All Optical Cross-Connect System Using Erbium-Doped Fiber-Based Optical Switching Unit

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ABSTRACT

A novel bidirectional 2×2 optical switch technique, based on the conventional erbium-doped fibers (EDFs) with an operation of pumped or unpumped power level, is proposed and demonstrated experimentally. By using the amplification and absorption function of EDFs and a simply architecture design, the input signals can be switched to a suitable position. The response time of wavelength switching will approach about 2 ms. Moreover, the behavior and system performance of the proposed configuration also have been studied.

Keywords: EDF, optical switching, cross connect

1. INTRODUCTION

Wavelength division multiplexing (WDM) is now widely used in transport networks around the world to carry multiple wavelengths on a single fiber. Recently, these wavelengths usually undergo optical-electrical-optical (OEO) conversions at intermediate switching points along their end-to-end paths. By switching wavelengths purely in the optical domain, all-optical switches obviate the need for costly OEO conversions, and provide bit rate and protocol independence. [1] This allows service providers to introduce new services and signal formats transparently without forklift upgrades of existing equipment. All-optical switching also promises to reduce operational costs, improve network utilization, enable rapid service provisioning, and improve protection and restoration capabilities. As the capacity of WDM transmission systems continues to advance, the most critical element in the widespread deployment of wavelength-routed all-optical networks is the development of efficient wavelength switching technologies and architectures. Two main types of micro-electromechanical systems (MEMS) optical switches have been proposed and thoroughly covered in previous literature: 2D and 3D. [2-4] Recently, several other optical switch techniques has been reported, such as using a deformable mirror for micro-optical fiber switch method, [5] the Multilayer Multigranular Optical Cross-Connects for waveband switch, [6] and an erbium-doped fiber (EDF)-ring coupled M-Z interferometer for all optical switch. [7]

In this paper, we propose and experimentally investigate a bidirectional 2×2 optical switch technique using the amplification or absorption function of an EDF. By properly turning the power of the 980 nm pump laser on, the input signal can be easily switched to suitable position. In addition, the wavelength switching response time of the proposed configuration and the system performance have also been studied.

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2. EXPERIMENTAL SETUP

Fig. 1 shows the experimental setup for the proposed bidirectional 2×2 optical switch module. This module consists of six 1×2 and 50:50 optical couplers, four 1550/980 nm WDM couplers, two 980 nm pump lasers (LD-1 and LD-2), and four lengths of EDFs with 12-m-long. Four couplers are used to connect the EDFs, and the others will provide the power sharing of 980 nm pump laser, as shown in Fig. 1. This optical switch has bidirectional function to the input signal switching for WDM networks. If the LD-1 turns on (LD-2 turns off), the input signals from the port "a" (λ_1, λ_3…) and "b" (λ_2, λ_4…) will pass out the port "c" (λ_1, λ_3…) and "d" (λ_2, λ_4…), respectively. On the contrary (LD-1 off and LD-2 on), the signals will pass out the port "d" (λ_1, λ_3…) and "c" (λ_2, λ_4…). According to Fig. 1, the input signals also can be placed into the port "c" or "d" for switching to port "a" or "b". By turning on or off the 980 nm pump lasers (LD-1 and LD-2), we can easily switch the input signal to the output port what we want. Due to the characteristics of EDF with the absorption or amplification function, we can drive the pump power levels of two LDs for turning on or off to determine the input signals passing out the output port "c" or "d" (or "a" or "b"). In other words, the EDF can provide the gain or loss to the input signals for lightwave propagating.

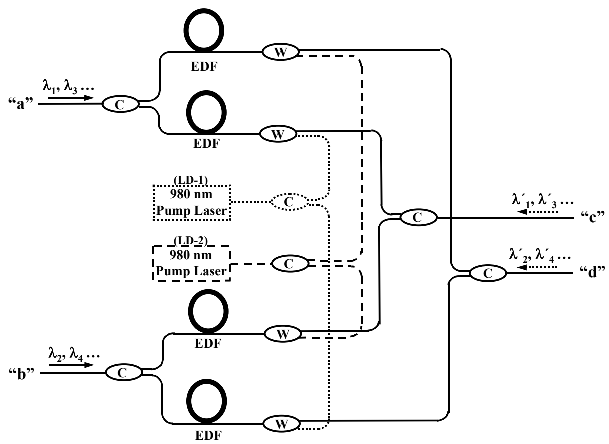

Fig. 1 The originally proposed 1×2 optical switch module.

