DOI 10.5162/SMSI2020/C4.5

FT-IR Coupled Goniometer Setup for Characterization of the Spatial and Spectral Emission of IR-Sources

A. Eberhardt[1], *C. Weber*[1,2], *M.-L. Bauersfeld*[1], *J. Wöllenstein*[1,2]
[1] Fraunhofer Institute for Physical Measurement Techniques IPM, Heidenhofstr. 8, 79110, Freiburg, Germany,
[2] Department of Microsystems Engineering–IMTEK, Laboratory for Gas Sensors, University of Freiburg, Georges-Köhler-Allee 102, 79110, Freiburg, Germany
Andre.eberhardt@ipm.fraunhofer.de

Summary:

We present a FT-IR coupled goniometer setup, which allows the simultaneous spatial and spectral characterization of optical components used in non-dispersive infrared gas sensor systems. The performance of the laboratory setup is demonstrated by comparing reflector and Fresnel lens equipped thermal infrared radiation sources. We show that even the simplest binary Fresnel lenses, when optimally designed, can achieve a thinner emission angle than parabolic mirrors at comparable radiation intensities.

Keywords: Infrared, FTIR, Goniometer, Spatial Emission, Spectral Emission

Motivation

Non-dispersive infrared sensors are widely used in the field of low-cost optical gas sensors. Most of these sensors contain modulated thermal emitters as infrared radiation source [1, 2]. In order to improve the radiation output and therefore the performance of these sources, parabolic mirrors are commonly used. However, these mirrors are complex and expensive to manufacture. Using planar diffractive Fresnel lenses as an alternative may reduce the costs at comparable performance, as they can be produced on a large scale at wafer level using silicon microsystems technology. Diffractive lenses, however, show a pronounced wavelength dependency of the focal length and consequently the emission characteristics of thermal sources depend on the wavelength and angle to the optical axis.

Measurement setup

For the spatially resolved measurements a goniometer setup was developed that can be coupled to a FT-IR-spectrometer. The setup was optimized using raytracing simulations in order to conserve as much radiation as possible without losing radiation inside the spectrometer due to outshining of optical elements while minimizing the captured cone angle. Figure 1 shows the presented measurement setup. The emission source was attached to a rotation stage (a) in a way that its center of front surface was located directly above the rotation axis of the stage. The emitted radiation was collimated using a spherical silver plated mirror (a) with a diameter of 1 “ and a radius of curvature of 1.000 mm and guided to a second silver plated spherical mirror (b) with a diameter of 1 “ and a radius of curvature of 500 mm. This mirror focused the collected radiation into the coupling port (d) of a Fourier-transform infrared spectrometer (FT-IR, Bruker Vertex 80v). The setup captured the radiation of a cone angle of ± 1.5 °. For a thermal IR-emitter with a Lambertian emission distribution this means about 0.07 % of the emitted radiation is collected. For this reason a liquid nitrogen cooled MCT-detector incorporated in the spectrometer was used.

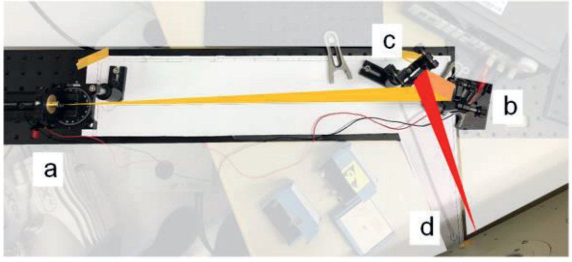

Fig. 1. Photograph of the measurement setup: (a) thermal IR-source, attached to a rotation stage, (b) spherical mirror (f = 1000 mm), (c) spherical mirror (f = 500 mm), (d) external coupling port of FT-IR-spectrometer and schematic of the optical path (orange to red).

Wavelength and angle-resolved emission spectra

The goniometer setup has been used to evaluate the performance of Fresnel lens equipped radiation sources in comparison to classical reflector based ones.

