ADMONT: Advanced Distributed Pilot Lines for More-than-Moore Technologies

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Abstract

The EU ECSEL funding project ADMONT has been successfully completed by April 30th 2019. Its vision to be for potential customers a ”One Stop Shop” and open technology platform which customers can use along the value chain from silicon wafer up to the final system has become reality. ADMONT’s basic idea of a nonstop value chain from chip design, the wafer fabrication in the X-FAB X*035 technologies, the sensor and actuator integration on CMOS as well as the 2.5/3D system integration found an impressive realization with its prototypes and demonstrators. The use of the virtual pilot line ADMONT for highly diverse application fields and its sustainable emphasis on industrial electronics and medical technology stands for long term success with a high potential.

The concept of ADMONT pilot line

The concept behind ADMONT is to merge four clean rooms located in Dresden with various technological capabilities to a “distributed” pilot line. This means the capabilities of these pilot lines are not centralised in a single clean room but they are distributed over multiple clean rooms of technology partners. Their expertise has been combined to create new functionalities – following the sense of “More-than-Moore”. Due to the local proximity of the single clean rooms short lead times and fast manufacturing processes are enabled (Figure 1).

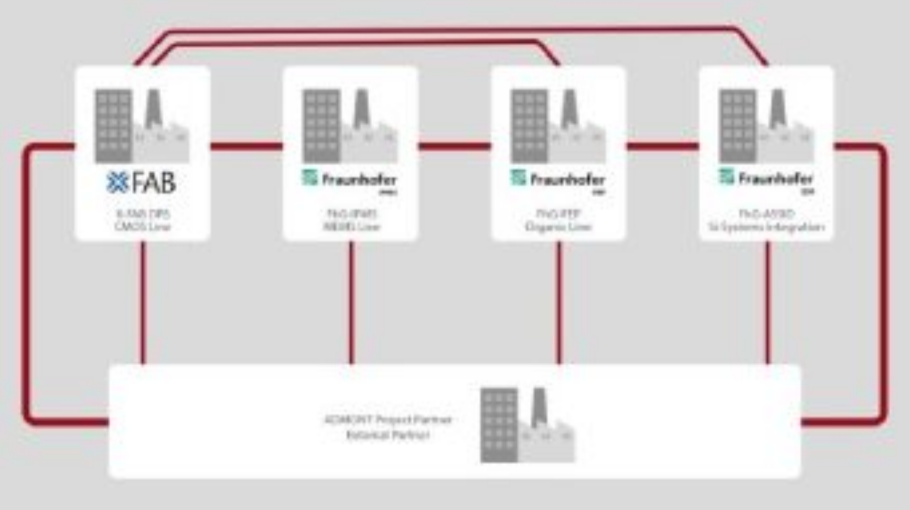


Figure 1. Principle of the distributed ADMONT pilot line

Construction and function of the ADMONT pilot line

The project was started on May 1st 2015 as an EU joined undertaking under ECSEL as KET (Key Enabling Technology) pilot line. The goal was to act in front of potential customers as a “One Stop Shop” with an open technology platform. After the first half of the project run time was achieved, the pilot line was ready for the manufacturing of prototypes and demonstrators of the partners from six European countries. To be able to manufacture wafers across the lines, several questions had to be answered in terms of the interfaces of the clean rooms e.g. wafer transport and logistics, contamination and defect specification, process and quality data transfer, wafer layout and alignment marks to enable a cross fab lithography as well as questions on cross pilot line control and lead time planning.

The close collaboration between the industry partner X-FAB and three Fraunhofer institutes in one project did lead to a new quality in the scientific and technical exchange and just enabled the use of the various competences. The integration of the internal users and their prototypes did lead to a highly effective development of process modules and devices which have awoken a strong interest in the market [1].

The prototypes and the demonstrators of the partners in the project represent a large diversity of end markets, especially medical technology and industrial electronics as well as applications such as infrared sensors and RFID transponder for mobile systems.

