10.1117/2.1200902.1505

Noninvasive mail inspection using terahertz radiation

Hiromichi Hoshina, Yoshiaki Sasaki, Aya Hayashi, Chiko Otani, and Kodo Kawase

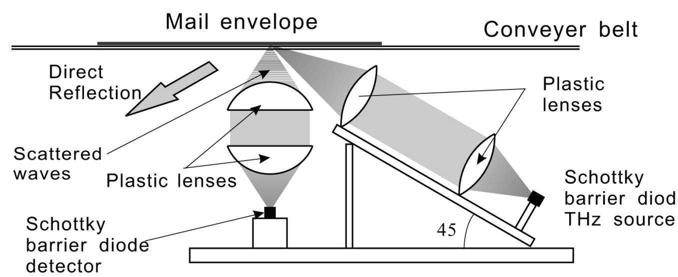
Telltale spectra can identify illicit drugs hidden in packages.

Detecting hazardous materials and illicit drugs inside posted mail is necessary because of security concerns and to deter drug trafficking. In Japan, confidentiality of private mail is guaranteed by law, and only noninvasive inspection methods are permitted. Detection (sniffer) dogs and x-ray imaging have been used, but x-rays cannot identify suspect materials and dogs are only useful if drug vapors leak from a package.

Systems using terahertz (THz) radiation have recently been demonstrated as quick and reliable mail-inspection devices.[1–4] Like radio waves, THz radiation is not significantly scattered by soft materials such as paper, wood, and plastics, and creates clear images of hidden objects. In addition, many materials exhibit unique THz-absorption spectra—fingerprint spectra—which can be used to identify the contents of suspicious packages.

A prototype apparatus has been built to inspect all mail handled in Japanese international post offices (around 100,000 items per day). However, the THz spectrometer takes too long to examine every package. Therefore, to achieve complete inspection, the process has been divided into two stages. The first involves rapid screening using x-rays and THz waves, and the second identifies the suspicious substances selected in the first stage. The initial screening stage uses x-rays to exclude envelopes containing only paper. Images revealing shadows are then scanned and measured at 0.54THz. A diagram of the THz system is shown in Figure 1.

According to Mie scattering theory,[5] which describes electromagnetic-radiation scattering by spherical particles, THz waves are intensely scattered when the particle size is comparable to the wavelength. Our experiment confirms that powders with particle sizes greater than 100μm result in a significantly stronger scattering signal than empty envelopes. Therefore, the rapid-screening system flags envelopes showing strong THz-wave scattering as suspicious mail.



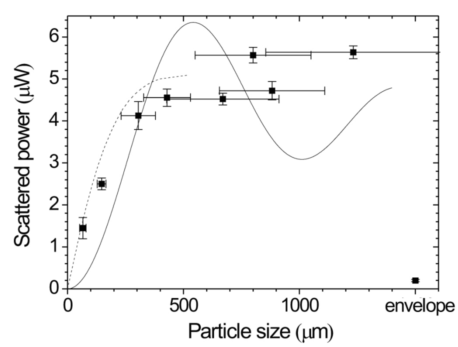


Figure 1. *(top) THz rapid-screening system. A Schottky diode is characterized by a very low forward-voltage drop. (bottom) THz-scattering signal intensity of sucrose powder of different particle sizes. The Mie-scattering extinction curves are for nonabsorbing (solid line) and partially absorbing spheres (dashed line). The data point labeled 'envelope' illustrates the extinction for a paper-only envelope.*

Substance identification is achieved with a THz time-domain spectrometer (based on time-resolved Fourier-transform spectroscopy) using femtosecond laser pulses. The absorption spectra are obtained from 0.1 to 3THz with a frequency resolution of 0.03THz and a measurement time of two minutes. Figure 2 shows typical spectra of (a) empty envelopes and (b) folders containing methamphetamine hydrochloride powder. The empty envelopes show weak absorption and almost no spectral features, while those containing methamphetamine hydrochloride

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10.1117/2.1200902.1505 Page 2/3

