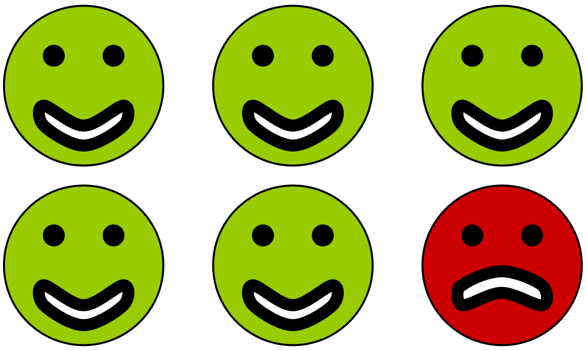
SMARTIEHS



SMART InspEction system for High Speed and
multifunctional testing of MEMS and MOEMS

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This In the following section the system parameters of the SMARTIEHS measurement system are evaluated versus the Melexis requirements. Based on this evaluation application scenarios of the two realized SMARTIEHS approaches (deformation and frequency measurements) are developed for Melexis products. Furthermore frequency reference measurements are done to validate the SMARTIEHS measurement results.

The conclusion of this validation is that the SMARTIEHS measurement system is, due to the parallel approach, well suited for cost-effective measurements and parameter identifications of IR sensors and pressure sensors e.g. provided that a flexible pitch will be realized. The flexible pitch is essential with regard to an industrial application in a medium size company like Melexis. There are no other parallel approaches known, so SMARTIEHS has a unique position on the market. The system parameters like frequency range and frequency resolution e.g. supply the needs of MEMS testing.

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COOPERATION

INTERNATIONAL DOCUMENT AVAILABLY:
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SMARTIEHS report

Creation date: December 26, 2011, Luc Buydens

1 Motivation

Melexis is a medium size microelectronics company (business volume 2010: 219 mill. €), with a focus on the automotive market. One part of the Melexis product portfolio are MEMS – micro-machined silicon technology coupled with mixed signal design has yielded infrared (IR) thermometers, inertial and pressure sensors that open new opportunities for customers in leading edge systems for cars, appliances, industrial machinery and consumer goods.

MEMS testing on wafer level is a big issue for Melexis which is certified to the most demanding internationally recognized Quality Standard ISO/TS 16949.Efficient test procedures on wafer level can reduce costs significantly by the detection of faulty sensors before the subsequent packaging and assembly steps. Furthermore the number of customers increases which require a 100% wafer test.

The efficiency criteria of test procedures is the measurement time which corresponds proportionally with the costs. Commercial optical measurement systems for the measurement of vibrations and deformations respectively topography are single channel systems. The bottleneck of single channel systems is the comparatively long measurement time. The parallel approach of SMARTIEHS which has a unique position on the market overcomes this drawback. The membership of Melexis at the Industrial Advisory Board (IAB) of SMARTIEHS is motivated by the innovative and promising approach.

The dynamic measurement approach as one of two measurement methods realized in the SMARTIEHS system is not yet well established as a MEMS test procedure. That might be due to a missing general statement regarding the identification possibilities by measuring the modal frequencies. First and foremost, it has to be checked for a new device type whether the frequencies are sensitive versus the interesting parameters by simulation and validation measurements. Melexis took the dynamic measurements for testing of IR sensors into account inspired by the SMARTIEHS consortium. The applicability of the dynamic approach is validated by measurements done within this subcontracting.

In the following section the system parameters of the SMARTIEHS measurement system are evaluated versus the Melexis requirements. Based on this evaluation application scenarios of the two realized SMARTIEHS approaches (deformation and frequency measurements) are developed for Melexis products. Furthermore frequency reference measurements are done to validate the SMARTIEHS measurement results.

2 Validation of SMARTIEHS measurement system parameters

Two measurement methods (frequency and topography) are integrated in the SMARTIEHS system. A laser interferometer (LI) array (Twyman-Green interferometer) is used to measure mode shapes and mode frequencies of the structures. The excitation of the structures is done by electrostatic forces. A glass wafer with transparent electrodes made of indium tin oxide (ITO) is positioned above the surface, and an impressed voltage of up to 200 V realizes the excitation of the structures.

