THz Radiation from High-Tc Superconducting Materials and Its Applications

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ABSTRACT

Electromagnetic pulses with a time width of less that 0.5 ps are emitted from high-Tc superconductors (HTSC's) by exciting with ultrashort optical pulses. The radiation is observed under various states, i.e., current biased, magnetic field applied, and magnetic flux trapped states. The radiation mechanism is ascribed to the ultrafast modulation of the supercurrent, which is brought about by the optical Cooper pair breaking. This new phenomenon is applied to noncontact supercurrent imaging and an optical flux trap memory.

INTRODUCTION

It is well known that terahertz (THz) radiation is emitted from semiconductor photoconductive switches by exciting with ultrashort optical pulses. In these switches, the transient current generated by the short optical pulses is the origin of the THz radiation following the classical Maxwell equations. About five years ago, we proposed and demonstrated the THz radiation by modulating the supercurrent with ultrashort optical pulses (Hangyo et al., 1996; Tanouchi et al., 1996). Later, we also found interesting THz radiation phenomena associated with magnetic fields (Tanouchi et al., 1997a). The radiation intensity is enhanced by improving the antenna structures of radiation devices and it exceeds 10 μW at present. Further, we proposed a method of visualizing two-dimensional current flow in superconducting thin films by scanning a focused laser beam on the sample with detecting the THz radiation amplitude (Shikii et al., 1999). We also proposed a new superconducting optical flux trap memory using the THz radiation (Tanouchi et al., 1997b). In this paper, we summarize the characteristics of the THz radiation from HTSC's and related applications including recent results.

CHARACTERISTICS OF THZ RADIATION FROM HTSC'S

The basic idea of THz radiation from superconductors is as follows. Under a bias current, the supercarrier is running with a constant velocity without scattering by phonons and impurities. The supercarriers are converted to the normal carriers instantaneously by the femtosecond laser excitation, and they undergo scattering and stop with a characteristic time constant of ~ 100 fs. This corresponds to the transient decrease of the supercurrent and becomes a source of the radiation following the classical electrodynamics. This is illustrated schematically in Fig. 1.

We fabricated THz radiation devices using 100-nm thick c-axis oriented $YBa_2Cu_3O_{7-\delta}$ (YBCO) films on an MgO substrate by conventional photolithography and chemical etching. The devices are cooled down to 10 ~ 15 K on a cold finger of a closed-cycle He cryostat. Fig. 2 shows the schematic diagram of a THz radiation and detection system. Optical pulses with a time width of 50 ~ 80 fs, a repetition rate of 82 MHz, and a wavelength of ~ 800 nm delivered from a mode-locked Ti:sapphire laser are

