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A VERY COMPACT InP-BASED INTEGRATED OPTIC MACH-ZEHNDER INTERFEROMETER WITH A DELAY DIFFERENCE OF 74 ps

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Abstract

A Mach-Zehnder interferometer with 6.0 mm arm length difference was realised on InP. The design is very compact, using deeply etched waveguides and circular bends with 50 μm radius. The devices show a sinusoidal frequency response with 13.5 GHz period and extinction ratios up to 20 dB.

Introduction

Mach-Zehnder interferometers (MZI) have many applications in optical systems. They can be used as phase-to-amplitude converters (in sensors, modulators, switches [1] and wavelength converters [2]) or as building blocks of optical filters. An example of the latter is a dispersion compensation circuit [3] consisting of a series of MZI-devices. Another example is to modify the modulation or noise content of an optical signal by the optical filter [4]. A Mach-Zehnder interferometer with a propagation delay difference $\Delta\tau$ between both arms will allow to cancel the frequency component around $1/2\Delta\tau$ in the modulation or noise spectrum. If this frequency is chosen around the resonance frequency of a laser diode it is able to flatten the frequency response or reduce the RIN-spectrum considerably.

Integration of MZI-structures makes the fabrication of reliable components with a very precise arm length difference and well controlled amplitude balance between both arms possible. A problem is that some of the applications mentioned above require devices with a relatively large arm length difference (millimetre to centimetre level) which would normally lead to an impractical large chip area. The use of deeply etched waveguides in InP allows to make curved waveguides with very small bend radii of the order of 50 μm [5]. Furthermore, for a given delay time difference the arm length difference is reduced by a factor equal to the high refractive index of this material. We have therefore used InP-technology to produce a Mach-Zehnder interferometer with an arm length difference of 6.0 mm, which corresponds with a frequency response with 13.5 GHz period. One possible application of this device is the suppression of the RIN-spectrum of a laser diode around 6.75 GHz.

Design

The waveguide is made of InP cladding layers and a quaternary InGaAsP 1.3 µm guiding layer. The cross section is schematically given in Fig. 1. It consists of a ridge which is completely etched through the quaternary layer, thereby achieving maximum lateral index contrast. This provides a large tolerance for the etch rate. The MZI structure is shown on Fig. 2. It consists of the following waveguide components: multimode interference (MMI) couplers, circular bends, tapers, controlled loss structures and of course straight waveguides. The waveguide width is 1.3 µm in the bended regions and 3.0 µm for the straight waveguides. In the bends a small width has been chosen in order to obtain a reasonably symmetrical field profile which can be efficiently coupled to a monomode straight waveguide. As the propagation loss of these waveguides is high (7 dB/cm), 3 µm wide waveguides have been applied (0.6 dB/cm propagation loss [5]) in all parts of the structure where the narrow waveguides are not necessary. The coupling between the two different guides is achieved by a linear taper of 50 µm length.

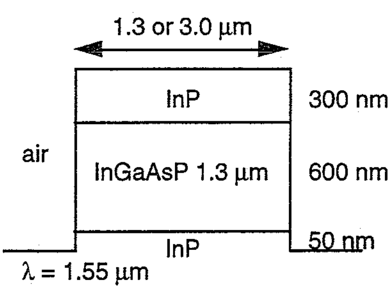

Figure 1: Waveguide cross section.

Light is launched in the access waveguides (see Fig. 2) with a nominal width of 3.0 µm. A 50/50 power splitting ratio is obtained by a *MMI coupler*. The length equals 281 µm and the nominal width is 8.0 µm. Since the performance of the MMI coupler depends critically on its width and the tolerance of the processing steps is a few tenths of microns, five different widths ranging from 7.6 µm to 8.4 µm in steps of 0.2 µm were defined on the mask. The main advantage of a MMI coupler compared to other couplers (like Y junctions or directional couplers) is the compactness of the device and the less critical tolerance in the etching process. Furthermore, since the performance of the device for a given width is not critically dependent on its length, it is easy to obtain the desired power splitting ratio.

After the MMI section, the light enters the two arms of the asymmetric Mach-Zehnder interferometer. The longer arm consists of a folded waveguide (see Fig. 2) introducing a geometrical path difference ΔL of 6.0 mm. The total device measures about 150 µm x 4 mm. The path difference leads to time delay τ of

$$\tau = \frac{n_{eff,group}\Delta L}{c} = 74 \text{ ps}$$

where $n_{eff,group}$ is the effective group index of the waveguide mode (estimated to be 3.69) and c is the speed of light in vacuum. This gives a frequency response period of $\nu_m = 13.5$ GHz. The loop *bends* are circular arcs with a radius of 50 µm and the longest bends span an angle of 181.85°.

The shorter arm of the interferometer is provided with an extra *controlled loss structure* to compensate for the additional propagation losses of the longer arm. The loss structure consists of a wide waveguide region of 10 µm width in which the beam expands due to diffraction. We aimed at an additional loss of 1 dB and 2 dB, corresponding with lengths of 12.35 µm and 18.81 µm (as calculated by FD-BPM). A structure with no excess loss, where the straight waveguide is continued, was also included.

