THz False-color Imaging with Flexible Tube-lattice Fiber Probe

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Abstract— A flexible tube-lattice fiber is introduced into a THz-TDS system to implement a THz false-color imaging system. The fiber, which has three low-loss transmission windows in the frequency range of 0.1–1 THz, can lead THz radiation out of the system and lead back to the detector. It can be used as a probe to break the spatial limit of the THz-TDS system and widen the range of applications. A cuvette filled with two different kinds of white powder was used as a sample in the experiment. One end of the fiber was fixed and the other end near the sample was scanned by a 2D translation stage across the sample. THz radiation from the fiber passes through the sample and is reflected by amirror at the back of the cuvette. The reflected THz radiation contains the sample's THz spectral information. Thus, the entire sample can be investigated by scanning the fiber. Three-primary colors (red, green and blue) are defined by spectral intensities of the fiber transmission windows. A 13×16 pixels false-color image was generated with the mix of values of the primary colors. In the false-color image,the two kinds of powder, the cuvette and the background present different colors and saturation which indicate different materials and the concentration, respectively. The resolution was also investigated by scanning slits in a metal sheet. The resolution of the imaging system is approximately 1 mm.

1. INTRODUCTION

Terahertz (THz) radiation can be transmitted through a wide variety of substances such as paper, cloth, plastics, wood, bone, fat, various powders, dried food, and so on [1]. THz radiation interacts with macromolecular materials, such as drugs, explosives, medicines and proteins [2, 3], allowing them to be identified through their unique fingerprint information, including absorption frequencies, amplitude and phase [4]. As such, THz imaging has great potential in security, forensic and medical applications. THz imaging is usually based on large THz time-domain spectroscopy (THz-TDS) systems, which is not suitable to move. The samples must be placed in the system, which is a limit for its applications. We demonstrate a low-loss flexible THz fiber [5] which can lead the THz radiation out and back to THz-TDS system to break the spatial limit. A false-color image has been generated to present frequency information in the THz domain.

2. LOW-LOSS FLEXIBLE TUBE-LATTICE FIBER

The structure of the low-loss flexible tube-lattice fiber is shown in Fig. 1. It has a hollow core with the diameter of 4 mm and a cladding composed of eight Zeonex tubes in a ring. The sample fiber length is 20 cm. The out diameter and thickness of cladding tubes are 2.4 mm and 0.378 mm, respectively. The cladding tubes are held in place by three short jackets at either end and in the center of the fiber. The outside is shrink tube which was used to enhance mechanical stability. Zeonex was used for its low absorption loss in the THz range [6]. Since the cladding tubes are not fused together and are free to slide against each other, the fiber is easy to bend.

Due to inhibited coupling, the energy can couple into cladding to cause high loss at only a few discrete frequencies, resulting in transmission windows for frequencies in between. A THz-TDS system (Fig. 3(a)) was used to measure the transmission spectrum of the fiber. The THz radiation passes through the fiber two times and couples back to the detector. The experimental result in Fig. 2 shows three transmission windows in the range of 0.1–1 THz, which are 0.1–0.35 THz, 0.35–0.7 THz and 0.7–1.0 THz.

3. FALSE-COLOR IMAGING SYSTEM

To visualize the THz image, the fake-color system was implemented with the integrated transmission over 0.23–0.32 THz corresponding to red, 0.45–0.65 THz to green, and 0.75–0.9 THz to blue, which are shown as color boxes on Fig. 2, and correspond the fiber's three transmission windows. Different materials have different absorption frequencies, and they will affect the integration value of each window, and hence the final color for the pixel of an image.

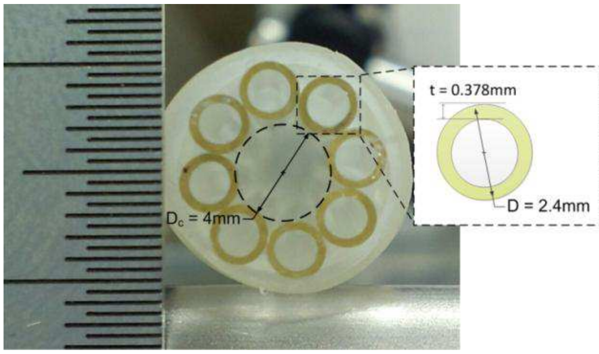

Figure 1: Fiber structure and structure parameters.

