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Flame Temperature Measurements by Time-Domain Based Supercontinuum Absorption Spectroscopy

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Abstract

Temperature is one of the scalar quantities of major interest in most technical combustion systems such as gas turbines, furnaces or internal combustion engines. In this work, we present for the first time quantitative temperature measurements in a flame by time-domain based supercontinuum absorption spectroscopy. In a 1-dimensional McKenna type burner temperature is inferred from broadband H_2O spectra by a multi-peak least-square algorithm to data from the Barber-Tennyson line list (BT2) within a spectral range from 1340 nm to 1485 nm. The results are compared with temperature measurements based on coherent anti-stokes Raman scattering (CARS). A good agreement is achieved, showing the capability of time-domain based supercontinuum absorption spectroscopy temperature measurements in a flame. Further the beneficial influence of high bandwidth detection equipment is presented, which allows for a more distinct detection of many week high temperature transitions.

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Supercontinuum, Absorption, Time-domain, Temperature, Flame

1. Introduction

Supercontinuum radiation (SC) is of special interest for various spectroscopic applications [1]. Commercially available SC sources feature variable repetition rates in the MHz-domain, ultra-high spectral bandwidth ranging from the visible to the near-infrared (NIR) accompanied with high spectral power densities of several mW/nm. For time-domain based sensing the NIR part of the initially short SC pulses is dispersed within a long dispersive fiber from a dispersion compensating module. The result are wavelength sweeps ranging from approximately 1300 nm to 1700 nm within a time span of several hundred nanoseconds. After transmitting the measurement volume the wavelength sweeps are detected in

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the time-domain with a high bandwidth photodiode and an oscilloscope. This wavelength range comprises many absorption lines of species like CH_4, CO_2 or H_2O.

The broadband character of the SC radiation itself allows for the simultaneous determination of multiple species concentrations and temperature from at least one transition pair of a species exhibiting a different temperature dependency [2, 3]. With this technique repetition rates exceeding 100 kHz can be achieved [2, 4]. Nevertheless, very few studies addressing temperature evaluation from the broadband spectra are currently found [3, 5]. In this work experimentally recorded high temperature H_2O spectra are matched to theory based on the Barber-Tennyson line list (BT2) [6] to infer temperature by a least-square method of multiple absorbance peaks. The results are compared with flame temperatures determined by coherent anti-Stokes Raman scattering (CARS). Finally, the advantages of a faster oscilloscope, resulting in a higher spectral resolution of the setup, are discussed with respect to flame temperature determination from the broadband H_2O spectrum.

2. Instrumentation

In Figure 1 the experimental setup used for the SC thermometry is depicted. The optical setup and theory for the CARS measurements are described elsewhere [7].

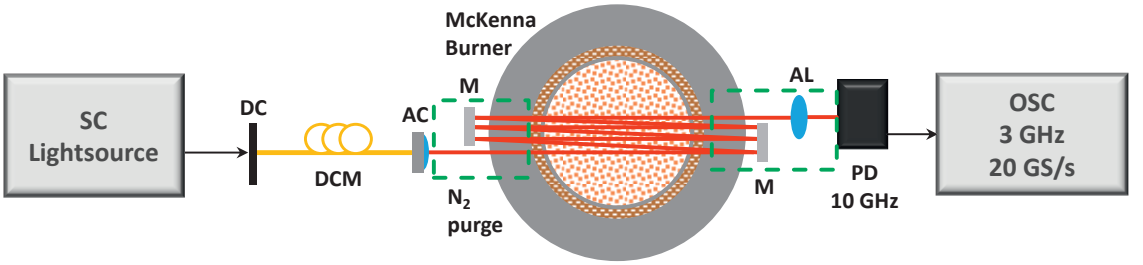

Figure 1. Experimental setup for time-domain based SC absorption spectroscopy. DC: dichroic mirror; DCM: dispersion compensating module; AC: achromatic collimator; M: mirror; AL: achromatic lense; PD: photodiode; OSC: oscilloscope

For SC generation a NKT (SuperK EXR-15) source was used. The repetition rate was adjusted to 1.178 MHz to prevent an overlap of successive pulses within the dispersion compensating module (DCM). The NIR part of the pulses was isolated and coupled into the dispersive fiber exhibiting a large negative dispersion of -1.72 ns/nm at 1550 nm. The wavelength sweeps of approximately 800 ns duration are collimated and passed through the flame of the McKenna burner. A multi-pass setup was built by two broadband mirrors, leading to 7 total passes in the middle of the burner through the flame. All non-fiber-coupled beam paths outside the flame region are constantly purged with N_2 to eliminate most of the background absorption from room temperature H_2O molecules.

The sweeps are detected with a high-bandwidth photodiode and a fast oscilloscope. To reduce the signal-to-noise ratio for each measurement, 1500 consecutive single pulses are detected in real-time and later averaged, leading to effective measurement time of 1.27 ms. With the equipment employed a spectral resolution of 0.29 nm at 1450 nm was achieved. The spectral resolution depends on the amount of dispersion provided by the DCM and temporal resolution of the detection equipment. The burner was fueled with CH_4 and operated at an equivalence ratio of Φ=1. For the non-quantitative experiments with a higher bandwidth oscilloscope (12 GHz 40 GS/s) C_2H_4 was used as fuel and a stoichiometry of Φ=1.1 was adjusted. In this case only a 5-pass setup was established, which was sufficient to achieve a distinctive absorbance signal with this setup. The distance of the stabilization plate to the burner surface was kept constant to 26 mm.