PROJECT FINAL REPORT

Deliverable D0.4:"Public report of project's results"

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Project acronym:	MEMSPACK
Project title:	Zero- and First-level Packaging of RF-MEMS
Funding Scheme:	FP7– Small or Medium-scale focused research project
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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the grant agreement

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm ; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

4.1 Final publishable summary report

Executive Summary:

A critical success factor hampering the commercialization of RF-MEMS has been the development, or, for that matter, the availability, of an appropriate packaging technology. Until the MEMSPACK project was launched, there had not been sufficient focused effort towards solving this issue. The FP7 supported MEMSPACK project has tackled the packaging issue. The project has started June 1, 2008 and has ended February 29, 2012.

The project's main objective is to develop and to characterize *generic* 0-level (or wafer-level) and 1-level packaging solutions for housing a large variety of RF-MEMS components and systems. This has been done through 2 or 3 development cycles, each cycle encompassing design, modeling, simulation, process technology development and full batch fabrication, and test and characterization. As many as 6 packaging technologies have been developed, of which three are based on 0-level "chip capping" (involving W2W or D2W bonding relying on BCB or solder bonds), two on 0-level "thin film capping" processing (relying on BCB thin film or on porous aluminum oxide thin films), and one on 1-level packaging technology (which is based on LTCC). These 6 technologies implement different topologies for the high frequency (RF) feedthroughs. Much of the development effort is dedicated to making the right trade-off between the RF characteristics, the hermeticity and the thermo-mechanical characteristics of the packages and of the electrical feedthroughs. Moreover, as an integral part of the project, test methodologies and dedicated test structures for characterizing the RF, thermo-mechanical and hermeticity characteristics of the packages, are developed.

The different packaging technologies have been evaluated on the basis of a set of baseline specifications defined with the help and input from the IAB. While some of the technologies under development score best on RF characteristics (good characteristics up to 70 GHz, and e.g., insertion loss down to 0.1 dB and return loss up to 30 dB) and on low processing temperature (down to 250 °C), others show better hermeticity (with helium leak rates currently down to 10^{-15}mbar•l/s), and/or better robustness against thermo-mechanical loads such as high ambient temperatures and high back-end pressure (e.g., 30 or even 90 bar as exerted during epoxy overmolding). All 0-level packaging technologies have been demonstrated with CPWs as RF signal lines, whereas the 1-level technology based on LTCC processing has been demonstrated with CPWs as well as microstrip lines.

A specific outcome of the project is the "RF-MEMS packaging design guidelines", which can be used by industry for the development and exploitation of RF-MEMS. These guidelines describe in a comprehensive manner the project outcome, thereby not only discussing the design of the package, but also the choice of materials and processes implemented for a wide span of (complementary) packaging technologies together with test procedures and characterization methods for the package. All of the MEMSPACK wafer level packaging technologies are capable of providing low profile packages, compatibility with front end MEMS and CMOS processing and compatibility with higher level packaging technologies. Not surprisingly perhaps, it was concluded that the "Holy Grail package" does not exist (at least was not among the 6 packaging concept as investigated by the consortium). Each one of the 6 packaging concepts has its own specific pro's and con's and the choice of the package can only be made in view of the application. Thanks to the generic nature of the 6 MEMSPACK packaging concepts, they cover a wide range of potential applications, in particular in consumer products (including hand held devices), automotive and space and aviation.

The technologies and the design, modeling and test competences as developed within the MEMSPACK are prepared for commercial exploitation and industrial application, in some cases through recent spin-outs from the below mentioned mother organizations. Several packaging technologies have reached a maturity level which allows direct transfer of the technology to any industrial party interested.

The consortium partners in the project have been selected so that the whole development chain from design&modeling via fabrication and test&characterization (including reliability testing) to benchmarking and demonstrator fabrication is fulfilled. The project partners are: Imec (Belgium), VTT (Finland), FhG-ISiT (Germany), University of Perugia (Italy), FBK (Italy), CNRS-IEMN (France) and MEMS Technical Consultancy (The Netherlands). Further, an Industrial Advisory Board (IAB), consisting of 9 members, has been installed at the beginning of the project. Apart from giving general guidance and providing input (on e.g. the baseline specifications), the IAB plays an important role in guiding the consortium partners on exploitation and industrialization of the results and on the follow-up of development activities. Contact details can be found on the project website: www.memspack.eu

MEMSPACK: Summary description of project context and objectives

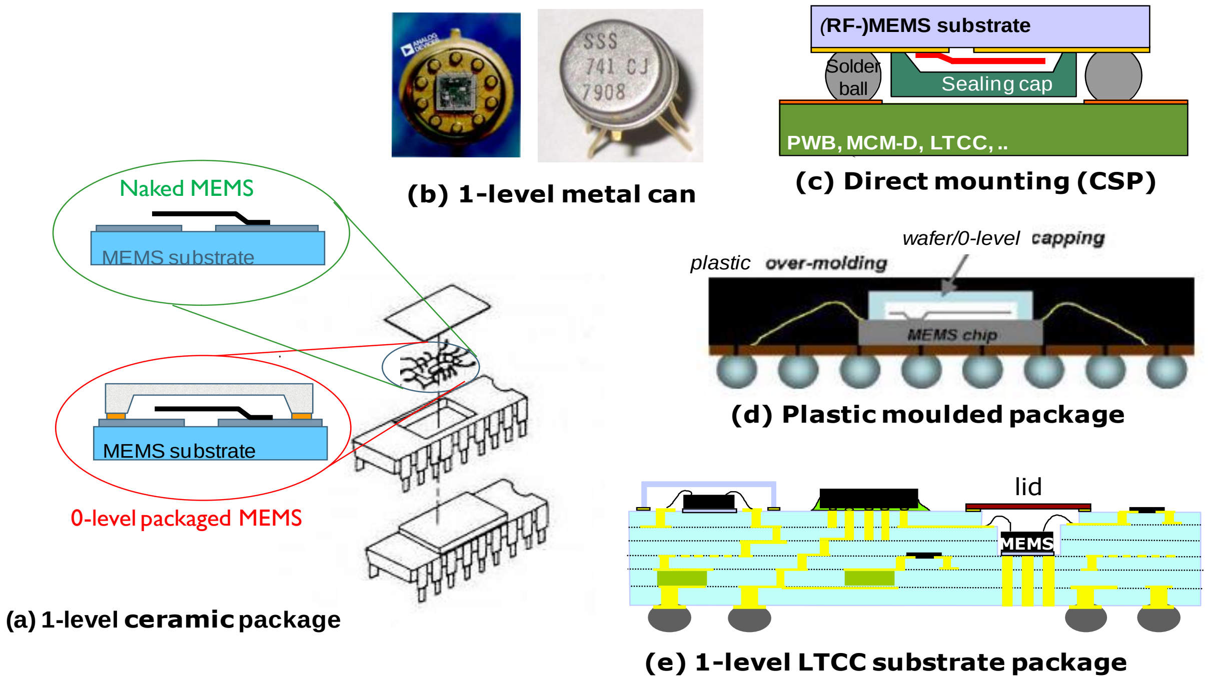
General introduction: (RF-)MEMS packaging

(RF-)MEMS devices, unlike ICs, contain movable fragile parts that must be packaged in a clean and stable environment. The package or encapsulation should not only offer protection to the MEMS during operation but also during fabrication. The specific ambient of the package housing depends on the type of RF-MEMS. RF-MEMS switches for instance are preferably housed in an inert ambient (*e.g.*, a dry nitrogen) at atmospheric (or "slightly" below atmospheric) pressure. The same applies to RF-MEMS varactors (variable or tunable capacitors) and variometers (tunable inductors). RF-MEMS resonators on the other hand require a high level of vacuum (*e.g.*, ambient pressure < 1 Pa) in order to attain high frequency stability and to have sufficiently low damping at resonance. Practically all MEMS are adversely affected by corrosive ambients like moisture. All in all and to ensure stability of the (RF-)MEMS device, the package must offer hermetic (or near-hermetic) seals. Sealing and encapsulation are crucial so as to provide the required reliability of the packaged devices.

Essentially two approaches for device encapsulation can be defined:

(1) encapsulation of the "naked" MEMS in a proven conventional 1-level ceramic package as in Figure 1(a) (*e.g.*, AlN or Low Temperature Co-fired Ceramic – LTCC as illustrated in Figure 1(e)), or metal can package (as in Figure 1(b)), and,

(2) encapsulation on the wafer by a 0-level package (see "inserts" in Figure 1(a),(c) and (d)), possibly followed by 1-level packaging (e.g., epoxy overmoulding as illustrated in Figure 1(d)).



(a) 1-level ceramic package

(b) 1-level metal can

(c) Direct mounting (CSP)

(d) Plastic moulded package

(e) 1-level LTCC substrate package

Figure 1: Illustration of 0-level/1-level packaging approaches for MEMS.

The 1-level package comprises what is usually interpreted as the package, *i.e.*, the chip capsule and the leads for interconnecting the chip to the outside world. For ceramic packages, encapsulation for instance can be achieved by soldering or brazing a (ceramic) cap lid to a metal seal band on the substrate, thus defining the cavity housing for the MEMS device (and/or electronic) chip. Metal hermetic packages are commonly welded, soldered, or brazed. Cavity formation during 1-level packaging is an established method and allows a certain flexibility with respect to the composition of sealing gas and the sealing pressure, but, on the other hand, requires the use of expensive ceramic or metal can packages. The high cost of 1-level packaging is viable for telecom base stations, satellite and defense systems, but not for volume applications like wireless handsets. Furthermore, 1-level packaging poses technological complications mainly due to handling of the MEMS after their release. For instance, the standard wafer sawing or the injection molding process of plastic packages cannot be used as it may destroy or contaminate the released MEMS device. Once the wafer is diced, the MEMS chips must be handled in an extremely clean environment as cleaning in a liquid is no longer possible at this stage. All this makes that packaging is preferably carried out according to the 2nd approach, i.e., on the wafer during wafer processing, prior to die singulation. This packaging step is referred to as wafer-level or *0-level packaging*. Illustration of 0-level capped MEMS are presented in (the inserts) of Figure 1(a),(b) and (c). There is clearly a trend observable towards 0-level packaging for MEMS.

The 0-level packaging creates an on-wafer device scale enclosure around (or sealed cavity for) the MEMS device, serving as a first protective interface. Zero-level packaging in fact leverages the batch fabrication features of front-end wafer processing. For the 0-level packaging, two general approaches have been taken, here referred to as “thin-film capping” and “chip-capping”, both of which have been addressed in MEMSPACK. In addition to a low-cost fabrication process and physical protection, the 0-level package must be strong, equipped with low-loss electrical RF signal feedthroughs and be (near-)hermetic, preventing any particles and moisture from migrating into the region of the MEMS and the region underneath the released MEMS structure. On the other hand, 0-level packaging should not increase the die form factor too much, both for cost reasons and for implementation reasons. Cell phones for instance put a constraint on the total height of the packaged die. Once 0-level packaged, the wafer can be diced without any danger of demolishing the MEMS device. The individual chip assemblies can next be mounted via wire-bond or flip-chip solder bumping in a low-cost plastic molded 1-level package, *e.g.*, SOIC-8 or BGA package, or, in a more costly 1-level ceramic or metal package. The latter is done in case the 0-level package only serves as a basic protection (e.g., during dicing) but is not sufficient in providing the required reliability and performance of the packaged MEMS. Alternatively, the 0-level packaged device can be handled as a chip scale package (CSP) to be directly joined to a printed wiring board. The 1-level package provides mechanical and environmental protection to the devices they hold, but not without degrading the electrical performance. At microwave frequencies (and higher) the impact the package has on the electrical performance becomes an important element in the design of the device. Plastic molded packaging is the most common low-cost 1-level packaging solution applicable for frequencies below several GHz. Careful choice of the plastic molding material and the RF design of the leadframe allows use up to 10 GHz. For use at higher frequencies, ceramic 1-level packages based on multi-layer LTCC (Low Temperature Co-fired Ceramic) or HTCC (High Temperature Co-fired Ceramic) technology, employing low loss dielectrics combined with flip-chip assembly of the device for short interconnects, exhibit the potential for good performance into the millimeter wave regime (as high as 80 GHz).

Without any doubt, packaging is one of the most important issues towards industrialization and commercialization. It is now recognized that the package is an integral part of the MEMS device: “*A MEMS without a package is not a MEMS*”. One of the functions of the package is signal distribution, and therefore, it is fairly obvious that the RF performance may very well be (adversely) affected due to interference of the package. In an ideal package the RF characteristics of the RF-MEMS device before and after 0-level packaging should be the same, but this is something that is not at all evident to achieve. In effect, low-loss RF transitions are required, in addition to minimal induced loss and detuning of the transmission lines due to proximity coupling to the package. Moreover, testing the RF performance during processing is important to improve yield and lower the costs. For this reason the design and technology should be chosen in a way to establish not only an acceptable off chip RF performance but at the same time an easily testable and properly packaged device while maintaining good device performance. The successful development of an (RF-)MEMS device or system requires an "integrated design concept". Therefore, the structural design, the design of the electromechanical transducer, the microwave design, design for proper testability, the micromachining fabrication technology and last but not least the package design and technology should be addressed at the same time, early in the design stage. Thus, in order not to be in for a surprise in the end, the choice of the package technology and the package design should be taken up in the design process right away from Day 1.

