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A multiwavelength erbium-doped fiber MOPA laser with partial overlapping linear cavities

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In this paper, we propose a multiwavelength erbium-doped fiber laser (MW-EDFL). The configuration of the MW-EDFL consists of several linear Fabry–Perot (FP) cavities and a master-oscillation-power-amplifier (MOPA). These linear FP cavities are partially overlapped and include several sections of EDFs, fiber Bragg gratings (FBGs), and a fiber loop mirror (FLM). In our design, a low cost broadband FLM and six narrowband FBGs were used to obtain a stable six-wavelength fiber laser at room temperature. Using a section of EDF as an MOPA near the output end, the output power of the MW-EDFL is promoted. The characteristics of the MW-EDFL were also simulated by the OptiAmplifier software tool. The results of simulations and experiments match each other very well. The optimizing EDF length of the MOPA is about 1.5 m and the MOPA gains are about 4 dB to 7.5 dB. The linewidth, wavelength drift, and power fluctuation of the MW-EDFL are about 450 kHz, 0.05 nm, and 0.4 dB, respectively.

Keywords: mutliwavelength laser, erbium-doped fiber (EDF), master-oscillation-power-amplifier (MOPA).

1. Introduction

All-fiber multiwavelength lasers have attracted considerable interest due to their importance in wavelength division multiplexed (WDM) fiber communication systems, fiber sensors, and optical instrument testing. Such kind of lasers can be built with semiconductors or rare-earth doped fibers. Most of the approaches use semiconductor lasers in arrays of independent gain media. These approaches require precise wavelength controllers as well as independent gain media for each channel. Difficulties often occurred in establishing power balance between channels and coupling with fibers. Due to the relatively long fluorescence lifetime of erbium-doped fiber (EDF), less crosstalk and better stability are expected for simultaneous multichannel operation of EDF lasers (EDFLs).

Several types of multiwavelength EDFLs (MW-EDFLs) have been reported [1–6]. A polarization maintaining (PM) EDF or highly nonlinear photonic crystal fiber (PCF) is inserted in a ring cavity to stabilize the power fluctuation of multiwavelength lasers [1, 2]. A straightforward approach is suggested by using Fabry–Perot (FP) structure to produce stable multiwavelength lasers [3, 4]. Cooling the EDF at 77 K by liquid nitrogen to reduce the wavelength competition [5, 6] caused by the homogeneous gain broadening of EDF [7, 8] has been used to achieve stable multiwavelength oscillations. In general, difficulties are usually encountered in obtaining a stable multiwavelength lasing at specific wavelength and power because of wavelength competition and cross coupling between adjacent lasing wavelengths.

In this paper, we present a stable MW-EDFL configuration with a fiber loop mirror (FLM) [9, 10], cascaded fiber Bragg gratings (FBGs), and a master-oscillation-power--amplifier (MOPA). It is economical, as six FBGs have been replaced by a single FLM, in solving the wavelength alignment problem of symmetrical FBGs structure. Hence, we have successfully obtained a low cost six-wavelength fiber laser in the C-band (1540–1560 nm) at room temperature.

2. Experimental setup

A schematic of the experimental setup for the MW-EDFL is shown in Fig. 1. It consists of a FLM, a fiber polarization controller (FPC), a 980/1550 nm wavelength selective coupler (WSC), six short EDF sections, six FBGs, and an EDF section as MOPA. Here, we combine two different fiber reflectors to design laser resonant cavities. A low cost FLM and six FBGs function as a broadband and six narrowband reflectors, respectively. Each laser cavity is partially overlapped with other laser cavities.

The FLM, which is equivalent to a Sagnac fiber interferometer, simply consists of a fused-fiber 3-dB coupler with the two legs connected together and a FPC installed

