Mid-IR Sensors for Hydrocarbon Fuel Measurements

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Motivation

Fuel concentration and temperature are critical parameters in combustion devices because of their effect on power output, thermodynamic efficiency, and pollutant emissions. In this research we are developing diagnostics based on absorption of mid-infrared (mid-IR) laser light that can be used to make nonintrusive measurements of fuel concentration and temperature in combustion systems including internal combustion engines, pulse detonation engines, and shock tubes.

Overview

Mid-IR diagnostics are well-suited for fuel sensing because transitions of the fundamental C-H stretching vibration are near 3400 nm (2950 cm^{-1}); thus, hydrocarbons exhibit strong absorption near this wavelength. A new class of tunable mid-IR lasers has become available that offers improved sensitivity and flexibility (See Fig. 1). These new lasers utilize difference frequency generation (DFG) to create mid-IR light from two near-IR diode lasers as described in more detail below.

Figure 1: Tunable mid-IR laser used for sensitive hydrocarbon detection.

Quantitative absorption measurements require a database of temperature-dependent cross section data for the hydrocarbons of interest. Using a temperature-controlled absorption cell and a Nicolet 6700 FTIR spectrometer, we investigated the absorption spectrum of many important hydrocarbon compounds and practical fuel blends. Figure 2 shows an example temperature-dependent data for regular gasoline. Fuel concentration and gas temperature can be determined from simultaneous measurements of absorption at two wavelengths.

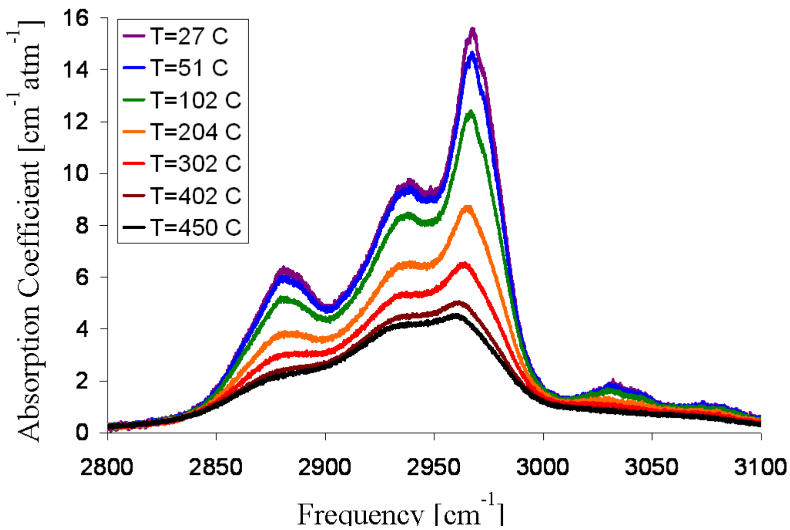

Figure 2: Temperature-dependent absorption cross section of regular grade gasoline measured by FTIR.

We have demonstrated dual-wavelength techniques for simultaneous measurement of fuel concentration and gas temperature. For example, using the laser architecture illustrated in Fig. 3, we use DFG to simultaneously produce two mid-IR wavelengths by combining two near-IR pump lasers ($\nu_{1;pump}$ and $\nu_{2;pump}$) with a single near-IR signal laser (ν_{signal}) in a temperature controlled ridge-waveguide PPLN crystal. Intensity modulation of the pump lasers appears on the intensity of the mid-IR light, which provides insensitivity to the detector's thermal background as it varies with measurement conditions.

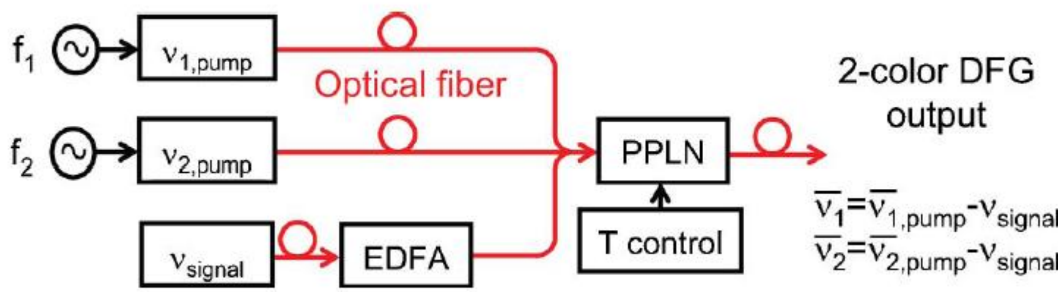

Figure 3: DFG scheme for simultaneous production of two mid-IR laser frequencies at ν_1 and ν_2 with intensity modulation at f_1 and f_2

Absorption measurements are conducted by detecting the two-color laser light transmitted through heated cells or across a shock tube, as illustrated in Fig. 4. The signals from the two mid-IR wavelengths are isolated by lock-in detection of the transmitted signal at the respective modulation frequency.

Next Steps

Mid-IR absorption measurements of gasoline have been conducted in cells, in shock-heated gases and in a production IC-engine. Future work includes measurements in shock-heated gases to determine the rates of formation of the decomposition products of selected fuels (e.g. n-heptane, dodecane, etc.), which will involve detection of smaller species (e.g. CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_6, C_4H_8) that have more structured absorption spectra. Such measurements will provide a unique database needed to refine and validate chemical mechanisms for practical fuels.

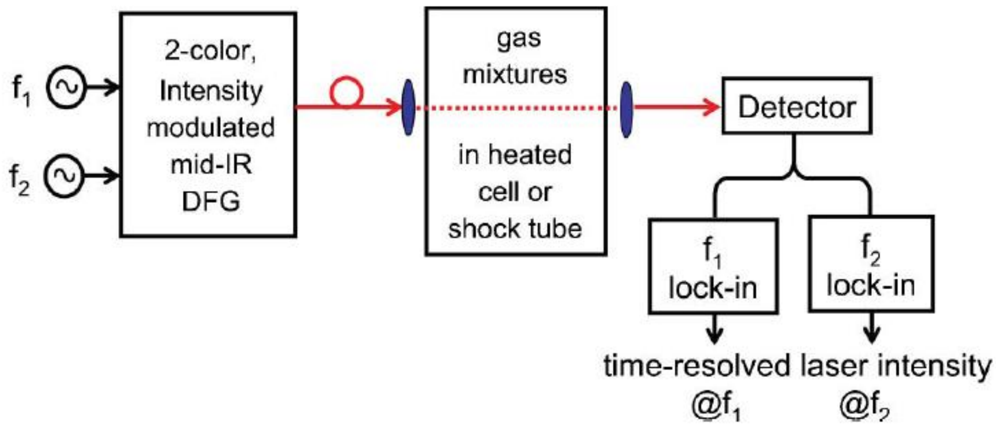

Figure 4: Experimental setup for absorption measurements of hydrocarbon fuel with two-color, intensity-modulated sensor

References

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