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DYE JET VELOCITY DISTRIBUTION MEASUREMENTS USING PHOTOTHERMAL DEFLECTION SPECTROSCOPY

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Abstract

We demonstrate that photothermal deflection spectroscopy can be used to measure velocity distributions in dye jets. Such measurements are useful in determining the quality of flow in dye jets. The quality of jets is very important for a stable and narrow linewidth operation of dye lasers.

Introduction

Recent advances in CW dye laser technology rely heavily on the ability to produce high-velocity thin sheets of flowing dye solutions. Generally, excellent optical quality and stability over substantial areas under high flow conditions are necessary [1-3]. Knowledge of the thickness stability of the jet versus operating pressure (velocity) would assist in choosing an optimum pressure for a stable single frequency operation [4]. In addition, a high flow velocity is necessary to remove the heat produced by nonradiative processes and Stokes shifts as well as to remove the dye molecules in triplet states generated in the active region [5,6]. The emission linewidth of the laser is determined by thermal fluctuations of the dye solution, mechanical instabilities of the laser, power fluctuations of the pump laser, and velocity fluctuations in the flow of the dye solution. After emerging from the nozzle, the stream starts to reduce its cross section due to surface tension and due to a non-constant velocity distribution. Optimum flow velocity is the one that corresponds to minimum thickness fluctuations [7,8]. The theory of flow of an incompressible liquid in a jet is rather complicated [9]. Thus, it would be easier to measure the flow velocity in a jet for the above purpose as well as for other reasons [10].

The velocity measurements in a pipe flow have been made by particle method [11], by hot wire method [12,13] and by injection of thermal pulse into the boundary layer [14]. Each method has its own limitation and generally speaking is not applicable to jet stream. This paper demonstrates that photothermal deflection spectroscopy (PTDS) [15,16] is a useful technique for this purpose.

In this technique, radiation from a pulsed laser is focused on a dye jet. The absorbed optical energy is quickly transferred into rotational-translational modes of the jet medium because of fast quenching collisions. That is, the laser irradiated region becomes slightly heated and a pulse of heat is produced. The temperature profile of the laser irradiated region is then a true replica of the intensity profile of the laser beam. The refractive index of the medium in the laser-irradiated region follows the temperature profile, and therefore it acquires a profile that is an image of the laser intensity profile. Since the medium is flowing, this thermal image moves downstream with the flow velocity of the medium. The thermal image broadens slightly owing to thermal diffusion as it moves downstream (this broadening is negligible in our case). The thermal image is probed by a second laser beam placed a distance Δx downstream from the pump beam. We refer to this beam as the probe beam. As the thermal image passes by the probe beam, this beam gets deflected by the gradients in the refractive index of the medium created by the absorption of the pump beam. The deflection of the probe beam can easily be monitored by a position sensitive optical detector. The temporal waveform of the signal is just the derivative of the spatial profile of the pump beam [16]. The temporal waveform can be captured by a transient digitizer or simply by an oscilloscope. The arrival

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time of the heat pulse is measured downstream at two points a known distance apart. A measurement of the transit time between the two positions of the pump beam yields the flow velocity of the dye jet.

Experimental Section

The experiment is shown schematically in Fig. 1. The pump beam was provided by a Quanta-Ray DCR-3 pulsed Nd: YAG laser. This laser produced ~10 nsec-long pulses of radiation and using a second harmonic generator the wavelength 5320Å was selected. The laser energy was ~0.5 mJ. This laser has a diffraction coupled resonator (DCR) which gives a non-Gaussian output beam. The dye jet was provided by a Coherent model 591 dye pumping system (part of the Coherent 699 ring dye laser). A solution of R6G dye in ethylene glycol (approximately 1 g/1) was used. A 0.8 mW He-Ne laser provided the probe beam. The pump and probe beams were focused on jet stream by lenses of focal lengths of 30 and 20 cm, respectively. The pump beam could be translated up or down using mirror M which was mounted on a translation stage to vary the separation between the pump and probe beams. Deflection of the probe beam was monitored by a quadrant detector. The difference signal from two quadrants was measured. The probe beam was arranged in such a way that it produced a null signal in the quiescent position of the probe beam. However, shortly after the firing of the pump laser, a deflection of the probe beam was detected as a transient signal from the difference amplifier. The difference amplifier was fed to a LeCroy Model TR8837 F transient digitizer. The output of a P-I-N diode provided the trigger to the transient digitizers. The digitizer output was transferred to an IBM PC/AT microcomputer through a LeCroy Model 8901A GPIB interface. The signal was stored in the computer and displayed on the computer monitor using LeCroy Catalyst plus software.

