Cesium-based Temperature and Pressure Sensor

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Overview

Previously we reported a multiple, fixed-wavelength sensor for measuring the gas temperature of detonation products. While this sensor provided important results, the rapid, broad-wavelength-scanning capabilities of advanced diode laser technologies allow for a simpler and more robust technique to measure both temperature and pressure simultaneously. This technique, described below, provides gas temperature and pressure histories, spanning 2000 - 4000 K and 0.5 - 30 atm, respectively, with microsecond time response.

Fig. 1 depicts a single-wavelength sensor used to measure PDE burned gas temperature and pressure. For this technique, a vertical cavity surface emitting laser (VCSEL) probes the absorption lineshape of the ~852 nm D2 transition of atomic cesium which is seeded (5 ppm seeding fraction) into the feedstock gases of the C2H4/O2-based Stanford PDE facility. Using aggressive injection current modulation, the VCSEL is scanned across a 10 cm-1 spectral window at 1 MHz rate providing absorption lineshapes with microsecond time resolution. As the detonation wave passes the measurement station, detector 1 monitors Cs absorption lineshapes, and detector 2 simultaneously monitors Cs emission from the volume probed by the VCSEL beam. Fig. 2 shows both laser the laser transition signal for multiple scans for different times throughout the PDE cycle. By performing a two-line Voigt fit on the Cs absorbance lineshape, the spectroscopic parameters including integrated area and collisional width can be extracted.

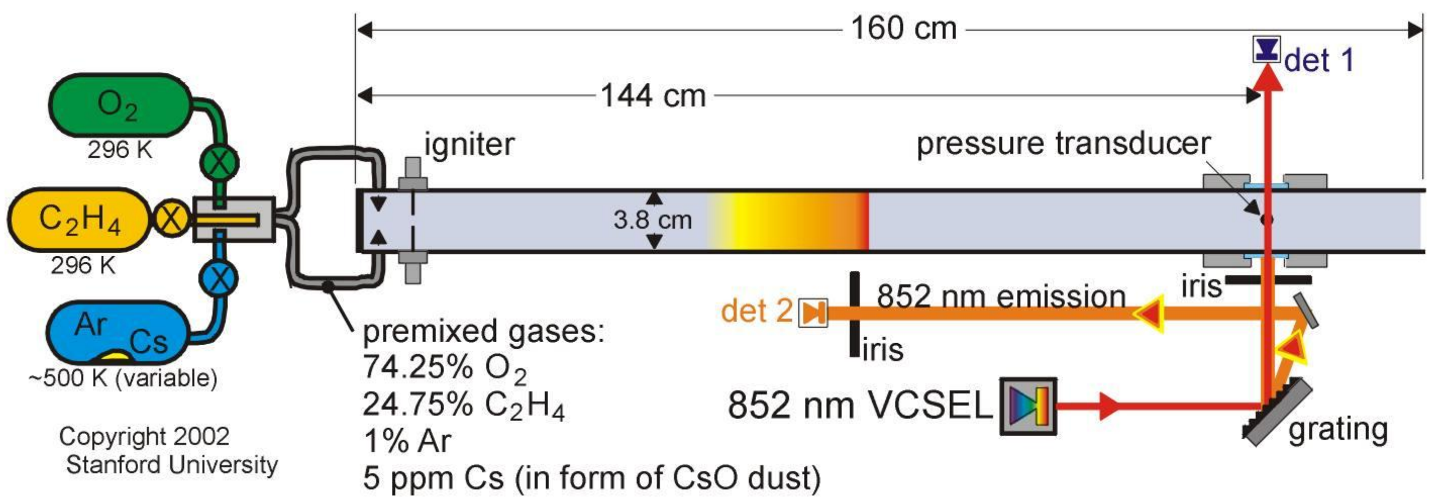

Figure 1: Schematic of the Stanford PDE facility, with VCSEL-absorption sensor applied to measure gas temperature and pressure near the exit. Detector 1 monitors Cs absorption lineshapes and detector 2 monitors thermal emission from Cs