Project context:

Future personal and ground RF communications systems and communications satellites necessitate the use of highly integrated RF front-ends, featuring small size, low weight, high performance and low cost. Off-chip, bulky passive RF components, like discrete PIN diode switches and ceramic filters, are limiting further chip scaling. MEMS technology is now rapidly emerging as an enabling technology to yield a new generation of high-performance RF-MEMS passives, like switches (displaying superior RF characteristics, like low insertion loss and good linearity), high-Q Si-based resonators (to replace the bulky quartz crystals) and tunable filters. RF-MEMS has been demonstrated to be a key technology for future adaptive and reconfigurable RF-communication systems. In various research initiatives, many of them supported by the European Commission, the specific advantages of RF-MEMS components, like lower loss, superior linearity and higher Q as well as lower power consumption have been shown. RF-MEMS devices allow to build up completely new RF-system architectures with increased performance and functionalities like reconfigurable RF-front-ends in handsets and base stations, or highly integrated phase-array antennas for agile communication links. Despite these initiatives however, following critical success factors, hampering the commercialization of (RF-)MEMS, can be identified:

(1) the accessibility of existing IC foundries
(2) the manufacturing cost
(3) the (long-term) reliability and,
(4) the development of an appropriate packaging technology.

The MEMSPACK project has tackled the latter: "*The packaging of the RF-MEMS*". Although MEMS packaging has been taken up in previous European funded projects, the attention for the research efforts in many of these projects was centred on the development and the demonstration of "a higher order system". Packaging, although addressed, was very often overshadowed by the drive of achieving "the system demonstrator". This has resulted in many unsolved packaging issues, which are addressed within MEMSPACK. MEMSPACK has explored and assessed RF-MEMS packaging on one hand with respect to the RF and encapsulation performance, but on the other hand also with respect to commercial targets. Manufacturability, testability, reliability, time-to-market and last not least, cost of MEMS packaging has been evaluated in depth.

The partners in the project have been selected such that the whole development chain from design&modeling via fabrication and test&characterization to benchmarking and demonstrator fabrication is fulfilled. The project partners with their main roles are:

- IMEC (Belgium): coordinator, supplier of 0-level packaging technology
- VTT (Finland): supplier of 1-level packaging technology
- FhG-ISiT (Germany): supplier of 0-level packaging technology
- University of Perugia (Italy): RF design and characterization of the package
- FBK-irst (Italy): supplier of (RF-MEMS) test vehicles to characterize the package
- CNRS-IEMN (France): RF design and test, supplier of 0-level packaging technology
- MEMS TC (The Netherlands): thermomechanical design, primary interface to the IAB

The fact that industry is not directly present in MEMSPACK as a full beneficiary does not at all mean that this project has aimed only on academic objectives. All beneficiaries have close bilateral industrial relationships in the RF-MEMS field and are well aware on the industrial needs. The absence of industrial partners (except for the SME MEMS TC) in the project, made that an Industrial Advisory Board (IAB) was established right from the start during the first month of the project. The alternative of including an industrial partner (playing the role of end-user, IDM, foundry service, etc.) would bring about "the risk" of developing a package solely for that particular industrial partner (or partners), and thus would jeopardize the generic nature of the project. And, this has never been the intention of the project. The main objective of the project (see also below) is to develop *generic* (RF-)MEMS packaging technologies and to be independent, *i.e.*, not linked somehow to any industrial company. Moreover, by installing an IAB, a larger community of end-users and foundries can be reached. The IAB has provided input (e.g., on specifications) and moreover guidance on which direction to take and where to put the focus of the developments within the project. The IAB is composed of 9 members: Baolab (Sp), DelfMEMS (Fr), EADS (D), EPCOS Netherlands (NL), NovaMEMS (Fr), NXP Research (NL), Optoi (It), Thales-Alenia-Space (Fr) and Selmic (Fin).

Project objectives

The *main objective* of the MEMSPACK project is:

- To (further) develop and to characterize generic 0-level & 1-level packaging technologies for housing (RF-)MEMS components and systems.

The project has primarily dealt with the 0-level packaging of (RF-)MEMS, but an example of 1-level packaging based on LTCC has been worked out in detail as well.

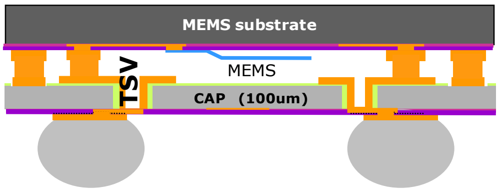
Specific objectives set forth at the start of the project are:

- To characterize the RF behaviour of the 0- and 1-level package through simulations
- To verify/validate the RF simulation against measurements
- To assess the range of applicability (RF performance, size, cost, compatibility, higher level packaging, assembly, interconnect, …) of the different RF feedthrough concepts/technologies
- To assess the impact/consequence of the 0-level package on the 1-level package (and the 2-level package) and vice versa
- To assess the compatibility of the 0- and 1-level packaging with the front end processing and vice versa.
- To assess and improve the reliability of the various 0-level packaging technologies
- To assess and compare the hermeticity of the 0- and 1-level package for the different packaging approaches in view of the application
- To assess and compare the thermomechanical and structural behaviour of the 0&1-level package for the different packaging approaches.
- To assess the impact of the 0- and 1-level packaging (technology, thermomechanical, electro-magnetic, ...) on the behaviour of the RF-MEMS.
- To assess the impact, the constraints and the potential of the RF-MEMS packaging on the system integration.
- To formulate 0- and 1-level RF MEMS packaging guidelines for RF(-MEMS) engineers.

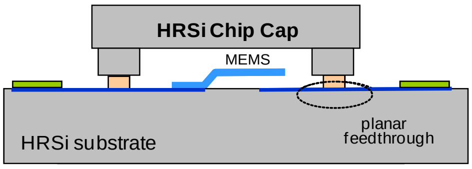
Description of the main S&T results/foregrounds

The main objective of the MEMSPACK project is to (further) develop and to characterize generic 0-level (or wafer-level) & 1-level packaging solutions for housing (RF-)MEMS components and systems. This has been done through 2 or 3 development cycles carried out for each packaging concept, each cycle encompassing design, modeling, simulation, process technology development and full batch fabrication, test and characterization and the package evaluation (impact of the package on the device performance towards meeting industrial specifications as defined by the IAB). As many as 6 packaging technologies or concepts (as they are called within the MEMSPACK project), have been developed. A schematic overview of the 6 concepts, indicating some specific characteristic of each concept, is presented in Figure 2. Three concepts (#1, #2 and #3) are based on 0-level "chip capping" (involving W2W or D2W bonding), two (#4 and #5) on 0-level "thin film capping" processing, and one (#6) on 1-level packaging technology based on LTCC. In the case of 0-level chip-capping, it is common practice to bond a (recessed) capping wafer (or die) onto the MEMS device wafer. The bonding & sealing ring is typically 50 to 300 μm in width, whereas the cap has a die thickness that is typically in the range of 100 to 700 μm. Chip-capping is done either as a chip-to-wafer (C2W), also called die-to-wafer (D2W), or as wafer-to-wafer (W2W). The MEMSPACK chip capping packaging concepts #1, #2 and #3, rely on a CuSn-based solder, BCB and AuSn solder bond and seal, respectively. For thin-film capping, the cap is made of a thin film of metal, dielectric or semiconductor with thicknesses in the range of 1 to 10 μm. Thin film capping typically relies on a 2nd level of surface-micromachining, this way leveraging on the front-end processing of the MEMS. The MEMSPACK thin film packaging concepts #4 and #5 rely on BCB thin film or on porous aluminum oxide thin films, respectively. Besides the packaging concepts quite a large effort has been spent on the development on the right test structures (e.g., humidity sensors or cantilever MEMS for pressure sensing) used to characterize the various packages (these test structure are conveniently referred to as concept#0).

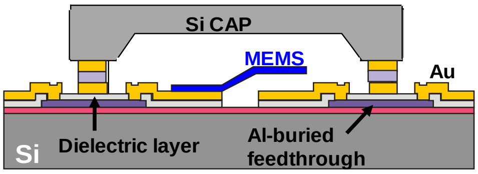
(a) Concept#1 (Chip cap; TSVs)



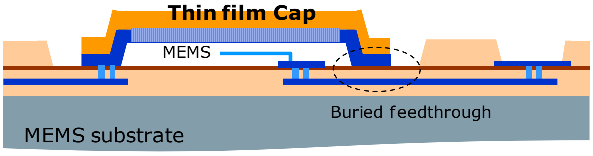
(b) Concept#2 (Chip cap; horizontal)



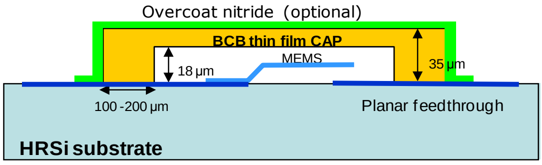
(c) Concept#3 (Chip cap; buried)



(d) Concept#4 (Thin film cap; buried)



(e) Concept#5 (Thin film cap; planar)



(f) Concept#6 (1-level; LTCC; vertical&horizontal)

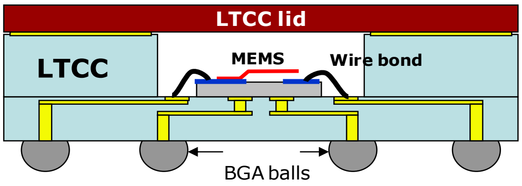


Figure 2: Schematic illustration of the six packaging concepts as developed in MEMSPACK.

Prior to completing the chip layout, extensive and detailed design, modelling and simulation (DMS) of each of the six concepts has been carried out. The DMS was carried out along two main paths:

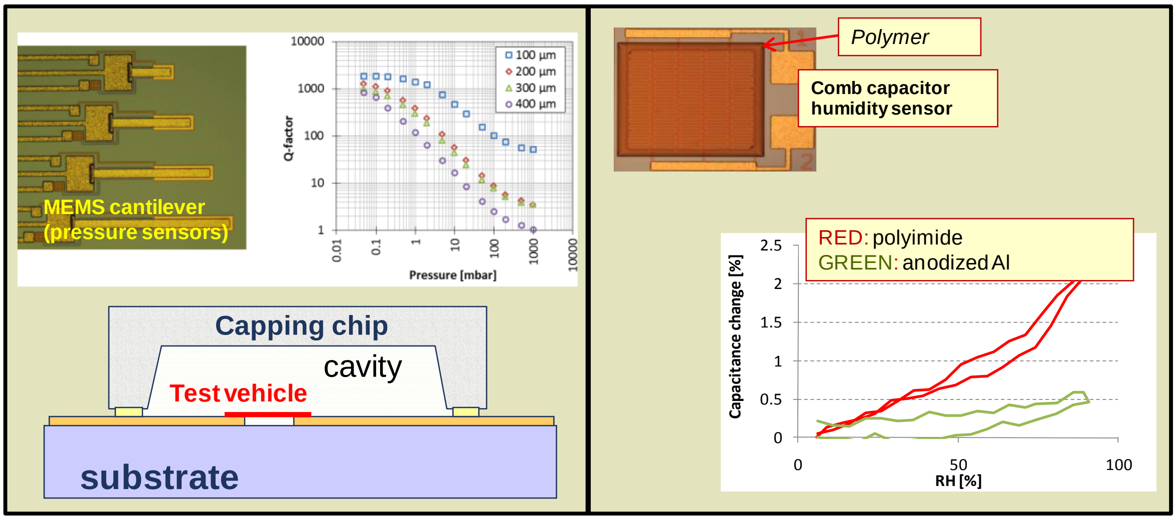
- Thermomechanical DMS, addressing the various mechanical specs, and dealing with: residual stress and/or initial strain in the packaging materials, maximum stresses occurring in the package, in the die and at interfaces, and, the impact on the RF-MEMS component and system characteristics due to deformations in the die and the package.

- Electrical (electromagnetic and circuit) DMS, addressing the various electrical (RF) specs and dealing with: design of (wideband) electrical RF feedthroughs (up to 220GHz); interaction between the package and the RF circuit, e.g., detuning due to proximity coupling of the cap to the RF circuit.Of importance, in particular for a package for RF-MEMS, these 6 packaging technologies implement different topologies for the high frequency (RF) signal feedthroughs. In designing the RF feedthroughs, a large portion of the development effort has been dedicated in making the right trade-off for achieving the desired RF characteristics on the one hand and, the hermeticity and the thermo-mechanical characteristics on the other hand.

In part in parallel with the DMS, the relevant critical parameters as identified in the process flows for each of the concepts were verified. The first development cycle(s) was(were) done for empty packages. This way a baseline process for all 6 packaging concepts has been set-up and empty package samples for all concepts have been fabricated and became available for test. For 4 chosen concepts, the so-called proof-of-concepts (based on concepts#3, #4, #5 and #6), a (third and) final development cycle was done with actual “MEMS inside”.

