

Trends in the Assembly and Packaging of Sensors

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SUMMARY

In this paper, some trends in the industrial assembly and packaging of sensors are described. We confine the analysis mainly to multifunctional housing technologies. In detail transfer moulded and pre-moulded packages, moulded interconnect devices and LTCC housing are compared. In the case of moulded packaging, multi-chip solutions for SiP as well as chip-scale packages are noteworthy. For pre-moulded housings of single components packages with standard outlines are used, while for sensor systems in mechatronics application-specific multi-functional packages will dominate. A further development is the injection moulded interconnect device MID which serves as a mechanical precision carrier, wiring substrate and package body altogether. In the field of hermetic packaging co-fired ceramics can be used as substrates and housings which are well suited for extremely harsh environments. The use of hermetic wafer-level packaging is an alternative which protects free-standing sensing structures effectively while at the same time the economic advantages of plastic packages can be maintained. All these technologies are evaluated comparatively.

INTRODUCTION

In recent years, the trends in the assembly, packaging and interconnection technologies of sensors have been driven both by a technology push and by application demands. In the field of the manufacturing of sensors, especially new technologies for substrates and housings of sensors were developed. In this paper, we give an overview of industrial trends for sensors and micro-systems. Due to space restrictions, we will have to confine the comparative evaluation to the 1st and 2nd level housing and packaging layers.

STANDARD PACKAGES

Today, many sensor types are supplied from semiconductor manufacturers. Due to economical reasons, the so-called moulded plastic packaging is dominating these sensor products, which are typically assembled in standard packages. Especially in the case of integrated circuits like Hall sensors, transfer-moulding with reactive epoxy compounds is the dominating process. For these package types, costs of approximately 1 \$ct per pin have to be taken into account. There are several trends to be noted:

Due to the use of super-low-stress moulding compounds with a low coefficient of thermal expansion (CTE), the influence of packaging stresses on the sensors can be reduced and the application temperatures have been increased up to 175 °C. Here, a chemical limit of the operating temperature can be expected around 200 °C. The principal applications comprise monolithic sensors, which have been produced with standard CMOS processes, e.g. for automotive applications [1].

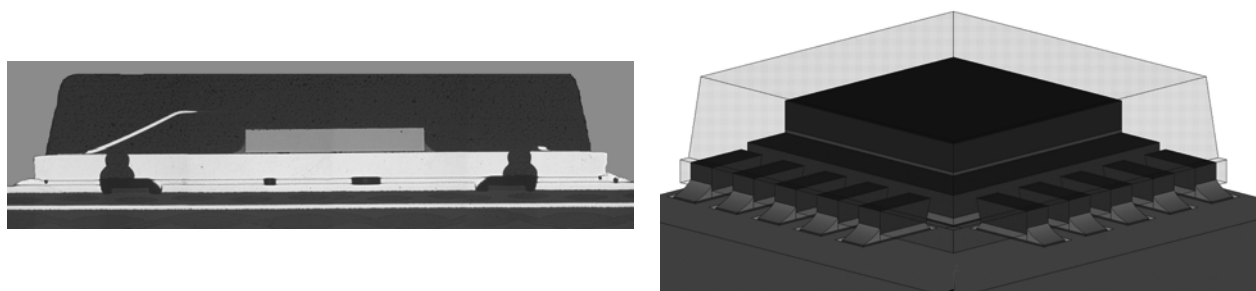


Figure 1: Chip-scale packages for sensor IC packaging. Left QFN (quad-flat-no-lead cross section, right Finite Elements model of a QFN (IMTEK)

Additionally in the field of ICs, so-called chip-scale-packages (CSP) have become quite relevant. These are surface-mounted devices with a package which is only 20 % larger than the size of the chip. Two basic technologies exist: The first one is lead-frame and moulding based one [2]. A typical package is the QFN, but also micro ball-grid-arrays are used, where the lead-frame is replaced by an organic high density substrate, which is a kind of printed wiring board. These components exhibit fine pitches or grids of their I/Os down to 0.5 to 0.3 mm and they are typically mounted on a printed circuit board. The main application of high density and high integration packages is not in harsh environments but more in cases where high functional integration has to be combined with small volume. Examples are sensors for cellular phones or for electronic video-game controllers.

