Recent progress in heterogeneous integration on the silicon nitride platform using micro-transfer printing

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Abstract:

Photonic integrated circuits enable the miniaturization of photonic systems by integrating key optical functions on a chip. While CMOS compatible silicon and silicon nitride are very efficient platforms for passive circuits, they lack active key functionalities for the realization of a full system on a chip. A versatile solution is to use micro-transfer printing for heterogeneous integration of active devices on such platforms. Here we present the recent advances of micro-transfer printing on silicon nitride and discuss the remaining challenges.

Introduction:

Photonic integrated circuits enable the miniaturization of key optical functions. Silicon (Si) and silicon nitride (SiN) photonic platforms have proven their maturity based on their compatibility with CMOS technology, giving rise to low cost, compact and scalable optical systems on a chip. Furthermore, in the case of SiN, the wide transparency window extends across the visible and near-infrared spectral regions [1], making it a strong candidate for numerous applications, including telecom/datacom, quantum technologies and bio-sensing. However, the SiN photonic platform lacks some important functionalities such as optical amplification, modulation, photodetection and intrinsic second order nonlinear frequency conversion. A versatile solution is to heterogeneously integrate devices, based on different materials, using the technique of micro-transfer printing [2], [3]. As such, diverse functionalities can be added to the SiN platform at the back-end level to retain the CMOS compatibility. In this presentation, several recent integration demonstrations of active devices on SiN using micro-transfer printing are discussed to show the current state-of-the-art. We will also discuss the mandatory characteristics requested for active devices heterogeneous integration using micro-transfer printing such as SiN-to-device light coupling, device and circuit wavelength compatibility, post-integration processing, limit of printed device sizes and multiple heterogeneous integrations.

Methods/results:

Micro-transfer printing is a versatile heterogeneous integration technique based on the back-end transfer of pre-processed devices on a host target.

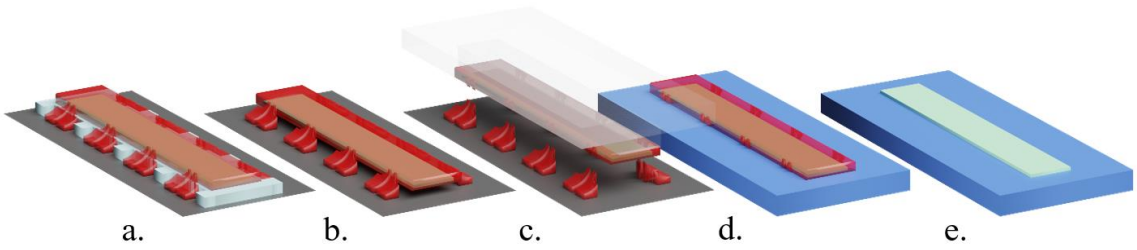

Fig. 1. Description of the steps involved in the micro-transfer printing operation, from device preparation (a), releasing (b), picking (c), printing (d) and encapsulation removal (e).

The devices are fabricated on their native substrate and encapsulated in a mechanical structure (Fig. 1.a). They are released using a selective etchant and can be left suspended while attached to the substrate via an array of mechanical tethers (Fig.1.b.). At that step, the suspended devices, commonly called coupons, can be picked-up (Fig.1.c.) with a polymer (elastomer) stamp and be transferred on a host substrate. The stamp is smoothly retracted from the coupon, enabling the printing of the device (Fig. 1.d.). At a last step, the encapsulation is removed, finalizing the process of micro-transfer printing.

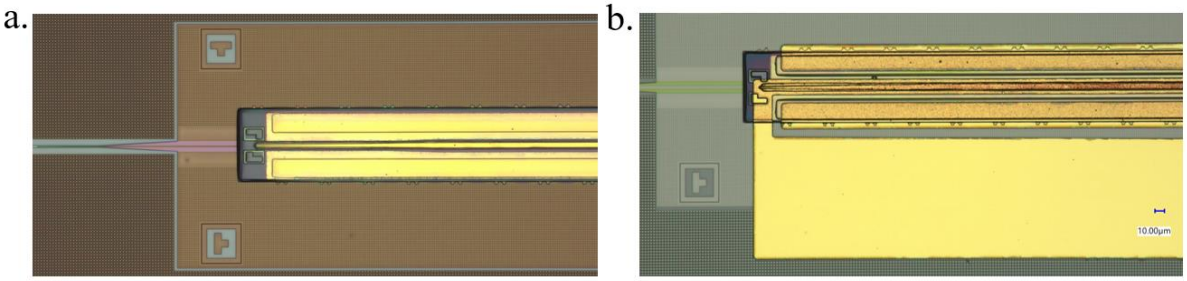

Fig. 2. Integration of an optical amplifier on a SiN circuit before (a) and after (b) post-printing contact pads fabrication.