A low coherent interferometer (LCI) array (Mirau interferometer) is used to measure shape and deformation of the dies. By moving the focus points of the LCI array at constant velocity parallel to the wafer surface a set of equidistant pictures is taken.

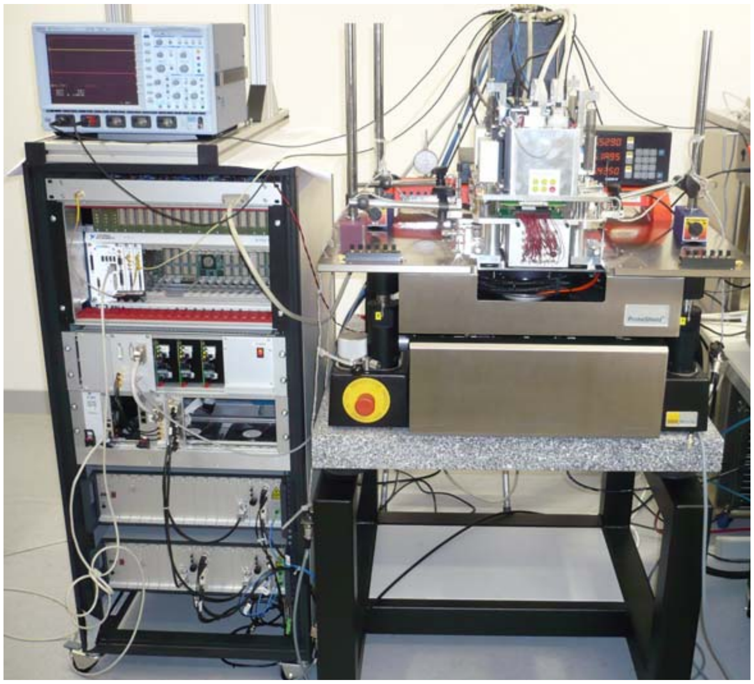

Figure 1: SMARTIEHS measurement system

The SMARTIEHS system shown in Figure 1 consists of two (LI and LCI) 5x5 parallel measurement units. The interferometer matrices including lenses, mirrors and gratings are realized as a wafer compound by microsystem technologies. The illumination is done by an array of laser diodes for the LI system and an LED array for the LCI system respectively. A 5x5 smart-pixel camera module detects the interferometer signal. For both interferometer arrays, the LCI and the LI type, a set of specification values was defined by the SMARTIEHS team. An extract is shown in the table below.

spec. nr.	specification	description	SMARTIEHS specifications
311	x-, y- (in-plane, spatial, lateral) resolution	defines the x,y- point resolution of the optical system, how large is the area on the object that contributes to the signal on one pixel?	5 µm
510	resolution of the camera / no. of pixels	determines the number of pixels in each imager chip	120 x 120
323	measurement time for shape measurement	defines the time for 1 measurement cycle including data processing	1 s

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324	measurement time for deformation measurement	defines the time for 1 measurement cycle including data processing	2 s
701	Number of objects on the MEMS wafer	defines the no. of objects and its distribution in x and y direction	1000-3000 on 6”
702	pitch between the objects on the MEMS wafer	defines the x,y- centre to centre distance between the structures on the MEMS wafer	1-3 mm
703	resonance frequency of the MEMS structures	First mode resonance frequency of the active area at the MEMS structure (given by its design)	10 kHz-1 MHz
704	Allowed deformation range of the MEMS structures	defines the range of the out-of-plane component of the deformation of the MEMS structure	50 nm - 50 µm
705	vibration amplitude of the MEMS structures during tests	vibration amplitude of the MEMS structure when it is excited at its resonance frequency by the excitation system	> 10 nm
706	max height difference on the MEMS structures	physical height of the object given by the highest - lowest point of the object shape	500 µm
707	MEMS structure size	physical size of the active MEMS area to be inspected by the instrument. It should include a reference point not moving during excitation.	500 µm x 500 µm to 1000 µm x 1000µm
711	size of the MEMS wafer	physical size of the MEMS wafer	up to 8”
713	reflectivity of the object surface in the VIS	reflectivity of the first interface of the MEMS seen from the camera	>10%

Table 1: SMARTIEHS device specification

The spec covers the requirements of relevant MEMS devices from the Melexis point of view. The realized SMARTIEHS system has a fixed pitch adapted to a specific sensor device, thus it addresses a high mass production. For a medium size company like Melexis the number of wafers per sensor type is not sufficient for a cost effective test by a parallel test system with fixed pitches.

