Fabrication and characterization of a dense optical bus attached to an AWG

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Highly integrated photonic InP circuits raise the demand for an augmented number of optical ports. Therefore, we present the integration of an optical bus in our generic platform consisting of a compact Spot-Size Converter (SSC) array, and we demonstrate it by connecting it to an 8 x 8 AWG. The SSCs have a 25 µm pitch and expand the mode from 0.5 µm in the AWG waveguide layer to 3 µm after the SSC. The adiabatic conversion is based on a vertical taper with two linear sections. We measured 0.7 dB loss per fiber-chip coupling for a 700 µm long SSC device.

Introduction

The complexity in Photonic Integrated Circuits (PICs) enabled through generic foundries is rapidly growing. Access is given through Multi-Project-Wafer Runs (MPW) [1] where users with different applications design Photonic Integrated Circuits (PICs) based on a common generic process. Here, a number of building blocks are combined to fulfill the specifications of the final application. Although a large variety of integration schemes for SSCs have been reported [2], only few are suitable for integration in a generic process. The barrier for monolithic integration with different components is the complex fabrication procedure. At present only one generic platform technology is available that supports integration of a dense SSC array with high-speed detectors and passive devices [3].

In this paper we present a dense SSC-building block that is compatible with our generic integration platform technology that supports integration of SOA's and lasers, rf phase modulators, detectors and passive devices [4]. For the integration with our generic process, we make use of a sliding raster technique as described by Soares [5]. We optimized the fabrication process to obtain a vertical taper with two slopes and reduced the substrate translation required during exposure of the grey-scale raster. We achieved a reduction to 65 µm as compared to the 180 µm reported earlier.

The vertical taper transfers the mode from a 3 µm thick Fiber Matched Waveguide (FMW) to the submicron mode of the generic waveguide. The FMW is a specially designed diluted waveguide with a spot size of 3 µm. By carefully positioning the high index layers of the diluted waveguide, we were able to drastically reduce the device lengths from millimeters to a few 100 µm.

The quality of the integration process is demonstrated by integration of an 8 x 8 AWG with an SSC array with a coupling loss of 0.7 dB to a lensed fiber. The SSC-array has a pitch of 25 µm and is a perfect tool for the formation of a hybrid platform technology by coupling chips from different material systems. An example is the combination with a Triplex interposer chips previously reported by UCSB and Lionix [6]. While InP can provide the active light manipulation, the interposer may contain passive functionality as low loss delay lines, high-Q filter or simply be a tool to achieve low loss coupling to fiber ribbons.

Fabrication of a vertical taper

The fabrication process is based on the development of a vertical taper in photoresist, which is transferred into the core layer using a nonselective dry etch. The vertical taper is realized using a sliding-window approach [4]. During the UV exposure, an open window on the mask is moving along the sample, thereby introducing a linear gradient in the exposure time of the photoresist underneath. It relies on the fact that the exposure depth of photoresist is dependent on the exposure time. This is a relatively simple and easy technique to realize vertical tapers. However, in order to obtain the long tapers required, the mask needs to be moved along the whole length of the taper. Since the exposure time of the positive photoresist is quite short, the window must be moved fast. Furthermore, it is not possible to realize tapers of different lengths in a single process. Multiple slopes will also require a complex time dependent control of the displacement.

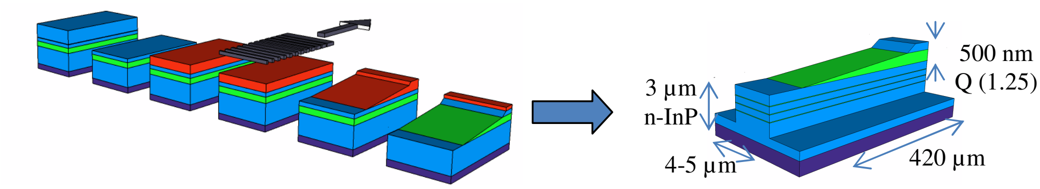

Figure 1: Fabrication of a vertical taper using a raster mask in proximity

We have used a modified process that is based on a mask with a raster instead of a single window. The technique illustrated in Figure 1 is described by Soares [5]. The mask consists of a raster of lines, equally spaced at 3 µm. The width of the lines on the raster is linearly decreasing along the taper. The regions of the photoresist covered by the narrow lines will be effectively more exposed than the regions covered by the wider lines. The linearly increasing opening along the raster introduces a linear gradient along the exposed surface. The image of the raster lines is averaged out by a substrate translation of 65 µm during the exposure in proximity. The taper is transferred into the core material using a non-selective ICP etch based on Cl2-Ar-N2. The ridge of the SSC is finally defined together with our standard waveguides.

Characterization

The loss of the SSC can be measured by dividing the structure into multiple sections. According to Figure 1, we can identify the vertical taper and the FMW used for coupling purposes. The loss of the FMW section is given by the sum of the fiber-chip coupling and the propagation loss. The propagation loss of the FMW has been measured to be 4 dB/cm. In order to determine the coupling loss, we measured the mode profile for a FMW of 4 µm and 5 µm width. The obtained mode profiles for the SSCs and a lensed fiber with a 2.5 µm MFD are displayed in Figure 2. The modes of the SSC appear very uniform. The fiber mode is slightly asymmetric which can be caused by a slight angle or rotation of the fiber. Nonetheless, this reproduces the reality quite well as it is not avoidable in conventional measurements setups. In our approach we now overlap the measured modes of the SSC with the mode profile of the lensed fiber. We calculate in this way a loss of 0.2 dB for the 4 µm wide waveguide and a loss of 0.3 dB for the 5 µm wide waveguide respectively. For further specifications it is a common approach to approximate the field profiles as Gaussians. This assumption introduces an error, which can be very small if the mode profile has been designed accordingly. In our case we measure the Gaussian MFDs as 3.7 x 2.7 µm and 3 x 2.7 µm for a 5 µm and 4 µm wide SSC respectively. The coupling losses and MFDs are in line with FMM simulations.