It should be noted that it is not necessary to use a transient digitizer and computer for dye jet velocity measurements. This data acquisition system was used because it was also being used for other ongoing experiments on photothermal spectroscopy in our laboratory. The signals are strong enough to be easily observed on an oscilloscope.

Results and Discussion

Figure 2 shows the typical data. The upper trace represents the case in which both the pump and probe beams coincide. The middle and lower traces show signals when these beams are 0.1 and 0.2 mm apart, respectively. The velocity was determined using $v = \frac{\Delta x}{\Delta t}$, where Δx was the distance between the pump and probe beams. The signal consists of a series of undulations which will be explained shortly. We measured the travel time of these signals, Δt, as follows: for each signal, we measured the temporal location of a peak (shown by arrow) with respect to the firing position of the trigger. As the pump beam got farther

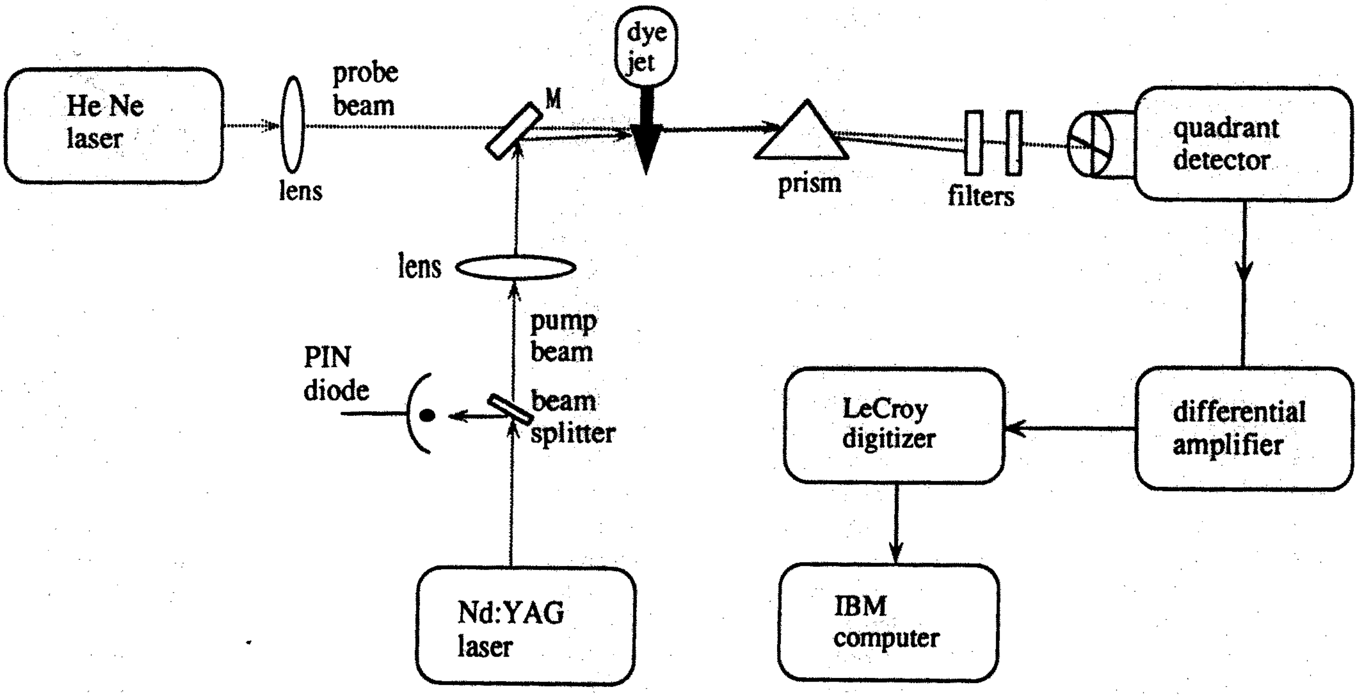

Fig. 1. Schematic illustration of the experimental arrangement

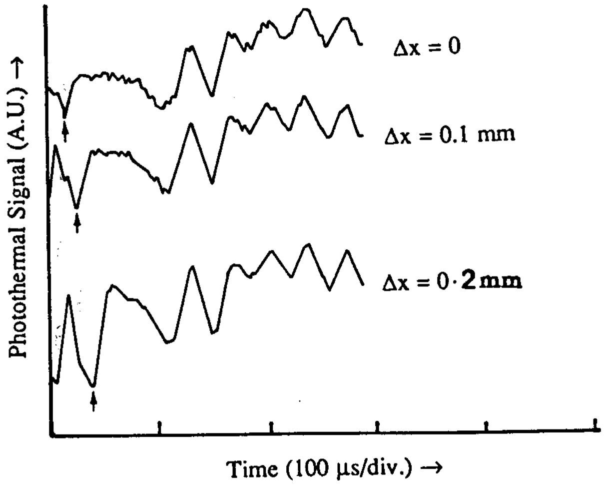

Fig. 2. Deflection of the probe beam as a function of time after the pump laser firing for various pump-probe beam distance Δx. The arrow indicates the peak that was used for these measurements.

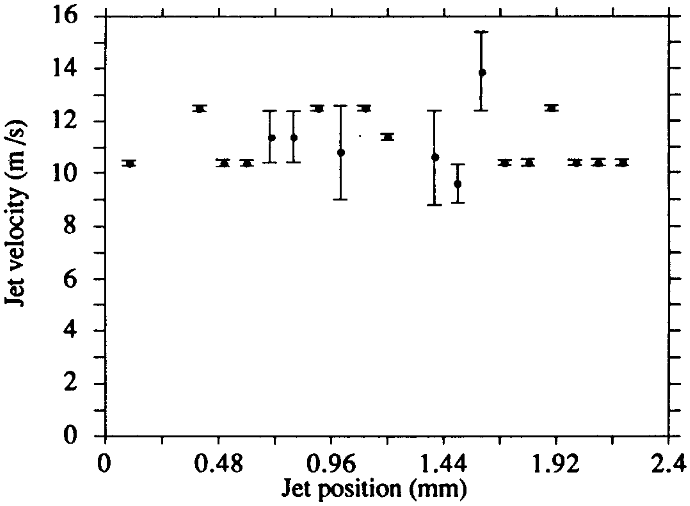

Fig. 3. Jet velocity (m/s) as a function of the jet position. The zero of abscissa has been arbitrarily chosen near one edge of the jet.