For all prototypes and demonstrators the aimed technology readiness levels were defined at the beginning of the project. These were either achieved or have been surpassed. The objective of ECSEL to bridge the "valley of death" between basic research and industrial use has been more than fulfilled. Some prototypes still need follow up projects to achieve production readiness. The functional principle of the ADMONT pilot line can be experienced in a video located on the project homepage. https://admont-project.eu/index.php/results

Technologies, added value and monitoring of the pilot line

The technology offer and the progression of the added value are shown in Figure 2. The technological capabilities of the partners have been enhanced and continuously improved during the project run time. The internal users of the pilot line did deliver the product idea, the design and the specifications. In X-FAB's clean room the CMOS wafers of the technologies XU035, XH035 or XA035 were manufactured. These technologies offer a large variety of process modules and devices.

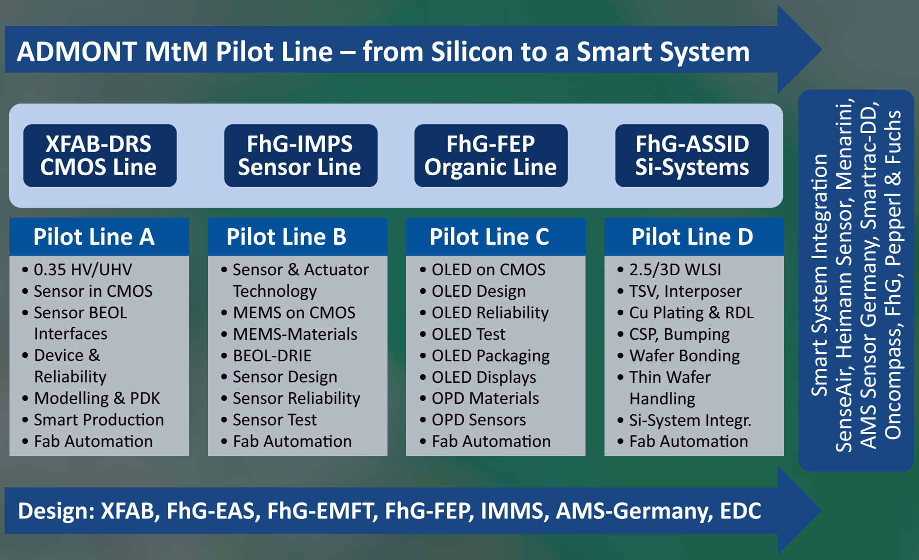


Figure 2. Technologies and added value along the pilot line and internal users who support system integration

Figure 3. Logistics and added value along the ADMONT pilot line with external supplier

In the FhG-IPMS clean room the sensor and actor integration on CMOS wafers was done. In the FhG-FEP clean room the processes for deposition of organic semiconductors were applied. The 2.5/3D integration and packaging was performed at FhG-IZM/ ASSID.

In parallel to technology and product development, design, modeling and characterization activities were executed. New modules, devices and IP blocks were integrated into the Process Design Kit and have been made available to the users of the pilot line. The complex logistics along the pilot line including the cooperation of an external supplier is shown in Figure 3.

The performance of the pilot line was measured through Key Performance Indicators (KPI), which have been agreed at the beginning of the project. For all prototypes and demonstrators the lead time was measured inline and quality data was collected, defect analyses as well as optical and electrical tests were performed. The collected data was stored in a central data system and was commonly used. Cross line a system "Measure-Learn-Improve" was set up and process improvements as well as extended technological capabilities were established. Some few examples are selected here to show process improvements at the partners within the pilot line and the cross site learning.

Process improvement and learning

In the wafer edge area (up to 5mm from wafer edge) of a 200mm CMOS wafer higher process variations appear and defects which have negative influence on quality and reliability of an integrated circuit. The yield may be reduced and also reliability can be worse. Therefore a test chip was developed which enables optical and electrical measurements as well as reliability investigations up to 1mm close to the wafer edge (Figure 4).

