RFICs on polydimethylsiloxane for flexible electronics applications

T. Wang, H.-C. Chen, P.-L. Huang, Y.-Y. Chiang and S.-S. Lu

RFICs were thinned down and transferred to the flexible substrate by the proposed polydimethylsiloxane-substrate transfer technology (PSTT). Measurement results show the feasibility of the proposed technique, and furthermore prove its ability to reduce the substrate loss in the high frequency range. With PSTT, the quality factor of a 3.5 turns inductor is improved from 9.3 to 13.4 and the noise figure of a 5–6 GHz direct-conversion receiver is reduced by 0.5 dB. The demonstration reveals the potential of PSTT for the flexible electronics in RFICs applications.

Introduction: Recently, flexible electronics has drawn significant attention owing to its variety of applications such as flexible displays, smart tags, and wearable products. To achieve this goal, there have been plenty of approaches discussed and developed [1–4]. Among these approaches, the organic thin film transistor (OTFT) is acknowledged for its superiority in mechanical flexibility, but it suffers from low operating frequency, short lifetime and limitation in circuit integration. Sparing the issues of OTFT manufacturing, a novel SOI substrate transfer technology (SOI-STT) [4] was proposed and was more likely to have transistors with better performances; however, the inevitable buried oxide during the SOI-STT process is unavailable in the standard CMOS technology and therefore limits the prospect of system-on-a-chip in the future. To resolve these difficulties, polydimethylsiloxane (PDMS)-substrate transfer technology (PSTT) is proposed in this Letter. With the similar goal, PSTT is, however, implemented in a very different way, which can be fully compatible with standard CMOS ICs and is easy to use for a variety of applications. The proposed technique is demonstrated with an inductor and an RF receiver. To our knowledge, it is the first CMOS RF receiver on flexible substrate that has been characterised and compared.

Fig. 1 PSTT processing flow

PSTT and demonstration on RF receiver: The proposed PDMS-substrate transfer technology (PSTT) is based on jellification of a viscous PDMS layer underneath an ultra-thin substrate. There are four major steps involved in PSTT (see Fig. 1). First, flip the silicon chip and post it on a dummy wafer with thermal dissipative adhesive glued on the chip front-side. The thermal dissipative adhesive was to prevent heat accumulation and possible damage during the following etching step. Secondly, etch the silicon substrate using deep RIE. No wet etching or grinding was involved, making the thinning process stable and safe. The etching rate of deep RIE was approximately 2 $\mu\text{m}/\text{min}$, which can be used to estimate the etching time. Thirdly, spread the viscous PDMS on the backside after substrate is thinned down to 20 μm . The viscous PDMS is able to flow uniformly on the backside surface without any void or seam left, which is of great importance

because any unfilled defect will induce the stress accumulation in probing/packaging and may cause the fragile substrate to crack. After spreading the viscous PDMS, a 20 min 90°C hard bake was continued to jellify the PDMS, forming a flexible cushion underneath the ultra-thin substrate. The elasticity of PDMS not only enables the substrate to distribute the contact stress from the chip front-side but also maintains the flexibility of the ultra-thin silicon. The final step is to dip the chip into the acetone to dissolve the adhesive and strip it off from the dummy wafer. Once the chip is stripped, the RF circuits will be clean and ready for test. PSTT is simple to apply in CMOS technology without any process change or additional mask alignments.

To evaluate its feasibility, the proposed PSTT was implemented on an inductor as well as an RF receiver. Fig. 2 shows the experimental results of these RF components/circuits after PSTT. The demonstrated circuits were included in a 5 $\times$ 5 mm, 0.18 μm CMOS chip, which was thinned and transferred onto the centre of the PDMS substrate bent to show its flexibility.

Fig. 2 Flexibility of PSTT chip

Fig. 3 Quality factor of inductor on silicon and on PDMS

Fig. 4 Measured S_{11} and noise figure of RF receiver

Measurement results and discussion: The quality factor of the 3.5 turns PSTT inductor was extracted from the on-wafer S -parameters measurement. It can be seen in Fig. 3 that the peak quality factor is

improved from 9.3 to 13.4 by PSTT. Such improvement represents a reduction of substrate loss contributed by PDMS substrate. Besides the inductor, a PSTT RF receiver front-end was demonstrated for further examination. The detailed schematic is the same as our previous work [5]. Measurement results of S_{11} and noise figure are shown in Fig. 4. The S_{11} curve is shifted to a higher frequency for the less parasitic capacitance of the thinned substrate and noise figure (NF) is reduced by 0.5 dB (from 8.7 to 8.2 dB at 10 MHz offset frequency) for less substrate loss. A summary is given in Table 1. These results have verified the adequacy of PSTT to be implemented on CMOS chips and the low-loss PDMS substrate can even improve the RF performance.

Table 1: Summary of comparison

	Parameters	Standard	PSTT
Inductor	Inductance	2 nH	2 nH
	Quality factor	9.3	13.4
Receiver	$S_{11} < -10$ dB	5.45 GHz	5.65 GHz
	Conversion gain	17.1 dB	17.3 dB
	NF (10 MHz IF)	8.7 dB	8.2 dB

Conclusion: A CMOS compatible PDMS-substrate transfer technology is proposed which has been proven by demonstration on 0.18 μm CMOS RF circuits. This approach has paved the way for CMOS technology towards flexible electronics applications.

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T. Wang, H.-C. Chen, P.-L. Huang and S.-S. Lu (*Graduate Institute of Electronics Engineering, National Taiwan University, Taipei, Taiwan, Republic of China*)

E-mail: sslu@ntu.edu.tw

Y.-Y. Chiang (*Institute of Applied Mechanics, National Taiwan University, Taipei, Taiwan, Republic of China*)

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