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High Efficient Production of 1.053 μm Pico-Second Raman Laser Excited by Ti:Sapphire Laser

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Abstract A high efficient conversion from the Ti: Sapphire laser to the Raman laser with 1053 nm wavelength at the area of picosecond (ps) pulse duration is reported. A Ti:Sapphire laser (808 nm wavelength, 450 ps pulse duration and 10 mJ pump energy) is employed as the pump source, acetone is stimulated to generate first-order Stokes wave with 1053 nm central wavelength. Inserting Nd:glass as a fluorescence enhancement medium, the first-order Stokes wave is obviously enhanced, the energy conversion efficiency from pump laser to the first-order Stokes wave reaches to 17.5%, the bandwidth of the first-order Stokes is 25 nm, and the pulse duration is 318 ps. The physical mechanism together with the potential applications are discussed .

Key words scattering; stimulated Raman scattering; fluorescence enhancement; C_3H_6O; Nd:glass

OCIS codes 290.5910; 320.5390; 140.3280; 300.2530; 160.2750

钛宝石激光激发高效率 1.053 μm 拉曼激光的产生

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摘要 在 450 ps 钛宝石(Ti:sapphire) 激光激发下，获得了 C_3H_6O 的受激拉曼散射(SRS)，以钕玻璃为荧光增强介质，放大了 1.053 μm 的 Stokes 辐射，能量转换效率达到 17.5%，一阶斯托克斯波带宽为 25 nm，脉冲宽度为 318 ps。讨论了皮秒脉冲激发的受激拉曼散射效应及荧光增强 SRS 机理及其潜在应用。

关键词 散射；受激拉曼散射；荧光增强；C_3H_6O；钕玻璃

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1 Introduction

The limitation on the active medium in pulse laser radiation sources has seriously shortened the spectrum range of ultra short pulses, the technical development of high power lasers demands the ultra short laser sources with a wavelength of about 1.06 μm[1], which can be directly output by Ti : sapphire lasers using tunable principle in theory now. However, the wavelength of 1064 nm locate in the boundary region of the gain curve of Ti: sapphire laser working material, the gain is small and the slope is large, thus the output is very unsteady[2].

Stimulated Raman scattering (SRS) is one of the important physical mechanisms to obtain coherent light sources with tunable wavelengths[3-4]. Compared with optical parametric oscillation (OPO), SRS has more simple equipment and relatively lower cost; compared with dye laser (DL), SRS has narrow output line-width, compressed pulse-width and higher spatial directionary[5-6]. In the field of pico-second and femto-second pulses, much attention has been paid to laser frequency tuning using SRS[7-9], but owing to many non-linear effect competitions in transient Raman process, SRS often outputs super-continuum white light when Raman medium is pumped by high energy laser, effective Raman laser with single frequency is hardly generated[10]. At the same time, the low conversion efficiency of SRS limits its real applications.

Cheng[11], Li[12] and Cheng AYS[13] *et al*. successively proposed the idea and method of using fluorescence enhancement to improve SRS conversion efficiency, which has achieved great advancement in SRS of nanosecond (ns) pulse lasers. Acetone (C_3H_6O) is pumped by a 532 nm laser (6 ns pulses), then the first-

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order Stokes wave is enhanced by DCM dye fluorescence, the energy conversion efficiency for the first Stokes wave of C_3H_6O is near 30%.

Based on the principle of SRS tuning and fluorescence enhancement, a high efficient Raman laser output (1053 nm central wavelength, 17.5% energy conversion efficiency) for the first-order Stokes wave of C_3H_6O is realized in this paper. A Ti:sapphire laser with central wavelength of 808 nm, broadband of 35 nm and pulse duration of 450 ps is employed as the pump source, and the fluorescence enhancement medium is Nd:glass.

