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The development of a wide-field infrared spectroscopic imaging apparatus using a bolometer camera and feasibility test for forensic examination

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HIGHLIGHTS

- Bolometer was used as a detector.
- An imaging interferometer was used for Fourier spectroscopy.
- Necessity of a wide-field infrared spectroscopic imaging apparatus was argued.

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ABSTRACT

A wide-field infrared spectroscopic imaging apparatus that uses a bolometer camera instead of a mercury cadmium telluride detector has been developed. The apparatus is equipped with a projection lens and utilizes, for Fourier spectroscopy, an imaging type interferometer resistant to vibrations. In contrast to the conventional systems, the apparatus has several advantages including short measurement times for large samples, low cost, and future portability. To test the applicability of this apparatus to forensic examination, a polystyrene film and different types of ink on an Al plate were tested.

When the spectroscopic imaging of a 40-μm-thick polystyrene film was obtained in transmission mode via the developed apparatus, very clear spectra were recorded. In reflection mode, the spectroscopic imaging of writing pen inks on a 10 cm × 10 cm aluminum plate could also be obtained. The developed apparatus could record spectra of 240 × 320 = 76,800 points with a wavelength resolution of approximately 5 cm^{-1} in ca. 1 min. Considering the time required for the analysis of the interferogram, the total time was ca. 2 min. By changing the projection magnification, the size of the area to be examined could be easily modified. The measurement time was constant regardless of the size of the area. As the developed apparatus is very compact and portable, in situ observation of crime material will be possible.

1. Introduction

Mid-infrared (MIR) spectral imaging involves the simultaneous collection of thousands of MIR spectra across a sample using a focal plane array (FPA) detector. This allows for the collection of chemically specific spectral data while maintaining the spatial information. Images can then be generated based on the spectral and chemical contrast between the components of a sample. Owing to the inherent characteristic of the vibrational spectra to provide specific information on the molecular structure of the materials, MIR spectral imaging is capable of producing detailed information concerning the chemical composition. As it is a very useful technique, MIR spectral imaging is used in forensic examinations in various fields. Obliterated writings that cannot be revealed by conventional methods may be uncovered by using MIR spectral imaging [1,2]. In addition, MIR spectral imaging has also been shown to be an excellent technique for the detection of latent and developed fingermarks on a number of challenging surfaces [3–11]. Attempts have also been made to apply this technique to the analysis of automobile paint chips, in medicine, etc. [12–14]. Hence, it can be a very effective technique for forensic examinations.

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All the studies mentioned above have been conducted by using a commercially available Fourier transform infrared (FTIR) imaging apparatus. Although such a system offers a convenient operability, it has the disadvantage of requiring a considerable amount of time to complete the measurement. For example, when we used our laboratory apparatus (Perkin Elmer Spectrum Spotlight 300), the sample size was limited to 20 mm × 20 mm and each measurement took 320 min. Therefore, the measurement of many samples or large specimens is virtually impossible. In addition, as the sample needs to lie on a movable stage, samples attached to the wall or samples whose surface is not flat cannot be measured. Besides, the commercially available apparatus employs a highly sensitive mercury cadmium telluride (MCT) detector that must be cooled with liquid nitrogen. Furthermore, as the system incorporates a Michelson interferometer, it is sensitive to vibrations and requires a vibration isolator. As a result, its weight increases, in turn limiting its portability.

A wide-field infrared spectroscopic imaging system that uses a bolometer camera instead of an MCT detector was developed at laboratory level. The bolometer, compared to the MCT detector, presents a series of advantages such as a large number of pixels, elimination of the liquid nitrogen cooling requirement, and low cost. The developed apparatus utilizes, for Fourier spectroscopy, an imaging interferometer rather than a Michelson interferometer. The imaging interferometer is devised by Ishimaru et al. and is very resistant to vibrations [15,16]. The system is also equipped with a projection lens. For all these reasons, the apparatus has several advantages including short measurement times for large samples, low cost, and future portability. Alcohol and milk have already been successfully analyzed by using this setup [17]. In this study, to test the applicability of this system to forensic examination, different inks and films were tested.

