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# MEMS MATURITY

# Final report

| Revision | Date | Writer | Comments/reference documents |
|---|---|---|---|
| Version1<br>Version 2 | | Olivier Gigan<br>Vincent Gaff | <br>Confidentiality removed |

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## 1. Project objectives

This document is the report of the work performed by TRONICS under WP6 of the MEMS MATURITY program, in the frame of Cleansky grant agreement 323458.

The MEMS MATURITY program is the opportunity to optimize the best technology process for maturity assessment of the performance and the integration of high-performance high-stability MEMS gyrometers, adapted to the need of future Smart Fixed Wing Aircraft (SFWA) Systems for Green Operation. TRONICS' SFWA partner is THALES AVIONICS.

The program MEMS MATURITY had four goals:

1. To miniaturize the high performance gyro cell (Gyrix G-HP10 of THALES AVIONICS).
2. To identify the critical parameters of the process influencing the cell performance.
3. To assess the impact of the variability of the critical parameters on the cell performance.
4. To optimize the process for a repeatable manufacturing and to deliver optimized gyro cells to evaluate their performances in the sensor operational environment, together with THALES AVIONICS.

The overall final objective of this program was also to develop an industrial manufacturing environment for the Gyrix cell object. This environment should meet the performances needed for civil aeronautics applications. During this program, TRONICS mission was to improve the maturity of the Gyrix cell to bring it to a TRL 5 level.

The main results obtained on the 20 Gyrix G-HP10 cells will be presented and further perspectives will be reviewed.

## 2. Work progress and achievements

The main results obtained during the project are summarized below.

### *a. Process and design optimization*

During the project, the critical design parts and the critical process steps were identified.

For each item several batches were manufactured to test individually each modification/optimization. Each batch was validated at process levels and at cell performance test levels including environmental tests

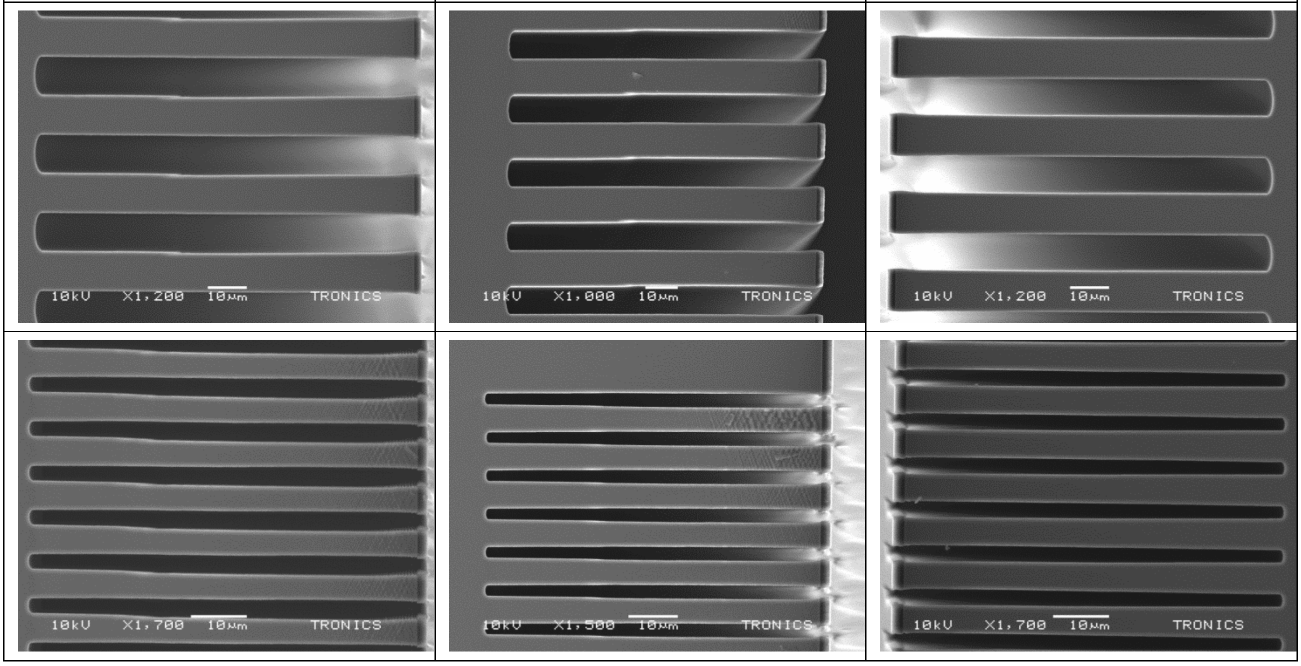
A selection of the more promising ones was performed and then included in a first demonstrator batch.