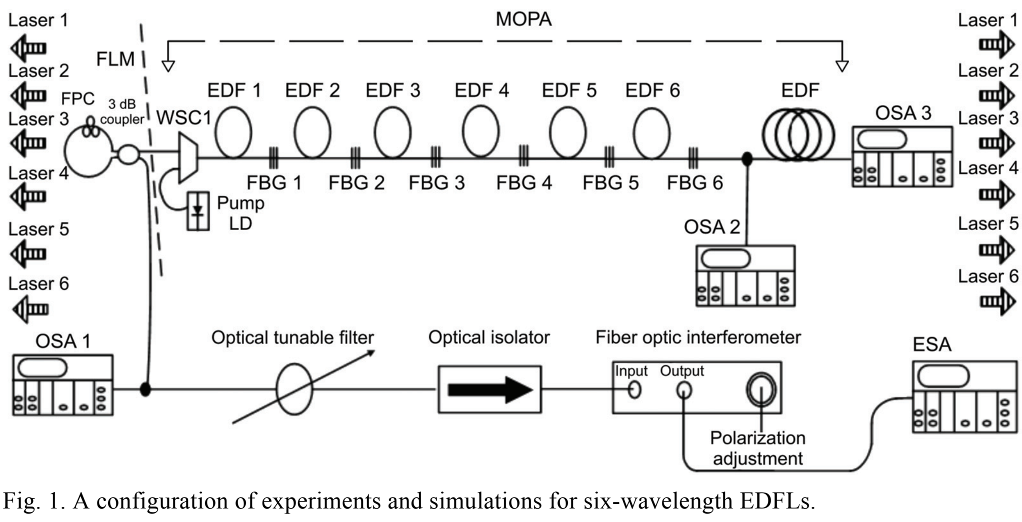

Fig. 1. A configuration of experiments and simulations for six-wavelength EDFLs.

inside. The FBG is an excellent all-fiber wavelength selection device in terms of the central wavelength, wavelength precision, and tunability. The FLM and the six FBGs establish six overlapping FP structures for lasing wavelengths λ_1, λ_2, λ_3, λ_4, λ_5, and λ_6. These wavelengths of FBGs can be chosen for any values within the EDF gain region. All the cavities are pumped by the same laser diode (LD) through the WSC. The optical output of the MW-EDFL is measured by an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

The EDF section at the output end of the fiber laser can be made as an MOPA. The MOPA does not need extra-pumping sources and the gain can be provided from the residual pump power of the fiber laser. The MOPA can simultaneously promote all output power of the multiwavelength lasers.

The output of the MW-EDFL could be observed at OSA1 and OSA2. The characteristic of the MOPA could be observed at OSA3. The linewidth of the MW-EDFL was measured by a delayed self-homodyne technique. The wavelength of the desired laser at OSA1 was selected by an optical tunable filter (OTF) and the laser passed an optical isolator (OI) into a fiber optical interferometer. The linewidth was observed through an electric spectrum analyzer (ESA). The wavelength drift and power fluctuation were measured at OSA1.

In our experiments, the pump source is a 980 nm LD. The absorption of the EDFs is 12.4 dB/m at 979 nm. The length of the EDFs is 10 cm for the fiber laser gain medium and 1.5 m for the MOPA. The reflectivity of the FLM is about 96.5% around 1550 nm. By adjusting the FPC of the loop, the reflectivity of FLM can be significantly changed. The central wavelength, the full-width at half maximum (FWHM), and the reflectivities of FBG1 to FBG6 (from λ_1 to λ_6) are 1554.0 nm, 1557.2 nm, 1559.7 nm, 1550.7 nm, 1548.3 nm, and 1542.1 nm; 0.15 nm, 0.16 nm, 0.15 nm, 0.15 nm, 0.15 nm, and 0.16 nm; 97.44%, 94.55%, 94.62%, 96.34%, 91.51%, and 95.1%, respectively. These parameters were also employed in our simulations using the OptiAmplifier software tool.

3. Results and discussion

Figure 2**a** shows the output laser power observed at OSA1 as functions of the input pump power in our experiments. The threshold pump power of the lasers at λ_1 to λ_4 is low. The lasers at λ_5 and λ_6 have higher threshold pump power. This is because the injection of pump power into the EDF5 and EDF6 is lower. Above the threshold pump power, the slope efficiency of output power to pump power is lower at λ_2 and could be mainly influenced by the characteristic of our EDF and laser polarization state control. At other wavelengths, the slope efficiency is similar. The output laser power was also simulated at OSA1 as functions of the input pump power using the OptiAmplifier software tool. The results of simulations, as shown in Fig. 2**b**, correspond with our experiments.

The inset diagrams of Figs. 2**a** and 2**b** show the output spectra of experiments and simulations at input pump power of 100 mW. The power variations among the six

