N87-10370

LINEWIDTH CHARACTERISTICS OF RAMAN-SHIFTED DYE LASER OUTPUT AT 720 AND 940 nm

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Existing DIAL systems for water vapor measurements in the troposphere operate at wavelengths near 720 nm[1,2]. The use of stronger water vapor absorption lines[3] in the range 930-960 nm will significantly improve DIAL measurements in the upper troposphere and lower stratosphere where water vapor concentrations are low. The generation of light at 940 nm using a frequency doubled Nd:YAG pumped dye laser is inefficient due to the small absorption of infrared dyes at the pump wavelength. However, 940 nm generation utilizing stimulated Raman scattering (SRS) of dye lasers is attractive because of a potentially high conversion efficiency plus the possibility of retaining the narrow linewidth available from some dye lasers. In this paper, the Raman conversion efficiency and line broadening are presented for first Stokes operation at 720 and 940 nm using hydrogen and deuterium as the Raman media.

Figure 1 illustrates the present experimental setup. The laser source is a Nd:YAG pumped Quanta-Ray PDL-2 dye laser. With the grating alone as an intracavity element, the dye laser linewidth is 0.2 cm^{-1} (FWHM), as recorded by a high finesse Fabry-Perot interferometer (Tropel Model 360) in combination with an Optical Multichannel Analyzer (Tracor-Northern OMA Model TN-1710). With hydrogen as the Raman medium, 940 and 720 nm were generated as first Stokes lines using pump wavelengths of 676 and 555 nm, respectively. The laser output energy was 50 mJ at 676 nm and 60 mJ at 555 nm. As observed by Byer[4], conversion efficiency decreases with increasing wavelength. In our case, we first used hydrogen in a conventional SRS cell (Quanta Ray RS-1) and corrected for losses in the optics. At 400 psi the conversion efficiency for output at 720 and 940 nm was 40 and 20 percent, respectively, and at

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200 psi the efficiency dropped to 20 and 10 percent, respectively. Figure 2 shows the first Stokes output energy as a function of hydrogen pressure in the SRS cell. In a second series of experiments, a waveguide Raman shifter (Lambda-Physik Model RS-4500D) was used with a 600-μm bore diameter for the fused silica capillary. First Stokes conversion efficiencies between 30 and 35 percent at 940 nm were observed for hydrogen pressures ranging from 150 to 350 psi. A reduction of the backward wave SRS as the pressure was lowered caused an increase in the net transmission of the waveguide. This led to a nearly constant overall conversion efficiency.

Inserting an etalon into the dye laser cavity, which narrows the laser linewidth to 0.02 cm^{-1}, we found the conversion efficiency to be the same as that measured for 0.2 cm^{-1}.

Particular emphasis was then put on the resulting SRS output linewidth, with the goal of obtaining lines as narrow as possible at 720 and 940 nm for lidar applications. Input linewidths at 555 and 676 nm and the output linewidth at 720 nm were measured with a Tropel Fabry-Perot interferometer using two sets of plates coated for these wavelengths. An additional interferometer (Tec-Optics Model FP-1) was used to measure the first Stokes linewidth at 940 nm. Fringe patterns for all wavelengths were recorded by an OMA. While the input laser linewidth at λ = 555 nm was measured to be 0.020 cm^{-1} FWHM, the first Stokes (λ = 720 nm) linewidth varied from 0.029 to 0.050 cm^{-1} for hydrogen pressures ranging from 150 to 450 psi. Fringe patterns for the input laser linewidth and the first Stokes linewidth, using a hydrogen pressure of 350 psi, are shown in Figure 3(a) and (b), respectively. Similar results were obtained for the shift from 676 to 940 nm. This broadening is due to the pressure broadened Raman linewidth that is characteristic of the gas[5]. Assuming a Gaussian spectral distribution for the laser line shape and a Lorentzian profile for the Raman line shape, we calculated the resulting Raman linewidth by deconvolution. Because the Raman linewidth broadens with pressure, the measurement accuracy becomes better at higher pressure. Figure 4 shows the output linewidths measured at different pressures and the calculated pressure broadened Raman linewidth. From these measurements the hydrogen pressure broadening coefficient was determined to be $9.2 \pm 0.9 \times 10^{-5}$ cm^{-1}/psi, which is in agreement with previous measurements[5]. A pressure shift coefficient of approximately twice the value measured for the pressure broadened Raman linewidth could be observed, but the lack of high pressure data precluded any precise measurements.

