Conference Chairs

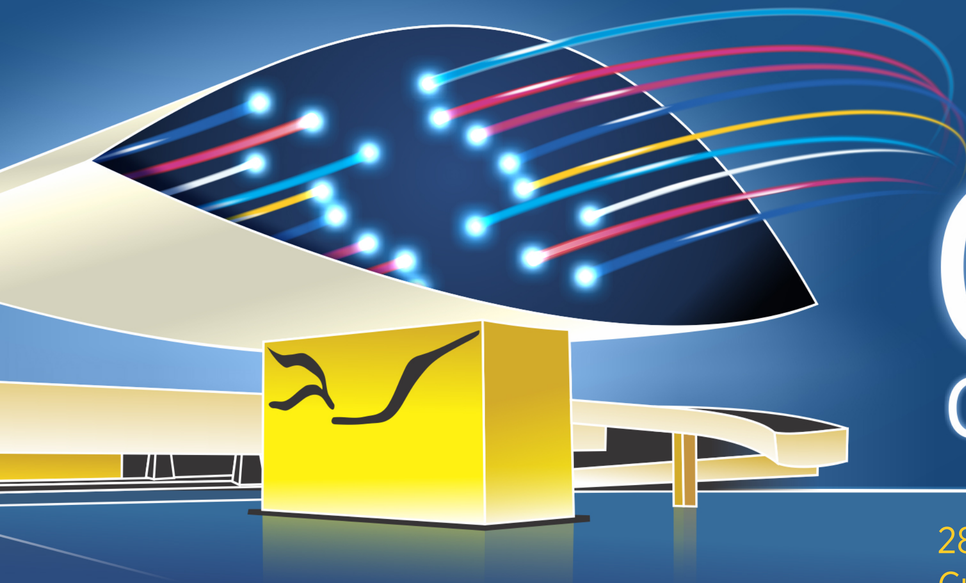
General Chair:

Hypolito José Kalinowski,
Univ. Tecnológica Federal do Paraná (Brazil)

Technical Co-Chairs:

José Luís Fabris,
Univ. Tecnológica Federal do Paraná (Brazil)

Wojtek J. Bock,
Univ. du Québec en Outaouais (Canada)



OFS 24th

CURITIBA·BRAZIL

28 September–2 October 2015

Curtiba, Brazil

PROCEEDINGS OF SPIE

24th International Conference on Optical Fibre Sensors

Hypolito J. Kalinowski
José Luís Fabris
Wojtek J. Bock
Editors

28 September–2 October 2015
Curitiba, Brazil

Organized by
Sociedade Brasileira de Micro-Ondas e Optoeletrônica – SBMO (Brazil)
Universidade Tecnológica Federal do Paraná – UTFPR / Grupo de Pesquisa "Dispositivos Fotônicos e Aplicações" (Brazil)

Sponsored by
Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Brazil)
Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – CAPES (Brazil)

Published by
SPIE

Part One of Two Parts

Volume 9634

Proceedings of SPIE 0277-786X, V. 9634

SPIE is an international society advancing an interdisciplinary approach to the science and application of light.

24th International Conference on Optical Fibre Sensors, edited by Hypolito José Kalinowski,
José Luís Fabris, Wojtek J. Bock, Proc. of SPIE Vol. 9634, 963401 · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2214760

The papers included in this volume were part of the technical conference cited on the cover and title page. Papers were selected and subject to review by the editors and conference program committee. Some conference presentations may not be available for publication. The papers published in these proceedings reflect the work and thoughts of the authors and are published herein as submitted. The publisher is not responsible for the validity of the information or for any outcomes resulting from reliance thereon.

Please use the following format to cite material from this book:
Author(s), "Title of Paper," in *24th International Conference on Optical Fibre Sensors*, edited by Hypolito J. Kalinowski, José Luís Fabris, Wojtek J. Bock, Proceedings of SPIE Vol. 9634 (SPIE, Bellingham, WA, 2015) Article CID Number.

ISSN: 0277-786X
ISBN: 9781628418392

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time) · Fax +1 360 647 1445
SPIE.org

Printed in the United States of America.

Publication of record for individual papers is online in the SPIE Digital Library.

SPIE Digital Library

SPIEDigitalLibrary.org

Paper Numbering: Proceedings of SPIE follow an e-First publication model, with papers published first online and then in print. Papers are published as they are submitted and meet publication criteria. A unique
citation identifier (CID) number is assigned to each article at the time of the first publication. Utilization of CIDs allows articles to be fully citable as soon as they are published online, and connects the same identifier to all online, print, and electronic versions of the publication. SPIE uses a six-digit CID article numbering system in which:

- The first four digits correspond to the SPIE volume number.
- The last two digits indicate publication order within the volume using a Base 36 numbering system employing both numerals and letters. These two-number sets start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B … 0Z, followed by 10-1Z, 20-2Z, etc.