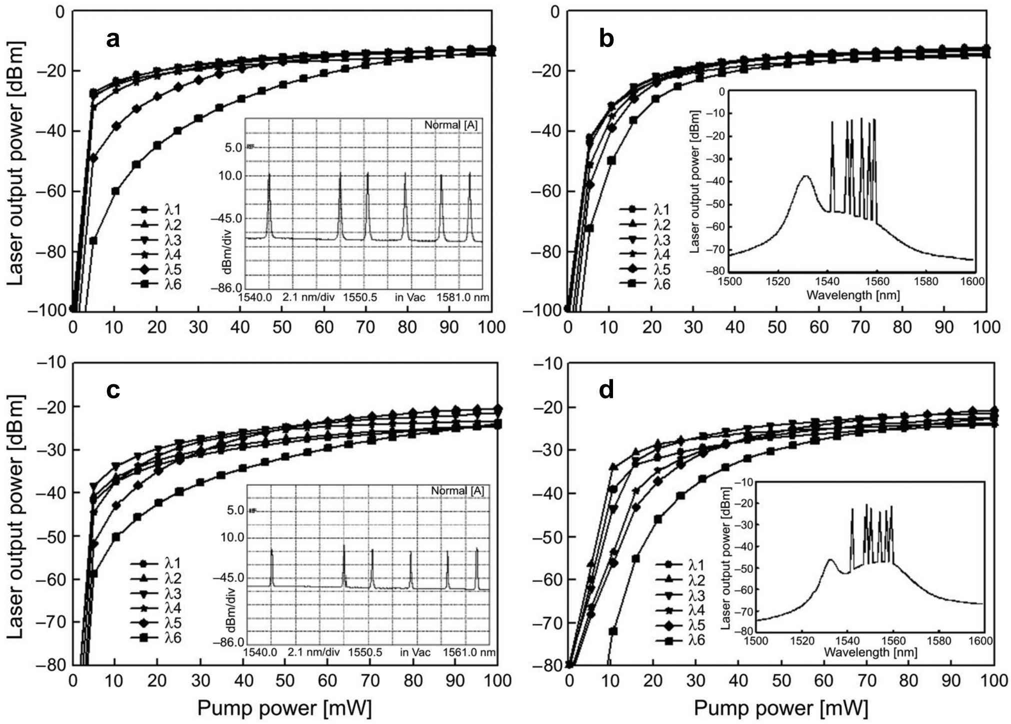

Fig. 2. Output powers of experiments (**a**) and simulations (**b**) observed at OSA1 and at OSA2 (**c** and **d**, respectively) as functions of the input pump power. The inset diagram is its output spectrum for the input power of 100 mW.

lasers are smaller than 1.8 dB and the optical signal-to-noise ratio (SNR) is over 45 dB for each laser. The output power equalization may be achieved by selecting more appropriate reflectivity of the FBGs and length of the EDFs, or precisely adjusting the FPC in the FLM.

At OSA2, the six-wavelength laser could also be obtained simultaneously. Figures 2**c** and 2**d** show the output power of our experiments and simulations as functions of the input pump power, respectively. The inset diagrams are the output spectra at the pump power of 100 mW. The results at OSA2 are similar to the ones at OSA1. However, the laser output power at OSA2 is smaller than at OSA1. Such low output powers are caused by short EDF lengths. If longer EDFs are used, then the pump power and the reflectivities of FBGs must be carefully adjusted.

In order to improve low laser output power at OSA2, we add an EDF section as an MOPA construction in Fig. 1. For the six-wavelength laser, the curves of MOPA gain of simulations and experiments versus EDF length are shown in Fig. 3. At a 100 mW pump power, the optimizing EDF length is between 1 m and 2 m and the maximum MOPA gain is obtained. The results of simulations and experiments match each other very well. In accordance with optimizing result, we choose a section 1.5 m long EDF as MOPA length in the following experiments.

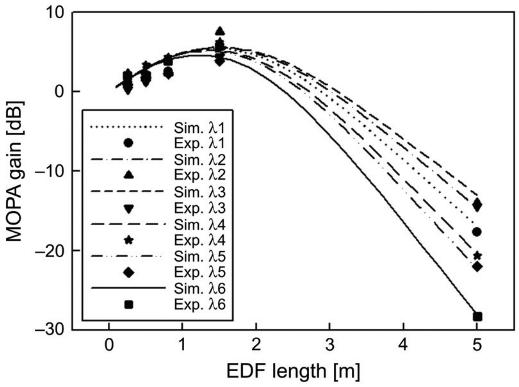

Fig. 3. The MOPA gain of simulations and experiments versus EDF length observed at OSA3.

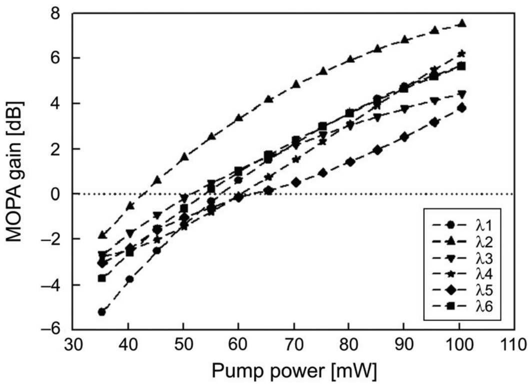

Fig. 4. The MOPA gain of experiments vs. input pump power observed at OSA3.

