Towards Automatic Control of Two ORR-based TTD PIC Optical Beamforming using a Neural Network

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In this work, we characterised a 2-ORR-based true time delay on InP photonic integrated circuit, with thermo-optical phase shifters and semiconductor optical amplifiers. The primary results show that the 2 ORRs can provide programable delay bandwidth up to 7.5GHz. We are developing a smart control of the phase shifters and SOA to enable stable optical delay and amplitude.

Keywords: *True Time Delay, Optical Ring Resonator, Photonic Integration, InP platform.*

INTRODUCTION

Optical beamforming networks (OBFN) technology provide advance phase control for modern radar and point-to-point wireless communication systems [1]. The optical ring resonator (ORR) is a promising solution to outperform the electric delay to enhance the bandwidth and avoid signal distortion due to the electromagnetic interference [2]. The development of the photonic integration technology profoundly changes the implementations of the optical components in terms of size, weight, and cost. The photonic integrated ORR-based delay line can provide continues tuning of true time delay (TTD) of the signal with on- and off-resonate operation. The photonic integrated ORR can achieve on- and off- resonate delay in ns [3] and 100's ps [4], respectively. TTD will be applied to the signal path feeding to the elements of a phased-array antenna (PAA), resulting in RF beams pointed to a single or multiple users. If users move, then the beam pointing should track them such that they are kept connected.

The loss of the optical delay line on chip is proportional to loss on the delay path, therefore for antenna array with different paths delay it will result in different signal amplitudes, which cause further loss after equalization [2, 5]. The on-chip gain is one of the solution to this problem. The InP platform is nowadays a matured platform that offers monolithic integration of active and passive photonic components [6]. In our work, we exploit semiconductor optical amplifier to compensate the loss due to the resonance of ORR and enable equalized amplitude at the output. And a 2-ORR structure is employed to tune the pass bandwidth as well as the true time delay of the delay path. We characterised the performance of the fabricated ORR-TTD circuits with tuning the phase shifter on the MZI and on the ring. We are developing the control of the heaters and SOA to mitigate the thermal cross-talk and to provide stable optical delay and signal amplitude for given light source wavelengths.

Experiments

Fig. 1 depicts the schematic of the experimental setup for characterisation of the ORR-TTD integrated chip. A tunable laser is exploited to measure the response of the race-track ORR. The dash box shows the scheme of on-chip optical delay line components on the fabricated chip, including 2 ORRs with individual Mach-Zehnder interferometers (MZIs) for controlling the coupling coefficient, and there is a SOA at the output to control the signal amplitude. The phase shifter 1 and 2 are for the control of phase in the optical ring while phase shifter 3 and 4 are for the control of optical delay by tuning the coupling coefficient, with thermal tuning by heater 1 to 4 as indicated as H1, H2, H3 and H4, in Fig. 1. For the recording the transmission spectrum of the ORRs, the tunable laser is tuned from 1549.7 to 1550.2 nm with 0.01 nm steps, with fixed power of 3.5 dBm. Since we have a SOA on the chip, this SOA can be operated as a photodetector, connecting to an ampere-meter, after calibration with input and output optical power.

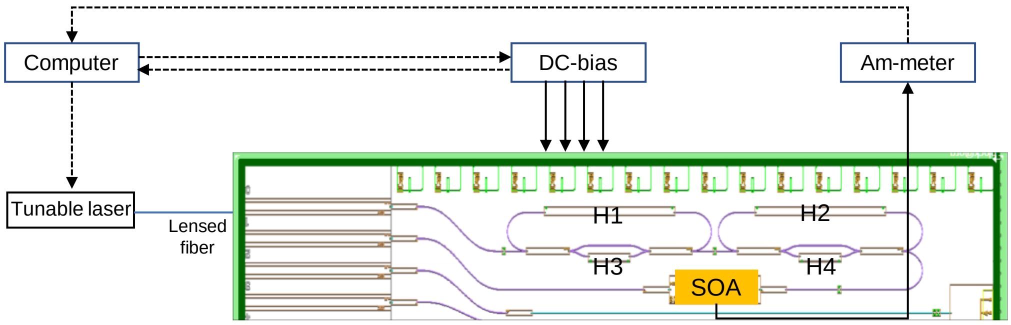

Fig. 1 Schematic of the characterisation experimental setup of ORR-TTD integrated circuit. The InP TTD chip is designed to work in K-band (17-22 GHz).