The CID Number appears on each page of the manuscript. The complete citation is used on the first page, and an abbreviated version on subsequent pages.

Ultra-long and high-stability Random laser based on EDF gain-media and Rayleigh scattering distributed mirror.

I. Aporta, M. A. Quintela, L. Rodríguez-Cobo, J. M. López-Higuera
Grupo de Ingeniería Fotónica, Edificio I+D de Telecomunicación, Universidad de Cantabria, Santander, España.

ABSTRACT

An ultra-long, low-threshold and high-stability Random distributed feedback fiber laser (RDF-FL) based on Erbium-doped fiber (EDF) to provide the gain medium, and single mode fiber (SMF) as a distributed mirror in combination with fiber-brag grating (FBG) to form the cavity is proposed in this paper. Typical random laser radiation for a SMF length of 50 km with a low-threshold of 10 dBm and high-stability (~0.1 dB) is achieved, thanks to the design of the cavity and the high-gain from the pumped erbium-doped fiber. Besides, 200 km quasi-losses random laser due to the distributed mirror and the FBG reflector is demonstrated.

Keywords: Random fiber laser, Erbium-doped fiber, fiber-brag grating, distributed feedback

1. INTRODUCTION

Since the first work about the random distributed feedback fiber laser [1], based on distributed Rayleigh scattering and Raman amplification in a long-distance single mode fiber, this new laser structure has been widely studied. Different configurations of these random fiber lasers have been proposed in order to obtain tunable lasers, multivawelength lasers, narrow linewidth, and optimization of the gain [2-4]. The main advantage of these lasers is that its configuration is simple without using mirrors to trap the light. However, the backward Rayleigh scattering is an optical effect very weak and consequently high threshold pump powers are required (aprox. 1,6W) and the linewidth is broad (aprox. 1nm). A simple method to improve these performances of these lasers is to use an optical mirror, e,g., an fiber Bragg grating at one end of the SMF [5].

The active fiber, such as the Erbium doped fiber, could be used as gain medium instead of the Raman gain [6, 7]. In this case, when the EDF was pumped this fiber itself can provide the necessary gain and the SMF behaves as a random distributed feedback mirror through Rayleigh scattering, to generate a lasing signal.

In this paper we have demonstrated a very stable, low threshold erbium fiber laser based on resonance between the distributed random Rayleigh scattering in a very long SMF (50 km) acting as a distributed mirror and a FBG reflector generating typical random laser radiation. In addition, we have achieved a 200 km lossless random fiber laser regarding setup with lower fiber lengths (100 and 150 km).

2. SETUP AND RESULTS

The schematic diagram proposed on figure 1 consists of a Raman fiber laser pumping on 1450 nm with a maximum output power of 0.5 W, a WDM working on 1480/1550 nm, a 7 meters EDF with a mode field diameter of 6,5 μm and a peak absorption coefficient of 30 dB/m at 1530 nm, a long-distance SMF-28 (over 200 km in stretches of 50 km), a FBG reflector with a central wavelength of 1552.45 nm, a reflectivity over 90% and a bandwidth of 0.4 nm, two 90/10 couplers and a 1550 nm circulator. The output is measured by using an OSA with a resolution of 0.01nm and a sensitivity of -70 dBm.

24th International Conference on Optical Fibre Sensors, edited by Hypolito José Kalinowski, José Luís Fabris, Wojtek J. Bock, Proc. of SPIE Vol. 9634, 96345D · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2194793

