A multipass hydrogen Raman shifter for the generation of broadband multifrequencies

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A multipass hydrogen Raman shifter for the generation of broadband multifrequencies

L. L. Losev,[a] Y. Yoshimura, H. Otsuka, Y. Hirakawa, and T. Imasaka[b]
Department of Applied Chemistry, Graduated School of Engineering Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka 812-8581, Japan

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A four-pass cell was employed for the multifrequency parametric Raman generation in gaseous hydrogen. More than 18 rotational-vibrational Raman lines from 450 to 830 nm were generated using an 80-mJ, 3-ns pump pulse at a wavelength of 532 nm. The output spectrum broadening was observed by increasing the number of passes of the pump pulse through the Raman cell. © *2002 American Institute of Physics.* [DOI: 10.1063/1.1468686]

Multifrequency parametric Raman generation (MPRG) by using rotational Raman scattering in gaseous hydrogen is currently a rather well researched phenomenon.[1,2] It has been shown[3–5] that the broadband frequency comb generated by parametric Raman scattering can cover the whole visible region. The comb frequency separation is 587 cm^{-1}, which corresponds to the pure rotational Raman transition of $S_0(1)$ in orthohydrogen.

Among the optical schemes used for MPRG, the broadest output spectrum with the maximum number of Raman lines was observed when the double-cell configuration was used.[6] In this scheme, the powerful first Stokes component is generated with a high efficiency in the first cell using circularly polarized laser radiation. Circular polarization is used in order to eliminate the parametric coupling of Stokes components and to provide the laser energy conversion to only the first Stokes component. The polarization of the Stokes radiation is then changed to the linear mode and the Stokes beam is combined with the pump beam. By focusing this dual-wavelength beam in the second cell, MPRG is observed. It has been found[4,7] that the intensity of the first Stokes component should be close to that of the pump to achieve the maximum number of parametrically generated Raman lines.

Although MPRG is a quite simple technique for expanding the capability of commercial lasers, the necessity of two cells results in a complicated optical scheme. Therefore, it is desirable to employ a one-cell scheme. In this article, we present some findings of MPRG, which involves the use of a one-cell multipass Raman shifter.

The layout of the experimental apparatus is shown in Fig. 1. The multipass hydrogen Raman shifter is constructed of stainless steel with fused silica windows, fused silica prisms, and planoconvex lenses. The cell, which has a length of 60 cm and a diameter of 2 cm is set between the prisms which are used to provide the four passes of laser radiation through the cell. The prism separation is 1 m. Two lenses with focal lengths of 50 cm are employed to focus the laser radiation in the middle of the cell at each pass. A λ/four plate is set at the entrance of the Raman shifter for pump radiation polarization tuning.

The 532 nm beam from a *Q*-switched linearly polarized Nd:YAG laser (Tempest-20, repetition rate, 20 Hz) with 3–5 ns pulse width was used for pumping the hydrogen Raman shifter. The pulse energy varied from 10 to 80 mJ. An unstable resonator of this laser employs a radially variable output mirror, in order to provide a uniform spatial beam profile with the diameter of 3 mm. The time-integrated output spectrum of the beam from the hydrogen Raman shifter was obtained using a spectrometer (Ocean Optics: USB 2000).

It is known[8,9] that the number of spectral components of a parametric beam from a hydrogen Raman shifter with fixed pump beam parameters and hydrogen pressure is dependent on the polarization of the pump radiation. To achieve the broadest output spectrum in our case, we tuned the laser polarization by rotating the λ/4 plate. The experimental results which are presented below, were obtained at a laser polarization corresponding to the maximum number of Raman components generated during four passes of laser pulse through the cell.

