Experimental System to Flame Temperatures Measurements Using Diode Laser Spectroscopy

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Abstract

The aim of this work is the development of a non-intrusive multiplexed diode-laser sensor system to determine the temperature in combustion processes. Since water is one of the main combustion products it is usually employed in experimental works to obtain combustion parameters. Our experimental system is comprised of two InGaAsP lasers and fiber optics components. The wavelengths of the lasers were independently current-tuned across two water transitions near 1392 nm and 1343 nm and the temperature is determined from the ratio of the measured peak absorbances that is compared with theoretical data. The system was applied to measure the temperature of an ethanol flame produced by an industrial GRION Ltda burner. The temperature measurement method based on the absorption spectroscopy can be used to obtain flame temperatures up to 2500 K, approximately, with a standard deviation of about 5%.

Introduction

High-resolution absorption spectroscopy technique using diode-lasers has been developed to provide fast, sensitive, and non-intrusive means to measure temperature and molecule concentration in combustion studies [1,2,3]. The water molecule is especially relevant to combustion since it represents a primary combustion product and has absorption bands that can be reached with commercial diode lasers [4]. Temperature determination requires measurements of two absorption lines from states with an energy separation of at least kT. The gas temperature is determined from the ratio of measured H_2O absorbances obtained by tuning the narrow-bandwidth diode lasers across transitions near 1343 nm ($\nu_1+\nu_3$ band) and 1392 nm ($2\nu_1$, $\nu_1+\nu_3$ bands). The experimental ratio is compared with theoretical predictions evaluated using the HITEMP database [5]. The use of tunable semiconductor diode lasers for this spectroscopy technique is attractive, as these diode lasers are compact, rugged, cost effective, compatible with optical fiber transmission, and simple to operate [6]. The use of fiber optics minimizes the influence of room water molecules and turns the alignment easier.

Experimental Setup

Figure 1 illustrates the experimental setup. The system includes two tunable diode-lasers operated independently. Laser-1 and laser-2 are InGaAsP distributed-feedback (DFB) lasers from Laser Components Co. and access H_2O transitions at 1343 nm (7446 cm^{-1}) and 1.392 nm (7184 cm^{-1}) regions. The laser controller (Newport Model 8000) consists of a temperature controller that maintains a constant laser case temperature, a current driver and a function generator that is used to ramp the injection current (1 kHz) and thus tune the lasers over the desired transition. A complete characterization of the diode lasers has been previously made using a Anritsu Spectra Analyzer Model MS9000. Laser-1 and laser-2 are coupled into 60 μm multi-mode fibers using 10 mm focus lenses and the beams are multiplexed using a 2×2 fiber combiner. The multiplexed beam with the two wavelength is divided into two paths (50/50 ratio). The first beam (I_o) is sent to a InGaAs differential Newport detector to record the reference signal. The other beam (I) is directed through the probed flame zone and focused into another differential detector. The detector voltages are digitized by a Tektronics 7D20 Digitalizer and transferred via GPIB to a Pentium-based (750 Hz) personal computer. To minimize the influence of room-air H_2O absorption the system is purged with N_2. The system was used to record H_2O absorption spectra over a 15 cm long path through the ethanol-air-O_2 flame generated by a GRION burner. The air is used to atomized the liquid fuel. The design of a system based on fiber-optic components reduces the complexity of alignment, minimizes the optical path length through room air and provides a flexible, fast and accurate means of measuring temperature in flows containing water vapor.

