Multiwavelength generation in a random distributed feedback fiber laser using an all fiber Lyot filter

S. Sugavanam,[1,*] Z. Yan,[1] V. Kamynin,[2] A. S. Kurkov,[2] L. Zhang,[1] and D. V. Churkin[1,3,4]

[1]Aston Institute of Photonic Technologies, Aston University, Aston Triangle, Birmingham B4 7ET, UK
[2]Prokhorov General Physics Institute, Russian Academy of Sciences, Vavilov Str., 38, 119991, Moscow, Russia
[3]Institute of Automation and Electrometry SB RAS, 1 Ac. Koptyug ave., Novosibirsk, 630090, Russia
[4]Novosibirsk State University, 2 Pirogova str., Novosibirsk, 630090, Russia
[*]sugavans@aston.ac.uk,

Abstract: Multiwavelength lasing in the random distributed feedback fiber laser is demonstrated by employing an all fiber Lyot filter. Stable multiwavelength generation is obtained, with each line exhibiting sub-nanometer line-widths. A flat power distribution over multiple lines is obtained, which indicates that the power between lines is redistributed in nonlinear mixing processes. The multiwavelength generation is observed both in first and second Stokes waves.

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OCIS codes: (140.3510) Lasers, fiber; (140.3550) Lasers, Raman; (140.3490) Lasers, distributed-feedback; (290.5910) Scattering, stimulated Raman; (290.5870) Scattering, Rayleigh.

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1. Introduction

Multiwavelength fiber lasers are of significant interest to the scientific community due to their application diversity. Multiwavelength fiber lasers find applications in DWDM systems, optical fiber sensors, spectroscopy, etc. They can be broadly classified in terms of the gain medium used, and/or the procedure used to generate the multiple wavelengths. Multiwavelength fiber lasers have been demonstrated using lasers employing erbium doped fiber [1], stimulated Raman scattering (SRS) [2,3], stimulated Brillouin scattering (SBS) [4], or a hybrid of the above [5]. The procedure used to generate the multiple wavelengths can be either passive or active. For example, passive elements such as fiber Bragg gratings (FBGs) [6], Fabry-Perot filters (FFPs) [7], Sagnac loop mirrors [8], and Lyot filters [9] have been used. Examples of 'active' nonlinear processes are SBS, nonlinear polarization rotation [10], or four wave mixing [11]. For a passive element based multiwavelength fiber lasers, the individual wavelengths and their inter-spacings are solely determined by the specifications of the incorporated device. Thus tunability (wavelengths and/or the free spectral range) can be achieved in such multiwavelength fiber lasers [2,12].

The choice of gain media is a factor determining the stability of the generated lines. Inhomogeneous gain media are the primary choice for making multiwavelength fiber lasers, as they provide more stability, in comparison to homogenous media. In this regard, gain obtained via the stimulated Raman scattering process is very attractive. While the Raman gain coefficient is small, this is compensated by its THz order bandwidth and the availability of ultra-low loss, ultra-long gain spans made available in the form of conventional telecommunication fibers. Multiwavelength generation employing the Raman gain mechanism has been demonstrated in many configurations [3,6,12].

Recently, a random distributed feedback (DFB) fiber laser operating via Raman gain and random feedback owing to the Rayleigh backscattering is demonstrated [13]. While the threshold of this laser is relatively high, the efficiency was noted to be quite comparable to existing CW lasers [13,14]. A number of different random DFB fiber laser configurations are realized up to date [13–34]. It can be tunable [21,22], operate in different spectral bands [23,24], provide cascaded operation at higher Stokes components [23,25] and made narrow-band [26]. Different ways to generate multiple wavelength simultaneously in random DFB fiber laser has been also demonstrated: for example by using a set of FBGs [18,19], or by using fiber loop mirror made of photonic crystal fiber [20]. Tunable, multiwavelength generation is obtained in the scheme with long period FBGs and microstructured fibers [32]. Co-operative Brillouin-Rayleigh interactions could results in a generation of frequency comb over a wide span (<40 nm) [33,34].

In the present work, multiwavelength lasing in the random distributed feedback fiber laser is demonstrated by employing an all fiber Lyot filter [35]. The all fiber Lyot filter operates on the principle of fiber birefringence and polarization interferometry – thus providing a transmission comb of well-defined frequency spacing. Being an all-fiber based architecture, it provides distinct advantages over fiber based Fabry-Perot filters and FBGs in terms of form factor and power handling. A properly designed filter does away the need of using multiple Bragg gratings. Stable multiwavelength generation is obtained with the use of the all fiber Lyot filter, with each line exhibiting sub-nanometer linewidth.

