High-Yield Heterogeneous Integration of Silicon and Lithium Niobate Thin Films

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Abstract: Microtransfer printing of silicon and lithium niobate thin films on generic integrated photonic platforms is demonstrated. An unprecedented integration yield is achieved using crack barriers as a way to mitigate stress-induced shears in the material.

Introduction

Applications such as optical communications, laser ranging and sensing benefit greatly from narrow-linewidth continuous wave lasers, high-speed optical modulators, or optical frequency comb sources on a photonic chip [1–3]. As high-volume and low-cost fabrication are essential for scalability, heterogeneous integration through microtransfer printing offers a compelling solution to realize such devices by integrating III-V compound semiconductor devices and thin material films on generic photonic integrated circuits [4]. This pick-and-place process relies on the kinetically controlled adhesion of an elastomeric stamp to pick devices or material films from a source wafer and print them on a target wafer. Using this method, III-V-on-silicon [7], III-V-on-silicon-nitride (Si_3N_4) [4,5], III-V-on-lithium-niobate (LN) lasers [6], and LN-on-Si_3N_4 modulators [3] have been demonstrated. The realization of such devices on commercial foundry platforms depends critically on the ability to integrate thin films such as silicon or lithium niobate on passive photonic circuits. For example, due to the low refractive index of silicon nitride compared to that of III-V semiconductors, an intermittent silicon coupling layer is indispensable to ensure efficient evanescent coupling between a silicon nitride waveguide and a III-V waveguide [8]. Furthermore, microtransfer printing thin film lithium niobate layers enables exploitation of its strong electro-optical and nonlinear properties on the same photonic chip [3]. A major yield limitation for microtransfer printing such thin material films is the occurrence of cracks in the material. These cracks originate from the supporting structures, often denoted as tethers (see Fig. 1(b)), which suspend the material film on the source wafer. During pick-up, stress induced at these tethers can result in crack formation and propagation through the entire structure, leading to severe and intolerable damage to the co-integrated material.

Here, we present an improved microtransfer printing process with crack barriers as a way to mitigate crack propagation originating from the supporting tethers of a suspended material membrane. These barriers greatly improve the process reliability, enabling high-yield manufacturing of complex, multifunctional integrated photonic devices.

Microtransfer printing of silicon

As a first demonstration, 400 nm thick silicon (Si) coupons with sizes of 3 mm×80 µm and 1.6 mm×50 µm are microtransfer printed on a commercial Si_3N_4 platform, here fabricated by Ligentec SA. The Si coupon is first patterned on its source silicon-on-insulator wafer using a single lithography and dry etching step. Next, the SiO_2 layer underneath the coupon is etched using hydrofluoric acid (HF) vapor to suspend the Si coupon on the source wafer without suffering from capillary forces. While traditional microtransfer printing approaches rely on photoresist or silicon nitride encapsulation of the coupon, the current approach reduces the number of required process steps and can hence lower the overall fabrication cost. Moreover, the absence of an encapsulation material eliminates incompatibility with some of the widely used release etchants such as HF, which are used to suspend the coupon on the source wafer. Figure 1(a) depicts a microscope picture of transfer printed Si coupons. As cracks induced at the supporting tethers can easily propagate through the coupon, the integration yield is low. To solve this problem, small trenches can be defined during the coupon definition to encircle the supporting tethers and terminate any cracks originating from the support structure. Suspended Si coupons with crack barriers are depicted in Fig. 1(b). A perfect yield was achieved for printing 100 Si coupons. A microtransfer printed Si coupon along with exemplified crack termination are shown in Figs. 1(c),(d) respectively. To enable the definition of a Si waveguide in the printed coupon, a 35 nm alumina etch stop layer was deposited on the Si_3N_4 target prior to microtransfer printing. After patterning of the Si waveguide, the III-V semiconductor optical amplifier (SOA) can be integrated on top (Fig. 1(e)). This two-step microtransfer printing approach hence offers a convenient avenue to build active devices such as III-V-on-Si-on-Si_3N_4 lasers using commercial passive photonic platforms.

Microtransfer printing of lithium niobate

Similarly to the heterogeneous integration of Si membranes, thin-film LN can be integrated using microtransfer printing. In this case, the LN coupon is patterned on the source LN wafer using an amorphous silicon hard mask and dry reactive ion etching (RIE). The sample is subsequently submerged in hydrofluoric acid to selectively remove the SiO_2 underneath the coupon. Figure 1(f) depicts a printed LN coupon with a size of 1 mm×50 µm.

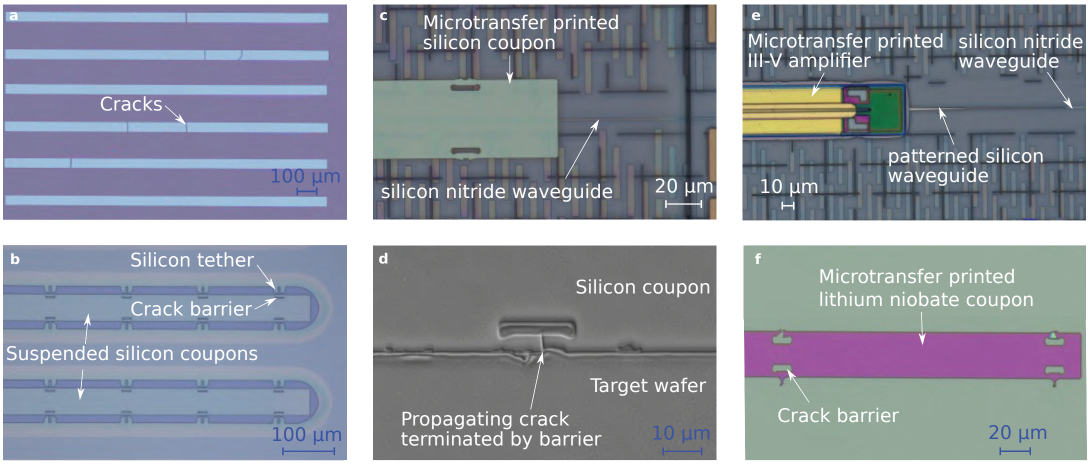

Fig. 1. Microscope pictures of microtransfer printed Si coupons without crack barriers (a), 400 nm thick suspended Si coupons with crack barriers on the source silicon-on-insulator wafer (b), a printed Si coupon in the recess of a Ligentec Si_3N_4 die (c), effective crack termination by the crack barrier (d), printed SOA on top of a printed and patterned Si coupon (e), printed LN coupon (f).

Conclusion

A refined microtransfer printing process is demonstrated to heterogeneously integrate thin semiconductor films with a low cost and an unparalleled yield. We believe this manufacturing method enables intriguing opportunities such as low-loss III-V integration on generic commerical foundry silicon nitride platforms, as well as the integration of electro-optic materials such as LN, to build complex and versatile devices on a single photonic chip.

References

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