

Single Polarization Unidirectional Distributed Feedback Fibre Ring Laser

Field of the Invention

This invention relates to an optical fibre laser configuration for low noise, narrow
5 linewidth, single polarization mode operation with power amplification. Its applications
are largely in the field of fibre optics communication systems, as well as optical fibre-
based sensor systems.

Background of the Invention

10 Single frequency, single polarization optical fibre lasers exhibit potential as next
generation optical network transmitters in view of advantages such as engineering
simplicity, narrow linewidth and low fibre-coupling loss.

Short cavity, Erbium/Ytterbium doped Distributed Feedback (DFB) fibre lasers, in
15 particular, are highly efficient and exhibit robust, stable single mode operations. However,
due to intrinsic birefringence within the fibre, a single polarization output cannot generally
be guaranteed. Moreover, the second polarization mode can begin to manifest at moderate
to high pump power.

20 Techniques such as self-injection locking have been proposed to ensure single
polarization output, as documented by S. Yamashita & G. J. Cowle ("Single-Polarization
Operation of Fibre Distributed Feedback (DFB) Lasers by Injection Locking", Journal of
LightwaveTechnology, 17(3), 1999). This configuration requires a short, low-loss
feedback cavity to ensure polarization stability and sufficient injection intensity.
25 Amplification of injection intensity through insertion of an Erbium doped fibre in the
external cavity thus tends to compromise mode stability. Furthermore, for a robust
architecture such as structure requires a well-matched end-reflector and low back-
reflections from the polarizer.

On the other hand, a single mode interactive DFB-DBR fibre laser which merges the merits of both laser configurations has been proposed J. J. Pan & Y. Shi ("166mW Single-Frequency Output Power Interactive Fibre Lasers with Low Noise", IEEE Photonics Technology Letters, 11(1), 1999). This structure reportedly achieves high
5 output power through a Master Oscillator Power Amplifier (MOPA) configuration and exhibits a linewidth of the order of 200kHz. The fabrication procedure is, however, critical to ensure optimal wavelength overlap between the Bragg gratings and the lasing wavelength of the DFB fibre laser. Accordingly, no polarization tuning mechanism can be incorporated to assure single polarization mode operation. Furthermore, amplification of
10 the fibre laser output through MOPA configuration leads to the introduction of Amplified Spontaneous Emission (ASE) noise which is highly undesirable for optical communication applications.

An alternative approach to obtain narrow linewidth, high output, single longitudinal
15 mode operation is through a fibre ring laser configuration. Mode selection elements, such as external reflectors or intra-cavity filters are highly stringent. Results also indicate they are susceptible to mode-hops due to the finite bandwidth of these wavelength-selective elements and the narrow free spectral range (FSR) of the long ring cavity. The use of an integral saturable absorber to form an effective, ultra-narrow band filter, however, reduces
20 the output power drastically.

Single longitudinal mode operation using a simple all-fibre DFB-Ring configuration was first demonstrated by D.Yu et al. ("Distributed-Feedback Ring All-Fibre Laser", OSA Trends in Optics and Photonics on Advanced Solid State Lasers, vol 1, 1996).
25 The laser therein disclosed achieves self-injection locking by coupling part of the output of the DFB fibre laser from one end to another, hence forming the ring configuration. However, self-pulsations at 65 μ s interval was observed when Er³⁺ doped fibre (1000ppm) was used as the laser gain medium. Since the DFB fibre laser lases bi-directionally, the configuration is prone to interference disturbance between the counter-propagating light
30 within the ring. Without polarization filter/control, polarization mode discrimination is

also not available. At high pump power, the configuration is also prone to multi-mode operation outside the stop-band of the DFB grating.

Summary of the Invention

5 In accordance with the present invention, there is provided a distributed feedback ring laser arrangement having a distributed feedback fibre laser arranged in an optical fibre loop, the loop including: a ring cavity of rare earth doped optical fibre; at least one laser pumping means; unidirectional optical isolation means; first and second polarization controllers; and an intra-cavity polarization means.

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In the preferred form of the invention, the distributed feedback fibre laser comprises a π phase shifted grating inscribed into Er/Yb co-doped fibre.

Preferably the at least one laser pumping means comprises first and second 980nm
15 laser diodes coupled into the optical fibre loop through wavelength division multiplexed couplers.

An output for the ring laser arrangement is preferably provided through a coupler and a polarization insensitive isolator.

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Brief Description of the Drawings

The invention is described in greater detail hereinafter, by way of example only, through a preferred embodiment thereof and with reference to the accompanying drawings, wherein:

25 Figure 1 is a diagrammatic illustration of a single polarization, unidirectional fibre DFB ring laser constructed according to a preferred embodiment of the present invention;

Figure 2 is a SFFPI trace showing one FSR of the single polarization mode output of the fibre DFB ring laser;

Figure 3 is a plot of the output power of the fibre DFB ring laser observed on an
30 Optical Spectrum Analyser (OSA) illustrating side mode suppression of >42dB;

Figure 4 is an Electrical Spectrum Analyser (ESA) plot of noise intensity for the

fibre DFB ring laser; and

Figure 5 is a spectrum obtained during linewidth measurement of the fibre DFB ring laser output.

5 Detailed Description of the Preferred Embodiments

A single polarization, unidirectional fibre distributed feedback (DFB) ring laser configuration constructed in accordance with the principles of the present invention is described hereinbelow. The laser structure of the preferred embodiment may achieve a combination of high cavity gain, narrow linewidth associated with ring lasers of the prior art, with the low noise characteristics of a DFB fibre laser.