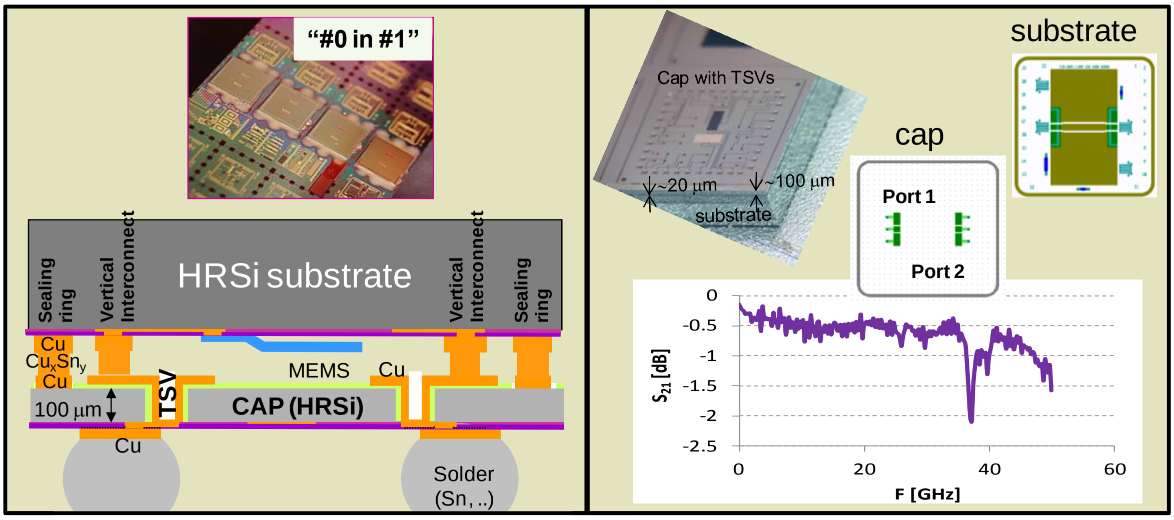
Test and characterization results, e.g., on the RF characteristics, mechanical strength and hermeticity, have been gathered for all 6 concepts. Extensive reliability testing (including “highly accelerated stress testing (HAST)”, pressure cooker test (PCT) and epoxy overmolding) has been carried out. The different packaging technologies were evaluated on the basis of a set of baseline specifications put together with the help of the IAB. While some of the technologies under development score best on RF characteristics (good characteristics up to 70 GHz, and e.g., insertion loss down to 0.1 dB and return loss up to 30 dB) and on low processing temperature (down to 250 °C), others show better hermeticity (with helium leak rates as low as 10^{-15}mbar•l/s), and/or better robustness against thermo-mechanical loads such as high ambient temperatures and high back-end pressure (e.g., 30 bar and 90 bar as exerted during epoxy overmoulding). All 0-level technologies have so far been demonstrated with CPWs as RF signal lines, whereas the 1-level technology based on LTCC processing has been demonstrated with CPWs as well as microstrip lines.

It is beyond the scope of this public report, in part because of the confidential nature of some of the results, to describe all the details of the development of the various packaging concepts. Without further comments, a flavor of the results obtained, together with some package specifics for each concept, is presented in Figure 3, Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, and Figure 9, for respectively concept#0 (front (MEMS) test structures), concept#1, concept#2, concept#3 (=PoC-1), concept#4 (=PoC-2a), concept#5 (=PoC-2b), and concept#6 (=PoC-3).



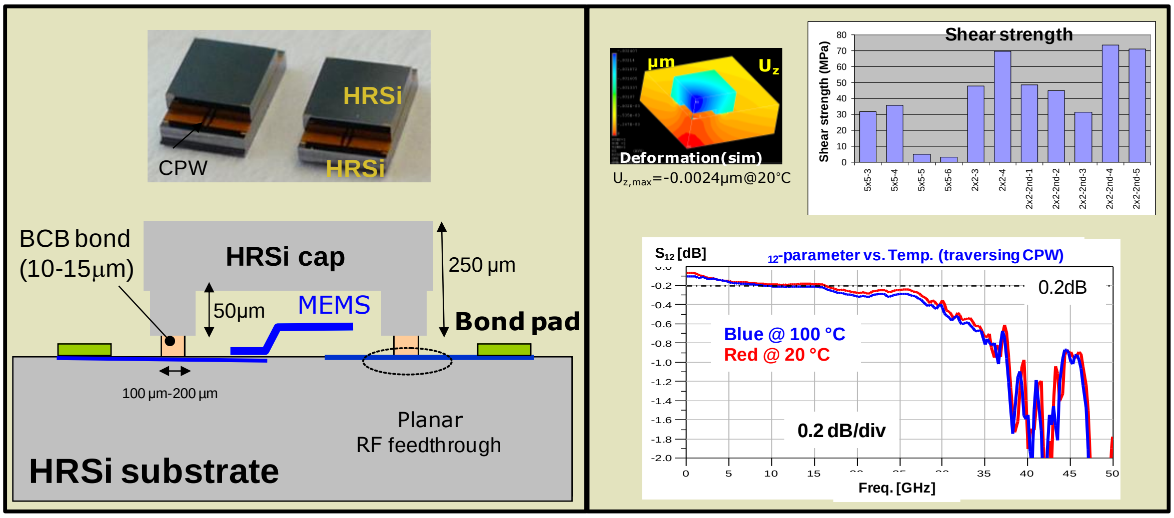
- **Concept#0; front-end (MEMS) test structures/vehicles**
- capacitive humidity sensors (using polymers or AlO_x), temperature sensors
- resistive strain gauges (poly-Si, metal)
- cantilever beam pressure sensors; clamped-clamped resonant stress sensors

Figure 3: Build-up of Concept#0 (test structures), driven by partner FBK, together with some specifics and results (simulation results, test results, ..).



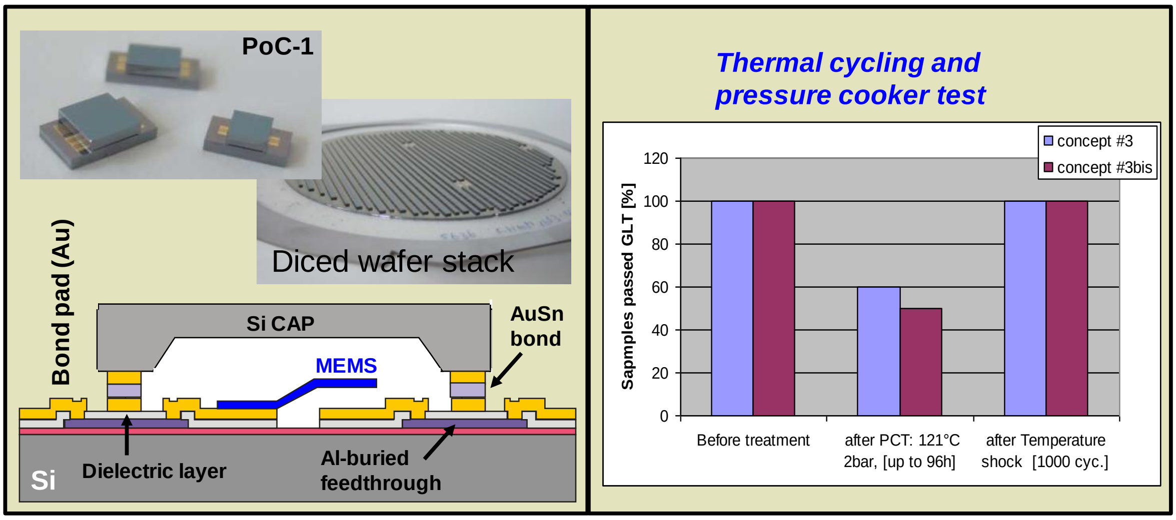
- **Concept#1; 0-level "chip capping"**; low real estate; flexible and versatile
- metal solder (Cu/Sn/Cu) bond & seal (low-T 250 °C) → hermetic
- 100 µm thick HRSi cap with Cu TSVs for vertical RF feedthroughs
- relatively complex technology (thinned wafers, TSVs, interconnect)

Figure 4: Build-up of packaging Concept#1, driven by partner IMEC, together with some specifics and results (simulation results, test results, ..).



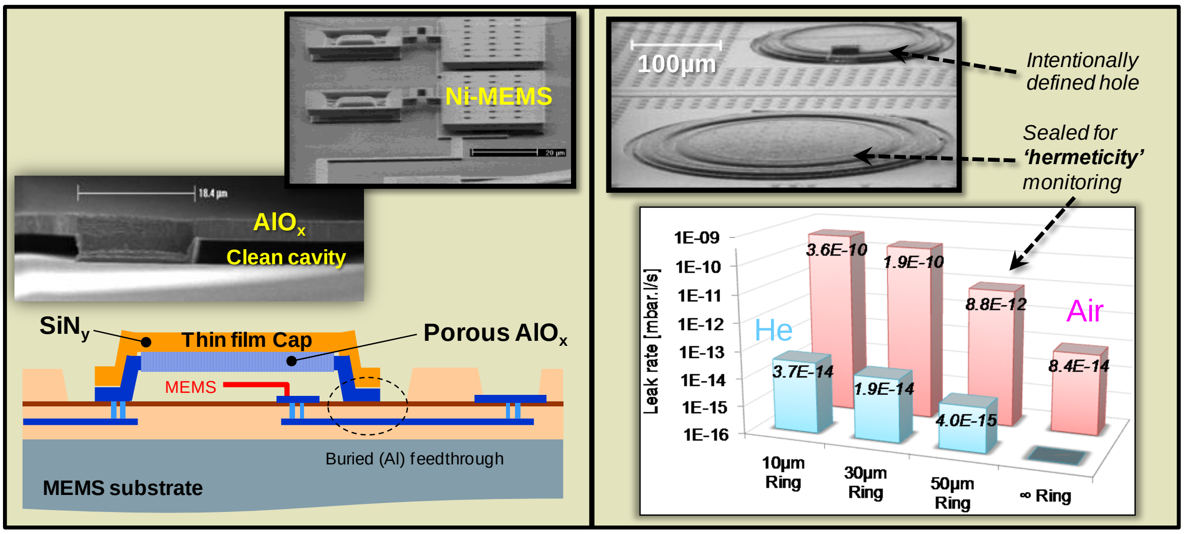
- **Concept#2; 0-level chip capping**; ~250 µm thick HRSi cap; flexible&versatile
- polymer (BCB) low-T (250°C) bond & seal → not hermetic
- horizontal planar RF feedthroughs → superior RF characteristics
- relatively simple technology (and low cost)

Figure 5: Build-up of packaging Concept#2, driven by partner IEMN, together with some specifics and results (simulation results, test results, ..).



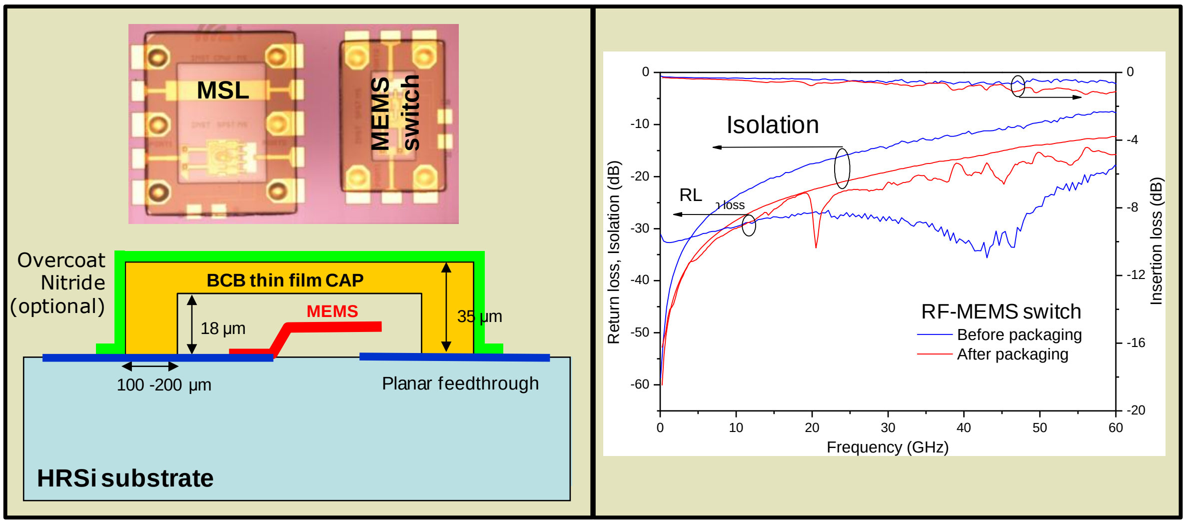
- **Concept#3/PoC-1**; **0-level chip capping (W2W)**; 200-500 μm thick Si cap
- metal solder (AuSn) bond & seal (280^{0}C) → hermetic
- horizontal buried feedthroughs → good RF performance
- mature technology; robust and reliable

Figure 6: Build-up of packaging Concept#3 (=PoC-1), driven by partner ISiT, together with some specifics and results (simulation results, test results, ..).