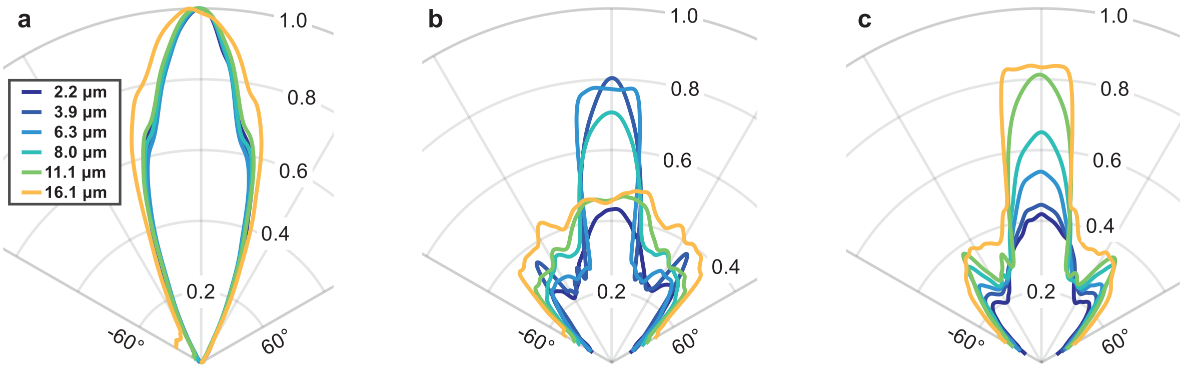

Fig. 3. Results of spectral resolved goniometer measurements for thermal emitters with an parabolic reflector (a), lens F1 (b) and lens F2 (c) in the angular range between -70 ° and + 70 °

For the measurements, broadband antireflective (AR) coated binary Fresnel lenses made of silicon with a focal length of f = 10 mm and design wavelengths of 4.3 µm (L1) and 10.5 µm (L2) were used. The lenses were placed on conventional cylindrical caps instead of commonly used windows. With this setup, the distance between the emitting and lens surface was about 6.9 mm. These emitters were compared to a source equipped with an externally identical parabolic reflector and a broadband AR-coated germanium window (figure 2). The emitters were operated with a power of 850 mW, resulting in a temperature of about 800 °C.

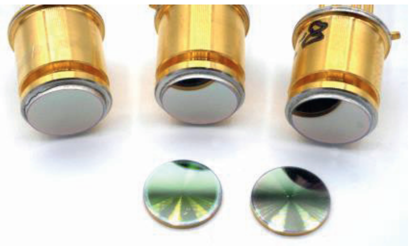

Fig. 2. Photograph of the used sources. From left to right: emitter with parabolic reflector, emitter with Fresnel lens for 4.3 µm (F1) and with Fresnel lens for 10.5 µm (F2).

We measured FT-IR spectra in the angular range between -70° and +70° in 2° steps. Figure 3 shows the resulting angular spectra of the investigated sources with parabolic reflector (a) and Fresnel lenses F1 (b) and F2 (c) from 2.2 µm to 16.1 µm. All spectra were normalized to the maximum value of the corresponding wavelength of source (a) at an angle of 0°.

As expected, the source with reflector shows no significant wavelength dependence. The two sources with Fresnel lenses show the expected wavelength dependence of the angular spectrum. Above and below the design wavelength, the focal length decreases resp. increases with increasing distance according to the diffractive nature of the lenses.

The geometric layout of sources (b) and (c) results in the best possible focusing performance of the lenses above their design wavelengths at 6.3 µm for L1 (f=6.8 mm) and 16.1 µm (f=6.5 mm) for L2, when the emission surface is imaged to infinity. Some spectra show intermediate maxima around ±40°. These maxima are caused by multiple reflections within the caps.

The full width half maximum angle of both Fresnel-lens equipped sources is 9.4° (L1) and 10.4° (L2) and therefore smaller than the classical reflector based solution with at least 15.1°.

Conclusion

We presented a laboratory setup that allows the simultaneous spatial and spectral characterization of IR-radiation sources with high resolution in the angular range of at least ±70 °. The setup has been used to compare classical mirror-based sources with novel Fresnel-lens-enhanced ones. It turned out that sources with binary Fresnel lenses achieve a performance comparable to parabolic mirror based sources despite their inherently low diffraction efficiency of around 40 %.

The presented setup allows the efficient evaluation of the performance and a subsequent optimization of diffractive element enhanced radiation sources.

Ackknowledgements

This work was funded within the “Nanostructured Fresnel optics for MEMS-based IR-emitter” project with the grant number 13XP5019E.

References

[1] J. Hildenbrand et al., “Micromachined Mid-Infrared Emitter for Fast Transient Temperature Operation for Optical Gas Sensing Systems“, IEEE Sens. J. 10.2 (2009): 353-362

[2] J. Hodgkinson, R. P. Tantam, “Optical gas sensing: a review”, Meas. Sci. Technol. 24.1 (2012):012004