Then a second demonstrator run with process optimization was manufactured to stabilize the process and reduce the variability on sensor performances. This run was constituted of 3 batches of 6 wafers.

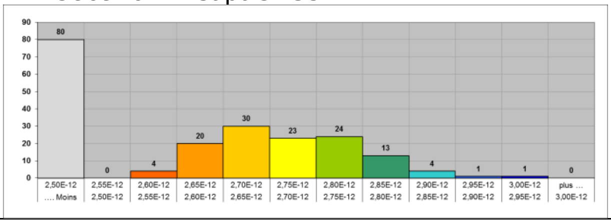
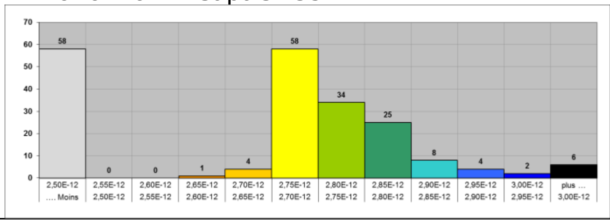
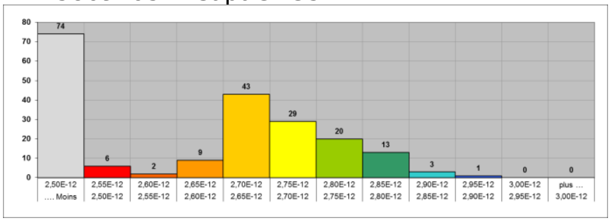
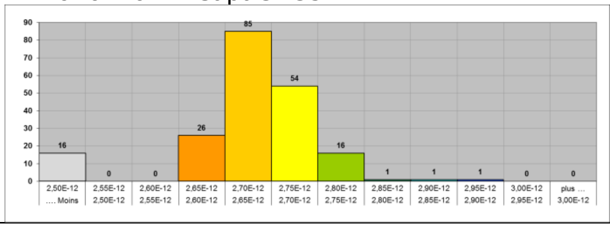
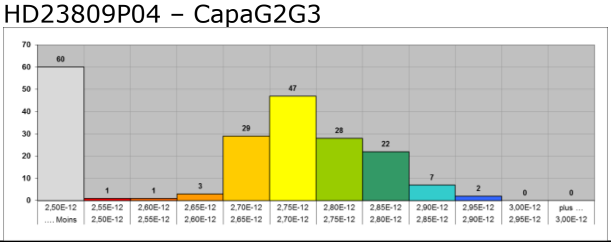
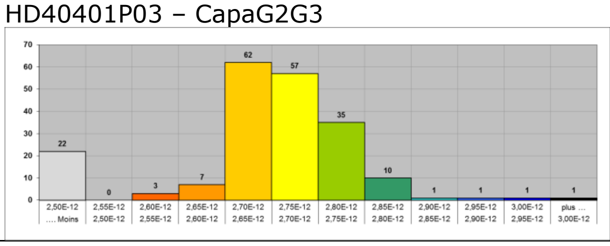
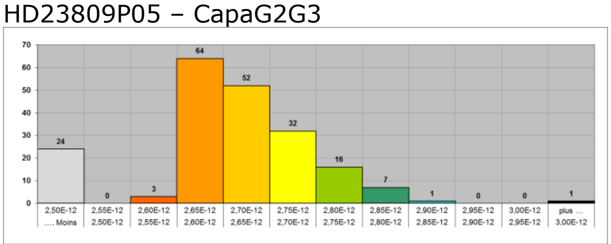
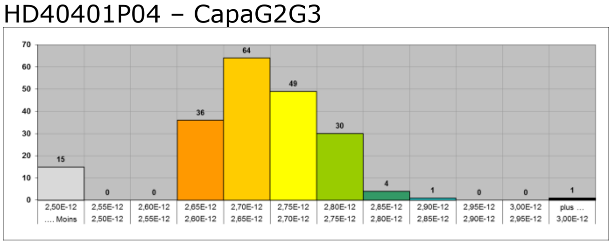
The main results of the design optimization are:
- A reduction of the silicon dies size of 15% with lead to an increase of the number of dies per wafer of +26% with associated consequence on cost.
- Improvements of the die attach design to reduce residual stress on the sensing element that leads to performance improvement. 3 different die attach definitions were evaluated.
- Improvement of the ceramic package design to suppress some process operations and to reduce the size of the cell.
- Change of getter inside the cell to a cheaper one. Validation of non-regression on the vacuum level

