An InP based generic integration platform for Photonic Integrated Circuits operating up to 2 μm wavelength

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We are developing a generic integration platform for Photonic Integrated Circuits with a target wavelength of 2 μm. The platform is based on the platform process for 1.55 μm which supports monolithic integration of a wide range of passive and active components as amplifiers, modulators and detectors. In this paper we discuss the extension to longer wavelengths and its impact on the performance of the passive components, supported by initial characterization results of the waveguide loss and an Arrayed Waveguide Grating in a wavelength window from 1.88 to 2 μm.

Introduction

Generic integration platforms offer a set of standardized components, which can be integrated monolithically to obtain the functionality for a broad range of applications. With this approach, which is conceptually similar to the CMOS process in electronics, a variety of integrated circuits have been demonstrated [1,2].
Driven by the needs of telecommunication applications, a platform with a range of capabilities has been established in the wavelength region of 1550 nm. An extension of the supported wavelength range will allow for new applications. Wavelengths around 2000 nm are especially interesting for medical and sensing applications. These comparatively long wavelengths, allow for efficient evanescent field sensors, gas sensors or low-cost OCT systems [3].
Technologically the extension of the platform requires only a few modifications. Our active-passive integration scheme used for the 1550 nm window [1,2], can easily be adapted for the desired wavelength region [4]. By keeping the passive waveguide section the same, the necessary platform adaptations are restricted to redesign and characterization on the basic component level. The fabrication processes can be maintained and we obtain a low-cost platform, allowing a wide range of applications.
In this paper we will evaluate the performance of the passive waveguide section, for wavelengths up to 2000 nm. We discuss the wavelength dependent propagation loss and compare the results to measurements obtained with the Fabry-Perot Method from 1880 nm to 2000 nm. Furthermore we demonstrate first experimental results from an Arrayed Waveguide Grating operating at 2000 nm.

Wavelength dependent absorption

A generic process is based on a common layer stack, shared among all users of the platform. For maximum compatibility with the existing process, it is convenient to change the stack as little as possible. One of the most important properties of the layer stack is the propagation loss, which is sensitive to the materials and the doping levels employed. For InP based platforms, the waveguides are based on an InGaAsP layer between two partially doped InP cladding layers. The doping is chosen to form a pin

diode around the waveguide core, with a gradually increasing concentration of p-dopant towards the top. This is done to make the layer stack also suitable for use in electro-optic modulators and amplifiers while minimizing propagation loss.
The decreasing confinement in the waveguide core with increasing wavelength, gives rise to an increase of the confinement in the highly doped regions. The absorption in the p-doped cladding is dominant. In the highly doped regions, the absorption can become higher than 100 dB/cm. Therefore even a small increase of the field in the p-doped region will lead to a substantial increase of the propagation loss.
In order to get a quantitative estimate of the increase of loss due to absorption we have performed simulations with the commercially available Finite Difference complex mode solver in Field Designer, offered by Phoenix BV. These calculations, which are based on the models mentioned below, are compared to waveguide loss measurements in the following section. The reference layer stack with detailed material parameters can be found in [5].
For our simulations we used the following assumptions. The real part of the refractive index is obtained by using the model provided by Fiedler and Schlachetzki [6]. The change in refractive index due to the presence of dopant is derived from the plasma effect. By distinguishing between different effective masses, we take into account the polarity of the dopant [7]. The absorption due to presence of dopant has been based on two different models. For n-type absorption, we assume that most of the loss is a result of scattering introduced through electron-optical phonon, electron-acoustical phonon, and electron-ionized impurity interaction [8]. For p-type dopant the loss can be reduced to intervalence band absorption, which has an exponential dependence on the wavelength [9].

Waveguide loss measurement

To verify the assumptions described above, we characterized waveguides using the Fabry-Perot Method. A proper estimation of the wavelength dependent reflection coefficients has been obtained with MIRF, a software tool developed by ETH Zürich. Two different types of waveguides have been considered. The first type is in agreement with the standard layer stack used in the 1550 nm platform [5]. The other has a core thickness of 600 nm and does not contain any p dopant. Both sets of waveguides are about 11 mm long and contain shallowly etched waveguides to reduce the influence of surface roughness. As source we used an external cavity laser in Littman configuration based on the tuneable laser kit, Thorlabs TLK-1950R. Prior to a wavelength scan, the SMSR of the laser has been checked over the tuning range using a YOKOGAWA AQ6375 optical spectrum analyser (OSA). By maximizing the power through the waveguide using a manual polarization controller, we assume that the best measurements will result in a TE polarization.
Typical measurement results are displayed in Figure 1. The plot contains the photodiode signal against the relative displacement of the external grating over time. The black circles represent a typical result obtained from the undoped waveguides. Compared to the doped waveguides plotted in dark gray, we measure a significant difference in contrast ratio at a wavelength of 1922 nm. The contrast ratio decreases further at 1990 nm, as waveguide absorption increases. This effect is further enhanced by decrease of the laser power when it is detuned from its central wavelength. This hampers the extraction of accurate loss values when approaching a wavelength of 2000 nm.