For some devices, for instance optical amplifiers, an extra step of metallization is required in order to fabricate driving electrical contact pads. This is done post-printing using a regular lithographic process followed by metal deposition and lift-off. The Fig. 2. shows for example the integration of a semiconductor optical amplifier on the silicon nitride circuit before and after the final post-printing metallization of the metal contact pads. We can note that doing the metallization after the printing maintains the CMOS compatibility of the general process, since this can be done out from the CMOS fab.

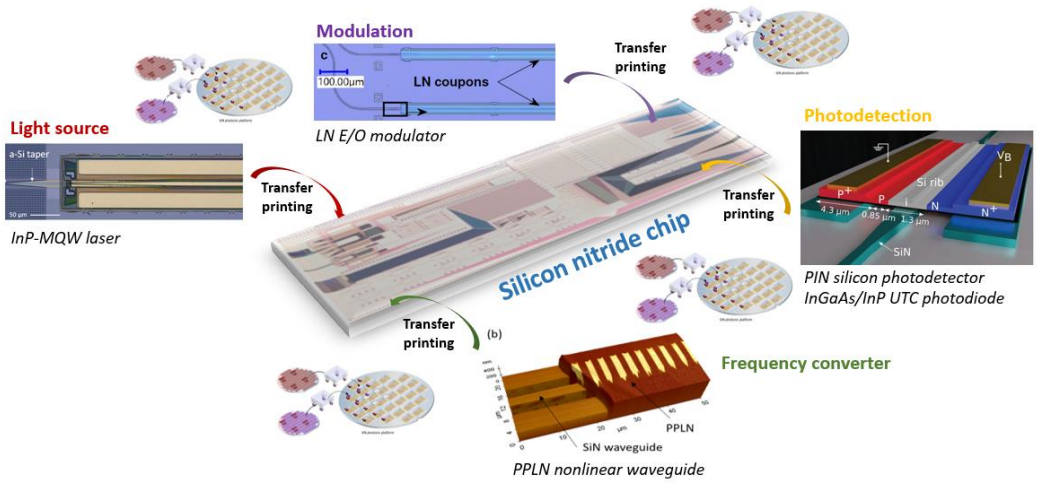

Fig. 3. Generic view of the heterogeneous integration of active devices on a SiN wafer via micro-transfer printing. The microscope pictures of transfer printed devices are coming from independent works from UGent-imec reported in the literature (see Table 1).

In the past years, micro-transfer printing has proven its versatility by several demonstrations reported in the literature. Here we focus on demonstrations done at UGent-imec on the silicon nitride platform. Fig. 3. shows a generic view of the possibilities offered by micro-transfer printing on that platform, by illustrating several examples of devices integration. Up to day, studies were conducted on the integration of functionalities not offered by the intrinsic SiN. An overview of the demonstrated devices integration demonstrated in the literature is shown in the table 1. The main objective is to fill the functionalities lacking from SiN, such as optical gain and laser sources, high speed modulators, nonlinear converters (second order nonlinearity) and detectors. With the help of micro-transfer printing, we successfully demonstrated the integration of the requested functionalities toward the building of a full integrated optical system on a SiN chip. These combined demonstrations have however not been done yet, due to additional compatibility requirements asking for some

more design challenge. Furthermore, another key demonstration would be the scalability of micro-transfer printing integration technique of such systems, which is fully compatible with this technology.

Property / functionality	SiN	Demonstration of micro-transfer printed devices at UGent-imec
Transparency window	0.25 to 5 µm	-
Propagation losses	0.01 to 0.1 dB/cm	-
Two-photon absorption	Negligible	-
Industry status	Low-volume production	-
Optical gain	Absent	InAlGaAs MQW [4] / GaAs [5], [6] / GaN [7] amplifiers
Fast modulation	No Pockels, no carriers	Lithium niobate electro-optic modulators [8], [9], [10]
Nonlinear conversion	no intrinsic $\chi^{(2)}$, $\chi^{(3)}$	PPLN [11] / GaP [12], [13] ($\chi^{(2)}$ *and* $\chi^{(3)}$) *waveguides*
Photodetection	No carriers	pin-Si photodiodes (slow) [14] / InGaAs UTC-photodiodes (fast) [15]

Table 1. Summary of the properties and the associated possible functionalities of the SiN. Example of devices transfer printed on the SiN platform at UGent-imec.

Conclusion:

In conclusion, we discussed the heterogeneous integration of active devices filling the gap of lacking functionalities from the SiN platform using micro-transfer printing technology. The demonstrations of devices integration done at UGent-imec are referenced to exemplify the possibilities offered by this technique. Two remaining challenges will also be discussed:

(a) The demonstration of fully integrated systems combining a full set of functionalities (light generation, modulation, detection…) on the same chip.

(b) The scalability of the heterogeneous integration of devices via micro-transfer printing.

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