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Next-generation Large-scale PIC Enabled by Micro-transfer Printing Technology

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Abstract: Here, we present micro-transfer printing as a versatile heterogeneous integration technique that allows dense integration of multiple material systems on the same waveguide platform through a parallel and scalable process. © 2023 The Authors(s)

Silicon photonics has already been in the data-center market for quite some time. Its rapid development was mainly fueled by the availability of silicon-based high-speed modulators and photodetectors from commercial electronics foundries. Due to lack of optical gain in silicon technology light sources still need to be integrated separately onto those silicon chips either by hybrid or heterogeneous integration techniques to realize full transceiver chip. In the hybrid scheme, lasers or any other element are integrated either by flip-chipping or by co-packaging. This makes hybrid integration more expensive and limited in scalability. In heterogeneous integration, on the other hand, two dissimilar materials are bonded together and the desired devices such as lasers are fabricated afterwards. Therefore, heterogeneous integration is a more scalable and cost-effective approach. Power coupling between two optical elements also gets improved since no active alignment is required here. This will directly lower the overall power consumption of the PIC since power loss is mitigated by improved coupling. Additionally, the overall device footprint becomes smaller for the latter case.

Silicon-on-insulator (SOI) or Silicon nitride-on-insulator (SiNOI) waveguide are going to be the platforms for next-generation large-scale PICs for various applications such as neuromorphic/AI, quantum photonics, LIDAR sensing, to name a few. In those applications current heterogeneous integration scheme based on wafer-to-wafer bonding or die-to-wafer bonding approaches will face tremendous challenges since the number of active elements on these next-generation PICs will be much higher than it is now. These multiple elements may not be made from the same material. For instance, lasers will be made from conventional III-V compound semiconductor whereas the modulator will be based on lithium niobate and so on. Therefore, we can see that there is a need for an alternate heterogeneous integration technology than the current technologies which can bring a lot of different materials on the same platform. Micro-transfer printing (MTP) is one such technology which enables integration of different materials with different geometries in the same waveguide platform [1 - 3]. Fig. 1(a) depicts the multi-wafer integration realized by MTP. Another key advantage of MTP over the conventional wafer bonding technology is the possibility of using both edge-coupling as well as evanescent coupling on same wafer which was not feasible for wafer bonding case. Fig. (b) and Fig. (c) schematically show the side-views of layer stacks for edge and evanescent coupling schemes, respectively when lasers are printed on silicon wafer. In [4] quantum dot laser was printed in a recess for the edge-coupling purpose.

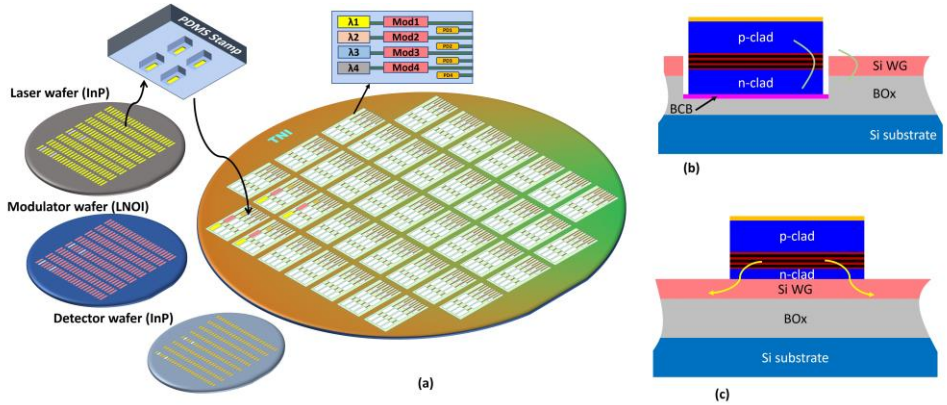


Fig. 1. (a) schematic of integrating devices made of widely different materials on silicon wafer using MTP. Achievable optical coupling schemes using MTP (b) edge-coupling and (c) evanescent coupling.