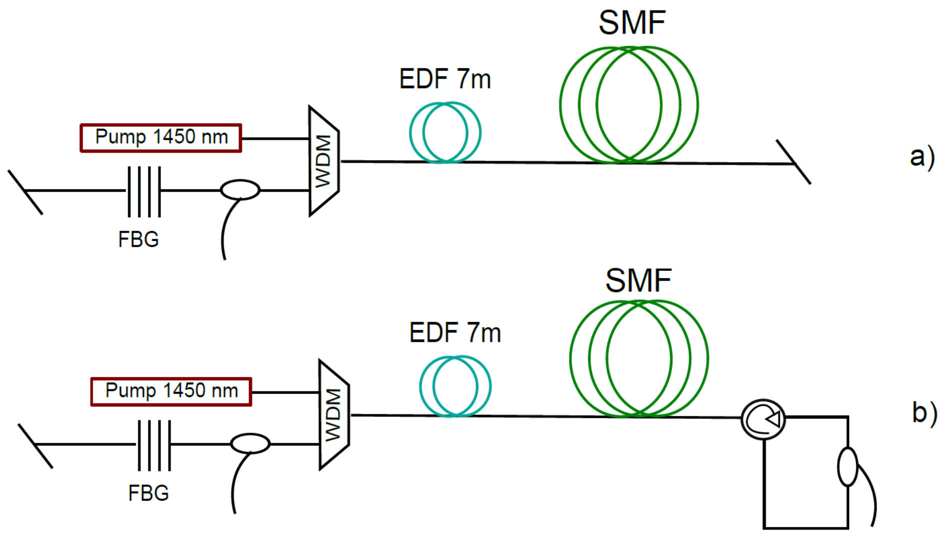


Figure 1. EDF-based random laser (a) with conventional cavity and FBG (b) with circulator and FBG.

As shown in figure 1, the fiber laser is pumped from the left side of the system, assisting the process of random lasing using the EDF gain and the cavity formed by the FBG and the random distributed feedback (RDFB) through Rayleigh scattering into the SMF. When the pump power emitted is enough to provide the necessary gain to overcome the cavity losses, the amplified spontaneous emission of the EDF allows the resonance between the reflector and the back-scattering effect that generates a selective wavelength random lasing with a low threshold. Furthermore, the gain profile generated by the EDF on C-band (1530 nm peak absorption) improves the random signal emission all over the cavity.

In this experimental setup, two random lasing systems (fig.1a and 1b) have been compared using different lengths (50, 100, 150 and 200 km) to study the effects of the long-distance SMF on random lasing. Figure 2 shows the corresponding spectrums in the forward and backward output end at 24 dBm pump power when is being used a 50 km SMF length. It can be seen that the output power spectrum measured from both ends are different, although it has the same SMF fiber length, due to the fiber propagation losses of the SMF. For this reason the peak power is reduced at the right end of the cavity in comparison with the output power measured at the left end. In terms of signal to noise ratio (SNR), attending to fig. 2, it's about 45 dB measuring from the left end and 55 dB from the right end. The difference in SNR for the two output ends is introduced by the differences in both the output power and the ASE noise level.

Considering this case, there is also a significant difference using a circulator at the end of the cavity, which allows recirculating the signal into the cavity improving the conditions of power temporary stability of the random lasing, and providing a better power response, increasing the output power level in 2~3 dB. Besides, the laser line width is practically the same (~1 nm), only changing in function of the pump power fixed, so the use of this type of passive devices gives stability without modifying the laser properties.

Another interesting factor, is the low lasing threshold due to the FBG reflector and the high gain medium from the EDF, achieving random fiber laser with a 10 dBm threshold, which is two magnitude orders lower than random lasing with distributed Raman effect. This low threshold is practically the same when the SMF length is 100, 150 and 200 km because of the cavity formed by the SMF fiber acting as a distributed mirror and working together with the FBG reflector.

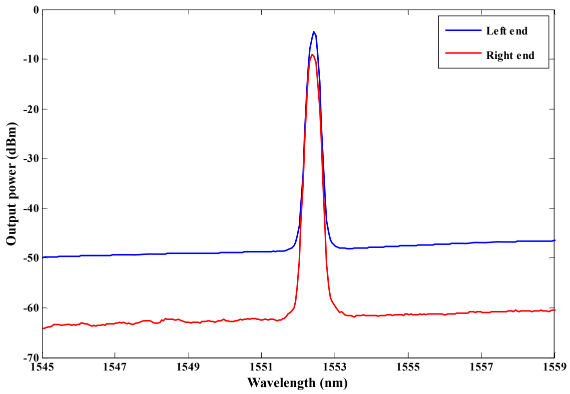


Figure 2. Output optical spectrum measured from both ends with 50 km SMF length and a pump power of 24 dBm

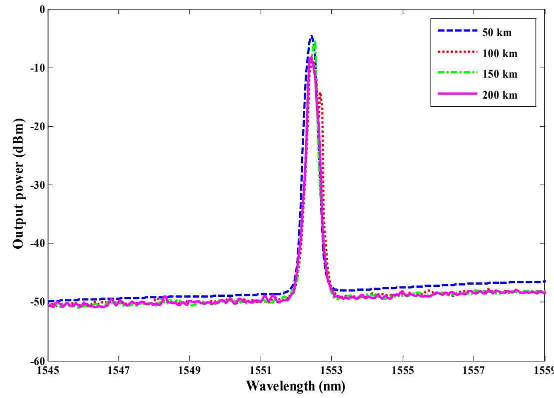


Figure 3. Laser spectrum measured from left end and a pump power of 24 dBm for different SMF lengths