In addition to hydrogen, deuterium was also used as a Raman medium. The conversion efficiency in a conventional single pass Raman shifter was too low to conduct good measurements. For this reason the waveguide Raman shifter was used instead. At a pressure of 350 psi, approximately 25 percent of the input energy was shifted to the first Stokes line at 720 nm. This number takes into account the large amount of backward wave SRS, which was significantly greater than for hydrogen. The linewidth at the first Stokes wavelength was measured to be 0.038 cm^{-1} at a pressure of 350 psi. This corresponds to a pressure broadening coefficient of 7.7×10^{-5} cm^{-1}/psi. This agrees roughly with prior results[5].

Using conventional cell and waveguide "Raman shifters", the shifting of dye lasers in hydrogen and deuterium was investigated. The linewidth at the first Stokes wavelength was found to be determined by pressure broadening in the Raman medium. The requirement for good conversion efficiency and narrow linewidth implies the use of a low pressure waveguide, or a low pressure Raman oscillator in combination with a high pressure amplifier. Further measurements will be made to identify the optimum technique for achieving high energy and narrow linewidth. Also, the Stokes beam spectral purity will be investigated to quantify the effect of the Raman process on the spectral quality of the input beam.

The authors wish to thank Neale Mayo, Barry Benson, and Kenneth Ritter for their excellent technical assistance on this experiment.

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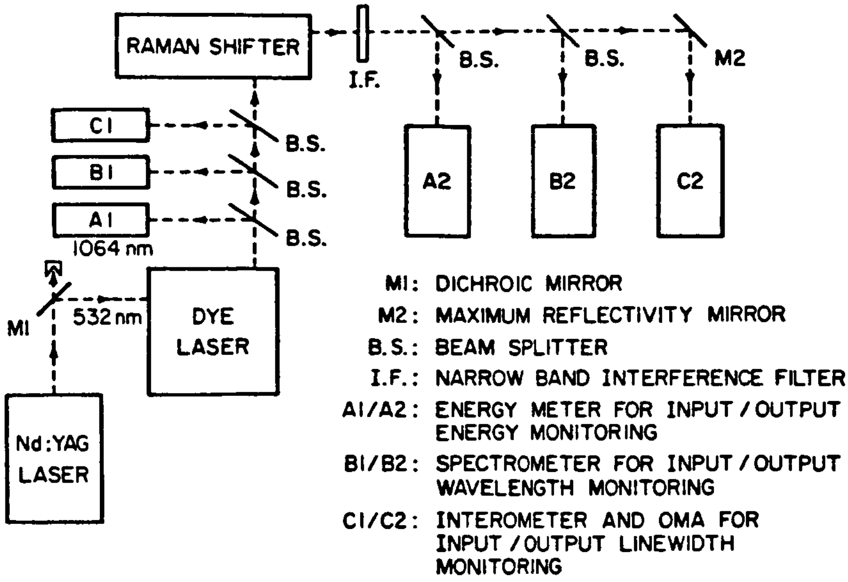


Figure 1: Experimental setup.

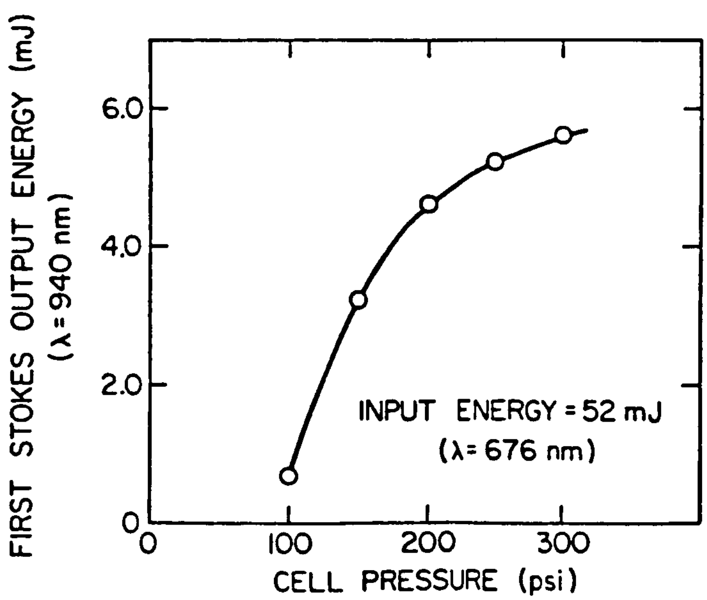
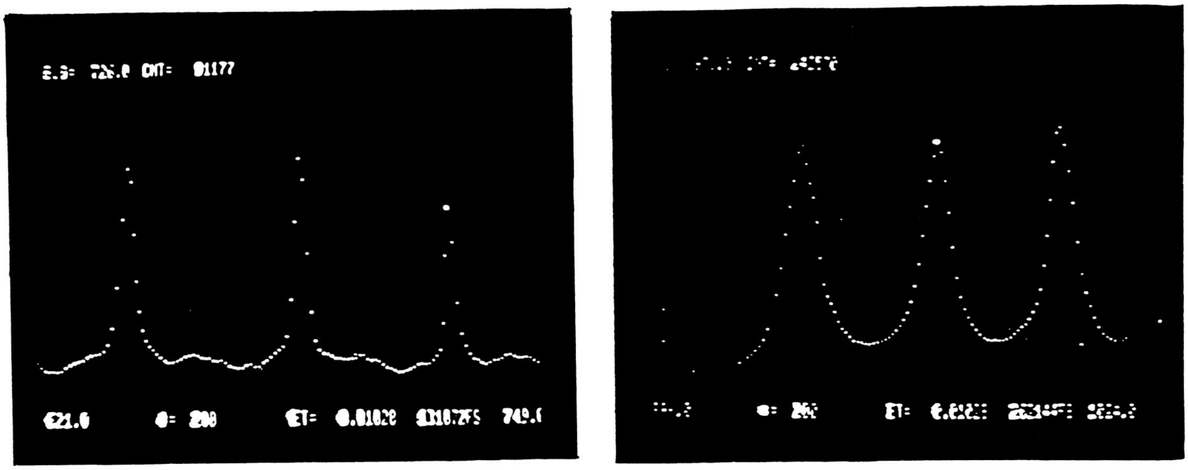


