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Stimulated electronic Raman and hyper-Raman scattering in potassium vapor

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ABSTRACT

Stimulated electronic Raman scattering and hyper-Raman processes in potassium vapor near the D_1 and D_2 lines have been observed using a stable resonator and pulsed laser excitation. First and second order Stokes and anti-Stokes lines were observed simultaneously and independently for a pump laser tuning range exceeding 70 cm^{-1}. The output energy increases by more than a factor of 10^3 as the potassium concentration increases from 0.25 to 2.2×0^{16} cm^{-3}. When the pump is tuned between the K D_1 and D_2 lines, an efficient hyper-Raman process dominates with a slope efficiency that exceeds 10%. The threshold for the hyper-Raman process is about 6 mJ per pulse, or 3.8 MW/cm^2 peak intensity. This Raman shifted laser may be useful as a target illuminator or atmospheric compensation beacon for a high power diode pumped alkali laser.

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1. Introduction

The diode pumped alkali laser (DPAL) employs diode bars or stacks as the pump source for a high power, gas phase laser system [1]. Typically, K, Rb, or Cs vapor is pressure broadened by a rare gas to efficiently absorb the spectrally narrowed diode emission on the D_2 transition. Collisional fine structure mixing by the rare gas or a hydrocarbon populates the upper laser level, and lasing to the ground state along the D_1 transition forms a three-level laser [2]. Recently, an efficient 1 kW Cs laser was demonstrated [3]. The DPAL system requires pump intensities of ~1 kW/cm^2 to bleach the pump transition, deplete the ground state and exceed lasing threshold [2]. The system has been scaled to >10 times threshold with diode pump sources [4], and to >1 MW/cm^2 with pulsed surrogate lasers [5].

At the higher pump intensities, nonlinear optical processes might compete with near IR DPAL and limit intensity scaling. For example, we have observed lasing in the blue by two-photon excitation of the ^2D and ^2S states in K, Rb, and Cs when pumping near but outside the D_2 line [6]. Stimulated Raman processes might also degrade the DPAL scaling. In the present work, we observe lasing from first and second order stimulated electronic Raman scattering and a three-photon hyper-Raman process when pumping in the vicinity of the K D_2 and D_1 lines. The observed threshold pump intensity is high and Raman lasing is quenched at higher pressures, indicating no impact on current DPAL development. However, these shifted alkali laser wavelengths may find beneficial applications as a target track illuminator or beacon to perform atmospheric compensation with adaptive optics [7].

Wavelength conversion from visible sources to the infrared using stimulated electronic Raman scattering (SERS) in K, Rb and Cs has been developed in some detail [8–11]. By tuning the pump wavelength in the vicinity of the various ground $^2S_{1/2} \rightarrow n\ ^2P_{3/2,1/2}$ transitions, infrared emission from ~1 to 100 μm can be achieved via SERS to the higher lying ^2S and ^2D states [11–14]. Infrared hyper-Raman and two photon up-conversion processes have also been investigated [15–17]. More relevant to the present study is the early work on SERS and near IR hyper-Raman scattering (HRS) in potassium [8–10]. In particular, the tuning range for stimulated Stokes, anti-Stokes and the hyper-Raman scattering was characterized in the far wings and in-between the K D_1 and D_2 lines [10]. Fig. 1a illustrates the K SERS processes where the pump source is tuned to pump the far wings of the K 4 $^2P_{3/2,1/2}$ states and a second pump photon induces Stokes or anti-Stokes scattering. In this work, we simultaneously observe first and second order, Stokes and anti-Stokes SERS in a laser cavity. The first anti-Stokes (AS1) stimulated emission from the cavity can be intense and become the source for additional, second order Raman transitions with a frequency shift of twice the fine structure splitting, $\Delta\nu_{fs}$. The three-photon hyper Raman process is fundamentally different, as shown in Fig. 1b. By tuning the pump source in between the $^2P_{3/2,1/2}$ states and scattering from this virtual state, the hyper-Raman frequency shift increases at twice the pump frequency scan rate. High efficiency ($>10\%$) for the deep red hyper-Raman scattering is achieved in the present work by scaling both alkali concentration and pump intensity.

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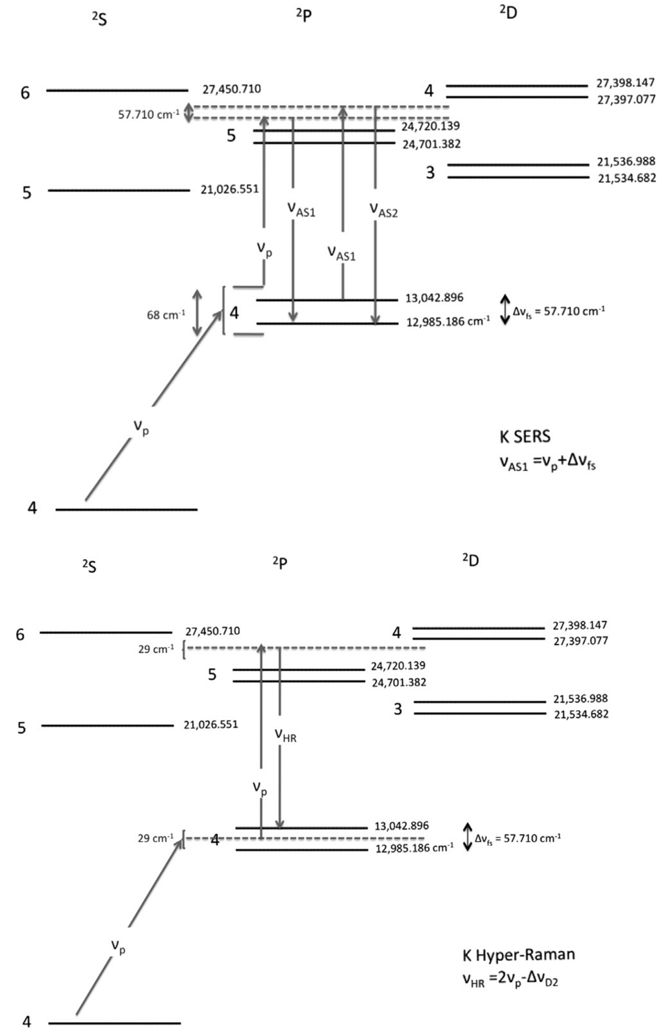

Fig. 1. Energy level diagram illustrating the: (a) SERS and (b) hyper-Raman scattering.

