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Integrated Acoustooptical Devices in $LiNbO_3$

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Introduction

In recent years a variety of integrated acoustooptical devices in $LiNbO_3$ such as wavelength filters, wavelength-selective switches and add-drop multiplexers has been developed [1,2,3]. They offer attractive features, for instance broad tunability, transmission control via electronic means and the unique property of simultaneous operation at several wavelengths. Most applications of the devices are in the area of wavelength division multiplexed (WDM) communication systems. State-of-the-art devices have now reached a state of maturity that a commercial exploitation is in progress [4].

Basic Building Blocks

The acoustooptical polarization conversion is based on a collinear interaction between optical modes of orthogonal polarizations guided in stripe waveguides and surface acoustical waves (SAW). Phase-matching is required to achieve an efficient polarization conversion, i.e. the difference between the optical wave numbers must be compensated by the wave number of the SAW. This requirement leads to the wavelength selectivity of the conversion process. Via a tuning of the SAW frequency the converted optical wavelength can be adjusted. For wavelengths in the third communication window around λ=1.55 µm the SAW frequency for phase-matching is around 170 MHz with a tuning slope of about 8 nm/MHz.

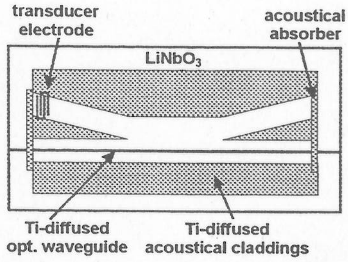

Fig. 1: Integrated acoustooptical polarization converter

Optical waveguides are fabricated using the mature Ti-indiffusion technology into X-cut, Y-propagating $LiNbO_3$. The dimensions of the guides must be chosen to yield single-mode guiding in TE and TM polarization within the whole tuning range of the converter.

The spectral response of the converter is approximately given by the Fourier transform of the strength of the acoustooptical coupling along the interaction length; details are presented in [5]. An appropriate tailoring of the spectral response ("passband engineering") can be obtained by using adequate acoustical distributions. To suppress sidelobes of the spectral responses a soft onset and cutoff of the coupling strength is required. This is typically achieved using acoustical directional couplers [6]. The optical waveguide is embedded in one arm of an acoustical directional coupler, which is realized via a Ti-indiffusion into the cladding regions of the guiding structure. The SAW is excited in the other arm and couples into the adjacent guide and back again.

Polarization splitters are applied to separate the TE and TM components of an incoming wave and route them to different optical waveguides. This can be obtained using passive optical directional couplers as shown in Fig. 2. With an appropriate design of the coupler it is possible to achieve splitting ratios of more than 20 dB for both polarizations.

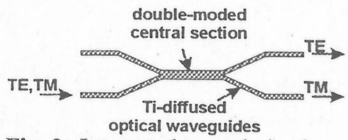

Fig. 2: Integrated polarization splitter

Device Family

A whole family of integrated acoustooptical devices can be realized using combinations of converters and splitters. A few examples are shown in Fig. 3. In this diagram symbolic representations of the converter (rectangle with an arrow indicating the SAW propagation direction) and the splitter (crossing) are chosen to simplify the drawing. An acoustooptical converter between two polarization splitters forms a single-stage wavelength filter. Polarization independent operation is achieved by applying the principle of polarization diversity, i.e. the two polarization components are converted separately and recombined by the rear polarization splitter. The device can be used either as band pass or as notch filter depending on which output waveguide is used. To improve the performance one can cascade two filters in series forming a double-stage wavelength filter.

A wavelength selective 2x2 switch is realized using two converters and two splitters. The device allows to switch each incoming wavelength channel independent of the switching state of the other channels. The acoustical waves in the two converters propagate in opposite directions in order to obtain for both polarization components the same frequency shift, which occurs due to the acoustooptical conversion.

The add-drop multiplexer consists of four converters and four splitters. Wavelength channels can be inserted and extracted from the transmission line. The device acts as a double-stage notch filter for the transmission line and the add- and the drop functions are spatially separated resulting in improved crosstalk performance.

Performance of Wavelength Filters

The performance of a double-stage tunable wavelength filter shall be discussed as one example to illustrate the potential of integrated acoustooptical devices.

Double-stage filters as shown in Fig. 4 have been developed [3]. The measured filter characteristics are also plotted in Fig. 4. A spectral bandwidth of 1.6 nm and a sidelobe suppression of more than 30 dB have been achieved. Fibre-to-fibre insertion loss could be kept below 4.2 dB with a polarization dependence below 0.1 dB. The tuning range of such devices exceeds the spectral range of typical WDM systems. The filter could be tuned from 1530 nm to 1570 nm without readjusting the drive power of about 100 mW for both stages together.

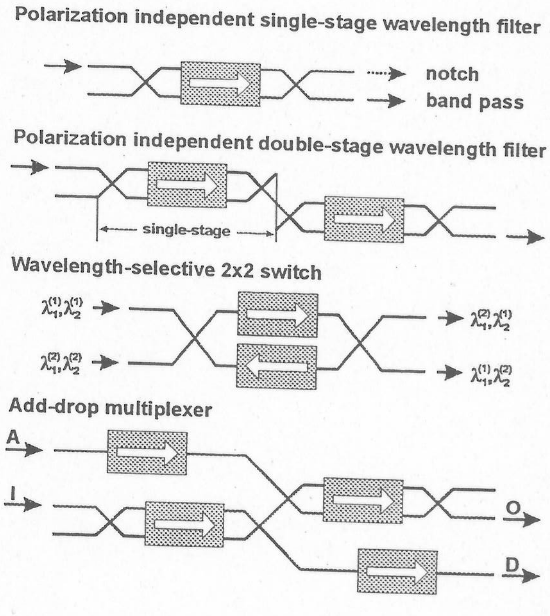

Fig. 3: Schematic drawing of some members of the aoustooptical device family.

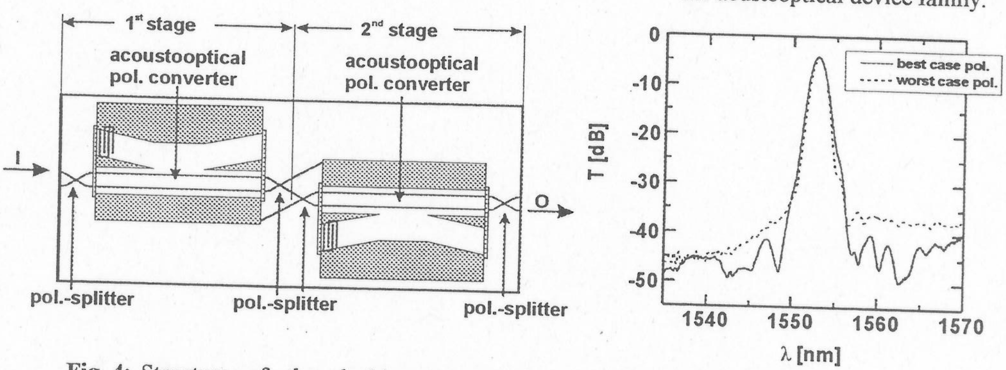

Fig. 4: Structure of the double-stage wavelength filter (left) and measured filter characteristics (right):

Conclusions

The development of integrated acoustooptical devices in $LiNbO_3$ has led to a variety of integrated circuits with several applications especially in WDM transmission systems.

Future challenges are a higher integration density, for instance to build monolithic 4x4 switches. Moreover, future demands for applications in dense WDM systems require tunable wavelength-selective devices with smaller bandwidth. Therefore, a narrowing of the spectral response must be a key challenge for future work.

References

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