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Research Paper

Flattening Few Mode Fiber Laser Source Based on PMF and Loop Mirror in a Ring Cavity Resonator

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Abstract:
A multi-wavelength source using a hybrid amplifier comprised of a Semiconductor Optical Amplifier (SOA) and an Erbium-doped fiber amplifier (EDFA) in a ring fiber laser set up is proposed. Multi-wavelength sources are less expensive and more efficient than deploying several laser diodes at different wavelengths. They are also compact, spend low energy, and emit low heat than multiple laser diode systems. A polarization maintaining fiber (PMF) and an interference comb filter are used in conjunction with the suggested few mode fiber laser source to create higer than 14 wavelength around -28 dBm at a SOA by current near 300 mA and a 980 nm pump power of 95 mW. This source is designed by a combined of EDFA and SOA presented in this report. By altering the birefringence of the ring cavity used as a loop mirror and changing the angle of the plates of the polarization controllers, the number of wavelengths produced may be managed. The suggested fiber laser operates at room temperature and has a constant channel spacing of 0.8 nm, making it appropriate for fiber communication and sensing applications.

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1. INTRODUCTION

Multi-wavelength fiber laser sources have recently got a lot of attention due to their potential use in various applications, including optical instrument testing, optical sensors, spectrophotometry, optical networks, and cross-connections transmission systems [1]. Additionally, there has been a lot of interest in using less-mode Erbium-doped fiber amplifiers for division multiplexing (DM) transmission, leading to the development of a less-mode gain-flattening filter based on high-period fiber gratings (HPFG) in double-cladding less-mode fiber for structural health monitoring systems (SHM) [2]. One approach for creating a multi-wavelength source is to employ a super continuum multi-channel source created by inserting a high repetition rate mode-locked optical pulse into a nonlinear fiber [3, 4]. However, this method requires a complex design and a costly mode-locking mechanism, which is not effective. At liquid nitrogen temperatures, the multichannel filter in an EDF laser can also provide multi-wavelength comb output [5, 6]. Unfortunately, this is difficult to achieve at normal operating conditions due to the EDF gain medium's homogenous broadening process, making this approach unsuitable for actual applications. An alternative approach involves utilizing a homogeneous gain medium such as a semiconductor optical amplifier (SOA), which can efficiently suppress mode competition [7, 8]. However, SOA has a rather high insertion loss and is highly polarization-sensitive. To overcome these issues, a few mode ring fiber laser is proposed as a combined design by merging an EDFA into a ring fiber laser by SOA. The erbium amplifier is utilized to improve and flatten the cavity gain, allowing for steady and virtually flat simultaneous multi-channel fiber laser array at room temperature.

The proposed design features an interference multimode flattening filter [9-13] formed by using two 3dB couplers as two loop mirrors, and polarization-maintaining fiber for part of ASE source into several channels as a loop mirror fiber configuration[14 - 19].

This configuration allows for the multi-channel laser output to be flattened, and the filter can also be adjusted to match specific wavelength spacing requirements. Additionally, the use of a few-mode fiber ring cavity reduces the sensitivity to environmental changes and polarization effects. The design of such a source can be complex and costly, making it challenging to develop cost-effective and efficient solutions. However, recent advancements in technology have led to the proposal of alternative designs, such as a few-mode ring fiber laser that features an erbium amplifier to improve cavity gain and generate a stable multi-channel fiber laser array.

2. CONFIGURATION

The experimental arrangement of this proposed design is outlined in Figure 1. The ring cavity comprises various components such as a semiconductor amplifier, an erbium amplifier, two polarization controllers, two 3dB couplers, two isolators, a PMF, and a 90:10 output coupler. The EDFA amplifies amplified spontaneous emission from the SOA and sends it through a comb filter. The EDFA is made from a 9m long EDF with around 950 ppm erbium ion density. The EDF is charged by a 980 nm diode laser with a power output of 95 mW. This experiment's SOA is built on an InGaAsP-InP waveguide with anti-reflection coated surface inclined at 10^o. It has a spectral width of 40 nm and a center operating wavelength of 1534 nm. Two isolators prevent some back reflections and spontaneous emission from occurring within the SOA and EDFA. A 400m length of PMF is put between the two loop mirrors, which were built with 3dB couplers to form a comb filter. Polarization Controllers are installed in the ring fiber laser to utilize beam processing by varying the plate degree. To tap the output of the ring fiber laser array, which is coupled to an optical spectrum analyzer, a 90:10 output coupler is used (OSA). The actual base of the setup shows that the EDFA amplifies amplified spontaneous emission (ASE) from the SOA and sends it through a comb filter. The multichannel are finally amplified by two amplifier in figure 1. However, the EDFA's gain begins to decline due to the homogenous line broadening property of the erbium-doped fiber. The SOA, which is an inhomogeneous spread gain medium, is introduced with a multi-frequency fiber laser. The combination of the spectral hole burning effect followed with the inhomogeneous broadening gain medium amplifies the multi-frequency features of the laser. After exit through the comb channel filter, a significant percentage of the multi-wavelength power is introduced and reinforced into the EDFA. This process continues until the hybrid medium's overall gain equals the cavity's loss. As a result, a stable multi-channel fiber laser operation can be established. Such a design provides a cost-effective and efficient solution to generate a stable and flat multi-wavelength source for various applications. With further research and development, multi-wavelength fiber laser sources are likely to find wider applications in various industrial and scientific fields.