2. Experiment

The laser pump source, potassium heat pipe, and optical resonator are shown in Fig. 2. A Quanta Ray Nd:YAG pumped Sirah dye laser provides up to 23 mJ at 10 Hz in a 4–8 ns pulse with a spot size of ~0.2 cm^2. The dye laser spectral width is ~31 GHz and is ~98% vertically polarized. A mixture of methanol and LDS-765 (Exciton) allowed the dye laser to be tuned over 766–771 nm. A stainless steel heat pipe 30 cm long and 2.54 cm in diameter contained about one gram of potassium metal. Sapphire windows coated for 765 nm are mounted at normal incidence. The ends of the heat pipe were cooled using an aluminum water jacket to a constant temperature of 20 C to prevent condensation of potassium vapor and damage to the windows. The central section of the heat pipe was enclosed in an aluminum heater block controlled by a Watlow single zone heater that provided a maximum temperature of 325 C and an active zone of 15 cm. A 50 cm radius of curvature high reflector and a flat output coupler with a reflectivity of 30% formed the optical cavity. The mirrors were separated by 48 cm. The vertically polarized pump and horizontally polarized laser radiation were separated using a polarization beam splitting cube. Coarse cavity alignment was performed using a He–Ne laser and fine adjustments were based on peak power output. A Coherent thermopile-type meter measured the average output power and the temporal shape of the output pulse was monitored by a photodiode and oscilloscope. The spectra of the pump and potassium lasers were analyzed by an Ocean Optics spectrometer. Further details regarding the heat pipe and optical apparatus have been reported previously [18,19].

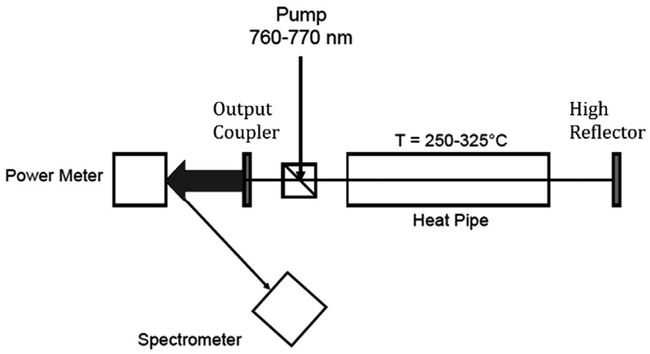

Fig. 2. Laser apparatus.

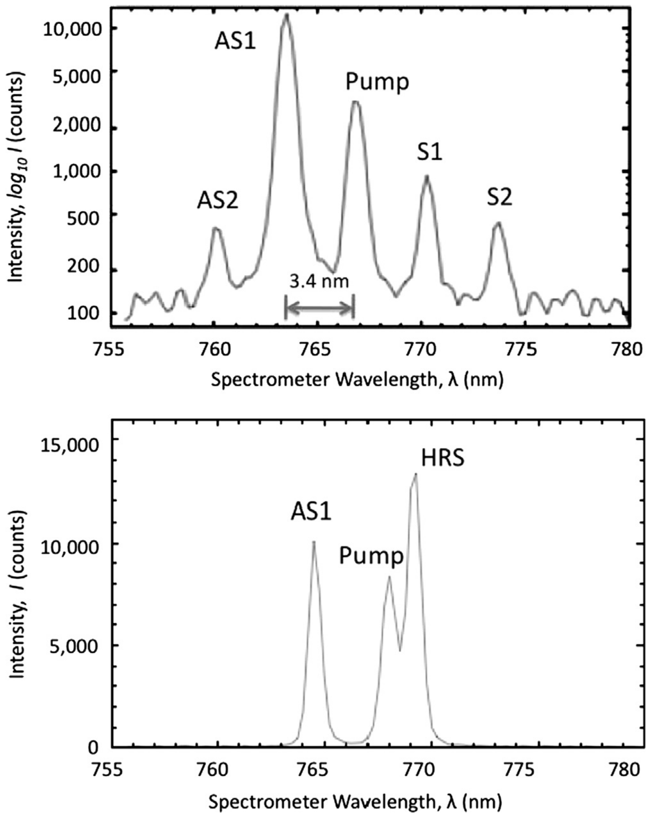

Fig. 3. Spectrum of the output beam for a heat pipe temperature of 325 C (a) SERS resulting from pumping at the D_2 frequency and (b) hyper-Raman and SERS when pumping halfway between the D_2 and D_1 lines. The frequency difference between the pump and the hyper Raman (HRS) line is red shifted by 2 nm for a nm tuning of the pump frequency.

3. Results

3.1. SERS and hyper Raman tuning ranges

A typical spectrum from the collimated SERS output beam with the pump tuned to the core of the D_2 line is illustrated in Fig. 3a. All four of the first and second order, anti-Stokes (AS1, AS2) and Stokes (S1, S2) lines are observed simultaneously. The first order