Modularly and Hybrid Integrated SiPh/InP Wavelength Blocker Switch for Metro Networks

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Abstract *We report the proof-of-concept functional demonstration of the first hybrid integrated wavelength blocker switch for metro network realized via hybrid integration of passive SiPh deMux/Mux AWGs and active InP SOA gates. Error free 10 Gbps/channel NRZ transmission per wavelength channel is demonstrated with <1.5dB power-penalty.*

Introduction

Boosted by cloud, IoT, and 5G applications next generation metro networks should be able to dynamically and efficiently handle large heterogeneous data traffics [1]. The PASSION project aims to implement SDN enabled network constituted by programmable metro nodes referred in this paper as Level-1 (L1) nodes as shown in Fig.1 to meet agile capacity demands of the metro network. The L1 node is a high capacity ROADM node which is equipped with color-less, direction-less and contention-less (CDC) capability and can transparently switch space division multiplexed (SDM) systems via Fan-out and Fan-in of multi-core fiber (MCF) bundles. The photonic space switch, handles the traffic flow in the spatial domain in the *express-in/out* path. As such it forwards an incoming *express-in* traffic either directly as by-pass traffic or forwards the incoming traffic to disaggregate switch in the drop path as *Drop traffic*. Similarly, it forwards *Add traffic* in the *express-out* path. Wavelength selective switches (WSS) play instrumental role in enabling dynamic reconfigurability and operate in the drop/add path functions as a disaggregating and aggregating switch respectively. Traffic with common destination are bundled and forwarded in the *express-out* path so that, at the next L1 node, express ports can transparently direct the traffic. On the other hand, the L1 node enables adding /dropping of traffic from/to access Level-2 (L2) network. Furthermore, local add/drop functionalities at L1 node are embedded at the WSS in the add directions via sliceable bandwidth variable transmitters (SBVT) and in the drop direction via multi-cast switches (MCS) and coherent receiver modules (CRM). As the network grows, new modules (grey boxes in Fig. 1) are added in the drop and add directions in a pay-as-you grow manner.

The functionality of monolithically integrated InP WSS PICs has been previously demonstrated [2]. However, high port count switch implementation is limited by wafer size on InP and insertion losses on monolithic SiPh switches [3, 4]. SiPh/InP hybrid integrated WSS is promising candidate to realize scalable switching functionality. Large scale integration of passives is possible on SiPh because of small bending radii [4]. In the hybrid WSS implementation SiPh enables large-scale integration of passive circuitry (AWG deMux/Mux) while SOAs on InP are used for fast switching functionalities while providing high extinction ratios. The SOAs on InP also provide boosting to compensate the excess loss within the hybrid WSS. In this paper, we present a proof-of-concept functional demonstration of the first hybrid wavelength blocker (WBL) switch based on SiPh AWG Mux/deMux and InP SOA gates. The integration is based on coupling InP/SiPh optical interfaces via a flip-chip bonding (FCB) technique. An error-free transmission of 10

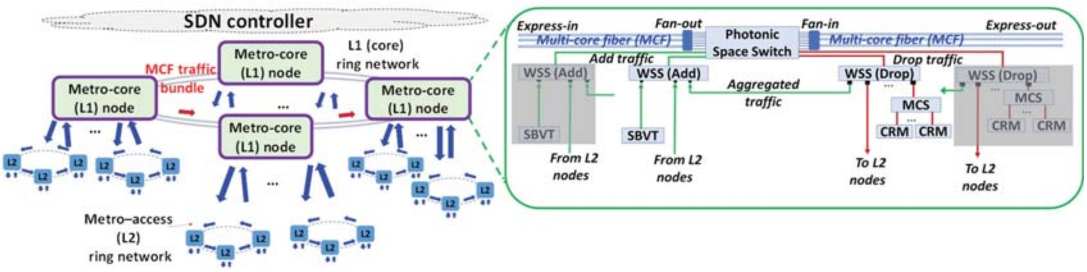

Fig.1 Schematic of SDN enabled L1(Metro core) node and L2 (Metro-access) ring networks

