Dual-Drive Directional Couplers for Programmable Integrated Photonics

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***Abstract*—Here, we propose and experimentally demonstrate the use of directional couplers with an independent phase actuator on each waveguide. We show the configurations that allow the setting of both the splitting ratio and the phase in a silicon nitride platform and their applications in programable photonic integrated circuits.**

***Keywords*—directional coupler, programmable photonics, multifunctional photonics, software-defined, signal processing, silicon nitride.**

I. Introduction

Directional couplers and phase shifters are two of the most frequently employed components present in current photonic integrated circuits (PICs). The former are designed to operate as a beam-splitter featuring a desired fixed-by-design optical power splitting ratio (*K)* at a certain wavelength, [1]. The integration of phase actuators is essential for the construction of PICs with reconfigurable capabilities that overcome fabrication errors and open the path for applications that require flexibility and dynamic operation. The combination of phase actuators with interferometric structures allows the reconfiguration of beam-splitters or tunable couplers.

A paradigm shift in PIC design explores the development of multiport interferometric programmable circuits, where common integrated optical hardware configurations, are programmed to implement a variety of functionalities that can be elaborated for basic or more complex operations in many application fields [2-4]. In this respect, these systems might compromise the overall power consumption, power budget and footprint to provide an unprecedented degree of flexibility and versatility that is inherited by the programmed systems. Most of the experimental demonstrations to date rely a reconfigurable optical core comprised by the interconnection of multiple instances of a dual-drive Mach-Zehnder Interferometer loaded with two phase shifters characterized by its high reproducibility, yield and performance, [2]. However, to ensure the future scalability of these systems, research should be done in the optimization of this Tunable Basic Units (TBU) architectures and tuning mechanisms to reduce their insertion loss, footprint, optical crosstalk, and power consumption. In this paper, we study the Dual Drive Directional Coupler (DD-DC) as a candidate for both classical PICs and waveguide mesh arrangements.

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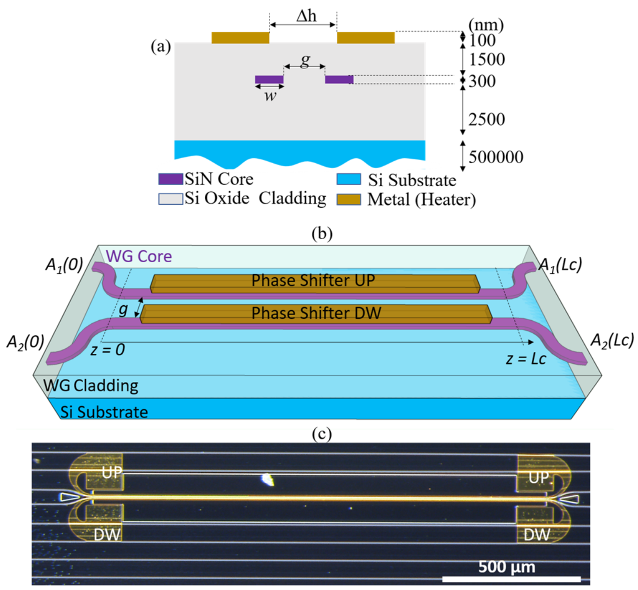

Fig 1. Dual-Drive Directional Coupler (a) cross-section, (b) top-view, (c) picture.

II. Fundamentals

The integration of a phase tuning mechanism in one of the arms enables the tuning of the effective index difference between the two waveguides, and therefore the resulting coupling coefficient. The single-drive operation has been proposed, providing a reconfigurable splitting ratio by enabling a propagation constant difference in the pair of waveguides by means of a thermal-tuner placed on top of one of the parallel waveguides or by applying electro-optic effect to introduce a propagation constant difference between the waveguides [5-6]. However, the setting of the coupling coefficient introduces an accumulated phase shift to each output, that must be corrected for most applications.

In order to increase the capabilities of TDCs, the integration of a second phase shifter in the other waveguide provides symmetric loss compensation, as well as both, an independent beam splitting and additional phase shifting capabilities by inducing a differential and common phase shift, respectively, on each waveguide [3]. Figure 1 illustrates the cross-section, the topview and a fabricated picture of the integration of a DD-DC

