# Liquid-crystal-based tunable optical filtering devices for DWDM

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## ABSTRACT

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 a broad-band AR-coated laser diode (lamda = 800 nm) as the signal light. For conceptual demonstration, we use optical fibers with a core diameter of 50 microns instead of the LC-SLM. A total of 37 channels, spanning 33.6 nm were successfully selected with channel spacing of 0.94 nm and bandwidth of 0.4 nm. With 100 micron-wide pixels separated by 5 microns in the LC-SLM and a 1800 lines/mm grating, we show selection of five channels with channel spacing of 0. 78 nm. The bandwidth is 0.43 nm. The channel isolation is better than 20 dB. At a wavelength of 1.5 micron, channel spacing as small as 12.4 GHz can be realized. This device is also expected to be useful for other DWDM applications, e.g., switching and routing.
**Keywords**: optical filter, switch, router, DWDM, liquid crystal, spatial light modulator

## INTRODUCTION

High-performance and cost-effective tunable optical filters are essential for the next generation of dynamic WDM systems and networks[1]. A number 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 report a new configuration of tunable optical filter for DWDM applications. A transmission-type liquid crystal spatial light modulator (LC_SLM) is 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 DWDM applications, e.g., switching and routing.

## 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 Fig. 1. This is a modification of our previous external-cavity design for multi-frequency tunable lasers[2]. Signal light is the broad-band emission from an AR-coated broad-area laser diode (LD, $\lambda$ = 830 nm). The laser is operated at 800 mA ($I_{th}$ = 570 mA) and 18 ± 0.01°. It is collimated with an objective lens (NA = 0. 47) and a cylindrical lens ( f = 20 cm), sent through an optical isolator before incidence on a grating (1800 l/mm) at the grazing-incidence angle. The first-order diffracted light is directed to a lens and focused on 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 μm × 2 cm stripes with 5 μm spacing. Using the grating equation, one can readily show that the dispersion of the filter is given by

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


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where a is the grating period (1/1800 mm), $\theta_m$ (= 30.7°) is the diffraction angle and f (= 25 cm) is the focal length of the lens. For pixels separated by $\Delta x$ in mm, the wavelength separation $\Delta\lambda$ (for the present experiment) is given by

$\Delta\lambda$ = 1.911 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).

## RESULTS AND DISCUSSIONS

For conceptual demonstration of the filter design, we first place a multi-mode optical fiber with a core diameter of 50 micron at the focal plane instead of the LC-SLM. The fiber was translated in 0.5 mm steps. A total of 37 channels were selected, spanning a spectrum of 33.6 nm. The channel spacing is 0. 94 nm and the filtering bandwidth is 0.4 nm. The result is shown in Fig. 3. A comparison of selected wavelength and theoretical prediction according to Eq. (1) is given in Fig. 4.

In our preliminary experiment using the LC-SLM in the filter, we sequentially select a set of five channels, separated by 3 pixels. The output of the filter for these five channels is shown in Fig. 5. It can be seen that a channel spacing of 0.78 nm, a pass band of 0.43 nm and channel isolation of 20 dB have been realized. The predicted wavelengths are also in good agreements with theoretical predictions (See Fig. 6).

In the channel-switching experiment, a 10kHz biasing signal was alternately applied to two pixels. These switching waveforms are shown as trace 1 and 3 of Fig. 7. A second grating was used to angularly disperse the output from the two channels, which were monitored by two photodiodes. These are shown as traces 2 and 4 in Fig. 7. Wavelength switching is clearly demonstrated. The switch-on time, the time it takes for a pixel to change from an off state to an on state, is ~ about 100 ms. This is primarily determined by the dynamic characteristics of the twisted NLC cell.