The trend in ICs towards the system-in-a-package or system-on-a-package (SiP/SoP) has lead to the development of multi-chip packages [3]. Using this technique highly functional systems can be built by combing sensors with analogue and digital circuits. While in the more conservative approaches a sensor chip and the signal and data-processing circuit are arranged side-by side, modern developments utilize stacking of thinned chips and typically interconnection by wire bonding, Fig. 2. Presently, SiP/SoP-technologies are not used frequently for sensors, but they have a clear potential of further application in intelligent sensor systems. Also stacked chips become more available also to smaller series applications as contract manufacturers increasingly offer such technologies.

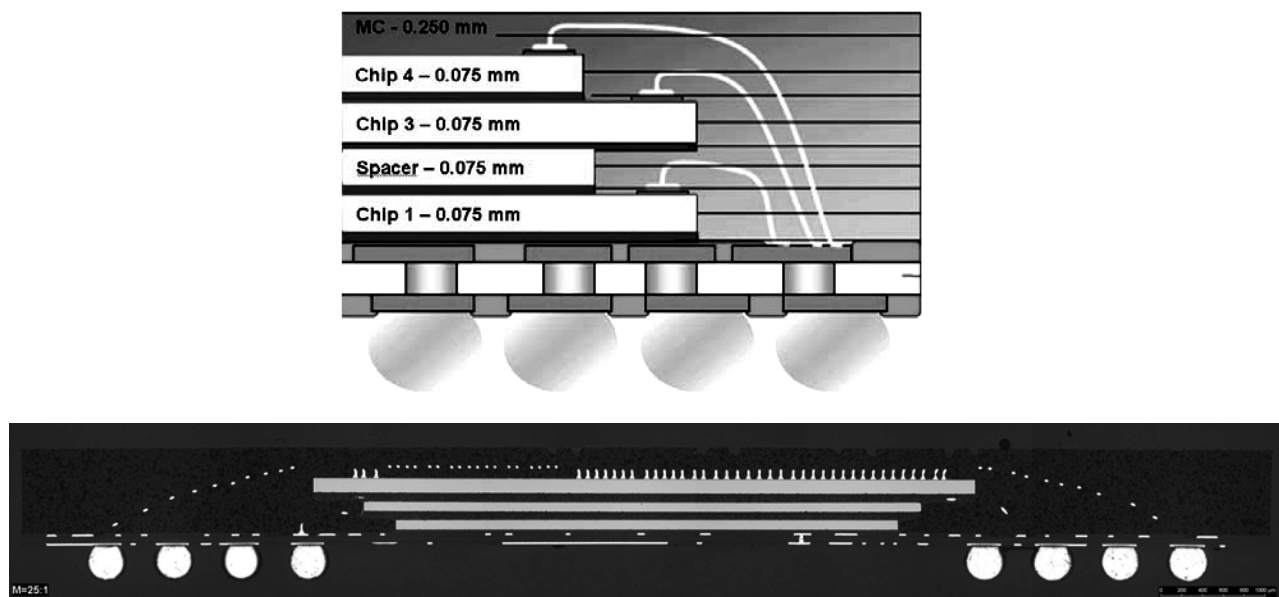


Figure 2: Stacked-chip packages for SiP (System-in-Package) of hybrid-sensor systems (courtesy of Infineon AG). Above: principle of chip stacking and interconnection [3], below: metallographic cross section.