The proof of concept is shown by measurements. In Figure 2, the deformation of an absolute pressure sensor under ambient pressure measured by the SMARTIEHS system is shown.

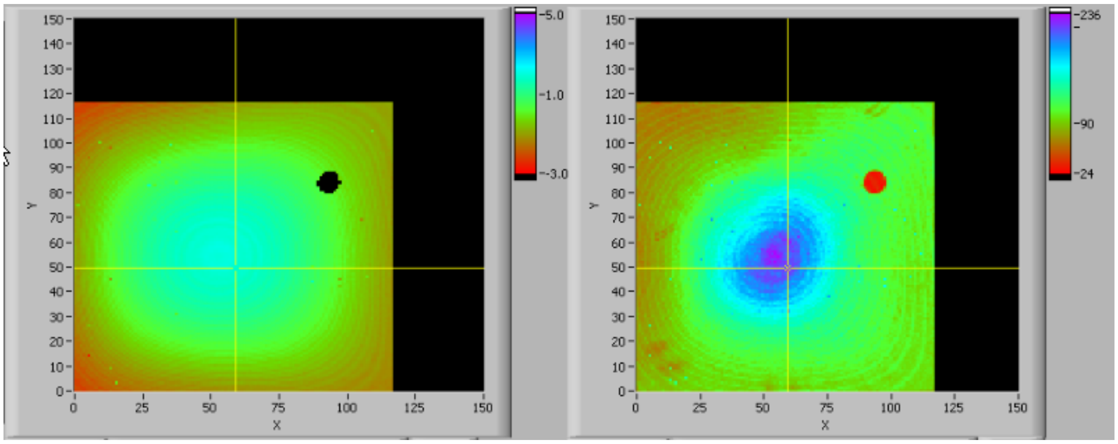
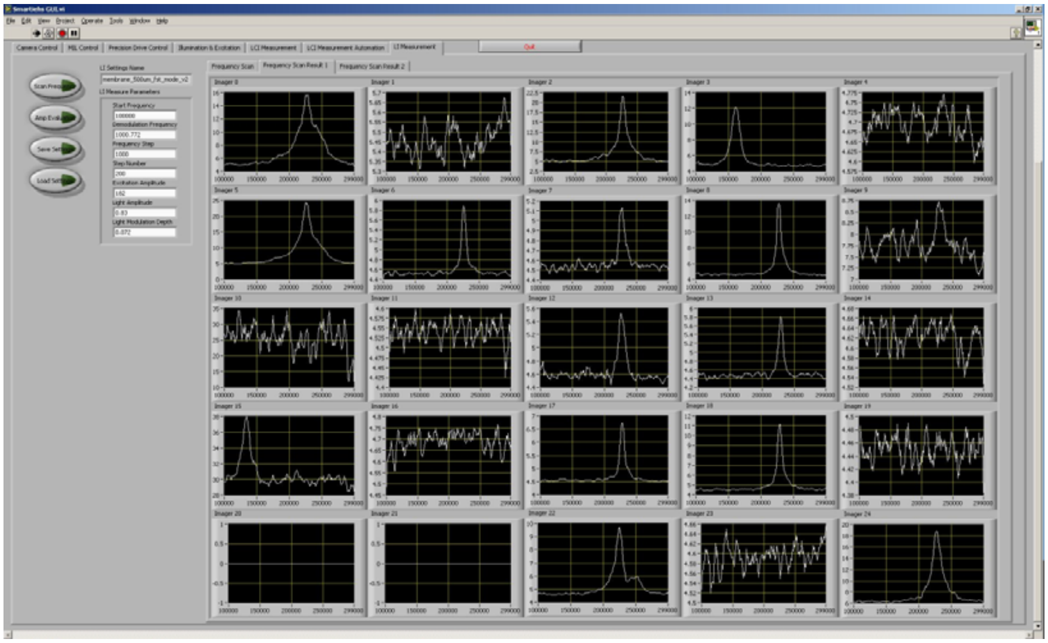