## 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 a broad-band AR-coated laser diode (lamda = 800 nm) as the signal light. For conceptual demonstration, we use optical fibers with a core diameter of 50 microns instead of the LC-SLM. A total of 37 channels, spanning 33.6 nm were successfully selected with channel spacing of 0.94 nm and bandwidth of 0.4 nm. With 100 micron-wide pixels separated by 5 microns in the LC-SLM and a 1800 lines/mm grating, we show selection of five channels with channel spacing of 0. 78 nm. The bandwidth is 0.43 nm. The channel isolation is better than 20 dB. At a wavelength of 1.5 micron, channel spacing as small as 12.4 GHz can be realized. This device is also expected to be useful for other DWDM applications, e.g., switching and routing.

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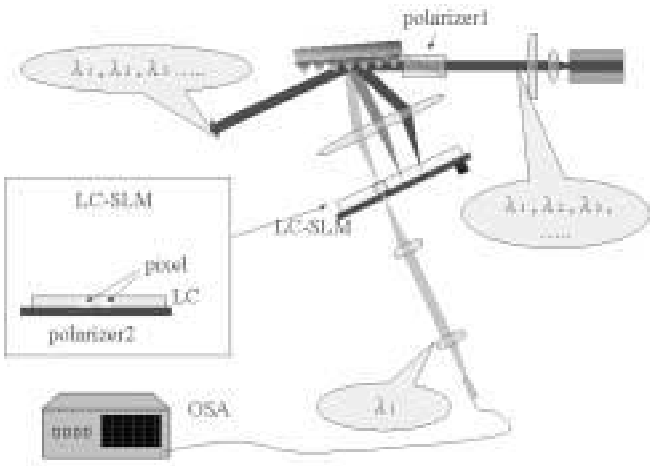
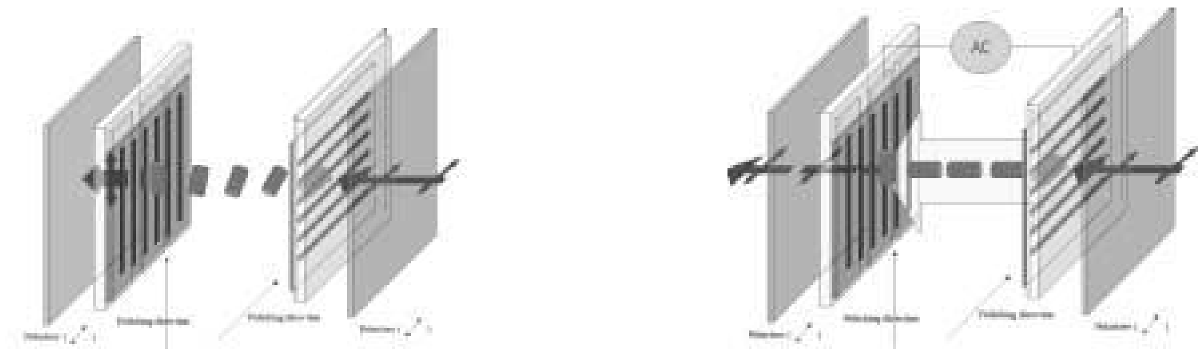
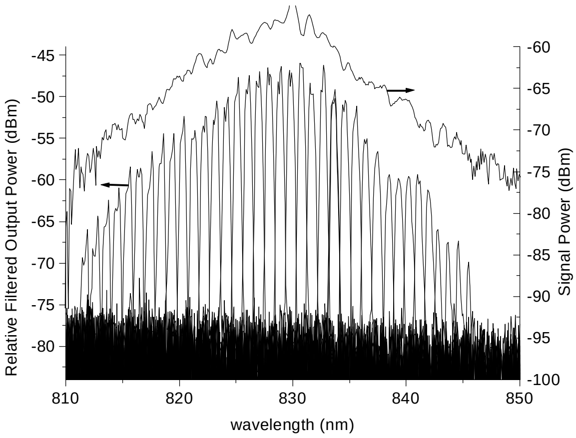