2 Experiment

The scheme of our experimental setup is shown in Fig. 1. A femtosecond (fs) self-locking-mode Ti:sapphire oscillator output pulse sequences (20 fs pulses, 808 nm central wavelength), then the laser pulses pass through expander, regenerative amplifier, preamplifier and main amplifier system. The output pulses are weakened (10 mJ for a single pulse) by a hole, then focused (20-cm focal length) into the Raman cell (20-cm-long cell) which is filled with C_3H_6O. The Stokes light of C_3H_6O together with the residual pump laser light of 808 m are allowed to continue forward and propagate into Nd : glass, The first Stokes light is enhanced in Nd : glass because of the interaction between Stokes wave and Nd:glass fluorescence which is excited by residual pump laser of 808 nm. The SRS spectrum of C_3H_6O with and without Nd:glass fluorescence enhancement are measured by a spectrometer (OMA) respectively. Energy meter E1 and E2 are used to monitor the pump laser energy (808 nm central wavelength) and the first Stokes wave energy (1.053 μm central wavelength).

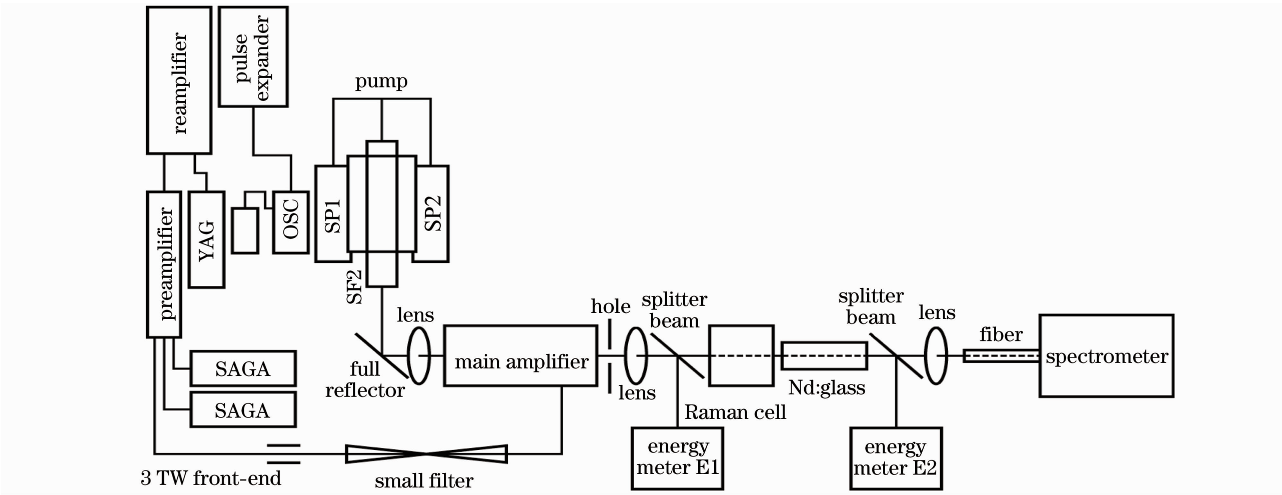

Fig.1 Experimental setup

3 Results and discussion

The measured spectrum in different conditions are shown in Fig. 2. When the fluorescence enhancement medium is not used, the normal SRS spectrum of C_3H_6O is shown in Fig. 2(a). The first-order Stokes wavelength is located at 1053 nm, the intensity of pump laser (808 nm wavelength) is far stronger than the first Stokes wave, and the intensity of the first anti-Stokes wave is slightly weaker than the first Stokes wave. When a Nd : glass with 20 mm in length is used as fluorescence enhancement medium, the spectrum of the residual pump laser and the first Stokes wave of C_3H_6O are shown in Fig. 2(b). It is clear that the intensity of the pump laser decreased greatly, the first-order Stokes wave is got enhancement, and the first-order anti-