Figure 2: Measured absolute pressure sensor deformation

Figure 3 displays the FRF (frequency response functions) of the membrane based IR sensors measured by the SMARTIEHS system. A resonance peak can be clearly detected about 220 kHz at 14 channels. Some broken membranes caused a noisy signal without resonance peak, and some channels did not work properly. The measured frequency peak corresponds with the first modal frequency of the IR sensors validated by FE simulations and reference measurements done with the commercial Polytec measurement system.



LI Settings Name
membrane_500um_fst_mode_v2

LI Measure Parameters

Start Frequency
100000

Demodulation Frequency
1000.772

Frequency Step
1000

Step Number
200

Excitation Amplitude
1.62

Light Amplitude
0.83

Light Modulation Depth
0.072

Figure 3: Measured first frequency mode of IR sensors

3 Application scenarios and reference measurements

Following the applicability of the parallel working SMARTIEHS measurement system with respect to the Melexis MEMS product portfolio (inertial and IR sensors as well as pressure sensors) is figured out respectively investigated.

Inertial sensors like accelerometers and gyroscopes are covered with a silicon top cap due to the required vacuum, so optical measurement approaches using visible light cannot be applied.

IR sensors of Melexis work on the thermopile principle. Thermopile elements are radially placed on a membrane. The different thermal resistance of membrane and bulk causes the required temperature difference between the ends of the thermopile elements. The mechanical characteristics of the membrane are not relevant for the sensor functionality, but they are important for the sensor reliability. The quadratic membrane is due to the ratio of small thickness (less than 3 µm) to the lateral dimension of 600 µm sensitive versus stress. This stress sensitivity can lead to membrane cracks on one hand at wafer level. The packaging process respectively the gluing process induces further stress, so membrane cracks can occur at packaging level on the other hand. Test procedures should detect such cracks and control membrane stress limits. Such a test procedure does not exist up to now. Crack detection can be done by LCI measurements, but a pixel-wise comparison of sensor surface pictures with defined pattern by commercial test systems is much faster. Furthermore the membrane deformation is not sensitive versus membrane stress. FE simulations at the IMMS have shown a sensitivity of modal frequencies versus membrane stress. Frequency measurements are done to validate the test approach.

A topographic measurement system like the LCI one could be predestined for the measurement of pressure sensors whose output signal depends on the membrane deformation. An application scenario is the substitution of pressure nozzles for the membrane excitation by membrane integrated electrodes. The resulting deformation can then be measured by a topography measurement system. The scenario is detailed in the subsection topographic measurements.

3.1 Modal frequency measurements

The reference measurements are done with the Micro System Analyzer MSA500 from Polytec. The confocal scanning laser Doppler vibrometer integrated in the MSA permits measurements in the interesting frequency range from 100 kHz to 1MHz with vertical picometer resolution. For the measurements the laser beam of the vibrometer is scanned automatically over a user defined grid at the surface of the MEMS device. An out-of-plane velocity measurement is performed for each scan point; hence the measurement time depends on the number of measurement points. An internal generator controls the electrostatic excitation of the MEMS device by a probe needle positioned above the membrane surface and synchronizes the phase between the measurement points.

Figure 4: Measurement setup for single channel dynamic measurements (MSA500 and Cascade probe station)

Two complete wafers with different process parameters were measured. The post processing of the measurement data like peak picking within the frequency response function (FRF)is done with parameter identification software module developed within the SMARTIEHS project. A wafer map with the first measured frequency mode is shown in Figure 5.