The evolution of the multiline Raman spectrum along the path into the cell was examined and the results are shown in Figs. 2 and 3. It can be seen that, after the first pass, the pump radiation is converted to only the first rotational Stokes component with a wavelength of 549 nm [Figs. 2(a) and 3(a)]. The energy conversion efficiency approaches 50%. Such a high conversion efficiency to the first Stokes compo-

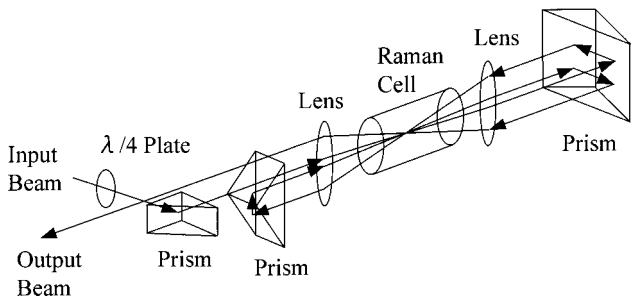

FIG. 1. Optical scheme for a Raman shifter.

[a]Permanent address: Division of Quantum Radiophysics, P. N. Lebedev Physical Institute, Leninsky Prospekt, 53, 119991 Moscow, Russia.
[b]Author to whom all correspondence should be addressed; electronic mail: imasaka@cstf.kyushu-u.ac.jp

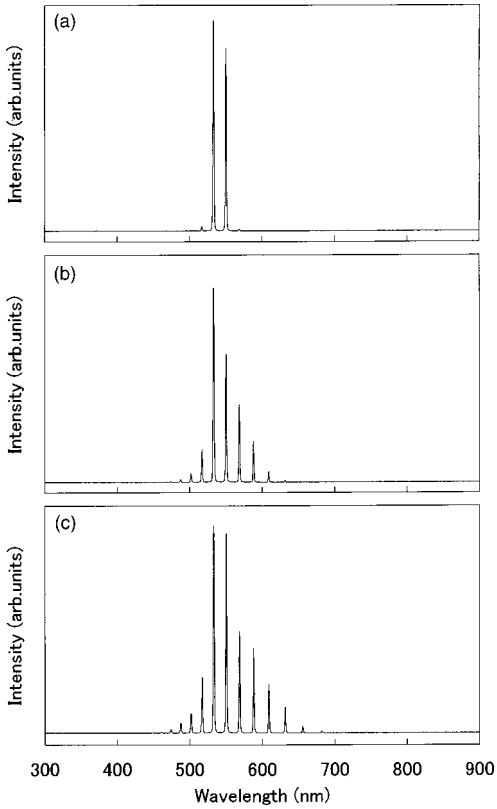

FIG. 2. Radiation spectra of a multicolor laser beam from a Raman shifter obtained after one pass of pump beam through the cell (a), two passes (b), and four passes (c). Pump–pulse energy is 80 mJ. Hydrogen pressure is 1.5 atm.

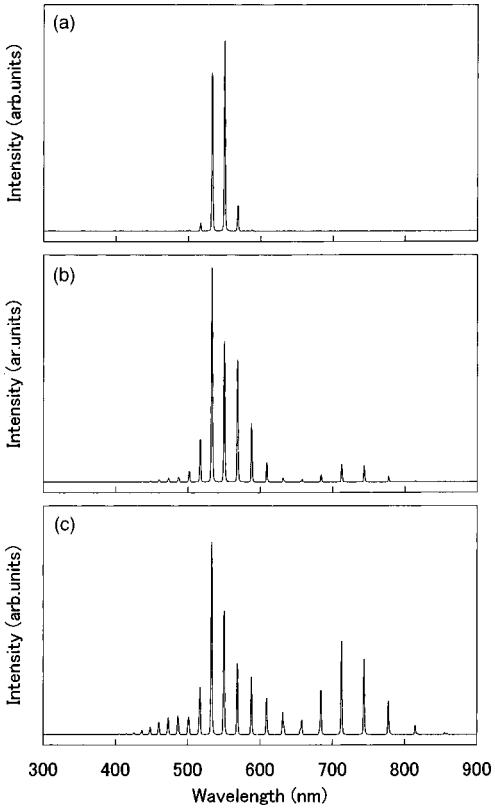

FIG. 3. Radiation spectra of a multicolor laser beam from a Raman shifter obtained after one pass of pump beam through the cell (a), two passes (b), and four passes (c). Pump–pulse energy is 80 mJ. Hydrogen pressure is 2 atm.

