A Nonlinear Optical loop Mirror enhanced three wavelength oscillations Erbium doped fiber laser source based on Fiber Bragg Grating reflectors

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Abstract. A three wavelengths erbium doped fiber laser source is developed. The configuration is a ring cavity comprises a single mode, single-clad 2.5 meter of Erbium doped fiber as a gain medium, an optical circulator, optical isolator for unidirectional operation and a 980/1550 nm wavelength division multiplexing (WDM) optical coupler for coupling the laser diode pump source and the optical feedback of the ring cavity laser source. The broadband spontaneous emission generated in the gain medium is coupled out of the ring cavity via port 1 through port 2 of the optical circulator. On this port, printed on a photosensitive single mode fiber, the Bragg gratings with 20% reflectivity at 1540nm, 1547nm and 1555nm are connected and their function is to select the oscillation wavelengths and to serve as the laser output coupler. To suppress the wavelength competition caused by homogeneous broadening of the Erbium doped fiber at room temperature, thereby enhancing the laser wavelength stability, a Nonlinear Optical loop Mirror with 2.5 km of single mode standard telecommunication fiber is used. Pumped by the 980nm laser diode at 80mW, the laser source has emission at 1540nm, 1547nnm and 1555nm with an average of 1 mW maximum optical power level in each oscillation wavelength.

1. Introduction

Multi-wavelength Erbium doped fiber lasers in recent years have attracted a great deal of research interest because of their applicability to telecommunications, fiber sensors and spectroscopy. For telecommunications, in particular, Erbium doped fiber lasers exhibit excellent characteristics that include their ability to emit simultaneous wavelength oscillations making them multi-wavelength optical sources that are potentially applied in wavelength division multiplexing (WDM) systems. In addition, these fiber lasers have emission in the optical fiber low loss wavelength region, commonly known as Telecommunications C-band, over which Erbium doped fiber Amplifiers (EDFA) operate.

The well-known pitfall of Multi-wavelength Erbium doped fiber lasers (MW-EDFL) is that, at room temperature, EDFL cavity tends to oscillate one wavelength at any particular time. This is caused by the wavelength competition that arises from the cross-gain saturation, existing as a result of the predominantly homogeneously broadened EDFA gain medium at room temperature, leading to unstable oscillations [1]-[2]. Much of the previous and current research in this area has focused on developing techniques to overcome this challenge. As such, several techniques to mitigate the effect of cross-gain saturation have been proposed and implemented with varying degrees of success. For example, it has been observed that the homogeneous line width of Erbium doped fiber exceeds 10nm at 290K and decreases with temperature, down to 1nm at 77K [2].

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Hence, cooling the EDFA in liquid nitrogen at 77K to reduce the homogeneous line width and inserting the intracavity Fabry-Perot etalon as oscillation wavelength filter have been used [2]. Exploiting the intracavity polarization evolution for emission wavelengths, the similar cooling mechanism proved effective [3]. However, this technique is suitable for laboratory environment and inconvenient for field applications due to its bulkiness. The simultaneous lasing was achieved by using the inhomogeneous gain medium provided by a twin-core Erbium doped fiber [4]. Complexity is still an issue in this design. Some of the required characteristics of MW-EDFL are that they should meet the International Telecommunication union standard ITU-T which specifies the frequency spacing between adjacent channels to be in the order of 1.6 nm, 0.8nm, 0.4 nm and 0.2nm [5][6]; and that the power distribution between channels be uniform. From a design perspective, that emphasizes the importance of having control over which wavelengths to oscillate in a laser system. Using separate gain media for each oscillation wavelength guarantees simultaneous wavelength oscillation at any given time [7]. However meeting ITU-T standards using this configuration will be a challenge. Incorporating Raman amplifier or semiconductor optical amplifier in the laser cavity can also mitigate the homogeneous broadening in MW-EDFL [8][9][10], however, this is not a pure Erbium doped fiber laser system, but a hybrid of gain media. That might need additional design consideration since the gain media behavior is different.