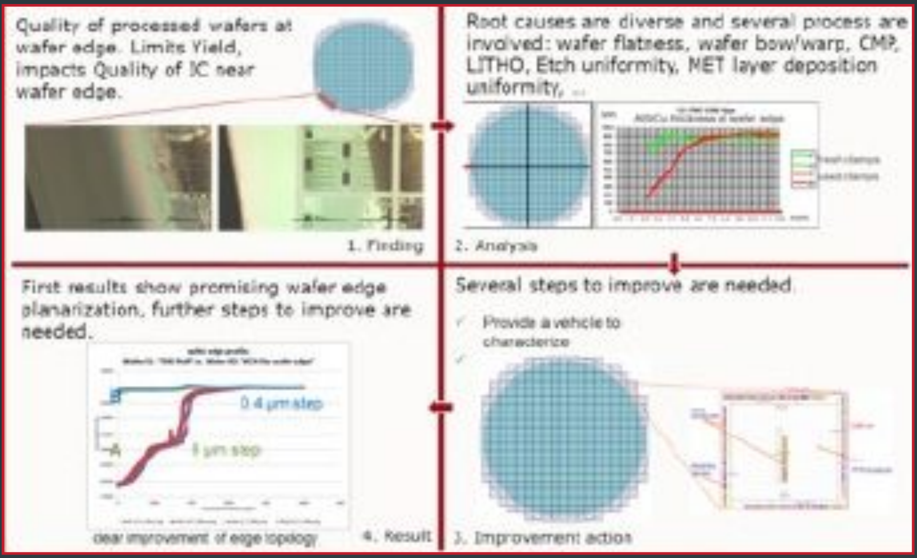
At FhG-FEP a higher particle generation appeared when shadow masks were used since the cleaning of the masks were executed at an external supplier. An improved cleaning process in the own clean room combined with optical inspection did significantly improve the defect density (Figure 5).

The CMOS-sensor-interface for Organic LED’s (OLED) sets very high requirements on metal and oxide planarity. A special sputter process for metal and CMP (Chemical Mechanical Polish) process was developed. During a common test chip manufacturing of two partners layout caused defects were identified. Further analysis showed that just one of both test chips was affected (Figure 6).

REM (Raster Electron Microscope) investigations confirmed that coincident position of OLED-metal edge and metal 4 edge causes stress induced cracks in oxide (Figure 7).

New design rules were defined and tested for various layout variants and isolators. A new set of design rules for Met4 and MetO were incorporated into the PDK and can be checked by automated design rule checking.

The process flow for the manufacturing of Thermopiles 80x64 TP-Arrays from partner Heimann Sensor with the virtual pilot line clearly demonstrates the collaboration and the advantages of the close interaction of all project partners (Figure 8).



Quality of processed wafers at wafer edge. Limits Yield, impacts Quality of IC near wafer edge.

1. Finding

Root causes are diverse and several process are involved: wafer flatness, wafer bow/warp, CMP, LITHO, Etch uniformity, MET layer deposition uniformity, ...

2. Analysis

Several steps to improve are needed

- ✓ Provide a vehicle to characterize
- ✓

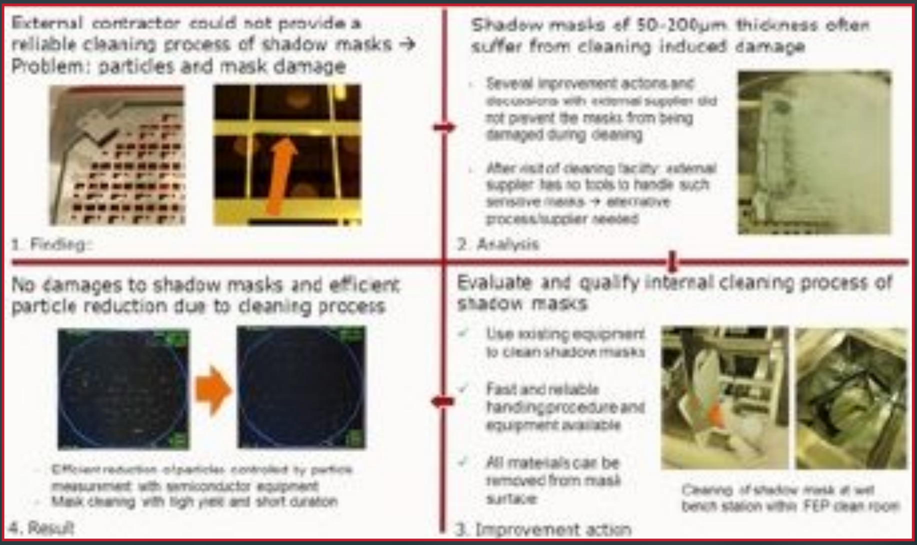
3. Improvement action

First results show promising wafer edge planarization, further steps to improve are needed.

clear improvement of edge topology

4. Result

Figure 4. Project to improve wafer edge quality, optical and electrical measurements are possible



External contractor could not provide a reliable cleaning process of shadow masks → Problem: particles and mask damage

