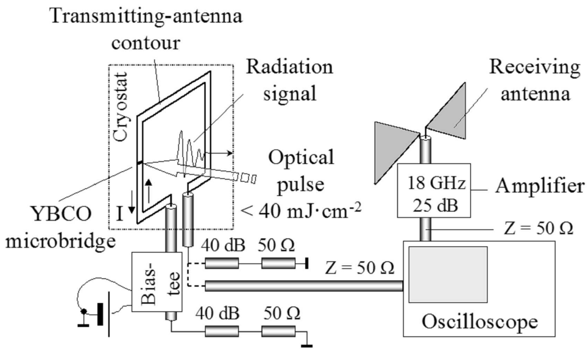

Fig. 1. The approach of PR driven transmitting-antenna radiation and scheme of the oscilloscope coupling (dashed-lines) for PR waveform measurements.

The dc-biased microbridge was illuminated with 100 fs wide, 810 nm wavelength and 1 kHz repetition rate FOPs from optical amplifier, pumped by a Ti:sapphire oscillator. The PR, propagating along antenna contour, resulted in a fast change of its magnetic field momentum and the generation of an electromagnetic radiation burst in the S- & C-frequency-band, with the maximum in the Fourier spectrum at 3.82 GHz. FFT amplitude of the radiation depended on laser fluence, bridge bias, and temperature. After being received by a bow-tie antenna (Fig. 1) the amplified signal was recorded with a 50 GHz sampling-oscilloscope, synchronized with our laser system. In addition, the PR waveforms were recorded with the sampling oscilloscope, coupled to the transmitting-antenna (see Fig. 1).

3. Results and discussion

Light absorption by the YBCO film at $T < T_c$, created highly energetic quasiparticles, whose ultrafast thermalization developed a hot spot in the superconductor and, depending on laser fluence and biasing conditions, a transition of the superconductor into resistive/normal state [1–4]. Suppression of superconductivity in the hot spot affected the amplitude and risetime of the photokinetic PR component, which appeared with no delay in respect to the FOP. The bolometric PR component, exhibited a few nanoseconds initial delay with respect to the FOP [2, 4], the nanosecond risetime, and amplitude, after a linear rise saturated at 16 mJ cm^{-2} when the laser fluence increased (see the inset to Fig. 2).

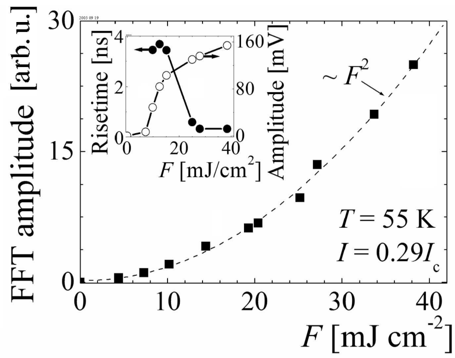

Fig. 2. Fourier amplitude of the 3.82 GHz component radiation by antenna, excited with PR from a dc-biased YBCO microbridge at $T = 55$ K vs. laser fluence. The inset shows the amplitude and risetime of PR vs. laser fluence measured at $T = 40$ K.

In contrast to PR waveform behaviour, the Fourier amplitude of 3.82 GHz component free-space radiation at $T = 55$ K exhibited a quadratic rise (see Fig. 2) in the same range of laser fluences, showing no evidence of saturation at $I_{\mathrm{bias}} = 0.29 I_c$. Assuming that the radiation power increases with an increase in PR amplitude and decreases in risetime [5], we conclude that the antenna radiation was excited by superposed photokinetic and bolometric PR components [2, 4].

The absorption of the high fluence illumination increased the temperature of our microbridge well above T_c and affected a decrease in repetition rate (calcu-

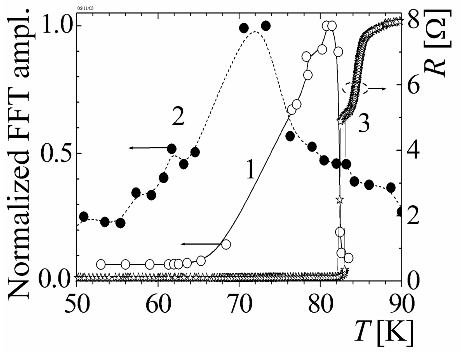

Fig. 3. Normalized Fourier amplitude of a 3.82 GHz component radiation (left axis) vs. temperature dependence. The radiation was excited with PR from a 100 mA biased YBCO microbridge, triggered with a 1 — 5.8 and 2 — 40 mJ·cm^{-2}/pulse laser fluence. Curve 3 shows $R(T)$ dependence (right axis) of this microbridge, biased with $I = 100$ mA.

lated from a full-width-at-half-maximum of the PR waveform) of our transmitting--antenna from 160 MHz to 20 MHz at a laser fluence of 40 mJ cm^{-2}/pulse (not shown in the figure). We assume that Joule heating is responsible for a 9.2 K shift (see Fig. 3) of the FFT amplitude's maximum of 3.82 GHz component radiation, excited by PR from the YBCO microbridge triggered with the 40 mJ cm^{-2}/pulse fluence. Following simple estimations of light absorption we can conclude that 2×10^{12} photons (40 mJ cm^{-2}/pulse) can penetrate the whole optically-thick YBCO microbridge and within a time of the FOP duration should suppress superconductivity in the volume of the film. However, a shift of FFT amplitude maximum confirms that the photokinetic PR component drives free-space antenna radiation. Thus we assume that the spectrum of the S- & C-band antenna radiation, excited by PR from YBCO film triggered with high fluence FOP depends on modulation of the kinetic inductance in the optically-thick film rather than on light induced direct breaking of Cooper pairs or film heating by FOP.

To generate the highest amplitude and the fastest risetime PR, the thickness of our photoswitch has to be decreased below the optical absorption depth ($\leq$ 40 nm) in the YBCO material. However, the technology of high quality thin films is still a problem. Therefore, to minimise heating while triggering with high fluence FOP, we are suggesting to shine simultaneously the top and bottom of the YBCO microbridge (see Fig. 4). When the optical axis of the incident light was tilted (5–10 degrees) in respect to the normal of the bridge, some part of the illumination was reflected from the bottom of the silver covered MgO and shined the bottom side of the film. For a 100 μm laser spot (i.e. equal to double the width of the YBCO bridge) we obtained that the PR amplitude increased almost one order of magnitude, when sample was illuminated on both sides with the same FOP.

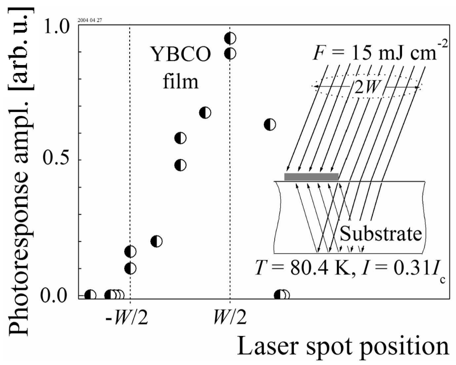

Fig. 4. PR amplitude vs. laser spot (Ø100 μm) position on the surface of a 50 μm wide YBCO microbridge.

In conclusion, the spectra of the S- & C-band antenna radiation, excited with PR from a high fluence FOP triggered YBCO film, depends on modulation of kinetic inductance and thermalization of photocarriers in the film.

Acknowledgment

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