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AIDAinnova

Advancement and Innovation for Detectors at Accelerators
Horizon 2020 Research Infrastructures project AIDAINNOVA

MILESTONE REPORT

AVAILABILITY OF PARTS AND DEFINITION OF TECHNOLOGIES FOR WAFER-TO-WAFER HYBRIDIZATION

MILESTONE: MS25

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Abstract:

Within WP6 (Hybrid Pixel Sensors for 4D Tracking and Interconnection Technologies) Milestone MS25 contains the availability of parts and definition of technologies for wafer-to-wafer hybridization.

This milestone has been successfully achieved and is reported in this document.

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Delivery Slip

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Executive summary

The development of wafer-to-wafer (W2W) bonding for hybrid pixel detectors has successfully started by defining the technologies for the proof-of-principle processing and procuring the material necessary for such process. It was decided to base the process on the well known Timepix3 readout ASIC which will be combined with dedicated sensor wafers manufactured in the LFoundry 150 nm process. Fraunhofer IZM has outlined the definition of technological approach and fabricated daisy chained process development wafers. These wafers will be used for the further process development and definition yielding into the final design for masks and process steps to be used the W2W bonding of TimePix3 wafers to the LFoundry sensors wafers.

1. INTRODUCTION

Part of task 6.4 of WP6 deals with the establishing of wafer-to-wafer bonding technique (W2W) for hybrid pixel detectors. The goal of this development is an ultra-thin low-mass hybrid pixel detector using wafer-to-wafer bonding technologies. This type of interconnection technologies allow to reach fine pitch bonding and very thin sensor-chip stacks. On the other side, it needs sensor and read-out chip wafers of the same diameter and with the exact same arrangement of structures within the wafer. In the HEP community the sensor wafers are normally produced in smaller sizes (150 mm diameter, slowly transictioning to 200 mm) with respect to ASICS (presently mainly on 300 mm diameter). Therefore the choice of the possible matching processes for sensors and ASIC is limited.

Target is the development of proof-of-concept ultra-thin hybrid pixel detectors as depicted in Figure 1 based on:

- 50 – 100 µm thick pixel sensor on 200 or 300 mm CMOS wafers (based on passive CMOS sensor development)
- ~20 µm thick pixel FE chip thickness on 200 mm CMOS (Timepix3)
- Hybridization method: Wafer-to-Wafer bonding with subsequent thinning of FE wafer

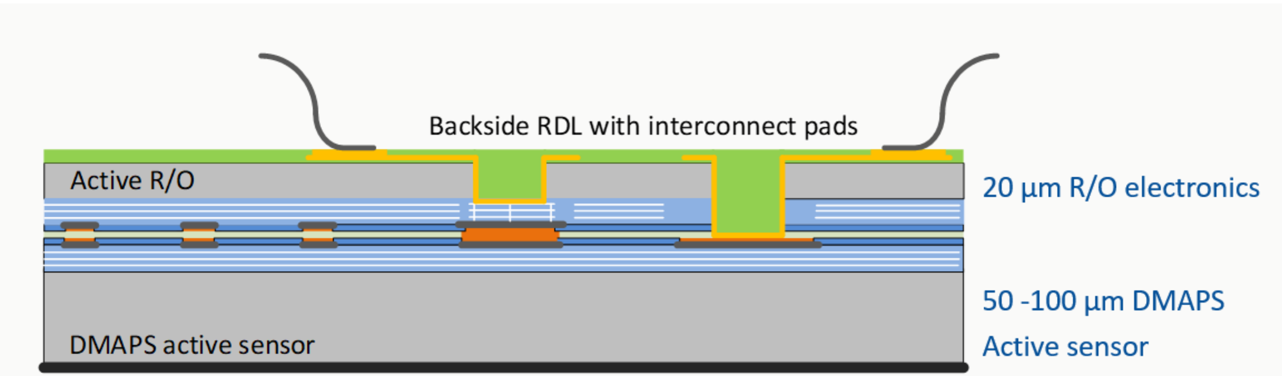


Figure 1: Schematic setup of ultra-thin low-mass hybrid pixel detector using wafer-to-wafer bonding technology.

