Invited Paper

Towards scalable heterogeneous integration of thin-film lithium niobate on silicon photonics using microtransfer printing

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ABSTRACT

Lithium niobate photonics provides a low-loss platform with great properties for high-speed modulation, wavelength conversion and quantum optics. Micro-transfer printing allows scalable integration with CMOS compatible silicon photonics technologies.

Keywords: Integrated Photonics, Silicon Photonics, Lithium Niobate, Heterogeneous Integration, Modulation

1. INTRODUCTION

With increasingly complex demands from photonic systems, comes a desire to try and integrate more and more on the same chip. This integration can reduce losses and increase performance as well as speed and stability. All important properties for the increasing range of applications industry is targeting, including data- and telecom,[1] LIDAR,[2] sensors[3] and medical devices,[4] optical neural networks[5] and on-chip (quantum) computing.[6] These applications also require an increasingly divers set of properties that makes it difficult to find one photonics plaform that has them all. Because of that, people are looking towards heterogeneous integration to be able to exploit the advantages of different platforms at the same time on the same chip. Lithium niobate (LN) has shown to be an excellent photonics platform for high-speed modulation[7,8] low-loss passive components,[9] and nonlinear processes.[10,11] Due to lithium contamination it is however difficult to convince commercial CMOS foundries to start processing LN. In order to try and continue to leverage the industrial maturity of the CMOS manufacturing industry, multiple groups are looking into the heterogeneous integration of lithium niobate on silicon (Si) and silicon nitride (SiN) integrated platforms.[12,13] There are different ways of heterogeneously integrating LN, we will be discussing micro-transfer printing (µTP) as a way of not only integrating LN but a whole range of different materials that can enrich the silicon photonics integrated platform in a scalable way. We also show recent demonstrations of high-speed modulation and second order nonlinearities demonstrated using this integration technique.

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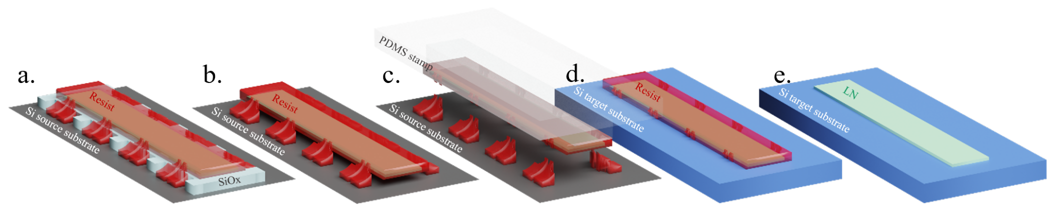

Figure 1. Process flow for printing of LN (a) The patterned device (LN) on top of it's release layer (Silicon oxide) is encapsulated in photoresist to tether it to the substrate. (b) The oxide release layer is etched away using Hydrofluoric acid, creating suspended devices. (c) The PDMS stamp picks up the coupon, breaking the tethers in the process. (d) The coupon is printed onto the target wafer. (e) The photoresist encapsulation layer is removed to expose the transferred device. Taken from 15

2. MICRO-TRANSFER PRINTING FOR VERSATILE AND SCALABLE HETEROGENEOUS INTEGRATION

In µTP one first patterns a device or thin film on top of a release layer that can be selectively etched away. The entire process is schematically depicted in Fig. 1. Before removing the release layer we make sure the device or thin film is securely anchored to the substrate using tethers that are strong enough to keep the 'coupon', as we call it, in place during the release but are easily broken afterwards. The suspended device is then picked up using an elastomeric PDMS stamp. By controlling the velocity at which the stamp is moving we can control the amount of adhesion between the device or thin film and the stamp. This allows us to pick up the coupons and break the tethers while depositing it on a target wafer. For the bonding process we tend to use an adhesive layer of Benzocyclobutheen (BCB) but also frequently print without the use of an adhesive layer. While there is process development needed for every new material, it is a very versatile technique that has been used to heterogeneously integrate InP, GaAs, AlGaAs, GaSb, GaP, LN, Si, Ce:YIG, several 2d materials and single photon sources as well as whole electronic integrated circuits 14. After an initial alignment of the angles, the printing process is relatively quick for our tabletop tool, printing one coupon every couple of minutes with an alignment accuracy of 0.5 µm (3 σ).