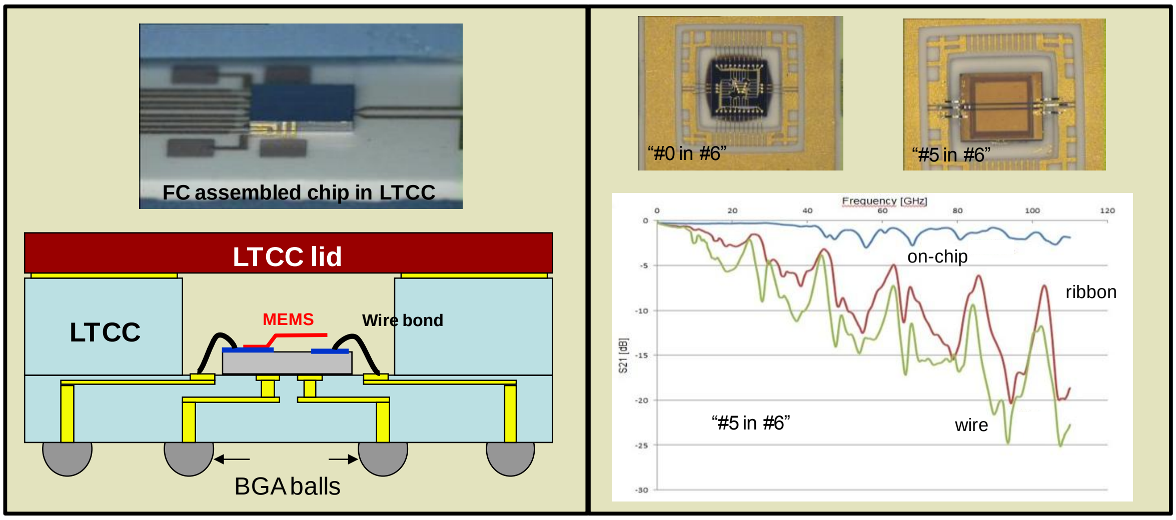
- **Concept#4/PoC-2a**; **0-level thin-film capping**; dielectric (AlO$_x$); 2-10 μm cap
- dielectric (SiN$_y$) or metal seal → "hermetic"; very low profile;
- horizontal buried RF feedthroughs → good RF performance
- reliable; high hydrostatic strength → epoxy molding up to 90bar

Figure 7: Build-up of packaging Concept#4 (=PoC-2a), driven by partner IMEC, together with some specifics and results (simulation results, test results, ..).



- **Concept#5/PoC-2b; 0-level "thin-film capping"**; low profile;
- polymer (5-20 µm BCB) cap (→ not hermetic) + overcoat nitride (→ "hermetic")
- horizontal planar RF feedthroughs → very good RF performance
- two-chip approach (unique process); flexible and versatile

Figure 8: Build-up of packaging Concept#5 (=PoC-2b), driven by partner IEMN, together with some specifics and results (simulation results, test results, ..).



- **Concept#6/PoC-3; 1-level packaging** using LTCC techno; LTCC cap (lid)
- ceramic and metal seal → hermetic
- horizontal&vertical RF feedthroughs; sub-optimal interconnects (wires, ribbon)
- mature technology (and low cost);flexible and versatile

Figure 9: Build-up of packaging Concept#6 (=PoC-3), driven by partner VTT, together with some specifics and results (simulation results, test results, ..).

One further important outcome of the project are the “RF-MEMS packaging design guidelines”, which can be used by industry for the development and exploitation of RF-MEMS. The evaluation results of the package technology demonstrators (together with examples from the literature) have been used to produce the RF-MEMS packaging design guidelines. These guidelines describe in a comprehensive manner the outcome of the project, thereby discussing not only the design of the package, but also the choice of materials and processes implemented for a wide span of (complementary) packaging technologies together with test procedures and characterization methods for the RF-MEMS package. Design guideline examples targeting a robust structural thermo-mechanical design and a high performance RF design are available. All of the MEMSPACK wafer level packaging technologies are capable of providing low profile packages, compatibility with front end MEMS and CMOS processing and compatibility with higher level packaging technologies. Not surprisingly perhaps, it can be concluded that the “Holy Grail package” does not exist (at least was not among the 6 packaging concept as investigated by the consortium). Each one of the 6 packaging concepts has its own specific pro’s and con’s and the choice of the package can only be made in view of the application. Below Table 1 presents a benchmarking among the different packaging concepts on a number of characteristics. Per characteristic, the best in class (indicated by a green circle) and the worst in class (indicated by a red circle) for the 0-level packaging concepts are indicated (because of its very different nature, the package concept#6, the 1-level LTCC package, did not take part in “the competition”). Thanks to the generic nature of the 6 MEMSPACK packaging concepts, they cover a wide range of potential applications, in particular in consumer products (including hand held devices), automotive and space and aviation. Several packaging technologies have reached a maturity level which allows direct transfer of the technology to any industrial party interested. The Table 1 can be used as an aid by users when selecting the right packaging concept for a certain application.

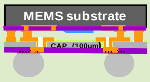
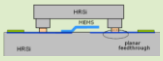
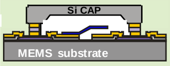
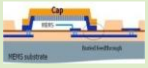
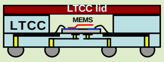
Characteristic	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**
	0-level Chip capping			**0-level Thin film capping**		**1-level**
						
“Specialty”	**Metal seal, TSV**	**BCB bond**	**Metal seal**	**Porous film initial cap**	**Transferred BCB cap**	**LTCC**
RF behaviour	🔴 **+/-**	**++**	**+**	**+**	🟢 **++**	**+**
Hermeticity	**+**	🔴 **-**	🟢 **++**	**+**	**- (+)**	**+**
Choice of cavity ambient	**+**	**-**	🟢 **++**	**-**	🔴 **-**	**+/-**
Hydrostatic Strength	**+/-**	**++**	🟢 **++**	**+/-**	🔴 **-**	**++**
Front-end compatibility	**+**	🟢 **+**	🔴 **+/-**	**+/-**	**+**	**+/-**
Back-end compatibility	**+/-**	**+**	🟢 **++**	**+/-**	🔴 **-**	**++**
Reliability	**+/-**	🔴 **-**	🟢 **++**	**+**	**+/-**	**+**
Size increase (OH MEMS)	🟢 **++**	**-**	🔴 **- -**	**+**	**+/-**	**+/-**
Height/Form factor	**+/-**	**+/-**	🔴 **-**	🟢 **++**	**+**	**+/-**
Complexity/Cost	🔴 **-**	🟢 **++**	**+/-**	**+/-**	**+**	**+**
Manufacturability	🔴 **- -**	🟢 **++**	**+**	**+/-**	**+**	**+**
Maturity	🔴 **-**	**+**	🟢 **++**	**+/-**	**+/-**	**++**
IP situation/uniqueness	**+**	🔴 **+/-**	**+/-**	🟢 **+**	**+/-**	**+/-**

Table 1: “Benchmarking” of the different packaging concepts as developed in MEMSPACK. Per characteristic, the best in class (indicated by a green circle) and the worst in class (indicated by a red circle) for the 0-level package concepts are indicated.

Impact, dissemination and exploitation

Impact

Wireless communication is showing an explosive growth of emerging consumer and military applications of radio frequency (RF), microwave, and millimeter-wave circuits and systems. Future personal (hand-held) and ground communications systems as well as automotive radar systems and communications satellites necessitate the use of highly integrated agile RF front-ends, featuring small size, low weight, high performance and low cost. Continuing chip scaling has contributed to the extent that off-chip, bulky passive RF components, like high-Q inductors, ceramic and SAW filters, varactor diodes and discrete PIN diode switches, have become limiting. Micro-machining or MEMS technology is now rapidly emerging as an enabling technology to yield a new generation of high-performance RF-MEMS passives to not only replace these off-chip (discrete) passives but moreover to allow for more integrated solutions in wireless communication (sub)systems. RF-MEMS technology offers the potential to build a multitude of miniaturized components as switches, voltage-tunable capacitors, high-Q inductors, film bulk acoustic resonators (FBAR), dielectric resonators, transmission line resonators and filters, and mechanical resonators and filters. These components offer specific advantages, like lower loss, higher isolation, superior linearity, higher Q, lower power consumption and improved tunability as well as improved “integratability”. In various research initiatives, many of them supported by the European Commission, the specific advantages of RF-MEMS components have already been demonstrated. The use of MEMS technology is now opening new perspectives for various wireless applications to achieve solutions with improved performance, compactness and also cost. RF-MEMS may revolutionize the choices made in the architecture of transceiver systems and/or radar antennas, by allowing completely new RF-system architectures with increased performance and functionalities like adaptive and reconfigurable RF-front-ends in handsets and wireless LAN (like 60 GHz radio), eventually leading to cognitive radio as the next generation standard (targeting the optimal use of the frequency spectrum by implementing opportunistic sharing of bandwidth). Furthermore, RF-MEMS will find use in base stations, wireless sensor networks, and/or in highly integrated phase-array antennas for agile communication links. For all these applications, it is fair to state that the major advantage of RF-MEMS is not so much in a replacement at the component level, but rather as an enabling technology at the system level. This means that smart system integration of RF-MEMS is the key for the success in industrialization. The MEMS components need to be integrated with other passive and active components to build up RF-modules or sub-modules with advanced functionalities. Needless to say, the challenge for most of the applications is high-density integration to further reduce the size and the cost. Advanced smart systems integration technologies will be the key element to secure competitiveness of European industry. Packaging is an integral part of these smart systems and can contribute significantly to the overall size and cost of the product, spanning from 25% up to 75%, both in cost as well in size. Furthermore the impact the package has on the device (or system) performance should not be taken too lightly. Strong R&D efforts in the packaging of RF-MEMS as MEMSPACK has undertaken are therefore clearly needed and justified in order to successfully build the smart RF systems of the future, displaying superior performance and new functionalities, and this for a reduced size and cost.

Although MEMSPACK is focused on RF applications, the project results are of significant value also for MEMS in general. The packaging issue is a major barrier to be overcome for the industrialization of MEMS, in general. The 0-level and 1-level packaging technologies as well as the encapsulation and reliability test methodologies are not restricted to RF-MEMS, but can easily be transferred to other MEMS, like accelerometers, micromirror devices, gyroscopes, magnetometer (electronic compass), microbolometer and many more. The MEMS however are limited to those that do not need to be in (direct) contact with the ambient for their operation. As such many type of MEMS sensors, like pressure sensors and flow sensors, and MEMS actuators, like microgrippers and micromotors, are excluded. Concluding, the impact of MEMSPACK is enlarged substantially by not only addressing RF applications, but by addressing also other key application areas, as MEMS for consumer or automotive.

Dissemination

With the consortium mainly consisting of national laboratories and two universities, dissemination has been a key aspect of the project. The main mechanisms that has been used for the dissemination of knowledge generated in the project among the scientific community was through submission and presentation of papers at scientific and trade conferences, workshops and journals, including, but not limited to, the EC's annual RF MST Cluster Meetings. The progress of the project can also be followed in the publicly accessible part of the MEMSPACK website, that has been updated regularly for rapid dissemination and which has been made accessible to the community at large. Moreover, the results have been disseminated through the EC networks of excellence PATENT-DfMM, AMICOM and RF PLATFORM, by the MEMSPACK beneficiaries that are also participating in those NoEs. The MEMSPACK consortium has interacted with other FP7 projects, including MEMS4MMIC, Regpot METU-MEMS, MOSART, WiserBAN, ARASCOM, AMICON TG EuMA, and COWIN. All beneficiaries have been in particular involved in dissemination activities by means of their industrial partnerships, leading role in state-of-the art R&D, and long-standing experience in EU funded projects. Progress has been presented to the Industrial Advisory Board in the 3 scheduled IAB meetings of which the last meeting was actually a one-day workshop. Moreover, results of the projects have been gathered in concise overviews, suitable for RF designers, and have been conveyed through publications and, outside the frame of the project, through education of students.

Exploitation

The national laboratories participating in the MEMSPACK consortium are all world-class R&D and training centres, which perform R&D ahead of industrial needs by 3 to 10 years in microelectronics, nanotechnology, design methods and technologies for ICT systems. Through their participation in the MEMSPACK project, they have strengthened their positions as Europe's leading Centres of Excellence for RF technology and design methods. 3 of the partners have founded spinouts shortly before MEMSPACK started (UPG spun out RF Microtech srl), or during the project in 2010 (FhG-ISiT and VTT spun out MEMS Foundry Itzehoe GmbH and VTT Memsfab Ltd., reps.). These spinouts offer, among others, results from MEPACK on a commercial basis. Collaborations between partners and IAB members that existed prior to MEMSPACK have been strengthened by MEMSPACK (UPG and FBK with Optoi,, VTT with Selmic, IEMN with DelfMEMS, IMEC with NXP and EPCOS). MEMS TC has provided services to several of the IAB members on a commercial basis, in some cases this concerned competence built up in MEMSPACK. Europractice has expressed interest in MEMSPACK technologies from partners or their spinouts that show commitment to maintain their technology and to continue to offer their technology. These cases are currently being explored. All in all, there has been a drive towards exploitation of the results in terms of:

- Services in the field of package fabrication, package design and package test (and infrastructure)
- Prototyping or low volume production at IMEC, VTT, ISiT and FBK, e.g., for IAB members but also to any other interesting industrial partner and existing spin-out/start-up.
- Technology transfer to industrial technology providers (foundries, package vendors) and component/system manufacturers. Making available the developed package technology platforms for industrialization in production fabs wherever an appropriate business case exists.
- Patenting and licensing of results to industry. The protection of Intellectual Property will be sought through patent applications. This is aimed at not so much for the beneficiaries to gain financial benefit, but rather to protect the interest of European industry seeking to make use of these innovations.
- Spinouts from the project itself

More in particular the exploitation by the different beneficiaries is presented in Table B2 in section B of this report.

Contact details

The 7 partners in the project are: (1) imec (BE), (2) VTT (FIN), (3) FhG-ISiT (DE), (4) UPG (IT), (5) FBK (IT), (6) CNRS-IEMN (FR) and (7) MEMS TC (NL).

- The coordinator of the project is imec (BE), contact details:

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- The primary contact for the consortium to the IAB is provided by MEMS TC (NL), contact details:

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  E-mail: sb@memstc.com).

