PZT micro-transfer printing for photonic MEMS

I. Ansari[*1,2], K. De Geest[1,2] , J. De Witte[1] , T. Vandekerckhove [1] , H. Rijckaert [2] , E. Picavet [2] , E. Lievens [1,2]
, G. F. Feutmba [1,2] , T. Van de Veire [2] , B. Kuyken [1] , J. Beeckman [2] , D. Van Thourhout [1]
[1] Photonics Research Group, INTEC dept, Ghent University-imec, Ghent, Belgium
[2] Liquid Crystal & Photonics Group, ELIS dept, Ghent University, Ghent, Belgium
[*]*irfan.ansari@ugent.be*

2023 IEEE Photonics Conference (IPC) | 979-8-3503-4722-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/IPC57732.2023.10360713

***Abstract*—This paper demonstrates micro-transfer printing of a photonics-compatible lead zirconate titanate (PZT) film. The PZT coupons were released by etching the underlying SiO_2 layer with HF vapor and successfully transferred onto a Si substrate. This technique enables the realization of piezo-MEMS for photonics applications.**

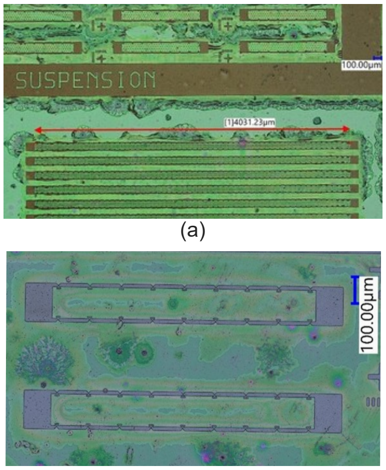
***Index Terms*—PZT, MEMS, PIC, Piezoelectric, Si photonics**

I. INTRODUCTION

Lead Zirconate Titanate (PZT) is a piezoelectric material widely used for micro-electromechanical (MEMS) technology, mainly due to its strong piezoelectric and electromechanical coupling coefficients [1]. However, its application in photonic integrated circuits (PICs) has been limited because of the loss from the Pt buffer, traditionally used for growing the PZT thin film [2]. A PZT film, grown with a transparent buffer layer ($La_2O_2CO_3$) through chemical solution deposition (CSD) method was reported [3], and its potential in photonic applications was demonstrated through Pockel's modulation [4]. But, spin-coating of the thin buffer layer used in this method demands a planarized sample surface, which limits its scope . Micro-transfer printing (μTP) could be a way to circumvent this bottleneck [5]. In this article, we report fabrication of suspended PZT coupons of length up to 4 mm and width up to 120 μm. We then successfully transfer printed a PZT coupon on a Si substrate. These results demonstrate a technique that could enable integration of a PZT film locally on the desired location of the chip without the full chip being uniformly planarized. Moreover, this method can offer additional freedom to design MEMS actuators for various photonics applications.

II. FABRICATION OF THE PZT COUPON

PZT coupons were released by undercutting a SiO_2 sacrificial layer with HF vapor. A 2 μm SiO_x was deposited on a Si substrate using plasma enhanced chemical vapor deposition (PECVD). Thereafter, a 165 nm thick PZT film was grown on top of the SiO_x layer [3]. Then, the sample was cleaned and photoresist was spincoated on top. Afterwards, the coupons were patterned using optical lithography process followed by reactive ion etching process. The photoresist mask was then removed with acetone and isopropyl alcohol (IPA), followed by a treatment with O_2 plasma for 10 min to remove any polymer residues. Before the under-etching process, the sample was heated on a hot plate for at least 10-15 min to ensure dehydration. Finally the sample was loaded in an HF vapor-phase etcher (VPE) while the temperature of the substrate holder was set at 40 °C. The extent of undercut was monitored through a microscope.



(a)

(b)

Fig. 1. (a) Up to 4 mm long and 120 μm wide released PZT coupons with stress-release hole pattern (b) up to 1 mm long and 120 μm wide suspended PZT coupons without the hole pattern.

Figure 1 (a) and (b) show the released PZT coupons with and without the hole pattern respectively. The hole pattern in the coupon enabled release of PZT coupons up to 4 mm. This was enabled by the stress being distributed uniformly over the suspended coupons rather than being concentrated around the tethers. Without the hole pattern, PZT coupons up to 1 mm were successfully released as shown in figure 1 (b). Moreover, the hole pattern reduced the time required for the lateral underetching needed to release the coupon. For example, the sample shown in figure 1(a) took only 15 minutes to release the widest coupon (120 μm), whereas for the similar structure of the sample shown in figure 1(b), it took 45 minutes.

III. TRANSFER-PRINTING

For the μTP test, two Si substrates were prepared as target samples. Both samples were thoroughly cleaned with

---

Funding: Ghent University-BOFGOA2020000103; Horizon Europe- grant 101070622 (VISSION); FWO- grant 1S68218N, 11H6723N, 1273621N and 1S69123N.