1. Finding:

Shadow masks of 50-200µm thickness often suffer from cleaning induced damage

- Several improvement actions and discussions with external supplier did not prevent the masks from being damaged during cleaning
- After visit of cleaning facility: external supplier has no tools to handle such sensitive masks → alternative process/supplier needed

2. Analysis

Evaluate and qualify internal cleaning process of shadow masks

- ✓ Use existing equipment to clean shadow masks
- ✓ Fast and reliable handling procedure and equipment available
- ✓ All materials can be removed from mask surface

Cleaning of shadow mask at wet bench station within FEP clean room

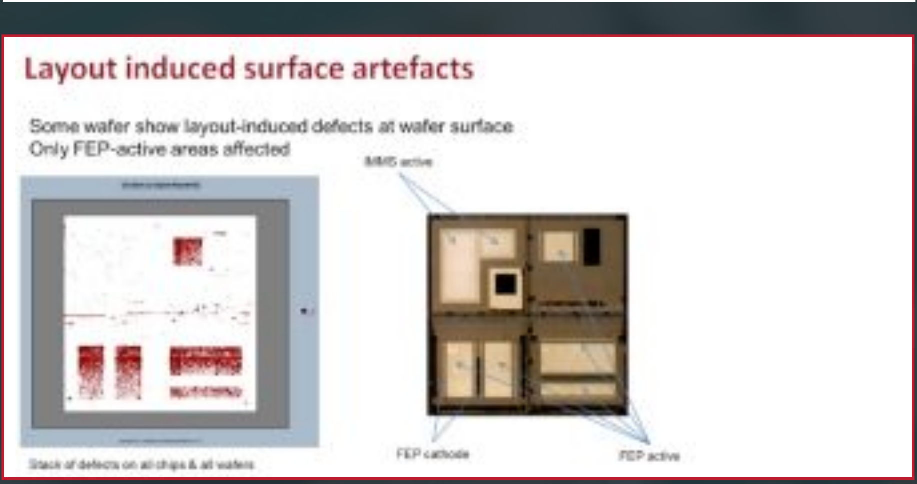
3. Improvement action

No damages to shadow masks and efficient particle reduction due to cleaning process

- Efficient reduction of particles controlled by particle measurement with semiconductor equipment
- Mask cleaning with high yield and short duration

4. Result

Figure 5. Reduction of defect density caused by shadow masks by improved cleaning and inspection



Layout induced surface artefacts

Some wafer show layout-induced defects at wafer surface
Only FEP-active areas affected

Stack of defects on all chips & all wafers

Figure 6. Layout induced defects at the test chip of one partner, the second test chip shows a defect free area

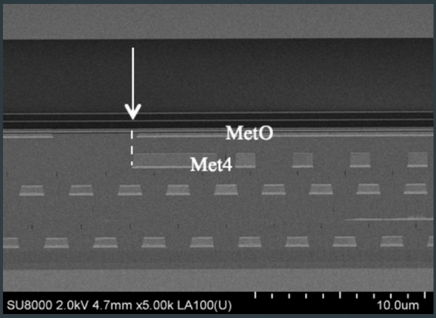


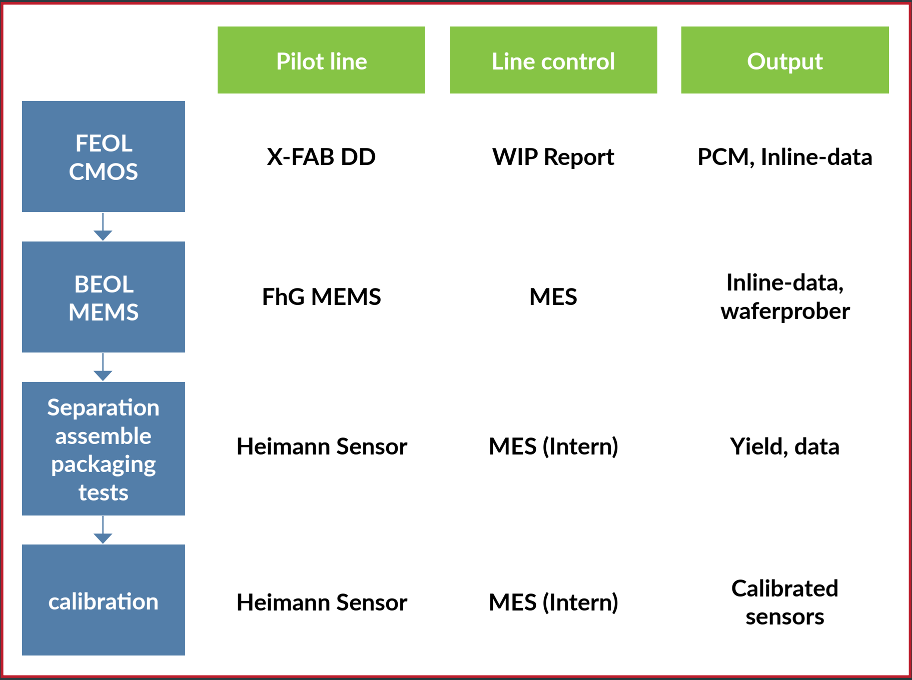
Figure 7. Critical layout location, Metal 4 (Met4) and OLED Metal (MetO) edges are drawn coincident

