Chemical remote and *in situ* sensing based on a flexible terahertz pipe waveguide

Borwen You[1], Ja-Yu Lu[2] and Toshiaki Hattori[1]

[1]Division of Applied Physics, Faculty of Pure and Applied Science, University of Tsukuba, Tennodai 1-1-1, Tsukuba, Ibaraki 305-8573, Japan
[2] Department of Photonics, National Cheng-Kung University, Tainan 70101, Taiwan
E-mail: you.borwen.gt@u.tsukuba.ac.jp

In the presentation, we successfully demonstrate the feasibility of *in situ* and remote chemical detection through the use of a reflective terahertz (THz) fiber-scan imaging system to trace the dynamic generation of a compound during a chemical reaction and concurrently to map out the spatial distribution of the chemical product. The reflective THz fiber-scan system is demonstrated at 0.4 THz emitted from a continuous THz wave source, and a simple Teflon pipe with low THz transmitting and bending loss [1–3] is used as a sensing and image scanning arm. The bending capability of the reflective THz–pipe–scan system is experimentally characterized and proven by identifying a tablet array through its pipe-scanned THz image. The chemical sensing/imaging capability of the system is validated through remote measurement of the reflected THz power from a chemical product, ammonium chloride (NH_4Cl) aerosols, which is dynamically generated by the reaction between hydrochloric acid (HCl) and ammonia (NH_3) vapors. The sensing mechanism and detection sensitivity of the chemical product is also discussed in the presentation.

The configuration of a THz pipe scan system is shown in Fig. 1(a). The system involves two parts: an electrical THz transmitting/receiving unit and a fiber scan unit. The signal from the Gunn oscillator passes through a frequency multiplier and feeds into a horn antenna for continuous-THz wave radiation. The adopted Gunn oscillator module provides THz power at 0.4 THz around 100 μW. The free-running THz waves are collimated and focused into a Teflon pipe fiber by a pair of off-axis parabolic mirrors (50 mm effective focal length). The flexible Teflon pipe has a length of 30 cm, an inner hollow core diameter of 8.5 mm, and a pipe wall thickness of 1 mm. The pipe is mounted on a 2D motional stage as the scanning fiber of the system. A plastic ball lens has a 5 mm-effective focal length and is glued at the output end of the pipe to focus the transmitted THz waves onto the sample surface.

To investigate the bending loss of the Teflon pipe, a gold mirror is assembled with the pipe 5 mm apart from the fiber output end to maintain the normal incidence and the same focused position at various bending angles. By holding the pipe as straight about 6 cm apart from the input end and laterally moving the pipe output end, the measured bending loss of the THz pipe as a function of bending angle and radius can be obtained in Fig. 1(b). The bending loss curves are almost identical in both clockwise and counterclockwise bending directions, and the performance of the bending loss is quite similar to the theoretical result demonstrated in the reference [4]. The bending loss is less than 10% within a +/−5 degree bending angle and can be neglected within a +/−1 degree bending angle, which is much smaller than that of the subwavelength plastic wire [5].

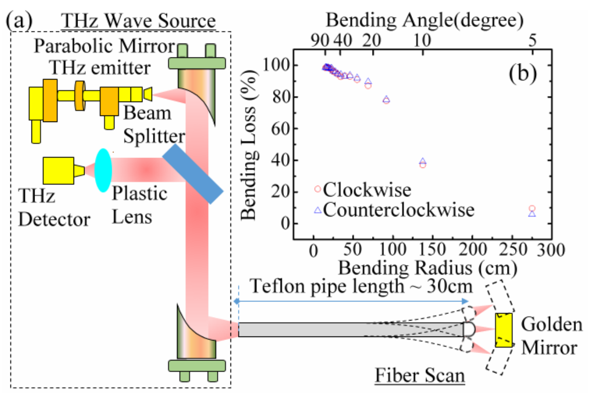

Fig. 1 (a) Optical configuration of a THz pipe scan system. (b) Bending loss performance of a Teflon pipe.

With a tightly focusing terahertz beam spot, the spatial and concentration distributions of the generated chemical product are successfully mapped out by the 1D scan of the flexible pipe probe. In consideration of the responsivity, power stability, and focused spot size of the system, its detection limit for the NH_4Cl aerosol is estimated to be approximately 165 nmol/mm^2. The reliable and compact terahertz pipe scan system is potentially suitable for practical applications, such as biomedical or industrial fiber endoscopy.

References

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