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MULTIPLE WAVELENGTH SIGNAL GENERATION FROM A BRILLOUIN ERBIUM FIBER LASER INTERNALLY PUMPED FROM FBG FIBER LASER

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ABSTRACT

A dual-ring Brillouin erbium fiber laser (BEFL) system sharing the same erbium doped fiber (EDF) had been demonstrated to output a single wavelength Stokes signal [1]. The system had been used to form a cascaded configuration for multiwavelength generation. The dual-cavity ring laser system demonstrated a multiwavelength output of 16 Stokes signals spaced at 0.088 nm. The Brillouin erbium fiber laser was in one cavity and a fiber Bragg grating (FBG) fiber laser in the other, which acted as a Brilloiun pump for the BEFL. No external Brillouin pump was used in the experiment.

INTRODUCTION

The properties of the BEFL had been thoroughly discussed for a single and multiple wavelength generation by several authors [1 – 6]. Several number of techniques used in the BEFL system generated multiple wavelength operation, where one featured a bi-directional operation using an intra-cavity fiber (DFB) laser in the ring laser [2]. An injection-locked seeding generated over ten lines in the ring resonator [5]. These lasers were demonstrated using a single ring system, while reference [6] employing the fight-of-eight cavity configuration.
These previous work on the BEFL configurations, with the exception of Yamashita *et al* [3] required an external Brillouin pump signal to initiate Brillouin gain in the single mode fiber (SMF). Yamashita used a fiber DFB laser as the Brillouin pump (BP) and the DFB laser was integrated into the BEFL resonator. The lossy bi-directional BEFL produced five Stokes signals separated by 10.6 GHz (0.085 nm) in both the clockwise and counter-clockwise directions. We present experimental results of the generation of multiple wavelength laser-source from a BEFL pumped from FBG fiber laser sharing the same EDF, which output 16 signals uniformly spaced at 11.0 GHz (0.088 nm).

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EXPERIMENTAL

The principle underlying the design of this two-ring laser system sharing the same gain medium is based on the cavity loss and/or wavelength matching between the two resonators. This concept is utmost important to ensure the operation of the BEFL, where the injected BP wavelength should be close to the wavelength of the EDF peak gain. An attenuated cavity induced a wavelength shift in the EDFL operation and this is illustrated in Figure 1.

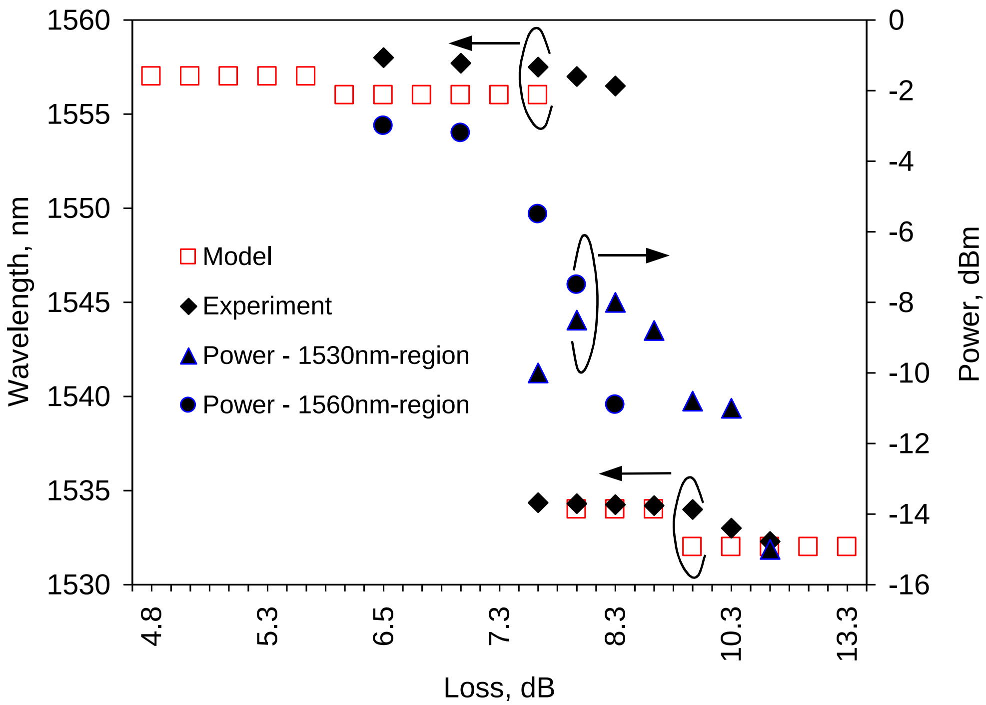

Figure 1: An attenuated cavity not only reduced the output power but also shifts the free-running operating wavelength of the EDFL to a shorter wavelength-region.

