Flexible packaging by film assisted molding for micro assembly technologies based on PCB

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1 Abstract

With the increasingly high demand for microsystems, their packaging technologies become more and more important. Requirements of reliability as well as integration of more functionality and miniaturization in combination with a need for cheaper production cost trigger the necessity for new solutions for modular, embedded microsystems. Small and medium sized product lines for new developments in the field of optics, medical devices, sensors and automation technologies require rapid methods for production while keeping the costs moderately low.
With Film Assisted Molding, the method of transfer molding can be used for manufacturing tailor made embedded microsystems with integrated functions. Due to the well matched CTE of the thermoset material, the soft compression of the ETFE foil and therefore the increased acceptable tolerances, common printed circuit boards with all their benefits like multilayer capability can be processed, leading to a much higher integration density of systems (systems in package). Additionally, multiple systems can be assembled and packaged on a single PCB board, enabling small series production. Within this study methods were developed for packaging of PCB based microsystems, including, but not limited to, standard QFN packages, image sensors as well as inertia sensors. The aim of this research is to provide proof for the possibility to employ the method as a reliable and flexible packaging solution for various advance microelectronic packages.

2 Introduction

The production of a smart packaging solution presents a major challenge in micro assembly technology [1]. Transfer molding of polymeric packages based on thermosets, especially epoxy molding compounds (EMC) offers a large set of advantages like very low coefficients of thermal expansion (CTE), thermal conductivity, good chemical resistance, a high Young-modulus, etc. Due to the reduced shrinkage and low viscosity of EMC compared to thermoplastic materials, even highly sensitive electronic assemblies using chip-and-wire techniques can be packaged [2,3]. Therefore, transfer molding is the most commonly used technology for packaging of microsystems [4]. However, transfer molding technology for production of micro system packages is mainly offered in Far East [5]. The packaging companies are interested in manufacturing large quantities and standard packages, like SO, PGA, QFN, LGA, or BGA [6,7]. Since small sized companies in Europe often require small or medium size productions with individual packaging solution for their highly innovative micro system packages, standard production in Far East is no viable alternative.

Film Assisted Molding (FAM) is based on standard transfer molding (TM) technology and presents a new, advanced industrial manufacturing technology [8]. The major modification compared to TM includes the application of a film of Ethylen-Tetrafluoroethylene (ETFE) with a thickness between of 50 µm to 100 µm. The advantage of using such a film is the protection of the tool from the EMC, leading to a virtually unlimited tool-life and therefore a first part identical to last part principle. Additionally, tool complexity and abrasion is reduced as mechanical ejector pins are unnecessary. Moreover, sealing of the tool is improved by the compression seal of the foil, leading to a simplified tool-making in regard to precision and tolerances. However, the major feature of the foil of FAM is the possibility that the tool can touch and seal sensitive sensor surfaces without causing breakage.

Combining the well-known processes of printed circuit boards (PCB) with FAM, a new set of packages, called FlexPacs, becomes available. PCBs can be easily designed and cost efficiently produced using multilayer technology. Compared to lead-frame packages, a much higher complexity and integration density can be achieved as routing of the electrically conductive tracks is possible and smart systems can be integrated. For example, leadless packages like QFN are in high demand due to the trend to use less space for an assembly. Providing an even further miniaturization, more complex circuitry can be embedded into the QFN. On the downside of the combinatory technology, PCBs show higher tolerances than lead-frames, for which reason alignment methods for FAM processes are not trivial.

3 Experimental

An Unistar Boschmann FAM Machine, able to process EMC pellets, was used for the development of the flexible PCB based packaging concept. EMC EME-G770H Type CD from Sumitomo Bakelite was chosen in order to provide a good CTE match for die packaging on PCB.