To investigate the behavior and performance of an EDF, some associated characteristics of an EDF are realized. Therefore, Fig. 2 indicates the amplified spontaneous emission (ASE) and absorption spectra of an EDF with 12-m-long. The retrieved ASE spectrum is pumped at 80 mW. A –8.3 dBm maximum power of the ASE spectrum occurs at 1532 nm, and the effective range is operated at 1520 to 1568 nm while the power level is above –40 dBm. Fig. 2 also shows the absorption spectrum of the EDF used. The maximum abruption power is 23.1 dBm at 1527 nm, and a 6.7 dBm absorption power is observed at 1550 nm. From the basic amplification and absorption spectra of EDFA in Fig. 2, the spectra width of the input and output signals with and without pumped EDF is nearly from 1520 to 1570 nm. That is to say, the WDM input signals can be used simultaneously into the proposed EDF-based optical switch in accordance with the characteristic of an EDF for the proposed switch.

Fig. 3 shows the gain and noise figure spectra of the EDFA with a 12-m-long EDF and pump power of 40 mW, when the input signal power is 0 and –25 dBm, in the wavelengths of 1520 to 1570 nm. The saturated power of 15.1 dBm (noise figure is 7.8 dB) occurs at 1534 nm while the input signal is 0 dBm. Fig. 3 also presents the maximum peak gain and noise figure of 35.1 and 5.6 dB at 1532 nm when the input signal is –25 dBm over the operation region.

Fig. 4 shows the gain and noise profiles of an EDF with 12-m-long at the wavelength of 1550 nm with –25 dBm, while the pump power of 980 nm laser is increased gradually from 0 to 80 mW. When the EDF is unpumped (0 mW), the input signal will obtain 34.5 dB loss (~34.5 dB noise figure), that is to say, the signal can't pass through the EDF. The input signal will begin to retrieve the gain value at the pump power of > 8 mW. Simultaneously, the gain will be saturated while the pump power of > 25 mW as shown in Fig. 4.

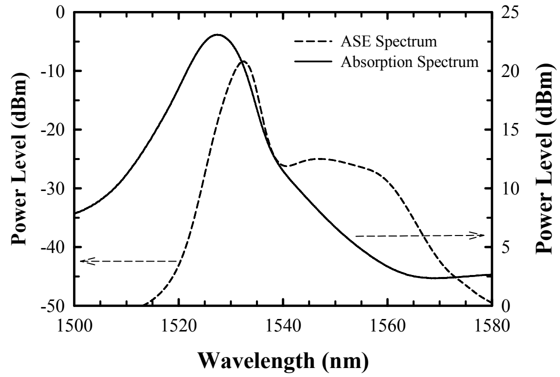

Fig. 2 The ASE and absorption spectra of an EDF with 12-m-long. And the ASE spectrum is operated at 100 mW pump power.

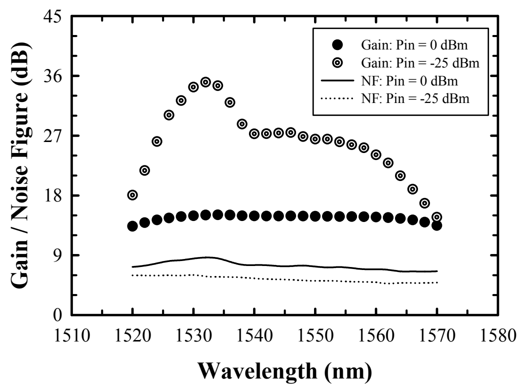

Fig. 3 Gain and noise figure spectra for an EDF with 12-m-long at 100 mW pump power, when the input signal power is 0 and –25 dBm, over the wavelength range of 1520 to 1570 nm.

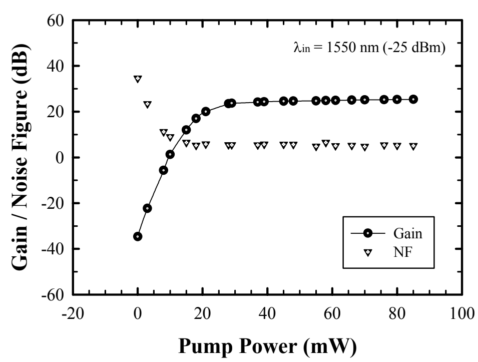

Fig. 4 Gain and noise profiles of a 12-m-long EDF at the wavelength of 1550 nm with –25 dBm, since the pump power level in increased gradually from 0 to 180 mW.