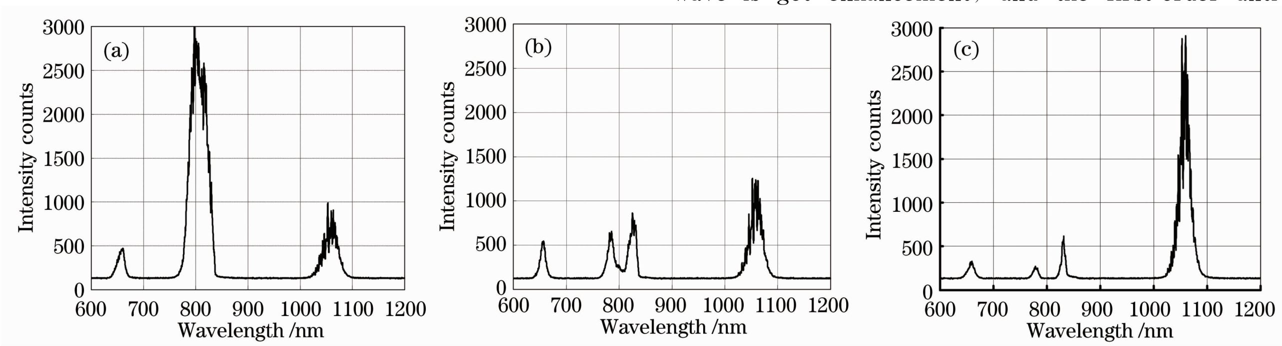

Fig.2 Spectrum of stimulated Raman scattering (SRS) of C_3H_6O with and without Nd:glass enhancement. (a) No Nd:glass; (b) with Nd:glass (20 mm); (c) with Nd:glass (14 cm)

Stokes wave is nearly keep the same. Changing the length of Nd:glass to 14 cm, the spectrum is shown in Fig.2(c). It is obvious that the pump laser is almost unobservable, the first-order Stokes wave is comparable with the ordinary pump laser, and the first-order anti-Stokes wave is very weak.

The enhancement coefficient η of the Stokes line can be defined as

$$\eta = I_{si}/I_{s0}, \qquad (1)$$

where I_{s0} is the intensity of the first Stokes wave of C_3H_6O without Nd: glass, I_{si} is the intensity of the stokes line enhanced by Nd:glass. Comparing Fig.2(a) with Fig.2(b), when the length of Nd:glass is 20 mm, the radiation intensity of Stokes wave before and after Nd: glass is 750 and 1209, respectively, so the enhancement coefficient of 1.61 can be calculated from Equation(1). Comparing Fig. 2(a) with Fig. 2(c), when the length of Nd:glass increases to 14 cm, the radiation intensity of Stokes wave of C_3H_6O before and after Nd:glass is 750 and 2767, therefore the enhancement coefficient is 3.69.

The single pulse pump energy measured by energy meter before Raman cell is 10 mJ. After passing through Nd:glass, the laser energy changes to 2.4 mJ. Considering the integral relation of intensities among the Stokes wave, residual pump light and the anti-Stokes light in Fig.2(c), the enhanced energy of the first-order Stokes wave is 1.75 mJ, therefore the energy conversion efficiency from the pump laser to the first-order Stokes wave is 17.5%.

The spectrum bandwidth of pump laser and Stokes wave are shown in Fig.2(a) and (b), the spectrum bandwidth of pump laser is about 35 nm, the spectrum bandwidth of Stokes wave is about 25 nm. Compared with the spectrum bandwidth of pump laser, the spectrum bandwidth of Stokes wave is slightly compressed.

Taking ethanol (C_2H_5OH) as a Raman medium and Nd: glass as the fluorescence enhancement medium, similar experimental results can be obtained. When the fluorescence enhancement medium is not be used, the conversion efficiency of Stokes wave is low. After inserting Nd: glass, the residual pump energy is consumedly decreased, the first-order Stokes wave is enhanced. With the increase of the length of fluorescence medium, the radiation intensity of Stokes wave is rapidly enlarged. The conversion efficiency of Stokes wave is a little lower than that of C_3H_6O. The experimental spectrum are shown in Fig. 3. Stokes wave as signal light traverses the active fluorescence medium, the power gain g can be defined as

$$g \approx \exp(\sigma \Delta n_0 L), \qquad (2)$$

where σ is the resonance absorption cross section, Δn_0 is the initial densities of inverted particles, and L is the interaction length between the incident beam and the