Adhesion of EMC to the different surfaces of the PCB was checked by molding of defined cones and subsequent shear testing with a Dage Series 4000P. The test panel was a PCB with three kinds of surfaces: PCB base material, solder resist and metal pads with gold finish as their uppermost layer. An insert for the tool was designed and manufactured by precision tool making to generate the EMC test structure on the test panel. For each kind of surface, three test structures were generated. Additionally, treatment of the surfaces by low pressure oxygen plasma (O_2-plasma) was tested to alter the adhesion properties. Three different packages were to be tested, namely a QFN package to determine basic design and process rules, a package for an inertia sensor to determine process parameters for sensitive

components, and an image sensor package to determine realization of clearances and direct tool to ASIC contact.
The tool inserts were designed using PTC ProE software and manufactured by high precision tool making using a Primacon PFM 24 3-axis high speed milling machine. Subsequently, the tool insert were checked by a Werth coordinate measuring machine for geometrical variations. This was done also for the testing the positions of the dies after die attach. The die attach itself was performed using an Amadyne die bonder and a gold wire bonding process with a wire bonding machine of Delvotek. Special alignment methods were required for the image sensors as the tolerances required a positioning variation less than 50 µm relative to the dowel pin system to align the PCB in the mold inserts as well as the sensors to each other.
Three different PCBs were designed using Eagle software: a 300 µm thick PCB panel for QFN packages, a 550 µm thick demonstrator board for an image sensor, and an 800 µm thick PCB for the inertia sensor. The integrated circuits were adhered to the specific boards and wire bonded for electrical contact using a 25 µm gold wire. Subsequent to the molding process, the PCB panel was diced using a wafer saw of Disco.
Reliability testing was performed by an initial electrical test followed by accelerated aging by temperature shock (TS), temperature moisture storage (K), high temperature storage (TL) and reflow testing (Soak). The parameters are shown in Tab. 1. Optical analysis of the packages was performed by light microscopy and x-ray radiography: Light microscopy to value the surface, quality of transitions between the image sensor surface and EMC, and detection of delaminating. X-ray tests to value the gold wire bonding after FAM process.

4 Results

4.1 Adhesion testing

In order to quantify the adhesion of the EMC on different PCB surfaces 18 test structure was sheared from each type of surface. The PCB base material showed the strongest and gold the lowest adhesive strength (Fig. 1). Treatment of the surfaces by O_2-plasma increased the adhesive strength effect on all surfaces. However, as the adhesion of EMC to base material without O_2-plasma provided sufficient strength, the process was not applied for further tests. If increased reliability is required, surface activation using O_2-Plasma is suggested. Moreover, the O_2-plasma treatment is also a method to remove surface contamination, thereby presenting a safer process as the quality of different produced PCBs and also there surfaces show less variations in terms of adhesion. Visual inspection of the breaking areas of each kind of surface showed cohesions breakage for both plastic surfaces. Adhesion breakage was observed for the gold surface (Fig. 2). In case of the plastic surfaces, adhesion of EMC to solder resist was stronger than the adhesion of solder resist to PCB base material and PCB base material to glass fiber. Consequently, solder resist should be avoided if possible and the following steps of investigation were performed without solder resist on the top surface of PCB.

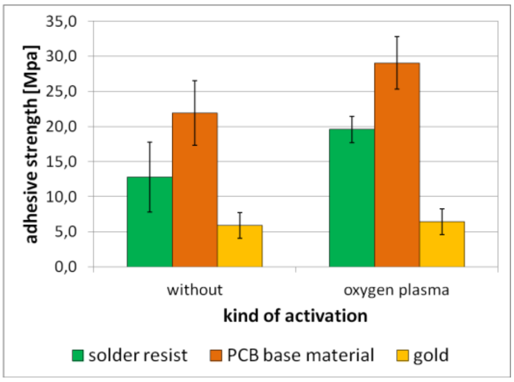

Fig. 1: Diagram of adhesive strength of EMC to different base materials of the PCB, untreated surfaces in comparison to O_2-plasma activated surfaces.

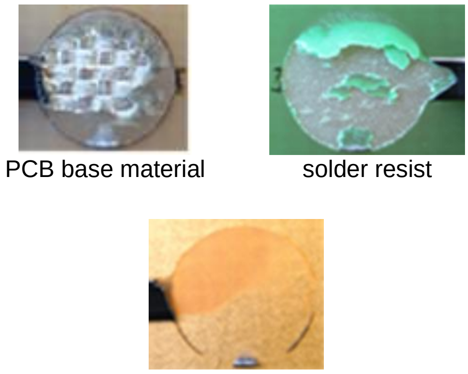

Fig. 2: Breakage areas of EMC on different base materials after shear tests of adhesion testing. Cohesion breakage could be observed for PCB base material and solder resist. Adhesion breakage was observed for the gold surface.

