Characterisation of Micro-Transfer Printed cm-scale Lithium Niobate on a Silicon Nitride platform

Margot Niels(1,*), **Tom Vanackere**(1,2), **Stijn Poelman**(1), **Tom Vandekerckhove**(1,2), **Günther Roelkens**(1), **Maximilien Billet**(1), **Bart Kuyken**(1)

1. *Photonics Research Group, INTEC, Ghent University - imec, 9052 Ghent, Belgium*
2. *OPERA-Photonique CP 194/5, Université Libre de Bruxelles, 1050 Brussels, Belgium*

**Margot.Niels@UGent.be*

Abstract: To introduce high-speed modulation on CMOS-compatible platforms, heterogeneous integration of electro-optic materials is essential. We demonstrate a process to enable the printing of up to cm-scale lithium niobate devices and show low propagation losses.

1. Introduction

Photonic integrated circuits have been designed on CMOS-compatible platforms like silicon (Si) or silicon nitride (SiN) for many years. This allows for seamless integration with electronic components and makes it possible to be processed in already existing foundries. While these platforms excel in accommodating passive structures, they often lack critical components like intrinsic second-order nonlinearity or gain. Lithium niobate (LN) offers promising features, including nonlinearity, acousto-optic, pyro-electric and strong electro-optic effects [1], that could fill this gap by being heterogeneously integrated. Integrating e.g. LN modulators onto CMOS-compatible platforms could therefore enable efficient optical modulation for advanced communication systems.

Various techniques already exist to integrate a material in a SiN platform: flip-chip bonding, where a prefabricated device on chip is directly bonded to the target wafer; epitaxial growth, where a full layer of the device material is grown on the target wafer, after which the device is patterned; die-to-wafer or wafer-to-wafer bonding, where the device material is first bonded on the target wafer, then the substrate is removed and the device is patterned. A more recently developed technique is micro-transfer printing (µTP) [2], where devices are fabricated on a source wafer and then pick-and-placed to a target wafer. This method allows for batch fabrication and testing of devices on a source wafer before transferring them to the target wafer (known-good die principle) without disrupting processing lines of the target wafers. For LN specifically, mostly bonding [3, 4] has been used to combine the two platforms. Sporadically, flip-chip bonding [5] and also µTP [6, 7, 8, 9] are utilised. Transfer printing, which preserves CMOS foundry processes, facilitates large-scale, cost-effective manufacturing while incorporating nonlinear functionality on the chip, enhances the accessibility of the LN platform [10].

Earlier research showcased the potential of transfer-printed LN for high-speed modulating a SiN platform [7]. Nonetheless, there remains room to enhance the modulator efficiency. Since the half wave voltage is directly inversely proportional to the interaction length, scaling up the length of printed devices consequently reduces the power consumption, leading to a competitive heterogeneous CMOS platform. Nevertheless, dealing with heterogeneous integration of up to cm-scale devices remains challenging. Here we demonstrate integration of such devices on SiN while maintaining decent propagation losses.

2. Micro-transfer printing of cm-scale lithium niobate thin films on SiN waveguides

Following previous process developments reported in [10], up to cm-scale LN coupons are prepared and transfer printed on a SiN platform on which propagation loss test structures are patterned. However, to minimise the reflection at the facets, this time, angled facets are introduced.

As a first test, coupons with different lengths are printed on identical SiN waveguides to deduce propagation losses, as shown in Figure 1a. Since only the length of the LN is differed, the propagation losses attributed to the LN can be derived from transmission measurements (cut-back method). All lengths of coupons are printed twice to have a backup and estimate the reproducibility. In a second test, the facet losses are examined by printing several shorter coupons in a row. Again, a copy of the structure was foreseen to have a backup, but to diversify, a different amount (three and seven) was printed on both structures. By doing so, it can both be compared to the reference and each other. Figure 1b shows the chip after printing those structures. Both printing routines where, in this case, carried out without any adhesive layer.