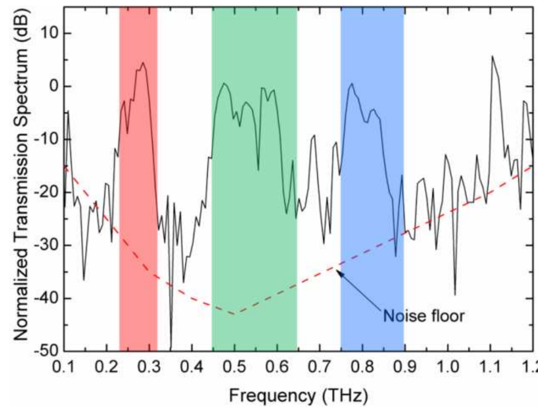

Figure 2: Normalized transmission spectrum.

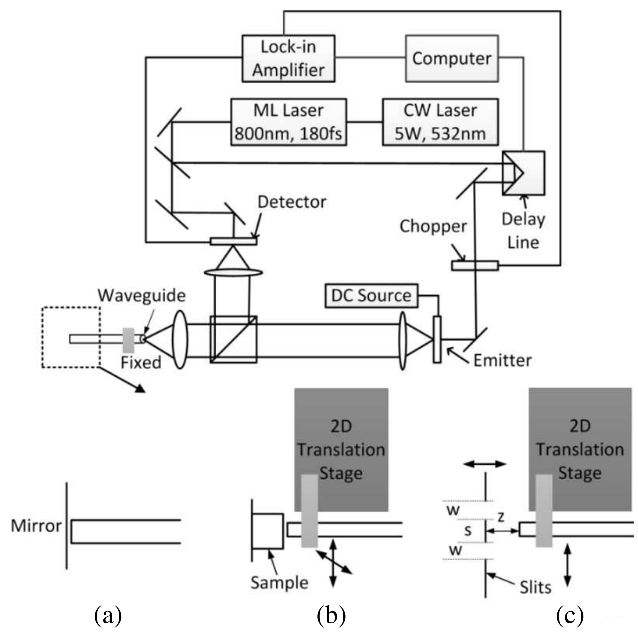

Figure 3: Experimental setups of THz-TDS. (a) is used to measure the fiber transmission spectrum, (b) is use to get the THz image of the sample, (c) is used to check the resolution of the imaging system.

A cuvette filled with two kinds of white powder, α-Lactose and 4-Aminobenzoic acid (PABA), was used. α-Lactose has one absorption frequency at 0.53 THz which is located in the second transmission window, and PABA has two absorption frequencies at 0.6 and 0.8 THz which are located in the second and third transmission windows.

The false-color imaging system is based on a THz-TDS system. One end of the flexible tube lattice fiber is fixed and the other end near the sample is scanned by a 2D translation stage (Fig. 3(b)). A 13×16 pixels image which is shown in Fig. 4(b), was obtained from the system. Compared to the optical image shown in Fig. 4(a), the background, cuvette, α-Lactose and PABA can been identified clearly due to their different colors and intensities. The α-Lactose absorbs only in the green windows, appearing magenta. PABA absorbs both in the blue and green windows, appearing red.

4. RESOLUTION

In order to explore the resolution of the imaging system, arrangement shown in Fig. 3(c) is used. The end face of the fiber was scanned across a pair of slits in a metal sheet. THz radiation incident on the metal would be reflected and some fraction would couple back into the waveguide for detection, whilst THz radiation passing through the slits would be lost. When two 1 mm slits, separated by 1 mm, are placed 1 mm away from the fiber ($w = s = z = 1$ mm), the two slits could

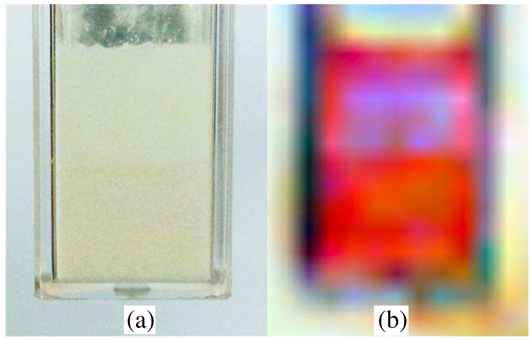

Figure 4: (a) Optical image and (b) THz fake-color image of the sample.

be clearly identified in the THz image, allowing the resolution to be estimated at 1 mm.

5. CONCLUSION

A low-loss, flexible tube lattice fiber was fabricated to have three transmission windows in the frequency range of 0.1–1 THz. The fiber was used to lead the THz radiation to a sample and lead it back to detector in the THz-TDS system. A false-color imaging system was set up with this fiber probe. A cuvette filled with α-Lactose and PABA is used as the imaging sample, and the different chemicals can be easily seen in through the false-color system. The resolution of the imaging system was estimated at 1 mm.

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