The experimental results of the MOPA gain versus input pump power are shown in Fig. 4. When the input pump power is 100 mW, the MOPA gains are about 4 dB to 7.5 dB. The MOPA gain is not large because the MOPA pumping is from the residual pump of the fiber laser. If a large MOPA gain is needed, extra-pumping sources should be supplied for the MOPA pumping. For all MOPA gains are positive, the input pump power must be larger than 60 mW.

Narrow linewidth lasers are critical for many scientific applications, including sensing, coherent signal generation, and phase sensitive systems. The laser linewidth of the MW-EDFL was measured by the delayed self-homodyne technique. One spectrum of the six-wavelength fiber laser at ESA is shown in Fig. 5. By fitting the lineshape to a Lorentzian curve, a laser linewidth of about 450 kHz is obtained. In our experiments, the linewidth variation of the MW-EDFL was not significant with changing input pump power.

The wavelength drift and the power fluctuation of the MW-EDFL were also monitored in our experiments. As shown in Fig. 6, the wavelength and power of the specified laser were observed at OSA1 for 15 minutes. The wavelength drift of the laser is about 0.05 nm, but it is limited by the resolution of the OSA (0.05 nm). The power fluctuation of the fiber laser is less than 0.4 dB. A stable six-wavelength fiber laser was obtained in our experiments.

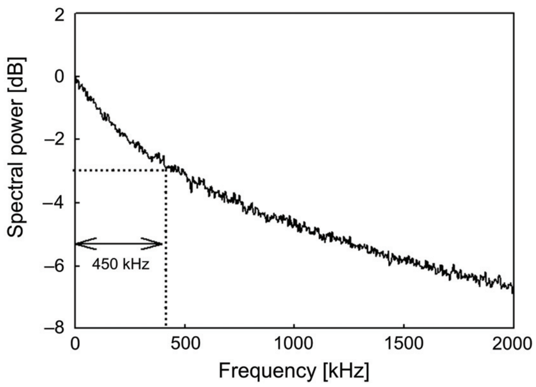

Fig. 5. Spectrum generated by a delayed self-homodyne technique. The solid line is a Lorertzian curve fit observed at ESA per laser beam.

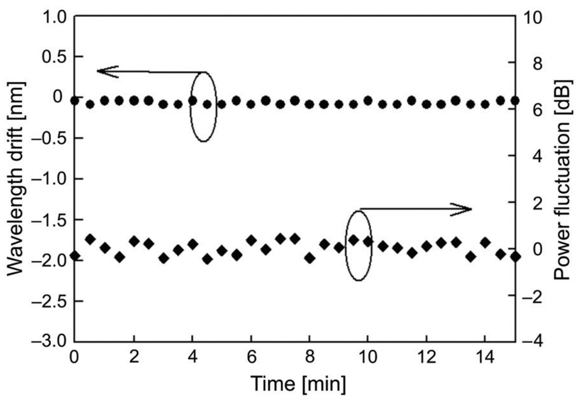

Fig. 6. The wavelength drift and power fluctuation of the MW-EDFL observed at OSA1 per laser beam.

In general, the power fluctuation of a multiwavelength laser using a single gain medium is large because of modal instability or wavelength competition. As an example, the power fluctuation of the six-channel fiber laser is about 3 dB in [11]. However, each laser cavity is partially overlapped with other laser cavities for our six-wavelength fiber laser (about 0.4 dB power fluctuation), *i.e.*, each wavelength operation of our laser just uses the partial same gain medium. Hence, the wavelength competition effect can be reduced in our fiber laser and we obtain a stable and low cost multiwavelength fiber laser.

4. Conclusions

We have demonstrated the six-wavelength EDFL with partial overlapping linear cavities and an MOPA. The MOPA without extra-pumping sources can still improve laser output power. Using the broadband FLM, the cost of our fiber laser could be kept down. For the characteristics of the six-wavelength fiber laser, the results of simulations and experiments match each other very well. Although the laser output powers were not completely equalized, the power equalization could be achieved by adjusting the EDF length and the FBG reflectivity. It is also demonstrated that the wavelength and power of our fiber laser are stable. Our stable and low cost MW-EDFL will be suitable for use in WDM transmission systems or fiber sensor systems.

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