In MTP technology the host platform is called as target and the epitaxial wafer as source. The coupons for lasers, modulators and detectors are prepared on respective source wafers. In parallel target SOI or SiNOI wafers are fabricated separately. Finally, the coupons are printed on the target wafer to realize the desired PIC. Coupons can vary in shape and size depending on the functions. For example, a typical evanescently coupled laser coupon is 1 mm long and 70 µm wide whereas a photodetector coupon is much smaller like 100 µm x 100 µm. Fig. 2 shows the basic schematic of a typical coupon preparation method for MTP. In order to perform transfer print of any kind, the source wafer should contain a sacrificial layer which will be etched away by a suitable wet etchant to release the coupon from the substrate. After the transfer only a few backend processing steps need to be performed for the final metal connections for electrical driving.

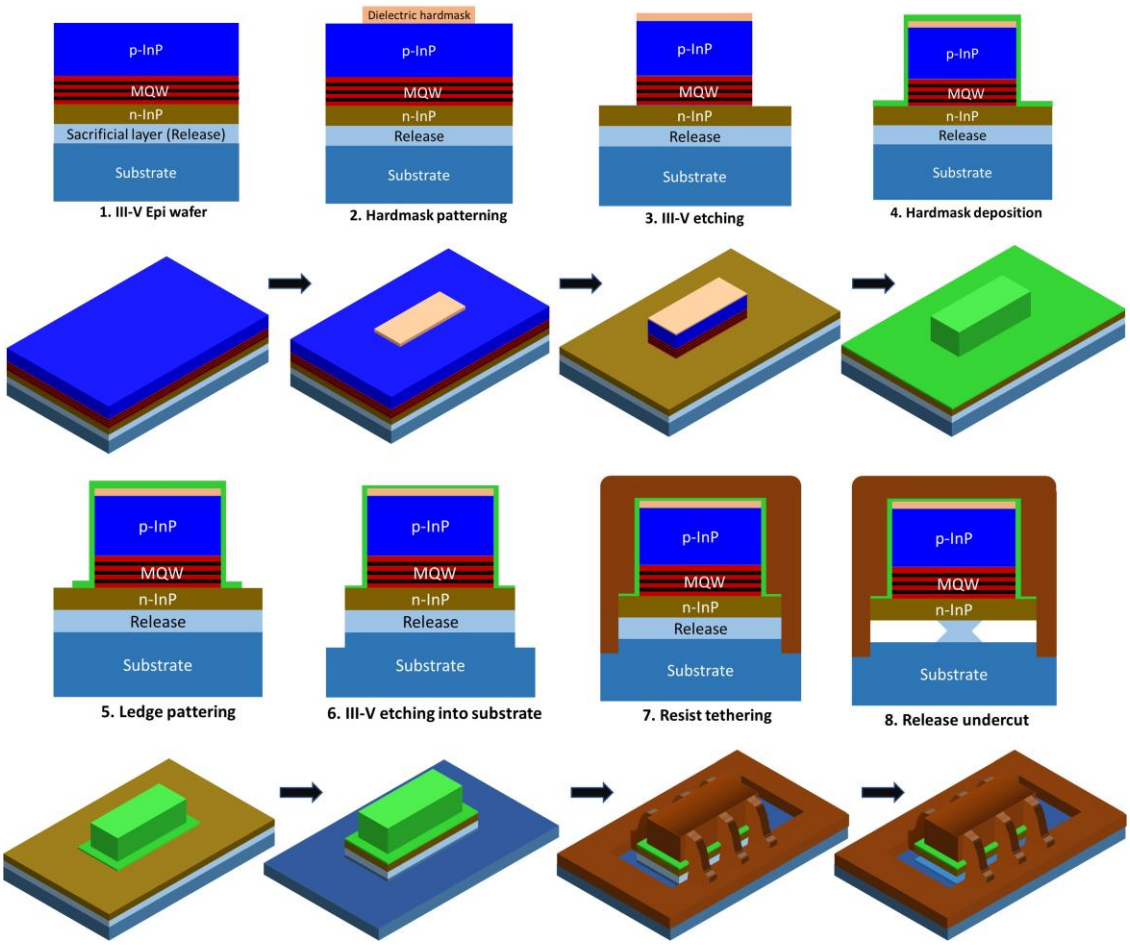


Fig. 2. A typical process flow for laser coupon preparation for MTP.

In conclusion, micro-transfer printing is going to be the key technology for realizing large-scale PICs for plethora of applications. Although plenty of works are yet to be done and explored, it is a promising technology to replace wafer bonding technology by a large extent.

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