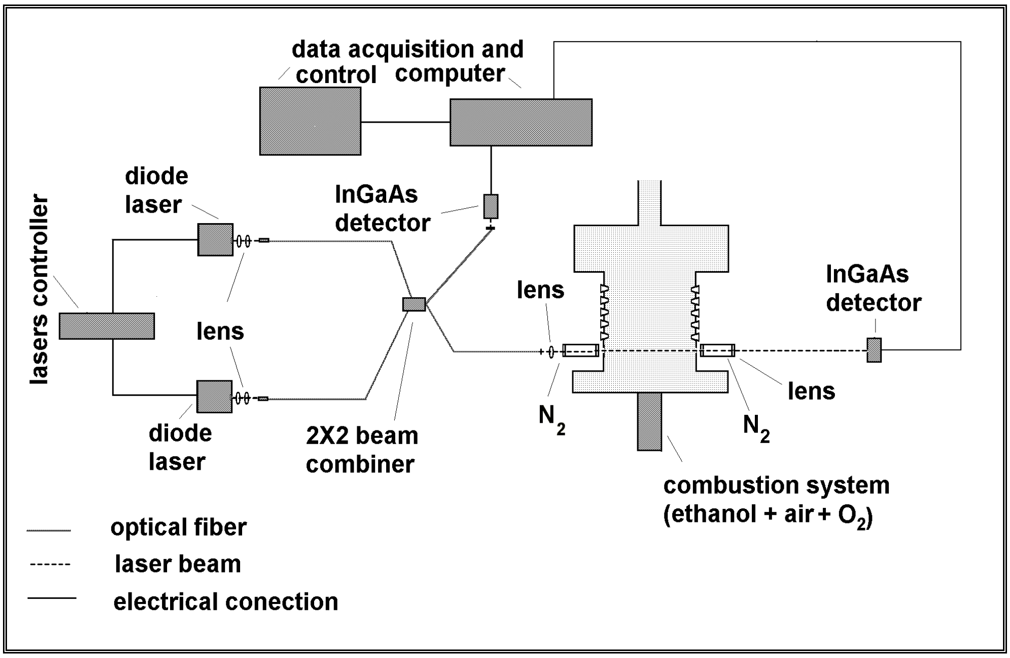

Figure 1: Schematic diagram of the combustion-control experimental arrangement.

Results and Discussions

Figure 2 shows the tuning of the diode laser with the laser temperature and injection current. The tuning of the laser 1 is [0,0134±0,005] nm/mA and [0,0880±0,0009] nm/ºC; The tuning of laser 2 is [0,0124±0,001] nm/mA and [0,0971±0,0004] nm/ºC. These data were used to correctly tune the diode laser over the desired water absorption lines.