979-8-3503-4722-7/23/$31.00 ©2023 IEEE

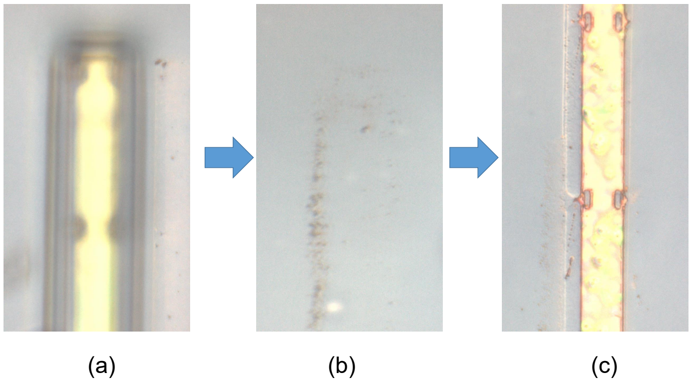

(a)
(b)
(c)

Fig. 2. (a) 30 μm wide PZT coupon picked up during μTP, (b) a soft press on the target sample to get rid of the residues, (c) a hard press on the target sample for μTP.

acetone and IPA, then dehydrated and treated with O_2 plasma. One sample was used as bare Si target sample to test the direct bonding, whereas on the other sample a thin adhesive BCB film (40-50 nm) was spincoated. The PZT coupons were picked with a transparent polydimethylsiloxane (PDMS) stamp, as shown in figure 2(a), and pressed against the target sample to transfer print the coupon. We found that the PZT coupons with the hole pattern could not be transferred on either of the target samples. This was due to a significant amount of SiO_x residues beneath the PZT coupon from the incomplete underetching. The PZT coupon without the hole pattern was rather clean but still could not stick to the bare Si target. However, after optimizing the printing process, coupons of 30 μm wide and 1 mm long could be successfully transferred, as shown in figure 2(c). This process was repeated with the other PZT coupons to verify the repeatability.

IV. APPLICATION

Figure 3 illustrates a potential application of a transfer printed PZT/Si layer for top-down MEMS actuation. The Finite element method (FEM) simulation shows that n_{eff} changes significantly with the small displacement (Δz) of the actuator and saturates when the actuator is too far to couple with the waveguide mode. This shows a strong n_{eff} modulation that can be realized through the μTP technique.

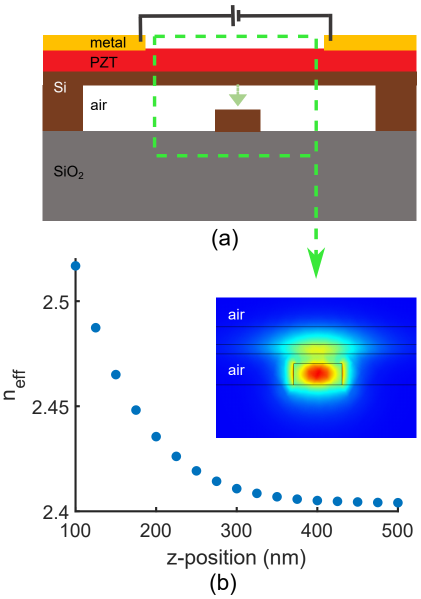


Fig. 3. (a) schematic of a piezo-MEMS actuator integrated on a Si waveguide. The vertical position (z) of the top actuator can be controlled through the piezoelectric effect in the PZT film (b) An FEM mode simulation showing the n_{eff} with respect to the position of the actuator (z) from the waveguide.

V. CONCLUSION

Our study demonstrated the fabrication and transfer printing of a photonic-compatible PZT coupon. The PZT film exhibited a strong tensile stress, allowing for the production of large coupons. The successful transfer-printing of PZT film onto a Si sample at a moderate temperature highlights the potential for integrating PZT films on passive photonic platforms. This can open up opportunities for developing efficient photonic components such as MEMS based phase modulators, tunable couplers and filters.

REFERENCES

[1] M. Safaei, H. A. Sodano, and S. R. Anton, "A review of energy harvesting using piezoelectric materials: state-of-the-art a decade later (2008–2018)," *Smart Materials and Structures*, vol. 28, no. 11, p. 113001, oct 2019. [Online]. Available: https://doi.org/10.1088/1361-665x/ab36e4

[2] N. Izyumskaya, Y.-I. Alivov, S.-J. Cho, H. Morkoç, H. Lee, and Y.-S. Kang, "Processing, structure, properties, and applications of pzt thin films," *Critical Reviews in Solid State and Materials Sciences*, vol. 32, no. 3-4, pp. 111–202, 2007.

[3] J. P. George, P. F. Smet, J. Botterman, V. Bliznuk, W. Woestenborghs, D. Van Thourhout, K. Neyts, and J. Beeckman, "Lanthanide-assisted deposition of strongly electro-optic pzt thin films on silicon: Toward integrated active nanophotonic devices," *ACS Applied Materials & Interfaces*, vol. 7, no. 24, pp. 13 350–13 359, 2015.

[4] K. Alexander, J. P. George, J. Verbist, K. Neyts, B. Kuyken, D. Van Thourhout, and J. Beeckman, "Nanophotonic Pockels modulators on a silicon nitride platform," *Nature Communications*, vol. 9, no. 1, pp. 4–9, 2018.

[5] B. Corbett, R. Loi, J. O'Callaghan, and G. Roelkens, "Transfer printing for silicon photonics," in *Semiconductors and Semimetals*. Elsevier, 2018, vol. 99, pp. 43–70.