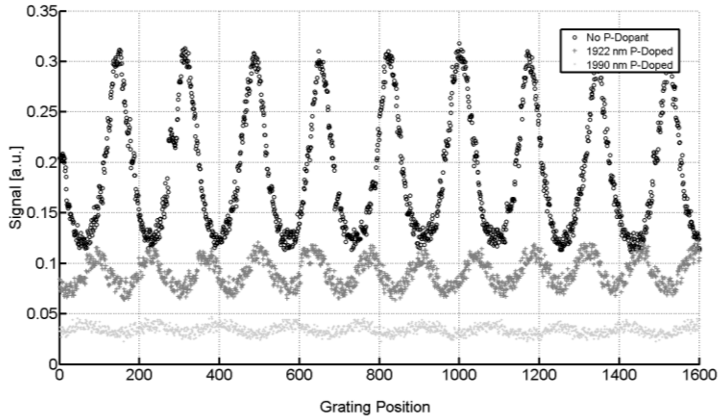

Figure 1: Typical Fabry-Perot measurements

The summarized loss dependence between 1880 nm and 2000 nm is shown in Figure 1. We see good agreement between the simulation and the measurement results. The samples containing no p-dopant have a low loss with negligible wavelength dependence. The measured value is slightly higher, as we did not take into account effects of surface roughness. As expected, the p-doped set of waveguides show a higher loss with a steady increase. The overall trend coincides with the prediction, which indicates that the p-dopant introduces strong exponential wavelength dependence.

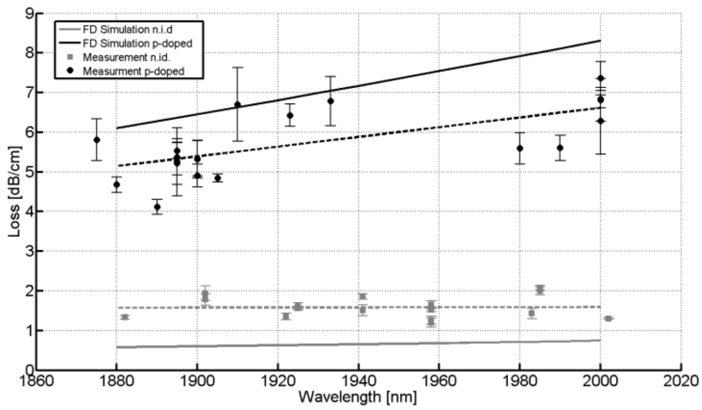

Figure 2: Wavelength dependent loss for n.i.d. (gray) and doped (black) waveguides between 1880 nm and 2000 nm (TE)

An Arrayed Waveguide Grating

Based on the measurements of undoped waveguide samples, we extracted the necessary parameters for our standard AWG module. In this way, we obtain a compact AWG with a deeply etched waveguide array section. The minimum bending radius has been set to 150 µm. This reduces the insertion loss of the device for longer wavelengths. The shallow to deep transitions have been adjusted and angled waveguide terminations were used to avoid back reflections at the coupling interface. Using the Thorlabs TLK-1950R, we display 2 channels of a 4x4 AWG with a target FSR of 1600 GHz and a channel spacing of 400 GHz in Figure 3. For wavelength reference, we measured the wavelength at the beginning and end of the laser sweep with the OSA and interpolated the points in between. From our measurement data we estimate an insertion loss of about 2.5 dB for the central channel, by comparing to a straight waveguide. This is a promising result for the long wavelength platform.

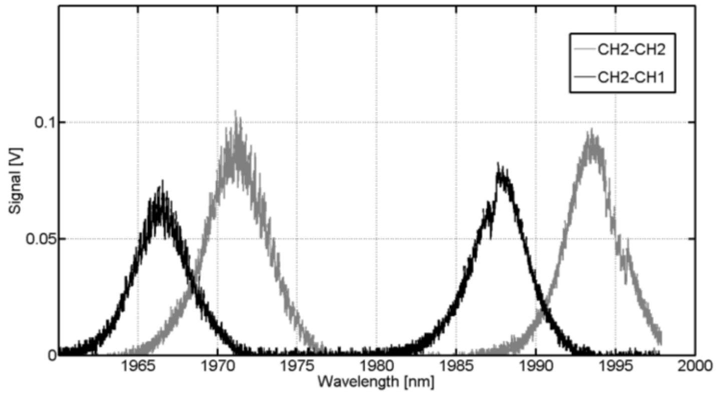

Figure 3: First demonstration of an AWG operating at 2 µm

Conclusion

We have modelled and measured waveguide loss, for InP ridge waveguides in the wavelength window between 1880 nm and 2000 nm. Measurement results obtained via the Fabry Perot Method show a loss of about 7 dB/cm for non-optimized InP waveguides at a wavelength of 2000 nm. We have verified that the main contribution for the high loss is the presence of p-dopant, as samples containing no p-dopant showed loss below 2 dB/cm with negligible wavelength dependence. We demonstrated an AWG with good performance on the long-wavelength platform.

Acknowledgments

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