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High Alignment Accuracy Transfer Printing of Silicon Coupons for Heterogeneously Integrated PICs

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A process flow is developed for releasing and transfer printing silicon-on-insulator devices. High alignment accuracy (better than ±1um) transfer printing of silicon coupons is demonstrated. Transfer printing alignment markers on source coupons and target wafers were used in a center-to-center alignment method. Notches on the sides of the devices and on the target were implemented for measuring misalignment using scanning electron microscopy. This work proves that transfer-printing technology can be used for the scalable heterogeneous integration of silicon photonic devices with optical interfaces allowing for a +/- 1μm misalignment.

Introduction

Micro-transfer-printing (μTP or transfer printing), proposed by Rogers et al. [1] is a novel integration technology in which materials or devices can be selectively removed from their source wafer and transferred to a new substrate in a massively parallel way, making use of a structured viscoelastic PDMS stamp. It is based on the realization of a dense array of devices on the source wafer, which can be sparsely integrated on a target wafer by selectively picking and printing devices in a high-throughput process, as schematically illustrated in Fig. 1. This technology can tackle many integration issues related to heterogeneous photonic integrated circuits (PICs). This is particularly interesting for scalable III-V-on-silicon integration [2] or the integration of active silicon photonic devices (photodetectors, modulators) on silicon nitride waveguide circuits.

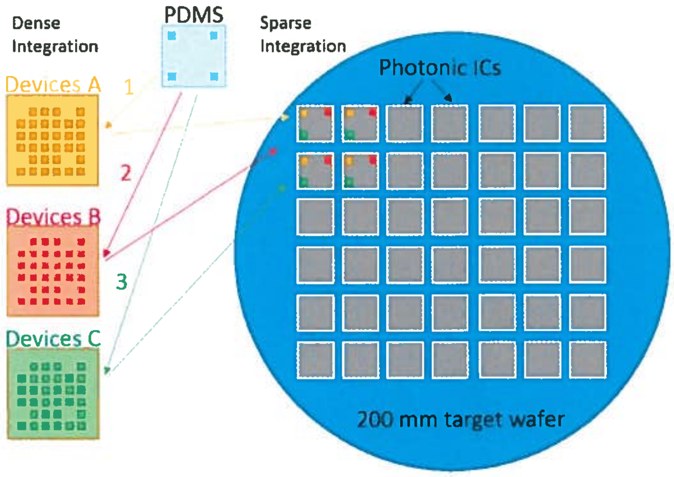

Fig. 1: Transfer printing for the scalable integration of opto-electronic devices on 200mm silicon photonics wafers

High alignment accuracy is probably the most stringent requirement for the transfer print integration of photonic devices. This paper focuses on the development of a process flow and transfer printing approach that allows for a +/- 1µm misalignment of silicon coupons.

Process flow

Dummy devices were fabricated on a silicon-on-insulator (SOI) substrate (220 nm silicon device layer, 2 um buried oxide layer thickness), following a process flow schematically depicted in Fig. 2. In a first step, 500 nm amorphous silicon (a-Si) is deposited (PECVD at 180°C, Fig. 2 b). The a-Si is patterned to define the size of the silicon coupon to be transfer printed (300 µm by 60 µm, Fig. 2 c). In the second step the buried oxide is locally exposed and the transfer-printing alignment markers are defined on top of the coupon (Fig. 2 d)). By immersing these structures in 40% hydrofluoric (HF) acid for about 11 minutes the buried oxide can be removed (release of coupons), keeping thin silicon membranes free-hanging, supported by Si tether structures (Fig. 2 e)).