3. Practical results and future work

After printing and removing their encapsulation, the aforementioned structures are measured. Transmission measurements are carried out at a wavelength of 1550 nm and the results are collected in the graphs below (see Figure 2). It should be noted that for the propagation loss structures, only the values for the successfully printed coupons are displayed. The yield in this case was 90%. The coupon that was not included, broke in several places, thus showed much lower transmission.

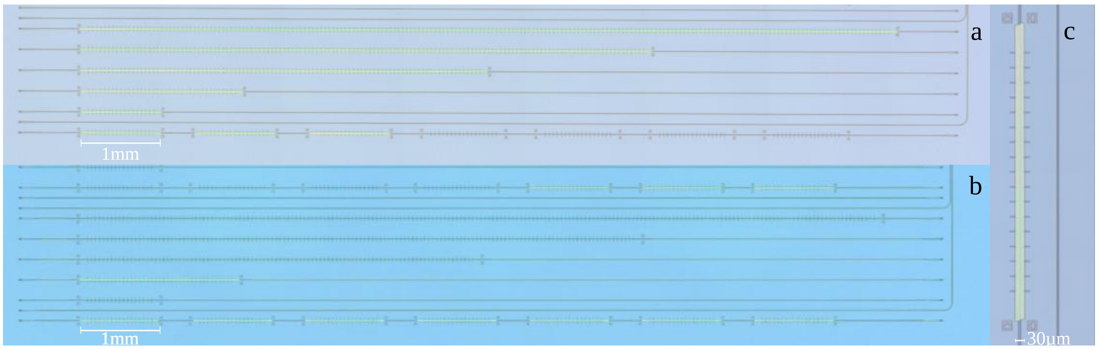
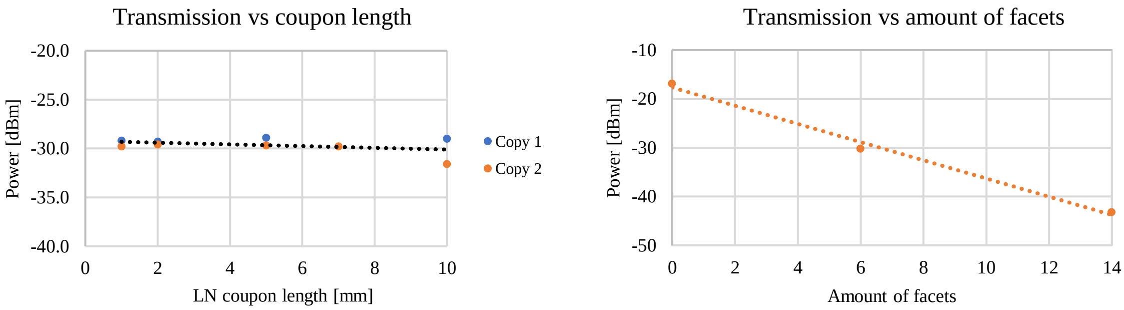


Figure 1: Printing of loss structures for measuring propagation losses (a) and facet losses (b) and a zoomed version of a 1mm coupon (c)

When the values for the first measurement run are plot (Figure 2a), a linear fit is added for the average of each coupon length. The gradient of this fit shows that the propagation losses are negligible, or at least not measurable with the used setup to which we attribute around 1 dB precision. The second measurement run shows the transmission power values with respect to the amount of facets the light passes by (Figure 2b). Comparing all different configurations and neglecting propagation losses, the facet losses are 1.9 dB/facet on average.



(a) (b)

Figure 2: measurements to deduce the transmission loss and facet loss for all well-printed coupons

With the promising low propagation losses of less than 1 dB/cm, one can imagine that the road towards integrated LN modulators with long light-matter interaction on a CMOS-compatible platforms is now paved. Our upcoming experiments will initially focus on validating the electro-optic effect by building heterogeneous SiN/LN Mach-Zehnder interferometer (MZI) modulators. Subsequently, the interaction length will be extended to achieve a CMOS-compatible power consumption level.

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