Multi-wavelength laser generation with Bismuth-based Erbium-doped fiber

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Abstract: A multi-wavelength laser comb is demonstrated using a nonlinear effect in a backward pumped Bismuth-based Erbium-doped fiber (Bi-EDF) for the first time. It uses a ring cavity resonator scheme containing a 215cm long highly nonlinear Bi-EDF, optical isolators, polarisation controller and 10dB output coupler. The laser generates more than 10 lines of optical comb with a line spacing of approximately 0.41nm at 1615.5nm region using 146mW of 1480nm pump power.

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References and links

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1. Introduction

Recently, Bismuth-based erbium-doped fibers (Bi-EDFs) have been extensively studied for use in compact amplifiers with short gain medium lengths. This fiber incorporates lanthanum (La) ions to decrease the concentration quenching of the erbium ions in the fiber [1], which allows the erbium ion concentration to be increased to more than 1000 ppm. A fiber with such a high erbium dopant concentration is expected to have enormous potential in realizing a compact erbium-doped fiber amplifiers (EDFAs) and EDFA based devices. The Bi-EDF also exhibits a very high fiber nonlinearity, which can be used for realizing new nonlinear devices such as wavelength converter and multi-wavelength laser source. Multi-wavelength lasers are required for dense wavelength division multiplexing (DWDM) optical system, which is an enabling technology to fulfil a demand of bandwidth in the modern information age.

Nonlinear effects such as four-wave mixing (FWM) can be used to achieve multi-wavelength operation. FWM can occur when two or more frequencies of light propagate through a nonlinear medium, provided that the condition known as phase matching is satisfied. In the FWM process, light is generated at new frequencies through the conversion of optical power from the original signal wavelengths, or in quantum-mechanical terms FWM occurs when photons from one or more waves are annihilated and new photons are created. These new photons, although created at different frequencies still conserve the net energy and momentum [2-3].

Recently, Bi-EDF ring lasers have been demonstrated with a tunable single wavelength operation [4-6]. These lasers provide a wide tuning range as well as a high signal to noise

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ratio. In this paper, a multi-wavelength laser is demonstrated using the Bi-EDF assisted by FWM process in a ring cavity resonator for the first time. The backward pumped Bi-EDF acts as both linear and nonlinear gain media. The linear gain will generate erbium laser lines which interact with each other in the same medium to generate a multi-wavelength comb with a constant spacing.

2. Experimental set-up

The experimental set-up of the proposed ring multi-wavelength laser is shown in Fig. 1. It consists of a Bismuth-based EDF (Bi-EDF) approximately 215cm in length with a nonlinear coefficient of $60(W.km)^{-1}$, an erbium concentration of 3,250 ppm and a cut-off wavelength of 1440 nm as well as a pump absorption rate of 83 dB/m at 1480nm. The Bi-EDF has a mode field diameter of 6.12μm at 1550nm and is fabricated by Asahi Glass Co. Ltd, Japan. The Bi-EDF is backward pumped using a 1480 nm laser diode. Wavelength division multiplexer (WDM) is used to combine the pump and laser wavelengths. Polarization controller (PC) is used to control the birefringence in the ring cavity so that the output laser generated can be controlled and optimized. Two optical isolators are used in our case to block the spurious back reflection from each component and to ensure unidirectional operation of the laser. A 10dB coupler is used to tap the output of the laser via 10% port as shown in Fig. 1, which is then characterized by an optical spectrum analyzer (OSA) with a resolution of 0.015 nm. The total cavity length of the ring resonator is approximately 7m. Fig. 2 shows the backward and forward ASE spectra of the Bi-EDF, which is pumped by 100mW of 1480nm laser diode. As shown in the figure, the forward ASE covers the long-wavelength band (L-band) region from 1570 to 1620 nm and peaks at around 1615nm. The operating wavelength of the multi-wavelength laser is determined by the Bi-EDF gain spectrum which peaks at around 1615nm as well as the cavity loss. The insertion losses of the isolator, PC, WDM and coupler are slightly wavelength dependent. The Bi-EDF amplifier has small signal gain of approximately 30dB at the L-band region with a pump power of 150 mW.

