Evolution of stokes pulses of stimulated Raman scattering in a GeO_2-doped multimode fiber

Yong-Woo Yi* · In-Duck Hwang**

GeO_2 첨가 다중모드 광파이버에서 유도라만산란에 의한 스토크스 펄스 발생

이용우* · 황인덕**

요 약

본 논문은 1064 nm의 Q-스위칭 Nd:YAG로 펌핑된 단일통과 라만레이저에서 nano-초의 스토크스 펄스 발생에 관한 연구이며, 라만 매질로는 GeO2로 도핑된 grad index형 다중모드 파이버 220 m를 사용하였다. 실험 결과에서 펌핑 에너지의 변화에 따라 1.5~2.7 nano 초의 펄스폭을 갖는 스토크스 펄스 트레인 성분이 효율적으로 발생함을 알 수 있었다.

ABSTRACT

We experimentally investigate the evolution of nanosecond Stokes pulses in a single-pass Raman laser pumped by a Q-switched Nd:YAG laser at 1064 nm. As a Raman medium, a GeO2-doped graded-index multimode fiber of 220 m long is used. We demonstrate that efficient generation of several Stokes components with 1.5~2.7 nanosecond pulsewidth is obtained by varying the input pump energy.

Keywords

Stokes pulse, stimulated Raman scattering, pulsewidth, pump energy

I. INTRODUCTION

While nonlinear optical effects present the transmission limitations in optical fiber communications, they are useful for frequency conversion, pulse amplification and shaping, and fundamental fiber studies. Optical amplification based on Raman con- version in fibers was one of the earliest optical amplification methods. It is based on a stimulated Raman scattering (SRS) in the core of the trans- mission fiber and accordingly does not require the insertion of a special gain medium. In the Raman amplification process, a high-power pump source is incident on the fiber input end, providing gain over a relatively broad range of wavelengths determined by the molecular- vibration frequencies of the fused silica core materials.

Most of all, the optical fibers are very effective media for tunable frequency con- version in the spectral ranges of UV, visible, and particularly near-IR through the nonlinear processes such as the cascade SRS, self-phase modulation, four-photon mixing, etc. Currently the frequency

*전남도립담양대학 초고속정보통신공학부

**삼성종합기술원 의용광학팀

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conversion by SRS in low-loss optical fibers has attracted considerable attention because of efficient generation of new light beams of multiple wavelengths by a fixed wavelength pump light.

Many papers report the generation of broad-band spectrum and pump pulse depletion in single-mode or multimode fibers by the efficient frequency conversion in the near infrared region[1-4]. For the visible region, Chinlon Lin et al. reported the nanosecond continuum generation through the use of 10-ns dye laser which is pumped by nitrogen laser, as a pumping source in a short single-mode fiber[5]. And also in the ultraviolet wavelengths, T. Mizunami reported the short-pulse generation by the control of input intensity in the XeCl (308 nm) pumped multimode fiber Raman[6].

In particular, from the multimode fiber, the generated nanosecond pulses in the near infrared region not UV and visible wavelengths, is very useful source because they can be effectively applied for analyzing the time characteristics of the fiber or optical devices which the higher Stokes energy is needed. It is known that the Raman scattering from multimode fiber can generate much higher energy than that from single-mode fiber. We have investigated the generation of nanosecond Stokes pulses by the variation of input pump energy using a Q-switched Nd:YAG laser as a pump source. The tunable nanosecond pulses will be useful for spectral and time-domain studies of fibers and optical devices.

In this paper, we experimentally investigate the Stokes pulse evolution with nanosecond pulse width in single-pass Raman laser pumped by a Q-switched Nd:YAG laser through use of a GeO2-doped graded-index multimode fiber of 220 m long. We can effectively obtain 1.5-2.7 ns pulses for several Stokes components by the variation of input pump energy that leads to the pump depletion of temporal pulse shape.

II. EXPERIMENTAL SETUP

The experimental setup for single-pass fiber Raman is shown in Fig. 1. The Q-switched Nd:YAG laser (Continuum Powerlite 8010) with the repetition rate of 10 Hz is used as a pumping source. At this experiment, the pump pulses with 8.2 ns(FWHM) are used for pumping.