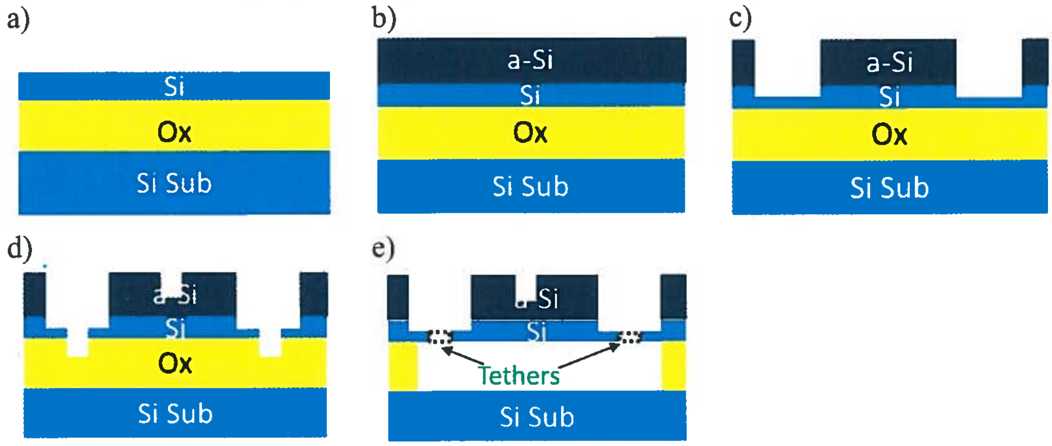

Fig. 2. Schematics of the process flow. a) standard SOI substrate; b) 500 nm a-Si deposition; c) coupon patterning; d) buried oxide exposure and alignment marker formation; e) release process by under etching the buried oxide in 40% HF.

Transfer printing with high alignment accuracy

The transfer-printing scheme used in our experiments is depicted in Fig. 3, using an X-Celeprint micro-TP100 lab-scale printer. By laminating a structured viscoelastic PDMS stamp to the suspended coupon and quickly moving it in the vertical direction, one is able to break the silicon tethers and hence pick up the released coupon (Fig. 3 a). Printing is performed by laminating the picked coupon against a DVS-BCB (soft-cured at 180°C) coated SOI target substrate (Fig. 3 b). By slowly moving the stamp in the vertical direction the Si coupon remains attached to the SOI target wafer (Fig. 3 c).

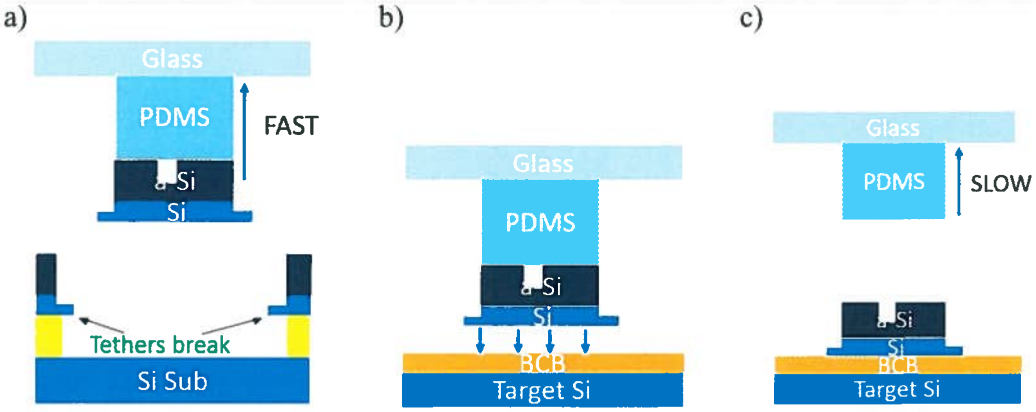

Fig. 3. Transfer printing scheme: a) device pick by moving the stamp fast in the vertical direction; b) transferring a picked device to a target substrate; c) printing by retracting the stamp slowly.

Such a coupon overlaid on the target wafer is schematically displayed in Fig. 4. Circular transfer printing alignment markers were defined on the coupons. Similarly, Tetris-brick shaped alignment markers were defined on the target substrate. Two alignment methods can be used by COGNEX™ image processing software. On the left hand side of Fig. 4 one can calculate the center of the pattern of the target markers (colored in dark red) and the source circle marker (colored in light blue) and add the coordinate difference in the software. On the right hand side, both of the selected markers have a common geometrical center, therefore we call it the center-to-center alignment method. The software can be trained to recognize patterns on the coupon and on the target allowing an automatic alignment. In this experiment we focused on center-to-center alignment.

