Integrated polarization filter for 1550 nm based on a narrow waveguide section

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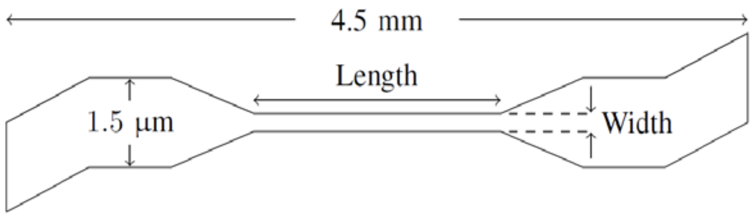
The polarization filter that is presented in this publication is based on a narrow deep etched waveguide. The measured suppression of the TE mode is 20 dB. The achieved bandwidth is larger than 130nm (limited by the setup). The filter width for an operating range around 1550 nm is 0.5 µm.

Introduction

Photonic integrated circuits (PICs) combine fundamental photonic functionalities such as generating, modulating, filtering and detecting light on a single chip. This gives the opportunity to replace complex bulky systems by a space and energy efficient PIC. The level of integration represented by the amount of components on a single chip shows an exponential increase over time. An analogy to Moore's Law in microelectronics is clearly visible [1].
The advantage of PICs based on InP is the direct bandgap material system, which offers efficient light sources for the 1.1 - 1.6 µm wavelength range [2]. Optical communication is one of the biggest application areas of PICs. The continuous growth of internet traffic requires steady development to enable high bandwidth. One solution uses the polarization of the light. To increase the bandwidth two polarization states are used. Therefore it is necessary to accurately define the different polarizations in the transmitter and receiver on chip. In this publication we present a polarization filter based on a narrow waveguide section that can provide this accurate polarization definition.

Design

The polarization filter is designed for a photonic integrated circuit (PIC). The design consists of a narrow waveguide section, further called filter, with a certain width and length. It is embedded in a standard deep etched waveguide. To connect this section to standard waveguides lateral adiabatic tapers are used. In the left part of Figure 1 a schematic top view of the polarization filter is presented, in the right part the cross section of the standard waveguide is presented. The input and output facets of the standard waveguides are angled to reduce reflection.



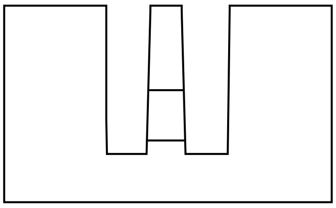


Figure 1: (left) Schematic top view of the polarization filter with a narrow waveguide section; (right) cross section of standard deep etched waveguide

The concept uses the difference of the effective index for the two linear polarizations. For the following, the propagation direction of the light is along the z- axis and the normal to the chip corresponds to the y-axis. TE polarized light oscillates in the x-z plane and its effective index depends stronger on the width of the waveguide than for the TM light [3]. For a certain width the fundamental mode of the TE polarized light is not guided anymore. This width depends on the wavelength. This condition implies that the effective index of the mode falls below the refractive index of the substrate. By reducing the waveguide width further (or by increasing the wavelength) the fundamental mode of the TM polarized light will not be guided either. In Figure 2 an example is given which shows the expected transmission behavior depending on the wavelength for a fixed filter section width.

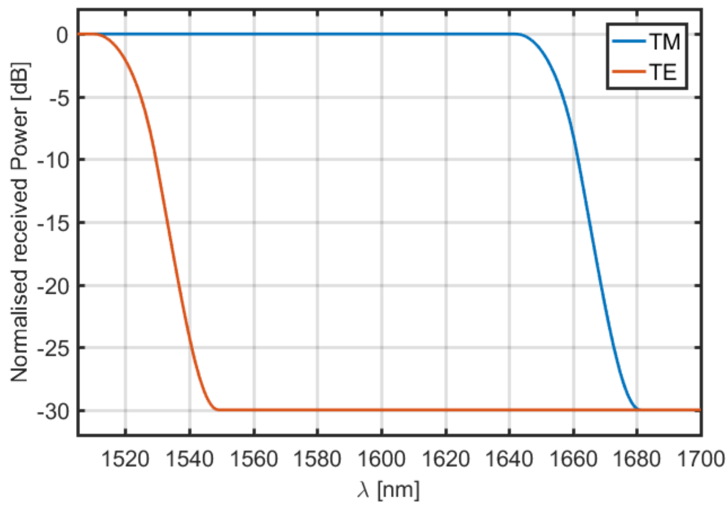


Figure 2: Expected transmission through the integrated polarization filter of TM and TE polarized fundamental modes.

A simulation of different filter section widths was done with a commercial mode solver [4]. A narrower filter section leads to a lower cut off wavelength. This affects both the TE and the TM cut off wavelengths. Therefore the filter width can be chosen to calibrate the filter to the correct wavelength regime. We targeted an operation around 1550 nm. Therefore we fabricated filter with 0.45 µm and 0.55 µm filter section width. The length of the filter section defines the extinction ratio between the two polarizations.