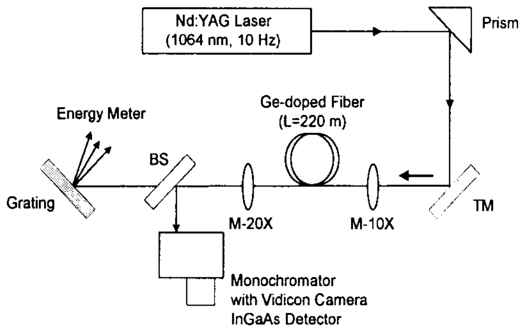

Fig. 1 Experimental setup for single-pass fiber Raman, M-10X, M-20X; microscope objective, BS; beam splitter, TM; total mirrors.

To reduce the energy to the fiber input end, the reflected beam by the prism is used. The input pump energy is focused on the fiber input end of Raman fiber through M-10X microscope objective. The used fiber is a 20 mol% GeO2-doped graded index multimode fiber of 220 m long and has core diameter of 50 μm, cladding diameter of 125 μm, relative maximum refractive index difference of 0.03 and numerical aperture (NA) of 0.3. The used fiber has the loss of 1.4 dB/km at 1.064 μm, 0.88 dB/km at 1.24 μm, and 0.75 dB/km at 1.30 μm, respectively. The generated Raman components by single-pass were collimated by M-20X microscope objective and dispersed by the grating with 600 lines/mm. The energy of incident and transmitted pump and generated Stokes components were measured with energy meter (Gentec ED-100) plus Amplifier EDX-1 of gain 1000.

The generated Raman spectra was measured with a Vidicon camera (Hamamatsu C2741-03) through a monochromator with grating of 600 lines/mm and 0.1 nm resolution. The temporal profiles of all pulses were detected with a InGaAs-PIN detector with fast rise time and LeCroy 1500 MHz oscilloscope.

III. RESULT AND DISCUSSION

To investigate the temporal evolution of the Stokes pulses with nanosecond pulse width in a GeO2-doped multimode fiber of 220 m long, we have measured the energy, spectrum, and temporal profiles of the Raman output components, respectively. The maximum pump energy is fixed at 85 μJ at the fiber input end throughout the experiment because the fiber end for the higher pump energy is easily damaged.

Fig. 2 shows the energy dependence of the transmitted pump(Pout), first Stokes(S1), second Stokes(S2), and third Stokes(S3) as a function of the input pump energy, respectively. As shown in Fig. 2, the transmitted pump energy is gradually saturated as the pump energy goes above 55 μJ, and its maximum energy is 26 μJ at input energy of 85 μJ. On the contrary, the Stokes energy continuously increases as the pump energy increase. For 85 μJ input energy, the obtained maximum energy corresponding to the first, second, and third Stokes lines are 9, 6, and 4.1 μJ, respectively.

Fig. 3 shows the typical spectra of Raman output obtained from a 220 m long and 50 μm core multimode fiber at the pump energy of 85 μJ. It is shown that the spectra of Stokes components is discretely observed until to the five Stokes order. The peak wavelength of observed Stokes lines are 1.12, 1.175, 1.23, 1.29, and 1.38 μm, respectively. We can see that the spectral width of higher Stokes order is a little broaden than that of lower Stokes order due to the cooperative action of several nonlinear processes, that is, sequential stimulated Raman scattering, self-phase modulation, and four-wave mixing[7].

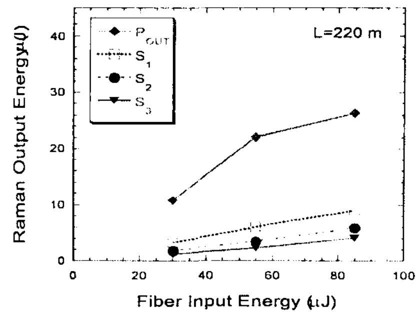

Fig. 2 Energy dependence of Raman output components as a function of input pump energy of 85 μJ.

The pulse width of input pump beam used to investigate the evolution of Stokes pulses with nanosecond pulse width in multimode fiber of 220 m long with the Q-switched Nd:YAG laser excitation is 8.2 ns(FWHM). Fig. 4 shows the evolution of temporal profiles of (a) transmitted pump, (b) the first Stokes, (c) the second Stokes, (d) the third Stokes at the fiber input energy of 85 μJ. Due to the efficient conversion of higher-order stimulated

Raman scattering, double-peaked pulses with partially depleted central regions are observed for the pump and lower-order Stokes wave- lengths. In particular, the pulse intensity of the leading part from the central depletion point is seriously low due to the large depletion compared to that of the trailing edge pulse. Accordingly we can effectively generate 1.5-2 nanosecond pulses for the three Stokes components. As shown in Fig. 4, the pulse width at the full width half maximum of the first, second, and third Stokes components are 2, 2, and 1.5 ns, respectively. But all pulse profiles of Stokes lines have the small depletion pattern similarly at the pump energy of 85 μJ.