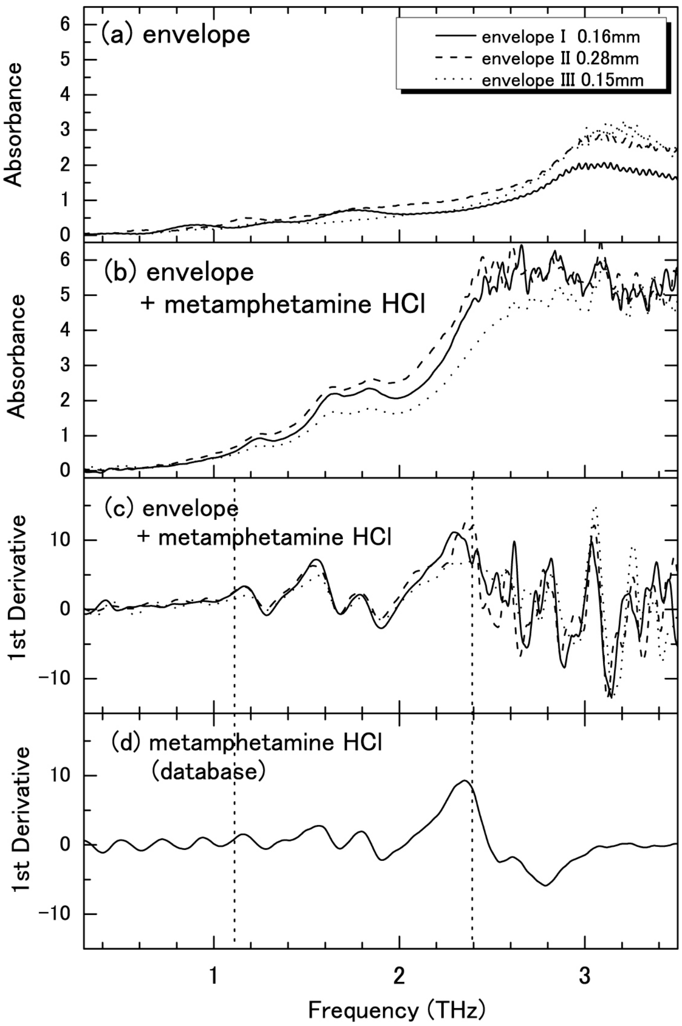

Figure 2. *(a) THz absorption spectra of different kinds of empty envelopes. (b) THz absorption spectra of methamphetamine hydrochloride (HCl) with a particle size of 170μm and (c) first derivative. (d) First derivative of the database spectrum of methamphetamine HCl. Dashed lines show the frequency range used for calculating the correlation coefficients.*

show strong absorption and fingerprint peaks at 1.2, 1.6, and 1.8THz. The spectral baselines in Figure 2(b) increase gradually with frequency due to the powder's scattering properties, and reach the detection limit at 2.4THz.

To identify controlled substances, we assembled a THz-spectrum database of widely used chemicals and drugs. Most of these show clear fingerprint spectra at 0.5–3THz, with different peaks, positions, and line shapes for each chemical. Any match between the spectra of suspicious envelopes and the database is evaluated using the correlation between their first derivatives, which removes the baseline slope and clarifies the spectral features: see Figures 2(c) and (d). The appropriate frequency range over which to calculate the correlation coefficients depends on the powder's particle size and the condition of the package. The range is determined on the basis of the spectrum's absorption intensity. A list of possible materials is displayed based on the correlation coefficient.

Procedures for spectral analysis and database retrieval are executed automatically and no special knowledge is necessary to operate the system. The prototype is now installed in Japanese post offices, and our current research focuses on evaluating the system's performance and its limits.

Author Information

Hiromichi Hoshina, Yoshiakim Sasaki, Aya Hayashi, and Chiko Otani
Terahertz Sensing and Imaging Laboratory
RIKEN
Sendai, Japan
http://www.riken.jp/lab-www/THz-img/English/index.htm

Hiromichi Hoshina received his PhD from Kyoto University in 2003. His current research focuses on developing spectroscopic applications using THz waves.

Yoshiaki Sasaki received his PhD from Yamagata University in 2004. His current research interests include the detection of scattered THz waves from powders, THz imaging, and THz heterodyne detection.

Aya Hayashi received her MSc from Meiji University in 2002. Her research is in bioimaging of cancer and DNA using THz waves.

Chiko Otani received his PhD in astronomy from the University of Tokyo in 1995 and is now head of the Terahertz Sensing and Imaging Laboratory. His research interests include superconducting THz detectors and their applications.

Koko Kawase
Optical Quantum Engineering Group
Nagoya University
Nagoya, Japan
http://www.nuee.nagoya-u.ac.jp/labs/optlab/kawase/

Continued on next page

10.1117/2.1200902.1505 Page 3/3

Kodo Kawase received his PhD in electronic engineering from Tohoku University in 1996. A professor in the Graduate School of Engineering (since 2005), he has been involved in research on THz-wave generation using nonlinear optics since 1992.

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