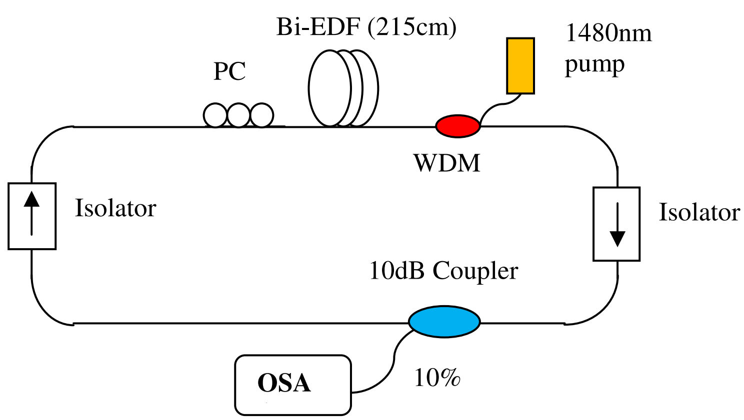

Fig. 1. Experimental set-up for the proposed a Bi-EDF based multi-wavelength ring laser

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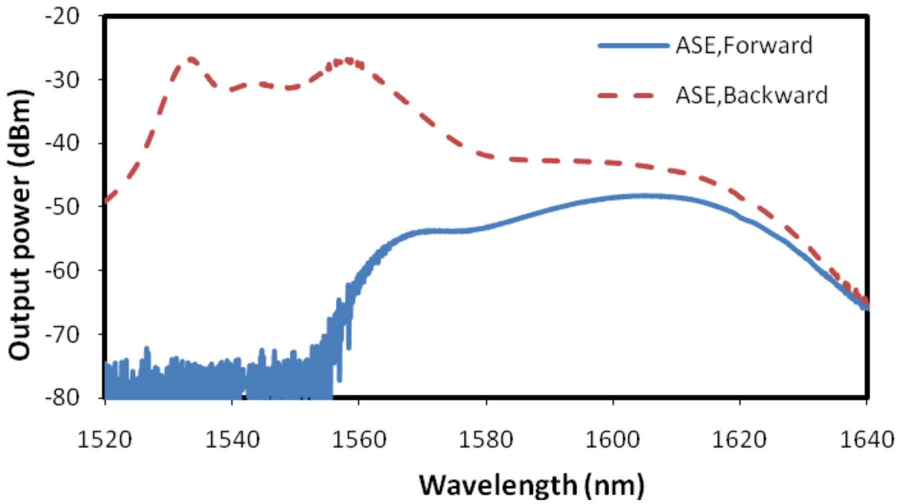

Fig. 2. Forward and backward ASE spectra from the Bi-EDF pumped by 100mW of 1480nm pump.

3. Result and discussion

Figure 3 shows the output spectrum of the multi-wavelength laser for different 1480nm pump power. As shown in the figure, the oscillating laser lines are observed in the 1615.5nm region, which is fall within an extended L-band region. The amplification bandwidth of the Bi-EDF is extended to this region due to the suppression of excited-state absorption (ESA). The laser operates at this region due to the cavity loss which is lower at the longer wavelength. The backward pumped Bi-EDF generates amplified spontaneous emission at this region which oscillates in the ring cavity to generate at least two oscillating lines with a constant spacing due to the longitudinal modes interference. The strong forward oscillating laser generates a backward propagating reflected light in the gain medium (due to Rayleigh scattering and Fresnel reflection) to form a standing wave which interferes each other to form a multiple modes. The multi-wavelength laser generation with a constant spacing is assisted by the four-wave mixing process, which annihilates photons from these waves to create new photons at different frequencies. A PC has been used to control the polarisation and the birefringence inside the cavity, which in turn control the number of line generated, channel spacing and the peak power.

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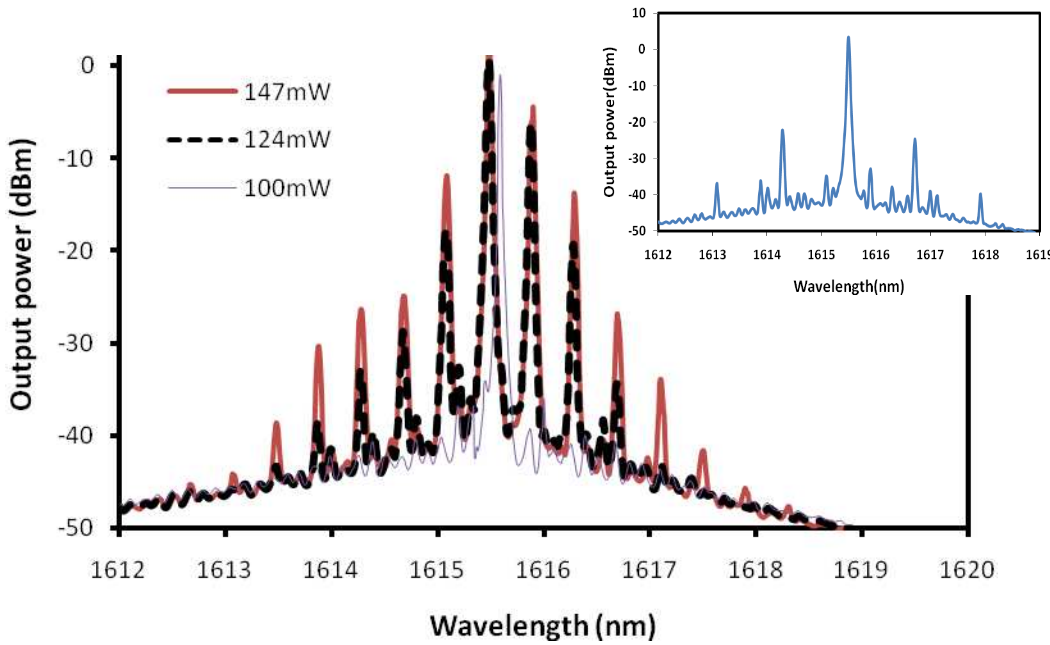