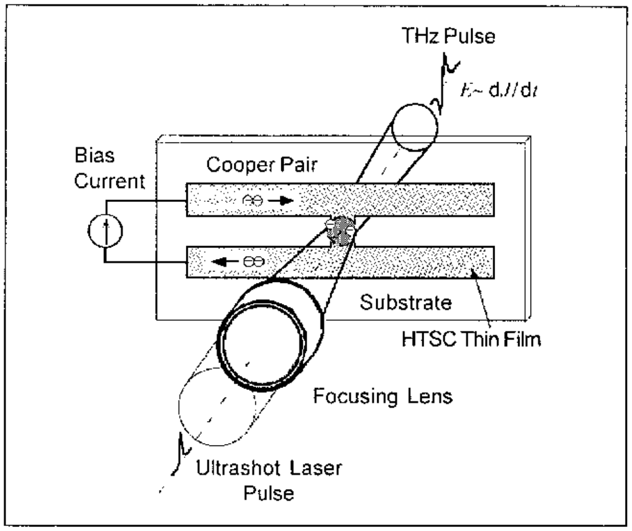

Fig. 1. Schematic illustration of THz radiation from a HTSC device

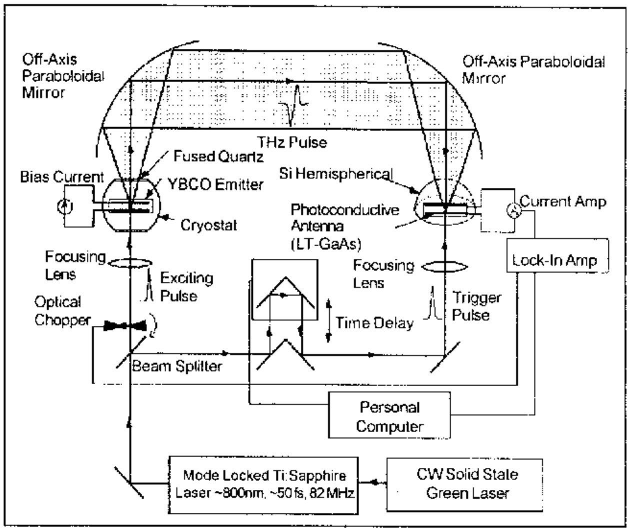

Fig. 2. Schematic diagram of the THz radiation and detection system

focused on the bridge of the radiation device. The THz radiation emitted into free space through the MgO substrate is collected and focused by a pair of paraboloidal mirrors into a detector. The detector is a photoconductive antenna made of a Ni/Ge/Au alloy electrode on a low-temperature grown GaAs thin film and triggered by laser pulses divided from the exciting laser pulses.

Fig. 3a shows the waveforms of the radiation emitted from a dipole antenna type device under various bias currents (Hangyo et al., 1996). The waveform is almost single cycle and its polarity is changed by reversing the bias current. No radiation is observed without a bias current. Fig. 3b shows the Fourier spectrum of the waveform, which extends from 0.05 to 2 THz. The radiation waveform and amplitude are significantly affected by the antenna structure of the device. The radiation power from the log-periodic antenna type device is about two orders of magnitude stronger than that from the dipole antenna type device when the exciting laser power and the bias current are the same.

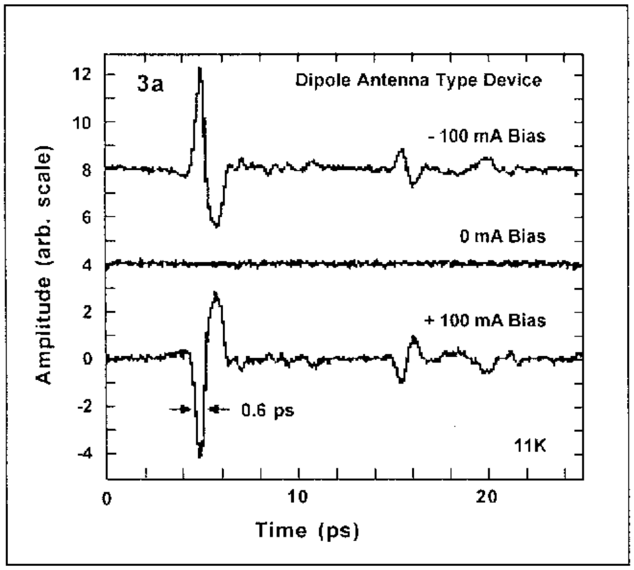

Fig. 3a. Waveform of the THz radiation

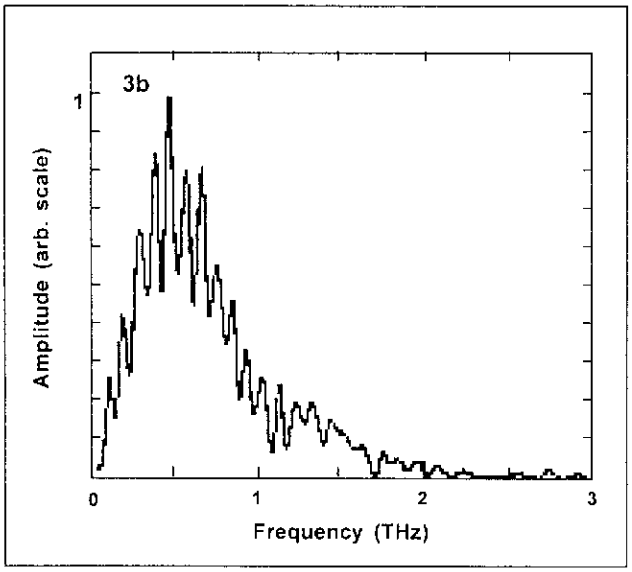

Fig. 3b. Waveform of the Fourier spectrum

The radiation power from the former device has reached ~ 10 μW under the exciting power of 100 mW and the bias current of 100 mA (Saijo et al., 1999).