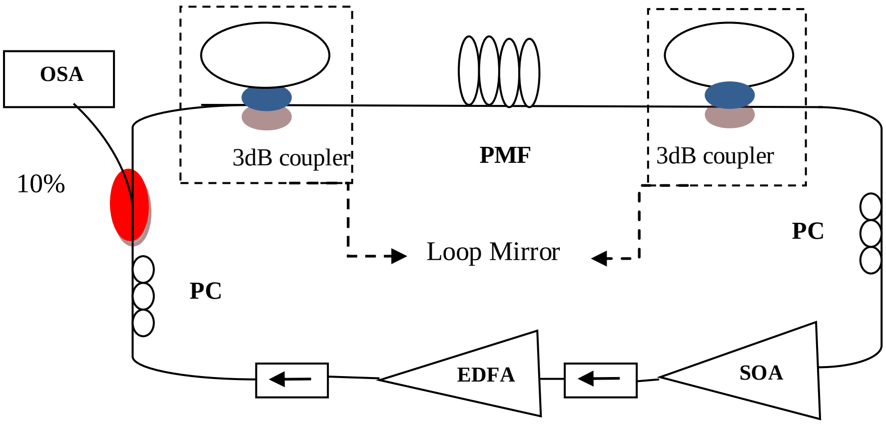

Fig. 1. Schematic of experimental set-up.

3. RESULTS AND DISCUSSION

Figure 2 presents the gain spectra of a hybrid amplifier consisting of an EDFA and a SOA. The figure shows that the gain is flat within the wavelength range of 1532 to 1560 nm, with a variation of less than 1 dB. The power of pump in EDFA and the bias current of SOA are fixed at 95 mW and 300 mA, respectively. While the wavelength of the incoming signal is set to -10 dBm. Additionally, the inset in Figure 2 displays the multi-wavelength laser output, which has 13 lasing wavelengths with peak levels greater than -27 dBm. The multi-wavelength laser has a channel spacing of about 0.8 nm (100 GHz) and a signal-to-noise ratio greater than 20 dB, making it a stable and reliable multi-channel fiber laser array suitable for various applications. According to stability analysis, any little perturbation in the laser cavity will result in a change in the energy distribution of the laser modes.

The polarization state of PC plates and the wavelength affects the net gains experienced by different modes in an EDF-based ring laser. However, the homogenous gain broadening of EDF results in severe mode hopping, making consistent multi-wavelength lasing at ambient temperature unfeasible. To address this, a SOA is inserted into the fiber ring laser, functioning such as an optical ring fiber laser to reduce mode competition by compressing and expanding the cavity length. This reduces the rate of cavity length shift, resulting in a simultaneous multi-wavelength comb as observed in Figure 2's inset.

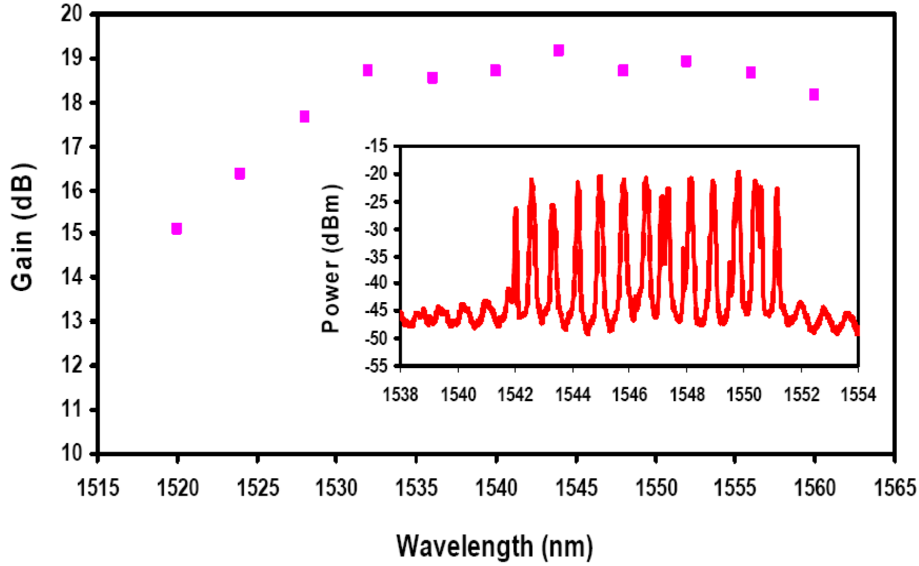

Fig. 2. The out put gain spectrum of the hybrid the SOA and EDFA optical amplifier. Inset shows the output spectrum of the multi-channel fiber laser.