Figure 2: First Stokes output energy for SRS in H_2 pumped by 52 mJ at 676 nm versus gas pressure.



(a) (b)

Figure 3: Recorded fringe patterns of (a) the input laser linewidth (interferometer FSR = 0.25 cm^{-1}) and (b) the first Stokes linewidth (interferometer FSR = 0.20 cm^{-1}) at a hydrogen pressure of 350 psi.

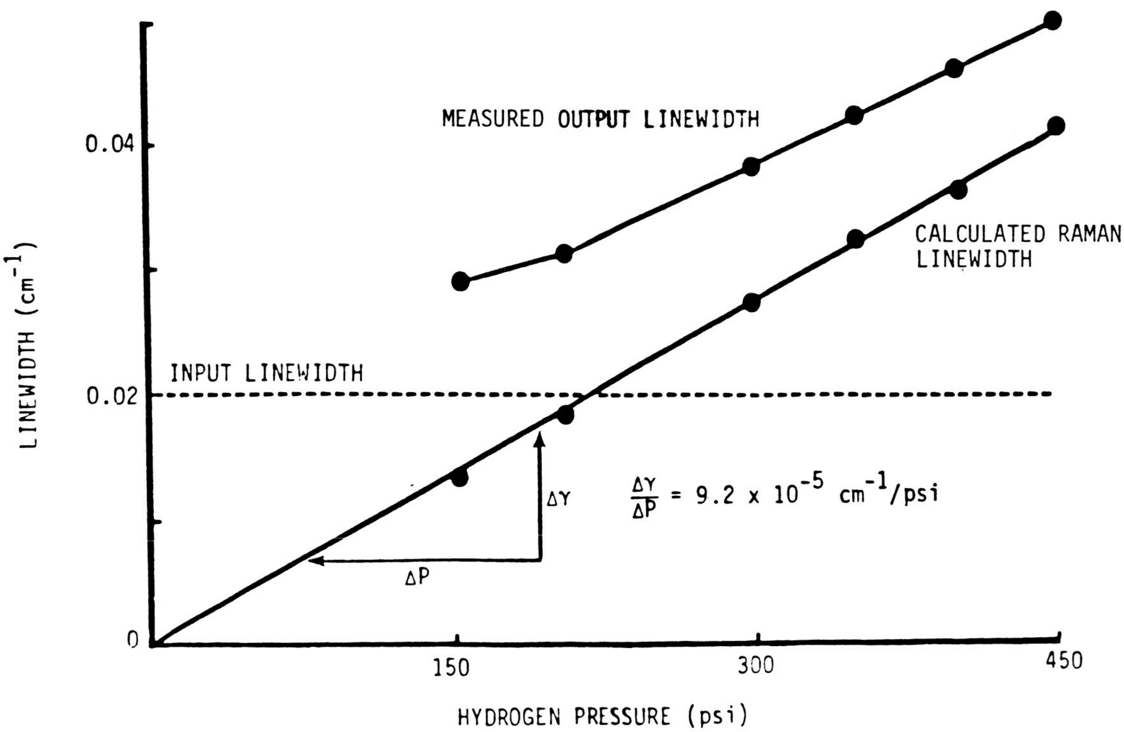


Figure 4: Output linewidth and Raman linewidth as a function of hydrogen pressure for 0.02 cm^{-1} input laser linewidth.