A diagrammatic illustration of an experimental set-up for a single polarization, unidirectional fibre DFB ring laser 10, constructed according to the principles of the present invention, is shown in Figure 1 and described hereinbelow. The ring structure 10 includes a DFB fibre laser 12 which is fabricated through inscription of a π phase-shifted grating into an Er/Yb codoped fibre. The Er/Yb fibre has a small signal absorption of ~23dB/m at 1535nm and 230dB/m at 980nm. The structure is pumped by two 980nm laser diodes 14, 16 through respective wavelength division multiplexed (WDM) couplers 18, 20. Output from the ring structure is obtained from a 50/50 coupler 22 having index matching gel, and a polarization insensitive isolator 24. A directional polarizer 26 is incorporated within the ring to enhance polarization selectivity. Two inline polarization controllers (PC's) 28, 30 are included in the ring to control birefringence and to select either of the two lasing polarizations of the DFB fibre laser. A length of approximately 5.5 metres of Erbium doped fibre 32 is included, resulting in a total cavity length of approximately 17 metres.

Round trip cavity loss for the structure as illustrated is $> 7\text{dB}$ due to the high excess loss of the polarizer and the use of the 50/50 coupler at the output. During experimentation the entire set-up is covered to shield away environment perturbations.

Prior to implementation of the configuration 10, the DFB fibre laser 12 exhibits dual polarization mode operation with a separation measured at approximately 555MHz. Output power at about 60mW pump power is approximately 0.4mW.

5 Experimental results from the output of the DFB-ring fibre laser 10 were obtained simultaneously through the use of a scanning fibre Fabry-Perot interferometer (SFFPI), Electrical Spectrum Analyser (ESA) and an Optical Spectrum Analyser (OSA). With the first 980nm pump 14 providing about 68mW and the second 980nm pump 16 providing about 20mW, single polarization mode operation was obtained through tuning the
10 polarization controllers 28, 30, resulting in a SFFPI trace as shown in Figure 2.

No mode beatings are registered on the ESA and side-mode suppression of >42dB is measured on the OSA (Figure 3). This further verifies that the laser operates in single polarization mode. The measured laser output is ~4mW (6dBm) which implies an
15 amplification of >10 times. RIN measurement using a low noise receiver (New Focus1811) indicates a peak RIN level of ~-117dB/Hz at its relaxation oscillation frequency (~1.1MHz) and which decreases sharply to <-135dB/Hz above 3MHz. These results are illustrated in Figure 4.

20 The linewidth of the laser output was measured using delayed self-homodyne technique through a commercial fibre Mach Zender (MZ) interferometer. The resolution of the device is limited to ~32kHz and the obtained profile on the ESA is as shown in Figure 5. The measured linewidth is largely resolution limited. Based on the steep gradient along the profile, it is concluded that the actual linewidth of the laser is well
25 below 32kHz.

The configuration can be further improved by incorporating low-loss polarization-sensitive isolators and through optimising the ratio of the couplers. Single pump diode configuration can also be achieved using an appropriate 980nm coupler. Further, a

bandpass filter within the loop can further enhance mode discrimination within the ring laser. The configuration may also be adopted for DBR-Ring laser configuration or Fabry Perot-Ring configuration that not only allows polarization mode discrimination but also wavelength control.

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The fibre laser configuration exhibits great potential in dense WDM optical communication network. Its narrow linewidth and low noise level competes favourably to present semiconductor transmitters. Due to its fibre-based configuration, it is also highly applicable to fibre optics sensor systems.

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The operation of the ring structure 10 is different from the Sagnac loop disclosed in the prior art in view of an optical isolator included for unidirectional operation. An intra-cavity polariser is also added for polarization-selectivity. Furthermore, the configuration the present invention relies on fibre birefringence tuning technique to induce Vernier effect between the two laser configuration. Even though the DFB fibre laser enhances single longitudinal mode operation within the ring cavity, the combination of high cavity gain at high pump power and wide gain spectrum of Erbium can lead to radiation outside the stop band of the DFB grating. To obtain single polarization mode operation at high pump power, the ring cavity is tuned through the polarization controllers to achieve polarization-selective injection locking to the DFB laser. Vernier effect and homogenous gain broadening in Erbium ensure suppression of all other potential radiation. Effectively, the configuration realises MOPA and self-injection locking without a tedious fabrication process or additional matching gratings. Power amplification is thus achieved without compromising output performance. This enables narrow linewidth, single polarization mode operation with Relative Intensity Noise (RIN) below -135dB/Hz (>3MHz) as described hereinabove.

The foregoing detailed description of the invention has been presented by way of example only, and is not intended to be considered limiting to the invention as defined in the appended claims.

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Claims:

1. A distributed feedback ring laser arrangement having a distributed feedback fibre laser arranged in an optical fibre loop, the loop including:
 - 5 a ring cavity of rare earth doped optical fibre;
 - at least one laser pumping means;
 - unidirectional optical isolation means;
 - first and second polarization controllers;
 - an intra-cavity polarization means.
- 10 2. A distributed feedback ring laser arrangement as claimed in claim 1, wherein the distributed feedback fibre laser comprises a π phase shifted grating inscribed into Er/Yb co-doped fibre.
- 15 3. A distributed feedback ring laser arrangement as claimed in claim 1, wherein the at least one laser pumping means comprises first and second 980nm laser diodes coupled into the optical fibre loop through wavelength division multiplexed couplers.
4. A distributed feedback ring laser arrangement as claimed in claim 1, wherein an
20 output is provided through a coupler and polarization insensitive isolator.
5. A distributed feedback ring laser arrangement as claimed in any one of the preceding claims, wherein the first and second polarization controllers are adapted for controlling birefringence and for selecting either of two lasing polarizations of the
25 distributed feedback fibre laser.