Since the optical components that made up the individual resonant cavities of the lasers in the two rings are not identical, hence the cavity loss may not be the same. Dissimilarity between these two cavities will result in different wavelength operation thus it gives unfavorable condition for the BEFL operation.
To overcome this situation, the cavity matching or similar wavelength operation of the two cavities has to be met and this can be done by a few techniques. One of the methods is to devise a wavelength selective element that can be tuned to within the operating wavelength of the BEFL. Another method is to incur an additional loss in the cavity that has relatively lesser cavity loss. Attenuating one of the cavities with a variable optical attenuator can match-up the cavity loss between the two systems and ensure both cavities to operate at similar wavelength. The latter technique was employed.

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The configuration of BEFL that was used in the experiment is shown in Figure 2. The lower ring of the dual-cavity system is the BEFL and the other (upper ring) is the FBG fiber ring laser, which is generally an EDFL with FBG-wavelength-locking. The BEFL cavity (the lower ring) had relatively lower cavity loss than the upper ring (FBG laser). The BEFL cavity had to be attenuated to match the cavity loss of the other ring. An optical variable attenuator was inserted in the BEFL resonator and the ring comprises of a 15 m EDF and 500 m SMF as the nonlinear gain media. No external Brillouin pump (BP) was used in this experiment. High reflectivity FBG that was incorporated in the fiber laser was devised to laser at around 1560nm and its output will be the Brillouin pump (BP) that will be injected into the BEFL.

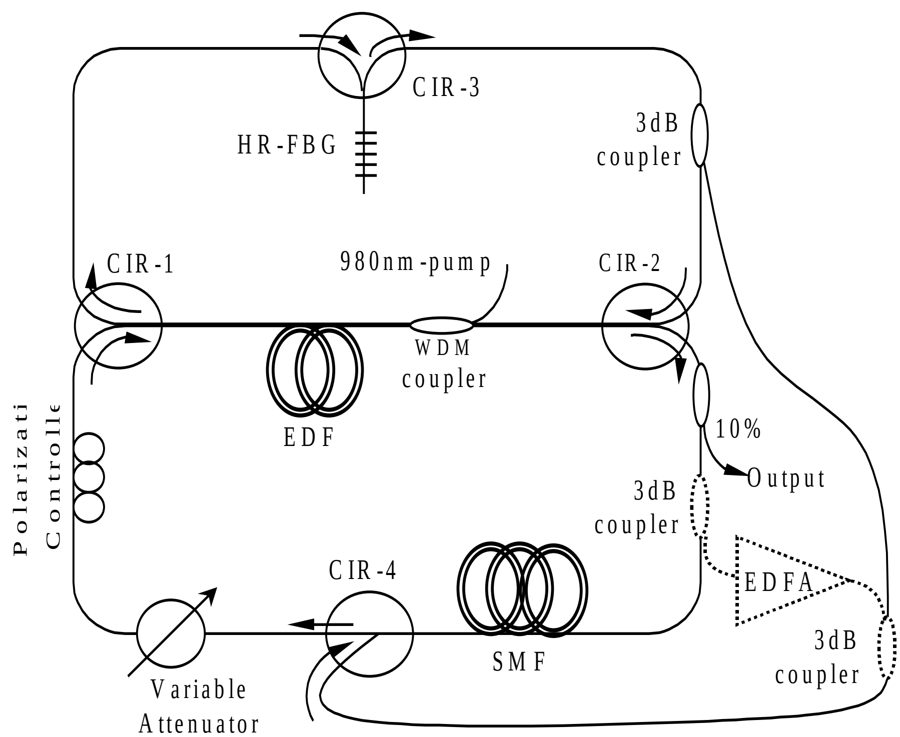

Figure 2: Schematic of Brillouin erbium fiber ring laser pumped from FBG fiber laser sharing the same EDF. An EDFA was used to amplify the subsequent Stokes signals feeding back into the SMF for multiwavelength generation.

