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BROADLY TUNABLE INTEGRATED ACOUSTOOPTICAL POLARIZATION CONVERTERS IN LiNbO_3

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For the first time an integrated acoustooptical polarization converter has been developed which is tunable in the whole wavelength range from 1.3 μm to 1.6 μm. Strong sidelobe suppression (> 20 dB) and narrowband filtering (1.6 nm halfwidth at $\lambda = 1.3$ μm) has been demonstrated.

Introduction

Integrated optical devices in LiNbO_3 based on the collinear acoustooptical interaction of optical fields with surface acoustic waves (SAWs) have achieved remarkable attraction in the last years (see e.g. [1][2]). Acoustooptical polarization converters are the basic devices of more complex structures like tunable wavelength filters, add drop multiplexers and wavelength selective switches which have many applications especially in wavelength division multiplexing (WDM) transmission systems. As most WDM systems are operated in the spectral range from about 1.52 μm to 1.57 μm due to the corresponding gain bandwidth of erbium doped fiber amplifiers, integrated acoustooptical devices have been optimized for this spectral range. However, there is an increased interest in extending the wavelength range as WDM systems for broader wavelength ranges are currently discussed. Moreover, a broad tuning range allows further applications especially in optical instrumentation.

To extend the tuning range of acoustooptical polarization converters the single components of the device (optical waveguides, acoustical waveguides, transducer electrodes) have to be optimized. For the first time a systematic study of the wavelength and frequency dependencies of these components has been performed resulting in a broadening of the tuning range of the converter including the 1.3 μm and 1.55 μm communication windows.

Integrated Acoustooptical Converters

The basic structure of an integrated acoustooptical polarization converter is shown in Fig. 1. It consists of a Ti-indiffused optical waveguide which is embedded in one arm of an acoustical directional coupler. The SAW is excited via a transducer in the other arm and couples into the adjacent acoustical guide and back again.

The operational principle of the integrated polarization converters is based on a collinear acoustooptical interaction of a surface acoustic wave and TE and TM polarized optical waves guided in an optical stripe waveguide. Due to the interaction a complete polarization conversion TE→TM or TM→TE can be obtained, if phase-matching is adjusted, i.e. the difference of the optical wave numbers must be compensated by the wave number of the SAW. This phase-matching requirement makes the devices wavelength-selective. By varying the SAW-frequency the phase-match wavelength can be tuned. For optical wavelengths around $\lambda \approx 1.55$ μm the phase-match frequency is about 175 MHz. To achieve phase-matching in the 1.3 μm spectral range, the SAW frequency must be tuned to about 210 MHz.

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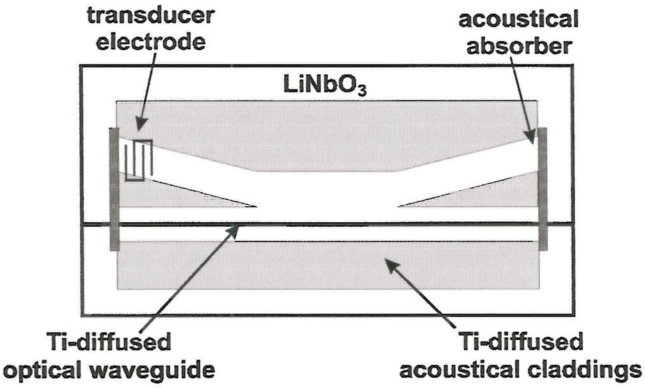

Fig. 1: Structure of the integrated acoustooptical polarization converter with an optical waveguide embedded in one arm of an acoustical directional coupler.

The guiding of SAWs in acoustical directional couplers has several advantages: The SAW remains localized in a small area of the substrate surface resulting in a high power density. Moreover, due to the soft onset and cutoff of the acoustooptical interaction strength in the directional coupler structure a weighted coupling scheme to suppress the sidelobes of the spectral conversion characteristic is achieved [3].

Fabrication

The devices have been fabricated on X-cut, Y-propagating $LiNbO_3$. First, the acoustical directional couplers were fabricated by a Ti-indiffusion (160 nm Ti, 24 h at 1060 °C) into the cladding region of the coupler. The coupler consists of 110 μm wide (undoped) acoustical waveguides. In the 6.9 mm long taper sections the gap between the two guides varies from 0 to 70 μm. The overall structure is 19.1 mm long. This coupler design is usually applied to get devices optimized for the 1550 nm range [3].