nent is usually observed in the case of the circular polarization of pump radiation[10] because of the absence of Stokes–anti-Stokes parametric coupling in this regime of scattering: the parametric coupling suppresses the Stokes wave amplification. After the first backward reflection by the prism, the polarization of the pump radiation and the first rotational Stokes component is changed. This permits the effective parametric Raman generation of higher-order Stokes and anti-Stokes components by the dual wavelength resonance excitation of the Raman medium during subsequent passes [Figs. 2(b), 2(c) 3(b), and 3(c)].[4,6] It should be noted that we observed broadening (an increasing number of Raman components) in the double-pass radiation spectrum after the next two passes (Figs. 2 and 3). After the fourth pass, the number of Raman components is approximately 1.5 times more than that after second pass, which constitutes an important merit of the multipass optical scheme.

The influence of the pump–pulse energy on the output spectrum is shown in Figs. 4 and 2(c). The maximum number of pure rotational Raman components was observed at a pressure of 1.5 atm and a pump–pulse energy of 70–80 mJ and was about 8–10 lines at the level of 0.1 to maximum intensity. The Raman lines cover the spectral range from 480 to 650 nm. Decreasing the pulse energy to 40 mJ results in narrowing the output spectrum to 5–6 lines.

At a hydrogen pressure of more than 2 atm, the first vibrational Raman component with a Stokes shift of 4155 cm^{-1} appears [Figs. 3(b) and 3(c)]. This is caused by the

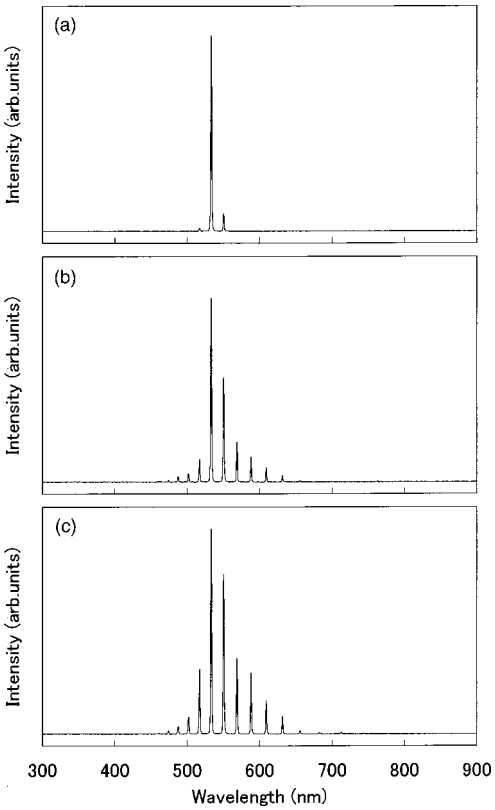

FIG. 4. Radiation spectra of a multicolor laser beam from a Raman shifter obtained after four passes at pump–pulse energy of 20 mJ (a), 40 mJ (b), and 60 mJ (c). Hydrogen pressure is 1.5 atm.

enhancement of the vibrational scattering Raman gain and a decrease in the vibrational Stokes–anti-Stokes parametric coupling.[9] The vibrational–rotational Raman components at a pump–pulse energy of 80 mJ occupies the spectral range from 450 to 830 nm [Fig. 3(c)]. The number of components is approximately 18.

We have also estimated the entire multicolor beam divergence by measuring the beam diameter along the trace of the propagation and the divergence was determined to be less than 2 mrad.

It has been found that the use of the multipass cell for multifrequency rotational Raman generation allows the optical scheme to be simplified and leads to an increase in the number of Raman components. Approximately 18 Raman lines covering the spectral range from 450 to 830 nm were generated into one collimated beam at a laser energy of 80 mJ.

The research described here shows that this simple and inexpensive device can be successfully used for nonlinear radiation conversion of visible (or UV) nanosecond pulse lasers with a peak power of 5–50 MW. The possibility of obtaining new spectral lines could significantly enlarge the areas of application of commercial lasers.

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