The BP signal originated from the FBG laser was injected into the SMF via an optical circulator CIR-4 and the injected signal was made non-resonant by circulator CIR-2. The output power of the BEFL was tapped out from the 10% output coupler for monitoring. The oscillating signals of both rings operated in clockwise directions and arrows at the circulators show the signal propagations.
High reflectivity FBG that was incorporated in the FBG laser was devised to lase at around 1560 nm and its output signal was split out from a 3 dB coupler, which will act

as the Billouin pump to the BEFL. With no BP signal injected into the SMF, the BEFL operated as an EDFL and due to low cavity-loss the resonator lased at a longer wavelength, which was at approximately 1567 nm.

The EDF peak gain in the BEFL should be set close to the operating wavelength of the BP [2] to generate the initial Stokes signal. The cavity was attenuated to 3.61 dB to achieve the preferred BEFL output.

RESULTS AND DISCUSSION

Single wavelength BEFL output was studied in the first setup, where the cascaded looping consisting of an EDFA and two 3-dB couplers excluded (dotted lines in Figure 2). With no BP injected into the SMF, the BEFL operated as an EDFL and it lased at a longer wavelength. The EDF peak gain in the BEFL should be set close to the operating wavelength of the BP [4] to generate initial Stokes signal.

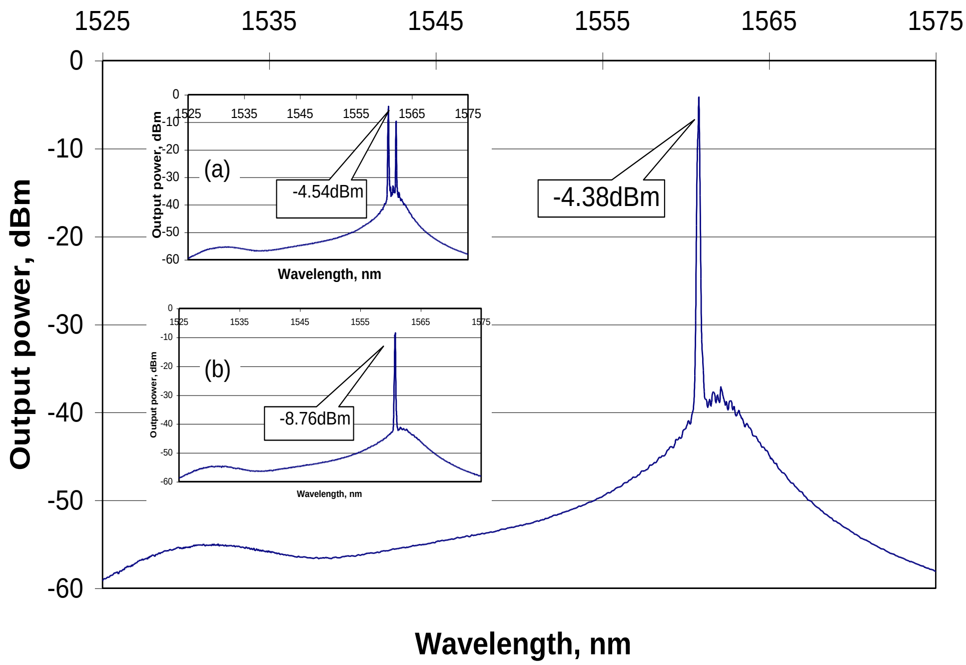

Figure 3: Single wavelength BEFL output spectra with optimum cavity loss setting. Unmatched cavity loss results to poor outputs (insets).

Considering that the intracavity loss affects the operating wavelength of the laser [5], the BEFL was made to operate to the desired wavelength by subjecting additional loss in the cavity with a variable attenuator. The cavity was attenuated to 3.61 dB to achieve preferred BEFL output, see Figure 3. The total cavity loss amounts to about 11.3 dB. Unmatched cavity loss results to undesired output spectrum as in (a) and (b) of the inset in Figure 3, with 3.55 dB and 3.70 dB attenuation respectively.