PRE-MOULDED PLASTIC PACKAGING

Many transducer principles need a cavity, in which a sensor is mounted and where the encapsulation material has no direct contact with the functional surface of the chip. This requirement is most relevant for pressure sensors, inertial sensors and optical or IR devices. To that purpose pre-moulded package types are suited well. Typically, these consist of a metal lead-frame which is embedded into a thermoplastic package body with an injection moulding machine [4]. Subsequently the sensor devices are mounted, and in a last step a lid is used to cover the cavity. Two families of this package type can be distinguished, depending on the device to be packaged, Fig. 3:

The pin design and the outline of packages for single sensor elements are rather similar to those of SMD standard devices which are mounted onto a wiring substrate. Thermoplastic standard types have penetrated the market just in recent years, also due to the lack of suppliers. The used materials like liquid-crystal polymer (LCP) are quite temperature stable, inherently flame retardant and more environment-friendly than bromine containing moulding compounds of the past. The quality of these packages alone will not be superior to that of hermetic packages [4]. This holds especially with respect to maximum operating temperature and hermeticity, but the packages can be combined with protection concepts on chip level. So by using wafer-bonded chips they will exhibit significant cost advantages in combination with competitive costs, Fig. 6.

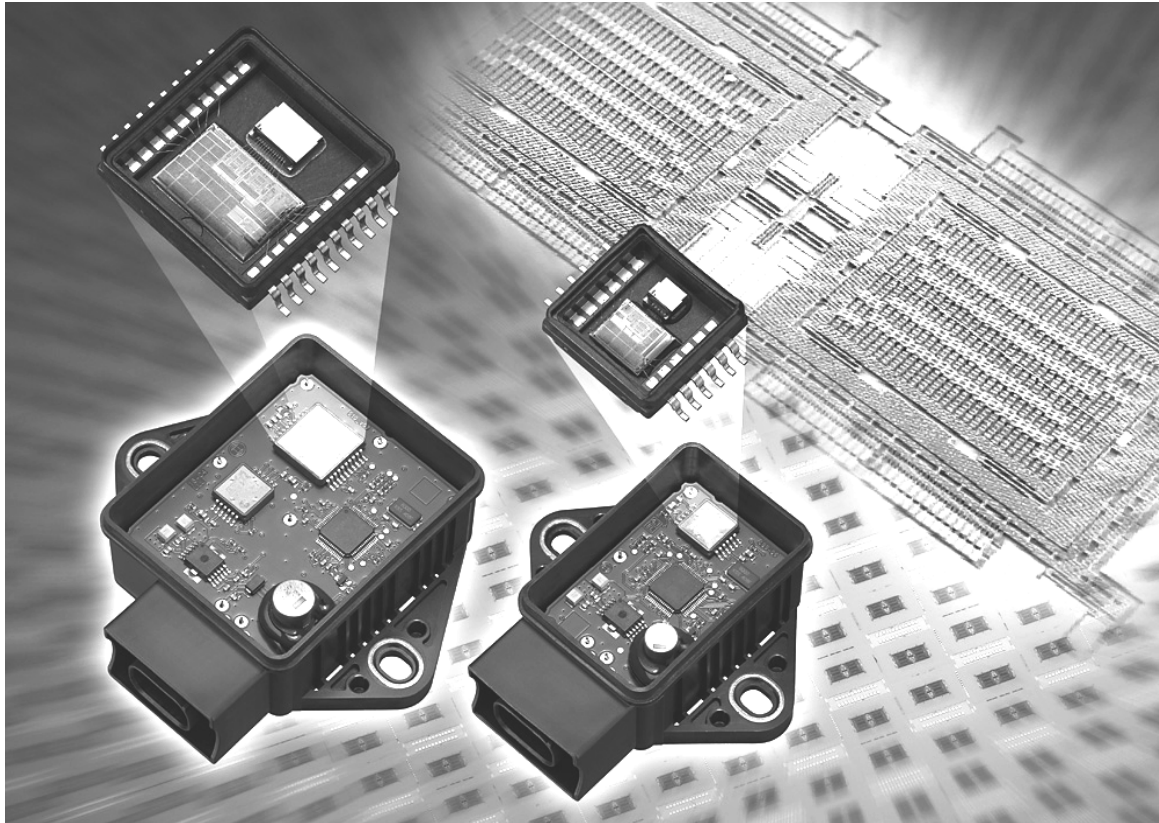


Fig. 3: top: Pre-moulded standard package for MEMS sensors
lower: Multi-functional pre-moulded packages for sensors (courtesy of Robert Bosch GmbH)