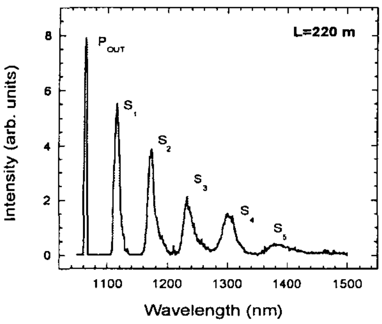

Fig. 3 Raman emission spectra obtained at fiber length of 220 m and input pump energy of 85 μJ.

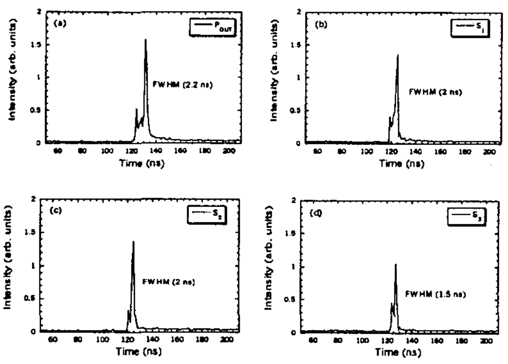

Fig. 4 Temporal profiles of (a) transmitted pump, (b) the first Stokes, (c) the second Stokes, (d) the third Stokes at the input energy of 85 μJ.

Fig. 5 shows the evolution of temporal profiles of (a) transmitted pump, (b) the first Stokes, (c) the second Stokes, (d) the third Stokes at the fiber input energy of 30 μJ. Compared with the transmitted pump of Fig. 4, the Raman output pump pulse of Fig. 5 has the small depletion in the central regions and then its pulse width has 3.5 ns(FWHM). Thisindicates that the intensity of generated Stokes shall be small compared to those of large depletion of Fig. 4. But we know that we can obtain the nanosecond Stokes pulses with the energy of a few μJ without the depletion shape in pulse profile. The 2.7, 2.2, and 2 ns pulses for the generated first, second, and third Stokes is obtained at the input pump energy of 30 μJ, respectively.

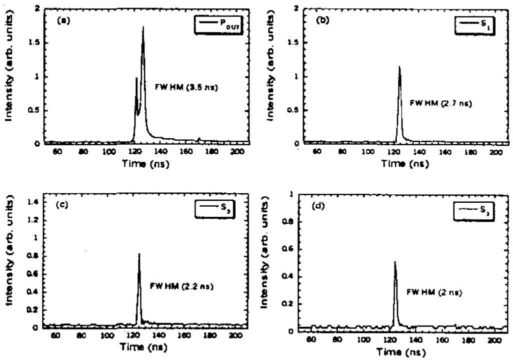

Fig. 5 Temporal profiles of (a) transmitted pump, (b) the first Stokes, (c) the second Stokes, (d) the third Stokes at the input energy of 30 μJ.

We demonstrated that we can effectively generate 1.5-2.7 nanosecond pulses for several Stokes components in the near infrared region by variation of the input pump energy. This short pulse sources in nanoseconds in the 1-1.23 μm regions shall be used in the application fields such as nanosecond time-resolved excited-state spectroscopy, spectroscopy, photochemistry, and analysis of multi- mode fiber characteristics.

IV. CONCLUSION

We experimentally investigate the Stokes pulse evolution with nanosecond pulse width in single-pass Raman laser pumped by a Q-switched Nd:YAG laser at 1064 nm. As a Raman medium, a GeO2-doped graded-index multimode fiber of 220 m long is used. We demonstrated that we can effectively generate 1.5~2.7 nanosecond pulses for several Stokes components in the near infrared region by variation of the input pump energy. The tunable nanosecond pulses in the

1~1.23 μm regions will be useful for spectral and time-domain studies of fibers and optical devices.

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저자소개

이용우(Yong Woo Yi)

러시아, General Physics Institute 교환연구원
담양대학 산학협동연구소장
담양대학 광기술지원센터 소장
담양대학 정보통신공학부 조교수

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