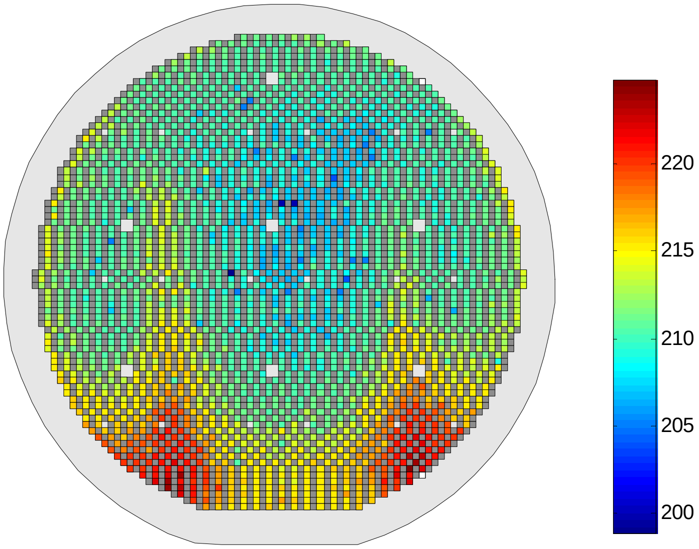


Figure 5: Wafer map of measured resonance frequency mode f_{11} in kHz

The frequency distribution which corresponds with the stress distribution features a significant center-edge effect which cannot be detected with conventional measurement approaches like the wafer-bow test. The measurement results were used to optimize the processing with respect to a more uniform stress distribution.

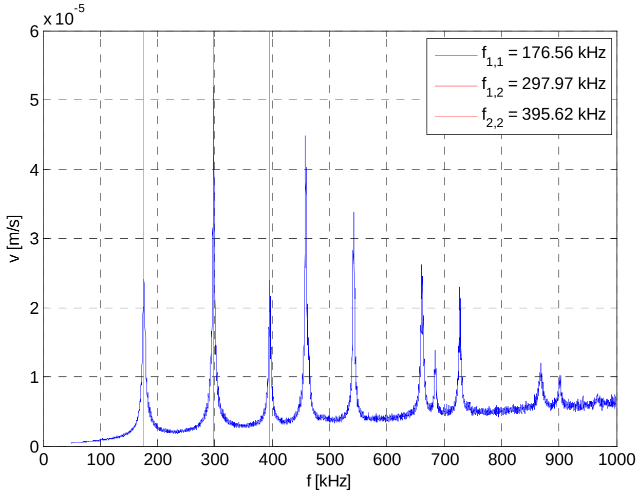
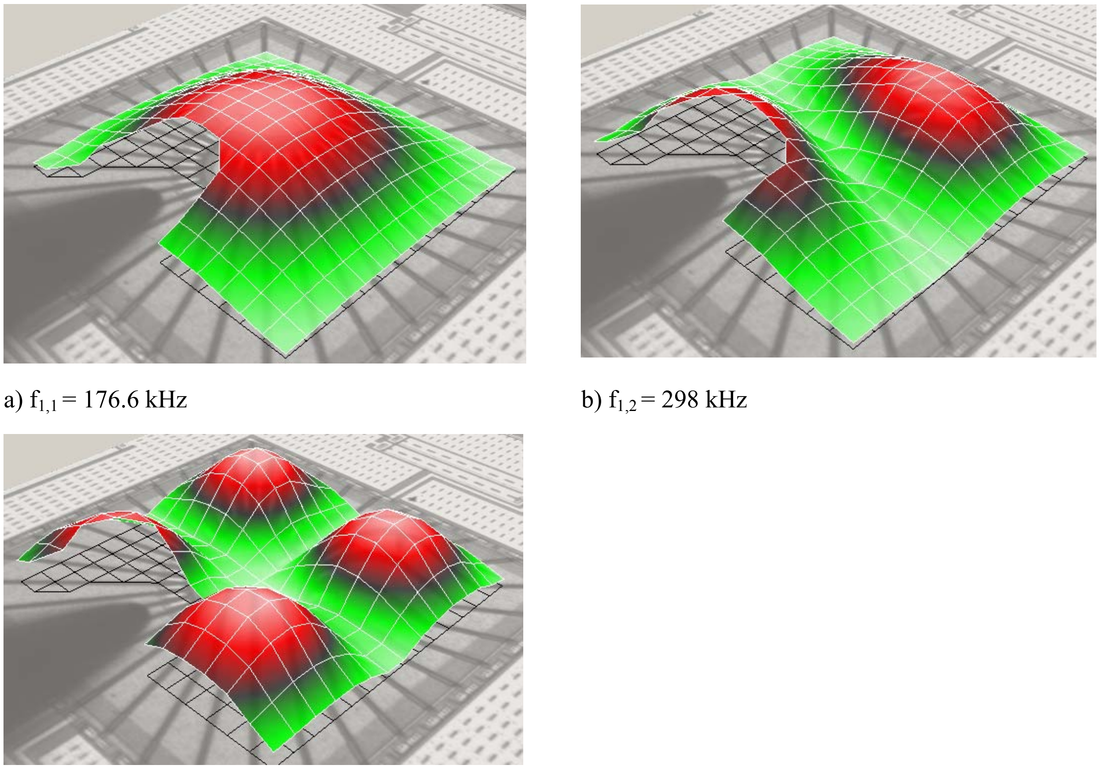


