$YBa_2Cu_3O_{7-\delta}$ high-speed detectors for picosecond THz pulses

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***Abstract*—High-speed $YBa_2Cu_3O_{7-d}$ detectors were developed to monitor terahertz picosecond pulses in the time domain. High-T_C superconducting thin-film $YBa_2Cu_3O_{7-\delta}$ microbridges with critical temperatures of $T_C = 85$ K were embedded into a planar log-spiral antenna to couple the broadband terahertz radiation (0.1 – 2 THz). The $YBa_2Cu_3O_{7-\delta}$ detectors were installed in a liquid nitrogen cryostat equipped with 18 GHz effective bandwidth readout electronics. THz pulses generated at the electron storage ring UVSOR-II have been resolved with a temporal resolution of 30 ps (full width at half maximum) limited by the readout electronics bandwidth.**

***Index Terms*—High-temperature superconductor $YBa_2Cu_3O_{7-\delta}$, thin-film THz detectors, picosecond THz pulses, coherent synchrotron radiation.**

Manuscript received June 19, 2012. This work was funded by the German Federal Ministry of Education and Research (Grant No.05K2010).

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I. Introduction

In recent years the generation of ultra-short and high-power THz pulses made significant progress. In electron storage rings the emission of broadband coherent synchrotron radiation (CSR) by accelerated electrons deflected by bending magnets is used to generate picosecond THz pulses [1], [2]. However, to optimize the generation of CSR THz radiation, a detailed understanding of accelerator physics e.g. beam dynamic effects is required. For the analysis of the emitted ultra-short pulses very fast detectors with a time resolution in the single picosecond range are required.

Standard detector technologies currently in use at electron storage rings are e.g. InSb bolometers [3] or Schottky diodes [4]. However, with response times in the microsecond range InSb bolometers [3] are lacking of speed. Whereas Schottky diodes can reach response times in the picosecond range, these devices show small responsivity values and are non-linear resulting in a small dynamic range [5].

The high-temperature superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO) is a promising candidate for ultra-fast detectors. Electron energy relaxation times of only a few picoseconds were measured by electro-optical sampling in the optical frequency range which can be explained by a very strong electron-phonon coupling in YBCO thin films [6], [7].

We have developed a fabrication process for thin-film YBCO THz detectors and demonstrated a dynamic range of more than 30 dB for our YBCO microbridges [8].

In this paper we describe a high-speed YBCO direct detection system with broadband high-frequency readout with an effective bandwidth of 18 GHz (Section II). Direct measurements in the time domain revealed a system temporal resolution of 30 ps (FWHM) which was limited by the bandwidth of the oscilloscopes. Results on the detection of pulsed CSR THz radiation emitted by the electron storage ring UVSOR-II in Japan are discussed in Section III.

II. YBCO Detection System

The YBCO thin film detector chip (3 mm x 3 mm) was mounted to the rear side of a silicon lens. The lens was

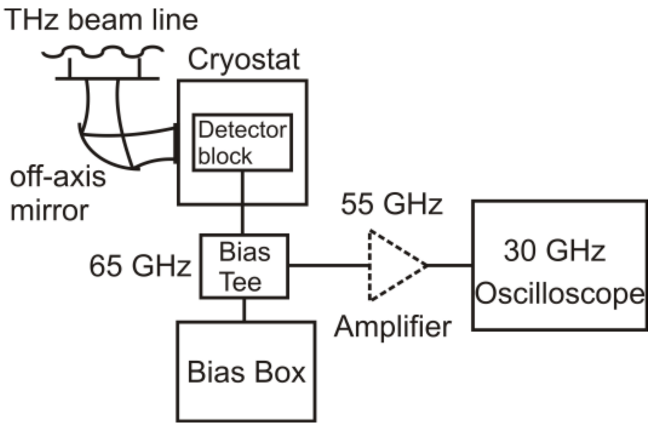

Fig. 1. Scheme of the experimental setup of the direct YBCO detection system to monitor picosecond THz pulses in the time domain. The room temperature amplifier is optional.

