

# FIBRE BRAGG GRATING SWITCHING BEHAVIOUR USING HIGH-POWER PUMP LASER DIODES

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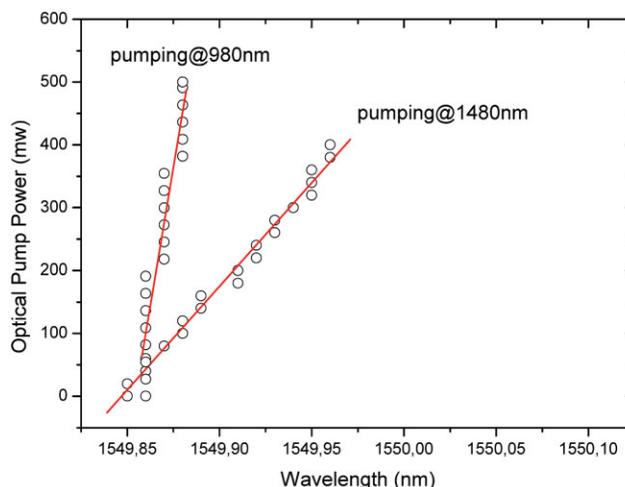
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**ABSTRACT:** All-optical switching devices based on fibre Bragg grating (FBG) structures written on a standard single-mode fibre and in an erbium-doped fibre have been experimentally demonstrated in the third telecommunication window. The switching devices work due to the thermal changes induced by a high-power continuous-wave laser diode. The filters tunability characteristics have been demonstrated for different pump powers (up to 900 mW) and different pump laser wavelengths (at 980 and 1480 nm), presenting different thermal absorption behaviour within different working regimes. © 2006 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 48: 1538–1540, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21680

**Key words:** switching; grating; undoped fibre; doped fibre; pump laser diode

## 1. INTRODUCTION

Wavelength division multiplexing (WDM) high-capacity networks have been the object of research in recent years due to their high performance capabilities. Therefore, research efforts to fulfill WDM requirements have led to the development of new optical components for the next generation optical communication networks. In optical networks, one of the most important operation is the wavelength selectivity that comprises multiplexing/demultiplexing, adding/dropping or switching of optical channels. In concrete, an optical switch has the ability to redirect an optical channel depending on its wavelength, becoming key components in WDM networking management.



**Figure 2** Measured dependency of the peak wavelength on the applied pumping power when an undoped fibre is used. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

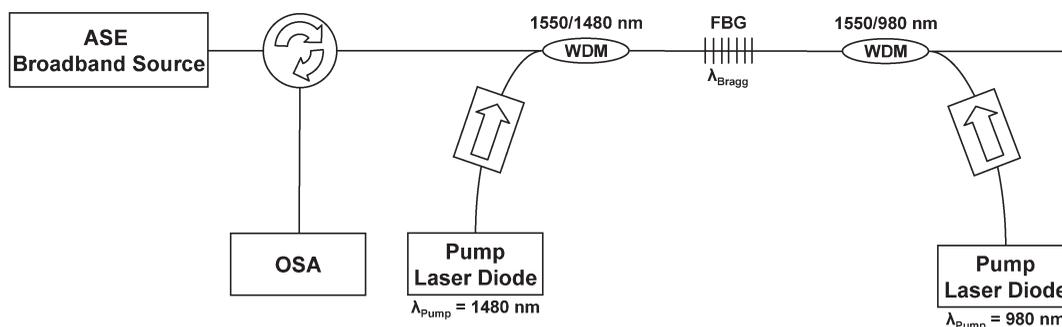
Several optical switches have been studied in the literature such as micro-electro-mechanical systems (MEMS) [1], thermo-optic switching [2], liquid-crystal switching [3, 4], “bubble” switching (Gel/Oil based) [5], acousto-optic switching [6, 7], and fibre Bragg grating (FBG)-based systems [8].

In recent years, several researchers have studied optical switching devices based on FBGs. The FBG structures have been chosen due to their inherent high wavelength selectivity, low insertion losses, or high reflectivity. To perform the switching function, two methods may be used to achieve the necessary shift in the Bragg grating central peak: modifying the fibre refractive index or changing the grating period. These variations can be induced thermally [8], through mechanical stress [9–12], or by nonlinear propagation effects inside of the grating [13, 14].

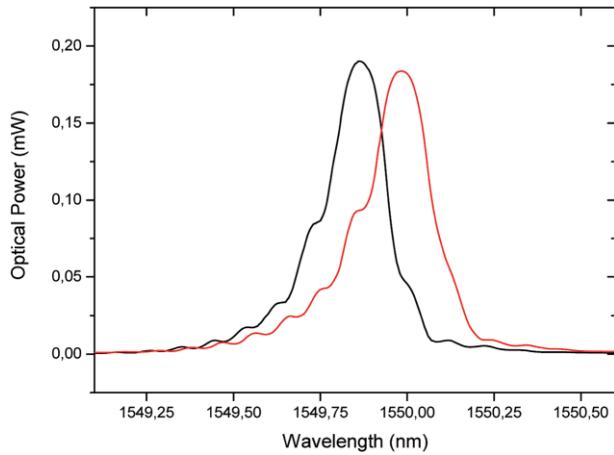
A new switching device is presented in this paper that uses a classical add-drop multiplexer structure, in combination with high-power pumping continuous-wave (CW) diode lasers.

