Technical University of Denmark

A unidirectional Er3+-doped fiber ring laser without isolator

Shi, Yuan; Sejka, Milan; Poulsen, Ove

Published in:
I E E E Photonics Technology Letters

Link to article, DOI:
10.1109/68.372749

Publication date:
1995

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Shi, Y., Sejka, M., & Poulsen, O. (1995). A unidirectional Er3+-doped fiber ring laser without isolator. I E E E Photonics Technology Letters, 7(3), 290-292. DOI: 10.1109/68.372749

A Unidirectional Er^{3+}-Doped Fiber Ring Laser without Isolator

Yuan Shi, Milan Sejka, and Ove Poulsen, *Member, IEEE*

***Abstract*—An Er^{3+}-doped fiber ring laser with unidirectional operation without optical isolator has been investigated for different cavity conditions. The fiber ring laser cavity is built in such a way that the optical fields propagating in the two directions suffer different losses. As a consequence, the laser oscillation appears in a quasi-unidirectional form. By incorporating a fiber pigtailed bandpass filter to enhance mode competition, a purely unidirectional tunable fiber ring laser is obtained with high efficiency and broad tunability.**

I. Introduction

Er^{3+}-DOPED fiber lasers and amplifiers at the 1550 nm band have many important applications in telecommunication and other fields [1]–[3]. Various Er^{3+}-doped fiber lasers with different cavity structures have been developed. Among these the doped fiber ring laser with an optical isolator to ensure unidirectional operation has been particularly attractive. Compared to other laser systems, unidirectional ring lasers have excellent lasing efficiency, less sensitivity to back-reflections, and better potential for operation in a single longitudinal mode. The main drawbacks for previous unidirectional ring lasers have been the high cost and intrinsic loss of the optical isolator.

In this letter, we report experimental results for an Er^{3+}-doped fiber ring laser with a structure which has a nonreciprocal loss of the two traveling directions leading to unidirectional operation. A detailed investigation with different cavity conditions has been carried out by incorporating various fiber optic components into the ring cavity.

The S-shaped fiber ring resonator has been used by Ja *et al.* [4]–[7] for various passive devices, such as bandpass/bandblock filters, wavelength division multiplexer/demultiplexer and butterworth-like filters. A quasi-unidirectional fiber ring laser using an S-shaped structure has recently been discussed [8] by scientists in Portugal's Centro de Optolectrónica. A quasi-unidirectional semiconductor ring laser in an S-configuration without optical isolator has been demonstrated by Hohimer *et al.* [9].

II. Experimental Setup

The experimental setup of the unidirectional fiber ring laser is shown schematically in Fig. 1. It has a ring structure of Er^{3+}-doped fiber with two fiber couplers, 1 and 2, to introduce nonreciprocal losses for the two lasing directions (cw for clockwise and ccw for counter-clockwise). A fiber coupler with two symmetrical output ports of 1% is used to monitor the lasing intensities in the two directions. A Ti : sapphire laser pump at 980 nm is coupled into the fiber laser by a wavelength division multiplexer (WDM). The Er^{3+}-doped fiber used in the fiber laser has a nominal doping concentration of 0.7×10^{19} cm^{-3} with Al^{3+}- and La^{3+}-codopants. It has a fluorescence lifetime of 11 ms. Below lasing threshold, a linear ray-tracing calculation gives the losses for the two directions in the fiber ring laser. When two 3 dB fiber output couplers (OC) are used, we can trace the evolution of amplified spontaneous emission (ASE), from which laser oscillation builds up. For the ray-tracing analysis, we assume that the Er^{3+}-doped fiber has a constant gain G for the cw and ccw directions without saturation. Losses of WDM, bandpass filter and monitoring coupler are ignored. For an identical output ASE power with A and F being the starting point of the cw and ccw respectively, ASE is transmitted through a 3 dB coupler at B and splits into two equal arms with 50% transmitted through B-C-D to the second 3 dB coupler at D, where the ASE is split into two arms with 25% transmitted back to the ring at F. This yields a return power at A of 0.25*G in the cw direction. Another 25% is transmitted back through D-E-B with 12.5% injected into the ccw direction and 12.5% going to OC top by the 3 dB coupler at B. The second 50% from the 3-dB coupler at B goes through B-E-D with 25% injected to ccw and 25% going to OC bottom by the 3-dB coupler at D. For the ccw direction, including the ASE injected from the cw direction at B and D, we obtain a return power at F of 0.50*G. The optical loss for the cw direction is 3 dB higher than for the ccw direction. This non-symmetrical fiber ring laser with a nonreciprocal loss is called a Ying-Yang fiber ring laser.

