Forward Raman amplification for the narrow band Stokes line by double-pass fiber Raman scheme in multi-mode fiber

In Duk Hwang* and Choo Hie Lee
Dept. of Electronic Engineering and Institute for Laser Engineering
Kyung Hee University, Yongin, Kyungki-do 449-701, Korea
leech@nms.kyunghee.ac.kr

The optical fibers are an interesting medium for effective tunable optical frequency conversion in the spectral range of UV, Visible, and near-IR through the nonlinear processes. A number of papers for developing the wideband and flat-gain amplifier for the WDM system applications through the combination of EDFA or thulium-doped fluoride fiber amplifier and Raman amplifier, are reported[(1)]. Even though a variety of papers related to Raman amplifications are published, the amplification with the feedback of the residual pump is not investigated yet. Accordingly, in this paper, we report the characteristics of forward Raman amplification by the simple and double-pass fiber Raman configuration through the feedback of residual pump beam.

The experimental setup for the forward Raman amplification with double-pass scheme through the feedback of residual pump is shown in Figure 1. The fiber input energy of 50-70 μJ is focused on the fiber input end of Raman fiber through 10X microscope objective. The used fiber is a 20 mol.% GeO2-doped graded index multi-mode fiber of 42 m long and has core diameter of 50 μm, cladding diameter of 150 μm, relative index difference (ΔnMax) of 0.03 and numerical aperture (NA) of 0.3. The incident and transmitted energy were measured with energy meter (Gentec ED-100) plus Amplifier EDX-1 of gain 1000. The Raman components generated by the first pass is dispersed by a one grating with 600 lines/mm. And the dispersed residual pump and narrow band first Stokes signal is reflected totally back for the forward Raman amplification with the adjustable time delay by total mirror position control of the first Stokes. The control of time delay allow us that the signal pulse (first Stokes) is superimposed on the pump pulse (residual pump) for efficient forward amplification. The generated Raman and amplified signal spectra is measured with a Vidicon Camera (Hamamatsu C2741-03) through a MC-30N monochromator with grating of 600 lines/mm and 0.1 nm resolution.

Figure 2 shows the relative spectral density of the amplified signal of 1116.4 nm (center wavelength) for some time delay between residual pump and Stokes signal (a), only selected narrow band Stokes signal without the feedback of residual pump (b), and only generated Stokes signal by the feedback of residual pump and without feedback of Stokes signal. The minus sign of time delay indicates that the Stokes signal is propagated faster than the pump. The full spectral range of horizontal axis which the image is displayed, is about 10 nm. The spectral bandwidth of the amplified signal is estimated to be a 1.5 nm. It is found that the relative intensity of the amplified signal beam is much higher that that of

the signal feedback plus the backscattered signal only. We can successfully obtain the amplification of narrow band signal with the gain more than 10 dB at even though the condition of no polarization maintaining fiber and without polarization adjustment between the pump and signal beams.
In addition, the detail analysis and results for the amplification gain, temporal effect, and the influence of pumping laser, will be presented.

This work is financially supported and performed in Laser Technology Laboratory, The Institute of Physical and Chemical Research (RIKEN), Wako, Saitama 351-0198, Japan. The authors thank Dr. Katsumi Midorikawa and Dr. Akira Suda for the financial and experimental support and helpful discussions.

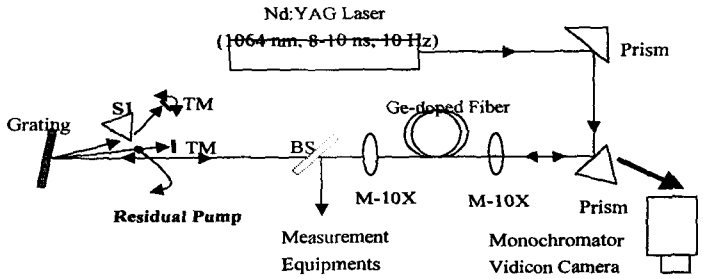
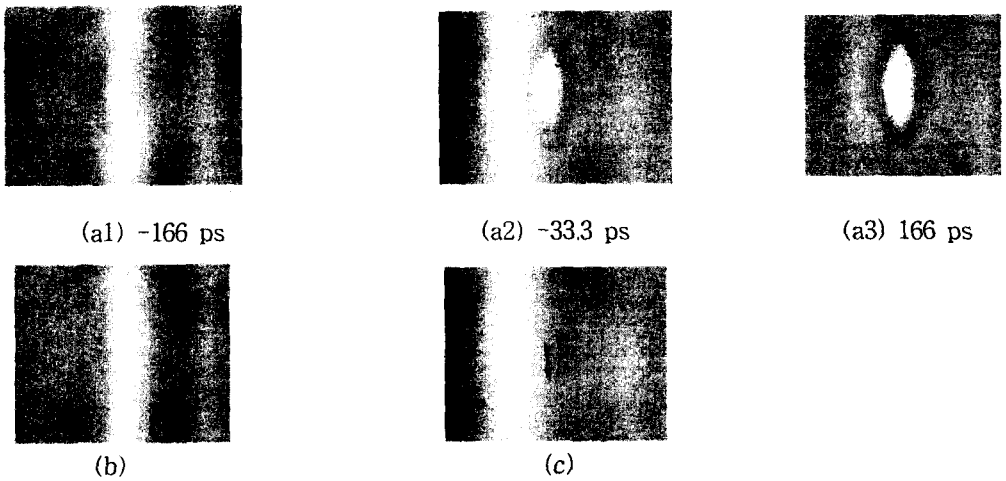


Figure 1. Experimental set-up for forward Raman amplification.



(a1) -166 ps (a2) -33.3 ps (a3) 166 ps

(b) (c)

Figure 2. The spectral density for (a) amplified signal with feedback of residual pump, (b) input signal without feedback of residual pump, and (c) the signal generated by feedback of only residual pump.

1. J. Kani and M. Jinno, "Wideband and flat-gain optical amplification from 1460 to 1510 nm by serial combination of a thulium-doped fluride fibre amplifier and fibre Raman amplifier", Electron. Lett. 35, 1004 (1999)