Figure 6: Measured FRF of die at wafer level

The FRF of dies on wafer level is consistent with the characteristic of symmetric membranes – the two phase shifted modes $f_{1,2}$ and $f_{2,1}$ have the same frequency values.



a) $f_{1,1}$ = 176.6 kHz

b) $f_{1,2}$ = 298 kHz

c) $f_{2,2}$ = 395.6 kHz

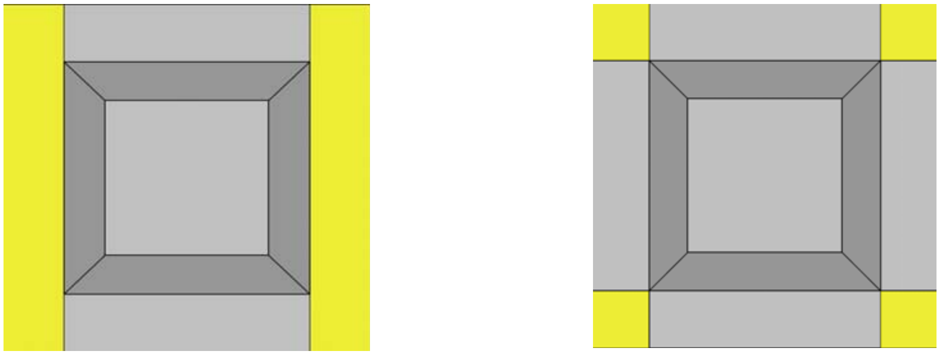
Figure 7: Measured mode shapes (die on wafer level)

The IR sensor consisting of 7 different material layers is tensile pre-stressed (the modal frequency of the first mode of a stress free membrane would be 130 kHz instead of 170-220 kHz). Different process parameters, respectively stress characteristics for the passivation layer (tensile or compressive layer stress) lead to dies with lower (wafer 1) and higher tensile stress (wafer 2).

	mean($f_{1,1}$)	σ($f_{1,1}$)	mean($f_{1,2}$)	σ($f_{1,2}$)	mean($f_{2,2}$)	σ($f_{2,2}$)
Wafer 1	163.7	3.2	278.3	5.1	369.6	5.7
Wafer 2	213.4	0.6	355.6	4.5	474.1	1.0

Table 2: Measured frequency values (mean value and standard deviation)

The gluing as part of the packaging introduces further stress ; the different coefficients of thermal expansion of copper and silicon will not fully compensated by the glue, a momentum acts via the frame on the membrane which results in stress.



a) Gluing with lines

b) Gluing with dots

Figure 8: Glue distribution types (glue - yellow)

Two different glue configuration types are applied at the packaging process. 12 dies were packaged from each wafer with the 2 different glue configurations (overall 48 dies).

