Bismuth erbium-doped fiber based multi-wavelength laser assisted by four-wave mixing process

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Abstract: We demonstrate for the first time a multi-wavelength laser based on a bismuth-based erbium-doped fiber (Bi-EDF) assisted by a four-wave mixing (FWM) process. Using a simple linear cavity resonator scheme containing a 49 cm long highly nonlinear Bi-EDF, we obtained about 8 lines of optical comb with a line spacing of approximately 0.52 nm at the maximum 1480 nm pump power of 160 mW.

Keywords: Bismuth-based erbium-doped fiber, Bi-EDF, Four wave mixing

Classification: Fiber optics, Microwave photonics, Optical interconnection, Photonic signal processing, Photonic integration and systems

References


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 multi-wavelength laser. Multi-wavelength lasers are one of the important components for wavelength division multiplexing (WDM) optical system, which is an enabling technology to fulfill a demand of bandwidth in the modern information age.

Nonlinear effects such as stimulated Brillouin scattering [2] and four-wave mixing, which occur in optical fibers can be used to achieve multi-wavelength operation. Multi-wavelength lasers with a high number of channels have been reported using a Brillouin erbium fiber laser. However, the spacing of this laser is fixed at 0.08 nm, which is too narrow for WDM applications. 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 [3].

The generation of new frequency components via FWM can induce crosstalk in wavelength division multiplexing (WDM) systems, especially around the zero dispersion wavelength which can limit its performance. However, the FWM process also can be used to make optical devices such as wavelength converter [4] and multi-wavelength lasers. In this paper, a multi-wavelength laser is demonstrated using the Bi-EDF assisted by FWM process in a linear cavity for the first time. The forward 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.

2 Experiment

The experimental setup for the multi-wavelength laser is shown in Fig. 1. It consists of a Bismuth-based EDF (Bi-EDF) approximately 49 cm 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 1480 nm. The Bi-EDF is forward pumped using a 1480 nm laser diode. Wavelength division multiplexer (WDM) is used to combine the

![Fig. 1. Experimental set-up for the proposed a Bi-EDF based multi-wavelength laser.](image-url)
pump and laser wavelengths. Polarisation controller (PC) is used to control the birefringence of the linear cavity so that the output laser generated can be controlled and optimized. Two optical circulators designated as OC1 and OC2 in which port 3 is connected to the coupler and then to port 1 is used at both ends of system to act as a reflector. A 3dB coupler is used to tap the output of the laser via Port A and Port B as shown in Fig. 1, which is then characterized by an optical spectrum analyzer (OSA) with a resolution of 0.015 nm.

3 Results and discussion

The operating wavelength of the multi-wavelength laser is determined by the forward pumped Bi-EDF gain spectrum which covers the conventional band (C-band) region from 1525 to 1570 nm as well as the cavity loss. The Bi-EDF amplifier has small signal gain of approximately 30 dB at the C-band region with a pump power of 150 mW. The output spectrum of the multi-wavelength laser at Ports A and B of Fig. 1 is investigated as shown in Fig. 2, in which the oscillating laser lines are observed in the 1565 nm region. The 1480 nm pump power is fixed at 150 mW. The laser operates at this region due to the cavity loss which is lower at the longer wavelength. The forward pumped Bi-EDF generates amplified spontaneous emission at C-band region which oscillates in the linear cavity to generate at least two oscillating lines which the spacing is determined by the cavity length and the birefringence in the linear cavity. 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. As shown in Fig. 2, the lines are more pronounced at Port A.

![Output spectrum of the proposed Bi-EDF based multi-wavelength laser at different output ports.](image)
Fig. 3 shows the output spectrum of the multi-wavelength laser at Port A for different 1480 nm pump power. At the minimum pump power of 28 mW, the erbium gain is very low and peak power of the oscillating laser lines is below the threshold of the FWM process and thus only two lines were observed. The number of generated line as well as the peak power is observed to increase as the pump power for the 1480 nm 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, 8 lines are obtained within a bandwidth of approximately 5 nm at the maximum 1480 nm pump power of 160 mW with 5 of these lines have a peak power above $-15$ dBm and the lines spacing is measured around 0.52 nm. The pump threshold of the laser is approximately 30 mW. The number of lines is limited by the availability of the 1480 nm 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.

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 8 lines at the maximum 1480 nm pump power of 160 mW with channel spacing of 0.52 nm.