Low loss waveguides in standardized TFLN platform

Arno Mettraux*, Alberto Della Torre, Jacopo Leo, Fatemeh Arefi, Homa Zarebidaki, Gregory Choong, Mattia Orivetani, Yves Pétremand, Ivan Prieto, Olivier Dubochet, Michel Despont, Hamed Sattari
Swiss Center for Electronics and Microtechnology (CSEM), Neuchatel, Switzerland
*arno.mettraux@csem.ch

ABSTRACT

We report the propagation losses of waveguides in thin-film lithium niobate photonic chips in the telecom C-band. The width of the waveguide was varied from 0.5 to 2.5 µm over different runs in a span of 2 years. The losses obtained were as low as below 0.5 dB/cm in the latest run for waveguides width of 1 µm or larger.

Keywords: Photonic Integrated Circuits, thin-film lithium niobate, resonator, propagation losses

1. INTRODUCTION

The domain of Photonic Integrated Circuits (PICs) is of great importance for telecommunications and data transmission, and the propagation loss is an essential parameter of quality for the different PICs platforms. Thin-Film Lithium Niobate on insulator (TFLN) is a promising and emerging platform for PICs due to its high first-order electro-optic coefficient, large nonlinear optical coefficient, and low propagation loss [1],[2]. TFLN enables lower losses and reduced power consumption thanks to its unique properties. However, as a young photonic platform, it requires significant development and improvements to reach maturity. CSEM is developing and offering an open-access TFLN PIC foundry with the aim of supporting the high demand in the PIC industry and make it more accessible.

The development of a reliable and large-scale fabrication technology assuring a low loss optical propagation is one of the key steps in the maturation of TFLN platform. For optical routing, a single-mode waveguide is preferred, but it comes with higher loss compared to a wider waveguide [3],[4]. In this paper we report the evolution of propagation losses of waveguides with widths ranging from 0.5 µm to 2.5 µm, single mode to highly multi-mode at 1550 nm, over 3 different manufacturing runs, and we show a noticeable improvement in fabrication quality over time, as evidenced by the decrease in propagation losses between the different runs.

2. TFLN PLATFORM

The fabrication of the photonic components is done on 150 mm TFLN wafers at CSEM [5]. The layer stack consists of a 600 nm thick mono-crystal x-cut $LiNbO_3$ layer, on top of a 4.7 µm buried thermal oxide (BOX). An oxide cladding is added at the end on top of the $LiNbO_3$ layer to protect it and enhance fiber to chip coupling efficiency. Figure 1 (a) presents a schematic of the cross-section of our technology. The platform includes 3 different types of waveguides (WG1, WG2 and WG3), two different metal layers (MET1 and MET2) and a via connecting them. The clad opening allows for the connection of probes to the metal pads to apply a voltage between metal paths, which is used to modulate light. Depending on the waveguide width, the different waveguides can be used to route light ranging from visible to infrared spectrum, thanks to lithium niobate's wide transparency window. All these designs enable us to manufacture a wide range of active and passive building block components, such as edge and grating couplers, multimode interference couplers (MMIs), directional couplers, phase shifters and EO modulators. Eventually, the chips are singulated using a deep reactive-ion etching (RE) technique to ensure smooth facets for high-efficiency coupling through edge couplers.

To develop a robust PIC platform, it is crucial to carefully monitor the optical loss of the waveguide used for routing, as it represents an overall indication of the chip's performance and the quality of the device layer's fabrication. For the measurement of propagation losses, we use a series of ring resonators, racetrack resonators and spiral waveguides, and vary the waveguide width and resonator gap [6].

(a) (b) (c)

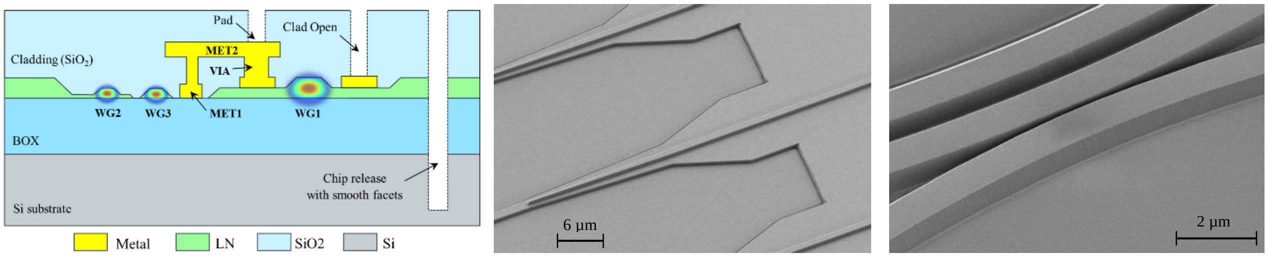

Figure 1. (a) Schematic of the TFLN PIC platform's technology cross section (b) SEM image of a double-layer edge couplers (c) SEM image of waveguides with small sidewalls and narrow gaps. Excellent layers overlays and smooth and dense device layer patterning are showcased.