So-called multifunctional pre-moulded packages (Fig. 3 below) will aim more at mechatronic applications. In many cases, a sensor must be attached to a mechanical structure like an automotive fuel injection system. In this case the sensor housing must also fit into the system structure mechanically. Fixtures, ducts for gases and liquids or socket-like electrical inter-connectors will be needed. The pre-moulded-packaging of sensor systems is dominating many automotive applications. All of these packages are designed completely customer-specific. Due to the large series volumes, tooling costs for lead-frames and injection moulds are no longer dominant with respect to the overall costs per part. Nevertheless the most important factor promoting their use is the high degree of freedom of design which is achieved with multi-functional pre-moulded packages. Besides mechanical elements, also supports for optical components like lenses, lasers, glass fibres or coils are integrated.

The dominant material for such packages is PBT (Polybutylene terephthalate), and for higher application temperatures polymers like PA6 (Polyamide) or PPS and LCP. Typically, the materials are composites with up to 30% of inorganic fillers. Unfortunately these packages are not very tight against moisture penetration [4]. Therefore additional silicone potting of the device and especially the interconnections is required.

MOULDED INTERCONNECT DEVICES

One of the most relevant novel technology for the fabrication of sensor packages is that of MID, Moulded Interconnect Devices [5]. A significant feature is the multi-functional use of a three-dimensional, injection moulded substrates as structural element, wiring substrate and package. As the injection moulding process can achieve high precision, also extremely well-defined supporting faces can be produced for the mounting of sensors. This is of special significance if the sensing element must be mounted in a very precise position, as it is the case for three-dimensional magnetic sensors, Fig. 4.

Presently several methods are state-of-the-art for the creation of a 3D wiring pattern on MIDs. The conductors are either formed by laser-structuring of functional layers at the surface or by lamination of a flexible circuit onto the MID-parts [5]. Also numerous variations like additive or subtractive metallization, or two-shot injection moulding are under development. It is possible to produce conductors which are fine

enough to mount and interconnect bare chips using wire-bonding or even flip-chip-technology on the MID [5]. It is expected that MIDs will be able to exhibit a high benefit in mass applications, as the tooling effort is quite high. Also, due to tooling a lower flexibility with respect to prototyping is a drawback. The use of laser-based patterning can help to reduce the costs which are affected by tooling. Besides materials like PBT, PPS und LCP, further high-performance polymers like PEEK are used.