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  Dr. N. Pham (E-mail: Nga.Pham@imec.be), and,
  Dr. V. Cherman (E-mail: Vladimir.Cherman@imec.be)

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- Contact persons for *partner FhG-ISiT (DE)* are:

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- Contact persons for *partner UPG (IT)* are:

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  Dr. P. Farinelli (E-mail: paola.farinelli@diei.unipg.it)

- Contact persons for *partner FBK (IT)* are:

  Dr. B. Margesin (E-mail: margesin@fbk.eu), and,
  Dr. A. Faes (E-mail: alefaes@fbk.eu)

- Contact persons for *partner CNRS-IEMN (FR)* are;

  Prof. P.-A. Rolland (E-mail: Paul-Alain.Rolland@iemn.univ-lille1.fr),
  Prof. N. Rolland (E-mail: nathalie.rolland@iemn.univ-lille1.fr), and,
  Dr. S. Seok (E-mail: seonho.seok@iemn.univ-lille1.fr)

- Contact person for *partner MEMS TC (NL)* is:

  Dr. S. Bouwstra (E-mail: sb@memstc.com)

The *MEMSPACK website* can be found at: http://www.memspack.eu.

EC
Theme ICT

Contract no.: 223882

4.2 Use and dissemination of foreground

Section A (public)

Below Table A1 shows all scientific publications (journals and conference publications) from the beginning until after the end of the project. Publications submitted and that are pending acceptance are also included.

TABLE A1: MEMSPACK LIST OF SCIENTIFIC PUBLICATIONS (STARTING WITH THE MOST IMPORTANT ONES, i.e., PEER REVIEWED JOURNAL PAPERS)

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	*Polymer-based zero-level packaging technology for high frequency RF applications by wafer bonding/debonding technique using an anti-adhesion layer*	*Janggil Kim (IEMN)*	*Int. J. Precision Eng. And Manufacturing*	*Vol. 13(10), Oct. 2012*	*Springer*	*Seoul (Korea)*	*2012*	*N/A*	N/A	No
2	*Modeling of gold microbeams as strain and pressure sensors for characterizing MEMS packages*	*Alessandro Faes (FBK)*	*Microsystem Technologies*	*March 4, 2012*	*Springer (Berlin / Heidelberg)*		*2012*	*1-7*	http://dx.doi.org/10.1007/s00542-012-1457-5	No
3	*Built-in self-limitation of masked aluminum anodization using photoresist*	*Joseph Zekry (IMEC)*	*Procedia Engineering*	*Vol. 25, 2011*	*Elsevier*		*2011*	*1633-1636*	http://www.sciencedirect.com/science/journal/18777058/25	No
4	*A Study on Millimetre-Wave Tunable Bandpass Filter Based on Polymer Cap Deflection*	*Seonho Seok IEMN)*	*Micromachines*	*Vol. 3, Jan. 6, 2012*	*MDPI Publishing*	*Basel, (Switzerland)*	*2012*	*28-35*	10.3390/mi3010028	Yes
5	*Wafer-level thin film vacuum packages for MEMS using nanoporous anodic alumina membranes*	*Joseph Zekry (IMEC)*	*Transducers 2011*	*June, 2011*	*IEEE*	*Beijing (China)*	*2011*	*974-977*	10.1109/TRANSDUCERS.2011.5969507	No

TABLE A1: MEMSPACK LIST OF SCIENTIFIC PUBLICATIONS (STARTING WITH THE MOST IMPORTANT ONES, i.e., PEER REVIEWED JOURNAL PAPERS)

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
6	*Modeling of gold microbeams for characterizing MEMS packages*	*Alessandro Faes (FBK)*	*Proc.of SPIE, Smart Sensors, Actuators, and MEMS V*	*Volume 8066, 2011*	*SPIE*	*Prague (Czech republic)*	*2011*	*80660Z 1-9*	http://dx.doi.org/10.1117/12.887571	*No*
7	*Wafer-Level BCB Cap Packaging of Integrated MEMS Switches with MMIC*	*Seonho Seok (IEMN)*	*IEEE/MTT-S International Microwave Symposium*	*June 17, 2012*	*IEEE*	*Montréal (Canada)*	*2012*		N/A	No
8	*Polymer-based zero-level packaging technology for high frequency RF applications by wafer bonding/debonding technique using an anti-adhesion layer*	*Janggil Kim (IEMN)*	*MINAPAD 2012*	*April 24, 2012*	*iMAPS*	*Grenoble (France)*	*2012*		N/A	No
9	*Zero-level packaging for (RF-)MEMS implementing TSVs and metal bonding*	*Nga Pham (IMEC)*	*ECTC 2011*	*May 31, 2011*	*IEEE*	*Florida, USA*	*2011*	*1588-1595*	10.1109/ECTC.2011.5898723	No
10	*Design of RF Feedthroughs in Zero-Level Packaging for RF MEMS Implementing TSVs*	*Hamza El Ghannudi (UPG)*	*MEMSWAVE 2011*	*June 28, 2011*		*Athens (Greece)*	*2011*		N/A	Yes
11	*Metal-bonded, hermetic 0-level package for MEMS*	*Nga Pham (IMEC)*	*EPTC 2010*	*Dec. 8, 2010*	*IEEE*	*Singapore*	*2010*	*1-6*	10.1109/EPTC.2010.5702595	No
12	*A capacitive humidity sensor using a positive photosensitive polymer*	*Nga Pham (IMEC)*	*21st MME workshop 2010*	*Sept. 26, 2010*		*Enschede (The Netherlands)*	*2010*	*60-63*	N/A	Yes
13	*A novel wafer level bonding/debonding technique using an anti-adhesion layer for polymer-based 0-level packaging of RF device*	*Janggil Kim (IEMN)*	*ECTC 2010*	*June 1, 2010*	*IEEE*	*Las Vegas (USA)*	*2010*	*323-328*	10.1109/ECTC.2010.5490954	No

TABLE A1: MEMSPACK LIST OF SCIENTIFIC PUBLICATIONS (STARTING WITH THE MOST IMPORTANT ONES, i.e., PEER REVIEWED JOURNAL PAPERS)										
NO.	**Title**	**Main author**	**Title of the periodical or the series**	**Number, date or frequency**	**Publisher**	**Place of publication**	**Year of publication**	**Relevant pages**	**Permanent identifiers (if available)**	**Is/Will open access provided to this publication?**
14	*Design and manufacturing of wideband buried RF feedthroughs for wafer-level RF MEMS package*	*Hamza El Gannudi (UPG)*	*European Microwave Integrated Circuits (EuMIC)*	*Sept. 27, 2010*	*IEEE*	*Paris (France)*	*2010*	*321-324*	N/A	No
15	*On the LTCC Characterization in millimeter-waves*	*V. Kondratyev (VTT)*	*European Microwave Integrated Circuits (EuMIC)*	*Sept. 27, 2010*	*IEEE*	*Paris (France)*	*2010*	*156-159*	N/A	No
16	*EM Modelling, Design and Manufacturing of a 0-level package for RF-MEMS applications*	*Hamza El Gannudi*	*MEMSWAVE 2010*	*June 2010*	*Editura Academiei Române*	*Otranto (Italy), and, Bucureşti (Rom)*	*2010 (digest)* *2011*	*-* *97-104*	N/A	Yes
17	*Thermo-mechanical design of a generic 0-level MEMS package using chip capping and Through Silicon Via's*	*Bart Vandevelde (IMEC)*	*EuroSimE 2010*	*April 26, 2010*	*IEEE*	*Bordeaux (France)*	*2010*	*7pages*	10.1109/ESIME.2010.5464539	No
18	*Thermo-mechanical simulations of RF-MEMS 0-level package based on wafer bonding by soldering*	*Siebe Bouwstra (MEMS TC)*	*EuroSimE 2010*	*April 26, 2010*	*IEEE*	*Bordeaux (France)*	*2010*	*9 pages*	10.1109/ESIME.2010.5464581	No
19	*Thermo-mechanical design and modeling of porous alumina-based thin film packages for MEMS*	*Joseph Zekry (IMEC)*	*EuroSimE 2010*	*April 26, 2010*	*IEEE*	*Bordeaux (France)*	*2010*	*7 pages*	10.1109/ESIME.2010.5464584	No
20	*Thermo-mechanical simulation of BCB membrane thin-film package*	*Seonho Seok (IEMN)*	*EuroSimE 2010*	*April 26, 2010*	*IEEE*	*Bordeaux (France)*	*2010*	*4 pages*	10.1109/ESIME.2010.5464577	No

TABLE A1: MEMSPACK LIST OF SCIENTIFIC PUBLICATIONS (STARTING WITH THE MOST IMPORTANT ONES, i.e., PEER REVIEWED JOURNAL PAPERS)

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
21	*Thermo-mechanical simulations of LTCC packages for RF MEMS applications*	*Jaakko Lenkkeri (VTT)*	*EuroSimE 2010*	*April 26, 2010*	*IEEE*	*Bordeaux (France)*	*2010*	*6 pages*	10.1109/ESIME.2010.5464591	No
Submitted, pending acceptance:										
22	*Wafer-level thin film vacuum packages for MEMS using nanoporous alumina membranes, Part I. Design and fabrication*	*Joseph Zekry (IMEC)*	*Sensors & Actuators A: Physical*	*Submitted April 2012*	*Elsevier*					No
23	*Wafer-level thin film vacuum packages for MEMS using nanoporous alumina membranes, Part II. Performance and reliability*	*Joseph Zekry (IMEC)*	*Sensors & Actuators A: Physical*	*Submitted April 2012*	*Elsevier*					No
24	*Wideband LTCC modules with vertical transitions*	*Mikko Kaunisto (VTT)*	*IEEE Trans. On Microwave Theory and Techniques*		*IEEE*					No
25	*Wideband LTCC modules with horizontal transitions*	*Mikko Kaunisto (VTT)*	*IEEE Trans. On Microwave Theory and Techniques*		*IEEE*					No
26	*LTCC filter based on via resonators*	*V. Kondratyev (VTT)*	*42nd European Microwave Conference*		*IEEE*	*Amsterdam (The Netherlands)*	*2012*			No

Below Table A2 shows all dissemination activities from the beginning until after the end of the project.

TABLE A2: MEMSPACK LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
1	Scientific Publications	"all"	see Table A1	See table A1	See Table A1	Scientific community	Various (10-1000)	all
2	Other: Closed meeting	MEMS TC	1st IAB meeting MEMSPACK	30 June 2008	Heraklion	MEMSPACK IAB	8	France, Netherlands, Germany, Italy, Finland, Spain, Denmark
3	Other: Closed webinar	MEMS TC	1st IAB webinar MEMSPACK	16 December 2009	Internet	MEMSPACK IAB	7	France, Netherlands, Germany, Italy, Finland, Spain,
4	Other: Closed meeting	MEMS TC	2nd IAB meeting MEMSPACK	28 June 2010	Otranto	MEMSPACK IAB	4	France, Netherlands, Germany, Italy, Finland, Spain
5	Other: Closed webinar	MEMS TC	2nd IAB webinar MEMSPACK	15 December 2009	Internet	MEMSPACK IAB	9	France, Netherlands, Germany, Italy, Finland, Spain
6	Other: Closed meeting & workshop	MEMS TC	3rd IAB meeting + workshop MEMSPACK	26 January 2012	Amsterdam	MEMSPACK IAB + EU officer	6	France, Netherlands, Germany, Italy, Finland, Spain
7	"Flyer"	MEMS TC	"RF MEMS Packaging"	May 2011	COWIN website	MST community	300	All
8	Poster	VTT	"RF MEMS Packaging", Euripides Forum 2011	June 2011	Helsinki (Finland)	MST community	300	All
9	Articles published in trade journals	MEMS TC	MEMSPACK: 0- and 1-Level Packaging Tech-nologies for (RF-) MEMS	April 2011	Yole Micronews	MST community	1,000	All
10	Articles published in trade journals	MEMS TC	MEMSPACK: 0- and 1-Level Packaging Tech-nologies for (RF-) MEMS	April 2012	MEMS Technology Review	MST community	30,000	All
11	Presentations	IMEC	"MEMSPACK overview", at *RF MST Cluster meeting*	June 2008	Heraklion (Greece)	RF MST community in Europe	60	EU + Assoc. countries
12	Presentations	IMEC	"MEMSPACK overview", at *RF MST Cluster meeting*	June 2009	Trento (Italy)	RF MST community in Europe	60	EU + Assoc. countries
13	Presentations	IMEC	"MEMSPACK overview", at *RF MST Cluster meeting*	June 2010	Otranto (Italy)	RF MST community in Europe	60	EU + Assoc. countries

TABLE A2: MEMSPACK LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities	Main leader	Title	Date	Place	Type of audience	Size of audience	Countries addressed
14	Presentations	IMEC	“MEMSPACK overview”, at *RF MST Cluster meeting*	June 2011	Athens (Greece)	RF MST community in Europe	60	EU + Assoc. countries
15	Presentations	IMEC	“MEMSPACK overview”, at *RF MST Cluster meeting*	July 2, 2012	Anatalya (Turkey)	RF MST community in Europe	60	EU + Assoc. countries
16	Presentations	MEMS TC	“MEMSPACK”, at *1st Turkish National MEMS Conference*	December 2010	Ankara (Turkey)	Turkey MST community	100	Turkey
17	Workshop	IMEC	MEMSPACK”, at *MINAmI Workshop (Parallel to ICT 2008)*	November 26, 2008	Lyon (France)	MINAmI project members	20	EU
18	Lectures	VTT, IMEC, IEMN	“RF MEMS Packaging”, at *3 AMICOM summer schools*	June 2009, 2010 and 2011	Toulouse (Fr), Padova (It), Toulouse (Fr)	Students, researchers	3x30	All
19	Lecture	VTT, IMEC	“RF MEMS Packaging”, at *RF microsystem workshop EuMIC2011*	2011	Manchester (UK)	Conference participants	100	All
20	Lectures	UPG, IEMN	“RF MEMS design”, at *university lecture courses*	2009 onwards		Students		Italy, France
21	Networking with other EU projects	all	MEMS-4-MMIC, METU-MEMS, MINAmI, WiserBAN, ARASCOM, AMICOM TG EuMA, COWIN	2008 onwards	Various places	EU project consortiums	200	Europe
22	Project website	MEMS TC	www.memspack.eu	2008 onwards	www	Public + restricted pages for IAB and for EC	>1,500 hits	world wide

Section B (confidential)

Part B1

Below Table B1 shows all applications for patents, trademarks, registered designs, etc. from the beginning until after the end of the project.