2. Experimental methods

The all fiber Lyot filter is a type of polarization filter, which comprises of two in-fiber linear polarizers based on 45° tilted FBG that was inscribed into a polarization maintaining (PM) fiber along its principle axis [35,36] and a PM fiber as cavity, as shown in Fig. 1(a). The filter

has both filtering and polarizing functions, and its bandwidth and free spectra range (FSR) could be adjusted by changing the length of the PM fiber. See [35,36] for detailed description of the all fiber Lyot filter. Here we use a filter having 20 m long PM fiber cavity (birefringence of PM fiber is around 3.47×10^{-4}) which results in a bandwidth of 0.2 nm and a FSR of 0.4 nm. The insertion loss of the filter is approximately 6 dB for unpolarized light.

The all fiber Lyot filter is incorporated in the random DFB fiber laser cavity as shown in Fig. 1(b). Two spans of 40 km standard Corning SMF 28 fiber are pumped from the central point by two Raman fiber lasers (RFLs) at 1450 nm. The all fiber Lyot filter is inserted between at the point where the generation power is very low because of specific distribution of the longitudinal power in the random DFB fiber laser [37,38].
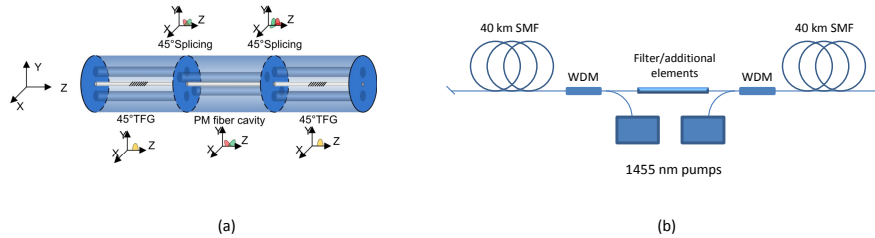

Fig. 1. (a) Schematic representation of the all fiber Lyot filter. (b) Experimental configuration of the random DFB fiber laser based on all fiber Lyot filter.

3. Results and discussions

The power transfer curve of the system exhibits a well-defined lasing threshold, Fig. 2. The stable quasi-CW multiwavelength generation is obtained above the power 1.3 W. Below this point, the generation is unstable because of influence of SBS [13]. The laser generates multiple wavelengths simultaneously in the whole range of the Raman gain spectral profile, Fig. 3(a). The position of each individual wavelength coincides with the passbands of the Lyot filter, Fig. 3(b). Because of the double-peak nature of the Raman gain, the multiwavelength generation is observed both near 1555 nm and 1565 nm.

The number of generated lines as well as overall generation spectrum shape depends on the generation power, Fig. 3(a). The generated power in each line is of order of 10 mW. Lines have a typical spectral width within 0.08-0.14 nm range. The spectral lines located near the center of the comb are wider than lines located at the side of the comb. However, the each line is narrower than the spectral width of the all fiber Lyot filter transmission peak of 0.2 nm. At higher pump power, the second Stokes wave is generated being also multiwavelength, Fig. 4(b) (bottom row). The spectrum width at second Stokes wavelength is about 0.2 nm.

Near the Raman gain peak, the power distribution of generated lines is exceptionally flat, with only about 0.5 dB of variation over a 4 nm, Fig. 3(b). The higher the pump power, the flatter is the power distribution and more lines are generated within 3 dB intensity difference.
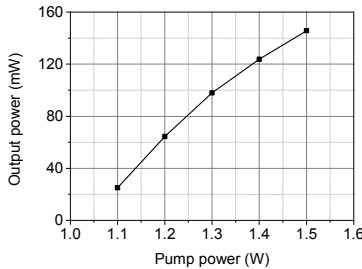

Fig. 2. Output power of the multiwavelength random DFB fiber laser based on Lyot filter.
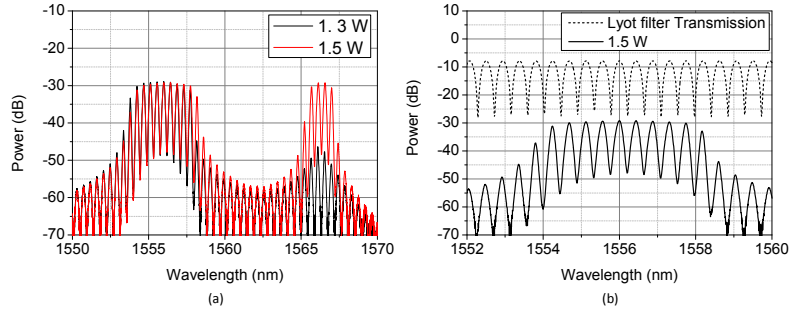
Fig. 3. (a) Generation spectra for two different pump powers. (b) Spectrum of the first Stokes wave at pump power 1.5 W and the all fiber Lyot filter transmission profile.