The integrated thermopile sensors including their signal conditioning circuit are produced in the CMOS line of X-FAB using the XA035 technology. It follows at FhG-IPMS the fabrication of the micromechanical membrane from the back site of the wafer, the thermal isolation of the thermopiles at the front site and the absorber deposition. The system integration, the final test and calibration of the sensors is done at Heimann Sensors. The calibration line was also built up as pilot line in the ADMONT project.

The In-line and PCM data gathered in the CMOS line (X-FAB) can be correlated with the data of the MEMS process (FhG-IPMS) as well as with the final product test data from Heimann Sensor. Thus a layout weakness could be identified which caused metal shorts or could lead to large defect cluster. By changes in design and improvements in the metal process the yield could be increased to more than 90% (Figure 9).

Scientific technical results

During the runtime of ADMONT 22 scientific-technical results were emerged which are considered as 'Exploitation Foreground' in terms of the EU funding guidelines. Amongst them are new high voltage devices included in X-FAB's XU035 technology for 100 V and 400 V used for driver IC applications in piezo ceramic micro pumps, a new metal process module for the XH035 technology with improved reliability for automotive and biomedical



	Pilot line	Line control	Output
FEOL CMOS	X-FAB DD	WIP Report	PCM, Inline-data
BEOL MEMS	FhG MEMS	MES	Inline-data, waferprober
Separation assemble packaging tests	Heimann Sensor	MES (Intern)	Yield, data
calibration	Heimann Sensor	MES (Intern)	Calibrated sensors

Figure 8. Process flow for a thermopile 80x64-TP-Array via distributed pilot line

applications, new sensor interfaces for OLED integration for lab-on-chip applications, a sensor interface for CMUT (Capacitive micro-machined ultrasonic transducer) inte-gration on CMOS, a new PDK with all new devices, modules and design rules for sensor interface integration including new aging models for transistors, a thermopile sensor module for gas detection, a thermopile 80y64-Array module in XA035 technology, a new absorber for thermopiles, a CMUT module, a pressure sensor module and process module for 3D integration like Laser Dicing, TSV's (Through Silicon Via's) for CMUT and OLED Packaging [2, 3, 4, 5].