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Since the two cavities sharing the same EDF, the BEFL output and Brillouin pump powers, which was taken from 10% output couplers increased proportionately with the 980 nm-pump, as shown in Figure 4 and inset of Figure 5 respectively. With the linear and nonlinear gain mediums that were generated from the EDF and SMF respectively, the BEFL system exhibits higher output power than that of FBG laser (BP).
The slope efficiencies of the BEFL and BP power were 0.5% and 0.1% respectively, where they were a function of the output coupling-ratio. Inset of Figure 4 shows the BEFL single wavelength output spectrum with the BP injected signal spaced at 0.088 nm. The EDF was pumped at 120 mW of power.

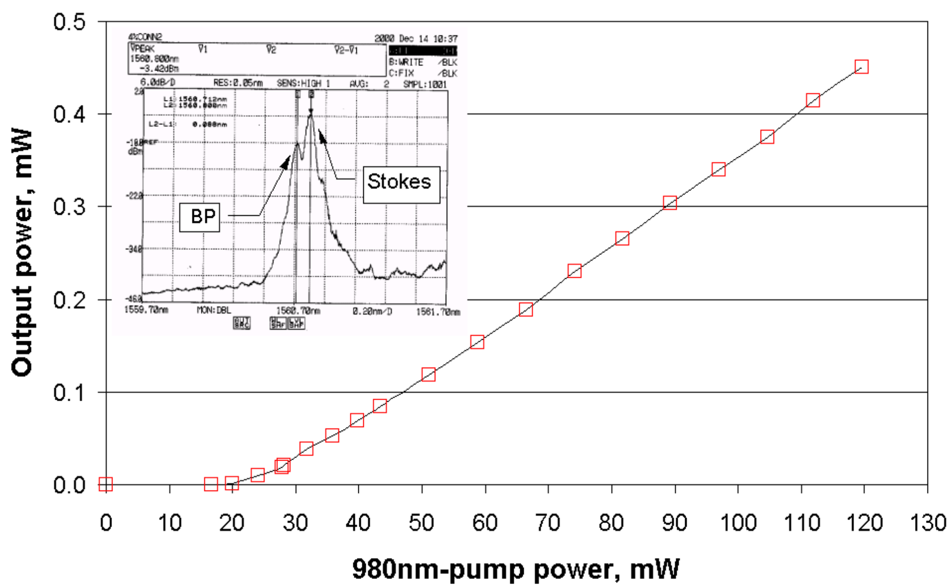

Figure 4: BEFL output power as function of the 980nm-pump power. Inset: BEFL single wavelength output spectrum with BP spaced at 0.088nm.

Above threshold, the output power increased with BP power, as illustrated in Figure 4, and that of the 980 nm-pump power. These characteristics demonstrated a distinct trend compared to a single cavity BEFL system with an external BP, where the output power saturated with increasing BP power [6]. It is believed that output power will increase further with increasing 980 nm-pump up to the limit of erbium-ion saturation. With high output coupler ratio and minimal intracavity loss, the laser could generate relatively higher output power and high efficiency.

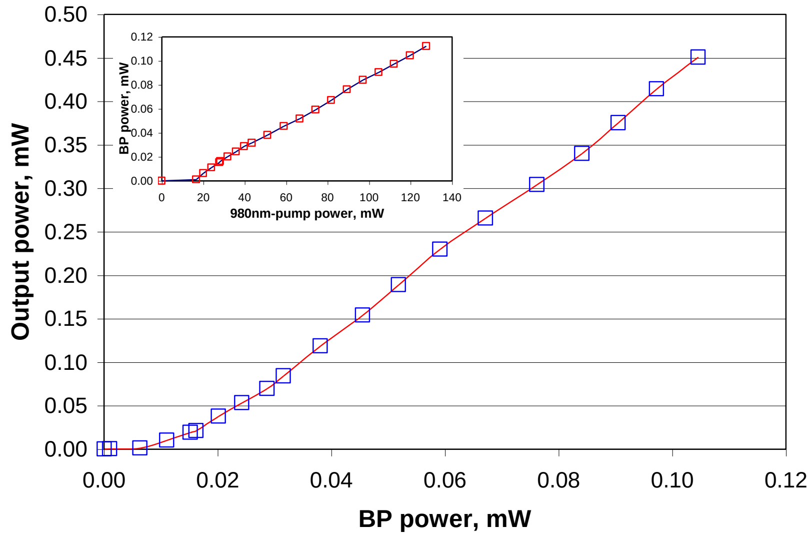

Figure 5: Increment of BEFL output power with BP power. Inset: BP power as function of 980nm-pump power.