The light of both arms is finally recombined in a second MMI coupler and launched in the output waveguides.

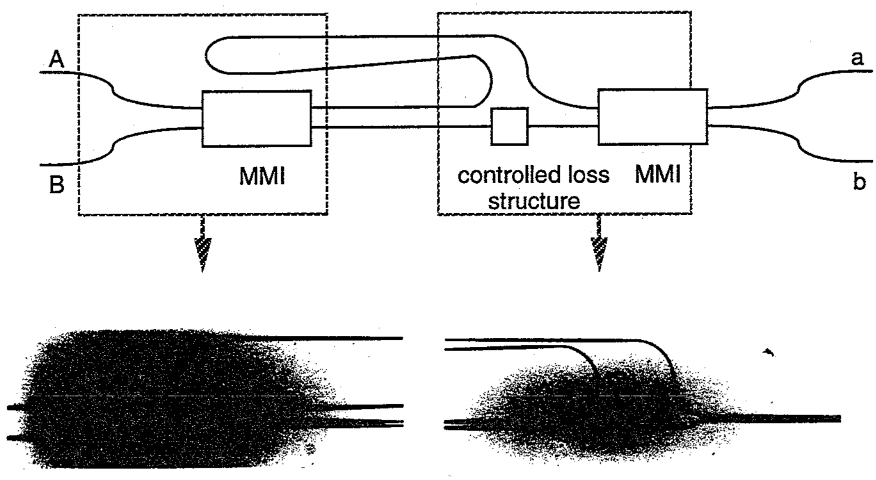

Figure 2: Schematic view of the asymmetric Mach-Zehnder interferometer (upper figure, not on scale) and details of the input and output parts of the interferometer, showing the circular bends, the MMI couplers and a controlled loss structure (down right) of 18.8 μm long.

Fabrication

The devices were made on a SI-InP substrate with MOCVD grown undoped epilayers [6]: 600 nm InGaAsP (λ_g = 1.3 μm) and 300 nm InP. The devices were patterned with a 140 nm thick RF-sputtered SiO_2 masking layer. 950 nm high ridges were etched with an optimised CH_4/H_2 RIE etching/descumming process [7].

Experimental results

The Mach-Zehnder structures are measured by coupling light from a tuneable 1.55 μm laser into each of the input arms and monitoring the output power in each of the output arms. Measurements were done both for TE and TM polarised light at the input. Because the Mach-Zehnder structure exhibits a small amount of polarisation conversion in the long arm a polariser was needed at the output to observe the interference pattern properly.

Fig. 3 shows a typical result for a MZI structure with a controlled loss structure of 12.35 μm length and a MMI width of 8.0 μm. The figure shows the transmitted power from each input to each output as a function of wavelength between 1550.000 nm and 1550.150 nm. The interference pattern has a period of 13.5 GHz and an extinction ratio of about 10 dB. The rippled deviation from a sinusoidal response is due to Fabry-Perot resonances between the end facets of the chip and can be easily avoided by anti-reflection coating. The best results were obtained for an MMI width of 8.0 μm which is the nominal design value. The best extinction ratio (but also the strongest Fabry-Perot ripple) was obtained for the Mach-Zehnder structure with no controlled loss structure, where it was 20 dB. This indicates that the long interferometer arm with the sharp bends has a very low loss.

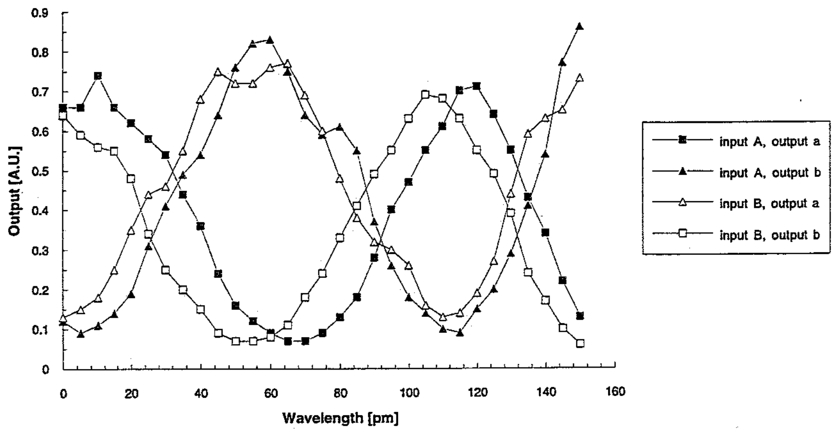

Figure 3: Transmitted power from each input to each output as a function of wavelength (relative to 1550 nm). The notations A, B and a, b, labelling the input and output ports are defined in Fig. 2.

Conclusion

An integrated Mach-Zehnder interferometer with large arm length difference and sharp bends has been designed and realised in InP. The devices show a good extinction ratio indicating low losses in the folded long branch. The device can be used for cancelling the laser intensity noise around 6.75 GHz.

Acknowledgements

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