LIQUID-CRYSTAL-BASED TUNABLE FILTER FOR WDM (λ=1550 nm)

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FOR WDM (λ=1550 nm)

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We report a new configuration of tunable optical filter for DWDM applications. In this design, first-order diffracted signal light by a grating is directed to a lens and focused on to a transmission-type liquid crystal spatial light modulator (LC_SLM). Wavelength channels are selected by opening the appropriate pixels of the LC-SLM for transmission. Filtering into 15 channels of the 1550 nm band is demonstrated in the initial experiment. The channels are designed according to the International Telecommunication Union (ITU) grid with channel spacing of 100 GHz. Channel crosstalk is less than −30 dB. The average 1 dB, 3 dB, and 30 dB passbands of the filter are 0.07 nm, 0.13 nm, and 0.91 nm, respectively. The extinction ratio can be as high as 24.7 dB.

1. INTRODUCTION

High-performance and cost-effective tunable optical filters are essential for the next generation of dynamic WDM systems and networks [1]. A number

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of designs have been implemented in the past, e.g., Fabry–Perot and Mach–Zehnder interferometers, Fiber Bragg Gratings, Acousto-optic as well as electro-optical tunable filters (AOTF and EOTF), and arrayed waveguide grating devices. Active filters based on laser structures operating below threshold are also attractive candidates.

In this work, we demonstrate a new configuration of tunable optical filter for applications in optical communication–systems of the 1550 nm band. A transmission-type liquid crystal spatial light modulator (LC_SLM) is used for channel selection. Wavelength channels are selected by opening the appropriate pixels of the LC-SLM for transmission. This device is also expected to be useful for other WDM applications, e.g., switching and routing.

2. BASIC PRINCIPLES AND EXPERIMENTAL METHODS

The basic principle of the present device is similar to that of many grating-based spectral filtering devices. A schematic of the device and the testing setup is shown in Figure 1. This is a modification of our previous external-cavity design for multi-frequency tunable lasers [2]. Signal light is either the broadband emission from an Erbium Doped Fiber Amplifier (C-band power booster, New Elite technology) or a tunable laser diode. It is collimated by a lens, sent through an optical isolator before incidence on a grating
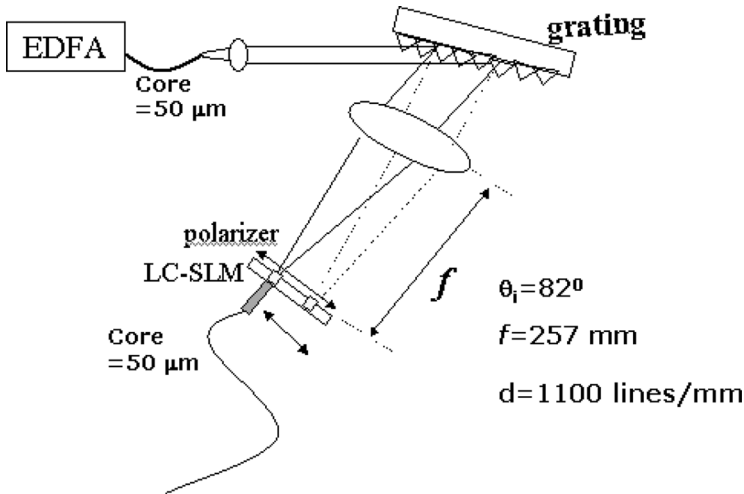

FIGURE 1 A schematic diagram of the experimental setup. LC-SLM: liquid crystal spatial light modulator; EDFA: Erbium-doped fiber amplifier.