Optical waveguides were fabricated by a subsequent indiffusion of 7 μm wide, 100 nm thick Ti-stripes (9 h at 1060 °C). Typical losses measured at $\lambda = 1523$ nm are around 0.2 dB/cm for TE and 0.1 dB/cm for TM.

Finally, photolithographically structured finger electrodes acting as transducers to excite SAWs were fabricated by sputtering an about 500 nm thick Al-layer. The acoustical absorbers were formed either by using Scotch tape or UV-curing glue.

Acoustical Properties

SAWs are excited by applying an electrical rf-signal to the interdigital transducer. Most efficient SAW excitation over a broad frequency range was obtained using chirped transducers consisting of 10 finger pairs with a linear chirp of the periodicity ranging from 14 μm to 25 μm. To match the electrodes to the rf drive source with 50 Ω impedance a matching network consisting of an adjustable series capacitor and a parallel inductor (100 nH) was used. The measurement of the reflected electrical power (Fig. 2) revealed that over a broad frequency range from about 173 MHz to 215 MHz the electrical reflection could be kept below -5 dB.

The SAW intensity at constant rf drive power was measured as function of the frequency using a laser probing technique (Fig. 2) by measuring the diffraction efficiency of the surface corrugation grating induced by the SAW. The diffracted power of a laser beam focussed on the surface directly in front of the transducer was recorded. Maximum efficieny is obtained at 194 MHz. From 176 MHz to 211 MHz the efficiency is larger than -6 dB of the maximum efficiency.

The properties of the acoustical directional coupler were determined as well using the laser probing technique. Spatially resolved measurements were perfomed to analyze the

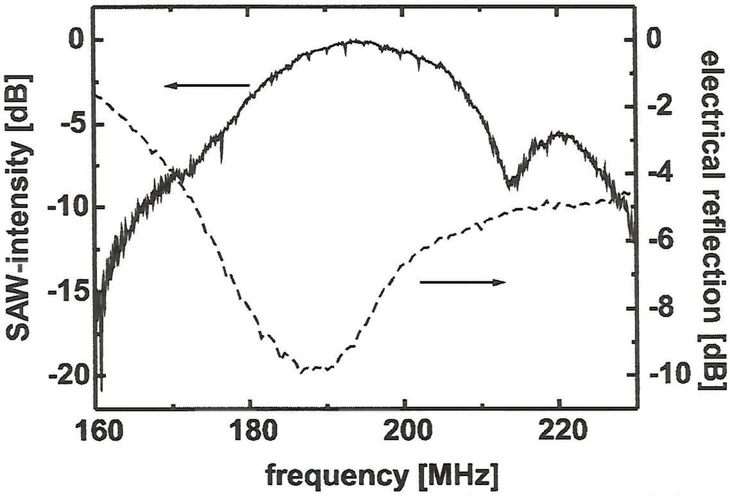

Fig. 2: Measured intensity of surface acoustic waves (at constant rf drive power) versus frequency using a chirped (14–25 μm) transducer with 10 finger pairs. Furthermore, the reflectivity of electrical power connected to the rf input port of the matching network of the transducer is shown.

SAW intensity distribution within the structure. Two results of such measurements are shown in Fig. 3. They were obtained at 211 MHz and 175 MHz acoustical frequency, respectively. One can clearly see that for both frequencies nearly a complete coupling cycle is fullfilled within the structure. No significant variation with the SAW frequency occurs in accordance with the theoretical modelling results.

Converter Performance

The conversion characteristics were measured using fixed optical wavelengths and varying the acoustical frequency. This is equivalent to the determination of the spectral characteristics by varying the optical wavelength at fixed acoustical frequency. External polarizers have been used to define the input polarization and to select the output polarization.

In Fig. 4 two measured conversion curves are shown. They were obtained using a fixed optical wavelength of 1310 nm and 1552 nm, respectively. The conversion characteristics at $\lambda = 1552$ nm shows an excellent sidelobe suppression of more than 20 dB. The spectral