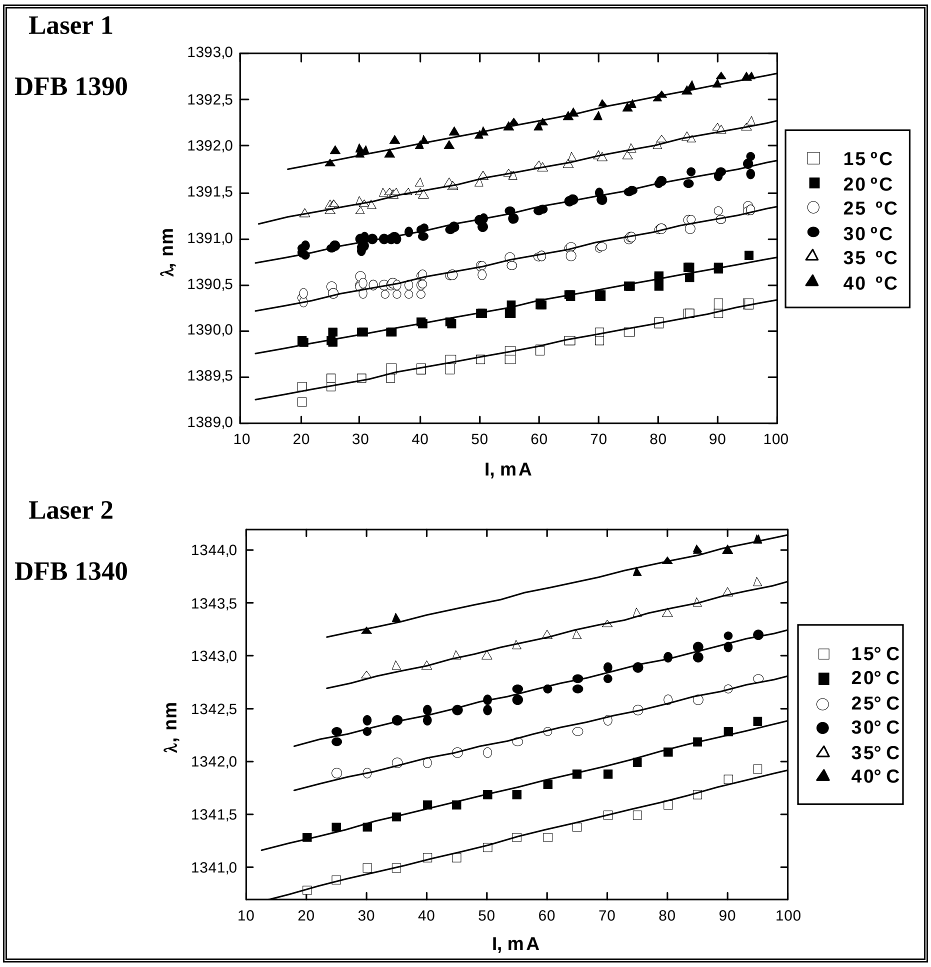

Figure 2: Tuning of the diode lasers.

Figure 3 shows single-sweep transmission signals obtained by tuning each laser independently at a 1 kHz rate across the respective H_2O absorption lines over the ethanol-air-O_2 flame. Each time-dependent transmission signal was normalized by the incident laser intensity. Measurements were made with and without the flame. The experimental absorbance ratio $A_{7444.36}/A_{7185.59}$ were compared with the previously calculated theoretical prediction [7] shown in Figure 4 and the flame temperature obtained.

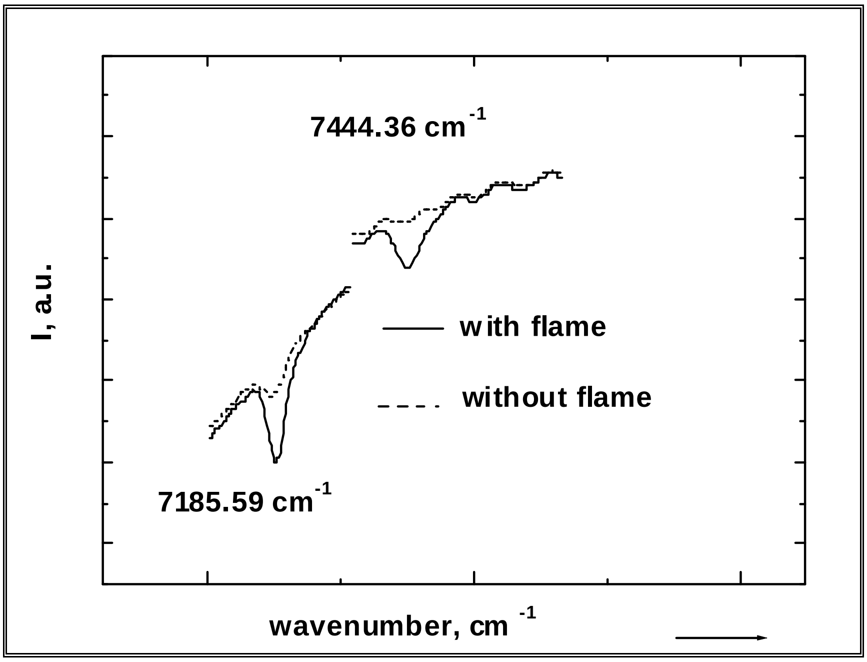

Figure 3: *In situ* spectra at ethanol-air-O_2 flame 20 cm above the burner. (Ethanol flow rate: 25 mL.min^{-1}, Atomization air flow rate: 36760 mL.min^{-1}, O_2 flow rate: 18310 mL.min^{-1}).

