High-Speed Frequency-Domain Terahertz Coherence Tomography

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***Abstract*—High-speed frequency-domain terahertz (THz) coherence tomography is demonstrated using frequency sweeping of continuous-wave THz radiation and beam steering. THz frequency sweeping with a kHz sweep rate and a THz sweep range is implemented using THz photomixing in which an optical beat source consists of a wavelength-swept laser and a distributed feedback laser diode. During the frequency sweep, frequency-domain THz interferograms are measured using the coherent homodyne detection employing signal averaging for noise reduction, which are used as axial scan data via fast Fourier transform. Axial scan data for 100×100 points can be acquired in 100 s while scanning a transverse range of 100×100 mm^2 using a THz beam scanner comprised of a two-dimensional galvanometer scanner and a telecentric f-θ lens.**

I. INTRODUCTION

FREQUENCY sweeping of continuous-wave (CW) terahertz (THz) radiation is combined with beam steering to demonstrate fast THz tomography. Beam steering enhances the speed of transverse scanning, and high-speed broadband THz frequency sweeping is used for fast axial scanning, which is performed using the photomixing method employing a wavelength-swept laser (WSL) and a distributed feedback laser diode (DFB-LD). We show a THz three-dimensional (3D) tomographic image of a glass fiber reinforced polymer (GFRP) sample with artificial internal defects, acquired using this tomography technique.

II. RESULTS

Our frequency-domain THz coherence tomography system using a high-speed broadband frequency sweep of CW THz radiation is illustrated in Fig. 1. To achieve the high-speed broadband THz frequency sweep, we use a beat-frequency-swept optical beat source with a kHz sweep rate in THz photomixing[1]. The optical beat source consists of a DFB-LD and a WSL based on a semiconductor optical amplifier and a fiber Fabry-Perot tunable filter. The DFB-LD is operated at a fixed wavelength of 1545 nm, and the output wavelength of the WSL is swept from 1544 to 1558 nm at 1 kHz sweep rate. Frequency-domain THz signals are measured in the frequency range up to 1.5 THz. The optical output of the WSL is amplified by an optical fiber amplifier and then combined with that of DFB-LD through 3-dB fiber coupler. One of the two output arms of the coupler is connected to a THz CW transmitter module (TOPTICA Photonics) and the other is connected to a THz CW receiver module (TOPTICA Photonics) through variable optical delay line. All the optical components are connected using polarization maintaining (PM) fibers without the need to control the optical polarization.

CW THz radiation emitted by the transmitter passes through a silicon beam splitter and is then steered with an optical angle θ of -20° ~ +20° along both the X and Y directions by a two-dimensional (2D) galvanometer scanner. Regardless of the optical angle, the THz wave is normally incident on a sample placed on the focal plane through a telecentric f-θ Teflon lens[2]. The reflected THz wave from the sample propagates back to the beam splitter along its original path. The THz wave reflected by the beam splitter is detected by the receiver and a photocurrent generated from the receiver is amplified using a current preamplifier with a bandwidth of 220 kHz and a gain of 1×10^7 V/A.

A digital delay/pulse generator triggered by a wavelength trigger signal at 1545 nm produces a 1 kHz TTL signal. Frequency-domain data are consecutively acquired at 1 kHz from the preamplifier by a digitizer with a sampling rate of 3 MS/s triggered by the TTL signal. At the same time, the TTL signal triggers a waveform generator to provide the transmitter with a bias voltage modulated at half the sweep rate. The signal to noise ratio of the THz data can be enhanced by subtracting the noise traces acquired with the bias off from THz data traces carrying noise acquired with the bias on and averaging the resultant THz data traces. Also, the galvanometer scanner is driven by a waveform generator triggered by the TTL signal. The fast Fourier transform results of the frequency-domain THz data are used as axial scan data. The total scan time depends on the number of points in a transverse range and the number of averaged traces for each axial scan data. For example, it takes 100 s for 100 × 100 points with the number of averaged traces of 5 and 4,000 s for 200 × 200 points with the number of averaged traces of 50.

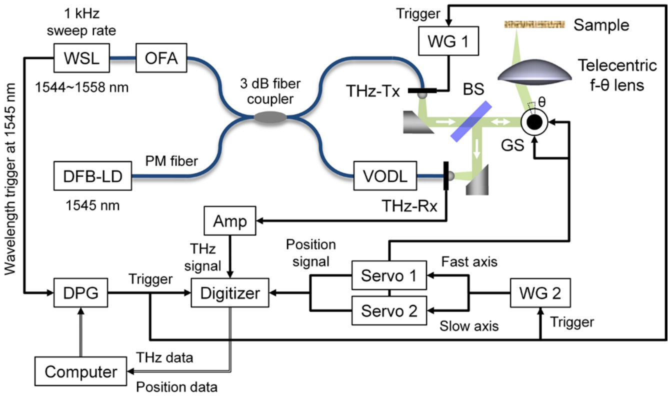

Fig. 1. Schematic diagram of our high-speed frequency-domain THz coherence tomography system. WSL: wavelength-swept laser, OFA: polarization-maintaining optical fiber amplifier, DFB-LD: distributed feedback laser diode, PM fiber: polarization-maintaining fiber, THz-Tx: THz CW transmitter, WG: waveform generator, VODL: variable optical delay line, THz-Rx: THz CW receiver, BS: silicon beam splitter, GS: 2D galvanometer scanner, DPG: digital delay/pulse generator, Amp: current preamplifier.

Figure 2(a) shows the schematic design for the GFRP sample with internal defects[2]. The sample has a dimension of 100 × 100 × 3 mm^3, and delaminations of 0.2 mm thickness are located at depths of 1 mm and 2 mm below the front surface. Teflon pieces of 0.025 mm thickness lie 1.5 mm beneath the front surface. The 3D tomographic image of the GFRP sample acquired in 100 s using the tomography system is displayed in Fig. 2(b).

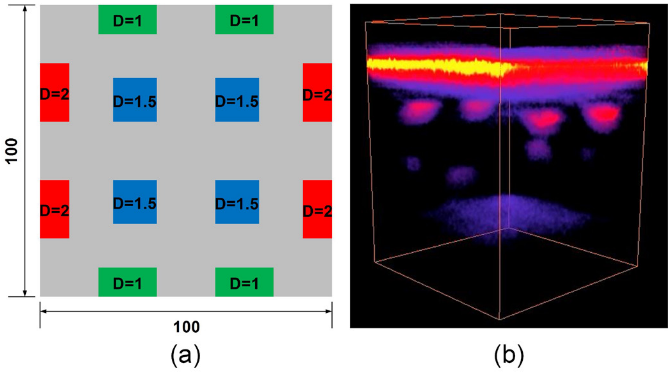

Fig. 2. (a) Schematic design for the GFRP sample. The blue squares represent Teflon inclusions and the green and red rectangles represent delaminations. The depths at which the defects lie are indicated in the design. The numbers are presented in millimeters. (b) 3D tomographic image of the GFRP sample.

REFERENCES

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