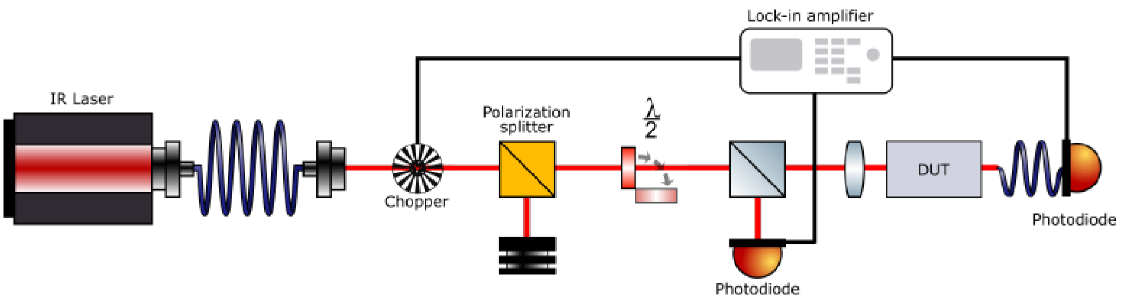


Figure 3: Schematic measurement setup.

A longer filter leads to a higher extinction ratio. The extinction ratio is determined by the presence of the non-guided modes. These are excited at the cut-off width in the taper and can couple back into the waveguide at the second taper if the length is too short
The fabrication of the chips was done in TU/e Nanolab using an ASML PAS5500 /1100B scanner to do the lithography. The scanner achieves a high accuracy in transferring the mask pattern to the wafer.

Measurements

The characterization of the chips was performed with a free space setup. In figure 3 a schematic drawing of this setup is presented. A tunable laser was used as an input signal. The light passed a chopper and a polarization splitter. One output of the polarization splitter was used to couple into the chip via a lens system. To verify the exact input power a 50:50 splitter was used to measure a reference value. The output of the chip was coupled via a fiber into a second photodiode. To switch the polarization of the light between TE and TM a half-wave plate was used.
In figure 4 the measured transmission of a 0.55 µm wide polarization filter with a 750 µm long narrow waveguide section is presented. The cut-off wavelength for the TE mode is 1540 nm and for the TM mode it is outside of the measurement range. The suppression of the TE mode is more than 20 dB. A higher suppression ratio couldn't be measured due to limitations of the setup.

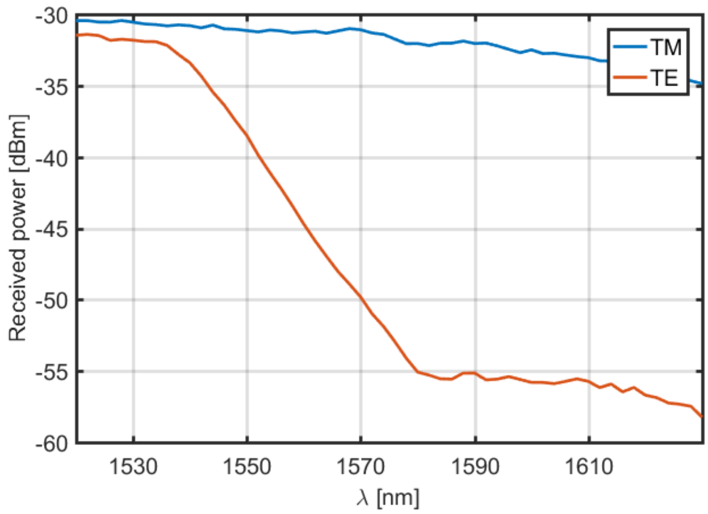


Figure 4: Measured transmission through the integrated polarization filter of TM and TE polarized fundamental modes.

We also measured a 0.45 µm wide filter with the same length. For this case we could see the TM cut off, but not the TE. The bandwidth of the filter was shifted to lower wavelength which confirms the simulation results. It showed more than 20 dB suppression over a bandwidth of more than 130 nm.
Based on both results we conclude that the filter will work over a bandwidth of 300 nm. It wasn't possible to measure the full bandwidth based on the limitation of the laser source.
Another important aspect that we analyzed is the length of the filter section. In theory this length defines the suppression ration. To analyze this effect we measured different filter section length. Up to 450 µm a lower extinction ratio was obtained. For lengths above

450 µm the extinction ratio was limited to the maximum extinction ratio defined by the setup.
Additionally we measured structures with 0 µm length, which include only the taper structures. The waveguide is tapered down to the aimed width and directly tapered back to the standard waveguide with. Comparing with standard waveguide transmission measurements it was possible to define the insertion losses to be 5 dB.

Discussion

The narrow waveguide filter can be realized with a simple waveguide definition step. It offers an extinction ratio greater 20 dB. The simulation promises an extinction ratio beyond the 40 dB, which couldn't be proven based on a limited measurement setup. Comparison with other state of the art polarization devices [5] show that the performance of this device is competing especially regarding its bandwidth of 300 nm. The insertion loss is 5 dB. This value can be improved by reducing sidewall roughness in the narrow waveguide parts.
The limitation of the filter is that it only works for one polarization. In theory it is possible to use the same concept and reduce the height of the waveguide. This would cut off TM at lower wavelength and waveguide width. Therefore both polarizations can be filtered, each with a specific design. For a TM-filter a vertical taper would then be needed, instead of a lateral one

Conclusion

In this publication we presented a simple concept to realize a polarization filter for the TE polarized light by reducing the waveguide width. The reported extinction is 20 dB which is limited by the measurement system. From the two measured polarization filters we can infer that the optical bandwidth is 300 nm, making it suitable for the combined O, S, C and L- bands.

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