Longitudinal power distribution in random DFB Raman fiber laser

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We have measured the longitudinal power distribution inside a random distributed feedback Raman fiber laser. The observed distribution has a sharp maximum whose position depends on pump power. Both analytic solution and results of direct numerical modeling are in excellent agreement with experimental observations.

Introduction

Recently, the novel concept of a fiber laser operating via the feedback produced by randomly distributed variations of refractive index in the fiber core was proposed and implemented [1]. The distributed feedback (DFB) results from the Rayleigh backscattered radiation, which is captured by the fiber waveguide and amplified through the Raman effect. Different fiber laser systems based on the random DFB concept were studied in the past year generating in different spectral bands, providing cascaded, tunable, multi-wavelength output [5-12] similar to conventional RFL performances, see, for ex., [13,14], including a potential for efficient frequency doubling [15]. It has been shown that noise level of RDFB fiber lasers could be lower than in conventional RFLs [16,17]. Important feature is that the random DFB laser has no limit in length in contrast to ultra-long Raman fiber lasers with conventional cavity of point-action reflectors, namely fiber Bragg gratings (FBGs) [18]. Potentially, ultra-long random DFB fiber lasers could be longer than conventional ultra-long Raman fiber lasers thus enabling quasi-lossless transmission over greater distances. For telecom applications, the study of longitudinal distribution of generated power is one of the key issues.

We present here measurement, numerical simulations and analytical description of the longitudinal power distribution in ultra-long random DFB fiber laser.

Experimental Results

We experimentally study the symmetrical configuration proposed in [1]. The two 1.455 μm pump lasers with maximum power up to 4 W each are coupled into the center of an 84-km span of standard telecommunication fiber SMF-28. For pump power above ~0.8 W (for each pump laser), the setup starts to generate radiation at ~1.56 μm in both directions due to the Raman gain and random distributed feedback provided by the Rayleigh scattering (RS), see [1] for details. To measure the longitudinal distribution we use intra-cavity coupler consequently spliced at the different coordinates along the resonator in two opposite directions making possible to measure independently powers of two waves travelling from left to right (so-called "right wave" further) and from right to left (“left wave”). The full longitudinal distributions of the generated first Stokes wave power at different pump powers are plotted in Fig. 1.

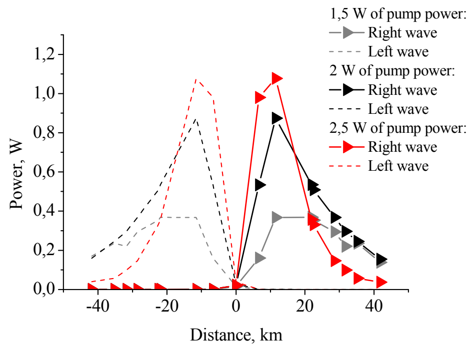

Fig. 1. Longitudinal power distribution for the first Stokes wave in the center-pumped symmetrical configuration at different pump power levels (1, 2 and 2.5 W).

The power distributions for opposite (left and right) travelling waves are symmetric: both waves increase rapidly after passing the pump coupling point (z=0), reach maximum power at some point near the middle of the fiber arm and attenuate exponentially after passing the maximum with a coefficient nearly corresponding to linear loss at 1.56 μm. The position of the power maximum along the fiber was previously found to be at the point where local value of the unsaturated Raman gain becomes equal to the loss level, $|z|=L_{RS}$, see [1] for details. In other words, $|z|=L_{RS}$ defines the boundary of a gain region. The measurements show that with increasing power the distribution becomes narrower.

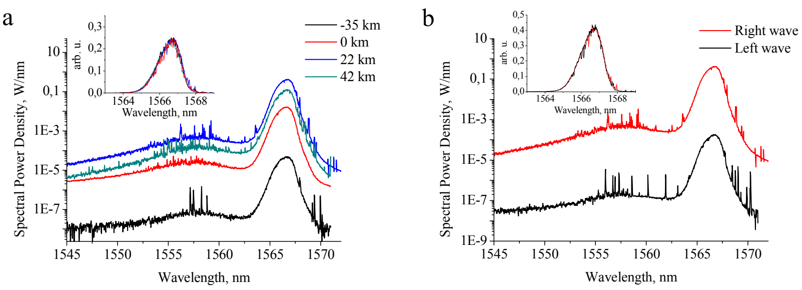

Fig. 2. (a) Spectra of right wave at specific pump power of 2 W at different points of the fiber span. (b) Right and left waves spectra at 22 km point, having the same shape. The normalized spectra in linear scale are shown in insets.

We have also measured the spectra of the generated radiation at different points along the fiber. The generated spectra have the same shape at all points along the cavity, Fig. 2(a). Moreover, left and right waves measured at the same coordinate also have the same spectral shape, Fig. 2(b). This fact confirms the principal role of the RS-based distributed feedback in the random fiber laser. Despite its extremely small value, the feedback couples both waves resulting in an identical spectrum for all points inside the distributed laser cavity.

Comparison with numerical and analytical models

The experimentally measured distributions have been compared to theoretical predictions. To calculate numerically the longitudinal power distributions, we use the well-known power balance equation model, comprising Raman amplification, fiber losses and Rayleigh backscattering. The numerically calculated profiles for the power distribution of the first Stokes wave obtained using this simple model are shown in Fig. 3a. Moreover, we have derived the analytical formula describing distribution of the Stokes power. Also, the analytical model allows to derive amplification length L_{RS}. Calculated values for both the longitudinal distribution and the amplification length demonstrate excellent agreement with experimental results as well as numerical simulations.

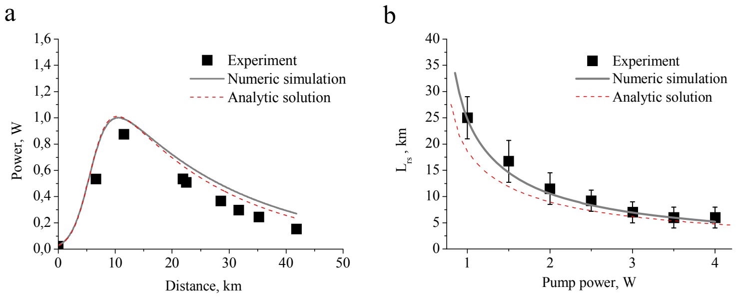

Fig. 3. (a) longitudinal power distribution at 2 W pump power, and (b) L_{RS} position.

Discussion and conclusions

Summarizing the obtained results, the longitudinal power distributions generated in the random DFB fiber laser in symmetric configuration have been studied both experimentally and theoretically. The simple analytical model describes with high accuracy first Stokes wave characteristics, namely amplification length as well as the spatial longitudinal distribution. The numerical and analytical calculations of the first Stokes wave give very close values which are also in good quantitative agreement with obtained experimental results.

It has been found that the spectral shapes are identical for the opposite waves and do not change during the propagation of the waves along the fiber. That is consistent with the idea of Rayleigh scattering feedback being responsible for the lasing and coupling of the spectral characteristics of both waves. In future, it is of interest to use NLSE-based model [19,20] to calculate spectral and statistical properties of RDFB fiber lasers and compare with experimental study of statistics similar to works [21-23].

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