(1100 lines/mm) at the grazing-incidence angle $\theta_i = 82°$). The first-order diffracted light is directed to a lens and focused onto a liquid crystal spatial light modulator (LC-SLM). The LC-SLM is basically a normally off-state twisted nematic liquid crystal (NLC) cell (See Fig. 2). The cell was constructed with a 6-μm-thick NLC (E7 manufactured by Merck) layer sandwiched between indium-tin-oxide (ITO) glass plates. One of the ITO-electrodes was patterned. The pattern consisted of fifty $100 \, \mu m \times 2 \, cm$ stripes with 5 μm spacing. Using the grating equation, one can readily show that the dispersion of the filter is given by

$$D_x = \frac{d\lambda}{dx} = a \cos\theta_m \bullet \frac{1}{f}, \tag{1}$$

where a is the grating period (1/1100 mm), $\theta_m (= 44°$ for $\lambda = 1532 \, nm$) is the diffraction angle and f(=257 mm) is the focal length of the lens. For pixels separated by Δx in mm, the wavelength separation Δλ (for the present experiment) is given by $\Delta\lambda/\Delta x = 2.547 \, nm/mm$.

Output of the filter is collected and analyzed by using an optical spectrum analyzer (Advantest Q8384 with a resolution of 0.01 nm). The authors presented demonstration of the design concept at 830 nm previously [3].

3. RESULTS AND DISCUSSIONS

In the first experiment, the channel spacing is designed to be 0.26 nm and the filtering bandwidth is 0.12 nm. Figure 3(a) is the output of the filter by turning on 10 neighboring channels in turn. For a channel with center wavelength of 1533.4 nm, we show the output spectrum with the pixel turned on and off, respectively (See Fig. 3(b)). The extinction ratio was 17.2 dB. Averaging over the 10 channels, the 1 dB, 3 dB and 20 dB passbands of the filter were 0.07, 0.13, and 0.52 nm, respectively. The channel cross-talk was less than −14.7 dB.

