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Unidirectional Ring Cavity Raman Fiber Laser with Continuous Wave Operation for Achieving Efficient Power

[1]K. Y. Lau and [2]P. J. Ker

[1]*College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, Kajang, Selangor, Malaysia.*

[2]*Department of Electronics and Nanoengineering, Aalto University, Tietotie , Espoo, Finland.*

Abstract

Raman fiber laser in C-band region has undeniable potential in optical communication systems due to the low attenuation at this wavelength band for signal processing and data transmission. Therefore, the extensive investigation for Raman fiber laser in terms of continuous wave and pulse regimes have been sought-after among the engineers and researchers. However, a simple design of the Raman fiber laser is always the merit to minimize the design complexity of the laser system. The main objective of this research work is to propose a simple design of Raman fiber laser which is designed with continuous wave operation. A unidirectional ring laser cavity is tailored by integrating an optical isolator within the Raman fiber laser configuration. The optical spectrum, power development, and the pulse validation for the Raman fiber laser will be thoroughly conducted in this work. The experimental result is expected with the absence of the pulse operation due to the continuous wave laser regime of the proposed Raman fiber laser scheme. The success of this work will contribute to a simple yet flexible design to a C-band Raman fiber laser for optical communication system.

Keywords: Raman Fiber Laser, Unidirectional Ring Laser Cavity, Continuous Wave, Ultra-long Fiber Laser,Power

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1 Introduction

Nowadays, ultra-long Raman fiber laser has received vast attention due to the significant application such as optical and data communications. Based on the literature, the longest Raman fiber laser was achieved as 270 km [1]. In [1], two fiber Bragg gratings were employed at the both ends of a linear laser cavity to reflect the first Raman stokes at approximately 1550 nm. Along the ultra-long optical fiber, pulse operation with 8.3 ms pulse width and 380 Hz repetition rate was generated. Apart from that self-pulsing experiment was demonstrated with Brillouin scattering [2], random fiber laser [3],[4], and Raman fiber laser with random distributed feedback mechanism [5]. With respect to the demonstration of this pioneer work, the author reported the analysis of Raman fiber laser with ring cavity laser architecture by manipulating the fiber length with 28, 56, and 76 km in [6]. Based on the previous result, pulse operation was observed as ~0.05 μs pulse width and ~14.1 MHz repetition rate for 56 km Raman fiber laser.

Therefore, the author has proven the validity of the ultra-long Raman fiber laser with bidirectional optical signal propagation in the ring laser cavity, which widens the design flexibility to [1]. However, the investigation of unidirectional optical signal propagation in ultra-long Raman fiber laser has remained at an early development stage. In addition, this signal propagation regime is unachievable in a linear laser cavity. As a result, an optical isolator is employed to force unidirectional optical signal propagation in the ring-structured Raman fiber laser cavity to investigate its effect to the experimental results.

In this work, we compare the experimental outcome in this research work to the previous experimental work in [6]. We discovered that by conducting the unidirectional optical signal propagation in the ring-structured Raman fiber laser cavity, the pulse operation of the laser is diminished. This contributes to flexible design for the optical communication engineers to design the ultra-long Raman fiber laser either with pulse or continuous wave laser regimes.

2 Experimental Setup

Figure 1 depicts the schematically experimental setup for the proposed Raman fiber laser. A 56 km Truewave REACH fiber was pumped by a 1455 nm Raman pump unit (RPU) via a 1455/1550 nm wavelength division multiplexer (WDM). This long optical fiber acts as the gain medium to provide the Raman gain for the entire laser cavity. A 1/99 optical coupler (OC) was employed to extract the optical signal for measurement via its 1 % output (OP) port, whereas the remaining 99 % of the optical signal is reverting into the laser cavity. An isolator (ISO) was spliced in between the

OC and WDM to ensure unidirectional flow of the optical signal in close-wise direction. The assembly of these components builds up a complete laser setup for Raman fiber laser.

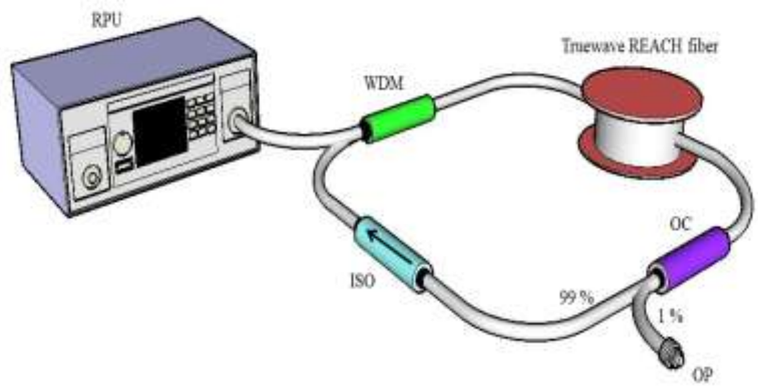

Figure1 Schematic diagram for Raman fiber laser.

