An Optical InP chip for Controlling the Beam Direction of a Phased Array Antenna

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Abstract:
The work presented in this paper reports on the design, fabrication and characterisation of an integrated InP chip for steering the beam of a four-element Phased Array Antenna operating at 40 GHz. The beam direction is determined by the time delays between the four antenna elements. The chip can introduce 8 different time delays to each of the four modulated optical signals that are used to control the four antenna elements. Measurement results of the switches and demultiplexers used in the chip are reported and the performance of the first integrated device is discussed.

Introduction

A Phased-Array Antenna (PAA) is a collection of regular antennas in close proximity to each other (in the order of the wavelength of the transmitted signal). The radiation patterns of the individual antenna elements will interfere with each other resulting in a total pattern with better characteristics (such as higher directivity, and lower beamwidth) than that of a single antenna element alone. Furthermore, by introducing a certain progressive time- or phase delay between the signals of the antenna elements, the direction of this total radiation pattern can be changed/controlled according to the applied time- or phase delay between the antenna elements.
This kind of antennas are becoming increasingly popular for applications, such as wireless communications and radars [1,2], due to their many advantages over regular single-element antennas. For PAAs operating at high frequency, beamformer circuits based on DSPs and RF circuits, which manipulate the phase- or time delay of each antenna element, becomes cumbersome. However, optical beamformer circuits can reduce the size and complexity of PAAs while offering a much higher bandwidth than electrical beamformers [1].
Many different approaches have been used to make these optical beamformers. Previously [3], we realized a 8x8.5-mm^2 chip in InP technology to steer the beam of a 16-element PAA by controlling the phase delay of each antenna element. However, these beamformers suffer from beam squint, i.e. the beam direction of the PAA changes as a function of the frequency of the transmitted signal. This paper reports on a compact (8x13mm^2) optical beamformer, based on InP technology, for a four-element PAA operating at 40GHz. This design uses the true-time delay technique with which beam squint can be avoided. The antenna elements are spaced at half the wavelength of the transmitted signal (3.75mm).

Design

Figure 1 shows the design of the fabricated InP beamformer. The operating principle is as follows. A four-wavelength optical input signal, onto which the signal to be transmitted by the antenna has been simultaneously modulated, is coupled into the chip at of the inputs. Then, the wavelengths are first demultiplexed in the Phased-Array Multiplexer/Demultiplexer (PHASAR). The PHASAR has been designed to have a channel spacing of half the spacing between the wavelengths of the input signal, so that the wavelengths are demultiplexed onto every second PHASAR output. Afterwards, each wavelength (except the first one to which no delay needs to be introduced) goes through a sequence of four cascaded Mach-Zehnder-Interferometer (MZI) switches connected to each other by three bypass-lines and three delay-lines. The lengths of the first-, second-, and third delay-line are progressive for the different wavelengths. By applying voltages to the switches, the wavelengths can be set to go through the same sequence of delay-line (for instance, all wavelengths go through the first- and second delay-line). In this way, 8 different optical path lengths can be set independently for each wavelength. Because the delay-line lengths are progressive, the time delay between the wavelengths will be progressive as well. Thus, beamforming is achieved. Afterwards, the signals are again multiplexed by the PHASAR and coupled out of the chip.

