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Riza, Nabeel

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Ferroelectric Liquid Crystal Polarization Switching-based High Speed Multi-Wavelength Add/Drop Filters using Fiber and Array Waveguide Gratings

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A number of approaches have been used to implement programmable add/drop optical filters for wavelength division multiplexed (WDM) optical communications. These include integrated-optic (IO) acousto-optic tunable filters (AOTFs) [1], all-fiber mechanically tuned fiber Bragg grating (FBG) devices [2], IO grating switch with IO coupler devices [3], array waveguide grating (AWG) multiplexer with IO thermo-optic switches [4], FBG devices with magnetic field tuning [5], IO Bragg gratings with multi-mode interference couplers [6], NxN wavelength grating routers and 1xN mechanical switches [7], AWG multiplexer with manually simulated 2X2 switches [8], free-space diffraction gratings-based filter using a linear array twisted nematic liquid crystal device [9], IO electro-optically controlled synthesized grating structure based filter [10], and bulk dual AOTF-based structures [11]. It is highly desirable to have a short reconfiguration time (e.g., 10 μs), low optical crosstalk (e.g., - 40 dB), low drive power (e.g., tens of mWs), low loss (e.g., 5 dB), add-drop filter. In addition, a low cost modular and scaleable filter design that is easily modifiable and repairable is also desirable. So far, to the best of the author's knowledge, no one filter satisfies all the mentioned requirements. In this paper, we propose three filter architectures based on high speed ferroelectric liquid crystal (FLC) devices, that have the potential to meet the above requirements.

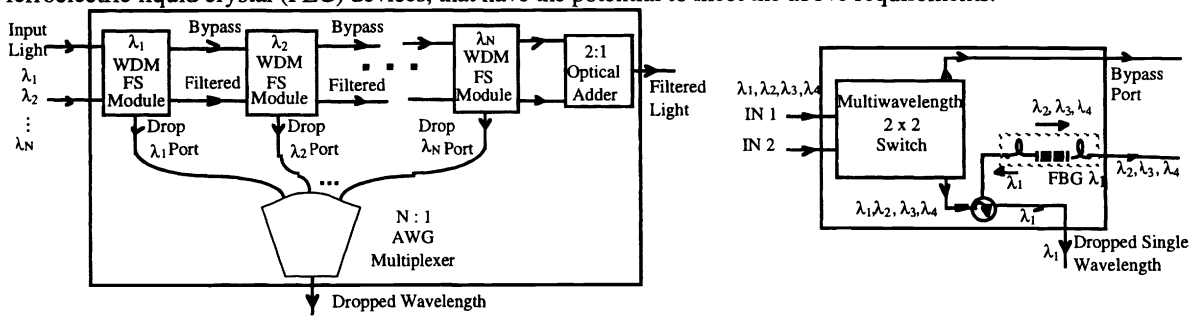


Fig.1 (a) Binary serial-format filter architecture using plug-in/plug-out type FBGs working in conjunction with several cascaded FLC-based single channel 2 X 2 optical switches; (b) An example of the WDM F-S Module used in (a). Note the specific wavelength FBG that is chosen to drop a single wavelength (shown for λ_1).

The first design (see Fig.1(a)) is a binary serial-format filter architecture using plug-in/plug-out type FBGs working in conjunction with several cascaded FLC-based single channel 2 X 2 optical switches. The attractive feature of this architecture is its flexibility as custom designed FBG elements can be readily inserted and removed (see Fig.1(b)) to change filter characteristics. In addition, the 2x2 switches can also be removed or added based on user needs. All interconnections are fiber-based using standard low loss (< 0.2 dB) fiber-optic connectors. As shown in Fig.1(b), note that each 2x2 switch in this cascaded design architecture must handle all the wavelengths simultaneously, and hence must have minimum wavelength dependent effects. As described later, FLC devices do indeed meet these broadband operation needs. The key limitation of the serial filter architecture is its higher losses due to cascading.

If filter requirements are known and expected to be hardwired, a preferable architecture involves first using a wavelength multiplexer to separate the wavelengths. Recently, an attractive 4 AWG-based architecture was proposed using an array of mechanically simulated 2x2 switches [8]. Later, this structure was implemented using slow millisecond response IO thermo-optic switches [4]. We propose the use of a compact bulk-optics based FLC switch array module with this 4 AWG architecture (see Fig.2), leading to much faster microsecond domain filter switching

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times and a much lower filter operational power consumption. To the best of our knowledge, no such proposal has been made using the compact FLC-based 2 X 2 switch design shown in Fig.3. Our switch features an easy to assemble planar and bulk-optics-based polarization independent design. The structure also uses passive polarization noise suppression via polarizers and noise rejection via output port cube polarization beam splitters (PBSs), to maintain high (e.g., > 35 dB) polarization extinction for the switched beams despite the fact that current FLC devices have limited (e.g., 20:1) extinction ratios [12].