The nonreciprocal optical loss or gain for the two directions in the ring laser arises from the fact, that there is a coupling of light from the cw direction into the ccw direction by the two fiber couplers. It will promote lasing in the ccw direction and suppress lasing in the cw direction, assuming that the doped fiber is a purely homogeneously broadened system. Unfortunately, the Er^{3+}-doped silica-based fiber has a substantial inhomogeneous broadening contribution. This reduces the mode competition and thereby counteracts the nonreciprocal loss, enabling bidirectional lasing of the fiber ring laser. By using a bandpass filter with a transmission linewidth comparable to the homogeneous broadening in the doped fiber we enhance the mode-competition and suppress laser oscillation in the cw direction.

Manuscript received August 22, 1994; revised November 8, 1994.
The authors are with Mikroelektronik Centret, Technical University of Denmark, DK-2800 Lyngby, Denmark.
IEEE Log Number 9408407.

1041–1135/95$04.00 © 1995 IEEE

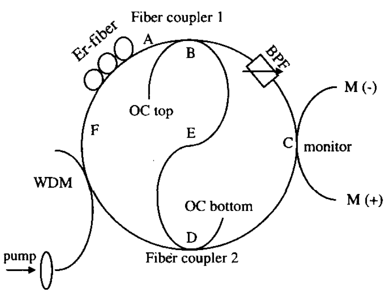

Fig. 1. The experimental setup of the fiber ring lasers. OC: output coupler. WDM: wavelength-division-multiplexer of 1550 nm/980 nm. BPF: bandpass filter. M(−) and M(+): monitor output of ccw and cw direction, respectively.

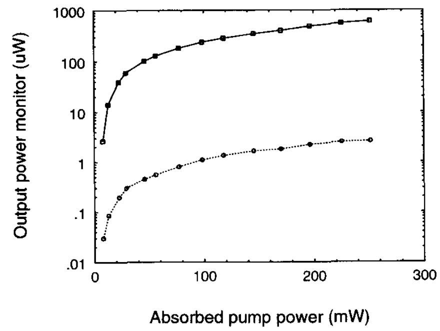

Fig. 2. The output power of the laser measured from the monitoring fiber coupler. The solid line represents the ccw direction and the dashed-line the cw direction lasing. The cw emission is due to amplified spontaneous emission.

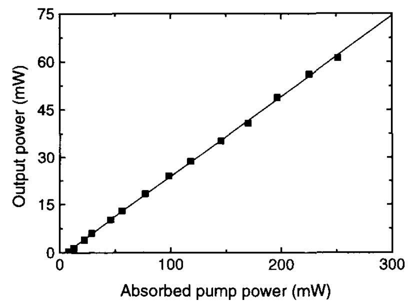

Fig. 3. The total output power as a function of input pump power for the tunable fiber ring laser.

III. Experimental Results and Discussions

In order to obtain a good understanding of the behavior of the fiber ring laser, we investigated it with three different cavity configurations: 1) two 3 dB couplers, 2) 70/30 and 80/20 couplers, and 3) incorporation of a bandpass filter in case 2).

With two 3-dB couplers and without filter in the laser cavity, we can not effectively obtain unidirectional lasing. A maximum output power difference of 10 dB between the two monitoring output ports is obtained. The two lasing directions have the same broad lasing spectrum and almost identical lasing thresholds. We attributed the non-unidirectional lasing to the too small loss difference between the two directions combined with the effect of inhomogeneous broadening of the gain medium. Under these conditions, the system is intrinsically unstable and back-reflections from the two output ports of the 3 dB couplers enhance the clockwise direction lasing even with angled fiber ends. The internal reflections due to fiber splicing and reflections from the fiber ends of the monitor coupler are so small that they can be ignored.

In order to increase the nonreciprocal loss for the two directions and obtain unidirectional lasing, we use a 70/30 coupler and an 80/20 coupler as fiber coupler 1 and 2, respectively. This increases the loss difference between the two lasing directions from 3 dB to 7.1 dB. It also enhances the useful laser output. With this cavity configuration we use the monitor output coupler to investigate the properties of the two lasing directions. The maximum difference in output power is ~20 dB during laser operation. By measuring output spectra at different pump levels, we find that the two directions still have similar output spectra with only a small difference in lasing threshold. In order to study the losses and dynamics of the laser more carefully, we investigated the relaxation oscillations for the two lasing directions by pulsing the pump laser. Without preventive measures against back reflections from the two output fiber ends we find similar relaxation oscillations, except for their different amplitudes. This indicates a coupling between the two directions. When we prevent the back-reflections from the two output ports by a large angled cleave of the fiber ends, the relaxation oscillation in the cw direction becomes very weak and acquires a longer buildup time. The relaxation oscillation in the ccw direction is unchanged. This indicates that the lasing oscillation in the cw direction is mainly driven by back-reflections from the laser output ports in the ccw direction. Even with the large angled cleaved fiber output ends, with an estimated back-reflection of ≈ −40 dB, laser oscillation can be observed in the cw direction. This is probably due to the inhomogeneous broadening properties of the doped fiber, which makes it very difficult to completely suppress the cw direction lasing.

