

Two photon LIF measurements of CO

U. Bhayaraju and S. Hochgreb

*Engineering Department, University of Cambridge,
CB2 1PZ, UK*

R. Barlow

*Combustion Research Facility, Sandia National
Laboratories, Livermore, CA 94550, USA*

Contact | sh372@cam.ac.uk

Introduction

CO is an important component of reacting flows and its detection is very significant in both experimental and numerical combustion research^[1]. Recently, developed non-intrusive optical techniques use two-photon excitation to populate the higher electronic states. CO can be detected through the visible wavelength fluorescence excited by two-photon absorption in $B \rightarrow X$ band. Two 230 nm photons promote transitions within $B \rightarrow X$ (0,0), and detection of the laser induced fluorescence (LIF) proceeds by collection of the blue-to-green fluorescence in the angstrom bands ($B \rightarrow A$). Calibration can be done with reference to well studied laminar flames. Experiments were performed to characterize the performance of the experiments and define the power necessary for measurements in turbulent flames.

The fluorescence signal peaks close to 86916 cm^{-1} which corresponds to $\sim 115.05 \text{ nm}$. This corresponds to 230.1 nm required excitation wavelength which is in UV range^[2]. The 230.1 nm is produced by a Dye Laser with a use of R590+R610 dye mixture. The following sections describe the experimental setup and the CO LIF setup.

Experimental setup

Experiments were performed on a 50 mm diameter laminar premixed flame, using methane and air (figure 1). The air from the supply unit and the methane are mixed approximately 1 m upstream before the mixture is fed to the burner. The air flow rate is held constant at 55 l/min. Methane flow rates are varied from 4.76 l/min to 6.67 l/min.

Two photon CO LIF is used to determine CO concentration. Figure 2 shows the schematic of the CO-LIF setup. The 230.1 nm laser beam to excite the CO radicals is produced by mixing 293.6 nm and 1064 nm IR beam in a wave mixer. An Nd:YAG laser (Continuum) operating at second harmonic (532 nm, 460 mJ/pulse) is used to pump the Dye laser (Sarah Make) to produce a 587.2 nm wavelength beam by adding the two frequencies. A Dye mixture of Rhodamine R610 and R590 solved in methanol is used for the oscillator and amplifier of the Dye laser. The R610 dye with a mixture fraction of 0.25g/l and R610 with a mixture fraction of 0.09 g/l are mixed with the ratio of 6:1 for the oscillator. The same mixture is diluted to 10% for the amplifier by adding methanol. The dye laser outputs after amplification a laser pulse of $\sim 120 \text{ mJ/pulse}$ at 587.2 nm. A KDP Crystal is used to double the frequency to obtain a UV beam of $\sim 17 \text{ mJ/pulse}$ at 293.6 nm. The IR beam at 1064 nm from the Nd:YAG laser and the 293.6 nm beam are mixed in a wave mixer



Figure 1. Premixed laminar flame burner.

(InRad make) to produce a 230.1 nm beam. The 1064 nm beam is stretched by $\sim 1.5 \text{ m}$ before it passes through the wave mixer to compensate for the path length in the Dye laser. A series of IR reflectors are used for this purpose. The beam after the wave mixer has a combination of 230.1 nm, 293.6 nm and 1064 nm wavelength beams. A set of

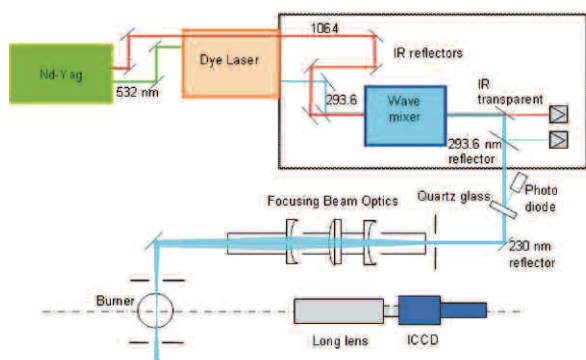


Figure 2. Schematic of CO LIF setup.

beam splitters and band pass filters are used to extract the 230.1 nm as shown in the figure. The laser beam has energy of about 4 mJ/pulse at 230.1 nm after the wave mixer. The energy of the 230.1 nm beam is measured to keep track of shot to shot variation in the laser pulse energy. A quartz glass is used to partially reflect the 230.1 nm beam. A photo diode with a UV filters is used to measure the energy of the partially reflected 230.1 nm beam. The 230.1 nm has energy of about 2 mJ/pulse at the burner. A set of focussing lenses are used to have a tight focus of the 230.1 nm beam at the burner. The beam waist is around 0.3 mm. This is essential as the absolute cross section of CO absorption determines the signal strength and the molecular concentration of CO radicals. The level of laser energy and the beam waist is required for photoionization to be the dominant mechanism from the CO excited state, such that the measured exponent for the dependence of fluorescence signal on laser power is nearly unity and the influence of collisional quenching on the fluorescence yield is suppressed^[4]. An Intensified CCD camera (Nanostar LaVision) is used to capture the CO fluorescence at ~484 nm. Figure 3 shows the CO-LIF setup after installation. To test the CO LIF setup initially a CO dye cell was used, as shown in figure 4. The concentration of CO in the cell was about 1% by volume mixed with air. The Dye cell has quartz UV transparent quartz. The cell is placed on top of the burner and the 230 nm beam is passed through the cell.