Using a tunable laser diode as the signal light, we demonstrate electronically tunable filtering operation of the device with 15 channels. This is shown in Figure 4(a). The nominal output wavelengths of the channels are precisely set according to the ITU (International Communication Union) grid with channel spacing of 100 GHz. It can be seen that a channel spacing of 0.79 nm, a 3 dB pass band of 0.12 nm and a 30 dB passband of 0.91 nm have been realized. The channel isolation is thus better than 30 dB. The average extinction ratio of the channels is 18.2 dB and can be as high as 24.7 dB. This is illustrated in Figure 4(b). The predicted wavelengths are also in good agreements with theoretical predictions (See Fig. 5).
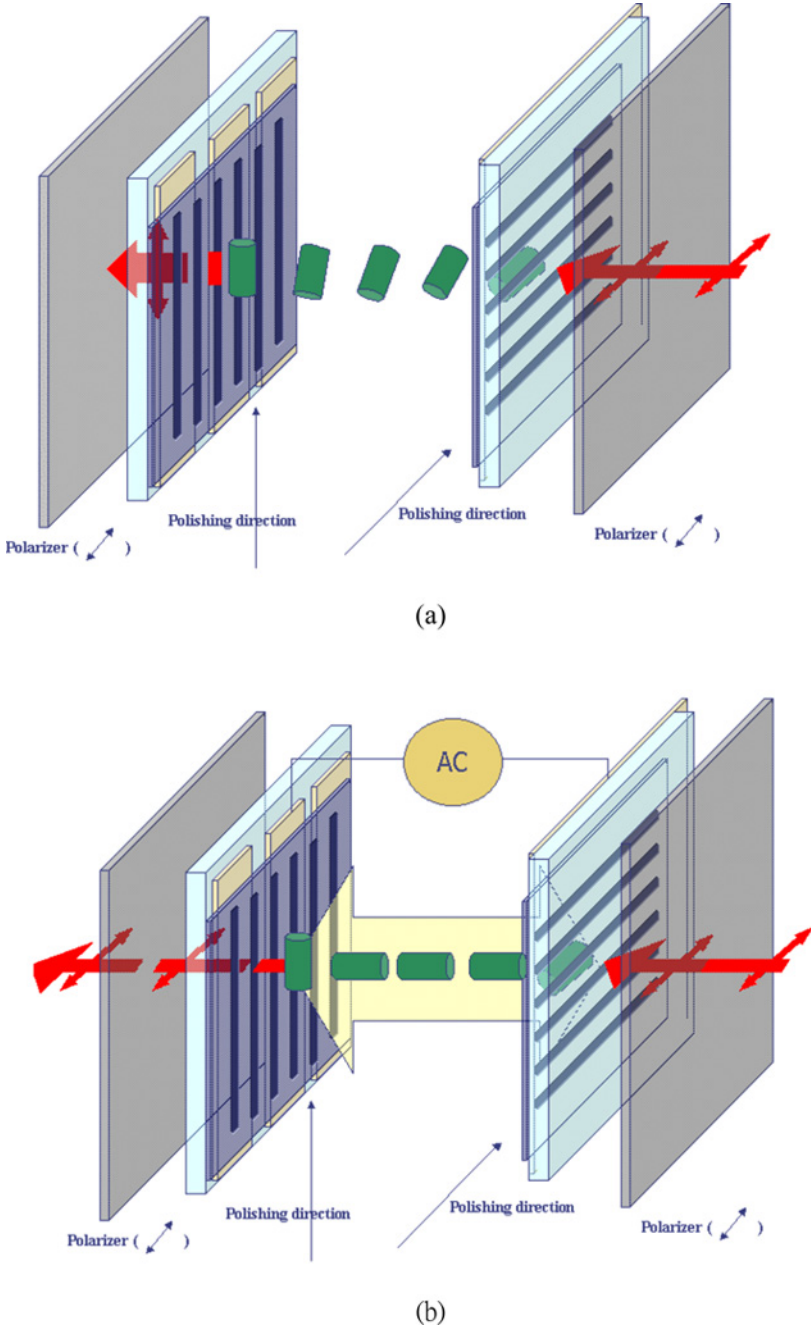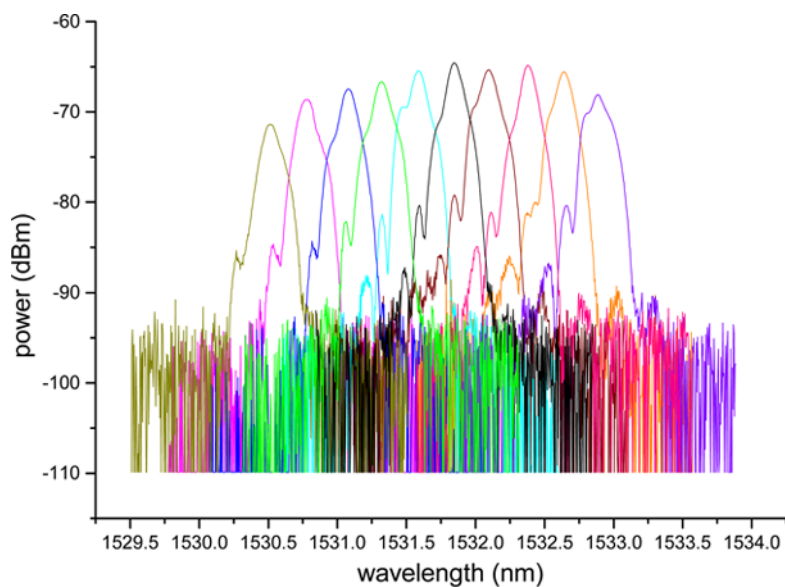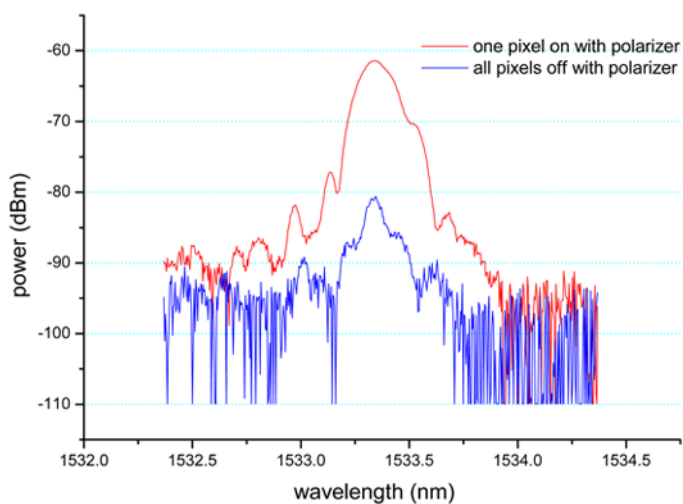
FIGURE 2 Configuration of the LC-SLM in the off-state (a) and on-state. (See COLOR PLATE XXXVII)