Fig. 3. Output spectrum of the proposed Bi-EDF based multi-wavelength ring laser at different 1480nm pump powers. Inset shows the output spectrum when the polarization is un-optimised.

As shown in Fig. 3, more than 10 lines are obtained at the maximum pump power of 147mW. At the minimum pump power of 100mW, the erbium gain is lower and only one strong oscillating laser is generated. Since another oscillating laser line is below the threshold of the FWM process and thus no additional frequencies lines were observed. The number of generated line as well as the peak power is observed to increase as the pump power for the 1480nm laser diode increases which is attributed to the increment of the erbium gain with pump power. This situation provides sufficient signal power for the FWM process to generate additional lines. In this experiment, the strongest line has a peak power of approximately -2dBm and the line spacing is measured to be around 0.41nm, which is determined by the cavity length and the birefringence in the ring cavity. Inset of Fig. 3 shows the output spectrum when the polarisation state in the ring cavity is un-optimised. In this case, 5 simultaneous lines are obtained with a constant spacing of approximately 1.23nm.

Figure 4 shows the peak power against 1480nm pump power for the best 4 lines of the laser comb. As seen in this figure, the pump threshold for the additional lines to be generated is approximately 100mW and the peak power increases with the pump power. The number of lines is limited by the availability of the 1480nm pump power or erbium gain, fiber nonlinearity and polarisation filtering effect in the linear cavity resonator. The multi-wavelength output is observed to be stable at room temperature with only minor fluctuations observed coinciding with large temperature variances.

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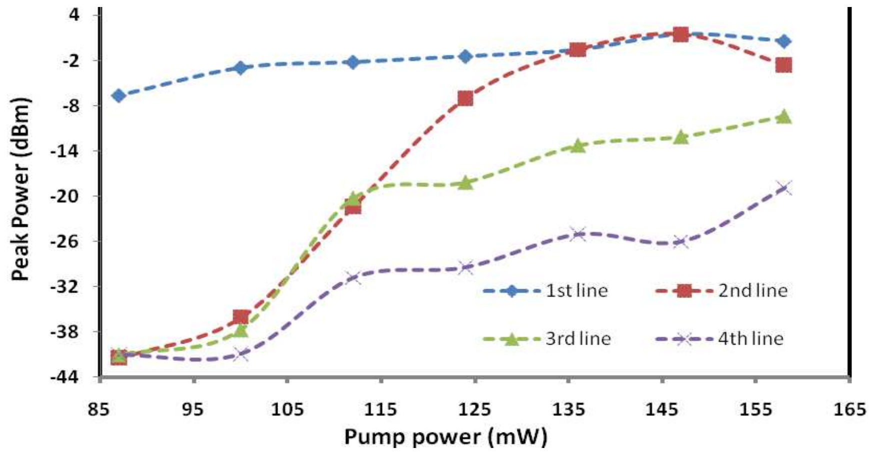

Fig. 4. Peak power against pump power of the 1480nm laser diode for first 4 lines in the multi-wavelength laser spectrum.

4. Conclusion

We have demonstrated a multi-wavelength laser comb using a Bi-EDF fiber as both linear and nonlinear gain media. The multi-wavelength generation is due to oscillating Bi-EDF laser lines which interacts each other to create new photons at other frequency via four-wave mixing process. The generated laser comb has more than 10 lines at the maximum 1480nm pump power of 147mW with a constant spacing of approximately 0.41nm.

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