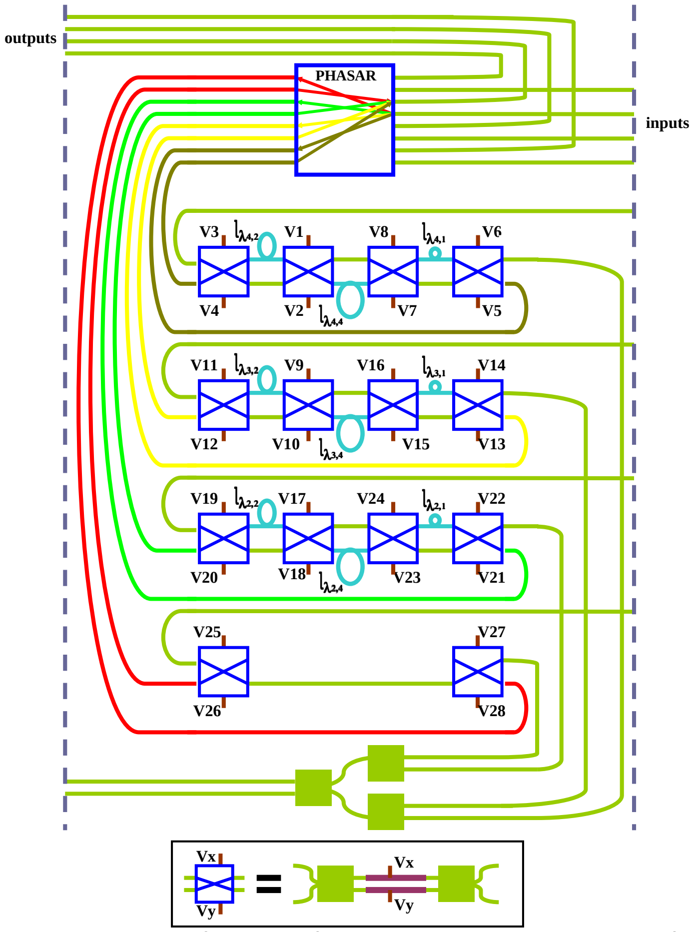


Figure 1 Symbolic representation of the beamformer design. The inset shows a figure of a Mach-Zehnder Interferometer switch.

Layout and Fabrication

Figure 2 shows a picture of the fabricated beamformer. The beamformer has been fabricated on InP technology. The PHASAR has been implemented as a double–etched PHASAR that contains a shallow-etched part as well as a deep-etched part [4]. The main advantage of this PHASAR for this design is its compactness (1.5x1.2mm^2), and the possibility to design it polarisation independent by choosing the width of the deeply-etched waveguides appropriately. The free-spectral range has been chosen as large as possible in order to obtain a uniform power distributions for all different outputs. The MZI switches have been placed under an angle of 30 degrees for polarisation-independent switching behaviour [5]. The phaseshifting sections of the switches are 2.8mm long, in order to obtain low swicthing voltages. The layout also contains several test structures to evaluate the fabrication, mainly two test PHASARs, several test switches, shallow- and deeply-etched straight waveguides, and deep-to-shallow waveguide transitions.

The beamformer has been fabricated using standard lithography- and dry-etching techniques. The layer stack consists of a 600nm InGaAsP layer ($\lambda_{bandgap}$=1.25μm) waveguide layer grown in between a highly-n-doped substrate and a highly-n-doped InP cladding.