An intensity dependent loss mechanism introduced by a nonlinear loop mirror is by far proving to be the simplest method of mitigating the cross-gain saturation in multi-wavelength Erbium doped fiber lasers [11][12][13][14]. In all the above reported work, the focus has been on multiwavelength generation on an Erbium doped fiber gain medium, with little or no intention to gain control on the wavelengths oscillation in the laser cavity. In this work, we exploit the cavity intensity dependent loss ability of the nonlinear loop mirror to stabilize the power and oscillation wavelength of the fiber laser with complete control over laser oscillation wavelengths. This is achieved by making use of the laboratory designed single mode fiber printed Fiber Bragg gratings as the wavelength selecting filters. Thus, the wavelength spacing, the number of wavelength and the exact center wavelength oscillation can be controlled using our laser configuration. The ability to control the above laser parameters is important for the ITU-T standardization of laser sources for WDM systems [6]. Experimental characterization have been performed, and a three wavelength laser with oscillations at 1540nm, 1547nm and 1555nm have been achieved. This comes after adjusting the length of the NOLM to an optimal value convenient for stability in our configuration.

2. Experimental Setup and principle of operation

A schematic of the experimental setup is shown on figure 1. A laser diode pump of 980nm wavelength and 80 mW of pump power is used. This pump power is coupled to the 2.5 m Erbium doped fiber gain medium by a WDM coupler. To ensure the uni-directionality of the laser, an optical isolator is inserted in the fiber ring cavity of the laser. A nonlinear Optical loop Mirror (NOLM) with a 70:30 loop power splitting ratio is inserted in the ring cavity to provide the intensity depend loss (IDL) for the lasing wavelengths. An optical circulator is used to couple out of the cavity, the amplified spontaneous emission (ASE) generated in the EDF from which the oscillation wavelengths are filtered by series configured Fiber Bragg gratings with 20 % reflectivity at 1540nm, 1547nm and 1555nm. The FBG also serve as the output coupler of the laser in which the feedback power is 20% of the cavity power and the output is 80% of the cavity power.

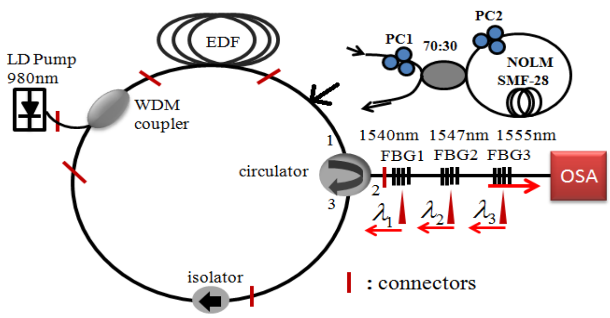

Figure 1: Schematic diagram of the experimental setup of the proposed three wavelength laser and the NOLM

The output of the laser was interrogated by a Optical spectrum analyzer (OSA) with resolution set to 0.05nm.The experiment was run at room temperature, with no loop mirror first and with loop mirror. The length of the loop mirror was varied. A loop mirror with lengths 500m, 1250m, 1700m, 2500m and 3000m was used.

3. Results and discussion

In a series of experiment the configuration in figure 1 was used, without the loop in the first place. The output of the laser was monitored over an approximately 3 hour period using the optical spectrum analyser and the laser spectrum in 3D view is shown in figure 2.

As can be seen in figure 2, there is only one wavelength at 1540 nm oscillating in the laser cavity suggesting a huge instability and strong cross-gain saturation. Then the NOLM was introduced with varying the length of the loop from 500 m -3000m. When the length of 500m was used, after careful adjustment of the polarization controllers, there was no change in the lasing wavelength and the power fluctuations remained between -5dBm and 5dBm as shown in figure 3 after a 3 hour monitoring. This suggests the persistence of the gain depletion by a dominant wavelength at 1540nm.

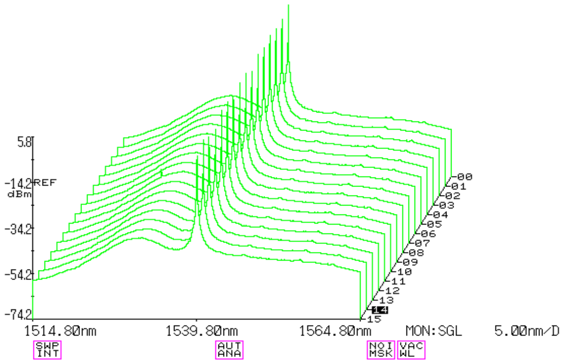

Figure 2: Spectrum of the laser without NOLM

For convenience, we have shown on figure 4, the change in the lasing wavelength and power stability improvement with the increase in the NOLM length. It was observed that when the loop length was 1250m, a change in the lasing wavelength was introduced, although it was only an addition of one more wavelength, suggesting the weakening of the gain depletion by a dominant wavelength, as shown on figure 4.