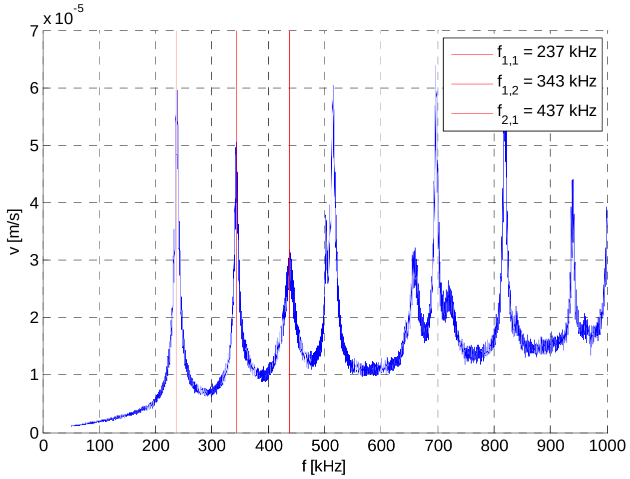
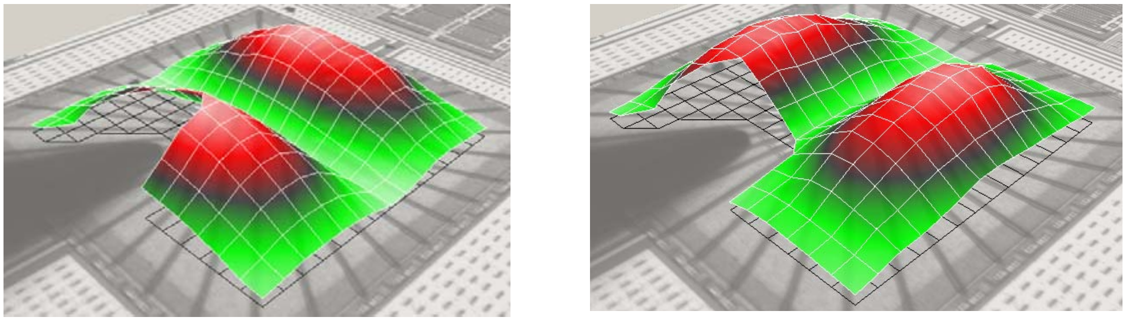


Figure 9: Measured FRF (packaged die)

The line gluing causes different momentums in x and y. This non uniform stress reflects in a splitting of the frequencies $f_{1,2}$ and $f_{2,1}$ (Figure 8 and Figure 9). On the other hand dies glued with the dot configuration show a symmetric characteristic, but a slightly increased first mode.



a) $f_{1,2} = 343$ kHz

b) $f_{2,1} = 437$ kHz

Figure 10: Measured mode shapes (packaged die, line gluing)

These first measurements have proven the applicability of the method for the monitoring of stress limits at IR sensors on wafer and package level. Defined frequency limits correspond with the classification of good and bad dies based on the yield on wafer level and after packaging respectively. Further investigations will be done to validate the first results with respect to qualify the approach for the characterization phase of the next generation IR sensors. Due to cost reasons the Polytec measurement system cannot be used for production test. A massive parallel measurement system like the SMARTIEHS one could be a solution if a flexible pitch can be handled.

	mean($f_{1,1}$)	σ($f_{1,1}$)	mean($f_{1,2}$)	σ($f_{1,2}$)	mean($f_{2,1}$)	σ($f_{2,1}$)
Wafer 1, line glued	177.5	3.9	222.2	5.5	367.5	4.0
Wafer 1, dot glued	200.3	2.8	339.1	6.6	339.1	3.9
Wafer 2, line glued	224.7	2.7	320.6	4.2	414.7	5.2
Wafer 2, dot glued	240.3	2.1	390.0	1.9	390.0	3.2

Table 3: Measured frequencies of packaged dies

3.2 *Topographic measurements*

Customers require for some sensor types a full wafer test of the sensitivity and nonlinearity characteristic of piezoresistive pressure sensors. A sensitivity and nonlinearity test at wafer level implies the measurement of the output voltage of the Wheatstone bridge at different membrane deformations. Currently the measurement respectively the deformation is realized by a pressure nozzle which is positioned about 30 µm above the sensor membrane. The pressure nozzle is adapted to the sensor membrane surface. Figure 11 shows the measurement principle.