For the process the main results are:
- Suppression of 2 major process steps leading to process simplification and reducing risk of contamination inside the cavity of the sensitive structure.
- Improvement on DRIE (Deep Reactive Ion Etching) vertical etching process by moving the process to new generation of DRIE equipment (GP3). The comparison between old process and new on profile definition is presented on the following figure

| GP1 (20130314_GP1) | GP2 (20130625_GP2) | GP3 (20130314_GP3) |
|---|---|---|

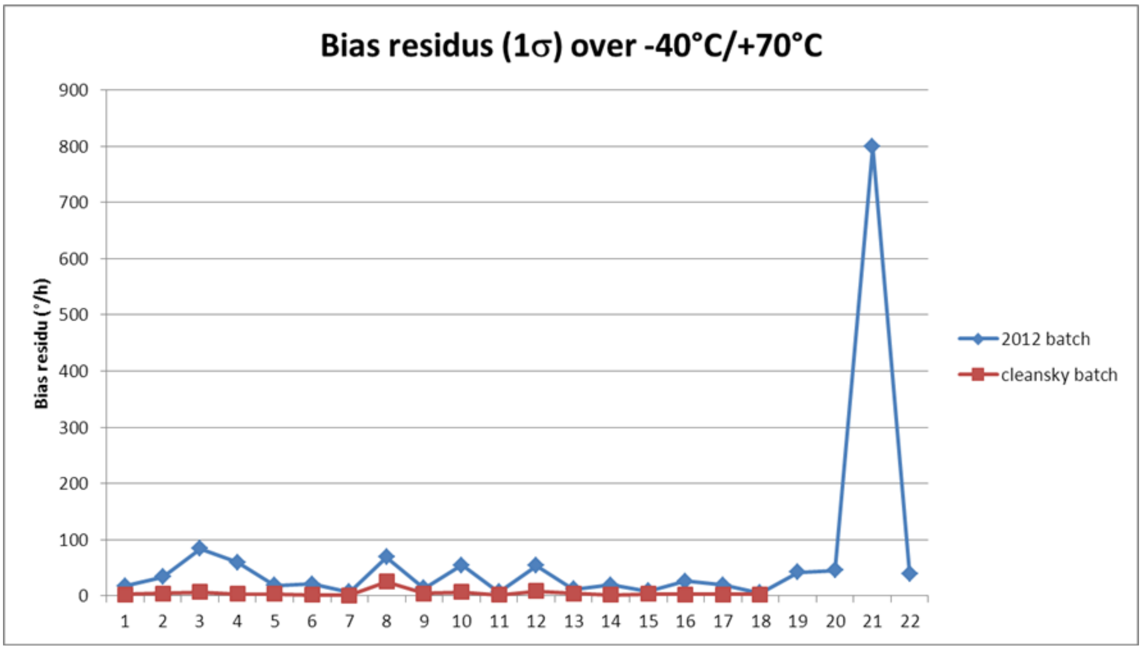


- Improvements of the die attach process in terms of quality and alignment that lead to yield increase.
- Improvement of dispersion on critical parameters such as capacitance of drive electrode. This is principally due to the use of new DRIE equipment. Regarding dispersion, the new equipment has reduced capacitance dispersion from about 5,5% for GP2 to about 3.5% on new GP3 (calculation on raw data for G2G3 capacitance value on several representative wafers on each equipment). Similar values are observed on drive frequency mode.

| GP2 (OLD) | GP3 (NEW) |
|---|---|
| HD23809P02 – CapaG2G3  | HD40401P01 – CapaG2G3  |
| HD23809P03 – CapaG2G3  | HD40401P02 – CapaG2G3  |
| HD23809P04 – CapaG2G3  | HD40401P03 – CapaG2G3  |
| HD23809P05 – CapaG2G3  | HD40401P04 – CapaG2G3  |

### *b. Results on the 20 Gyrix cells*

20 Gyrix cells were delivered to Thales. Only 18 cells are functional with electronics (90%)
The bias performances in temperature were improved by a factor 4 by the definition and process optimization done on the cell during the project as shown on the curve below.
No regression has been measured on the other parameters (Scale Factor, Noise, Bias stability) which were already compliant with the target specifications.