TABLE B1: MEMSPACK LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.

Type of IP Rights:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s)	Subject or title of application	Applicant (s) (as on the application)
Patent	*YES*	*31/05/2012*	*- US provisional application no.: 61/418,194 (filed Nov. 30, 2010)* *- US Patent Application No. 13/086,735 (filed April 14, 2011)* *- EP Application No. 11162495.3-1227 (filed 14 April 2011)*	*A method for precisely controlled masked anodization*	*IMEC*

Part B2

Below Table shows an overview of all exploitable foreground gathered from the beginning until after the end of the project. All information given in Part B2 is confidential!

Type of Exploitable Foreground[3]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[4]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
1. GENERAL, for whole CONSORTIUM:								
General advancement of knowledge? YES! *Commercial exploitation of R&D results? YES!* *Exploitation of R&D results via standards? NO!* *Exploitation of results through EU policies? MAYBE!* *Exploitation of results through (social) innovation? NO!*	*Various MEMS Packaging Technologies,* *Thermomechanical and Electromagnetic Design, Modeling and Simulation for RF-MEMS packaging,* *Test Structure Designs to evaluate MEMS packages,* *Test Infrastructure for MEMS packages* *Technical Consultancy on MEMS packaging in the broadest sense*	*NO*	*N/A*	*Services*	*C26.1.1*	*2008 onwards*	*1 patent filed (see Table B1)*	*All, see exploitation plans per partner*
2. SPECIFIC, PER PARTNER (SEE ALSO EXPLOITATION PLANS PER PARTNER AS SUMMARIZED IN "SLIDES" BELOW THIS TABLE)								
Commercial exploitation of R&D results	*Solder bonded chip-capping (with TSVs in cap) packaging technology for (RF-)MEMS*	*YES*	*N/A*	*Technology transfer, Prototyping, or LVP*	*C26.1.1*	*2012 onwards*	*none*	*IMEC*
Commercial exploitation of R&D results	*Thin-film capping packaging technology based on porous AlOx membranes for (RF-)MEMS*	*YES*	*N/A*	*Technology transfer, Prototyping, or LVP*	*C26.1.1*	*2013 onwards*	*YES (see Table B1)*	*IMEC*

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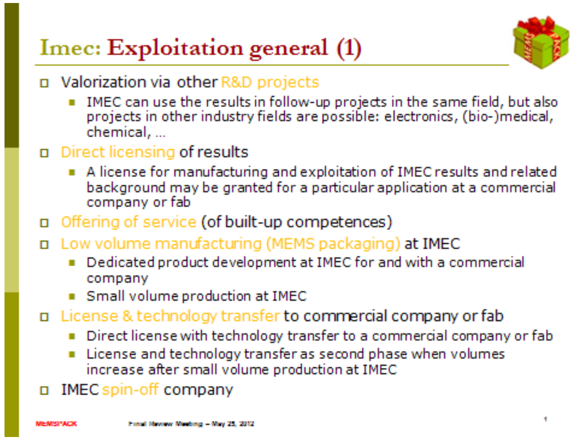
[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[4] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

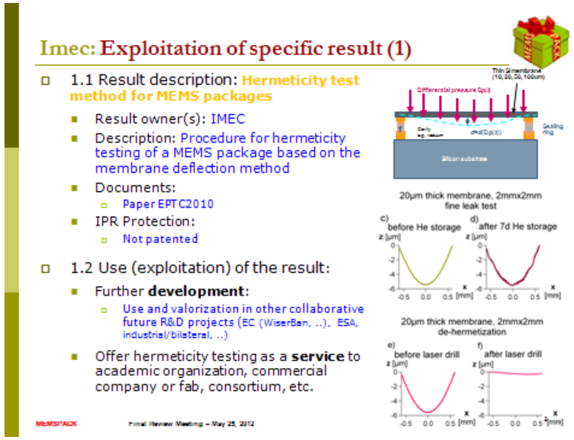
Type of Exploitable Foreground[3]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[4]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	*Hermeticity test Infrastructure for MEMS packages*	*NO*	*N/A*	*Test Services*	*C26.1.1 M72.1*	*2010 onwards*	*none*	*IMEC*
Commercial exploitation of R&D results	*LTCC-based RF MEMS packaging technology*	*YES*	*N/A*	*Services, prototyping*	*C26.1.1*	*2011 onwards*	*none*	*VTT*
Commercial exploitation of R&D results	*LTCC-based RF MEMS packaging design and integration*	*YES*	*N/A*	*Services*	*C26.1.1 M72.1*	*2011 onwards*	*none*	*VTT*
Commercial exploitation of R&D results	*Wafer-level chip-capping MEMS packaging technologies based on solder bonding*	*YES*	*N/A*	*Services, prototyping*	*C26.1.1*	*2009 Onwards*	*none*	*ISIT*
Commercial exploitation of R&D results	*Hermeticity test Infrastructure*	*NO*	*N/A*	*Test Services*	*C26.1.1 M72.1*	*2009 Onwards*	*none*	*ISIT*
General advancement of knowledge	*Design and simulation of compensation structures for wideband RF feedthroughs*	*YES*	*N/A*	*Design Service*	*C26.1.1 J61.2.0 J61.3.0 M72.1*	*2008 onwards*	*none*	*UPG*
General advancement of knowledge	*RF characterization of components and circuits, including RF MEMS*	*NO*	*N/A*	*Test Services*	*C26.1.1 J61.2.0 J61.3.0*	*2008 onwards*	*none*	*UPG*
General advancement of knowledge	*Test structure design and calibration*	*NO*	*N/A*	*Design and Test Services*	*C26.1.1 M72.1*	*2010 onwards*	*none*	*FBK*
Commercial exploitation of R&D results	*Test structures fabrication and packaging technologies*	*YES*	*N/A*	*Services and Prototypes*	*C26.1.1*	*2011 onwards*	*none*	*FBK*
Exploitation of results through EU policies	*Measurement techniques for characterizing MEMS packages*	*NO*	*N/A*	*Test Services*	*C26.1.1 M72.1*	*2011 onwards*	*none*	*FBK*
Commercial exploitation of R&D results	*Packaging Technologies for RF-MEMS based on BCB bonding and capping,*	*YES*	*N/A*	*Prototyping*	*C26.1.1 J61.2.0 J61.3.0*	*2009 onwards*	*none*	*IEMN*
General advancement of knowledge	*Thermomechanical and Electromagnetic Design, Modeling and Simulation*	*NO*	*N/A*	*Design Services*	*C26.1.1 J61.2.0 J61.3.0 M72.1*	*2009 onwards*	*none*	*IEMN*
General advancement of knowledge	*RF Test Infrastructure and Technical Consultancy*	*YES*	*N/A*	*Test Services*	*C26.1.1 J61.2.0 J61.3.0*	*2009 onwards*	*none*	*IEMN*
General advancement of knowledge	*Technical Consultancy on (RF-)MEMS packaging in the broadest sense*	*YES*	*N/A*	*Services*	*C26.1.1 M72.1*	*2009 onwards*	*none*	*MEMS TC*

Below excerpt from a presentation provides more detailed information on the exploitation plans per partner. The slides provide a first and more detailed description on how and by whom certain foreground might be exploited.



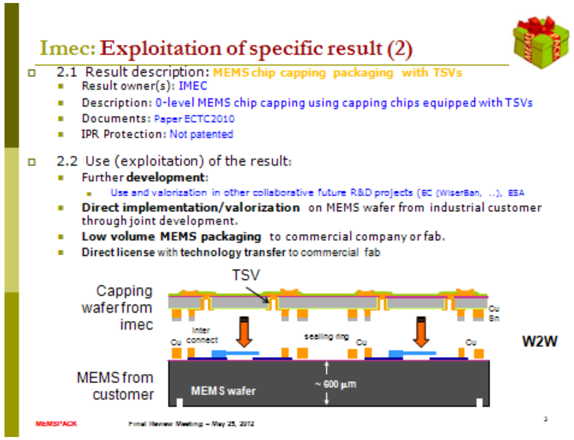
Imec: Exploitation general (1)

- Valorization via other R&D projects
  - IMEC can use the results in follow-up projects in the same field, but also projects in other industry fields are possible: electronics, (bio-)medical, chemical, …
- Direct licensing of results
  - A license for manufacturing and exploitation of IMEC results and related background may be granted for a particular application at a commercial company or fab
- Offering of service (of built-up competences)
- Low volume manufacturing (MEMS packaging) at IMEC
  - Dedicated product development at IMEC for and with a commercial company
  - Small volume production at IMEC
- License & technology transfer to commercial company or fab
  - Direct license with technology transfer to a commercial company or fab
  - License and technology transfer as second phase when volumes increase after small volume production at IMEC
- IMEC spin-off company



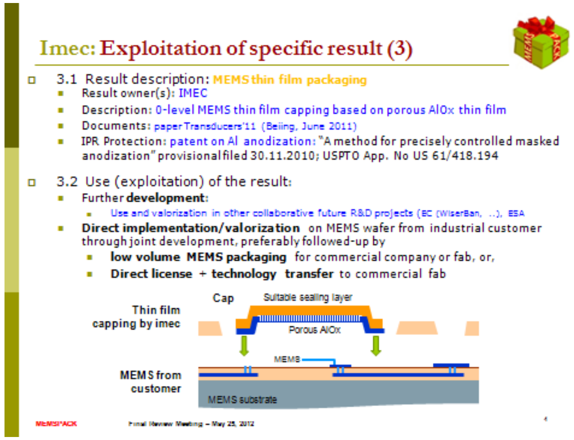
Imec: Exploitation of specific result (1)

- 1.1 Result description: **Hermeticity test method for MEMS packages**
  - Result owner(s): IMEC
  - Description: Procedure for hermeticity testing of a MEMS package based on the membrane deflection method
  - Documents:
    - Paper EPTC2010
  - IPR Protection:
    - Not patented
- 1.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (EC (WiserBan, ..), ESA, industrial/bilateral, ..)
  - Offer hermeticity testing as a **service** to academic organization, commercial company or fab, consortium, etc.



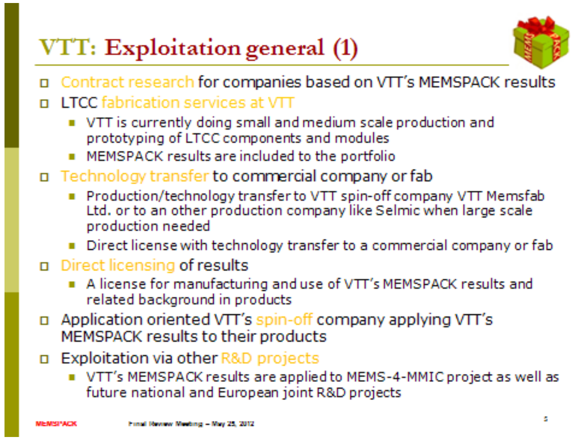
Imec: Exploitation of specific result (2)

- 2.1 Result description: **MEMS chip capping packaging with TSVs**
  - Result owner(s): IMEC
  - Description: 0-level MEMS chip capping using capping chips equipped with TSVs
  - Documents: Paper ECTC2010
  - IPR Protection: Not patented
- 2.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (EC (WiserBan, ..), ESA
  - **Direct implementation/valorization** on MEMS wafer from industrial customer through joint development.
  - **Low volume MEMS packaging** to commercial company or fab.
  - **Direct license** with **technology transfer** to commercial fab



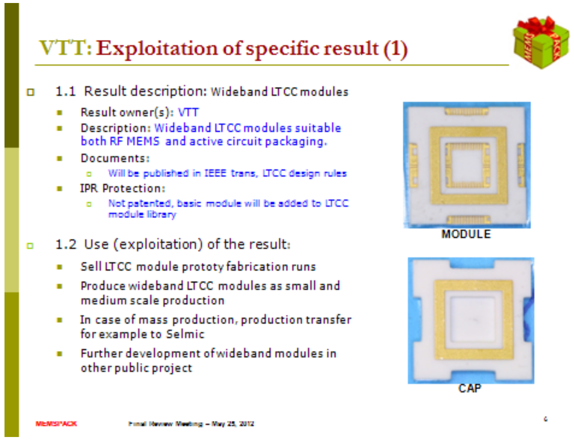
Imec: Exploitation of specific result (3)

- 3.1 Result description: **MEMS thin film packaging**
  - Result owner(s): IMEC
  - Description: 0-level MEMS thin film capping based on porous AlOx thin film
  - Documents: paper Transducers'11 (Beiing, June 2011)
  - IPR Protection: patent on Al anodization: "A method for precisely controlled masked anodization" provisional filed 30.11.2010; USPTO App. No US 61/418.194
- 3.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (EC (WiserBan, ..), ESA
  - **Direct implementation/valorization** on MEMS wafer from industrial customer through joint development, preferably followed-up by
    - **low volume MEMS packaging** for commercial company or fab, or,
    - **Direct license + technology transfer** to commercial fab