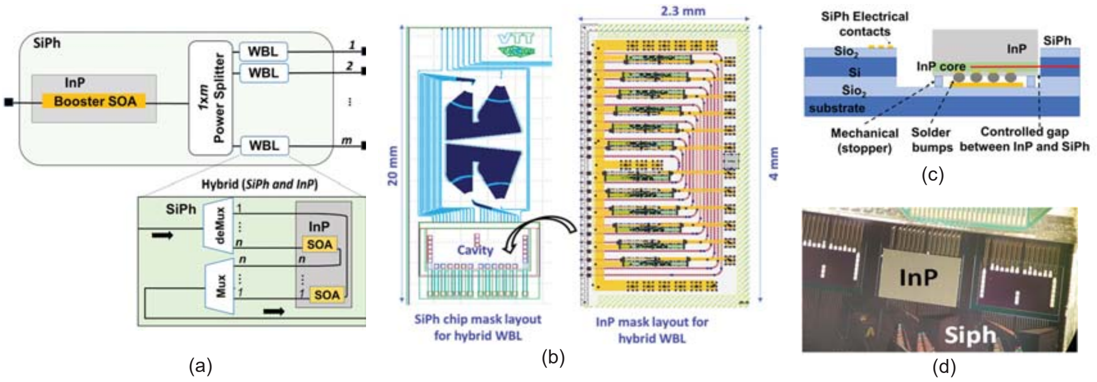

Fig.2 (a) Architecture of hybrid integrated wavelength selective switch; (b) mask layout of SiPh passives and zoomed out InP actives; (c) hybrid integration via FCB; (d) photograph of hybrid integrated WBL.

Gbps per wavelength channel is conducted.

Siph/InP hybrid integrated wavelength blocker switch

The implementation of hybrid wavelength blocker switch involves SiPh deMux/Mux AWGs and InP SOA switching gates which are then co-integrated via FCB. Fig.2(a) shows the schematic representation of a modularly integrated hybrid WSS. It is based on broadcast-and-select scheme, in which the WDM signal is broadcast by a 1x*m* splitter and is selected by *m* wavelength blocker (WBL) modules at the output ports. A hybrid WBL with *n*-channels uses 1x*n* deMux/Mux SiPh AWGs and *n* SOA switching gates for the *n* wavelength channels. The SOA switching gates are used to pass/block the desired wavelength at each of the output ports. The port count *m* of WSS is scalable by adding a WBL switching module.

In this presented work, a hybrid WBL module of *n*=12 wavelength channels (10 functional and 2 test channels) with a spacing of 0.8 nm is implemented. The mask layouts of 1x12 AWGs on SiPh and 12 SOA gate arrays on InP are shown in Fig. 2(b). The SOA switching gates on InP are placed in a U-shape where the input/output straight waveguides are accessed from the same side**.**

The scheme for FCB assembly process of the hybrid WBL is presented in Fig. 2(c). The InP chip is directly bonded with the SiPh cavity via a thermal compression (TC) technique. The Au-coated contact pads of the InP and Sn-coated SiPh contact pads are bonded together with the combined effect of elevated temperature of 220°C and applied bonding pressure. The presence of patterned mechanical stopper on SiPh for self-aligning alignment between the SiPh and the InP waveguide in the vertical direction was chosen. The top contact areas of the SiPh mechanical stoppers and recessed areas in InP chip are lithographically defined to overlap in order to ensure the alignment in the lateral direction. Vertical precision of +/- 500 nm is expected to be guaranteed. More optimization of the process is ongoing to achieve better performance with respect to this first trial results. Fig.2(d) shows the photo of the hybrid WBL switch after assembly.

Experimental Setup and Results

Fig. 3(a) shows the experimental setup for the characterization of SiPh/InP hybrid WBL switch. A tuneable laser source is used to generate light for wavelengths corresponding to the channels of the WBL. A 2^7-1 NRZ 10Gbps data is externally modulated and transmitted through the hybrid WBL switch. Lensed fibers are used to couple light in/out of the hybrid WBL switch.

Prior to the data transmission test, the hybrid WBL is electrically and optically characterized. Out of the 10 wavelength channels, 8 channels Ch1, Ch3,…,Ch9 are working and were characterized optically and electrically. Fig. 3(b) shows the I-V curve of the SOA gate switches before and after FCB. Comparing the I-V curve before and after integration, only a variation of 4.5 Ohms in resistance is observed. Fig. 3(c) show transmission characteristics of eight wavelength channels when the SOA gates are *On/ Off* for an input optical power of 0 dBm. Solid lines represent the WBL output when the gate SOA is *On* state and dashed line shows the WBL output when the gate SOA is in the *Off* state. Typical measured On/Off ratio is around 30 dBs.

The fiber-to-fiber losses for Ch1, Ch3, Ch6, Ch7, Ch8 range from 32.2 - 37.5 dBs. The current for each gate SOA is optimally tuned to minimize the fiber-to-fiber loss and the effect of back reflection on the hybrid WBL. An alignment accuracy of less than ± 0.5 µm in the vertical direction and an air-gap less than 2 µm in the horizontal direction is required to keep hybrid coupling losses below 3 dB. We believe the measured excess losses are the result of tight alignment tolerance which can be relaxed by using on-chip integrated spot-size converters [4].