(a)

(b)

FIGURE 3 (a) Output of the filter for a succession of 10 channels. The input signal was a broad band EDFA. Extinction of a given channel can be observed in (b). (See COLOR PLATE XXXVIII)
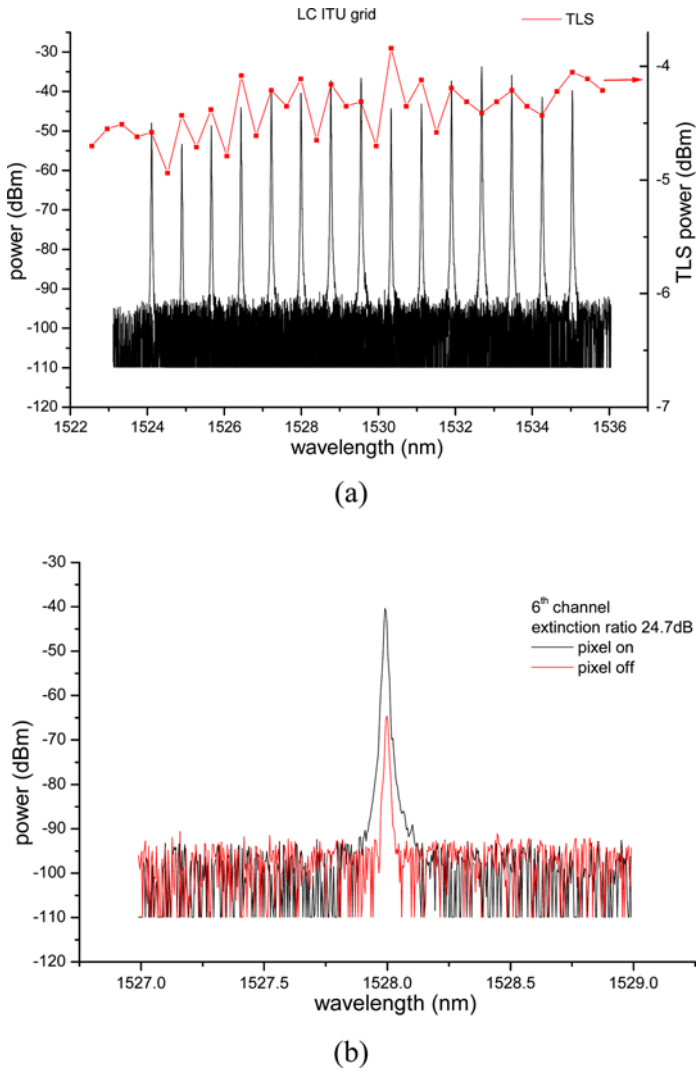
(a)

(b)

FIGURE 4 (a) Performance of the tunable filter channels according to the ITU grid with a channel spacing of 100 GHz. (b) Extinction of a particular channel. (See COLOR PLATE XXXIX)