Results and discussion

The absorption band of CO at room temperature is around 0.030 nm wide. A 90 mm grating with groove density of 1800 lines/ is used in the Dye laser which has an absolute wavelength error of <0.03 nm with a wavelength reproducibility of 0.005 nm and a calibration error of 30 pm. The individual lines are very close compared to the laser linewidth. The dye laser is slowly scanned at a rate of 0.002 nm per second from 587.4 nm to 586.5 nm repeatedly. The CO fluorescence is observed peaking at 586.94 nm. The dark blue line on top of the burner in figure 5 shows the emission of the CO fluorescence at around 584.94 nm. In this particular experiment, Instead of the CO cell, CO-Air mixture is fed through the burner. A CCD camera is used as the signal is too weak to be captured by the camera. The wavelength is compared with the most prominent data available in the literature. Table 1 shows the scan compared with other scans. The various

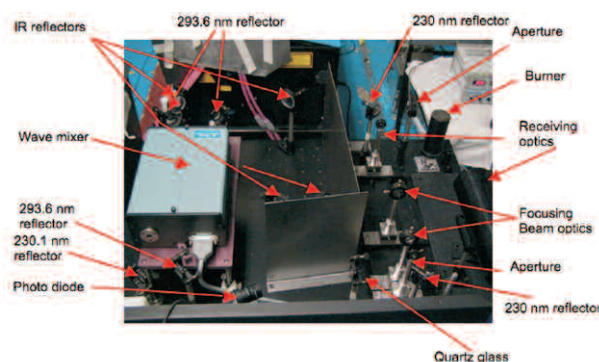


Figure 3. CO LIF setup elements.

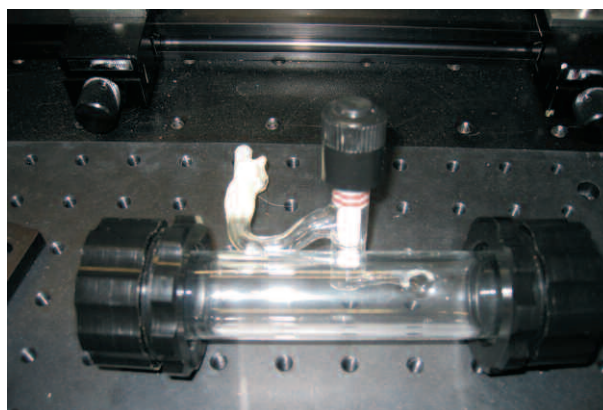


Figure 4. CO quartz cell.



Figure 5. CO-LIF image, taken with a digital unintensified video camera. The image is clearly visible with to the unaided eye.

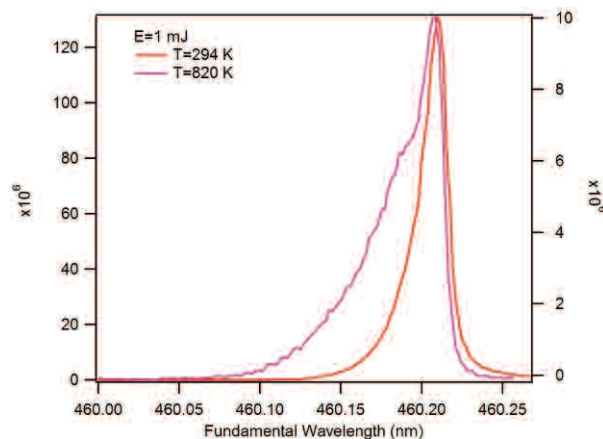


Figure 6. CO fluorescence at 230.025 nm (Courtesy Dr J Frank, Sandia National Labs).

wavelength ranges where the peak of fluorescence observed are within 0.25 nm at the 587 nm dye stage.

The cold emission spectra of CO signal has a width of 0.03 nm FWHM (full width at half maximum). The bandwidth of the spectra is shown in figure 6 at two temperatures. As can be observed from the graph the CO spectrum broadens as the temperature increases. At high temperatures, typically flame temperature of 2000 K, the CO spectrum is very flat towards the shorter wavelength side of the peak. For measurements in flames, typically, the peak in the cold spectrum is obtained first and then moved over to the 75% level in the shorter wavelength direction as the results at flame temperature are not sensitive to the exact wavelength.

Conclusions and further work

Further quantification of the CO fluorescence signal in cold flow and in flame could not be achieved. There were several technical problems encountered during this period. Lower power than specifications, requiring a change of flashlamps, and a bursting of the dye laser tubes required major clean up and further realignment of the optical units in the dye laser. After achieving the CO signal in cold flow, the experiments are conducted to capture the signal in the flame and continue with quantification of the CO signal. However, the Intensified CCD camera triggering circuit did not work to the requirements with any further success.

We are happy with the results of the experiment, however, which allowed us to become experienced in the probing of CO in flames, and enabled us to determine whether the technique is appropriate for use in our laboratory, as well as what kind of equipment and infrastructure is required.

References

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