Development of a Spectral Filtering Technique for Lidar Applications Through Generation of a 420 nm Coherent Beam

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Abstract: Methods to separate and filter Mie, Rayleigh and Raman scattering are required in many atmospheric lidar systems and other laser diagnostic applications. This work reports on progress towards a novel filtering technique to spectrally separate components of a backscattered signal through coherent light generation in an atomic vapor cell. Specifically, this work characterizes 420 nm (blue) light generation in a heated rubidium cell arising from the mixing of 776 nm and 780 nm pump beams. The work finds the optimal pump frequencies and cell temperature and detects a signal using pump beams as low as 0.7 µW. Progress towards using the technique to detect scattered light in a lidar application is described.

1. Introduction

A major challenge in laser diagnostics and remote sensing is separating the signal of interest from noise and other scattering types. For instance, interrogation of Raman or Rayleigh scattering is often difficult because their intensities are sometimes orders of magnitude lower than Mie scattering. Several techniques have been developed in recent decades to filter these types of scattering and separate them from each other. One notable technique, which is often implemented in High Spectral Resolution Lidar (HSRL) systems, is filtered Rayleigh scattering [1]. This method takes advantage of a frequency dependent absorption medium such as a molecular iodine vapor cell to block Mie scattering and allow analysis of Rayleigh scattering [2]. Frequency dependent absorption filters also exhibit changes in their refractive index near changes in absorption, which may also be utilized to separate scattering types of different frequencies. For instance, an atomic rubidium vapor prism cell was demonstrated to spatially filter signals with sub-GHz resolution [3] while slow light imaging spectroscopy (SLIS) was used to temporally separate the signal [4,5].

This paper introduces a method to spectrally filter a signal by using a narrow portion of the signal's frequency spectrum to generate light far detuned from the original frequency of the signal. In this technique, two narrowband beams of light, one of which could be a portion of a backscattered signal, pass collinearly through an atomic vapor cell. If the frequencies of the beams are resonant with an energy level transition of the vapor, some atoms are excited first to an intermediate state, then an upper excited energy state. A portion of the excited atoms then decay through a different energy level pathway, emitting a coherent beam at a wavelength far detuned from the original beams.

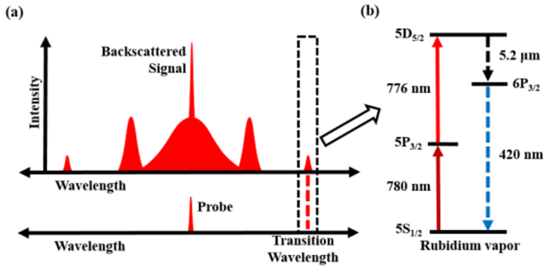

Figure 1. (a) Example backscattered signal and probe versus resonance. (b) Target 4-wave mixing pathway.

Figure 1 parts (a) and (b) depict this process. Part (a) shows a sample backscattered signal spectrum consisting of multiple components (Mie, Rayleigh, Brillouin and Raman scattering). Note that the signal intensities and wavelength spectrum are not to scale. The probe is tuned so a portion of the backscattered signal is resonant with one of the energy level transitions of the vapor cell. This offset is shown on the lower axis of part (a). Figure 1 part (b) illustrates the beam path studied in this work. Heated atomic rubidium first excites to the $5P_{3/2}$ state using a 780 nm beam. A collinear 776 nm beam, which can originate from the backscattered signal, then excites the rubidium to the $5D_{5/2}$ state. The atoms decay rapidly to the $6P_{3/2}$ state emitting infrared light at 5.2 µm, then back to the ground state releasing both fluorescent and coherent blue light at 420 nm. Blue light generation utilizing this transition pathway has been studied in past works [6-8], generating up to 1.1 mW of blue light [9].