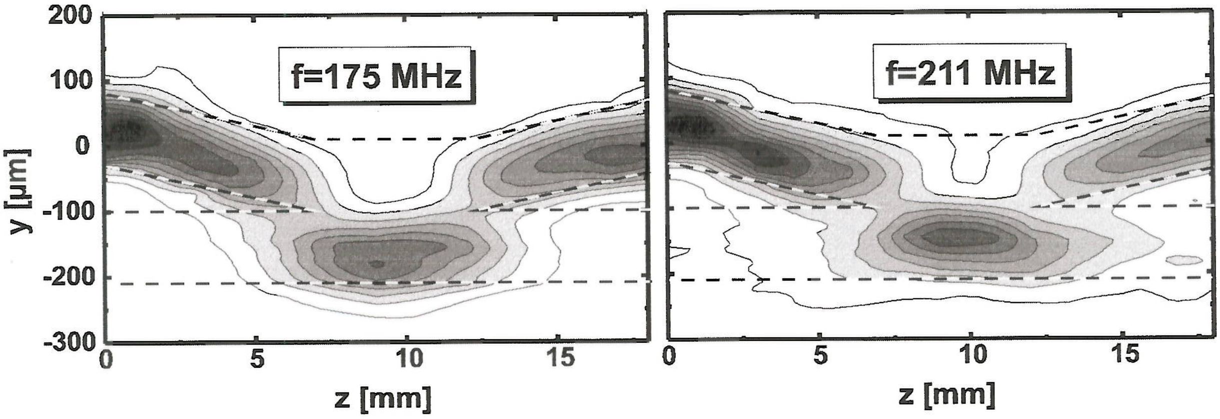

Fig. 3: Measured intensity distributions of the surface acoustic wave in the acoustical directional coupler structure for SAWs of 211 MHz (upper diagram) and 175 MHz (lower diagram) acoustical frequency, respectively. The dashed lines indicate the borders of the acoustical waveguides. The contour lines correspond to intensity levels of 10 %, 20 %,..., 90 %.

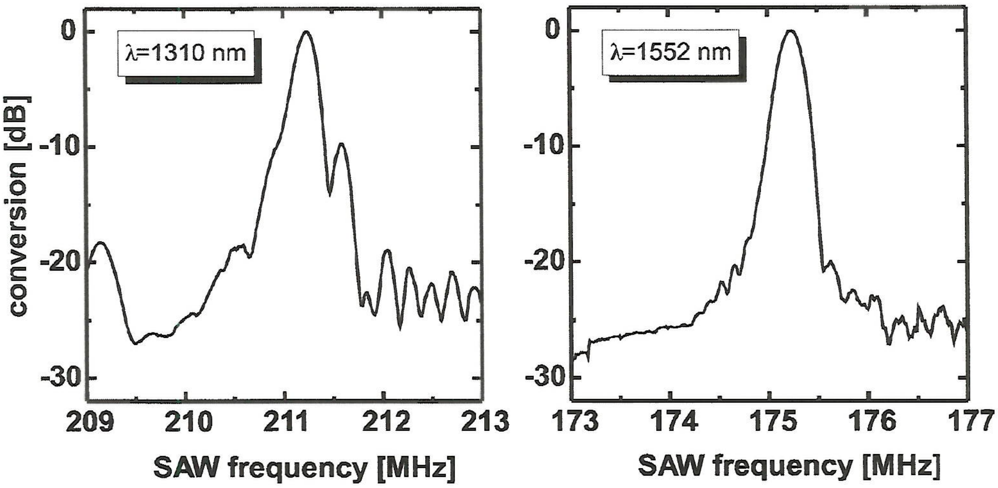

Fig. 4: Measured conversion characteristics of the integrated acoustooptical polarization converter as function of the SAW frequency at a fixed optical wavelength of $\lambda = 1310$ nm (left) and $\lambda = 1552$ nm (right), respectively.

width, i.e. the full width of the conversion curve at half maximum, is 250 kHz corresponding to an optical spectral width of 2.1 nm. At $\lambda = 1310$ nm the conversion curve shows only one pronounced sidelobe of about -10 dB. The half width is 260 kHz (1.6 nm). The electrical drive powers to obtain complete polarization conversions are 190 mW and 218 mW for $\lambda = 1310$ nm and $\lambda = 1552$ nm, respectively. By increasing the wavelength to 1580 nm an increase of the required power to 470 mW is necessary. According to the frequency dependence of the excitation efficiency of SAWs (Fig. 2) the drive power should have a minimum (around 50 mW) for optical wavelengths around $\lambda \approx 1400$ nm. Unfortunately, no optical source was available to experimentally confirm these data.

Conclusions

Integrated acoustooptical polarization converters optimized for a broad tuning range have been developed. Excitation efficiencies for surface acoustic waves and the performance of acoustical directional couplers have been optimized. For the first time a converter with strong sidelobe suppression (> 20 dB) was realized capable to cover the wavelength range from about 1.3 μm to 1.6 μm. Together with integrated polarization splitters – which have to be optimized for broadband operation, too – a series of broadband integrated acoustooptical devices can be realized. Most of them are double-stage devices leading to strongly improved spectral characteristics [4]. These devices will be used in WDM systems and optical instrumentations.

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