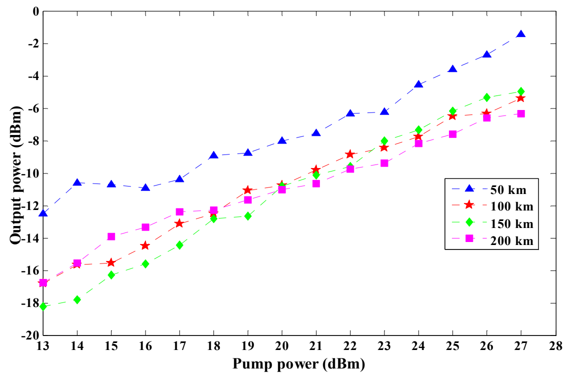


Figure 4. Output power versus pump power for different SMF lengths

In terms of output power, figure 3 and 4 shows the measured spectrum of random lasing at the left end of the system when the SMF length is 50, 100, 150 and 200 km using a 24 dBm pump power, and the output power versus pump power respectively. As it can be appreciated, the signal hardly incurs losses achieving an ultra-long lasing with no propagation losses due to the same reason exposed above. On another hand, the instability was defined as the output power variations (measured in dB for a given interval of time and a specific confidence level (CL), that is the probability value associated with a confidence interval, given as a percentage. In these experiments a confidence level of 90% was used and each configuration was tested 160 times during 40 minutes. In this case, the temporary stability worsens when the SMF length increases from 50 km to 100 km and above, so including the circulator on the right end point of the system only ensures high-efficient stability for 50 km SMF length which is ~0.09 dB, while if the circulator is removed instability increases to ~4 dB.

3. CONCLUSIONS

An ultra-long, high-stability, low-threshold and narrow line width random laser based on EDF as gain medium and the distributed mirror formed by RDFB through Rayleigh scattering in long-distance SMF has been achieved. The stability has been measured for different fiber lengths, obtaining high-stability and efficiency not exceeding 50 km lengths. The threshold for random laser excitation is very low (~ 10 dBm) due to the high gain provided by the EDF and the mirror formed by the random distributed feedback in conjunction with FBG and the optical output power measured is almost the same for all SMF lengths, ignoring propagation losses introduced by the fiber itself. The maximum pump efficiency is comparable to normal erbium-doped fiber lasers.

ACKNOWLEDGMENT

Financial support from the Spanish Comisión Interministerial de Ciencia y Tecnología within project TEC2013-47264-C2-1-R.

REFERENCES

[1] S. K. Turitsyn, S. A. Babin, A. E. El-Taher, P. Harper, D. V. Churkin, S. I. Kablukov*, et al.*, "Random distributed feedback fibre laser," *Nature Photonics,* vol. 4, pp. 231-235, 2010.

[2] A. Pinto, O. Frazão, J. Santos, and M. Lopez-Amo, "Multiwavelength Raman fiber lasers using Hi-Bi photonic crystal fiber loop mirrors combined with random cavities," *Journal of Lightwave Technology,* vol. 29, pp. 1482-1488, 2011.

[3] S. Babin, A. El-Taher, P. Harper, E. Podivilov, and S. Turitsyn, "Tunable random fiber laser," *Physical Review A,* vol. 84, p. 021805, 2011.

[4] I. D. Vatnik, D. V. Churkin, S. A. Babin, and S. K. Turitsyn, "Cascaded random distributed feedback Raman fiber laser operating at 1.2 µm," *Optics express,* vol. 19, pp. 18486-18494, 2011.

[5] M. Fernandez-Vallejo, S. Rota-Rodrigo, and M. Lopez-Amo, "Comparative study of ring and random cavities for fiber lasers," *Applied optics,* vol. 53, pp. 3501-3507, 2014.

[6] L. Wang, X. Dong, P. P. Shum, C. Huang, and H. Su, "Erbium-doped fiber laser with distributed Rayleigh output mirror," *Laser Physics,* vol. 24, p. 115101, 2014.

[7] W. L. Zhang, S. W. Li, R. Ma, Y.-J. Rao, Y. Y. Zhu, Z. N. Wang*, et al.*, "Random distributed feedback fiber laser based on combination of Er-doped fiber and single mode fiber," 2015.