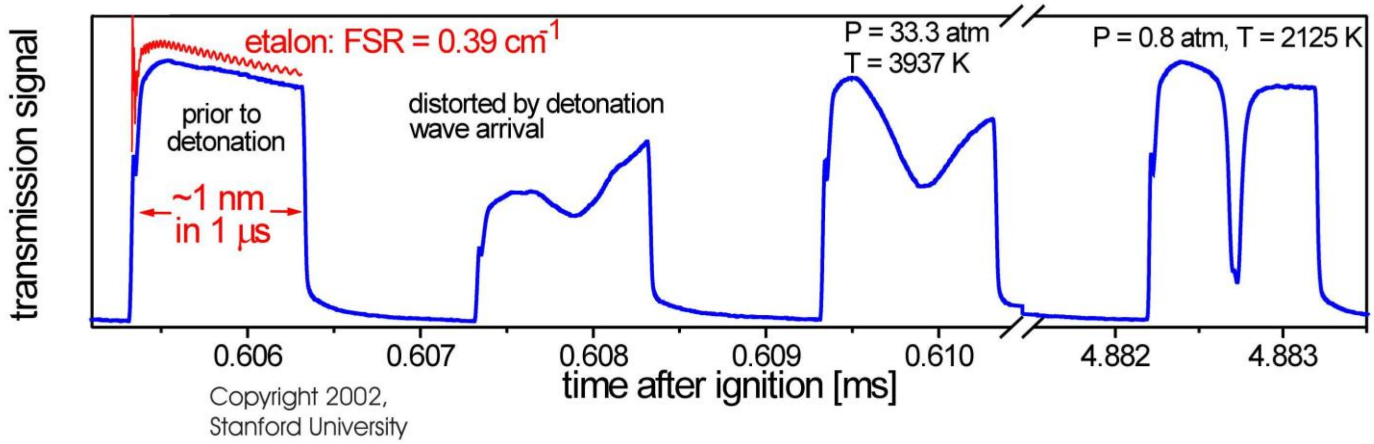

Figure 2: Raw transmission data recorded by detector 1 of Fig. 1, with etalon trace overlaid. The first scan is prior to the detonation wave arrival. The detonation arrives during the second scan, and for this scan only the associated beamsteering noise is on the order of the scan repetition rate, thus preventing an accurate absorption measurement. The third scan provides a high-quality absorption feature exhibiting strong collisional broadening. The fourth scan is approximately 4 ms after the detonation wave arrival, and reveals hyperfine splitting.

Temperature can be measured by two methods using this technique; the results are shown in Fig. 3 compared to a simulation performed by the Naval Research Laboratory (NRL). The electronic temperature, TCs, electronic, is obtained from the ratio of the Cs population in the excited state (emission signal) to the Cs population in the ground state (integrated absorbance area). The kinetic temperature, TCs kinetic, is calculated using a pressure measurement obtained from a sidewall transducer and the temperature-dependent collisional width of the absorption lineshape. Spectroscopically measured pressure, shown in Fig. 4 compared to both NRL simulations and transducer measurements, can be calculated using the electronic temperature and the measured collisional width of the Cs absorption lineshape. For both the temperature and pressure results, trends in measurements agree with the NRL simulations although discrepancies in the magnitude are apparent. These results are an important component of an ongoing effort to advance PDE development by validating numerical simulations.

