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Advanced Silicon Integration Technologies for Lab-on-Chip and Implantable Device Applications

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1. Introduction

In order to reduce the ever-increasing cost of healthcare, radical innovations are needed. Personal digital healthcare (or eHealth) has been identified as one of the important approaches to reach this required cost reduction. Silicon is a cornerstone of eHealth: ultra-low-power circuits can enable wearable wireless health assistants, advanced silicon integration and packaging can enable miniaturized implantable systems, and silicon-based sensors and microsystems can enable Lab-on-Chip (LoC) solutions for personal diagnostics.

2. Lab-on-Chip technology

In this paper recent innovations in the field of silicon-based LoC are presented. A specific application concerns the detection of various SNPs in DNA. Since fast DNA analysis is favored, the various SNPs should be detected simultaneously. In order to realize this, the various DNA segments sensitive to the presence of certain SNPs need to be amplified by smart primer design [1], followed by a fast and efficient separation with high selectivity. To obtain this, a micro-pillar based filter is ideal. Therefore, there is a clear advantage of using advanced deep-submicron silicon processing, in contrast to the commonly used glass substrates or standard MEMS processing for LoC applications. Indeed, the superior dimensional control allows the creation of filters with submicron spacing between the pillars. This strongly ordered and very regular submicron pillar array improves the separation speed by a factor of five compared to traditional filter process methods [2]. Figure 1 shows a detail of the micromachined filter. After separation of the various DNA segments, a system of valves and micro-channels will transport each DNA segment to its SNP detector.

The use of such pillar filter requires a pump able to generate a high pressure, in order to realize the required fluid flow through the filter. Such a micropump is fabricated, applying a conductive polymer based actuator, using doped Polypirrole as active material [3]. On-chip high pressure generation is favored, related with miniaturization and portability of our LoC system. Hence heterogeneous integration techniques are required for adding both the micropump and the detectors to the passive microfluidic filter subsystem.

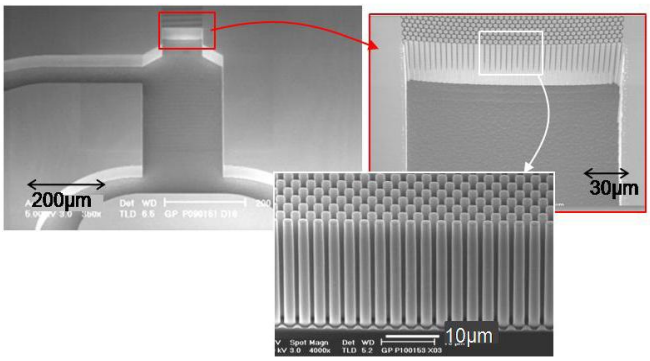

***Fig. 1**. Details of the micro-pillar filter, including wide channels and small pillars with high aspect ratio. For this filter, pillars are 25µm high and 2µm wide, with an inter-pillar distance of 1µm.*

3. Advanced Packaging for wearable and implantable sensor systems

To enable smaller patient-centric sensor modules on or inside the human body, new advanced packaging techniques are needed. For wearable applications, an advanced board level integration process called UTCP is under development [4].

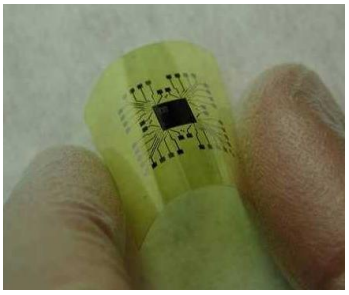

***Fig. 2.** UTCP: flexible carrier with embedded IC.*

The UTCP technique enables to embed ultra-thin chips in highly flexible carriers, offering interesting possibilities for wearable sensor systems. A demonstrator of such flexible chip embedding embodiment is shown in Figure 2.

For implantable applications, and in order to allow cost reduction and extreme miniaturization, a biocompatible wafer- and die-level packaging process flow is under development, as shown schematically in Figure 3.