VTT: Exploitation general (1)

- Contract research for companies based on VTT's MEMSPACK results
- LTCC fabrication services at VTT
  - VTT is currently doing small and medium scale production and prototyping of LTCC components and modules
  - MEMSPACK results are included to the portfolio
- Technology transfer to commercial company or fab
  - Production/technology transfer to VTT spin-off company VTT Memsfab Ltd. or to an other production company like Selmic when large scale production needed
  - Direct license with technology transfer to a commercial company or fab
- Direct licensing of results
  - A license for manufacturing and use of VTT's MEMSPACK results and related background in products
- Application oriented VTT's spin-off company applying VTT's MEMSPACK results to their products
- Exploitation via other R&D projects
  - VTT's MEMSPACK results are applied to MEMS-4-MMIC project as well as future national and European joint R&D projects



VTT: Exploitation of specific result (1)

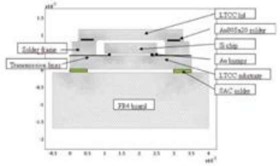
- 1.1 Result description: Wideband LTCC modules
  - Result owner(s): VTT
  - Description: Wideband LTCC modules suitable both RF MEMS and active circuit packaging.
  - Documents:
    - Will be published in IEEE trans, LTCC design rules
  - IPR Protection:
    - Not patented, basic module will be added to LTCC module library
- 1.2 Use (exploitation) of the result:
  - Sell LTCC module prototy fabrication runs
  - Produce wideband LTCC modules as small and medium scale production
  - In case of mass production, production transfer for example to Selmic
  - Further development of wideband modules in other public project

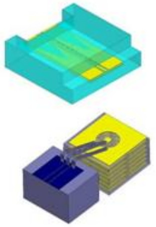
MODULE

CAP

VTT: Exploitation of specific result (2)

- 2.1 Result description: LTCC module design
  - Result owner(s): VTT
  - Description: Electromagnetic and thermomechanical design of multi-chip LTCC modules
  - Documents: several publications
  - IPR Protection: no patents
- 2.2 Use (exploitation) of the result:
  - Sell EM and thermomechanical design services
  - Apply results in connection with fabrication services
  - Development of IP blocks
  - License of designs





ISiT: Exploitation general

- Valorization via other R&D projects
  - The results can be used for the Acquisition of follow-up R&D projects in a comparable field.
- Low volume manufacturing (MEMS packaging) and Prototyping
  - Product development at ISiT for and with commercial companies
  - Prototyping, pilot and small volume production at ISiT
  - Hermetic encapsulation of customer provided MEMS-Systems
- License & technology transfer to commercial companies
  - Technology transfer to the on site foundry partner for medium volume production
  - *Mems Foundry Itzehoe GmbH*, … http://www.memsfoundry.de
  - License and technology transfer to European MEMS foundries for large volume production *Silex Microsystems AB*…
  - License and technology transfer to Package vendors or Component / System manufacturers
- Service in MEMS packages test & qualification
  - Hermeticity, leak test, pressure cocker test, mechanical stability, shear test

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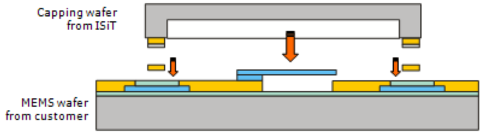
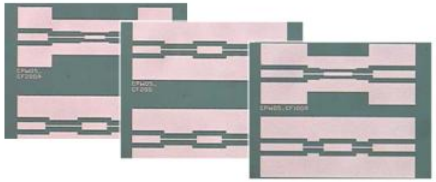
ISiT: Exploitation of specific result (1)

- 1.1 Result description: MEMS chip capping & packaging
  - Result owner: ISiT
  - Description: 0-level MEMS chip capping using cap wafers including release-etch and critical point drying of customer provided active MEMS-devices
  - IPR Protection: basic approach is not patented
- 1.2 Use (exploitation) of the result:
  - Further development: Use and valorization in future collaborative R&D projects
  - Direct implementation/valorization on MEMS wafer from industrial customer
  - Low volume MEMS packaging to commercial company or fab
  - Direct license with technology transfer to commercial fab



ISiT: Exploitation of specific result (2)

- 2.1 Result description: Fabrication of RF wave guides and inductors
  - Result owner: ISiT
  - Description: Cu damascene process in SiO_2 for lateral feedthroughs and waveguides
  - IPR Protection: basic approach is not patented
- 2.2 Use (exploitation) of the result:
  - Further development: Transfer to more complex RF configurations
  - Direct implementation according to industrial customers needs
  - Direct license with technology transfer to commercial fab

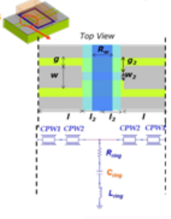


UPG: Exploitation general

- Valorization via other R&D projects
  - UPG can use the knowledge acquired in MEMSPACK in other projects in the same field. As an example UPG has just extended the design procedures developed in MEMSPACK to carry out the design of a package in the framework of a national Finmeccanica project (CONFIRM project, funded by Selex-Comms, Selex-SI, TAS-I, in collaboration with FBK and Optoi).
- Offering of design and characterization service
- Knowhow & competences transfer to UPG spin-off RF Microtech
  - Dedicated product development in collaboration with FBK (MEMSPACK partner) and Optoi (IAB member) for commercialization of RF MEMS switches and components
  - RF Microtech offers the RF package design service for private companies as well as academicals bodies.
- Seminar and education for master and PhD students

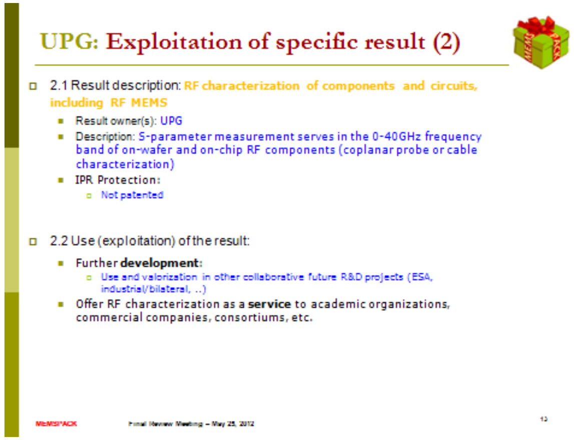
UPG: Exploitation of specific result (1)

- 1.1 Result description: Design of compensation structures for wideband RF feedthroughs
  - Result owner(s): UPG
  - Description: Procedure for designing wideband RF feedthroughs
  - Documents: :
    - Paper EuMW 2010
  - IPR Protection:
    - Not patented
- 1.2 Use (exploitation) of the result:
  - Further **development:**
    - Use and valorization in other collaborative future R&D projects (ESA, industrial/bilateral, ..)
  - Offer RF package design as a **service** to academic organizations, commercial companies, consortiums, etc.



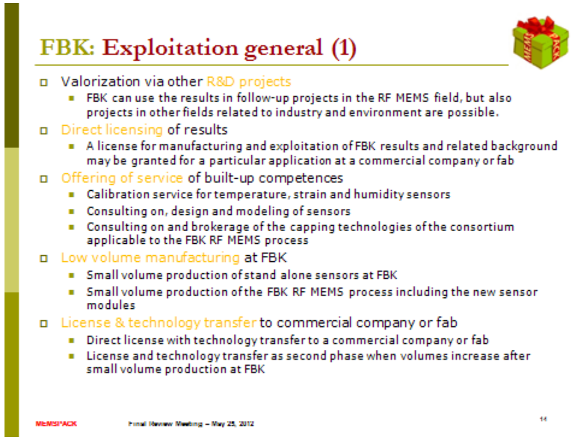
$$f_{res} = \frac{1}{2\pi\sqrt{L_{ring}C_{ring}}}$$

$$C_{ring} = \varepsilon_0\varepsilon_{r\_pass}\cdot\frac{w_2\cdot R_w}{h_{pass}}$$



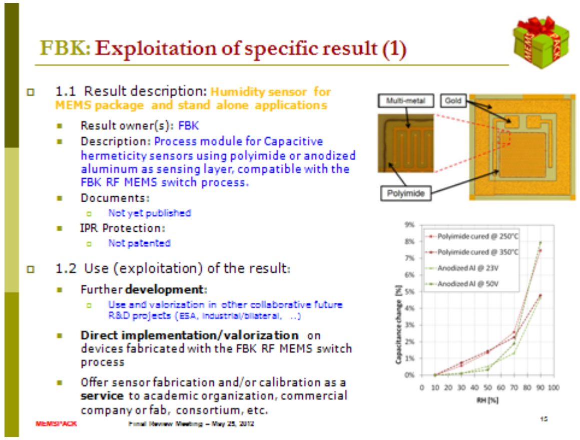
UPG: Exploitation of specific result (2)

- 2.1 Result description: RF characterization of components and circuits, including RF MEMS
  - Result owner(s): UPG
  - Description: S-parameter measurement serves in the 0-40GHz frequency band of on-wafer and on-chip RF components (coplanar probe or cable characterization)
  - IPR Protection:
    - Not patented
- 2.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (ESA, industrial/bilateral, ..)
  - Offer RF characterization as a **service** to academic organizations, commercial companies, consortiums, etc.



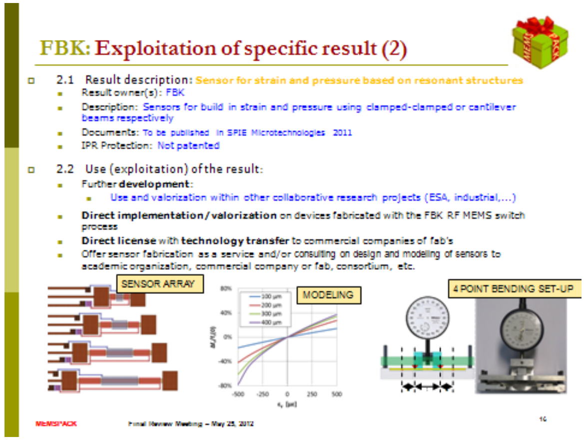
FBK: Exploitation general (1)

- Valorization via other R&D projects
  - FBK can use the results in follow-up projects in the RF MEMS field, but also projects in other fields related to industry and environment are possible.
- Direct licensing of results
  - A license for manufacturing and exploitation of FBK results and related background may be granted for a particular application at a commercial company or fab
- Offering of service of built-up competences
  - Calibration service for temperature, strain and humidity sensors
  - Consulting on, design and modeling of sensors
  - Consulting on and brokerage of the capping technologies of the consortium applicable to the FBK RF MEMS process
- Low volume manufacturing at FBK
  - Small volume production of stand alone sensors at FBK
  - Small volume production of the FBK RF MEMS process including the new sensor modules
- License & technology transfer to commercial company or fab
  - Direct license with technology transfer to a commercial company or fab
  - License and technology transfer as second phase when volumes increase after small volume production at FBK



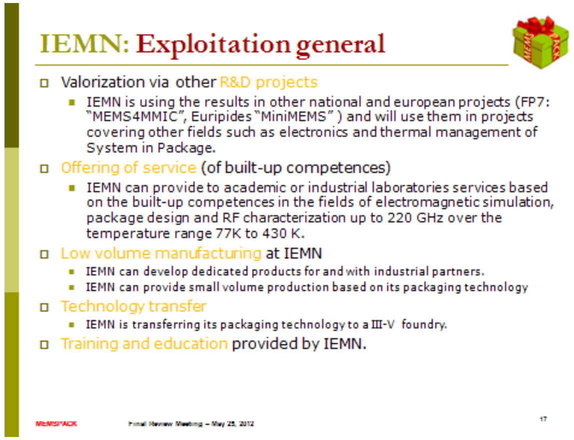
FBK: Exploitation of specific result (1)

- 1.1 Result description: Humidity sensor for MEMS package and stand alone applications
  - Result owner(s): FBK
  - Description: Process module for Capacitive hermeticity sensors using polyimide or anodized aluminum as sensing layer, compatible with the FBK RF MEMS switch process.
  - Documents:
    - Not yet published
  - IPR Protection:
    - Not patented
- 1.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (ESA, industrial/bilateral, ..)
  - **Direct implementation/valorization** on devices fabricated with the FBK RF MEMS switch process
  - Offer sensor fabrication and/or calibration as a **service** to academic organization, commercial company or fab, consortium, etc.



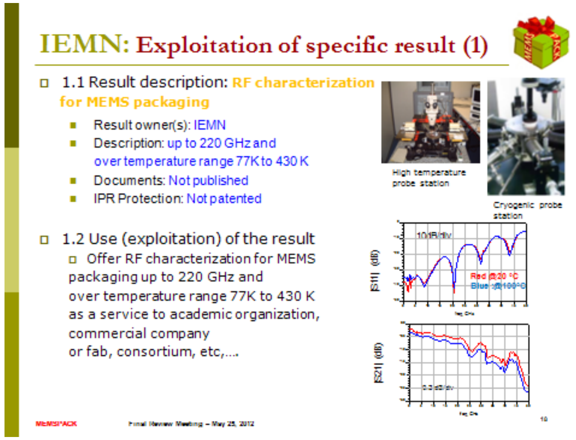
FBK: Exploitation of specific result (2)

- 2.1 Result description: Sensor for strain and pressure based on resonant structures
  - Result owner(s): FBK
  - Description: Sensors for build in strain and pressure using clamped-clamped or cantilever beams respectively
  - Documents: To be published in SPIE Microtechnologies 2011
  - IPR Protection: Not patented
- 2.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization within other collaborative research projects (ESA, industrial,...)
  - **Direct implementation/valorization** on devices fabricated with the FBK RF MEMS switch process
  - **Direct license** with **technology transfer** to commercial companies of fab's
  - Offer sensor fabrication as a service and/or consulting on design and modeling of sensors to academic organization, commercial company or fab, consortium, etc.