Now the gyrometer is compatible of applications of 10°/h accuracy.


Bias residus (1σ) over -40°C/+70°C
Bias residu (°/h)
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
2012 batch
cleansky batch

## 3. Project management

### a. ***Main meetings***

All along the project, TRONICS conduct with SFWA partner (THALES AVIONICS) a weekly basis conference call meeting to review current technical action progress and organization. This meeting addresses all technical topics including planning and schedule and current task, manufacturing progress and issues, problems and corrective action.

To reach the performance objective of the Gyrix gyro cell for SFWA partner, the mains difficulties was on the manufacturing of the MEMS sensing element and also on the final packaging integration process. A specific regular meeting was defined between TRONICS and SFWA partner the review integration and packaging issue. Those meeting were held on a monthly basis between technical expert on both sides to define and select the more promising process to be implemented on the Gyrix cell.

- 20/5/2014
- 19/06/2014
- 26/6/2014
- 25/7/2014
- 26/6/2014
- 26/8/2014
- 8/9/2014
- 2/10/2014
- 13/11/2014
- 18/11/2014
- 20/11/2014
- 4/12/2014
- 7/1/2015
- 22/1/2015

(Note: Meetings have also been held regularly in 2013 and early 2014. Unfortunately our electronic agenda erases themseleves automatically after 1 year, thus we can not provide the exact dates anymore).

Every quarter a coordination meeting was organized between TRONICS and SFWA partner to review program achievement and progress and orientation. Between 2014 and 2015 the meeting was held on the following date:

