A Raman fibre amplifier generating simultaneous gain across multiple Stokes orders by using step shaped optical pulses

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Optical amplification based on stimulated Raman scattering (SRS) in optical fibres offers the potential to generate gain at any arbitrary wavelength with an appropriate pump source. This has proved a very effective and successful way of providing gain at those wavelengths not directly available with rare-earth doped fibres. However most of this success has been achieved using CW pump sources, but in recent years there has been renewed interest in the pulsed pumping of Raman amplifiers. This has been mainly in the telecommunications area through time–division multiplexed (TDM) pumping schemes [1], but also in other areas due to advances in diode-seeded high power fibre MOPA systems [2]. The MOPA configuration allows for excellent control of the pulse parameters which is not easily available from Q-switched or mode-locked lasers. This opens up new opportunities for controlling the Raman gain spectrum through control of the pulse parameters. Here we experimentally investigate the Raman gain spectrum produced from pumping a Raman fibre with step shaped optical pulses delivered from an ytterbium (Yb) doped fibre MOPA source. Such pulses contain sections with different peak powers which can be controlled by adjusting the height of each step. By adjusting the height of each step appropriately we show that we can tailor the peak powers so that different parts of the pulse transfer their energy to different Stokes orders leading to a controllable gain spectrum covering multiple Stokes orders. We believe this could open up opportunities for an ultrabroadband Raman amplifier. Also here we are only interested in the counter-propagating Raman gain, so the relevant duty cycles are important [3].

The experimental set-up is shown schematically in figure 1. The MOPA uses a directly-modulated semiconductor diode as the seed laser which is driven by electrical pulses from an arbitrary waveform generator (AWG) to provide the desired pulse shape. This is then amplified by two cascaded Yb-doped fibre amplifiers. The MOPA is single mode, has a wavelength of 1064 nm and can reach an average output power up to 4 W for the purposes of this experiment. The pulsed pump source is then free-spaced launched via a dichroic mirror into a 2 km long highly nonlinear fibre (HNLF) fabricated by Sumitomo Electric Industries, Ltd. We measure the counter-propagating Raman gain using a supercontinuum source which covers the spectral region from 1000 to 1700 nm (limited by the optical spectrum analyzer). This is then sliced using a monochromator to give a tunable input seed signal to the Raman amplifier.

Figure 3 shows the Raman gain spectrum obtained using the optical pulses shown in figure 2 as the pump pulses. The pulse has a total duty cycle of 50% with each step having a duty cycle of 25%. The resulting gain spectrum shows a peak on/off counter-propagating gain of more than 12 dB over both the 1st and 2nd Stokes orders. We will also present results obtained using different duty cycles and using pump pulses with 3 steps. Furthermore we will also show how to extend the bandwidth of the Raman gain spectrum by using two pump wavelengths from our MOPA source to fill in the gaps between the Raman gain peaks shown in figure 3. We also investigate the performance of using optical fibres with different germanium content as the Raman generating fibre. Acknowledgements: The HNLF was provided by Masashi Onishi, Masaaki Hirano and Takashi Sasaki of Sumitomo Electric Industries, Ltd.

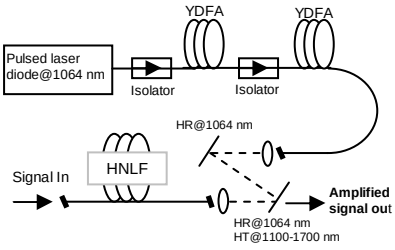

Fig. 1 Experimental set-up. YDFA: ytterbium-doped fiber amplifier, HR: high reflectivity, HT: high transmission.

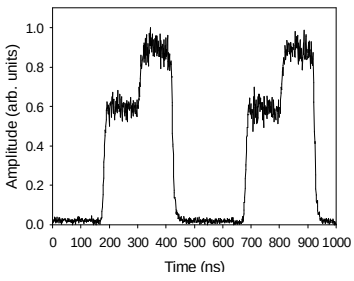

Fig. 2 Typical step shaped optical input pulse.

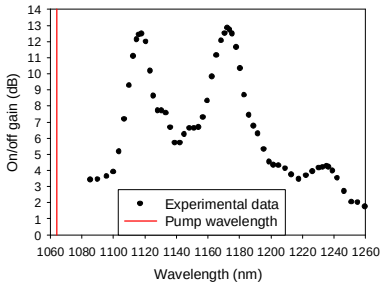

Fig. 3 Counter-propagating on/off Raman gain vs. wavelength for the pump pulse shown in figure 2.

References

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