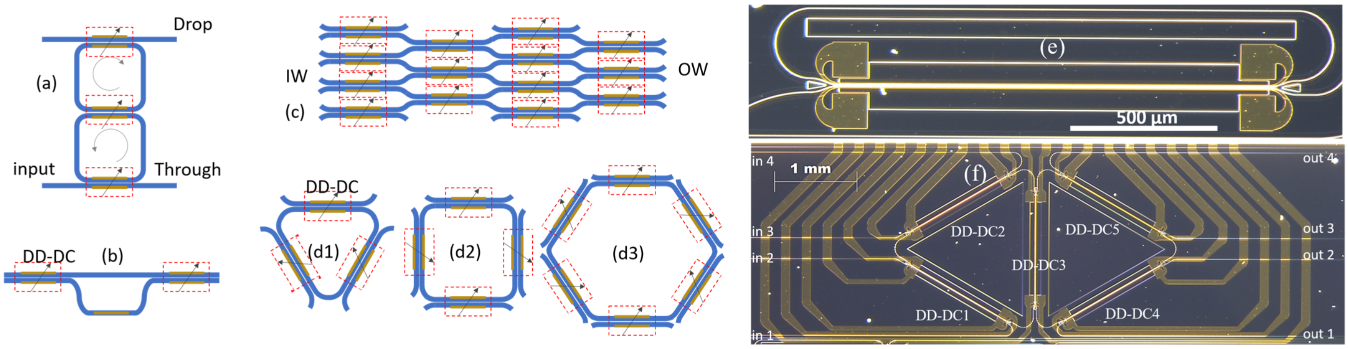

Fig 2. Photonic integrated circuits with Dual-Drive Directional Couplers. (a) add-drop, (b) Mach-Zehnder Interferometer, (c) arbitrary unitary linear multiport interferometer, (d) feedback-enabled waveguide meshes, (e) picture of fabricated ring resonator, (f) picture of fabricated two-cell triangular waveguide mesh arrangement.IW: input waveguides, OW: output waveguides.

in a silicon nitride platform. This additional feature can find applications in conventional and programmable PICs.

III. DD-DC in in Photonic Integrated Circuits

DD-DCs can be integrated as a building block providing a reconfigurable power splitting between two waveguides and an independent overall phase control. Figure 2 illustrates examples of PICs with at least one DD-DCs. In Fig. 2a-b two schematics of a second-order add-drop filter and an unbalanced Mach-Zehnder Interferometer, respectively, are shown. The DD-DC allows the configuration of the splitting ratio, directly linked to the extinction ratio of the optical filter. A single-drive configuration would lead to an arbitrary position of the resonance. However, the application of an extra common drive can place the resonance in the desired wavelength. A potential use of DD-DC is to perform as TBU in waveguide mesh arrangements, either in feedforward multiport interferometers [4] or in feedback-enabled meshes [2]. Fig. 2e-f illustrates the fabricated DD-DC assisting an optical ring resonator (ORR) and a two-cell triangular waveguide mesh arrangement.

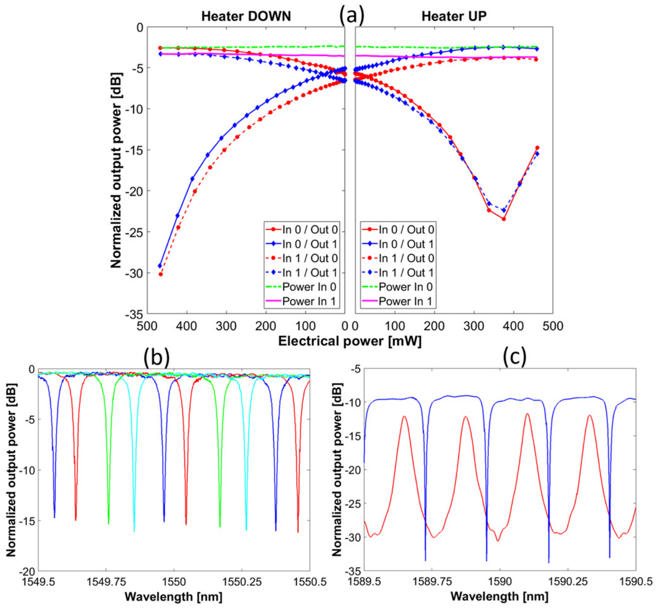

Fig 3. Experimental espectral response of (a) a DD-TDC when upper or lower phase shifters are actuated, (b) ORR with DD-TDC where a common drive is applied, (c) add-drop response programmed on a two-cell triangular waveguide arrangement with a programmed ORR.

Figure 3 illustrates three experimental responses of the fabricated devices. Fig. 3a illustrates the switching behavior of a standalone DD-DC when single-drive operation is applied to each arm. Note that the cross-port optical power goes in opposite direction when driving the upper and lower phase shifters. Next, in Fig. 3b, we show the response of an ORR assisted by a DD-DC. Once set the splitting ratio, we can move the position of the notch without altering the extinction ratio over the full Free-Spectral Range with an additional common-drive operation. Finally, Fig. 3c illustrates the through and drop responses of the two-cell arrangement represented in Fig. 2f, after its configuration as a first-order add-drop. We employed '*in* 1' as an input and '*in* 2' and '*out* 1' as the through and drop ports, respectively.

IV. Cooncl usions

We proposed and experimentally demonstrated the use of dual-drive directional couplers. We showed the configurations that allow the setting of splitting ratio and phase in a silicon nitride platform and their applications in programable photonic integrated circuits and waveguide mesh arrangements.

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