Photonic chip for steering a four element phased array antenna

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PHOTONIC CHIP FOR STEERING A FOUR ELEMENT PHASED ARRAY ANTENNA

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Abstract
A polarization independent Photonic Integrated Circuit for phase steering of a four element Phased Array Antenna has been fabricated on InP. The chip is extremely small and suitable for packaging.

Introduction
Phased Array Antennas (PAAs) are becoming increasingly important and are under study for radar and wireless communication applications, see [1,2]. Optical processing of microwave signals is attractive because glass fiber has extremely low losses and a very high bandwidth. Photonic integration brings down the number of components in the optical beamformer. Previously we have realized a Photonic Integrated Circuit (PIC), for adjusting the phase and amplitude information for a 16 element PAA, see [3]. However this chip only worked for the TE polarization, it suffered from a high insertion loss and its output waveguides were not designed for coupling to a fibre array. The device we present here addresses those issues.

Chip Design
Basically this chip combines the signals of two lasers such that a microwave beat signal is formed in a photodiode behind the chip. Any optical phase shift will translate, by heterodyning, to a microwave phase shift behind the photodetector. Two lasers with stable difference frequency, e.g. from an optical phase locked loop, are connected to inputs 1 and 2. 1x2 Multi-Mode Interference (MMI) splitters [4] are used, for splitting the signal into four equal parts. The waveguides are sorted in four pairs such that waveguides with signals from inputs 1 and 2 appear alternatively. In every waveguide a 2.57 mm long phase/amplitude modulator is included in the [110] direction (split in two parts, see Fig. 1) and a 1.13 mm long phase/amplitude modulator in the [110] direction. In the [110] direction the phase shift experienced by the TE polarized light is slightly larger than for the TM polarized light. In the [110] direction however the phase shift for the TM polarization is much larger than for the TE polarization. Therefore it is possible, with adjusting the voltage on both sections, to obtain a polarization independent phase shift. Before the light leaves the chip the signals in the waveguide pairs, coming from inputs 1 and 2, are combined in a 2x2 MMI 3dB coupler. The width of the in- and output waveguides is increased for optimal coupling to a lensed fiber. In this way the coupling loss can be reduced to around 5 dB.

Figure 1: Design of phase controller chip.
Fabrication

This chip was fabricated on an N-doped InP substrate. Using an MOCVD a non doped 600 nm InGaAsP film layer with cut-off wavelength of 1.3 μm, a 1 μm p-doped cladding layer were and a 50 nm P-doped contact layer were deposited. First the contact layer was removed by wet chemical etching everywhere outside the phase/amplitude modulators. Ridge waveguides were etched with a CH₄/H₂ plasma in a RIE machine using a SiN masking layer. The applied waveguide width was 2 μm and the etch depth was 150 nm into the film layer. For planarization and passivation a polyimide layer was spun on. The Ti/Au (20/180 nm) metallization was patterned using a lift-off process.

Measurements

The total excess loss of the device is 6.5 dB, total on chip losses including the splitting loss are 15.5 dB. All outputs are within ±1.5 dB from this value. The propagation losses for a 2 μm waveguide losses are 1.5 and 1.8 dB/cm, for TE and TM polarization respectively. The total on chip waveguide length is about 1 cm. Each of the three phase/amplitude modulation sections gives around 1 dB insertion loss, because of discontinuities in the cladding layer which are used as electrical insulation. The input signal is distributed over eight output waveguides, therefore there is 9 dB splitting loss. The 2 dB that are left can be attributed to the excess loss of the MMI-couplers. In figure 2 the phase shift of the phase/amplitude modulators, both parallel and perpendicular to the [1 1 0] direction, is plotted as a function of the applied voltage. The phase shifting along the [1 1 0] direction is more efficient because the electrode is 2.57 mm long vs. 1.13 mm in the perpendicular direction.

A voltage on the phase/amplitude modulator does not only change the phase of the signal, it also introduces an extra attenuation. When a voltage of 15 V is put on the phase/amplitude modulator parallel to the [1 1 0] direction, an attenuation of 7.5 or 11 dB is incurred for the TE or TM polarization respectively. This effect is linear with electrode length and roughly independent of the waveguide orientation. The attenuation effect is not linear with applied voltage and will be larger at higher voltages.

To make sure that a polarization independent phase shift is applied, the ratio of the voltages applied to the phase/amplitude modulator in the parallel and the perpendicular to the [1 1 0] crystallographic direction must be fixed. A combined phase and amplitude state can be reached by first applying a certain phase shift, or in this case attenuation, to both input signals. Secondly a phase difference between the two input signals can be reached by changing these voltages slightly.

The operation of the chip was further tested by coupling two laser signals in the chip and looking at the signal that is generated in a photo diode. The measurement setup is shown in figure 3.
Two external cavity lasers were used as input lasers. Light was coupled into and out of the chip using an array of cleaved fibers. Which resulted in a coupling loss around 10 dB. An Optical Spectrum Analyzer was used to monitor the signals coupled in and to position the input wavelengths closely together. The coupled signal from the two input lasers was mixed in a photodiode, amplified by 40 dB and visualized on an Electrical Spectrum Analyzer (ESA).

In Figure 4 the resulting signal in the ESA is shown. The two input lasers were tuned at a frequency difference of 800 MHz. As a tuning range of 1 nm in wavelength corresponds to 120 GHz and lasers can be easily tuned over 5 nm, the tuning range of the output microwave frequency is almost unlimited, it is only restricted by the speed of the detector which can be larger than 50 GHz. The power of both input lasers is around 3 dBm. The chip gives a total insertion loss of 40 dB (16 dB on-chip loss, two times 12 dB coupling loss from the chip without AR-coating to a cleaved fiber). So the signal at the photo diode is around -34 dBm. If the modes of the waveguides at the in and out coupling facets were adjusted to a cleaved fiber with a Spot-Size Converter, with 2 dB loss each, and if 20 dB of optical amplification could be included on the chip using Semiconductor Optical Amplifiers, than this chip would not produce any insertion loss.

**Conclusion**

We have realized a, small (2.5 x 3 mm), polarization independent photonic integrated circuit for controlling the phase of a 4 element phased-array antenna. The on chip losses are 15.5±1.5 dB. All phase settings can be reached with a driving voltage below 4 V. The width of the in and output waveguides is optimized for coupling to a lensed fiber array with a coupling loss around 5 dB.

**References**