A first task in the project is the development and procuring of the material needed for the wafer-to-wafer bonding, namely:

- Readout chip wafer (Timepix3)

- DMAPS active/passive sensor wafer, design adapted to wafer bonding process onto TIMEPIX3 wafer
- Process development wafers, for the final W2W bonding process

The second task is the selection and definition of the technologies of the W2W bonding and the conduction of the processing on the material mentioned above. This task is a two-stage process. In the first stage the process development wafers are used to carefully evaluate the technologically available W2W bonding options and define the final process flow for the Timepix3 and DMAPS sensor wafers. The second stage is the processing of the ultra-thin hybrid pixel detectors by the final W2W bonding process, including all necessary post-processing such as backside wafer processing and TSV formation.

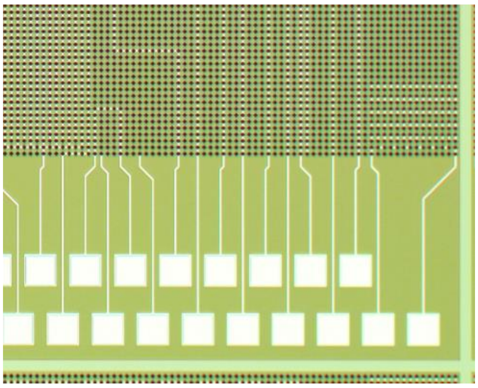
This milestone report summarizes the first part of this task together with the definition of technological options chosen for the process development run.

2. MATERIAL PROCUREMENT AND PROCESS DEVELOPMENT FOR THE W2W PROCESS

2.1. AVAILABILITY OF MATERIAL

After carefully evaluating the options for the readout part which are either already available ASICs such as ATLAS FE-I4, Timepix3/4 and a newly developed chip, it was decided to use the TimePix3 chip [1]. This chip is very well known in the community and offers a 14 mm x 11 mm chip size on 200 mm wafers. The pixel size is 55 µm x 55 µm and features the possibility of TSV formation on the wire bond pad frame as required for this project. The Medipix/Timepix collaboration supports this development and wafers have been transferred to Fraunhofer IZM. Evaluations of the wafers in terms of surface nature and reticule placement revealed that no showstoppers could be identified. The wafers topography and absolute reticule alignment between wafers is within the requirements needed for the W2W bonding processing. Meanwhile, University of Bonn (UBonn) designed a dedicated sensor wafer matching the Timepix3 chip in LFoundry 150nm technology based on previous work [2]. This sensor wafer layout is now being taped-out and will be processed at LFoundry.

For the process development work, at Fraunhofer IZM dedicated daisy chain wafers in 200 mm have been designed and manufactured, referred to as process development wafers. For the design, a Medipix design has been adapted, to produce a layout of the sensor part and the readout chip part with the same pitch and total dimensions of the Medipix chip. Both parts are integrated into the same wafer layout in such a way that, after the face-to-face W2W bonding of two wafers, rows of resistive chains through the individual bumps are connected in a daisy chain. In this way by a simple electrical resistance measurement the integrity of the interconnections can be proved. In addition, open and short structures are included to the design too. Figure 2 shows layout details of the daisy chain readout and sensor part.



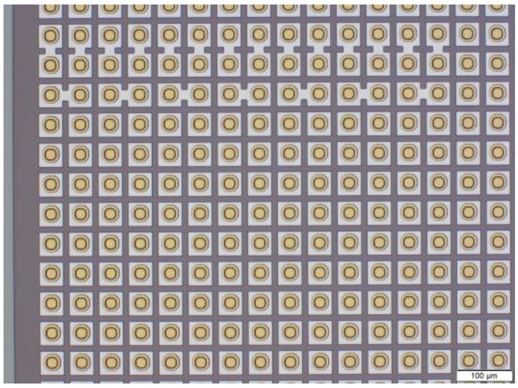


Fig. 2: Design details of the daisy chain readout chip (left) and sensor chip (right).

