Fiber-connected terahertz time-domain spectroscopy system

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***Abstract*—A flexible terahertz (THz)-time domain spectroscopy (TDS) system has been fabricated by using air guided photonic crystal fibers for 1.56 μm laser and a DAST crystal as an emitter. Using this system we could obtain reliable refractive index value *n* of Si in the frequency ranges from 0.2-2.8 THz.**

I. Introduction And Background

TERAHERTZ time-domain spectroscopy (THz-TDS) is a useful spectroscopic technique to probe the properties of various kinds of materials from biological & chemical to industrial materials, because THz wave is transparent to many materials and safe for biological tissues.[1] To expand the application of THz-TDS and utilize it more flexibly at a various conditions, such as in vacuum, at low temperature, in the condition of particular gas, etc., it is important to construct a more flexible system.[2-4]

In the present study, we fabricated a fiber-connected THz-TDS system in which the THz optics and the femtosecond laser source part are connected with optical fibers and evaluated the spectroscopic performance.

II. Experimental Setup

Figure 1 shows a schematic illustration of fabricated system. In this system the THz optics is set up on a breadboard independently of the optics for femtosecond pulsed laser source [TOPTICA FFS.SYS.HP: maximum power 350 mW, pulse width 110 fs, repetition rate 80 MHz]. In the laser source part, 1.56 μm femtosecond pulsed laser is divided into two laser beams for pump and trigger pulses. After being modulated at 2 kHz by using an optical chopper, the pump pulses enter an air guided photonic crystal fiber with a 10.9 μm-air core [Newport: F-AIR-11/1550] through a precision fiber coupler and come out from the fiber through a GRIN lens fiber coupler set on a breadboard. The trigger pulses are also introduced to the THz optics in the same way after passing a time-delay stage.

On the breadboard, the trigger pulse beam is collimated by using a GRIN rod lens, and then focused onto a PPLN crystal in which its wavelength is converted to 780 nm to effectively excite photo-carriers in photoconductive switch. Here, a low temperature grown (LT)-GaAs photoconductive switch of bowtie antenna type was used as a detector. The maximum power conversion efficiency of the PPLN is about 30 %.

On the other hand, the pump pulse beam is also focused onto a high quality DAST (4-demethylamino-N-methyl-4-stilbazolium Tosylate) crystal as a THz emitter. Then the radiated THz pulses are collimated and focused onto the detector by using a set of off-axis parabolic mirrors.

Using this system we carried out THz-TDS measurements on Si wafer, and compared the data with those obtained by a non-fiber THz-TDS system.

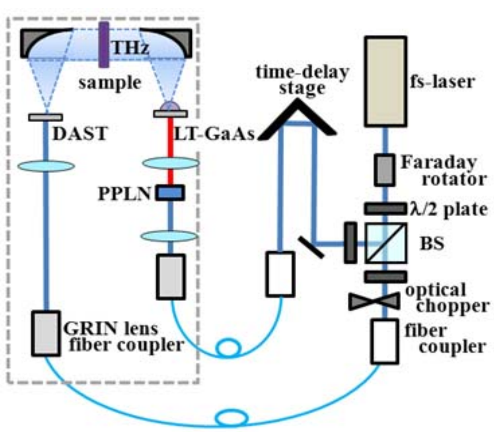

Fig.1 A schematic illustration of fabricated fiber-connected THz-TDS system. Dashed box indicates a breadboard.

III. Experimental Results

Figures 2a and 2b show the time-domain terahertz waveforms observed by using a non-fiber and a fiber-connected TDS system, respectively. It can be seen that the THz signal amplitude for the fiber-connected system is reduced down to ~12 % of that for the non-fiber system. There are several matters causing the signal reduction, as follows. Using the optical fiber, the efficiency of output laser power to the focused laser beam at the inlet of the fiber is 50-60 %. Furthermore,

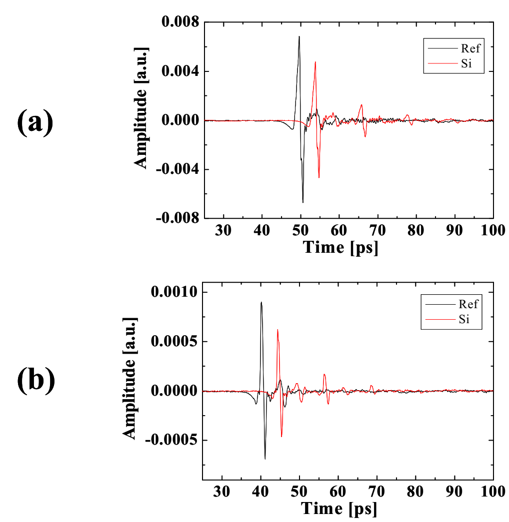

Fig.2 Time-domain terahertz waveforms observed by (a) a non-fiber THz-TDS system and (b) a fiber-connected THz-TDS system, respectively. Red lines show the THz-pulses transmitted through a Si wafer.