## 2. EXPERIMENTAL RESULTS

A schematic diagram of the proposed optical switch scheme is shown in Figure 1. The architecture is composed of an FBG, pump laser diodes (1480 and 980 nm), and two WDM filters (1480/1550 nm and 980/1550 nm). The setup includes a broadband source and an optical spectrum analyzer connected to the device through an optical three-port circulator. The FBGs used to provide the all-



**Figure 1** Experimental setup of the all-optical switch

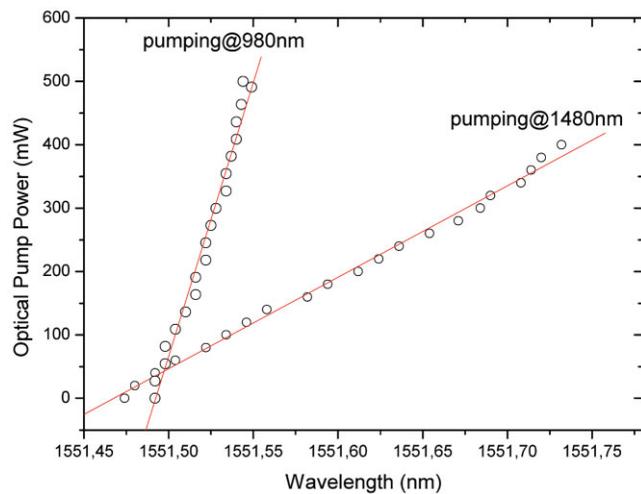


**Figure 3** Measured reflection spectra with maximum pumping power (red line) and without (black line) of the FBG written in an undoped fibre. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com)]

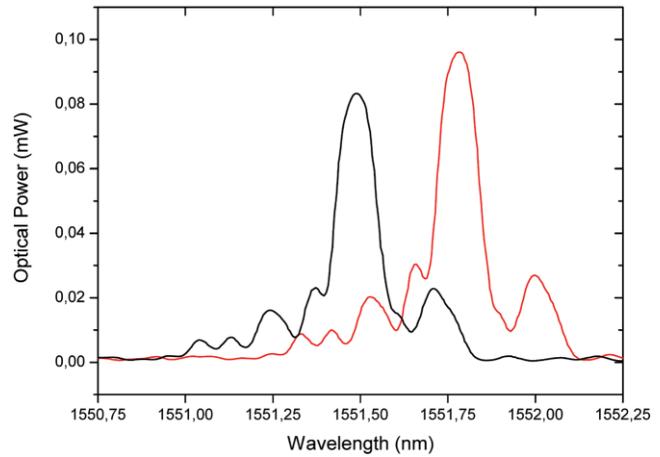
optical switching were written, prior to hydrogeneration loading [15], firstly in a single-mode fibre and secondly in an erbium doped fibre. The FBGs have the following characteristics: length of 10 mm, FWHM of 0.2 nm, and  $\sim 100\%$  reflectivity.

The FBGs' reflection spectra response for both types of fibre, when varying pump laser power or pump laser wavelength, have been investigated. Firstly, an FBG (with a central wavelength of 1549.86 nm) written in a undoped single-mode fibre was illuminated by a continuous pump laser diode with a central wavelength of 1480 nm and a peak power up to 400 mW. Secondly, the same FBG was submitted to the emission spectra of a 980-nm continuous wave pump laser diode with a maximum peak power of 500 mW.

Figure 2 shows the dependence of the central wavelength of the Bragg grating with pump power. The pump laser diode allow us to induce high power density inside the core of a single-mode fibre and consequently to achieve thermal switching due to the silica thermal expansion coefficient of  $10\text{--}11 \text{ pm}/^\circ\text{C}$  at  $1.5 \mu\text{m}$  [16]. The figure shows a different behaviour of the grating when different



**Figure 4** Measured dependency of the peak wavelength on the applied pumping power when a doped fibre is used. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com)]



**Figure 5** Measured reflection spectra with maximum pumping power (red line) and without (black line) of the FBG written in a doped fibre. [Color figure can be viewed in the online issue, which is available at [www.interscience.wiley.com](http://www.interscience.wiley.com)]

pump laser diodes were used. It can be seen that the central peak of the FBG is  $\sim 5$  times more sensitive to pump power for the pump wavelength at 1480 nm, near the third communication window, than for the 980-nm wavelength. This effect is a consequence of the strong absorption due to the presence of OH ions in the 1400 nm region.

