Volatile-organic-compound sensing through a terahertz pipe waveguide

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Remote detection of hazardous gases is important in many applications, such as environmental monitoring, ecology, defense, and antiterrorism. Available gas sensors based on electrical, chemical, and optical sensing methods have been demonstrated. Gas sensors using optical methods, especially fiber waveguide schemes, are relatively safe without temperature control and environmental electromagnetic interference. The fiber waveguide for sensing the gas at remote positions basically follows two functions. One function is as an extrinsic sensor, which simply delivers optical sensing signals for a long distance. The other function, as an intrinsic sensor, monitors the waveguide field, which meets the gas inside a fiber waveguide, from optical signal change to sense the presence of gas. To detect the optical absorption of gas that results from molecular polarity or low-frequency vibration, fiber waveguides that operate in a terahertz (THz) frequency range of 0.1–10 THz are specifically required. In the presentation, a THz waveguide based on a large-core glass pipe is presented as one intrinsic sensor in fiber-waveguide optics for sensing volatile organic compounds (VOCs). Two sensing mechanisms of frequency and intensity interrogation methods are realized using the resonant and anti-resonant waveguide modes, respectively. The measured results shows that the sensing ability of intensity interrogation at anti-resonant frequencies is 23-fold higher than that of frequency interrogation at resonant frequencies. High sensitivity to recognize volatile gases in the density level of low part-per-million (ppm) can be achieved owing to the largest spatial overlap between the sensing field and gas molecules inside the core. Therefore, the feasibility of remotely identifying VOC gases by a THz pipe waveguide is demonstrated from one THz continuous-wave configuration, analysis of waveguide modal field, and sensitivity calibration.

An optical gas-sensing system based on a THz pipe waveguide is illustrated in Fig. 1. The system is constructed by a wave transmitting–receiving (WTR) unit and a waveguide-gas-sensing (WGS) unit. Figure 1(a) schematically plots the components of a WTR unit. A Gunn oscillator module works as the emitter to radiate THz waves. The spectral range of THz waves is 0.316–0.408 THz, and the corresponding frequency resolution is 4 GHz. The zero-bias Schottky diode is used as a THz wave detector. The emitter and detector are electronic devices without any photoexcitation. The WGS unit, as shown in Fig. 1(b), involves a THz waveguide and a sample chamber. The focused THz waves from a parabolic mirror are coupled into a 30 cm-long THz pipe waveguide. THz waves output from the pipe waveguide and then enter a sample chamber. The mechanical assembly between a THz waveguide and a sample chamber in the WGS unit is shown in the inset of Fig. 1(b), which is a photograph of the top-view configuration. In the gas-sensing experiment, a liquid inlet and a gas outlet are machined on the sample chamber to manipulate volatile liquids and their vapor gases. Figure 1(c) illustrates the mechanical construction and dimensions of a THz waveguide, a sample chamber, a liquid inlet, and a gas outlet. The THz waveguide is a hollow-core pipe and constructed using a 2 mm-thick glass pipe wall and an 8 mm inner core diameter. During the gas-sensing process, the sample loading, natural volatilization, and sensing processes are performed at room temperature and normal atmosphere without any active layer and external pumping source to adsorb analytes.

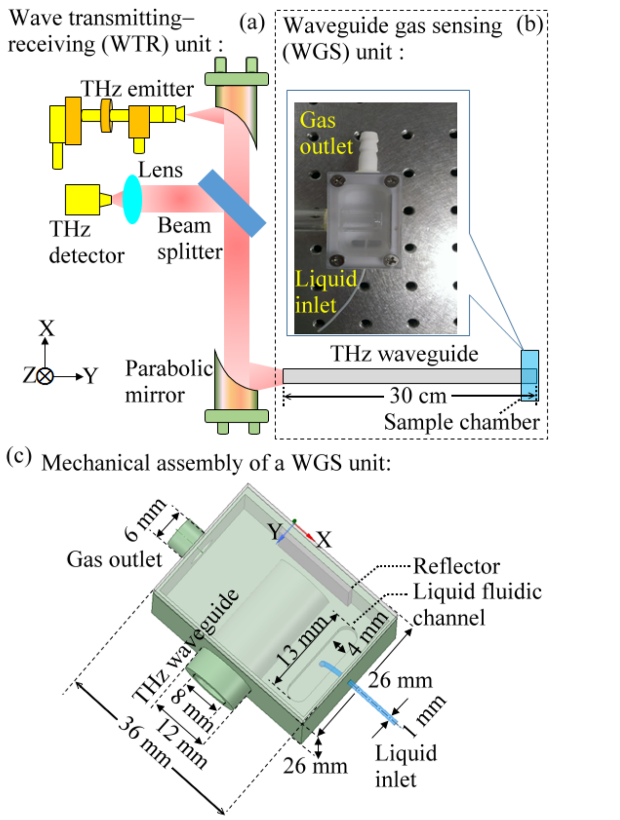

Fig. 1. Configurations of (a) wave transmitting–receiving (WTR) and (b) waveguide-gas-sensing (WGS) units. (c) Mechanical assembly of a sample chamber, a glass pipe, a metal reflector and tubing kits.