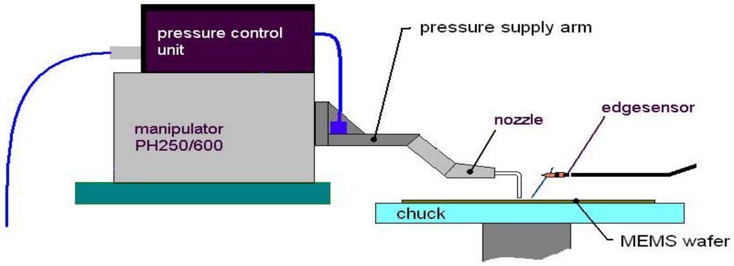
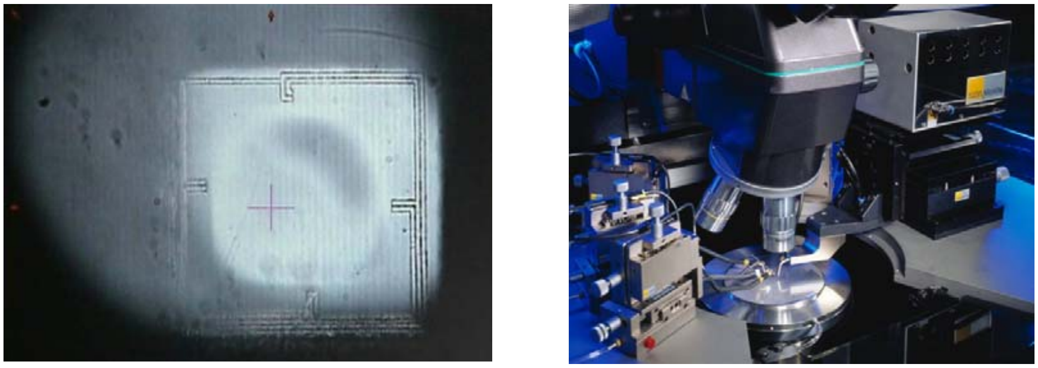


Figure 11: Sketch of the static measurements by pressure nozzle

This setup realizes a single die measurement. The measurement time per die depends on the number of pressure setting points and differs between at least 1 second up to 10 seconds, so the test is really cost intensive. A parallel excitation of several dies cannot be done because the airflow of the different channels will interact. An excitation from the backside by a chuck with integrated air channels does not work for absolute pressure sensors; furthermore such a chuck has to be designed for every sensor type. Sensor specific chucks cannot be a test solution for a medium size MEMS company like Melexis due to cost reasons.



a) Measured membrane deformation b) Pressure nozzle

Figure 12: Measurement setup for deformation measurements

A solution might be given by a self-exciting membrane whose deformation can be measured than by a topographic measurement system, simultaneously the bridge output voltage is measured via the probe card. Such a self-exciting membrane can be realized by the integration of laminar electrodes into the membrane - electrostatic forces will cause a deformation.

The development of self-exciting pressure sensors which can use the parallel LCI measurement system is planned within the next sensor redesign. The development project covers a redesign of the probe cards and the probe card adapter too, the current setup cannot be used to contact a matrix of 5 by 5 dies e.g. at the same time.

4 Summary and outlook

The SMARTIEHS measurement system is due to the parallel approach well suited for cost-effective measurements and parameter identifications of IR sensors and pressure sensors e.g. provided that a flexible pitch will be realized. The flexible pitch is essential with regard to an industrial application in a medium size company like Melexis. There are no other parallel approaches known, so SMARTIEHS has a unique position on the market. The system parameters like frequency range and frequency resolution e.g. supply the needs of MEMS testing.

The proof-of-concept of the parallel testing approach is done by the realized prototype respectively the corresponding measurements. Further development objectives to turn the prototype into a product should be a mass reduction of the measurement system e.g. by splitting the 2 approaches into 2 setups and the mounting of the system at conventional mounting points like the scope adapter to permit the use of standard probe stations.

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