2. Setup

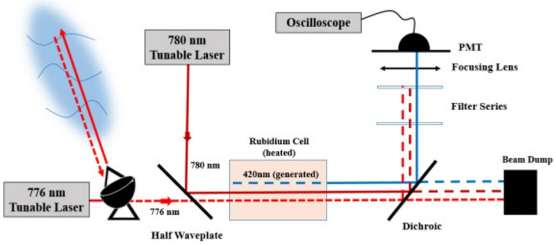

Figure 2. Experimental Setup

This work first aims to characterize the strength of the coherent 420 nm output over different pump frequencies and cell temperatures in order to generate a coherent beam using a minimal amount of pump power, since the backscattered signal is often of very low intensity. A potential setup using this technique for remote sensing measurements is pictured in figure 2. For initial experiments, a 776 nm CW beam is applied to the vapor cell instead of a backscattered signal from a pulsed probe beam as pictured. Two narrowband, tunable CW beams are produced at 780 nm (Toptica DLC TA Pro 780S) and 776 nm (MSquared SolsTis) and are combined using a half waveplate. The beams pass through a rubidium vapor cell heated up to 130° C. Inside the cell, blue light is generated both through fluorescence and coherent scattering. Upon exciting the cell, the original pump beams and the newly generated beam pass through a dichroic mirror and a series of filters to block all but the 420 nm blue light. This light is then detected by a photomultiplier tube (PMT), which is positioned approximately 35 cm from the cell to reduce the amount of fluorescent light in the signal. Part (a) of figure 3 shows the cell producing fluorescent light at 420 nm while part (b) shows the coherently generated beam scattering onto a surface positioned at the location of the PMT. Note that the color of the fluorescent and coherent light is skewed due to the camera. Part (c) of figure 3 shows the wavelength spectra of the light fluorescing from the cell in this configuration. Fluorescence at both pump beam frequencies (776 and 780 nm) is present as well as at 420 nm. Note that there is some additional scattering at both 762 nm and 795 nm, due to fluorescence from atoms decaying from the $5D_{5/2}$ state through the $5P_{1/2}$ state back to ground.

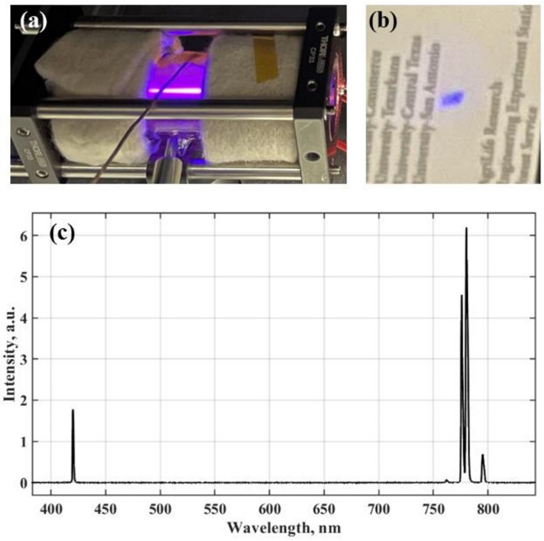

Figure 3. (a) Fluorescent and (b) coherently generated light generated in mixing configuration. (c) Wavelength spectra of fluorescence.

Since the initial setup uses tunable narrowband lasers as pump sources, the frequency of the pump beams may be modified to map the strength of the generated 420 nm signal.

3. Results and Application to Lidar

Figure 4 shows the intensity of the coherently generated 420 nm light produced under different frequency shifts offset from resonance with the energy level transitions (780.241 nm and 775.979 nm respectively). In this example, the cell was heated to 108°C and a peak in signal occurred approximately 1.7 GHz offset from the 780 nm transition and -1.5 GHz offset from the 776 nm transition. A few smaller local signal peaks are also present due to the hyperfine transitions at each energy level. These values agree with findings from other literature [9]. Testing a range of temperatures and frequency offsets found the strongest peak to occur at 780.2375 (1.7 GHz offset) and 775.9785 nm (0.2 GHz offset) with a cell temperature of 120° C. Using these conditions, 420 nm coherence could be detected with input beams as low as 0.7 µW. Detection of the 420 nm signal generated by even lower pump powers is anticipated with more sensitive PMTs and improvements to the alignment and focusing of the beams.

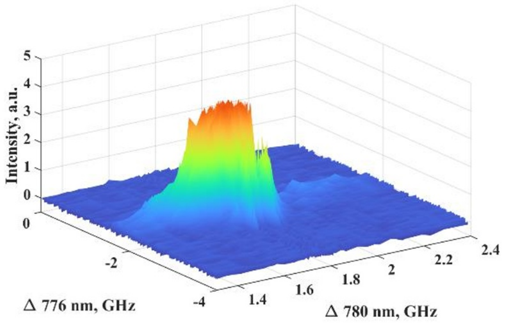

Figure 4. Coherent signal intensity under applied frequency shifts.

This information will help determine the configuration required to use this technique as a filtering method in a lidar system. Since molecular scattering from a probe beam is often very weak, and Raman is orders of magnitude weaker than Rayleigh scattering, it is essential that 420 nm light generated from the signal beam is as efficient as possible. The optimal frequencies and temperatures found here are anticipated to be used to detect light scattered from air. This technique may also be applied to other excitation pathways, such as excitation of rubidium to the 10S state using 795 nm and 532 nm pump beams and emitting 420 nm light.

4. References

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