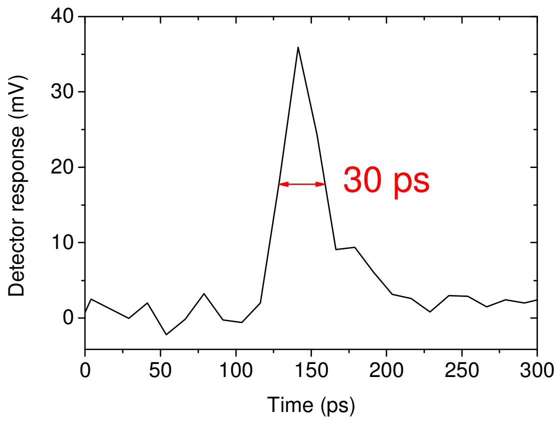

Fig. 2. Laser induced CSR pulse measured with the YBCO detection system at UVSOR-II. The full width at half maximum of 30 ps was limited by the bandwidth of the readout electronics.

embedded in a copper detector block to ensure good thermal coupling to the cryostat cold plate. The critical superconducting temperature of the fabricated detector ($T_C \approx 85$ K) allows us to integrate the detector into a liquid nitrogen bath cryostat. The detector block including bonds, readout lines and connectors was simulated with CST Microwave Studio® and revealed a -3 dB roll-off frequency of 30 GHz. The focused synchrotron THz radiation entered the cryostat through a polyethylene window.

The detector block was connected by a 65 GHz broadband semi-rigid cable to the room-temperature bias-tee (50 kHz – 65 GHz). If required, a room-temperature amplifier (200 kHz – 55 GHz) was used before reading out the detector signal in the time domain via a real-time oscilloscope. For our measurements discussed in Section III a 30 GHz LeCroy (LabMaster 9 Zi-A) real-time oscilloscope was used. The scheme of the complete experimental setup is displayed in Fig. 1.

The effective readout bandwidth for our detection system can be calculated according to [10] as

$$f_{eff} = \left[\sum_i f_i^{-2} \right]^{-1/2}, \quad (1)$$

where f_i are the electronic bandwidths of the single components. For our detection system including the room-temperature amplifier the effective bandwidth amounts to $f_{eff} \approx 18$ GHz which corresponds to a time resolution of ≈ 20 ps (full width at half maximum (FWHM)). Due to dispersion and reflections along the readout chain a slightly larger time constant is expected.

III. Measurements

UVSOR-II, the electron storage ring of the Institute for Molecular Science in Okazaki, Japan, is operated in the beam energy range between 600 and 750 MeV. The radio frequency and the revolution frequency of the ring are 90.1 and 5.6 MHz, respectively. At UVSOR-II, CSR is emitted not only from short bunches but also from electron bunches with longitudinal microstructure of radiation wavelength scale. Laser bunch slicing is a technique for creating sub-millimeter dip structure on electron bunches using femtosecond laser pulses [11], [12].

In Fig. 2 a single shot of the detector response to CSR pulses generated by laser slicing at a laser modulation frequency of 0.15 THz is displayed. The 7 ps wide THz pulses (FWHM) resulted in pulses on the oscilloscope of 30 ps which was the limit of the readout electronics. These very fast detector responses are explained in the framework of the vortex flow model which was recently presented by the authors [9].

IV. Conclusion

We have developed ultrafast YBCO detectors for picosecond THz pulses which are operated at liquid nitrogen temperatures. The single THz pulses from UVSOR-II were detected with a temporal resolution of 30 ps (FWHM) allowing for the study of beam dynamic effects.

Acknowledgment

Many thanks go to LeCroy for borrowing the real-time broadband oscilloscopes. The authors are also very grateful to the technical staff at UVSOR who made these measurements possible.

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