Figure 3 depicts on the left side a photograph of a fully processed process development 200 mm wafer which shows both parts, readout and sensor chip right next to each other. One can appreciate that if two of these wafers are placed face to face on top of each other, a sensor chip will always be placed on a readout chip and vice versa. The right side of the Figure 3 shows a close-up between the daisy chain readout and sensor chip. The readout chips hold the pads of the daisy chains which will be used for the electrical resistance measurement once the W2W is done on these wafers. The daisy chain wafers are fully processed and will now be used for the W2W process development run.

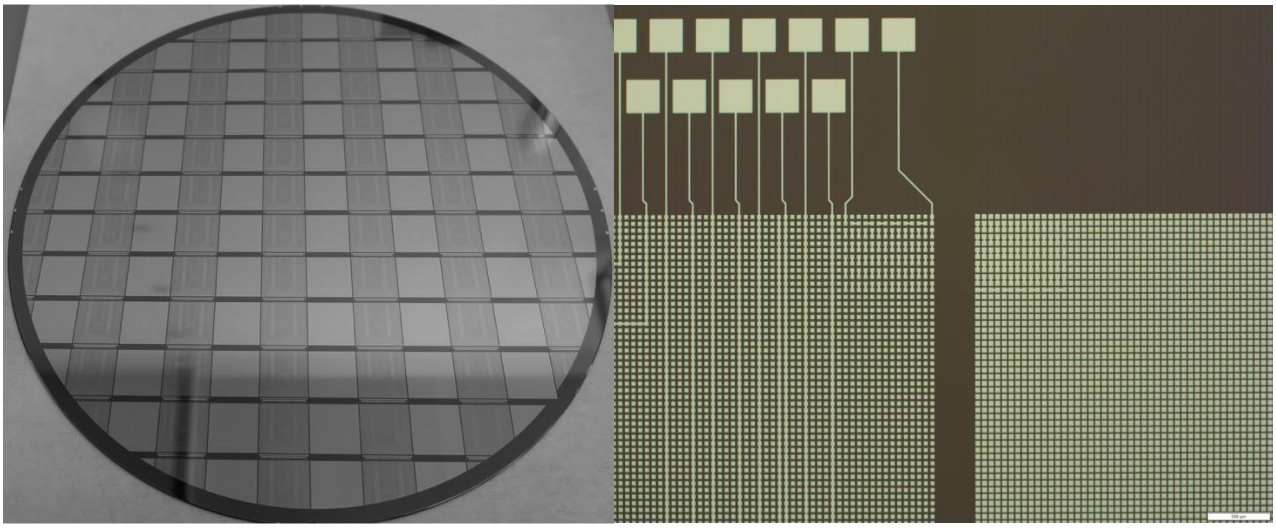


Fig. 3: Photograph of the processed daisy chain wafer (left) and detail photograph showing the parts of daisy chain readout and sensor chip (right).

2.2. PROCESS DEFINITIONS FOR THE W2W BONDING

Fraunhofer IZM has defined the work packages required for the entire development of ultra-thin hybrid pixel detectors using W2W bonding:

- WP1: Design development and manufacturing of process qualification wafer, design preparation of functional Timpix3 and DMAPS sensor wafer
- WP2: Wafer bonding and thinning process
- WP3: Wafer bonding with capacitive coupled IOs and conductive IOs

- WP4: Backside wafer process with TSV-etching and backside metallization process

The detailed description of the work package WP1 is the topic of the second part of this milestone, namely the definitions of the technologies for the process:

- Definition of technological approach for ultra-thin low-mass hybrid pixel detectors
- Process qualification design including test structures
- Fabrication of process development wafer
- Design and mask preparation for TIMEPIX3 readout electronics and LFoundry sensor wafer