3. HIGH-SPEED MODULATOR

Using this technique we created a proof of concept high-speed modulator on SiN. The device was patterned using electron beam lithography in 300 nm thin SiN. A slab of 300 nm LN was printed on top creating a hybrid waveguide mode. The coupons were printed with tapers on both interfaces to reduce coupling losses into the LN hybrid mode. GSSG differential electrodes were patterned with a design meant for high-speed driving. The devices were electrically and electro-optically characterised. The 2 mm long device has an insertion loss of 3.3 dB and an extinction ratio of 39 dB. The $|S_{21}|$ measurement show a bandwidth exceeding 50 GHz. Fig. 2 shows a summary of the device, including measurements of the characteristic impedance around 100 Ω, the electrical attenuation attenuation and effective index important for velocity matching in the travelling wave design are also plotted. Using this device open eye diagrams with Bit Error Rates (BER) below the KP4 Forward Error Correction limit have been transmitted at up to 70 Gb/s. We are working on a next iteration that will be longer and more efficient.

4. SECOND HARMONIC GENERATION

We also demonstrated the nonlinear properties of LN[16] through heterogeneous integration. Before fabricating the coupons, we first poled the LN periodically with a poling period of 3.5 µm. We then created 1 mm long coupons for transfer printing. A similar waveguide structure as for the modulator consisting of a 300 nm SiN waveguide with a 300 nm LN thin film slab on top is used to convert light from the infrared to the visible. As shown in Fig. 3(b) the poling survives the µTP process well. Phase matching is observed at a pump wavelength of 1620 nm which is converted to the visible at a normalized conversion efficiency of 2500 %/Wcm^2 as shown in Fig. 3(d).