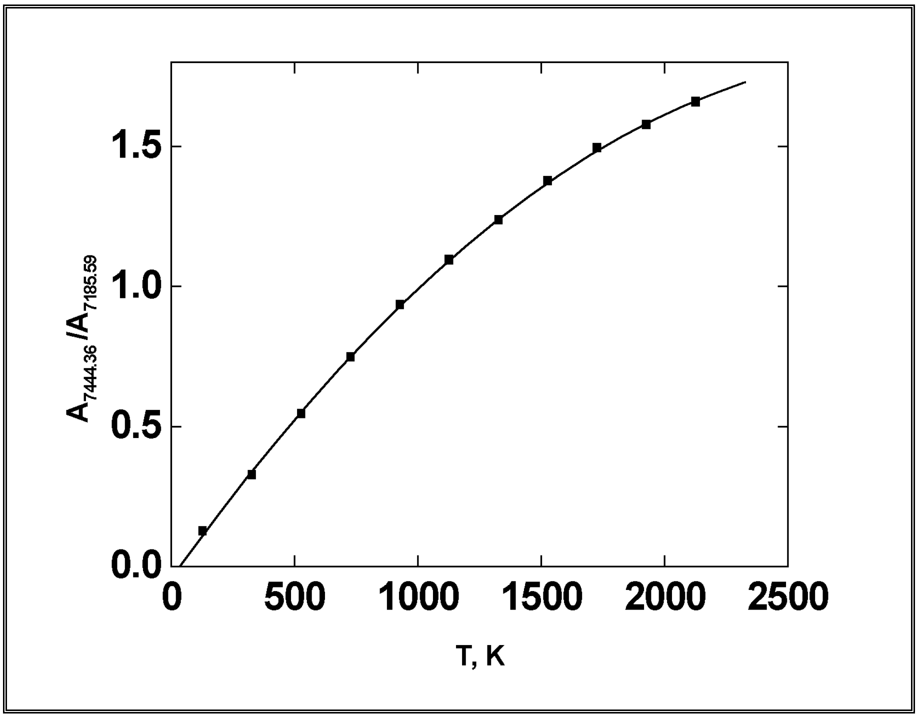

Figure 4: Temperature dependence of the line strength ratio of the 7444.36 cm^{-1} (1373.30 nm) and 7185.59 cm^{-1} (1391.67 nm) lines of water used for temperature determination; calculation based on HITEMP data [7].

Table 1 shows the experimentally data for the ethanol/air/O_2 flame of our experiment at 20 cm from the exit of the burner. At this point we obtained a temperature of [1550±100] K. Using the thermodynamic constants to calculate the flame temperature (GASEQ software), we obtain a temperature of 2500 K for this combustion condition. The difference between the expected temperature and the obtained in our experiment can be explained by the fact that the measured spectroscopy temperature is a mean value across the 15-cm burner internal path length (the flame do not cover all this path length).

Table 1: Flame temperature obtained using diode laser spectrtoscopy in a ethanol/air/O_2 system.

Ethanol/air/O_2 flow rate (mL/min):25/36760 /18310			
$A_{7444,36}$	$A_{7185,69}$	$A_{7444,36}/A_{7185,69}$	T (K)
0,152±0,004	0,125±0,005	1,21±0,06	1550±100

The comparison with the thermocouple measurement could not be made because the flame temperature surpassed the operational limit of our thermocouple, around 1500 K. However it can be said that the temperature is greater than 1500 K.

Conclusions

A multiplexed diode-laser sensor system comprising two diode lasers and fiber-optic components has been developed to nonintrusively monitor the temperature over a single path using scanned-wavelength laser absorption spectroscopy. The system may be useful for a variety of applications including combustion control. To the best of our knowledge, this is the first work employing diode laser to combustion studies in Brazil.

Acknowledgements

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