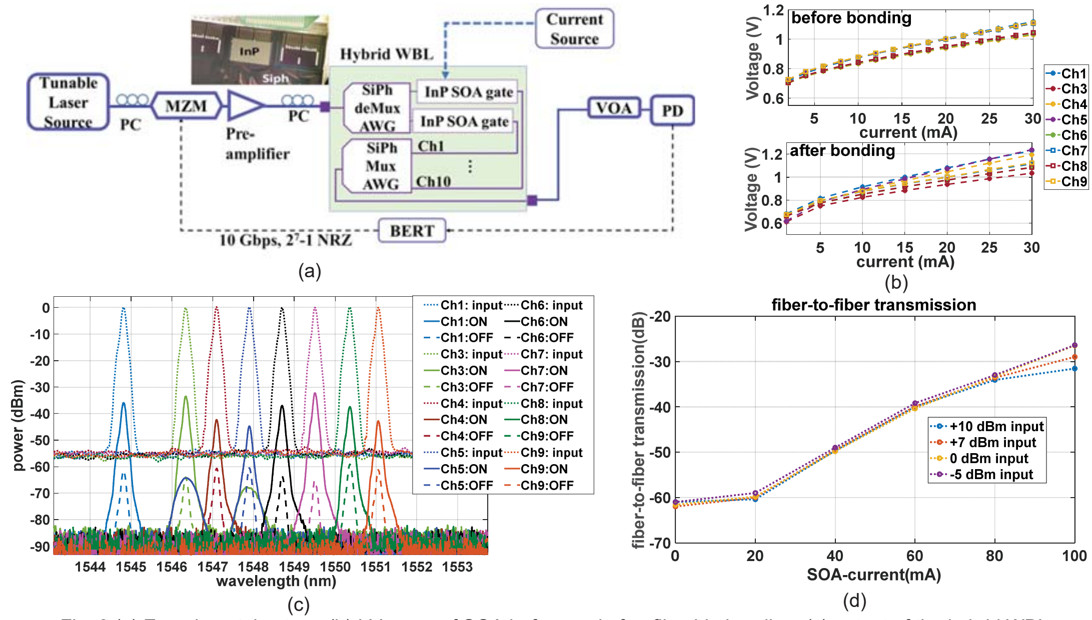

Fig. 3 (a) Experimental set-up; (b) I-V curve of SOA before and after flip-chip bonding; (c) output of the hybrid WBL switch ON/Off state; (d) fiber-to-fiber transmission and gain characteristics of SOA for Ch3;

In our future implementation, we plan to use angled waveguides to alleviate the impact back reflection and fully employ the gain of SOAs. Fig. 3(d) shows the gain characteristics of the gate SOA for Ch3 for varying current (mA) and varying input power. It clear that fiber-to-fiber loss varies from 60 dB at the absorption state of the SOA at 0 mA to 26 dB due to gain provided by the SOA at 100mA. The fiber-to-fiber loss is in the order of 33 dB at 80 mA for all input power values. The loss decreases to 26 dB at SOA current of 100mA ; for input power of 0 dBm and -5 dBm. Effects of SOA saturation on the fiber-to-fiber loss is slightly observed at 100 mA for input power of 7 dBm and 10 dBm resulting fiber-to-fiber losses of 29 dB and 31.57 dB respectively. Table.1 summarizes the fiber-to-fiber loss of each channel, and the corresponding current of the SOA gate. For the data transmission bit-error rate test, the input optical modulated data was boosted to 17 dBm to compensate the losses in hybrid WBL. After transmission through the WBL, the output signal is variably attenuated before being input to the receiver. Fig. 4 shows the BER measurements of five channels Ch1, Ch3, Ch6, Ch7 and Ch8 at 10Gbps 2^7-1 PRBS NRZ data. Error free transmission is obtained with power penalties ranging from 0.3 dB to 1.5 dB. Clearly opened eye diagrams of the five channels are obtained (Fig. 4).

Table 1 fiber-to-fiber insertion loss

Ch #	1	3	4	5
Fiber-to-fiber loss (dB)	36	33.4	42.3	44.8
SOA current (mA)	40	80	80	80
Ch #	6	7	8	9
Fiber-to-fiber loss (dB)	37.0	32.2	37.5	42.8
SOA current (mA)	90	40	80	28

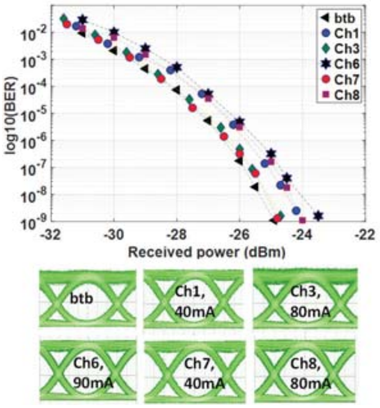

Fig 4 BER and eye diagram measurements.

Conclusions

In this paper, we presented the proof-of-concept functionality demonstration of the hybrid integrated WBL switch, which includes passive Mux/deMux AWGs in SiPh and InP gate SOAs aligned and assembled via flip-chip bonding. The demonstrated error free transmission of 10 Gbps per wavelength channel opens up to scalable switching functionality, which is pivotal for next generation modular metro-networks.

Acknowledgements

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