RESULTS

The response of the 2-ORR structure is shown in Fig. 2. Fig. 2(a-d) show the response transmission spectrum of the 2-ORR TTD, individually tuning voltage on heater H1, H2, H3, and H4, from 0 to 4V with 0.1V per step, with all other heaters off, with the tunable laser scanning in 0.01 nm steps. For increasing the voltage of the heaters, the resonates of the ORRs are shift to the longer wavelength. In Fig. 2(a,b), the extinction ratio of the ORR is 6.7dB and the resonates shift with increasing voltage. And these two figures show that there are two groups of power dip (indicated with blue) shift when tuning the heater voltages. The darker tracks are from the ORR on the effective ring under tuning, while the lighter tracks of dip shift are from the other ORR, which is influenced by a fraction of heat from the other heater. The change of the spectrum from H2 is slightly different to H1 as shown in Fig. 2a due to the resistance of H2 is different to H1. Fig. 2(c,d) show that the extinction ratio increases to maximum when voltage of H3 and H4 are rising up to 2.5V, i.e. increasing the couple coefficient of the ORR, reaching to 14dB. Then it decreases attributing to the further increase of the coupling coefficient with the coupling MZI. However, the resonate wavelength also shifts, due to the thermal cross-talk from H3 and H4, to the race track waveguide of the ORRs, which suggests that the cross-talk demands an accurate control. Fig. 2(e,f) shows the response spectrum variation when tuning the voltage on H3 and H4 when setting bias voltages on the other heater. For tuning H3, the other heaters, H1, H2, and H4, are biased at 2.5, 1, and 0 V, respectively. For tuning H4, the other heaters, H1, H2, and H3, are biased at 2.5, 1, and 2.5 V, respectively. Fig 2(e,f) show that the wavelength resonance can still be controlled by the phase shifters in the rings albeit the patterns become complicated. Nonetheless, the 2-ORR is capable to tune bandwidth and time delay of the delay line. Fig. 2g shows the spectrum of 2-ORR TTD with different pass bandwidth of 3, 4, 6.5, and 7.5 GHz, which are realized by setting different voltages on the heaters to detune the two resonance patterns on the two ORRs.

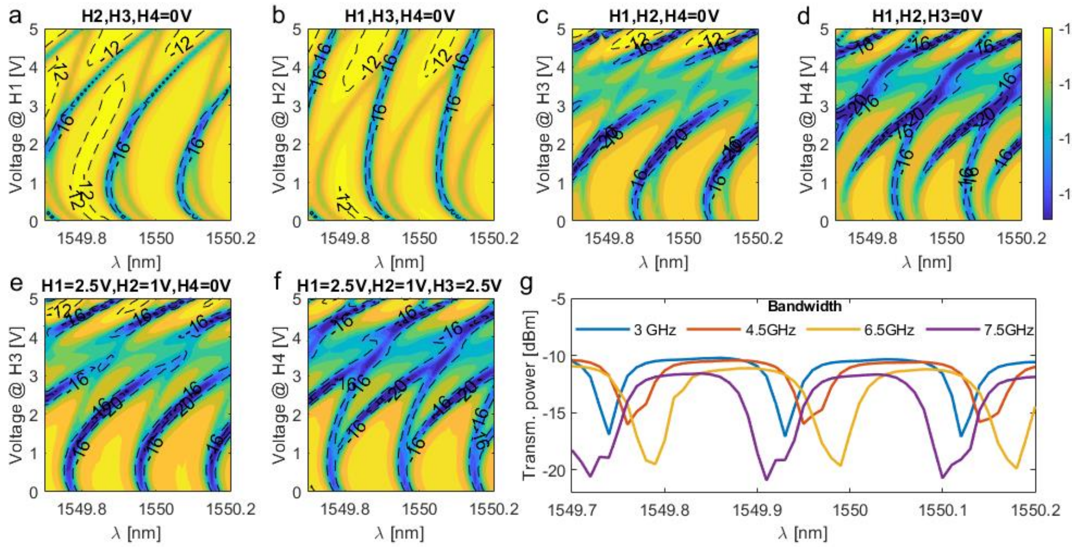

Fig. 2 The response of the 2-ORR TTD on InP photonic integrated circuit, with tuning 4 different heaters.

DISCUSSION

The optical beamforming network comprises cascaded ORR time delays, with 2-ORR TTD components, and connected by MZI or couplers, with equalized output optical power. The loss induced by the on-resonate delay of ORR and the equalized output can be compensated by the gain of the SOA on-chip. So far, the beam pointing control is done by adjusting the voltage level of individual heaters according to a look-up table. For a static and semi-mobile or nomadic user, this way of controlling the beam pointing may be sufficient since once the correct value of voltages is reached, the control will keep the same value and possibly with some adjustments due to the inevitable thermal cross-talk between the heaters. However, if users move, then the look-up table must be updated with new values according to their speeds and direction. Therefore, an automatic, accurate, and fast beam tracking and pointing control is needed to provide seamless connectivity to mobile users. In this context, we are developing the control of thermal crosstalk on the heaters, to have a fast automatic tuning according to the target beam steering angle. The control makes use of a combination of electrical and optical signal processing employing a neural network concept with an optimized cost function regarding latency, complexity and update speeds to serve users moving at walking speeds, i.e. 1-5 m/s. The schematic of the control part is shown in Fig. 3.

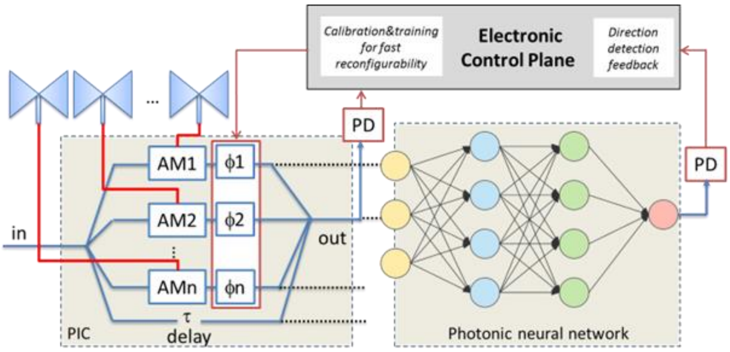

Fig. 3 Schematic of a hybrid electro-optical neural network RF beam pointing controller.

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