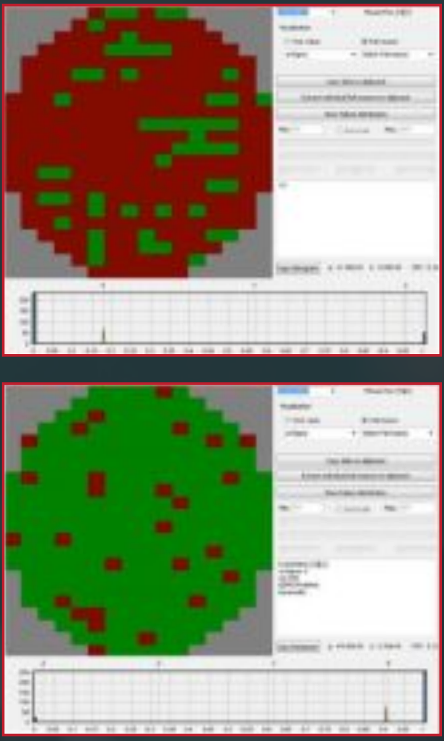
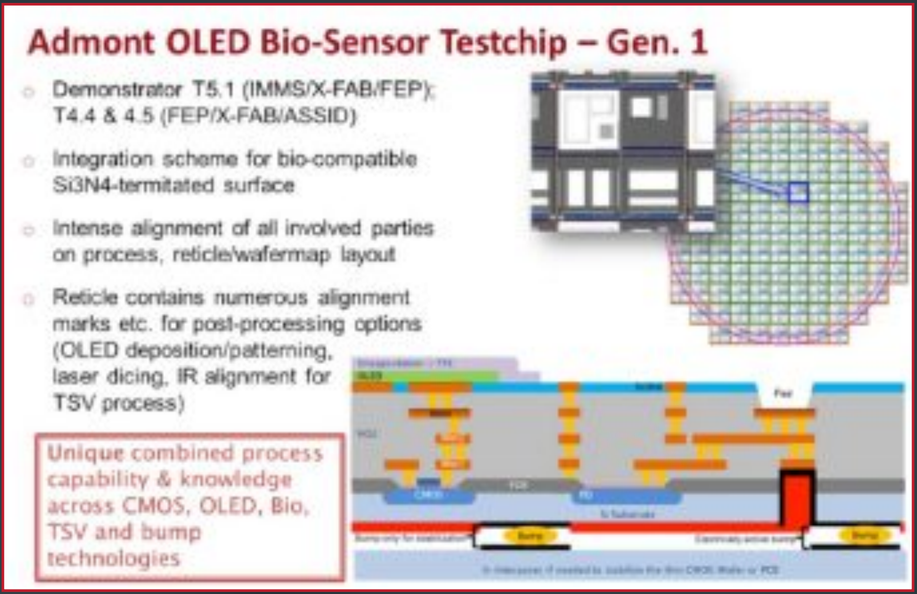


Figure 9. Yield increase of 80x64-TP-Array by layout changes and improvement of metal process (red = fail chips, green = pass chips)

An OLED Bio-Sensor test chip is shown in Figure 10.

An overview of important demonstrators and prototypes is shown in Figure 11.

The 3-channel mobile gas sensor for a direct alcohol measurement in the breathing air from partner SenseAir from Sweden contains an innovative and miniaturized IR spectrometer with improved mirror optics and the thermopile module as sensor. Within ADMONT also the pilot line for assembly of the gas sensors has been developed. The size of the gas sensors could be reduced by 50% and the response time could be improved to <10s.



Admont OLED Bio-Sensor Testchip – Gen. 1

- Demonstrator T5.1 (IMMS/X-FAB/FEP); T4.4 & 4.5 (FEP/X-FAB/ASSID)
- Integration scheme for bio-compatible Si3N4-termitated surface
- Intense alignment of all involved parties on process, reticle/wafermap layout
- Reticle contains numerous alignment marks etc. for post-processing options (OLED deposition/patterning, laser dicing, IR alignment for TSV process)

Unique combined process capability & knowledge across CMOS, OLED, Bio, TSV and bump technologies

Figure 10. Cross section and layout of an OLED sensor test chip for Lab-on-Chip applications, combination of photo diodes, OLED, TSV's and bumping