apart from the probe beam this peak occurred at a later time (middle and bottom traces). Using the cursors on the computer monitor, we could directly measure the travel time Δt. For each position of jet stream at least three measurements were made. The average of these measurements at a given position in the jet is plotted in Fig. 3. The error bars show the statistical as well as systematic uncertainties. The errors were mostly statistical. The uncertainties in measuring the position was 0.01 mm and in time was 1μ sec. The large error bars in the middle of Fig. 3 may be due to turbulence in the jet.

For a uniform medium, one expects the shape of the signal to be a derivative of the pump beam profile [16]. However, the signal that we obtained consisted of a series of undulations. At first it was suspected that this signal shape was due to the nonuniform spatial profile of this laser, which has a diffraction-coupled resonator, and consists of diffraction rings near the outer edge. To understand the signal shapes further, we repeated the experiment with a Chromatix CMX-4 flashlamp pumped dye laser which has a nearly Gaussian profile. The signal shape obtained was similar to that shown in Fig. 2. We believe that this signal shape arises due to the fact that the dye jet is very nonuniform with perhaps several layers of liquid moving with different velocities. Three different jets were examined and all of them gave similar data.

In conclusion, we have demonstrated that the PTDS can be used to measure the velocity distribution in a dye jet stream. This technique is nonintrusive, has a high degree of spatial resolution and is simple. The information given by PTDS on the magnitude and quality of flow can be used to improve the dye jets which in turn will improve the optical quality, stability, linewidth, etc. of dye lasers.

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