Pillar-Based High-Yield Heterogeneous Integration of Lithium Niobate and Gallium Phosphide Thin Films

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Abstract: Several established photonic platforms lack a nonzero Pockels and nonlinear coefficient. We developed a micro-transfer printing method to heterogeneously integrate thin-film lithium niobate and gallium phosphide with an experimentally shown transfer yield of near-unity.

Introduction

Photonic integrated circuits benefit greatly from $\chi^{(2)}$ processes such as high-speed Pockels modulation and efficient frequency conversion. While the silicon and silicon nitride platforms have both established themselves as mature photonic platforms, they naturally lack a $\chi^{(2)}$ nonlinearity due to their inversion symmetry. A solution is provided by heterogeneous integration of thin films with large Pockels and nonlinear coefficients through micro-transfer printing (µTP) [1–3]. This pick-and-place method relies on kinetically controlled adhesion to a polymer stamp that picks a suspended device film, referred to as a coupon, from a source wafer and prints it onto the intended target chip. Especially with very thin films, the challenge often lies in the preparation of the source chip to fully suspend large-area coupons. Their flexibility severely limits the area that can be suspended, as these collapse to the substrate and prevent reliable pick-up. In this work, we developed a versatile source preparation method to transfer print large-area thin films and experimentally obtain a near-unity transfer yield of thin-film lithium niobate (LN).

Pillar-based micro-transfer printing method

Similar to a conventional transfer printing process, we start from a source wafer with the to-be-transferred thin film on top of a sacrificial release layer. The thin film is etched through dry reactive ion etching into rectangular coupons with anchor points known as tethers, to the side. Simultaneously, holes are etched locally inside the coupon, providing access to the layer beneath (Figure 1a). Through the holes, the release layer is partially etched, creating voids below the thin film (Figure 1b). These are filled with a support material e.g. photoresist, establishing

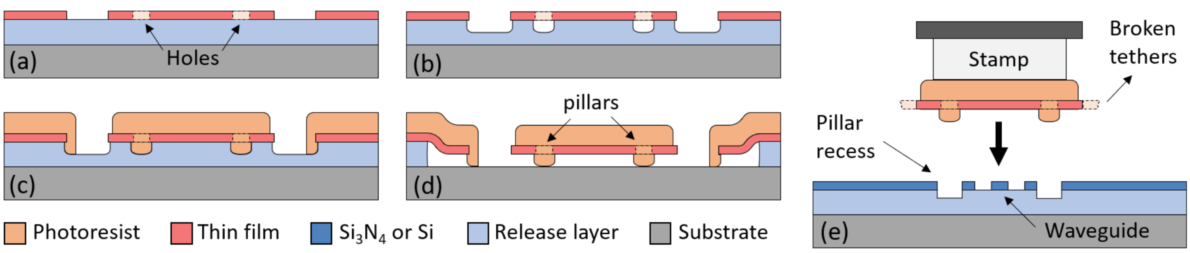

Fig. 1. Conceptual sketch of the pillar-based µTP method: (a) Patterning of coupons with holes (tethers not depicted), (b) Partial etch of release layer below the holes, (c) Filling the voids with support material, (d) Etching the release layer to suspend the coupon, (e) Pick and place of the coupon with a polymer stamp onto a target chip with dedicated pillar recesses.

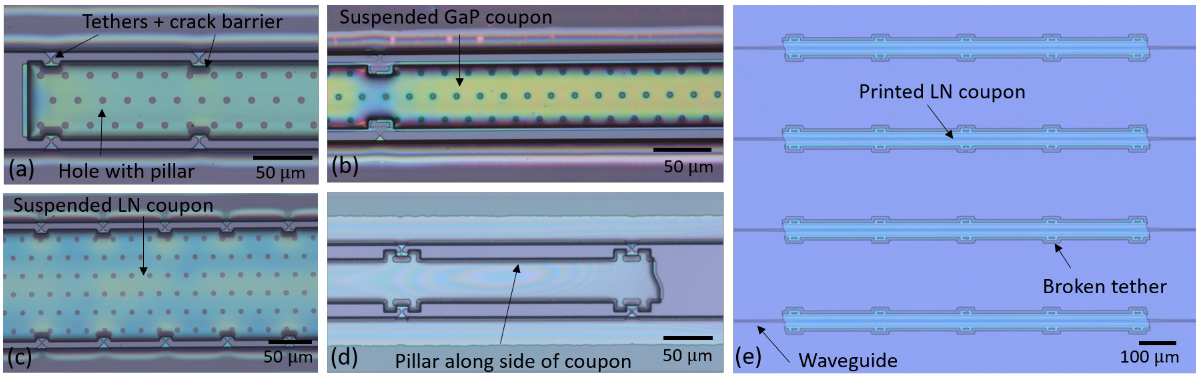

Fig. 2. Microscope pictures of LN and GaP coupons: (a) Suspended LN coupon, (b) Suspended GaP coupon, (c) 120 µm wide suspended LN coupon, (d) Suspended LN coupon with pillars along its sides, (e) Four LN coupons printed on silicon nitride waveguides.

pillars underneath the coupon (Figure 1c). Additionally, depositing support material on top increases the coupon strength, facilitating its suspension. Lastly, the release layer is etched away, resulting in a suspended thin film that rests on top of the pillars, preventing its collapse onto the substrate (Figure 1d). Due to the small contact area and bad adhesion of the pillars to the substrate, the coupon can easily be picked and placed with a polymer stamp onto the intended target, containing locally etched recesses to fit the pillars (Figure 1e). Afterwards, the support material is removed from the thin film e.g. through a standard cleaning process in case of photoresist, and the printed thin film remains.

Heterogeneous integration of lithium niobate and gallium phosphide

While the method has been developed for LN, it can readily be adapted to other materials. Figure 2a and 2b show a suspended coupon of 300 nm thick lithium niobate and 300 nm thick gallium phosphide (GaP), respectively, with dimensions 60 µm x 1 mm. The coupons are secured to the source chip through side tethers, accompanied by previously reported crack barriers to avoid crack propagation during pick-up [4]. A grid of holes with pillars is visible inside the coupons that keeps them suspended. In contrast to typical µTP techniques, the suspension no longer relies on the tethers, but solely on the pillars. Therefore, the coupon area can easily be increased without the film collapsing to the substrate by adding more pillars, as demonstrated by the suspended 120 µm x 1 mm lithium niobate coupon in Figure 2c. While referred to as pillars, their shape can be freely changed and for a sufficiently narrow coupon, moved to the side (Figure 2d). To demonstrate the high yield, 25 lithium niobate coupons were subsequently printed on top of silicon nitride waveguides without fail, giving a transfer yield of near-unity (Figure 2e).

Conclusion

We have developed a versatile source preparation method to micro-transfer print large-area thin films. We demonstrate the method for LN and GaP films, for large-area coupons and for different pillar designs. Experimentally, we obtain a near-unity transfer yield, demonstrating high-yield integration of electro-optic materials. We believe this manufacturing method opens important routes to heterogeneously integrate low-loss high-speed modulators and efficient frequency converters onto established photonic platforms such as silicon and silicon nitride.

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