2. Methods

Fig. 1 shows a schematic of the optical system of the newly developed wide-field infrared spectroscopic imaging apparatus. Rather than a Michelson interferometer, the apparatus utilizes, for Fourier spectroscopy, a very robust imaging type interferometer devised by Ishimaru [15] The MIR light emitted from the light source is reflected by the sample before passing through the projection lens and the interferometer, finally reaching the bolometer camera. The interferometer acts as a Fourier spectrometer. The Fourier spectrometer has two mirrors arranged vertically. A piezo-stage allows moving one of the mirrors back and forth: 1500 pictures were taken while moving the mirror by 1-μm-wide steps. The bolometer camera (Nippon Avionics Co., Ltd. C100V) that detects infrared light in the wavelength range of 8–14 μm is equipped with a 240 × 320 pixels detector, and has a

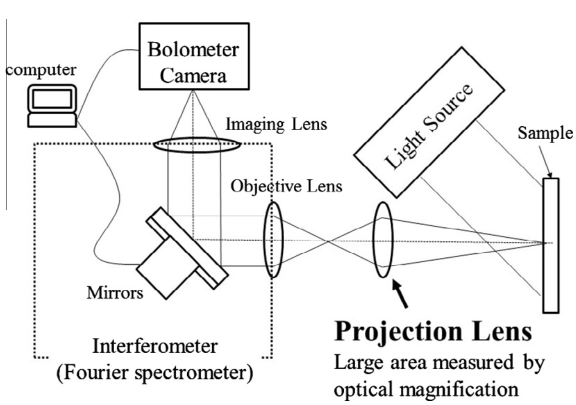

Fig. 1. Schematic of the optical system of the developed apparatus.

temperature resolution of 50 mK and a frame rate of 30 Hz. The light source is a black body light source of CC-100–350 and ceramic heater. There are three lenses—objective, imaging, and projection lens—with a 50 mm diameter and a 100 mm focal length for the objective and imaging lens, and a 25 mm focal length for the projection lens. Fig. 2 shows the procedure of the interferogram analysis. From the 1500 pictures taken by the apparatus, 240 × 320 interferograms were synthesized for each pixel by piercing the intensity of the pictures. All the interferograms were multiplied by the Blackman window function and then Fourier-transformed to obtain the 240 × 320 spectra. All the spectra were simultaneously obtained from the pictures. To enhance the signal to noise ratio, a typical Fourier transform spectrometer drives the mirror back and forth many times, collecting a series of measurement to calculate the average spectrum. Conversely, the developed apparatus drives the mirror back and forth only once and calculates the average spectrum from adjacent pixels.

Fig. 3 shows two photographs of the samples investigated in this study. The developed apparatus was used in transmission mode to obtain wide-field spectroscopic imaging of a polystyrene film. The polystyrene film, obtained from JASCO Corporation and used as the control sample, had a thickness of 40 μm and a sample size of 25 mm × 15 mm. Two types of writing pens were chosen from a set containing several samples: a Mitsubishi PA-151T marking pen and a Zebra WYT2-R marking pen. The pens were used to write the alphabet and numbers on an aluminum plate in order to test the wide-field spectroscopic imaging in reflection mode. The letters "S" and "R" were written with the Mitsubishi PA-151T marking pen, whereas the letters "T" and "A" were written with the Zebra WYT2-R marking pen. The reference spectra were measured by a commercial FTIR (Spectrum Spotlight 300, PerkinElmer Co. Ltd.) to check the accuracy of the obtained spectra.

3. Results and discussions

The main purpose of this study is to develop an infrared spectral imaging apparatus that can analyze a large sample within a short period of time. Besides, the study aims to test the applicability of this setup to forensic examination.

3.1. Wide-field spectroscopic imaging of polystyrene film in transmission mode

Figs. 4–7 show the results of a wide-field spectroscopic imaging of the polystyrene film. The interferogram shown in Fig. 4 presents a signal fluctuation at $z = 750$ μm with an amplitude of about 15, which is fairly larger than the signal noise. The fluctuation implicates the occurrence of the interference. Fig. 5 shows the measured spectra. The bold line indicates the spectrum obtained by the developed apparatus—the spectrum was averaged from 5 × 5 adjacent pixels—whereas the thinner line indicates the spectrum obtained by the commercial FTIR. Thus, in transmission mode, an accurate spectroscopic imaging of the polystyrene film was obtained in the short wavelength region. The height of the peak located at 13 μm was quite different in the two spectra. This is probably because the sensitivity of the bolometer camera and the amount of radiation from the black body light source are low in that wavelength region. Fig. 6 shows the effect of averaging the spectrum from adjacent pixels; n is the number of pixels used to calculate the average. Even without averaging, the main peaks were clearly observed, but small noise peaks appeared. Averaging the spectra from more than 25 pixels determined a decrease of the noise peaks. Fig. 7 shows the spectra, averaged from 25 pixels, at different locations of the film sample. Although the shape of the peaks was slightly different, similar spectra were measured.