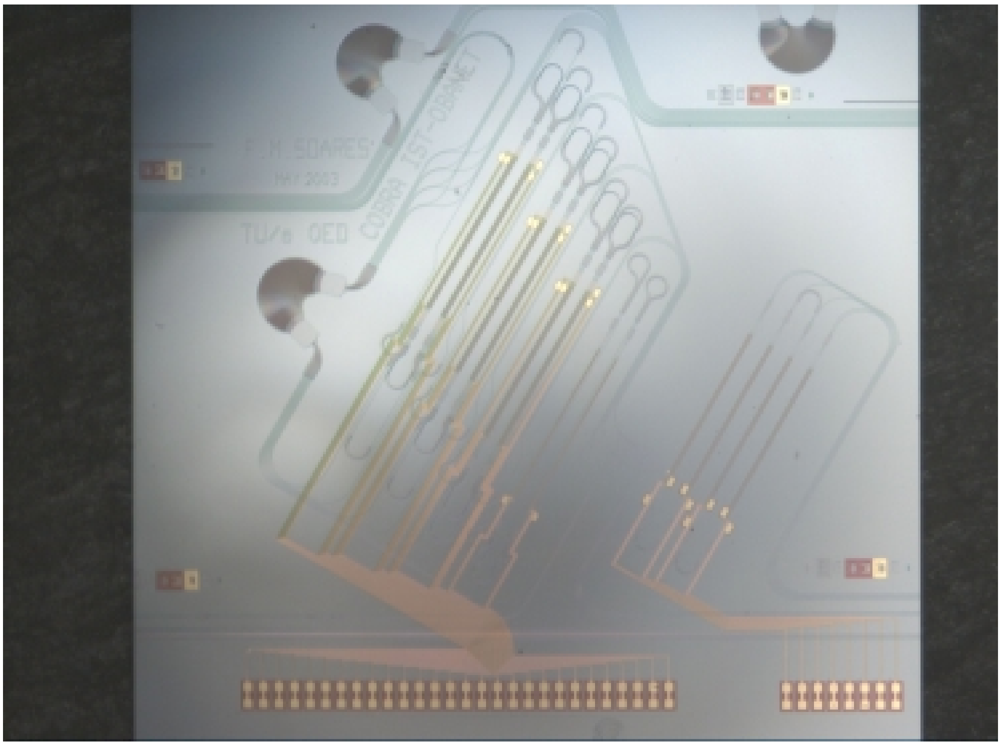
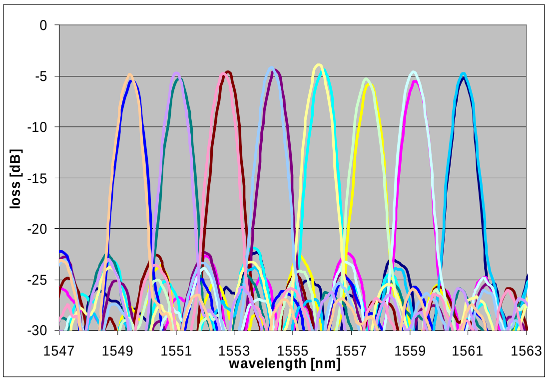


Figure 2 Picture of the fabricated beamformer.

Results

Transmission measurements, using the spontaneous emission of an EDFA, on the PHASARs show an insertion loss of 5dB and good polarisation-independent behaviour (see figure 3a). The test MZI switches were measured using a tunable laser source. These measurements show a switching voltage of 6V, and an extinction ratio on the bar port of 28dB. The losses of the MZI switches suffer from an increased insertion loss for reasons not yet understood, since Fabry-Perot measurements on the straight waveguides show losses of 1dB/cm for shallow-etched waveguides. Experiments are ongoing to determine the insertion loss of the complete beamformer and to investigate its beamdirecting capabilities.



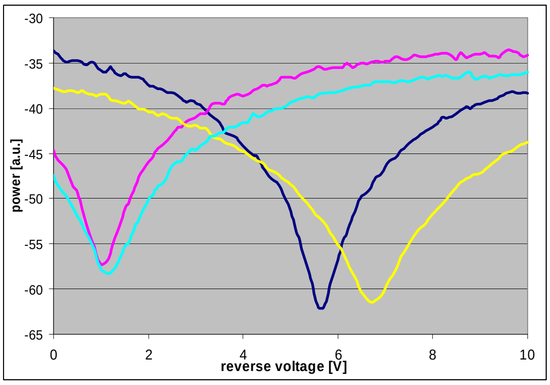


Figure 3 TE- and TM- transmission characteristics of the PHASAR a), and switching curves of the MZI switches for both TE- and TM polarisation b).

Conclusions and Further Experiments

A compact integrated beamformer for controlling a 4-element PAA operating at 40GHz has been designed, fabricated, and partly characterized. The PHASARs used in the circuit show 5 dB insertion loss and excellent polarisation independence. The MZI switches show a switching voltage of around 6V and an extinction ratio of 28dB. Further experiments will be carried out to determine the total losses of the beamformer and its beamdirecting capabilities.

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