The liquid crystal element allows additional functionalities for the present device: The channels can be switched on and off at a rate limited by the LC_SLM. To demonstrate, a 1 kHz biasing signal was applied to one of the pixels. Results are shown in Figure 6. The upper trace is the switching waveform. The lower trace is the filter output. The switch-on
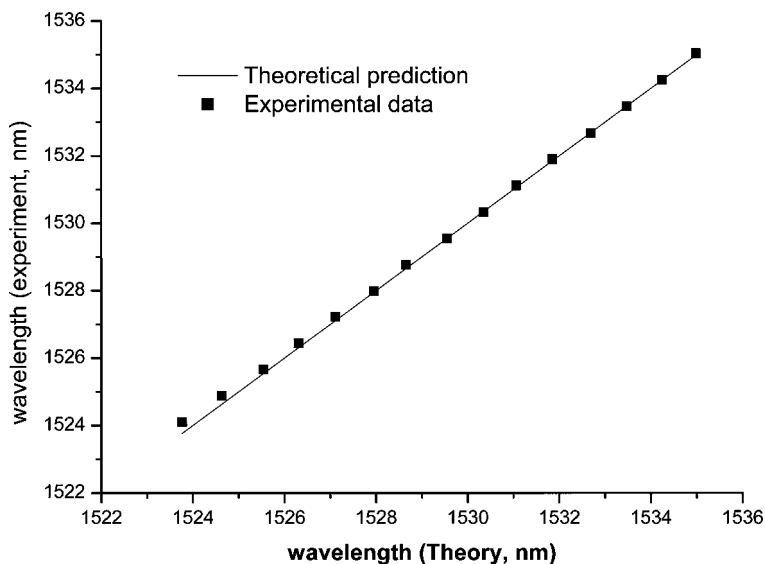
FIGURE 5 A comparison of the output wavelength of the channels and the theoretical prediction according to Eq. (1).

time, the time it takes for a pixel to change from an off state to an on state, is about 16 ms. The switch-off time is about 242 ms. This is primarily determined by the dynamic characteristics of the twisted NLC cell.
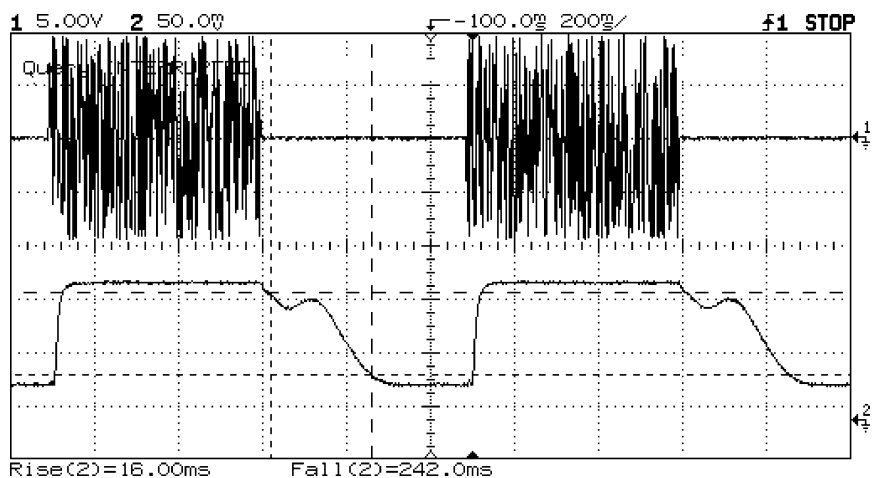

FIGURE 6 The channels of the filter can be switched on and off electronically. The upper trace is the switching waveform. The lower trace is the filter output.

4. CONCLUSIONS

We report a new configuration of tunable optical filter for DWDM applications. In this design, first-order diffracted signal light by a grating is directed to a lens and focused on to a transmission-type liquid crystal spatial light modulator (LC_SLM). Wavelength channels are selected by opening the appropriate pixels of the LC-SLM for transmission. The device is demonstrated by using EDFA and tunable laser diode as the signal light. With 100 micron-wide pixels separated by 5 microns in the LC-SLM and an 1100 lines/mm grating, we show selection of 15 channels with channel spacing of 0.79 nm (or 100 GHz) according to the ITU grid. The 3dB bandwidth is 0.13 nm. The channel isolation is better than 30 dB. This device is also expected to be useful for other DWDM applications, e.g., switching, demultiplexing, routing, and gain equalization.

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