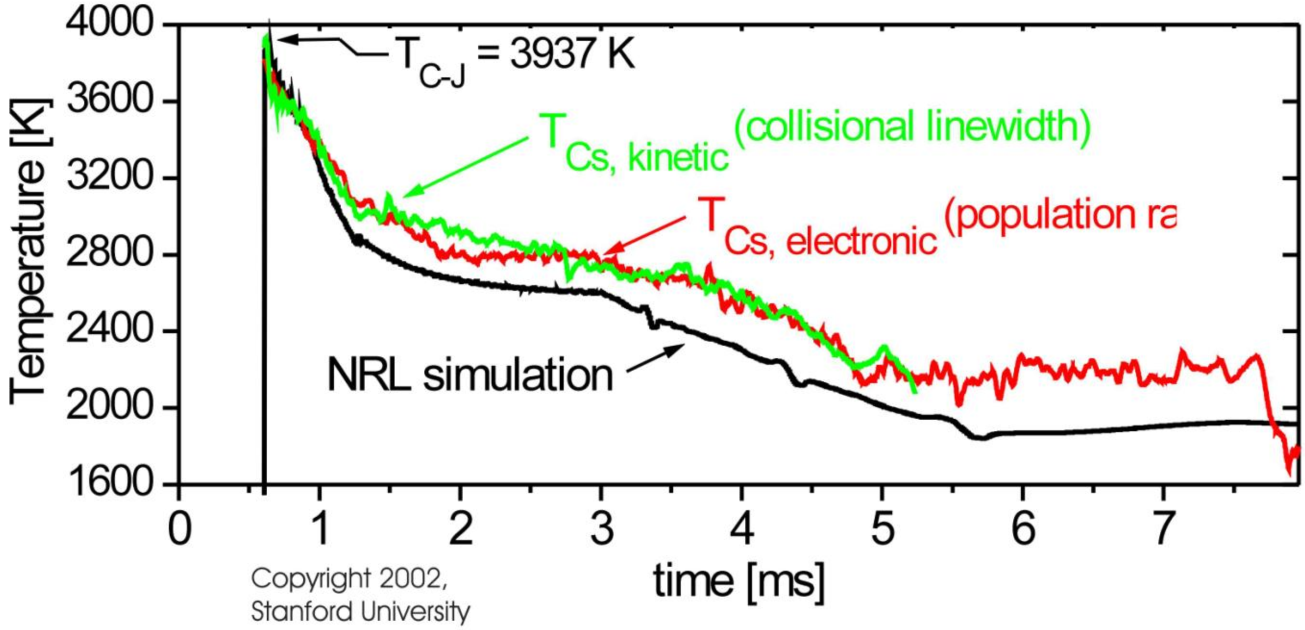

Figure 3: Measured and computed gas temperatures for detonation of stoichiometric C2H4 / O2. The computational simulation was supplied by K. Kailasanath at the Naval Research Laboratory.

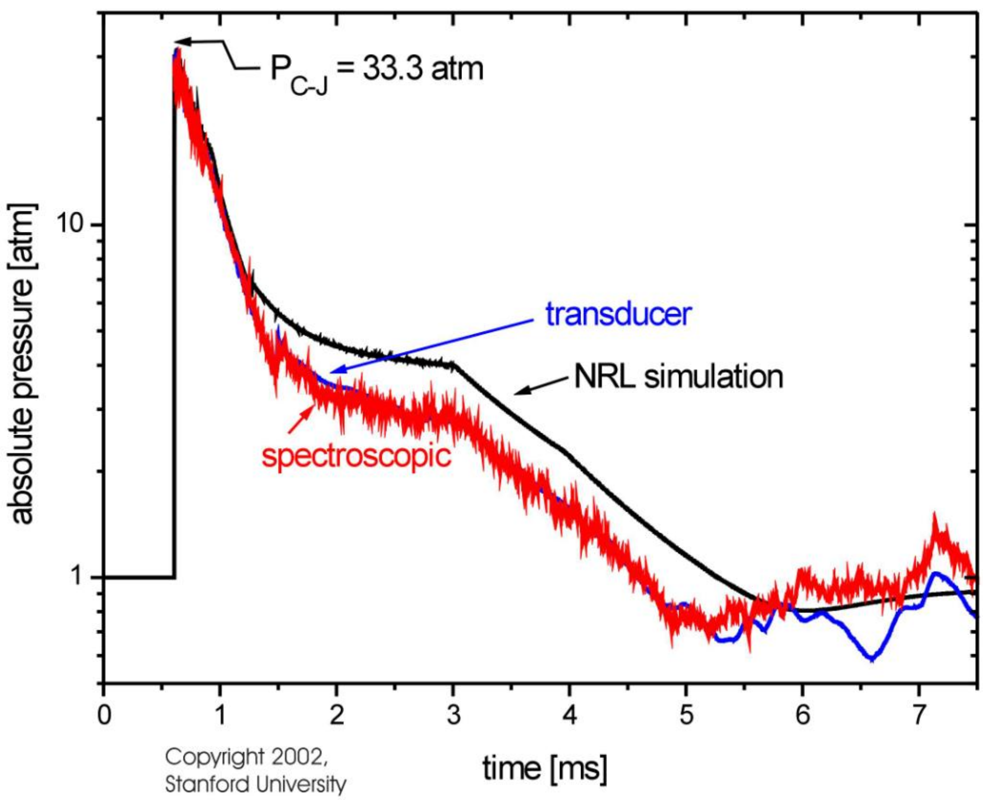

Figure 4: Measured and computed pressures for detonation of stoichiometric C2H4 / O2. The computational simulation was supplied by K. Kailasanath at the Naval Research Laboratory.