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# SIMULTANEOUS MEASUREMENT OF RELATIVE OH CONCENTRATION, TEMPERATURE, AND FLOW VELOCITY IN $H_2/0_2$ FLAME BY SATURATED PHOTOTHERMAL SPECTROSCOPY

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## SUMMARY/OVERVIEW:

The object of our experiments is to develop photothermal deflection spectroscopy (PTDS) into a technique capable of measuring minority species concentration, temperature, and flow velocity, simultaneously in a flame. We have demonstrated the simultaneous measurement of *relative* OH concentration, temperature, and flow velocity in an $H_2/O_2$ flame using saturated PTDS. By working in the saturation regime, relatively large signal-to-noise ratio is obtained, and effect of pulse-to-pulse energy fluctuation is minimized. In the next period we will try to obtain *absolute* concentration measurements, along with the temperature and the flow velocity.

## TECHNICAL DISCUSSION:

The goal of our experiments is to develop photothermal spectroscopy (PTDS) for a simultaneous measurement of the minority species concentration, temperature, and flow velocity in a flame. The basic idea is as follows: A laser beam (hereafter called the pump beam) passes through the flame. The laser is tuned to the absorption frequency of the molecules to be measured. The molecules absorb energy from the laser. Subsequently, most of the molecules decay by nonradiative means (i.e., they are collisionally de-excited). Thus, the optical energy eventually appears in the thermal modes of the flame gases. In other words, the optically irradiated region gets slightly heated. The heating is accompanied by a change in the index of refraction. This refractive index change is probed by another, weaker laser beam which we shall refer to as the probe beam. The change in the refractive index has a spatial profile that mimics the spatial profile of the pump beam. The pump beam is assumed to have a Gaussian spatial profile. Thus, the probe beam experiences an inhomogeneous refractive index, and gets deflected by a small amount. We measure this deflection and the amplitude of the deflection is proportional to the concentration of the absorbing species. We use a pulsed laser for the pump beam. Thus, the absorption of the pump beam produces a pulse of heat. In a flowing medium, the heat pulse travels downstream with the flow. We set our probe beam slightly downstream from the pump beam. We measure the transit time of the heat pulse and, from it, deduce the flow velocity of the medium. The heat pulse broadens due to thermal diffusion as it travels downstream. From a measurement of this broadening we determine the thermal diffusion constant of the medium. Since the thermal diffusion constant is proportional to the temperature of the medium, we can measure the temperature of the medium. Thus, the measurements of the amplitude, transit time, and the broadening of the photothermal deflection signal can yield measurements of the species concentration, flow velocity, and temperature, respectively, all simultaneously in a single laser pulse.

We started our experiments in a well-characterized cold flow (a room-temperature jet of $N_2$, seeded with 0.5% of $NO_2$). We chose $NO_2$ as the seed gas for experimental convenience. $NO_2$ is gaseous at room temperature, and has a quasi-continuous absorption throughout the visible range of the spectrum. Photothermal signals from laser absorption by $NO_2$ were observed. For laser energy necessary to obtain sufficient signal-to-noise ratio, the PTDS signals were observed to have significant optical saturation. The analysis of the signals in the presence of optical saturation is complicated. The effect of optical saturation on the PTDS signals, with the absorbing species modeled as a two-level system, was investigated.[1] The PTDS signals from $NO_2$ were analyzed for $NO_2$ concentration, temperature, and the flow velocity by a multiparameter fitting procedure and, after correction for the effects of optical saturation and flow velocity gradients, reliable values of the three parameters were obtained.[2]

Having learned about all the issues that can complicate the analysis of the PTDS signals and could possibly lead to erroneous results in a well-characterized cold flow, we have now started the flame experiments. PTDS signals generated by OH in a stiochiometric $H_2/O_2$ flame have been observed, and analyzed to yield relative OH concentration, temperature, and flow velocity by the multiparameter fitting procedure. Figure 1 shows the three measured parameters as a function of the position from the center of the flame. Panel (a) shows the relative OH concentration; Panel (b) shows the temperature; and, Panel (c) shows the flow velocity. In Panel (a), the solid circles represent the profile of the relative OH concentration determined from the PTDS signal amplitude with the probe beam 0.03mm upstream from the pump beam where the maximum PTDS amplitude occurs immediately after the laser excitation. The open circles represent profile of the relative OH concentration obtained from the PTDS signal with the probe beam 0.33m downstream from the pump beam. The general agreement between these two profiles gives us confidence that the relative OH concentration shown here is the true profile of the OH concentration. The measured temperature shown in Panel (b) is obtained from the measured thermal diffusivity via the temperature dependence of the thermal diffusivity of the $H_2O$ steam. The dashed line in Panel (b) indicates the theoretical temperature of 3080K, for a 1:1 $H_2/O_2$ flame. It shows that the measured temperature is close to the literature value. The open circles in Fig. 1(c) show the measured values of the flow velocity. The solid line is a fit to the data, assuming that the velocity profile is given by an ideal laminar flow. The fitted value of maximum velocity is 45.0m/s, which is close to the value, 43.2m/s, derived from the measurement of the flow rate of the gases by a flowmeter and assuming the radius of the flame at the measurement height to be 4.4mm (which is the half-width of the solid curve in Fig.1(c)) and the flame temperature to be 3080K. These results have been submitted for publication to *Applied Optics*.[3]