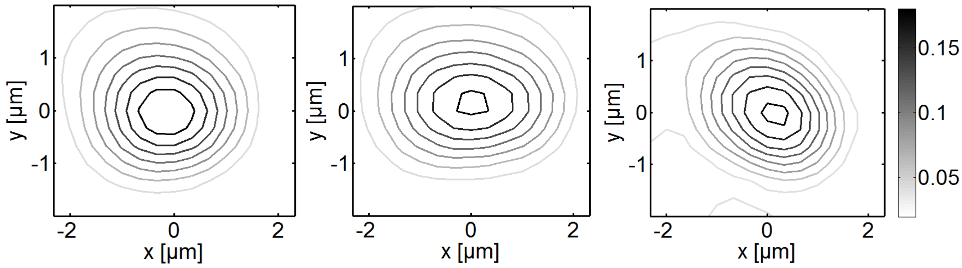

Figure 2: Modes of a 4 µm wide FMW, 5 µm wide FMW and 2.5 µm MFD lensed fiber respectively

The loss of the second section is given by the vertical taper. We fabricated shallow waveguides connected to SSCs at the input and output of the chip to estimate the loss of this section. By comparing with waveguides without SSCs, we were able to deduce the loss of the vertical ramp. For simulation of the device we have used two dimensional BPM, where we reduced one dimension by the effective index method. The results of the measurement and simulation can be found in Figure 3.

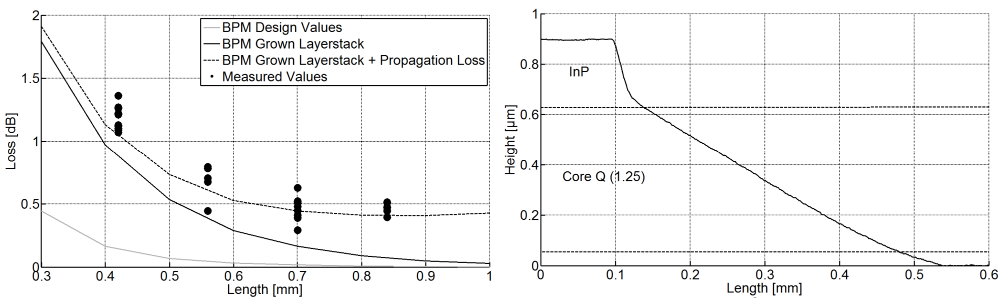

Figure 3: Extracted loss of the vertical taper and fabricated ramp indicating the core layer

We found that the loss of the ramps is higher than the BPM simulations predict for our target design. The reason is a significant deviation of the grown layer stack, compared to design values. We measured that our layers were on average 15% thicker than expected. Thus our taper will suffer higher loss as a consequence of reduced adiabaticity. Correcting the simulations for the actual values and adding the measured propagation loss of 4 dB/cm for the FMW, results in a good agreement. In this sense we believe that our design is suitable for low loss devices as short as 400 µm.

Integration into a Generic Process Run with an 8x8 AWG

We fabricated test cells containing two 8 x 8 AWGs connected to SSC arrays using low loss shallow bends. The fabrication was done on 2 inch wafers. The waveguide loss of the shallow waveguides was measured to be 1 dB/cm. The displayed chip in Figure 4 shows in total 84 SSCs. The AWG was chosen to have a FSR of 1600 GHz, with channels spaced by 200 GHz. The central channel was designed to be located at 1.55 µm. One order of the periodic spectrum is depicted in Figure 4. The design values were reproduced quite accurately. The channel separation is uniform but the pass bands of the AWG show small shoulders. Those are either left or right of the pass band, depending on the position relative to the central channel. These could be caused by a slight accumulated phase error in the arms of the AWG. Using a tunable laser the insertion loss of the AWG and the attached waveguides was determined to be 2.5 dB. By adding the measured losses for the central channels of the AWG to the taper and coupling losses of the input and output SSCs, we report a value of 4 dB from input to output fiber. We measured 5.1 dB in direct transmission as we are missing an AR coating.

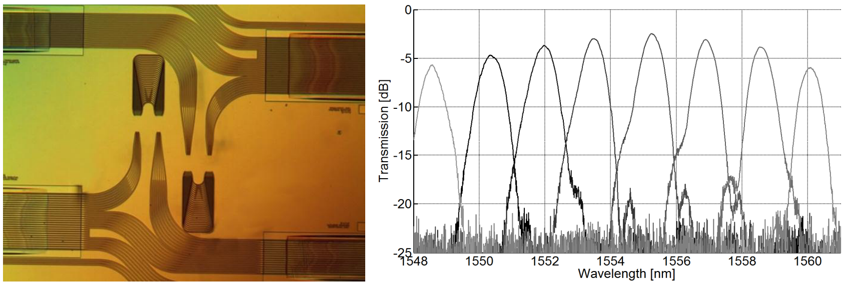

Figure 4: Image of fabricated chip containing 84 SSCs and measured AWG transmission

Conclusions

We present an 8 x 8 InP-based AWG integrated with a dense Spot-Size Converter array for low-loss fibre coupling. The AWG has central channel loss of 2.5 dB. The SSCs have 0.7 dB coupling loss. For the chip with integrated SSCs we measured a loss between lensed fibres of 4 dB, which is very low for an InP-based device. It demonstrates the high quality of the generic integration process. The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement ICT 257210 PARADIGM.

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