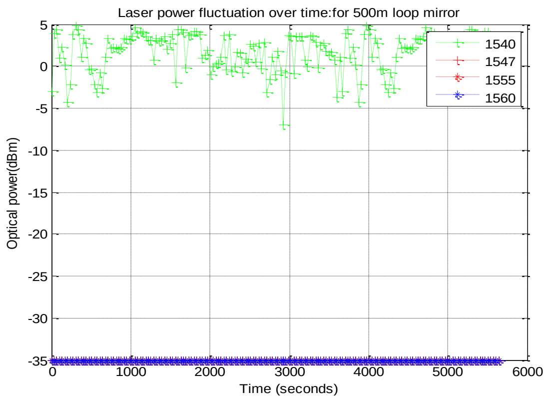

Figure 3:Wavelength and laser power stability of 1aser without 500m of NOLM length

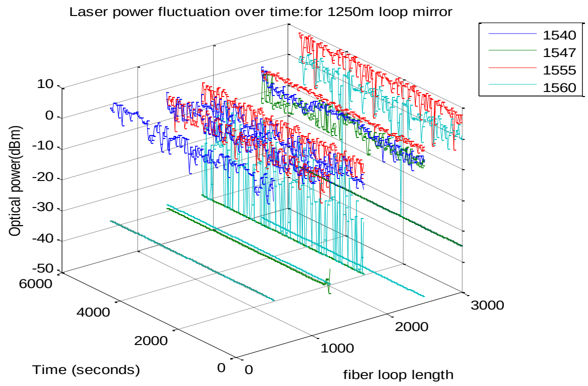

Figure 4:Laser power stability and lasing wavelength as a function of NOLM length.

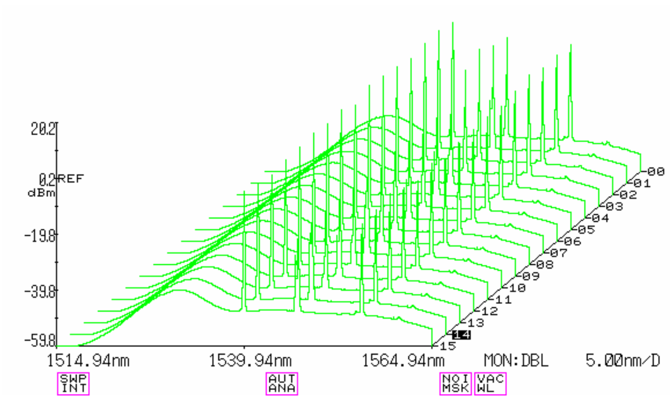

Figure 5:Emission spectrum of a three wavelengths laser with 2.5km Of NOLM length

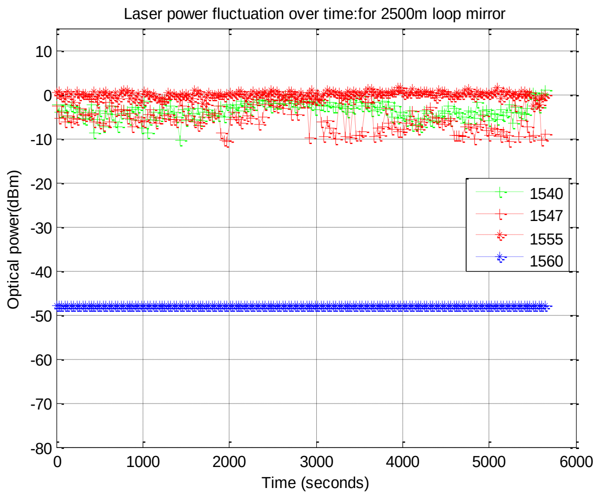

Figure 6: Laser power and wavelength stability of a three wavelength laser with 2.5km of NOLM length

From figure 4, it can be seen that the increase in the length of the loop NOLM increase the number of wavelengths oscilatting the cavity. However, it was also obseverved that there is a length above which the further increase in the loop length affects both the stability and the lasing wavelength of the laser. In our experiments, the length above which the satability start to decrease is 2500m, as seen in figure 4. This suggest an optimal length of 2500m is apropriate for both the maximum laser power stability and the lasing wavelength under this configuration. In figure 5, a spectrum of a three wavelength fiber laser with a NOLM length of 2500m is shown.