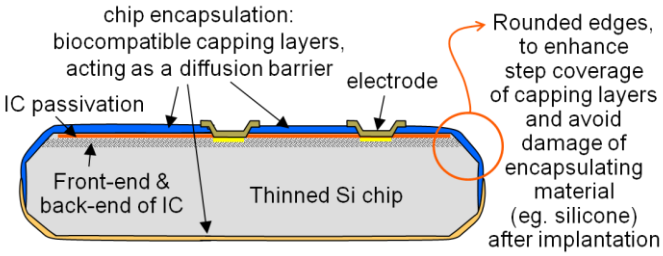

Fig. 3. *Schematic biocompatible chip packaging process.*

An early demonstrator of the encapsulation process is fabricated, using the process flow shown in Fig. 4. By rounding the chip edges and optimization of the deposition processes used for encapsulation, very nice step coverage can be obtained (See Fig. 5). Diffusion tests revealed that these encapsulation layers act sufficiently well as diffusion barriers, preventing the diffusion of harmful materials through the encapsulation.

All processes used during this packaging technique are carried out using conventional Silicon processing tools. This shows that active electronics can be hermetically encapsulated using a stack of encapsulation layers covering the individual dies. Such compact package may avoid the use of traditional titanium can packages in select implantable applications and will provide increased functionality.

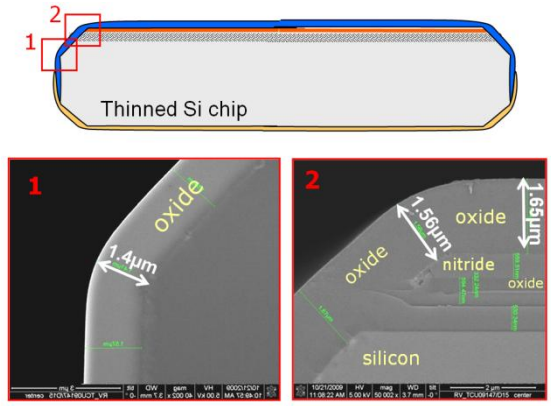

Fig. 5. *Detail of a biocompatible chip encapsulation process. Excellent step coverage of the chip edges is obtained.*

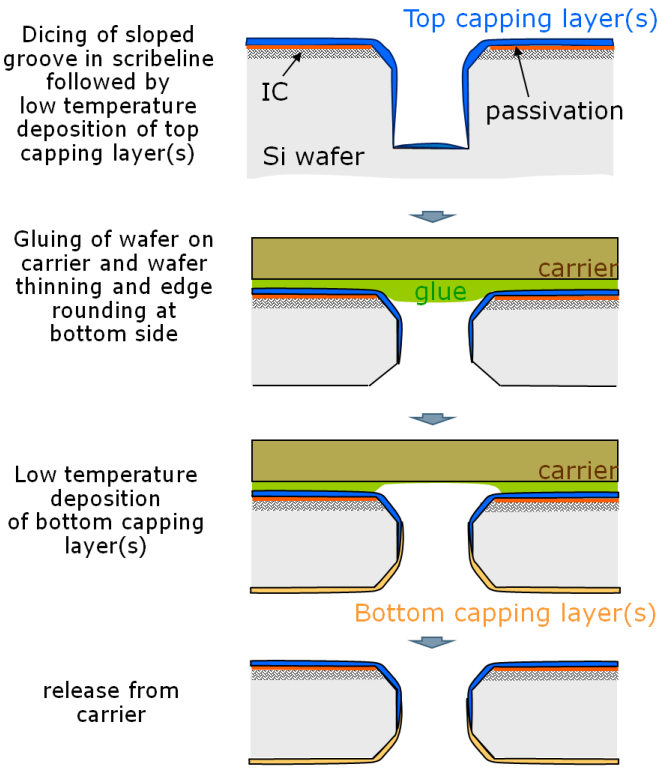

Fig. 4. *Process scheme of a hermetic wafer level chip encapsulation technique using only two deposition steps in order to cover all sides of the dies.*

3. Conclusions

This paper presented new advances in lab-on-chip technology and wearable and implantable packaging technology. Lab-on-chip technology is driven by the need for personalized individual healthcare monitoring. For wearable and implantable packaging, key driver applications are transdermal and subdermal drug delivery, cochlear implants and nerve stimulation applications.

Acknowledgments

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