1 Introduction

Passive remote sensing by infrared spectrometry allows detection and identification of hazardous clouds from long distances. Typical applications of the method are automatic surveillance of industrial facilities and identification of hazardous clouds after chemical accidents. A conventional remote sensing Fourier transform infrared spectrometer is based on an interferometer with a single detector element. The output of the system is usually a yes/no decision by an automatic identification algorithm that analyses the measured spectrum. The analysis of the measured spectrum by the operator is complicated and thus this task requires an expert. Even if a scanning system is used for surveillance of a large area the operator is dependent on the decision of the algorithm. In contrast to that, imaging systems allow automatic identification but also simple interpretation of the result, the image of the cloud. An imaging spectrometer with these capabilities is the scanning infrared gas imaging system (SIGIS)\(^1\). The system is based on an interferometer with a single detector element in combination with a telescope and a synchronized scanning mirror. The results of the analyses of the spectra are displayed by an overlay of a false color image, the “hazardous chemical image”, on a video image. However, the temporal resolution of the system is limited by the sequential measurement of all fields of view within the field of regard. In order to measure a complete image by a single scan of the interferometer, an imaging Fourier-transform spectrometer (IFTS) with a detector array instead of a single detector element is currently being developed at TUHH. In this work, the first measurements are presented.

2 Imaging Fourier-Transform Spectrometer

2.1 Principle

Fig. 1 illustrates the basic setup of an imaging Fourier transform spectrometer with a Michelson interferometer. The interferometer modulates the incoming radiation. Instead of a single detector element that is used in a conventional Fourier transform spectrometer, a detector array is used to detect the radiation.
Fig. 1: Principle of an imaging Fourier transform spectrometer.

2.2 New IFTS

The spatial resolution of the IFTS is $128 \times 128$ pixels. The detector material of the focal plane array (FPA) is HgCdTe (AIM Infrarot-Module, Heilbronn, Germany). The array is cooled by a stirling cooler. The interferometer of the IFTS system is a modified Michelson interferometer with cube-corner reflectors (Bruker Optik, Ettlingen, Germany). As in conventional Fourier transform spectrometers, a laser is used to measure the optical path difference in the interferometer. The spectral resolution of the system is $5 \text{ cm}^{-1}$ (full width at half maximum of the instrument line shape). The choice of the resolution is a compromise between higher selectivity at higher spectral resolutions and higher signal-to-noise ratios at lower spectral resolutions.

Table 1: Design parameters of the imaging FTS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Spectral range</td>
<td>1000 - 1300 cm$^{-1}$</td>
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<tr>
<td>Spectral resolution ($\Delta\sigma_{\text{FWHM}}$)</td>
<td>5 cm$^{-1}$</td>
</tr>
<tr>
<td>Focal plane array</td>
<td>AIM 128 LWIR ($128 \times 128$ pixels)</td>
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<tr>
<td>Size of detector elements (Pitch)</td>
<td>40 µm $\times$ 40 µm</td>
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2.3 Data Analysis

The first step of the data analysis is the calculation of the brightness temperature spectrum for each pixel. The basic display is the image of the brightness temperature (false color representation) at a frequency (wavelength) selected by the user (Fig. 2). Moreover, images of brightness temperature differences may be displayed. Additionally, the spectra are analyzed by the identification algorithm of the SIGIS system. The brightness temperature
spectrum of each pixel is sequentially analyzed for target compounds in a spectral library. For simple interpretation of the results, the image of a video camera is overlaid by the image of the results of the analysis (false color image) in this mode (Fig. 3).

3 Measurements

Fig. 2 shows results of a measurement of 4000 ppm m methanol and 1000 ppm m diethyl ether vapor in gas cells with polyethylene windows. The background was a heated black plate \( (T = 320 \text{ K}) \). The distance between the gas cells and the IFTS was approximately 4 m. For the measurement of the interferograms, a single scan of the interferometer was recorded (Measurement time for the complete image: 2 s).

<table>
<thead>
<tr>
<th>Image at 1050 cm(^{-1})</th>
<th>Image at 1150 cm(^{-1})</th>
<th>Video Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>(strong methanol absorption lines)</td>
<td>(strong diethyl ether absorption lines)</td>
<td></td>
</tr>
</tbody>
</table>

![Strong absorption of radiation by methanol vapor](image1)

![Strong absorption of radiation by diethyl ether vapor](image2)

**Fig. 2:** Measurement of methanol vapor and diethyl ether vapor in gas cells. Images at different frequencies and a video image of the scene.

Fig. 3 shows the measurement window of the IFTS software. Moreover, Fig. 3 shows results of a measurement of methanol in a gas cell with NaCl windows. The background was a heated black plate \( (T = 320 \text{ K}) \). The automatic identification algorithm\(^{4}\) has been applied. The pixels with a positive result of the identification of methanol are shown in the video image.
4 Summary

An imaging Fourier transform spectrometer has been developed. The measurements presented in this work demonstrate the remote chemical imaging capabilities of the system. The spectral resolution of 5 cm$^{-1}$ allows automatic identification of hazardous gases. Future work will include a radiometric analysis of the system and measurements without artificial radiation sources.

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5 References