Figs. 5 (a) and 5(b) show the optical spectra of the original input signal and the output signal with the unpumped EDF, while the input signal power is 0 and –25 dBm at 1550 nm. When 0 dBm input signal into the optical switch module, then the output power will be obtained at –21.85 dBm under a umpumped status, as seen in Fig. 5(a). Identically, since the input signal is –25 dBm, then the out power will turn to –60.34 dBm, as shown in Fig. 5(b). Since the 0 and –25 dBm input signals at 1550 nm pass through the proposed switch (form the port "a" to "c" or "d") under 8.7 mW pumped status, then the output power will become –0.2 and –24.9 dBm, respectively, as shown in Figs. 5. So, the length of EDF is determined to give a 4 to 5 dB gain when pumped to overcome splitting loss, and a 22 dB loss when unpumped to avoid crosstalk. According to results of Fig. 2 to Fig. 5, the proposed bidirectional 2×2 optical switch module is suitable in lower power propagating input signals.

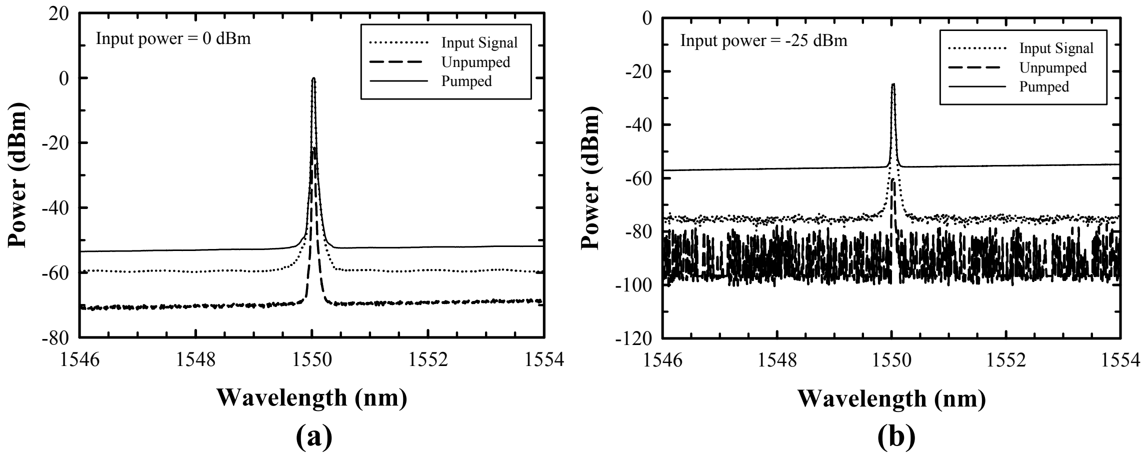

Fig. 5 Optical wavelength spectra of the original input signal and output signal after passing out the unpumped EDF, when the input signal power is (a) 0 and (b) –25 dBm at 1550 nm.

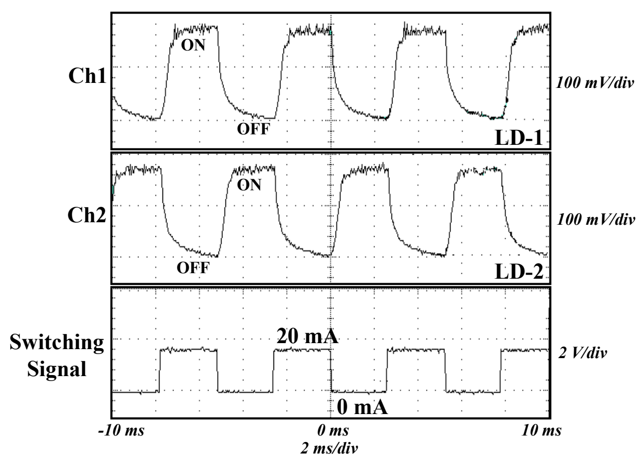

Fig. 6 The signal waveforms of channel 1 (LD-1) and channel 2 (LD-2) of the digital scope in Fig. 2 for the pump power operation (power on or off) and the waveform of the switching signal, when a 1550 nm input signal with –25 dBm passes through the proposed configuration.