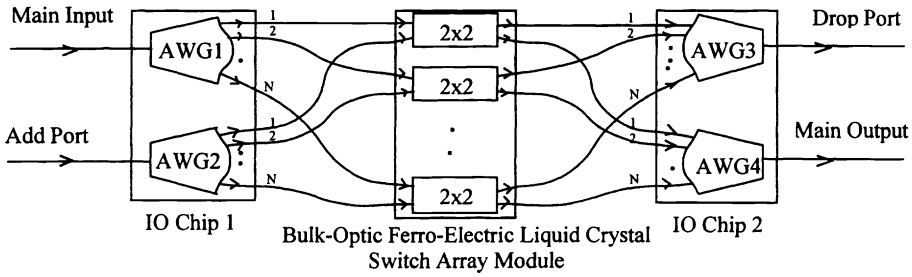


Fig.2. Parallel filter design using 4 AWGs and one bulk-optic FLC switch array-based compact switching fabric of N 2x2 switches.

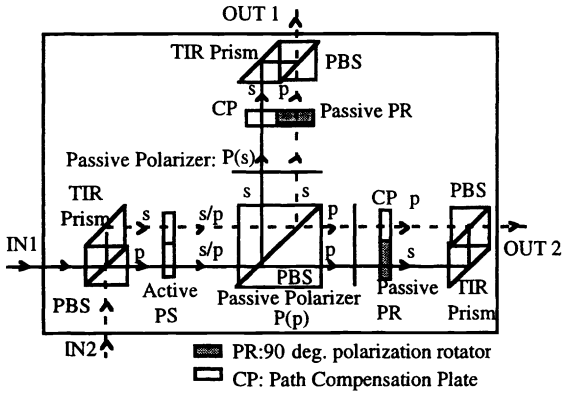


Fig.3. Our proposed FLC-based high speed 2x2 switch structure using passive polarization noise suppression and rejection. The active polarization switch (PS) is the 2-pixel FLC device for single beam operation as needed in Fig.1. For the Fig.2 design, PS is a 2-D 2N pixel device for a N-wavelength input beam. Light enters and leaves the switching fabric via fiber ports (not shown in the Figure). TIR: Total Internal Reflection.

As anti-reflection coated PBSs and TIR prisms operate well over the 1550 nm broadband optical spectrum, we theoretically analyzed this switch gain variation versus wavelength for a commercial FLC device. Following the basic half-wave plate theory described in our earlier work [13], the wavelength dependent retardation Γ is given by $\Gamma(\lambda) = \frac{2\pi}{\lambda} \cdot \Delta n \cdot d$, where d is the FLC device thickness calculated to give a retardation of π at the chosen center wavelength, and Δn is the birefringence of the chosen FLC material. For a typical commercial Displaytech FLC material, $\Delta n(\lambda) = 0.142 - \frac{40.1}{\lambda} + \frac{19692.5}{\lambda^2}$. As derived previously, the wavelength dependent retardation leads to an expression for the percentage optical power variation that is given by $\Delta I = 1 - \sin^2(\Gamma/2)$. This expression is normalized with reference to the device designed central wavelength that gives the optimum retardation of π required for perfect 90 degree polarization rotation.

The plot on the next page shows the wavelength dependent normalized optical power variation in dB for a FLC device (Displaytech Material) designed to act as a half wave retarder at a center wavelength of 1546 nm. The chosen optical spectrum is from 1532 nm to 1560 nm. Note that the retardation varies from 1.0084 π to 0.9917 π. This leads to a maximum deviation of ~0.85 % from the desired retardation of π obtained for the center wavelength. This is equivalent to a very small maximum -0.00076 dB optical gain variation, or a maximum -0.00152 dB modulated electrical signal loss. Hence, this design result concludes that FLC devices can be effectively used for WDM-band multi-wavelength optical polarization switching.

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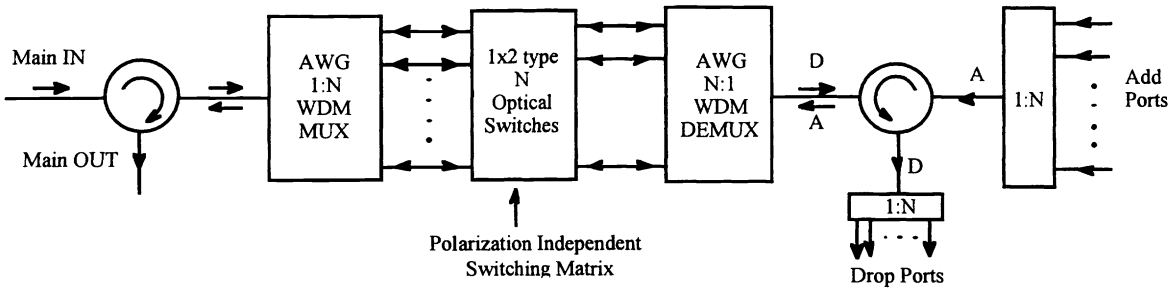


Fig. 4. Reflective add-drop architecture.