IEMN: Exploitation general

- Valorization via other R&D projects
  - IEMN is using the results in other national and european projects (FP7: "MEMS4MMIC", Euripides "MiniMEMS") and will use them in projects covering other fields such as electronics and thermal management of System in Package.
- Offering of service (of built-up competences)
  - IEMN can provide to academic or industrial laboratories services based on the built-up competences in the fields of electromagnetic simulation, package design and RF characterization up to 220 GHz over the temperature range 77K to 430 K.
- Low volume manufacturing at IEMN
  - IEMN can develop dedicated products for and with industrial partners.
  - IEMN can provide small volume production based on its packaging technology
- Technology transfer
  - IEMN is transferring its packaging technology to a III-V foundry.
- Training and education provided by IEMN.



IEMN: Exploitation of specific result (1)

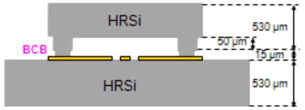
- 1.1 Result description: RF characterization for MEMS packaging
  - Result owner(s): IEMN
  - Description: up to 220 GHz and over temperature range 77K to 430 K
  - Documents: Not published
  - IPR Protection: Not patented
- 1.2 Use (exploitation) of the result
  - Offer RF characterization for MEMS packaging up to 220 GHz and over temperature range 77K to 430 K as a service to academic organization, commercial company or fab, consortium, etc,….

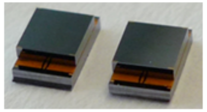
High temperature probe station

Cryogenic probe station

IEMN: Exploitation of specific result (2)

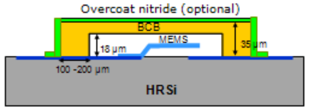
- 2.1 Result description: Si packaging with BCB sealing ring
  - Result owner(s): IEMN
  - Description: 0-level Si packaging of MEMS using BCB sealing ring
  - Documents: Not published
  - IPR Protection: Not patented
- 2.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in SIPCOM project for SIP implementation
  - **Direct implementation/valorization** on MEMS wafer from industrial customer through joint development.
  - **Low volume MEMS packaging** to commercial company or foundary.

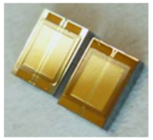




IEMN: Exploitation of specific result (3)

- 3.1 Result description: BCB thin film packaging
  - Result owner(s): IEMN
  - Description: 0-level BCB thin film packaging
  - Documents: Paper ECTC 2009
  - IPR Protection: Not patented
- 3.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in MEMS4MMIC project for packaging of MMIC with MEMS
  - **Direct implementation/valorization** on MEMS wafer from industrial customer through joint development.
  - **Low volume MEMS packaging** to commercial company or foundary.





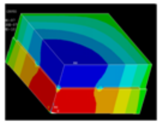
MEMS TC: Exploitation general (1)

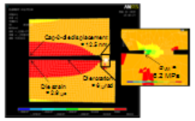
- Valorization via other R&D projects
  - MEMS TC can use the results in follow-up projects in the MEMS and RF MEMS field
- Offering of service (of built-up competences)
  - Consulting on selection, integration and brokerage on (RF) MEMS packaging technologies
  - Consulting on selection, integration and characterization of test structures
  - Therm-mechanical Design, Modeling and Simulation of (RF) MEMS packaging technologies and of their test structures
  - Technical consultancy on technology transfer

  Note: Offering technical consultancy services is the core business of MEMS TC

MEMS TC: Exploitation of specific result (1)

- 1.1 Result description: Thermo-mechanical Design, Modeling and Simulation
  - Result owner(s): MEMS TC
  - Description: Simulation service
  - Documents:
    - Paper at EuroSimE 2010, Bordeaux
  - IPR Protection:
    - Not patented
- 1.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (EC (METU-MEMS, WiserBan, ..), ESA, commercial, ..)
  - Offer **service** in particular to industry, in particular to SMEs





MEMS TC: Exploitation of specific result (2)

- 2.1 Result description: Technical Consultancy on (RF-)MEMS Packaging Approach, Brokerage, Integration, Characterization and Test
  - Result owner(s): MEMS TC
  - Description: MEMS Technical Consultancy
  - Documents: www.memstc.com
  - IPR Protection: Not patented
- 2.2 Use (exploitation) of the result:
  - Further **development**:
    - Use and valorization in other collaborative future R&D projects (EC (WiserBan, METU-MEMS..), ESA, commercial, ..)
  - Offer **service** in particular to companies, also to research organizations, academia , EC, …

MEMS TC: Exploitation of specific result (3)

- 3.1 Result description: Technical Consultancy on technology transfer of packaging technologies and test structure designs to volume production vendors (foundries and packaging houses)
  - Result owner(s): MEMS TC
  - Description: Technology transfer, industrialization of technologies
  - Documents: www.memstc.com
  - IPR Protection: Not patented
- 3.2 Use (exploitation) of the result:
  - Offer **service** to MEMSPACK partners and industrial Technology Providers

With the consortium consisting of four national laboratories (IMEC, VTT, FhG-ISiT and FBK), two university partners (Un. Perugia and Un. Of Lille-IEMN) and one technical consultancy firm (MEMS TC), there is no immediate drive by the consortium partners to commercial exploitation of the results of the project in the form of *products*. There is however a drive towards exploitation of the results in services, licensing and technology transfer (to e.g., European MEMS foundries) or prototype manufacturing and, for some (IMEC and FhG-ISiT), in low volume manufacturing of packages for (RF-)MEMS. Through the outcome of the MEMSPACK project, the national laboratories have strengthened their positions as Europe's leading Centres of Excellence for RF technology and design methods. The partners in MEMSPACK have each increased their technical competence. Packaging technologies have been developed, modeling and simulation methods have been developed for the thermomechanical and electromagnetic (high frequency) behaviour of the packages, and, test structures and test procedures have been developed to characterize the packages. These are all to the benefit of European industry, either through education of students, training of engineers, direct servicing or prototyping to end-users, and licensing and technology transfer to commercial technology providers such as European MEMS foundries and packaging houses but also to spin-out companies, spun out by the partners.

Three of the partners have established a spin-out company during the course or shortly before the start of the MEMSPACK project. The University of Perugia has established RF Microtech srl (2007), VTT has established VTT Memsfab Ltd. (2010), and, FhG-ISiT has established MEMS Foundry Itzehoe GmbH (2010). All 3 spin-out companies exploit results from MEMPACK:

> RF Microtech was established in September 2007 as spin-off of the University of Perugia participated by FBK, both partners of MEMSPACK project. RF Microtech offers consultant services, product development and prototyping of microwave and radiofrequency devices, specifically in the areas of RF MEMS, Beam Scanning Antennas and Microwave components. The RF MEMS manufacturing and packaging is carried out in Trento by FBK, whereas the design and RF characterization is done in Perugia. Currently the company has 5 employees and 4 external collaborators. Since January 2010 RF Microtech operates in autonomous offices and laboratories but still maintain an important and constant collaboration with the University of Perugia.
>
> VTT Memsfab Ltd was established in 2011 (www.vttmemsfab.fi). VTT's focus is in R&D while commercial production of microelectromechanical systems (MEMS) and other micro- and nanoelectronic devices is carried out by VTT Memsfab Ltd. The company offers versatile contract manufacturing services based on extensive technical expertise, a unique equipment environment and a comprehensive co-operation network. VTT Memsfab Ltd. provides manufacturing services for both national and international customers.
>
> MEMS Foundry Itzehoe GmbH (MFI) started operation in January 2010 as a pure-play 8" wafer foundry for MEMS technologies and MEMS wafer level packaging (http://www.memsfoundry.com). Currently the company has 18 employees. MFI is sharing with FhG-ISIT the cleanrooms and equipment in a dual-use concept. This cooperation model will also be applied for the new cleanroom dedicated to MEMS and backend-of-line technologies currently being built at the ISIT site in Itzehoe (Germany).

One patent application related to the thin film capping based on porous anodized aluminum oxide has been filed by IMEC. This patent demonstrates the evidence in the particular technology area and can be a great aid in winning competitions for contracts with industrial partners.

Further research and development is required, in particular on further maturing the packaging technologies and on the integration of the developed packaging technologies with particular front end (MEMS) and back end (higher level packaging) technologies.

The potential impact is large and diverse, but is also difficult to quantify.

4.3 Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	223882
Title of Project:	MEMSPACK
Name and Title of Coordinator:	Dr. Harrie Tilmans (IMEC), Principal Scientist

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***0Yes [✓ 0 No]***
2. Please indicate whether your project involved any of the following issues (tick box) :	**None of the below**
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	

• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	0 Yes X No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis). **Note: people have not been counted twice, e.g., if WP leader is experienced researcher then this is not added to the experienced researchers.**

Type of Position	**Number of Women**	**Number of Men**
Scientific Coordinator	**0**	**1**
Work package leaders	**2**	**6**
Experienced researchers (i.e. PhD holders)	**3**	**25**
PhD Students	**0**	**4**
Other	**9**	**15**

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**1**
Of which, indicate the number of men:	**1**

D Gender Aspects

5. **Did you carry out specific Gender Equality Actions under the project?**	● ○	Yes No

6. **Which of the following actions did you carry out and how effective were they?**

		Not at all effective				**Very effective**
☒	Design and implement an equal opportunity policy	○	○	●	○	○
☒	Set targets to achieve a gender balance in the workforce	○	○	●	○	○
☐	Organise conferences and workshops on gender	○	○	○	○	○
☐	Actions to improve work-life balance	○	○	○	○	○
○	Other:					

7. **Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?**

○ Yes- please specify

● No

E Synergies with Science Education

8. **Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?**

● Yes- please specify: Lectures in university curriculums, and in summer schools

○ No

9. **Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?**

● Yes- please specify: Presentation slides summer schools

○ No

F Interdisciplinarity

10. **Which disciplines (see list below) are involved in your project?**

● Main discipline[5]: **2** (2.2&2.3)

○ Associated discipline[5]: ○ Associated discipline[5]:

G Engaging with Civil society and policy makers

11a **Did your project engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	○ ●	Yes No

11b **If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?**

○ No

○ Yes- in determining what research should be performed

○ Yes - in implementing the research

○ Yes, in communicating /disseminating / using the results of the project

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[5] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?

○ Yes
○ No

12. Did you engage with government / public bodies or policy makers (including international organisations)

○ No
○ Yes- in framing the research agenda
○ Yes - in implementing the research agenda
○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
○ No

13b If Yes, in which fields?

Agriculture
Audiovisual and Media
Budget
Competition
Consumers
Culture
Customs
Development Economic and Monetary Affairs
Education, Training, Youth
Employment and Social Affairs

Energy
Enlargement
Enterprise
Environment
External Relations
External Trade
Fisheries and Maritime Affairs
Food Safety
Foreign and Security Policy
Fraud
Humanitarian aid

Human rights
Information Society
Institutional affairs
Internal Market
Justice, freedom and security
Public Health
Regional Policy
Research and Innovation
Space
Taxation
Transport

13c If Yes, at which level?

○ Local / regional levels
○ National level
○ European level
○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	4 accepted + 4 more submitted and pending acceptance (as of 13-5-2012). Together with 17 papers published at conferences, and 1 more submitted to a conference and pending acceptance.
To how many of these is open access[6] provided?	No clear information at hand, but we guess 4.
How many of these are published in open access journals?	No clear information at hand, but we guess 1.
How many of these are published in open repositories?	No clear information at hand, but we guess 3.
To how many of these is open access not provided?	No clear information at hand, but we guess 22.
Please check all applicable reasons for not providing open access:	
☐ publisher's licensing agreement would not permit publishing in a repository ☐ no suitable repository available ☒ no suitable open access journal available ☐ no funds available to publish in an open access journal ☐ lack of time and resources ☐ lack of information on open access ☒ other[7]: top-level journals and conferences do not provide open access	We don't have clear information at hand regarding open access or not.

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	1

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	0
	Registered design	0
	Other	1

17. How many spin-off companies were created / are planned as a direct result of the project?	3
Indicate the approximate number of additional jobs in these companies:	30

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

☐ Increase in employment, or	☐ In small & medium-sized enterprises
☐ Safeguard employment, or	☐ In large companies
☐ Decrease in employment,	☐ None of the above /not relevant to project
☒ Difficult to estimate / not possible to quantify	

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	☒

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[6] Open Access is defined as free of charge access for anyone via Internet.

[7] For instance: classification for security project.

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ● No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ● No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

☐ Press Release
☐ Media briefing
☐ TV coverage / report
☐ Radio coverage / report
☒ Brochures /posters / flyers
☐ DVD /Film /Multimedia
☒ Coverage in specialist press
☐ Coverage in general (non-specialist) press
☐ Coverage in national press
☐ Coverage in international press
☒ Website for the general public / internet
☐ Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

☐ Language of the coordinator
☐ Other language(s)
☒ English

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)
1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]