To demonstrate the driving response time of the LD-1 and LD-2 for the power turning on or off, two pump lasers are operated at the bias current of 10 mA (~4 mW) and modulated by a square signal, when a 1550 nm input signal with –25 dBm is applied, as shown in Fig. 1. By using a digital scope with 20-GHz bandwidth, the response time of two pump lasers, which turn on or off, can also be retrieved from the trace of the electrical signals. A function generator is used to provide the switching signal of LD-1 and LD-2 and the synchronous trigger signal into a digital scope. As a result, two pump lasers will be operated at the driving current of 0 and 20 mA (~9 mW) for low and high levels (on and off). The applied square signal has the signal width of ~2.5 ms. That is, when the LD-1 turns on, then the LD-2 off. The rising and falling time is nearly 0.4 and 2 ms as seen in Fig. 6. From Fig. 6, the effective response time (or switching time) of ~2 ms is observed for the two LDs switching in the power level turning on or off. The signal-to-noise ratio (SNR) of the input signals would be reduced after passing through the switch due to the background ASE of the EDF-based switch. We can demonstrate the module performance of the switch by measuring the bit error rate (BER), as following the discussion as below.

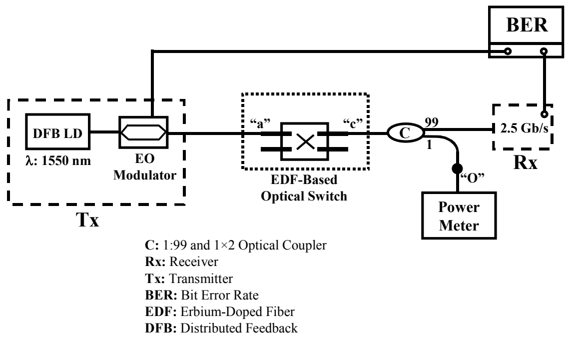

Fig. 7 Experimental setup for the BER measurement for the back-to-back type and proposed switch module in a 2.5 Gbit/s modulation system.

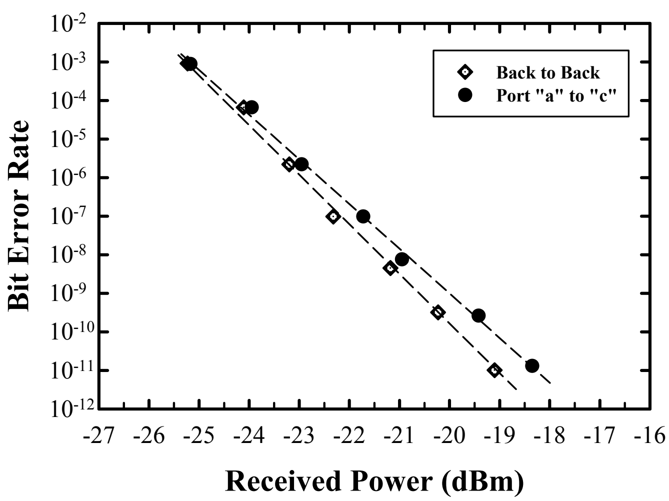

Fig. 8 Performances of the bit error rate (BER) at a test signal of 1550 nm in a 2.5 Gbit/s modulated system.

To realize the proposed experimental optical switch performance, we use a test input signal at 1550 nm, which is modulated by a 2.5 Gbit/s non-return-to-zero pseudorandom binary sequence with the pattern length $2^{31}-1$ on the EO (electro-optical) modulator, when the 980 nm LD is operated at 25 mW, as shown in Fig. 7. The received power is observed at the "O" point (in Fig. 7) before into the receiver. However, back-to-back should be the BER performance without the proposed EDF-based optical switch, characterizing the transmitter and receiver. A 2.5 Gbit/s optical receiver is applied to measure the system performance. Fig. 8 shows the measured bit error rate (BRE) of the proposed optical switch against the received power for the back-to-back type and the test signal through the optical switch from the port “a” to “c”. Since a test input signal passes through the switch, the observed optical power penalty is nearly 0.55 dB while the BER is 10^{-9}.

3. CONCLUSION

In conclusion, we propose and demonstrate a novel bidirectional 2×2 optical switch technique, based on the conventional erbium-doped fibers with an operation of pumped or unpumped power level. By employing the amplification and absorption characteristics of EDFs and a simply architecture design, the input wavelengths can be suitably switched. The response time of wavelength switching will approach about 2 ms. Moreover, the behavior and system performance of the proposed configuration also have been studied. Therefore, the proposed optical switch will be promising to WDM networks.

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