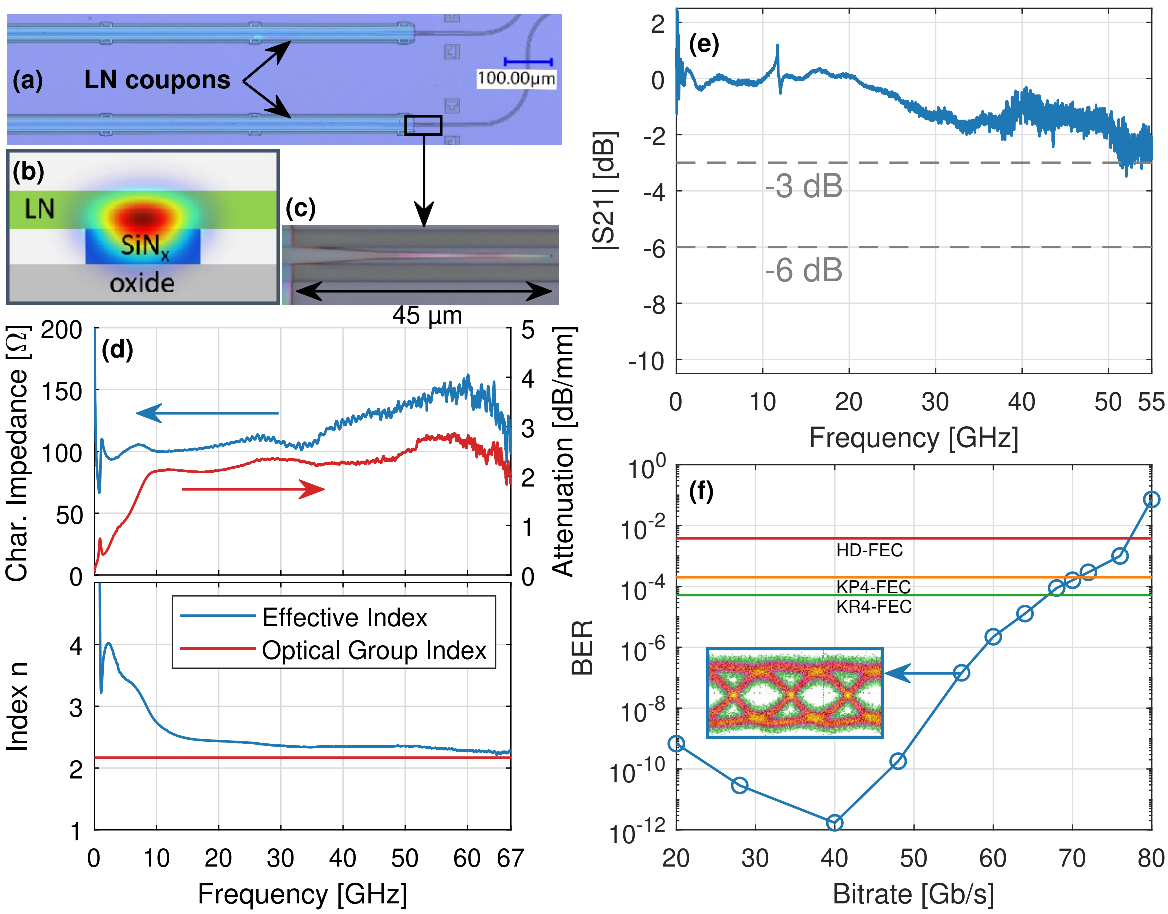

Figure 2. (a) Microscope image of half of the printed LN coupons in the Mach-Zehnder structure. (b) Hybrid SiN/LN mode profile (c) Zoom of the taper (d) Electrical parameters of the differential mode in the electrodes. (e) Small signal response of the modulator (f) NRZ bit error rates of the eye diagrams generated using the modulator compared to bit error rates required for conventional forward error corrections. Taken from Ref. 12

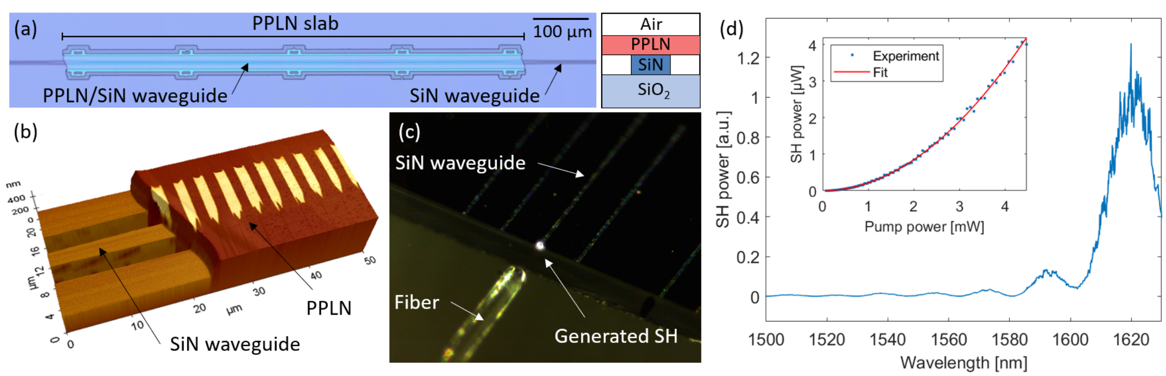

Figure 3. (a) Microscope image of a transfer-printed PPLN slab onto a SiN waveguide, with a cross section on the right. (b) AFM image with PFM overlay, showing the periodically inverted domains. (c) Picture of the generated SH at the cleaved SiN edge facet. (SH looks white due to camera's color filters). (d) SHG spectral response, inset: on-chip SH power vs. on-chip pump power, with a quadratic fit. Taken from Ref. 17.

5. CONCLUSIONS

We show promising results demonstrating the capability of micro-transfer printing to heterogeneously integrate LN onto different silicon photonics platforms. By using this technique we hope to bring a scalable and versatile path towards wafer scale integration of LN on silicon photonics. Here we included demonstrations of both a high-speed electro-optic modulator and efficient second harmonic generation using µTP. The quality of these devices are close to expected values from simulations demonstrating the quality of the material is preserved during the heterogeneous integration process.

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