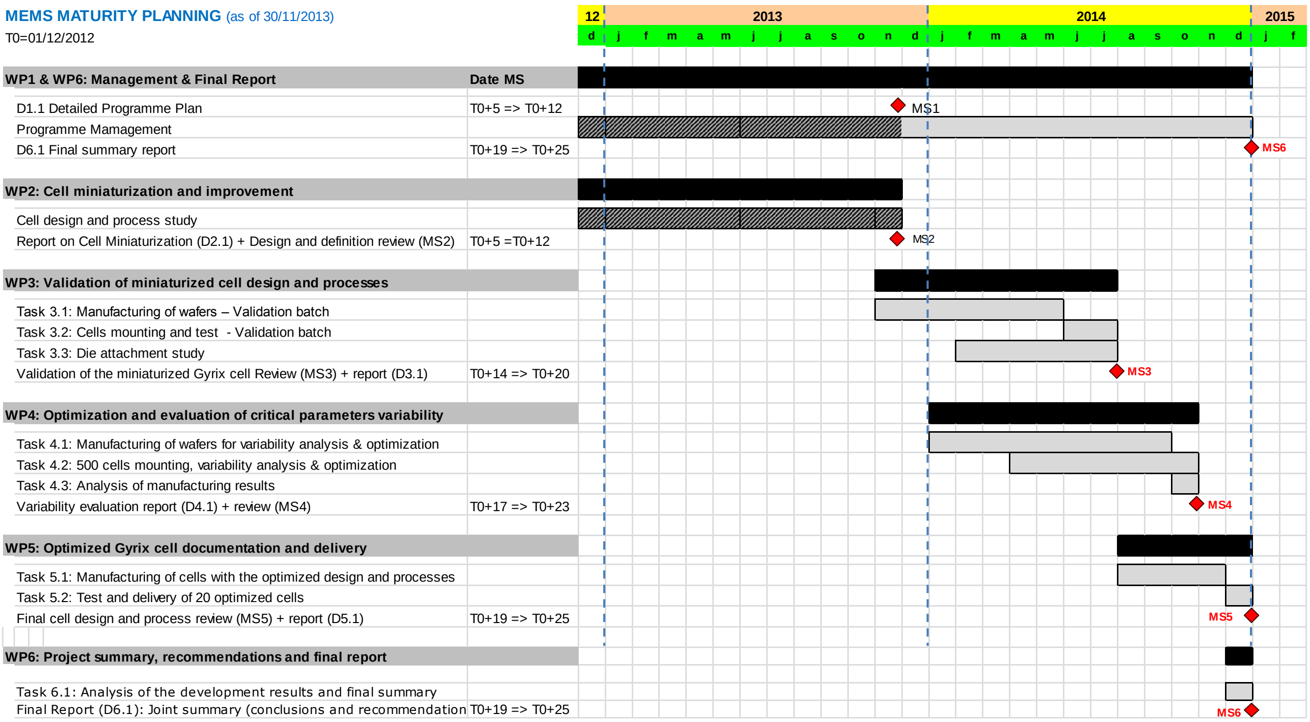
- 16/4/2014
- 26/6/2014
- 8/9/2014
- 18/11/2014
- 22/1/2015

(Note: Meetings have also been held regularly in 2013 and early 2014. Unfortunately our electronic agenda erases themseleves automatically after 1 year, thus we can not provide the exact dates anymore).

### *b. Planning*

The overall project has to face several technical issues related manufacturing delay and process definition. Several additional development batches have been necessary to conduct all necessary work for optimizing both Gyrix cell design definition and process implementation to reach performances for SFWA partner.

This has an impact on the planning of the project and a 6 month extension have been asked and validate by consortium.



## 4. General conclusion and recommendations

During the first part of the project design and process optimization at different level (sensing element, die attach, ceramic package, getter) have been studied and validated of evaluation batches.

Then on the second part all the most promising improvements were selected and put together in several demonstrator batches. These batches demonstrate significant improvement on silicon etching quality (dimensions, dispersions…) and on critical parameters measurements (capacitances, frequency, Q factor). The modifications lead to fewer steps in the process that reduce the cost and increase the yield.

The functional yield at cell level has increased to 60% that is quite satisfying even if further progress seems still possible.

The dimension of the sensing element and of the ceramic package was reduced to obtain a smaller and cheaper cell.

The performances measured at sensor level on 20 gyrix cells show a great improvement on the bias behavior in temperature (by a factor 4) and no regression on others parameters (scale factor, ARW, bias stability) that were already very good.

Now all the performances of the gyrometer are compatible with the specifications needed for future Smart Fixed Wing Aircraft (SFWA) Systems.

The technology developed during the project could also be applied to accelerometers that THALES designs and wishes to develop for avionics applications. This may be the subject of a new project ion the future.