The THz radiation has been observed even without the bias current when external magnetic fields are applied. Further, the THz radiation has been observed after removing the external magnetic fields (Tonouchi et al., 1997b). These phenomena are ascribed to the optical modulation of the persistent current associated with the magnetic flux trapped in the films.

APPLICATION OF THZ RADIATION PHENOMENA

We have proposed two applications of the THz radiation from HTSC's. One is the visualization of the supercurrent flow in HTSC thin films and the other is the superconducting optical flux trap memory.

Since the THz radiation amplitude is proportional to the current density at the laser spot, we can obtain the supercurrent density distribution by measuring the THz radiation amplitude with scanning the focused laser spot on the HTSC films. Fig. 4a shows the distribution of the THz radiation amplitude, which corresponds to the supercurrent density, in the bow-tie antenna type device (Shikii et al., 1999). An MgO hemispherical lens is attached to the backside of the MgO substrate to enhance the collection efficiency of the radiation. It is seen that the supercurrent flows mainly near the edge of the bridge. This is seen more clearly in the cross-sectional distribution in Fig. 4b. This method of visualizing the supercurrent has been extended to include the current direction by measuring the polarization of the radiation (Morikawa et al., 1999).

The magnetic flux trapped in the films can be controlled by optical pulses. We proposed and demonstrated that the magnetic flux trapped in a hole within a YBCO film can be controlled by optical pulses and the persistent current associated with this magnetic flux is read out by the THz radiation excited by optical pulses. This is a very unique optical flux trap memory (Tonouchi et al., 1998).

SUMMARY

Basic characteristics of the THz radiation from the HTSC films excited with femtosecond laser pulses are described. The radiation intensity has reached ~ 10 μW with 100 mW excitation for the log-periodic antenna type device. The supercurrent distribution in YBCO thin film devices is visualized by using the THz radiation effect. A novel superconducting optical flux trap memory using the THz radiation effect is proposed.

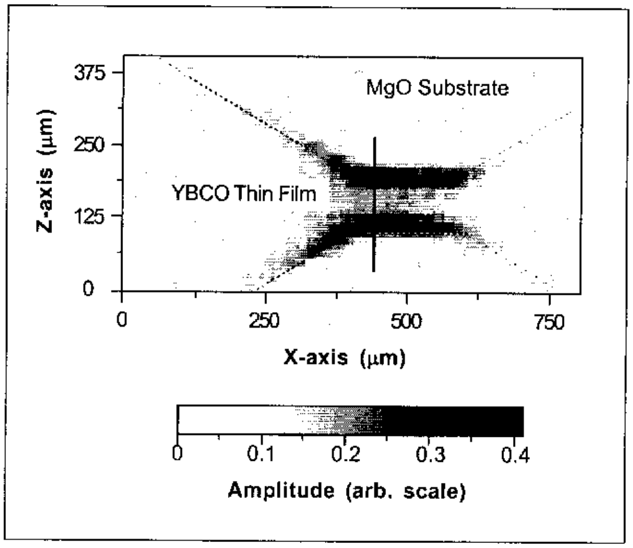

Fig. 4a. Distribution of the radiation amplitude in the bow-tie antenna type device

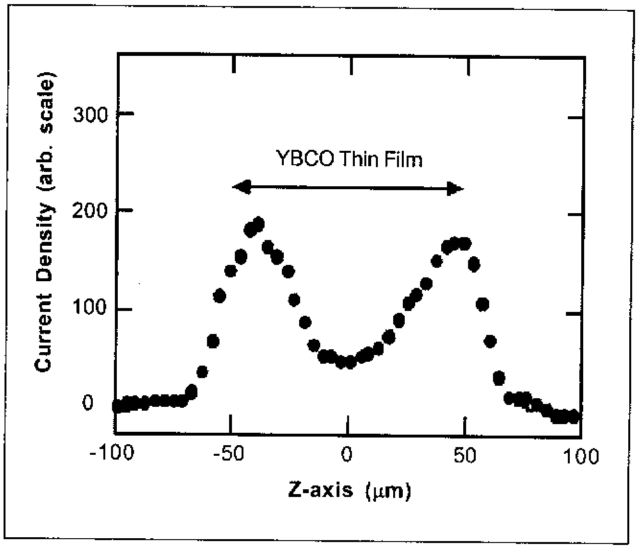

Fig. 4b. The cross-sectional distribution along the A-B line

HTSC's open a new field "superconductor photonics" which combines the superconductive electronics and optoelectronics.

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