The wafer-to-wafer bonding process has to fulfill different requirements in order to enable the functionality of the ultra-thin-hybrid detector. Every pixel of the sensor has to be connected to the readout cell by a metallic interconnect. In addition, the area around the pixel connection has to provide a mechanical stabilization of the wafer stack forming the ultra-thin-hybrid pixel detector. The bonding interface should be stable during the complete fabrication process including post-bonding vacuum process steps and process steps at elevated temperature. To meet these requirements, a combined polymer-metal-bond process flow has been developed in detail.

The process flow will be validated and optimized using the setup wafer described in section **Error! Reference source not found.**. After the patterning of the redistribution (RDL) layer and the deposition of the oxide passivation and via opening process the wafer batch will be divided into a top wafer and a bottom wafer batch, representing the readout chip wafer and the sensor wafer, respectively. Using electroplating technology, a solderable under-bump-metallization (UBM) will be deposited onto the sensor side whereas a Cu-Sn pillar bump will be deposited onto the readout chip side. The area around the metal interconnects will be filled by a spin-on polymer and planarized. In the following wafer-to-wafer bonding process the electrical interconnects between sensor and readout chip cell will be formed by the formation of intermetallic compounds. The polymer layer results in a strong adhesion between sensor and readout chip side. The polymer layer will be diced together with the silicon layer. The dicing process may require still some optimization, but no issues was noticed in the past experience with dicing of polymer bonded to wafer.

In order to get access to the probe pads on the front-side of the setup wafer, the top wafer will be thinned down to a thickness between 50 µm and 20 µm. The remaining silicon and the polymer on top of the probe pads will be removed by reactive ion etching (RIE). The general process steps are summarized in Figure 4.

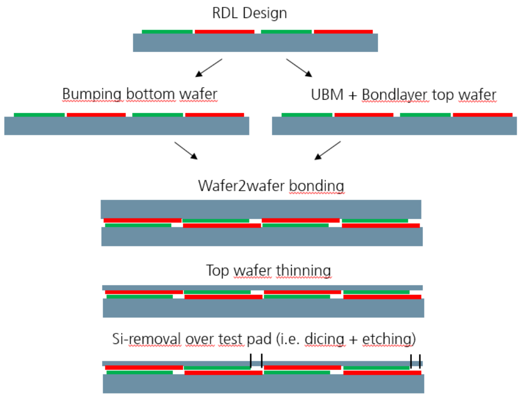


Fig. 4: Simplified process flow of the process development run.

The process flow developed and evaluated using the technology setup wafer will be transferred to the fabrication batch of the ultra-thin-hybrid detector in a second step.

3. CONCLUSIONS

The preparation work for the W2W bonding task to build ultra-thin hybrid pixel detectors is nearly finished. In particular, the needed material for the readout and sensor component has been selected and for the readout chip already transferred to Fraunhofer IZM. The DMAPS sensor wafers have been designed for the project and will be manufactured in the next year. The process technology choice and development is well advanced and the necessary material, namely the daisy chain wafers for the process development run, is ready so that the run can be started as expected in December. We expect both tasks, the sensor wafer processing and the process development run to finish in time next year so the final W2W bonding process with active material can start as planned by end of next year. Thus, we conclude that milestone M 25 is fully met by November 2022.

4. REFERENCES

[1] T. Poikela et al., Timepix3: a 65k channel hybrid pixel readout chip with simultaneous toa/tot and sparse readout, Journal of Instrumentation 9 (2014), no. 05 C05013.

[2] Y. Dieter et al., Radiation tolerant, thin, passive CMOS sensors read out with the RD53A chip. Nuclear Instruments and Methods in Physics Research Section A (2021).

ANNEX: GLOSSARY

Acronym	Definition
W2W	Wafer-to-wafer
TSV	Through silicon via