Multiwavelength operation of the BEFL was accomplished using the amplified cascaded setup comprised of an EDFA and two 3-dB couplers (dotted lines, Figure 2). This was done by looping in the Stokes signal that was previously generated in the BEFL cavity to seed the next signal by allowing this signal to be re-injected into the SMF. The looping arm comprised of two 3-dB couplers and an optical amplifier. The Stokes signals generated were amplified and compensate the loss in the two 3-dB couplers.

Figure 6 shows the output spectrum of the multiwavelength BEFL with 16 Stokes generated and the first line is the BP signal injected from the FBG fiber laser. The first Stokes signal in the cascade acted as a pump to produce the second Stokes and the process subsequently iterated and resulted in the generation of multiple Stokes line. The generated Stokes line increased with 980-nm pump power to within the gain bandwidth of the EDF. A number of anti-Stokes signals have also been demonstrated.

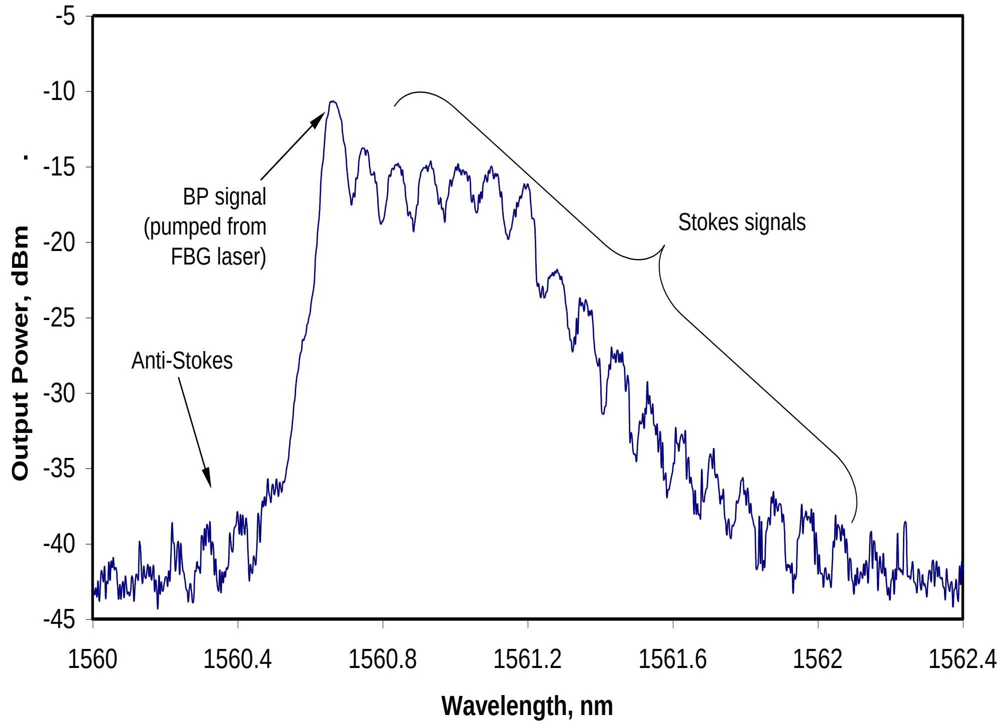

Figure 6: Spectrum of multiwavelength BEFL demonstrating 16 Stokes signals with the first line being the BP pumped from the FBG laser.

The spectrum was monitored at an optimum cavity-setting of the BEFL with the EDF pumped at 120 mW of power. Bidirectional and four-wave mixing process in the SMF introduced anti-Stokes signals, which were more obvious with increasing 980 nm-pump power.

CONCLUSIONS

In summary, we have presented a multiwavelength BEFL that was devised from a two-cavity system where one of the cavities was the BEFL and the other being the FBG fiber laser, which acted as a Brillouin pump to the BEFL. No external BP was used in the experiment. Both of the lasers gained power from the same EDF. Any design or technique, with ease of implementation and compatible to the existing system, which contributes to reducing the capital cost in the dense wavelength division multiplexing or DWDM system, will be very much desirable. DWDM systems are based on the ability of an optical fiber to carry many different wavelength of light simultaneously without mutual interference. Each wavelength represents an individual optical channel within the fiber. A single laser source, such as the internally-pumped BEFL that could generate multiple wavelength is cost-effective and advantageous to the application in DWDM system.

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