Note, that demonstrated power distribution among different lines is much flatter when compared to the spectral profile of the Raman gain or that of a random DFB fiber laser without any filtering elements. Indeed, in Fig. 4 we compare spectral properties of different configuration of random lasers at power 3.5 W. Without any spectral elements, the generation spectrum is smooth for both first at second Stokes waves, Fig. 4(upper row). The spectral width at 0.5 dB level is only 0.8 nm for first Stokes wave being much less than total bandwidth in the multi-wavelength regime of 4 nm, Fig. 3(b). If the Lyot filter is placed at the laser output, the envelope of generated spectrum repeats in general the generation spectrum of the random DFB fiber laser without any filters, Fig. 4 (middle row). The spectral width of individual line repeats the spectral width of the Lyot filter transmission peak being equal to 0.2 nm. So in this case the Lyot filter is just a passive filter which filters out the output laser radiation but does not affect the generation properties. However, if the Lyot filter is placed inside the resonator, the resulting generation spectrum is very different being significantly flatter for both first and second Stokes waves, Fig. 4 (bottom row). This proves that the Lyot filter placed inside the cavity does not just filter the radiation, but acts as a real intra-cavity filtering element despite random feedback. Note that at the power level of 3.5 W, the additional flattening for the first Stokes wave is resulted from the cascaded pumping for the second Stokes wave. The flatness could be potentially increased further by opting for a multiple pump configuration, or by nonlinear broadening of pump linewidth [19].

The demonstrated flatness and narrow linewidth suggests that nonlinear processes play an important role in the formation of generation in multiwavelength random DFB fiber laser and different lines could interact nonlinearly with each other. In particular, each generation line could have its own longitudinal distribution of the power along the power thus decreasing the competition of the different lines for the same pump [19]. This effect, however, does not account directly for the observed line narrowing when compared with a configuration where the Lyot filter passively filters the generated radiation, Fig. 4 (middle row). Note that existence of possible mode correlations in the random DFB fiber laser has been reported recently in [38] that resulted in non-Gaussian intensity statistics similarly to the statistics of conventional RFLs [39–43] as well as in Ytterbium-doped fiber lasers [44]. Moreover, dark and grey solitons can be generated in normal dispersion quasi-CW RFL [45]. The origin of these correlations is unknown. The multi-wavelength random DFB fiber laser could be used as a test bed for experimental investigation of possible nonlinear interaction and correlations as spectral width of individual line (0.08-0.14 nm being equal to 10-18 GHz) is within the electrical bandwidth of real time oscilloscopes. Simultaneous measurements of the intensity dynamics in different lines could be of interest as it could reveal directly spectral correlations.
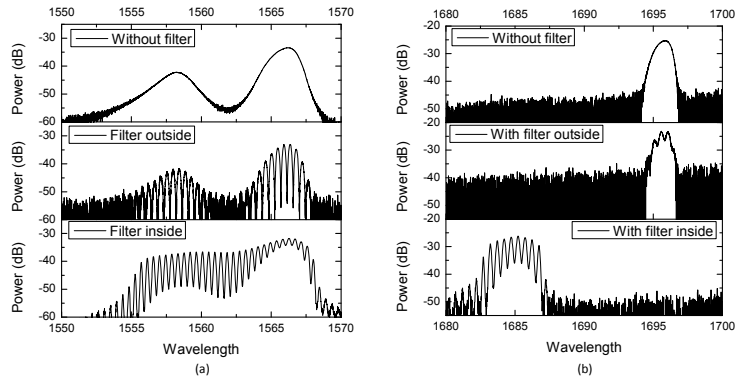
Fig. 4. Generation spectra in random lasers in different configurations: upper row – without any filter, middle row – with Lyot filter placed at the laser output, bottom row – with a Lyot filter placed in the middle of fiber span. (a) first Stokes wave (b) second Stokes wave.

One can control the properties of the generated radiation by managing the all fiber Lyot filter properties: spacing between the generated lines can be controlled by adjusting the length of the PM fiber in the filter. Linewidth of the individual lines can be controlled by employing a cascade of such Lyot filters. This is a significant advantage over existing Brillouin-Raman fiber lasers, where there is a minimal control over the width of the individual lines [33,34]. Previously, the random DFB fiber laser has been demonstrated to sustain picometer order linewidth [26], hence the above Lyot based system can be potentially used to obtain narrow-linewidth multiwavelength generation. It is also possible to control generation properties in a different way, as the PM fiber in the Lyot filter can be replaced by any suitable birefringent device, allowing room for possibility of wavelength and spacing tuning.

3. Summary

Here we have demonstrated a robust multiwavelength random DFB fiber laser based on Lyot all-fiber filter. The laser generates multiple lines both in first and second Stokes waves. The separation between lines is defined by the transmission profile of Lyot filter. However, the individual linewidth of the generated lines is found to be less than the spectral width of Lyot filter transmission profile. Nonlinear interaction between different lines could play an important role in formation of multiwavelength random DFB fiber laser generation properties.

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