Thirdly, the FBG was simultaneously excited by the two pump lasers, as showed in Figure 1. The variation of the spectral response is presented in Figure 3, which shows the results when the laser diode is off and when the total pump power is near 900 mW. The switching wavelength tuning range observed is  $\sim 120 \text{ pm}$ , corresponding to a variation in temperature of  $\sim 12^\circ\text{C}$ .

The functionality of the device presented in Figure 1 was also investigated when an FBG, with a central wavelength of 1551.49 nm, was written in an erbium doped fibre. The results are shown in Figure 4. The experimental procedure was similar to the one previously described. In this case it can be seen that the Bragg wavelength of the grating is  $\sim 6$  times more sensitive when the pump laser diode near the third communication window at 1480 nm is used in comparison with the 980 nm pump diode.

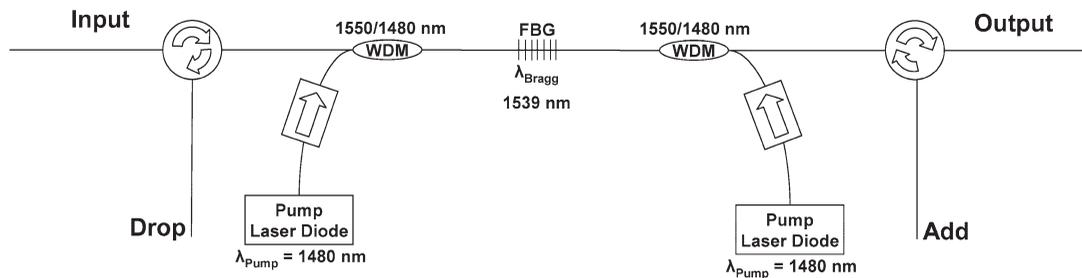
Figure 5 shows the results when the FBG is illuminated simultaneously by the two pump laser diodes (total pump power of 900 mW) versus the result when the two sources are off.

Another important topic is the switching time. It was observed in this experiment that the tuning speed depends mainly on the laser-diode time response.

It is also observed that, in the range of the pumping power used in the experiment, the wavelength changes linearly with power.

**TABLE 1** Optical Pump Power Required for Switching Between Adjacent Channels in Different WDM Systems

Channel Spacing [GHz]	Wavelength Spacing [nm]	Optical Pump Power at 1480 nm for Undoped Fibre [mW]	Optical Pump Power at 1480 nm for Doped Fibre [mW]
12.5	0.1	340	154
25	0.2	669	298
50	0.4	1328	586
100	0.8	2646	1163



**Figure 6** Architecture of an OADM with wavelength selectivity

Moreover, this type of wavelength switching, provided by the fibre-intrinsic absorption, turns the grating insensitive to the external low temperature fluctuations.

Another important topic in optical switching is the required optical power to switch between adjacent channels according to the ITU-T recommendation G.694.1. Table 1 shows the required optical pump power to perform all-optical switching in the different WDM systems, with the CW 1480-nm pump. Note that, when the grating is written in the doped fibre, the required pump power is more than two times lower than in the case of the FBG written in the undoped fibre. Structures based in Er-doped fibre gratings will be more viable and will achieve a higher dynamic tuning range.

One of the possible applications of the device based in the technology presented herein is an OADM with wavelength selectivity, shown in Figure 6. This is a classical optical add-drop multiplexer (OADM), but with switching-enhanced capabilities.

### 3. CONCLUSION

An all-optical switch has been proposed and demonstrated. The spectral characteristics of the architecture were presented.

The operation of the all-optical switch has been experimentally investigated and its performance evaluated. It was shown that the tuning range can be enhanced by using two pump laser diodes.

This all-optical switching technique, apart from finding a direct application in an OADM architecture, can also be integrated in different all-optical networking devices, such as optical cross connects, optical multiplexers and demultiplexers, and other types of wavelength routers.

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## PERFORMANCE EVALUATION OF A CWDM SYSTEM OPERATING IN THE O AND E BANDS OVER STANDARD FIBER

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**ABSTRACT:** We present an optimized coarse wavelength division multiplexing system with 16 channels operating at 2.5 Gb/s in the O- and E-bands with 10 nm of channel space. The system performance was evaluated by analyzing the directly modulated uncooled laser with low wavelength thermal drift in addition with standard fiber-wavelength dependence on attenuation and dispersion. © 2006 Wiley Periodicals, Inc. *Microwave Opt Technol Lett* 48: 1540–1544, 2006; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.21679

**Key words:** wavelength division multiplexing; metropolitan area networks; optical fiber dispersion; optical fiber losses

### 1. INTRODUCTION

The substantial growth of telecommunication broadband services has caused an expressive traffic increase, imposing to the metropolitan networks a demand for bandwidth increase. This environ-