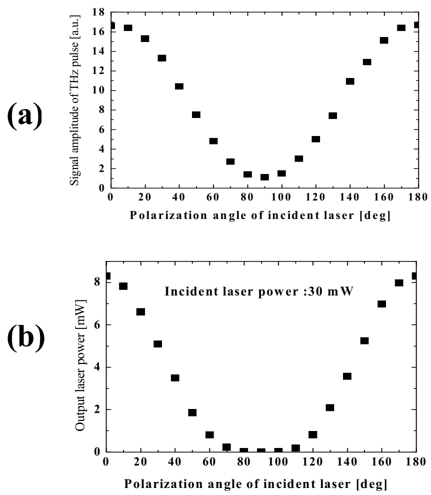

Fig.2 Dependence of (a) signal amplitude of THz pulse and (b) output laser power (λ=780nm) on polarization angle of incident laser (λ=1.56μm).

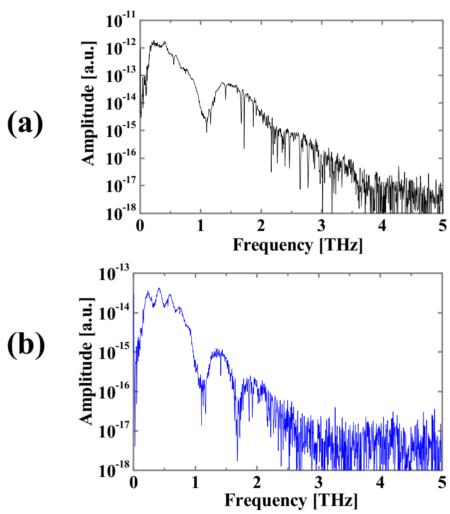

Fig.3 FFT spectrum of THz pulse transmitted through Si wafer obtained by (a) a non-fiber THz-TDS system and (b) a fiber-connected THz-TDS system.

linearly-polarized laser at the inlet is converted to elliptically-polarized one (elliptical polarization ratio 2:1) after passing through the optical fiber. Particularly, since the THz radiation efficiency of DAST crystal and wavelength conversion efficiency of PPLN crystal depend a great deal upon the polarization of incident light [see Figs. 2a & 2b], the conversion to the elliptical polarization caused serious reduction of the signal amplitude.

On the other hand, Figures 3a and 3b show the Fast Fourier Transform (FFT) spectrum of THz pulse transmitted through the Si sample for both the systems. These FFT spectra show that the bandwidth of THz radiation for the fiber-system is about 3 THz which is narrower than 4THz for the non-fiber system. This is probably due to dispersion of femtosecond pulsed laser in the optical fiber.

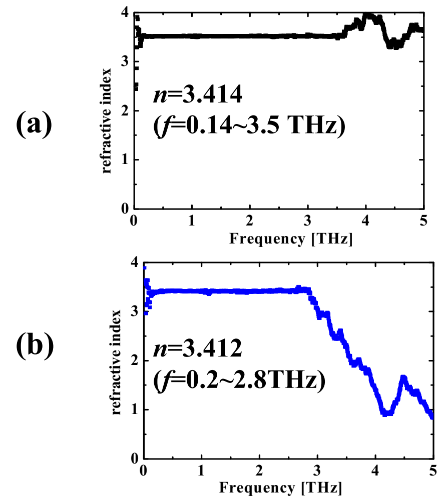

Fig.4 FFT spectrum of THz pulse transmitted through Si wafer and the refractive index *n* obtained by (a) a non-fiber THz-TDS system and (b) a fiber-connected THz-TDS system. Reliable *n* value was obtained in the frequency ranges from 0.2 to 2.8 THz by using the fiber-connected system.

Using the obtained FFT spectra, refractive index *n* of Si was calculated, as shown in Figs. 4a and 4b. It is found from the data that high-precision optical parameters of Si can be obtained from 0.2 to 2.8THz by using the fabricated fiber-system.

IV. Conclusions

A fiber-connected THz-TDS system has been fabricated. Using this system we could obtain high-precision optical parameters of Si up to 2.8 THz.

▪ ACKNOWLEDGMENTS

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