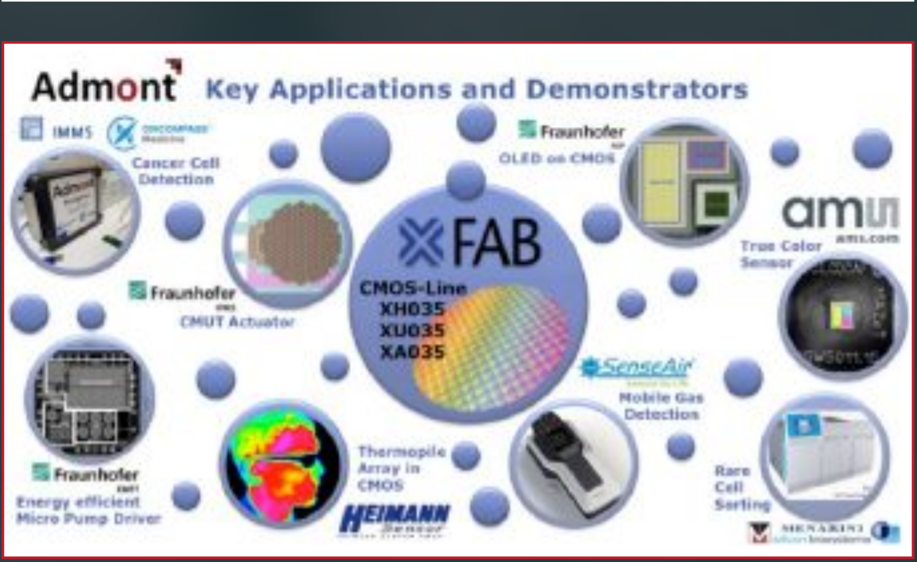


Figure 11. Selection of demonstrators and prototypes

The 80x64-TP-Array from Heimann Sensor with its pixel count of 5120 pixel is the largest TP-Array worldwide and has a temperature resolution of < 0,25 K per pixel. Within ADMONT were developed the TP-Array-Modul in the XA035 technology at X-FAB, the Pixel isolation , a new absorber at FhG-IPMS, the complete camera PCB-Board and an automatic calibration line at Heimann Sensor [6].

Partner Menarini SiliconBiosystems has developed and qualified a new device generation for cell sorting of can-cer cells (DEPArray™). Core is a Lab-on-Chip platform, based on a sensor interface made with XH035 technology with an additional 5th metal. The size of the system could be reduced by a factor of 5, the optical resolution could be improved by a factor of 3, based on 9-colour fluorescence. Additionally the throughput could be increased also by a factor of 3 [7].

Additionally a platform was created, based on OLED on CMOS for breast cancer detection (IMMS Ilmenau, On-Compass from Hungary), a real colour sensor for LED control (ams Sensor Germany), a three channel sensor for RFID transponder including ASIC for pressure, humidity and temperature monitoring (Smartrac, FhG-IPMS) and a CMUT sensor system with ASIC, which can measure air-coupled distances and contours in cm range (FhG-IPMS, FhG-IZM, Pepperl&Fuchs) [8].

A further part from ADMONT was development of soft and hardware solutions for fab automation for small microelectronic facilities and clean rooms of institutes. The prototypes which were developed enable an effective and cost efficient manufacturing at growing diversification of technologies and new process modules for sensors and MEMS (X-FAB, FhG-IPMS, Systema, Fabmatics) [9].

ADMONT funding and partner

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Project Coordinator: X-FAB Dresden GmbH & Co. KG. Partners: Heimann Sensor GmbH, Okmetic Oy, Systema Systementwicklung Dipl Inf. Manfred Austen GmbH, Fabmatics GmbH, Smartrac Technology GmbH, SenseAir AB, Menarini Silicon Biosystems S.p.A., AMS Sensors Germany GmbH, EDC Electronic Design Chemnitz GmbH, Technikon Planungs- und Forschungsgesellschaft mbH, Fraunhofer-Gesellschaft zur Förderung der ange-wandten Forschung e.V., IMMS Institut für Mikroelekt-ronikund Mechatronik-Systeme GmbH, and OnCompass Medicine Hungary Korlatolt Felelossegu Tarsasag.

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SUMMARY

The project results show that the heterogeneous integration of technologies and different fabs to final virtual production lines can boost technological development and fabrication. It was verified that joint developments could be realised which would be impossible in single fabs. Completely new ways are opened now. Combinations of leading edge-technologies in different research units and fabs are possible now.The benefit of these ways makes the industrial place Germany in the middle of Europe much more attractive for future developments and strengthen its position in a global competition.

PROJECT PARTNERS

Project Coordinator: X-FAB Dresden GmbH & Co. KG. Partners: Hellmann Sensor GmbH, Okmetic Oy. Systems Systementwicklung Dipl Inf.Manfred Austen GmbH, Fabmatics GmbH, Smartrac Technology GmbH, SenseAir aB, Menarini Silicon Biosystems S.p.A., AMS Sensors Germany GmbH, EDC Electronic Design Chemnitz GmbH, Technikon Planungs - und Forschungsges-ellschaft mbH, Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., IMMS Institut für Mikroelektronik-und Mechatronik-Systeme GmbH, and OnCompass Medicine Hungary Koriatolt Felelossegu Tarsasag.

PROJECT LEAD

X-FAB is the leading analogue/mixed-signal and MEMS foundry group manufacturing silicon wafers for automotive, industrial, consumer, medical and other applications. X-FAB offers worldwide marketing and sales support for foundry business with production facilities in Asia, America and Europe.

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