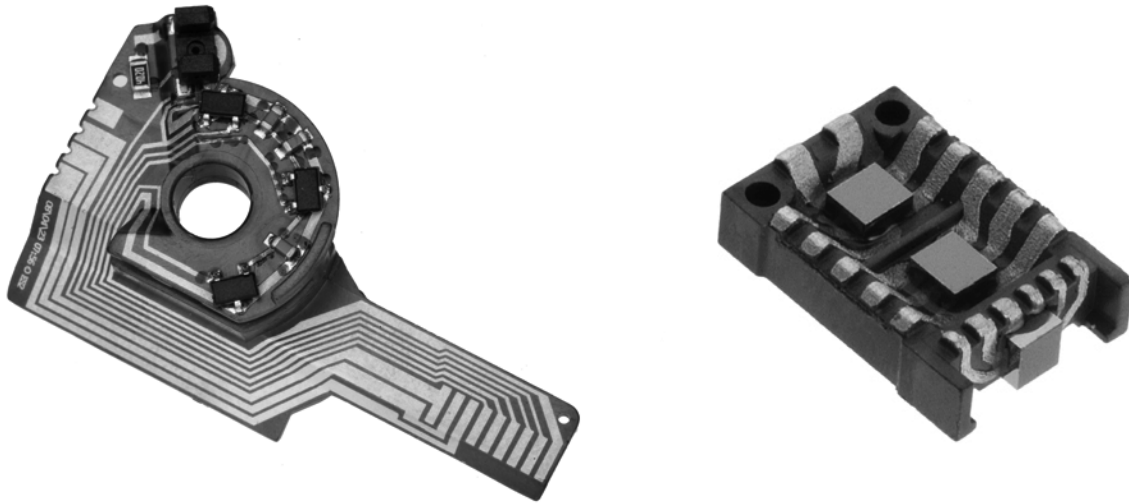


Fig. 4: Moulded Interconnect Devices: Left: MID for a rotary position sensor sensors (courtesy of Continental AG/Harting Mitronics AG), right MID for a 3D magnet sensor (courtesy of Harting Mitronics AG)

HERMETIC PACKAGING

Hermetic housings are a well-established technology, which allows to package sensors. The principal requirements are a size-dependent low helium leak rate $< 10^{-9}$ Pa m³/s and restricted moisture contents < 3000 ppm, as demanded for example by the MIL STD 883. Metal and ceramic housings are utilised both as standard components as well as application-specific packages. Special hermetic variants are applicable up to temperatures of 200 °C, in some cases up to 250 °C. The packaging costs are relatively high, roughly 10 ct per I/O-pin for higher pin-count standard packages. Especially metal and ceramic housings are advantageous for optical components as they combine both hermeticity and the ability to integrate of optical elements like windows for visible and IR light, Fig. 4. Therefore it is expected that hermetic housings will have a demand in market segments where a cavity, hermeticity or suitability for high temperatures are the primary selection criteria.

A clear trend in the application-specific packaging is the use of low-temperature co-fired ceramic LTCC materials, Fig. 4. The process flow is similar to that of HTCC packages: The metal conductor pattern is screen-printed onto thin green sheet. Several of such layers are laminated together and the whole part is fired at around 900 °C. Although first industrial applications of LTCC were aiming at large-series products, the LTCC technology has been spread to smaller series applications, where the technical requirements are relevant, like excellent high-frequency behaviour up to almost 100 GHz.

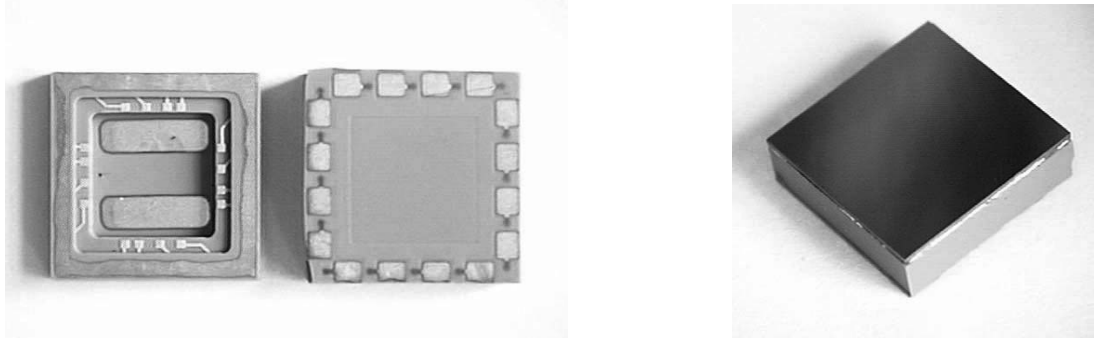


Fig. 4: Hermetic package for IR sensors using the LTCC technology. Left: empty package, right: sealed with IR-transparent silicon lid (courtesy of IFW Jena and Micro-Hybrid Electronic GmbH).