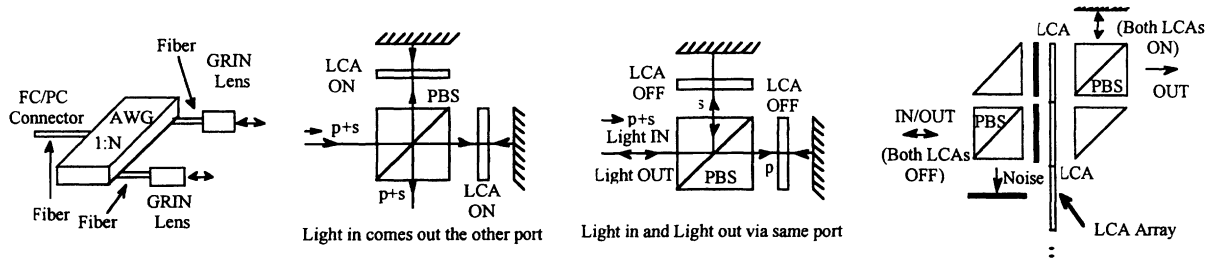


Fig. 5. (a) AWG free space-fiber coupling approach; (b) Novel polarization independent operation 1x2 optical switch, mode-1 and (c) mode-2; (d) Alternate 1x2 optical switch that uses polarization noise suppression. LCA: Liquid Crystal Array.

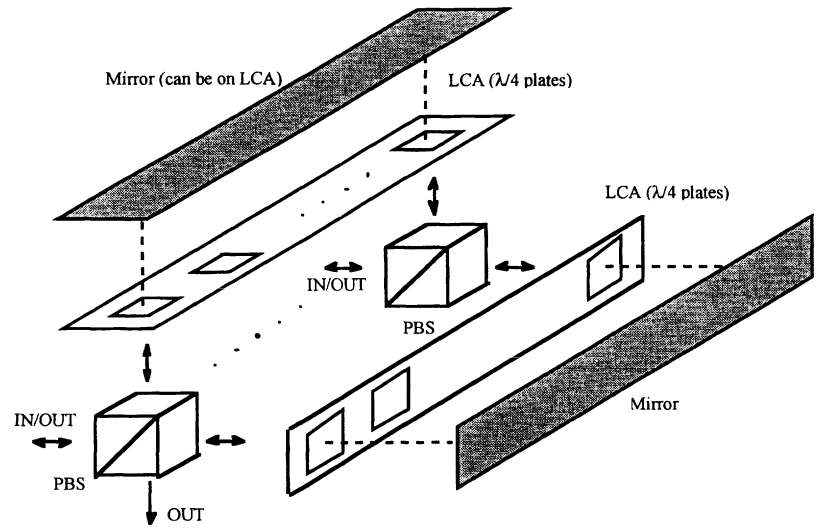


Fig.6. 3-D packaged view of filter in Fig.4.

Fig. 4 shows an alternate add-drop filter architecture that uses two optical circulators in a parallel control design (unlike Fig. 1). Unlike the filter in Fig.2, the Fig.4 design uses N 1x2-type optical switches. Fig.5 (a) shows how fiber and free-space optics can be merged with an AWG device. Fig.5 (b) and (c) show our proposed 1x2-type FLC device-based optical switch modes. This novel and simple switch design has a polarization independent operation with two mirrors placed in spatially orthogonal positions. Fig.6 shows a 3-D view of this filter indicating how

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compact low cost packaging can be implemented. Fig.5(d) shows an alternate 1x2 switch design that uses passive polarization noise filtering for improved switching isolation.

In conclusion, we have proposed three high speed add/drop filter designs based on FLC devices, although nematic devices can also be used. The serial filter design uses FBG elements as wavelength routers, where the 2x2 switches are arranged in a cascade and operate simultaneously on all the wavelengths. This filter design gives very high flexibility for changing filter characteristics via use of custom designed (e.g., chirped) FBGs. The second parallel design uses one compact FLC-based optical switching fabric connected with 4 AWGs, to give a lower loss filter at the cost of less flexibility. Finally, the third filter design uses a reflective architecture with circulators to form a compact 3-D design. All three options have their cost versus performance tradeoffs.

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