To address this problem, we use a bandpass filter to enhance mode competition, which should suppress lasing in the cw direction. The fiber pigtailed bandpass filter used has a transmission linewidth of ~2 nm, which is narrower than the homogeneous linewidth [10]. Its peak transmission can be tuned from 1480–1550 nm. The performance of the fiber ring laser with the bandpass filter inserted into the cavity are investigated in detail. The output powers of the cw and ccw directions in the monitor coupler are shown in Fig. 2. There is a power difference of ~25 dB almost independent of pump power. The output power of the cw direction from the monitor coupler is mainly due to amplified spontaneous emission. By pulsing the pump laser, we do not observe any relaxation oscillations in the cw direction. This indicates that a unidirectional lasing operation in the ccw direction is achieved. The output power, which is the sum of the output from the 80/20 coupler and the 70/30 coupler is shown as a function of absorbed pump power in Fig. 3. It has a slope efficiency of 25% and a fitted threshold of ~5.5 mW. A tunability from 1512–1550 nm, primarily limited by the bandpass filter, is observed.

Using an optical spectrum analyzer we find that the linewidth of the laser is less than 0.05 nm limited by the resolution of the optical spectrum analyzer. We expect that the laser spontaneously acquires single-mode operation. With a proper stabilization technique it could therefore be turned into a tunable single-mode ring laser.

IV. Conclusion

We have investigated the properties of an Er^{3+}-doped fiber ring laser with a Ying-Yang structure. This structure gives rise to unidirectional lasing without the need of optical isolator. The properties of the fiber ring laser have been studied for different cavity conditions. Various difficulties to obtain pure unidirectional laser operation are addressed. By using a bandpass filter in the structure, we obtain wavelength tunability for the Er^{3+}-doped fiber ring laser and enhance mode-competition, allowing efficient unidirectional laser operation.

Acknowledgment

The authors gratefully acknowledge Dr. B. Pedersen from NKT Research Center for lending us the bandpass filter, and Dr. B. Pálsdóttir from Lycom for providing the Er^{3+}-doped fiber.

References

[1] J. E. Townsend, M. N. Zervas, and R. I. Laming, "Design and fabrication of high-performance Er^{3+}-doped fiber devices," *Proc. of SPIE*, vol. 1789, *Fiber Laser Sources and Amplifiers IV*, pp. 128–136, 1992.
[2] P. R. Morkel, G. J. Cowle, and D. N. Payne, "Traveling-wave erbium fiber ring laser with 60 kHz linewidth," *Electr. Lett.*, vol. 26, pp. 632–634, May, 1990.
[3] C. V. Poulsen and M. Sejka, "Highly optimized tunable Er^{3+}-doped single-longitudinal-mode fiber ring laser, experiment and model," *IEEE Photon. Technol. Lett.*, vol. 5, no. 6, pp. 646–648, 1993.
[4] Y. H. Ja, "Simultaneous resonance of an S-shaped two coupler optical fiber ring resonator," *Opt. Comm.*, vol. 102, pp. 133–140, 1993.
[5] ——, "A Vernier S-shaped fiber double-loop resonator with double couplers and degenerate two-wave mixing," *J. Lightwave Technol.*, vol. 11, no. 2, pp. 258–264, 1993.
[6] Y. H. Ja and K. Terms, "Butterworth-like filters using an S-shaped two-coupler optical fiber ring resonator," *Microwave Opt. Technol. Lett.*, vol. 6, no. 6, pp. 376–378, 1993.
[7] Y. H. Ja, "Densely spaced two channel wavelength division demultiplexer with an S-shaped two-coupler optical fiber ring resonator," *Appl. Opt.*, vol. 32, no. 33, pp. 6679–6683, 1993.
[8] J. R. Salcedo, "Unidirectional Ring Laser Needs no Isolator," in *Opto & Lasers Europe (OLE)*. Bristol, UK: Institute of Physics Publishing Ltd., 1993, p. 11.
[9] J. P. Hohimer and G. A. Vawter, "Unidirectional semiconductor ring laser with racetrack cavities," *Appl. Phys. Lett.*, vol. 63, no. 18, pp. 2457–2459, 1993.
[10] J. L. Zyskind, E. Desurvire, J. W. Sulhoff, and D. DiGiovanni, "Determination of homogeneous linewidth by spectral gain hole-burning in an erbium-doped fiber amplifier with GeO_2-SiO_2 core," *IEEE Photon. Technol. Lett.*, vol. 2, no. 12, p. 869, 1990.