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Supercontinuum absorption spectroscopy: Theory, optical design and application for high-speed multiparameter diagnostics

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As a non-invasive measuring technique, absorption spectroscopy has proven its capabilities in many fields of research and application, including medicine, chemistry, astrophysics and power engineering. Aim of the present investigations is to inferring multiple parameters, namely temperature and species concentrations, with supercontinuum absorption spectroscopy (SCAS) at kHz detection rates.
Supercontinuum laser light combines a broad spectral bandwidth of typical 400 nm to 2400 nm with a high total power. Due to the broadband and near-infrared emission, this laser is ideal for the application for multi-species measurements as the energy levels of the absorption bands are specific to the gas molecule and absorption increases with higher wavelengths. In addition, the acquisition of the rotational-vibrational spectrum of a molecule band allows to infer other system parameters such as temperature and pressure. At the same time, the short exposure times in the case of high-speed measurements require high spectral power densities to ensure a sufficient signal-to-noise ratio. The high spatial coherence of supercontinuum light is also an essential advantage, if the application requires a single mode coupling to the spectrometer due to lack of space or harsh ambient conditions.
After a brief introduction to the physical basics, the modelling of absorption in the gas phase and the application to high-speed combustion diagnostics are discussed [1,2]. We show how the typical system measurement precision based on camera noise is approximated and correlations between parameters are inferred with an inverse analysis. Furthermore, variations and improvements in the optical design of the spectrograph are highlighted with the optical design software Zemax OpticStudio® (Figure 1). The contribution also highlights how the evolution of SCAS has benefited from the framework of SAOT.

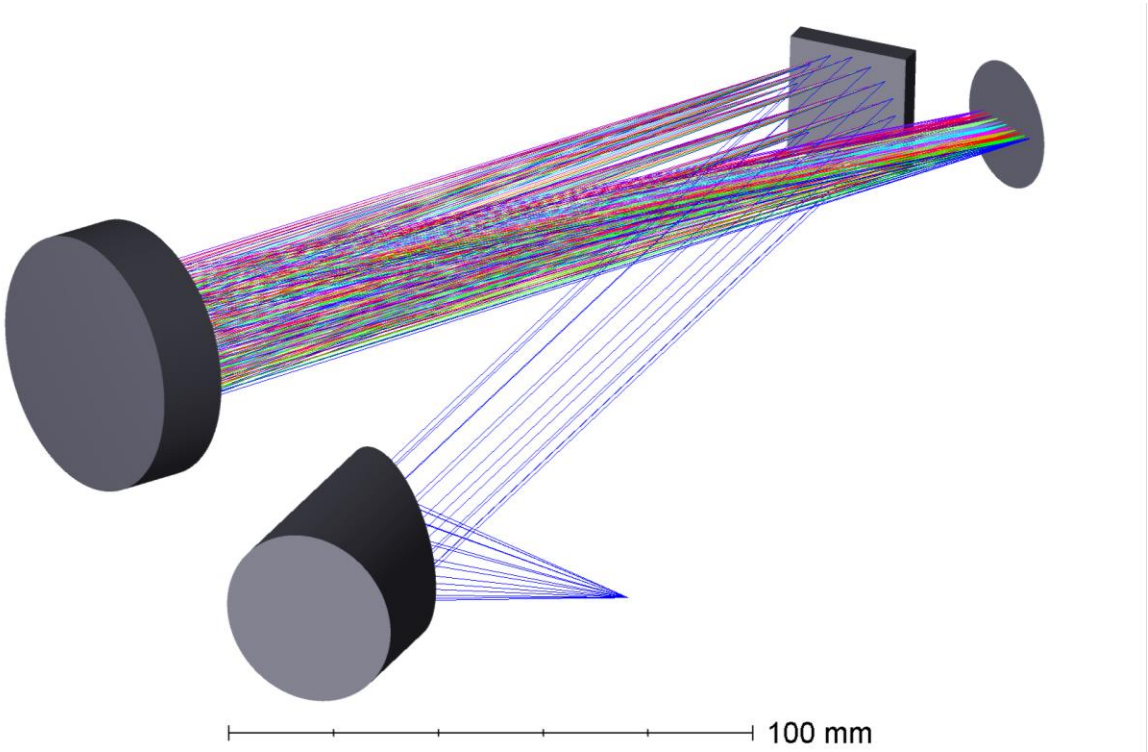

Fig. 1. Optical design in Zemax OpticStudio® for a near-infrared spectrometer with off-axis parabolic mirror collimation.

References

[1] I.E. Gordon, L.S. Rothman, C. Hill, E.J. Zak, et al., "The HITRAN2016 molecular spectroscopic database", J. Quant. Spectrosc. Radiat. Transfer 203, 3-69 (2017)

[2] T. Werblinski, P. Fendt, L. Zigan and S. Will, "High-speed combustion diagnostics in a rapid compression machine by broadband supercontinuum absorption spectroscopy," Appl. Opt. 56, 4443-4453 (2017)