In conclusion, we have demonstrated, for the first time, the measurement of the kinetic temperature of a flame by the PTDS technique, and also demonstrated that a simultaneous measurement of the relative concentration of minority species, temperature, and the flow velocity can be made from the analysis of a *single data trace*. To the best of our knowledge, no other technique has demonstrated the *simultaneous* measurement of these three parameters in a flame.

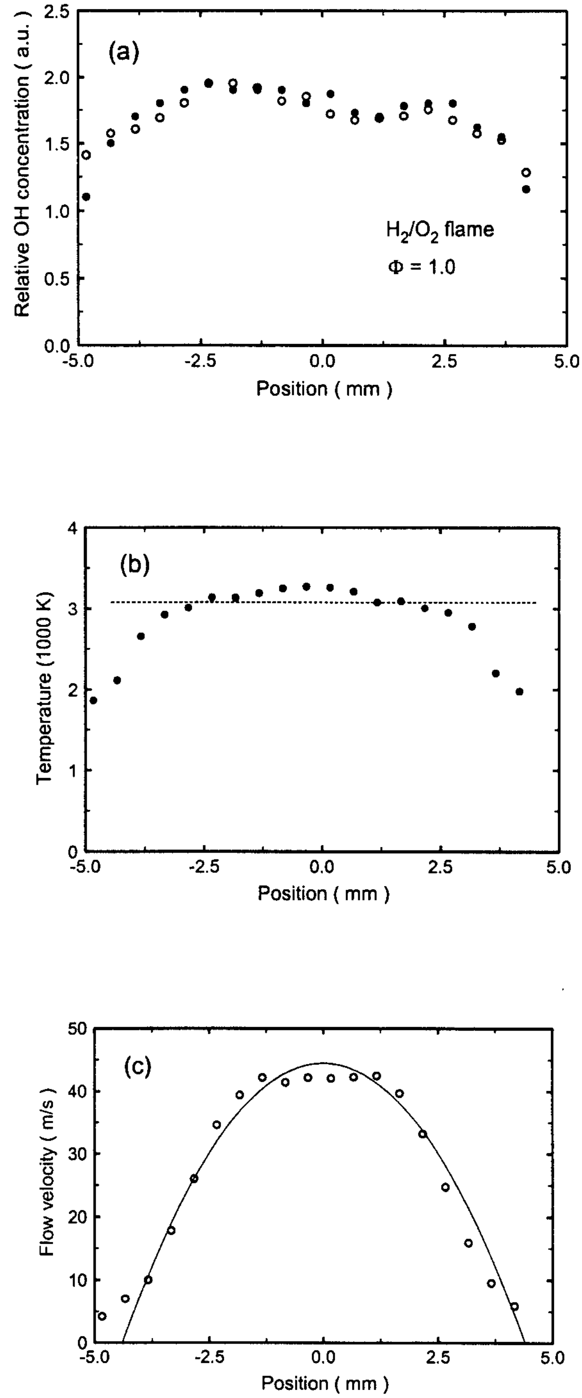


Figure 1. The radial distribution of the (a) relative OH concentration; (b) temperature; and, (c) flow velocity, simultaneously measured in a 1:1 $H_2/O_2$ flame. The open circles in (a) represent the relative OH concentration measured with the probe beam 0.33mm downstream from the pump beam whereas the solid circles represent that measured with the probe beam 0.03mm upstream. The dashed line in (b) shows the theoretical value of the temperature. The solid curve in (c) is the best fit to the data by the velocity distribution of an ideal laminar flow.

We have worked in the energy range where the PTDS signal is optically saturated, thus, an accurate measurement of the laser pulse energy is not important and pulse-to-pulse fluctuations in energy do not significantly degrade the reliability of the results.

OH concentration measurements we have made are the *relative* concentration measurements. It is the goal of our experiments to measure absolute concentrations without calibration against a flame with known concentration. In order to obtain absolute concentration without calibration, we need to have a quantitative understanding of the effects of optical saturation on a real molecule like OH, which cannot be modeled as a simple two-level system. Our goal in the next reporting period is to achieve such an understanding and to make absolute concentration measurements simultaneously with temperature and flow velocity.

**References:**

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