WAFER-LEVEL PACKAGING AND TESTING

In applications which require hermetic encapsulation and especially for MEMS, presently a new protection strategy is developed. In many new sensor designs hermeticity is no longer achieved by a metal or ceramic package. The MEMS structure is protected on wafer-level using a capping wafer which forms a hermetic cavity with the substrate wafer(s). The interconnection between the silicon and also the glass substrates is accomplished by wafer bonding using thin glass or metal layers, electrostatic forces or attractive atomic forces. Contrary to this, wafers bonded with adhesives are under investigation, but they will not be hermetic. Novel wafer-level packaging also allows for the integration of optical as well as fluidic feed-through structures. Electrical interconnections into the cavity are formed by metal or implanted conductors. Sensor elements which are already sealed hermetically on-chip or on-wafer will become more significant in the future. The principal advantages are the potential for low-cost 1st level packaging, easier handling and wafer-level testing, and lower required cleanliness in backend processes. Provided that such sensor elements become available as bare dies, they will allow attractive packaging concepts both small and large series applications. An example of such a packaging concept is found in Fig. 3 top. The sensor combines a wafer-level protected MEMS and an ASIC, mounted together in a pre-moulded SMD package. Also the combination of wafer-level sealing with MID is promising.

Another trend that is connected to assembly and packaging is wafer-level testing [6]. Up to now it was necessary to package a sensor in order to stimulate it for functional testing. For many sensors the package will constitute a large portion of the device costs. Therefore the possibility to check for functional and parametric defects of bare devices can lead to large economic savings because only the sensor chips and not the completely packaged sensors have to be scrapped. This significant economic disadvantage can be overcome by the possibility to test sensor ICs on wafer, without package. By using special wafer-probers with the possibility to stimulate also functional tests of the transducer devices are possible. With such a strategy, the loss due to the limited bare-chip-yield is lower than in a test strategy based purely on packed sensors [6].

COMPARISON OF PACKAGING TECHNOLOGIES

As summarized in Table 1, the transfer-moulded packages are ideal for housing of monolithically integrated sensors at optimised costs. Three important but rather independent trends are high temperature application, chip-scale packaging and multi-chip systems. The transfer-moulded packages are used when a cavity is needed especially for surface mounted devices under harsh environments. Multifunctional packages are used for modules with application-specific mechanical design, as it is frequently the case in automotive under-the-hood applications. Those packages exhibit inter-connectors for electrical, fluidic or mechanical interfaces. MID is a new technology, which aims at multifunctional parts for large series applications. It allows novel concepts of system design, due to the high degree of constructive freedom. It still has to be qualified for more harsh environments. Wafer-level protection is an additional measure which can increase reliability and ruggedness of sensors in non-hermetic plastic packages significantly, while it limits the packaging costs. Hermetic packaging with heat-resistant packages will still have its share, e.g. because hermetic radiation windows can be accomplished with standard methods. LTCC is a technology which can combine the fabrication of complex carriers and housings. This also gives the possibility for multifunctional ceramic interconnect devices.

FURTHER TRENDS

The following trends are also considered as important, but can just be mentioned here: A application-driven trend is condition monitoring of technical systems. To that purpose, sensors for temperature, moisture, vibration, or mechanical load are integrated into mechatronic systems, consumer goods or even into aircraft structures. Traditional schemes of assembly and packaging will have to be abandoned, as the sensors must be integrated directly into structures [7] comparable to the presently dominating strain gauges. The reason is that excessive substrates and housings can affect the transducer element and produce artefact signals.

Package type	Transfer-moulded package	Pre-moulded thermoplastic package	MID	Hermetic LTCC package
Property				
Main application	single and multiple sensor ICs	sensors chips sensor modules multifunctional devices	3D multifunctional devices	single chip devices
Manufacturing	++	+	-	0
Prototyping	0	+ [*] -- ^{**}	-	0
Design-freedom	-	+	++	0
Multi-functionality	-	+	++	+
Costs	++	+	+	-
Thermal stability	+	+	0	++
Hermeticity/ media protection	- ^{***} ++ ^{****}	-- ^{***} ++ ^{****}	-- ^{***} ++ ^{****}	++
Reliability	+	+	0/+	++
"Green" materials	0	+	+	0

Tab. 1: Comparison of packaging technologies for sensors and micro-systems
** standard types ** application specific *** standard chip **** wafer-bonded chip*

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