Further experiments were conducted to examine the laser performance at different channel filter arrays, as shown in Figure 3. The use of PMF with 3dB couplers provides optimum filtering, resulting in the greatest number of regular lines with fluctuations less than 3 dB and power level. Without loop mirrors, the multi-wavelength comb is moved to a longer wavelength, while removing 3dB couplers reduces cavity loss and pushes the working wavelength towards the greatest gain region, which is at a longer wavelength, as illustrated in Figure 3.

The channel spacing in all three designs is determined by the birefringence in the ring cavity, which is essentially identical. Computers are used to regulate the number of wavelengths produced, channel spacing, and peak power. With its larger channel spacing and stable operation at normal room condition of temperatures and pressure, the proposed fiber ring laser has many professional applications as multi-wavelength sources in communication [20-22], spectrophotometry, and sensor applications compared to traditional Brillouin erbium fiber lasers (BEFL)[23-25] and Multi-wavelength erbium-doped fiber lasers (MWEDFL).

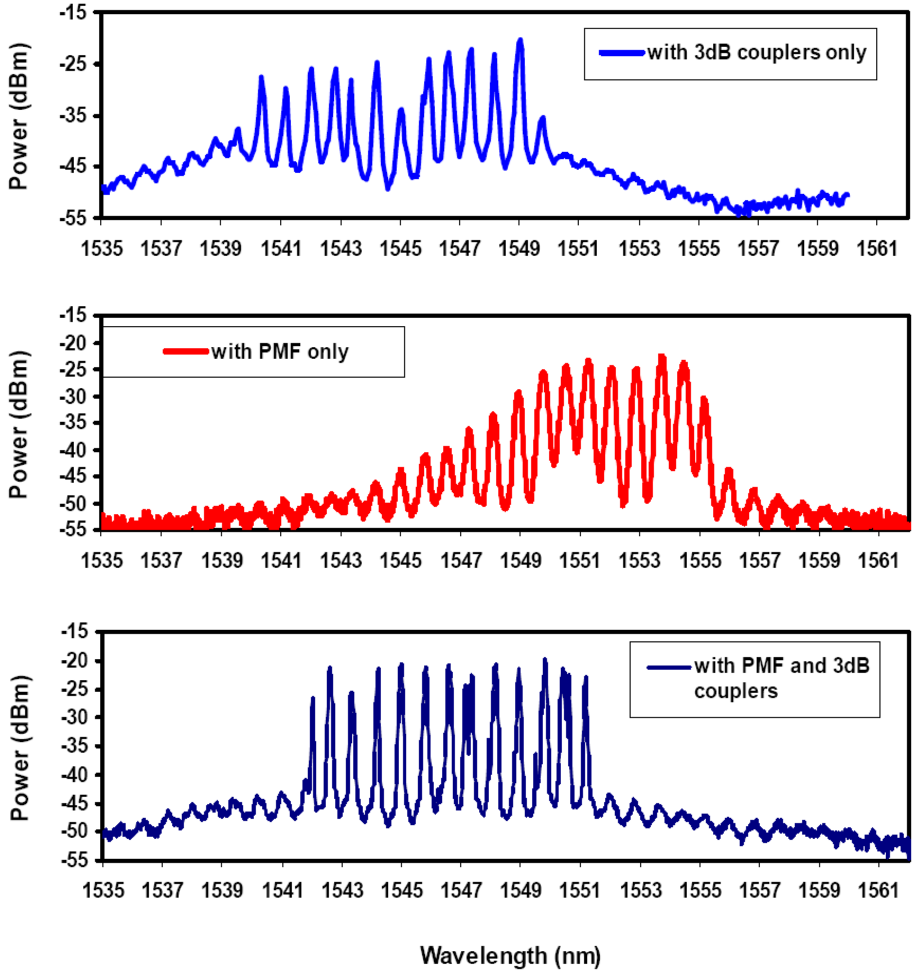

Fig. 3. Power output spectrum of the multi- channel fiber ring laser at different comb filter array: (a) 3d B couplers only, (b) PMF only, (c) PMF and 3d B couplers.

4. CONCLUSION

In this study, a few-mode fiber laser with 13 lines is demonstrated by combining a SOA and an EDFA in a fiber ring cavity configuration. The use of a comb filter for multi-wavelength generation is achieved by using two 3dB couplers as loop mirrors along with a PMF. By altering the birefringence inside the cavity with PCs at various angles, the number of wavelengths produced can be varied. With a bias current near to 300 mA and a pump output power by 92 mW at 980 nm, more than the 13 channels with 0.8 nm spacing and power greater than -27 dBm can be obtained.

Unlike traditional EDF-based multimode sources that suffer from high mode competition and unstable lasing due to homogenous broadening of laser modes, the proposed fiber laser uses a hybrid design that combines the advantages of a SOA's inhomogeneous gain medium and compactness, lightness, lower power consumption, and mass production. Additionally, the low power energy consumption and broad channel spacing make it suitable for DWDM systems in telecommunication and sensor networks.

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