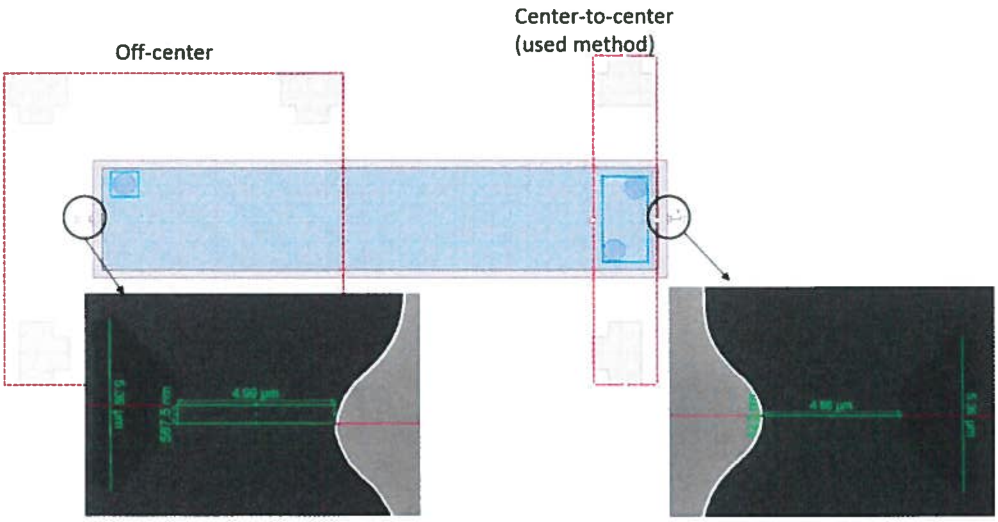

Fig. 4. Coupon overlaid on the target position (top) with marked off-center (left) and center-to-center alignment structures (right) and a misalignment measurement example on the left and the right hand side using scanning-electron microscopy.

Experimental results

After training the model, a number of devices were picked, aligned and printed. We designed notches on the silicon coupons and on the target (circled in black on Fig. 4) in order to accurately measure the misalignment in x and y directions using scanning

electron microscopy (SEM). The notches on the landing sites were designed to be 5 µm away from the same notches on the printed devices in the x-direction on the left and right hand sides. We printed 15 devices using the center-to-center alignment method and assessed the misalignment in Fig. 5. The red points on the graph depict misalignment measured on the right hand side of all coupons. As we can see, most of the measured points are within the ±500 nm misalignment window in x and in y.
The left hand side measurement results however, show significantly higher misalignment values in particularly in y. This is an indication of a rotational misalignment, which will be tackled by better aligning the orientation of the source and target wafer on the tool.

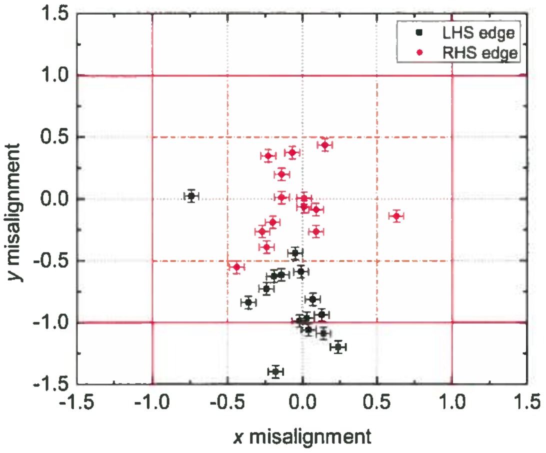

Fig. 5. Misalignment measurement results for left- and right-hand side.

Conclusions

In this paper we demonstrated a transfer printing misalignment of silicon coupons better than ±1 µm. We fabricated a batch of Si coupons, which were picked, aligned and printed with high yield. The designed transfer printing alignment markers worked efficiently for realizing center-to-center alignment. The obtained results indicate the strong potential of the transfer printing technology, enabling silicon optical devices which use one sided input/output couplers to be accurately printed. However, in order to transfer print devices with two-sided input/output couplers, rotational misalignment still has to be better managed.

References

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