3 Result and Discussion

This experiment is the extended study of the author's previous work in [2]. In comparison to [2], an additional isolator was employed to investigate the effect of Raman fiber laser with unidirectional propagation of the laser signal. The Raman fiber laser is measured with the optical spectrum with 0.1 nm and 0.02 nm resolutions for the wavelength span from 1450 to 1700 nm and 1520 to 1600 nm, as illustrated in Figure 2(a) and (b), respectively. According to Fig. 2(a), the first Raman stoke wave is generated with ~100 nm red-shifted from the 1455 nm pump at 1565.76 nm. Moreover, this first Raman stoke wave becomes the pump for the generation of second Raman stoke wave at 1684.64 nm. However, the second Raman stoke wave is insufficiently to be generated when the pump power is as low as 0.70 W. In this work, the first Raman stoke wave is focused due to the laser emission at C-band wavelength region which is very suitable for optical communication systems. The C-band region of the first Stoke Raman fiber laser is illustrated with better resolution as illustrated in Fig. 2(b). Based on the experimental findings, the optical spectrum was broadened with blue-shifted regime at higher pump power. This phenomenon is attributed to the combination of Raman gain from 1455 nm pump and dispersive-wave radiation up to the maximum pump power of 2.48 W [7].

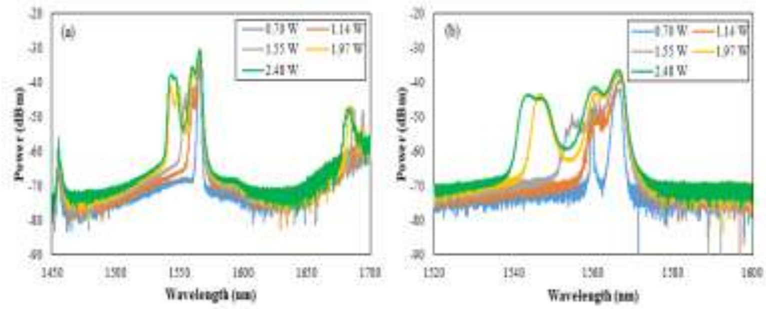

Figure 2 (a) Long and **(b)** short wavelength spans for Raman fiber laser.

Figure 3 presents the power development of the average output power as a function of pump power for the Raman fiber laser with an optical power meter measured at 1565 nm. Based on the observation, the laser threshold is acquired at the pump power of 0.33 W. Following laser theory, the average output power is increased at higher pump power. The maximum average output power was recorded as 199 µW at 2.48 W pump power. Higher average output power can be achieved with higher output coupling ratio than 1 %. In this circumstance, the maximum tolerance of the optical device should be carefully checked before the measurement was taken to avoid optical damage to the equipment.

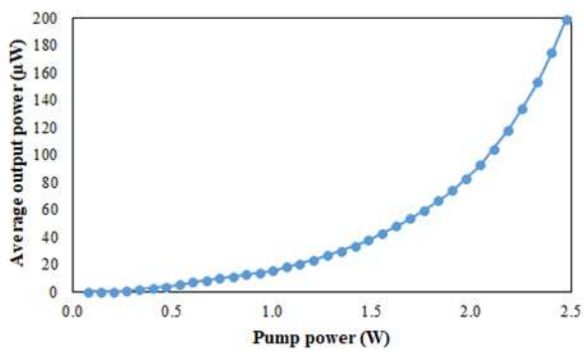

Figure 3 Power development curve of the Raman fiber laser.

The oscilloscope trace of the Raman fiber laser is shown in Figure 4. Based on the observation, the optical pulse operation is absent in the proposed Raman fiber laser cavity. In comparison to [2], the integration of an additional optical isolator inside the laser cavity converts the pulsed laser regime into continuous wave laser regime. This is a huge contribution for the optical communication engineers to design the Raman fiber laser with either pulse or continuous wave laser regimes by the incorporation of an optical isolator.

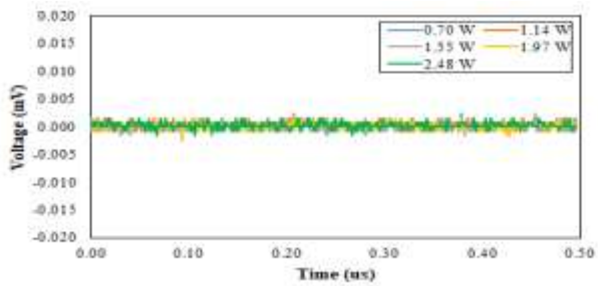

Figure 4 Oscilloscope traces of the Raman fiber laser.

4 Conclusion

This study contributes to the generation of a unidirectional ultra-long Raman fiber laser in C-band wavelength region. This 56 km Raman fiber laser system is helpful for long distance optical communications. Based on the result, investigation of unidirectional Raman fiber laser to the author's previous work on bidirectional Raman fiber laser is conducted. The research outcome shows that:

- The first Raman stoke is red-shifted by approximately 115 nm from the 1455 nm Raman pump.
- The optical spectrum of the Raman fiber laser is broadened at higher pump power due to the combination of Raman gain from 1455 nm pump and dispersive-wave radiation.
- The continuous wave Raman fiber laser can be designed by forcing unidirectional propagation of laser signal with the incorporation of an optical isolator inside the laser cavity.
- Flexible in tailoring of continuous wave or pulsed Raman fiber laser with and without an optical isolator, respectively.

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Biographies

K. Y. Lau, College of Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, Kajang, Selangor, Malaysia.

P. J. Ker, Department of Electronics and Nanoengineering, Aalto University, Tietotie, Espoo, Finland.