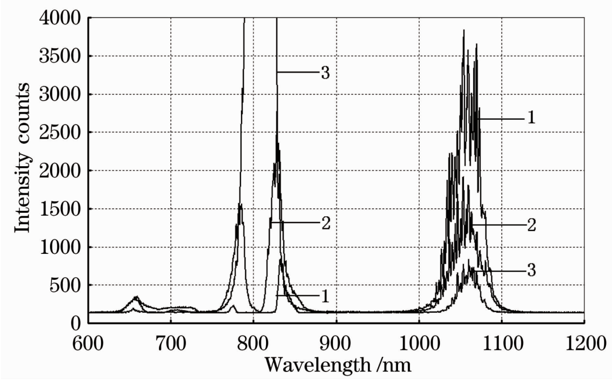

Fig.3 Spectrum of the pump laser and the first-order Stokes emission of SRS in C_2H_6O. 1: with Nd:glass (29 cm); 2: with Nd:glass (20 mm); 3: no Nd:glass

gain medium. According to Equation (2), with the increase of resonance absorption cross section σ, initial densities of inverted particles Δn_0 and the interaction length L, the power gain of Stokes wave will be enhanced by the exponential law.

C_3H_6O, as a Raman medium, has stable performance and relatively large Raman shift (2921 cm^{-1}). When excited by a Ti: sapphire laser (808 nm central wavelength), the central wavelength of the first-order Stokes wave is located at 1.06 μm. Nd:glass is a typical solid working-laser material, the wavelength of the Ti:sapphire laser (808 nm) face in the strong absorption band of Nd:glass, therefore the residual pump light is efficiently absorbed by Nd:glass. Moreover, with the increase of the length of Nd:glass, the absorption effect is more obvious. Furthermore, the central wavelength of the fluorescence spectrum of Nd:glass is near 1.053 μm, which is also in the strong fluorescence band (see Fig.4). When the first-order Stokes wave of C_3H_6O and the residual pump light pass through Nd:glass medium, Nd particles are excited to metastable energy level (particles in reversal state), and Nd:glass becomes a gain medium of Stokes radiation, Stokes wave is efficiently enhanced by the gain medium.

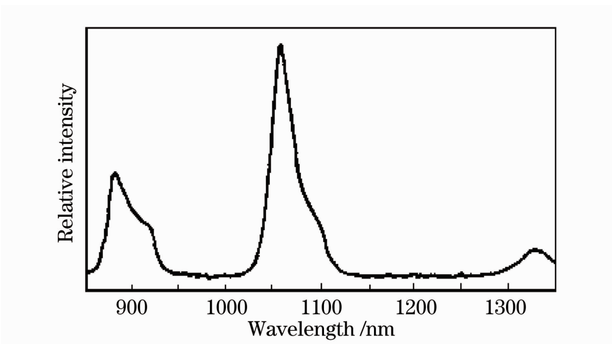

Fig.4 Fluorescence spectrum of Nd:glass

In general, if Stokes spectrum of some Raman medium situates in spectrum range of some matter, and furthermore pump laser wavelength lies in the absorption band of the fluorescence matter, the fluorescence matter can selectively enhance the Stokes spectrum of Raman medium using residual pump light energy.

4 Conclusion

Taking C_3H_6O as a Raman medium, and excited by a Ti: sapphire pulse laser (450 ps pulse width, 808 nm central wavelength, 35 nm bandwidth), SRS of C_3H_6O is observed with radiant central wavelength of 1053 nm for the first-order Stokes wave. Inserting Nd: glass as a fluorescence enhancement medium, the first-order Stokes wave is obviously enhanced, the energy conversion efficiency from the pump laser to the first-order Stokes wave reaches to 17.5%, the bandwidth of the first-order Stokes is 25 nm. The experimental results indicate that conversion is very efficient from Ti: sapphire laser to the 1053 nm central wavelength laser by using SRS of C_3H_6O and fluorescence enhancement of Nd: glass at the area of picosecond pulse duration.

The above research results are applicable in the area of laser physics and laser technique, especially in the tunable laser with a picosecond duration.

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