3. MEASUREMENTS AND RESULTS

For the measurement of the propagation losses, we devised three parallel methods. The first one is the use of a series of increasingly longer waveguides forming spirals on the chips. These spirals have lengths ranging from 30,000 µm to 60,000 µm and by comparing the optical transmission for spiral waveguides of increasing length, we expect the losses to increase linearly with the length, and from that we can have a first estimation of the propagation loss of the waveguide. This method is relatively straightforward, but subject to variations, especially to differences in the quality of the coupling between the edge couplers and the optical fibers, and the fidelity of the edge couplers.

The second method implies the use of several ring resonators, with increasing gap between the ring and waveguide to vary the coupling mode of the resonator. From this variation, we can identify overcoupled and undercoupled resonators and calculate the propagation losses in the ring. This method is quite reliable but requires more extensive measurement and data analysis. The results are shown in Figure 2 (a).

The third method implies racetrack resonators, with a straight path with increasing length over the different racetracks. This allows us to estimate the propagation losses in the straight path of the waveguide, at the condition that we either already have an idea of the coupling mode thanks to the ring resonators, or that we have a first estimation of the propagation losses thanks to the spirals. Once the propagation losses of the racetracks are known, we can estimate the straight losses by varying the straight path of the racetrack.

By using these 3 methods, we measured the propagation losses of waveguides with varying widths over 3 different fabrication runs. A decreasing loss trend was observed in the most recent run compared to the oldest, showing a significant improvement of the fabrication method. Waveguides with 0.8 µm width had losses decreasing from 2.7 dB/cm down to 0.67 dB/cm. Expectedly, the wider waveguides present lower losses, as they guide the fundamental mode with less light interaction with the waveguide sidewalls where scatter the light due to the roughness. Still, for waveguides of 1 µm to 2.5 µm we also observe a decrease of losses over the different runs, going down from 0.69 dB/cm to 0.26 dB/cm in 2.0 µm waveguides.

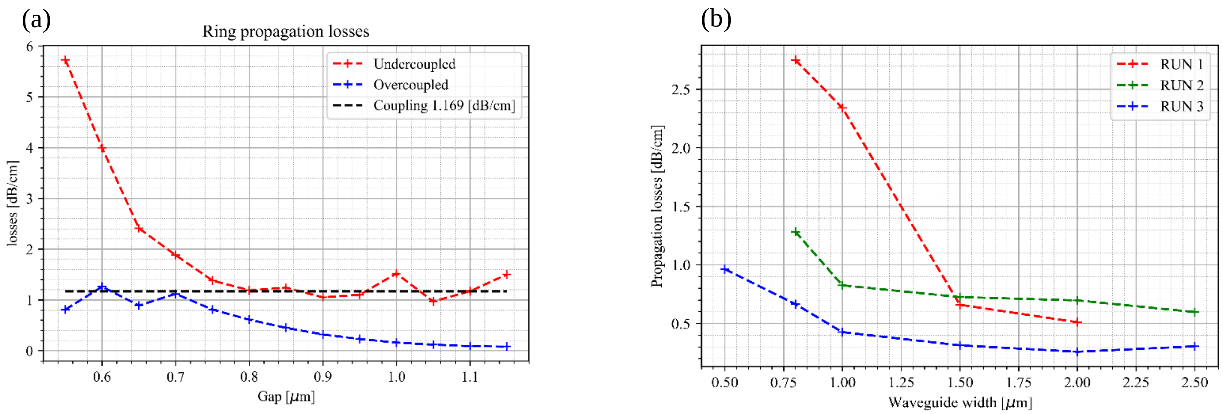

Fig. 2. (a) Measurement of propagation losses in 200 µm radius ring resonators from RUN 2 with increasing gap with waveguide width of 800 nm. The coupling line corresponds to the critical coupling and shows the estimated propagation loss of the waveguide. (b) Mean propagation losses in waveguides of different widths over 3 fabrication runs.

4. CONCLUSION

We presented progressive waveguide loss improvement in three fabrication runs through three measurement methods relating our manufacturing quality progress from run to run. Waveguides with different widths were measured showing a noticeable decrease of the losses in the most recent run. For 0.8 µm wide waveguides, the losses dropped from 2.7 dB/cm in the first run down to 0.67 dB/cm in the latest. These results demonstrate significant improvements in fabrication quality, promising progress toward a reliable TFLN PIC foundry.

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