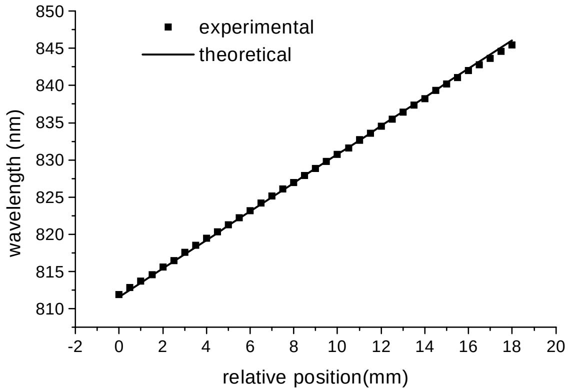

Fig. 1 A schematic diagram of the experimental Setup. LC-SLM: liquid crystal spatial light modulator; OSA: Optical Spectrum Analyzer.



(a) (b)

Fig. 2 Configuration of the LC-SLM in the off-state (a) and on-state.

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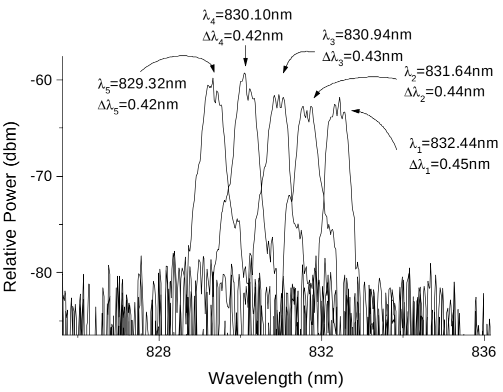
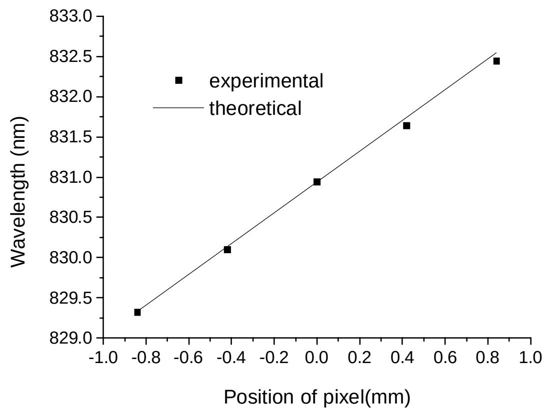
| Fig. 3 Filter performance with 50μm-core fiber for concept demonstration. Both the signal spectrum and spectrum of the filtered output are shown. | Fig. 4 Comparison of the wavelength of the channels with prediction according to Eq. (1). The squares are data points. The solid curve is the theoretical curve. |

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| Fig. 5 Selection of five channels by using the LC-SLM in the filter. | Fig. 6 Output wavelengths of the five channels are squares. The solid curve is theoretical prediction according to Eq. (1). |

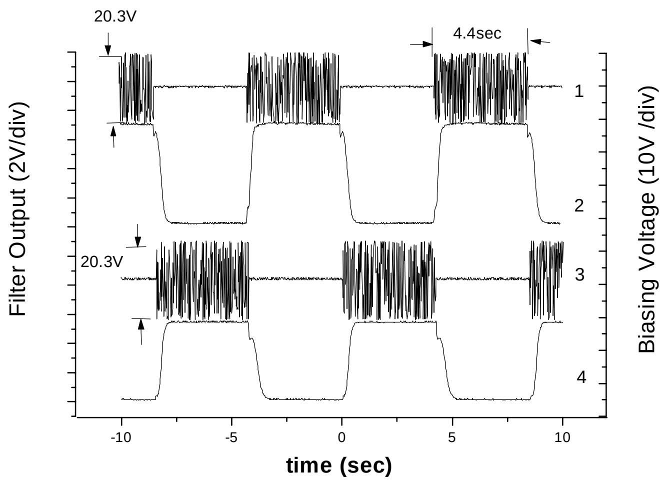


Fig. 7 A demonstration of channel switching capability of the filter. Traces 1 and 3 are the biasing voltage. Traces 2 and 4 are output of the two channels.