4.2 QFN-FlexPac

The main task in realising the QFN package based on PCB (QFN-FlexPac) was to check all processing steps as well as the reliability on a rather simple and typically sensitive assembly. In a first step, this includes the development of processing parameters for nondestructive molding of gold wire bonds. 25 ASICs were die bonded on one PCB panel, whereas each ASIC was electrical connected with 55 gold wire bonds to the PCB. After the FAM and dicing process, the electrical test resulted in a yield of 98 %. By means of x-ray test, it was shown that all gold wires were molded without any destruction (Fig.3). Some gold wires showed slight bending due to the mass flow of the EMC, but were still connected. Failures of the remaining 2 % of the electrical connectors were linked to general deficiencies in the wire bonding process, e.g. weak bonds between gold wire and PCB.

Furthermore, the PCB test panel was designed to check different design rules of the PCB for testing if the via design and the option of routing influences the reliability of the functional properties. Two of the ASIC were connected using vias which connected top to bottom layer directly, while the others were realized using all four layers of the PCB. However, no differences could be detected.

Electrical testing was performed with a pin adaptor tool which contacted the 48 gold coated pads on the bottom layer in parallel. To determine the best geometries of the contact pads of the QFN-FlexPac for reliable for testing, 15 ASIC positions on the panel had rectangular and 10 ASIC positions circular shaped pads. Rectangular pads could be contacted more reliably. Pads with a size less than 0.30×0.25 mm² were too small for the pins as the alignment of pin adapter tool and QFN-FlexPac could not be achieved in all cases. In a redesign the pads were designed with a rectangular geometry and a size of 0.35×0.25 mm².

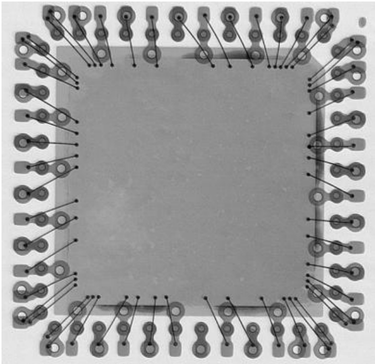

Fig. 3: X-ray radiography of a packaged QFN-FlexPac to determine possible failures of gold bond wires due to mass flow during molding.

Fig. 4: QFN-FlexPac. Design rules and process parameters were optimized to qualify the method for general packaging.
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Due to the thinness of the PCB panel of the QFN-FlexPacs a back injection of the panel was detected, whereas EMC intrudes below the PCB panel as bending of the panel occurs. Tuning the clamp force acting on the PCB panel, the failure mode could be removed. If the clamp force is too high, the risk of back injection increased because of warping of the flexible PCB on the gate side. If the clamp force is too low, sealing at the edges of the PCB panel fails.

Tab. 1: Parameters and results of the reliability tests of the QFN-FlexPacs.

Procedure	**TS**	**K**	**TL**	**Soak**
Condition	1000 cycles 150 °C / -65 °C	1000 h 85 °C / 85 %rH	2000 h 125 °C	192 h 30 °C / 60 %rH
Failure/Samples	0/10	0/10	0/10	0/10
Reference	0/10	0/10	0/10	0/10

Subsequently to the design and process development, all QFN PCB panels could be packaged and diced without any problems using the FAM process (Fig. 4). Reliability testing proved the QFN package based on PCB is competitive to the QFN based on lead frame packages, which were tested as a reference. No delaminations or other failure modes could be observed within the testing conditions (Tab. 1).

4.3 Image sensor package

With a small tool modification it was possible to package image sensors. A recess structure in the package was required in order to achieve a clearance on the sensor area free of EMC. The sensor could be packaged damage free based on the soft compression of the foil (Fig. 5 and Fig. 6)
Processing of image sensors as FlexPacs proved to be complex, also in the preprocessing to FAM, because of the high tolerances of a PCB, i.e. contour to circuit layout tolerances of up to 0.3 mm or alignment holes to circuit layout tolerances of 0.1 mm. Hence, absolute positioning in regard to the contour or the alignment hole is no valid option as the tolerances of the clearance to pixel array allow for not more

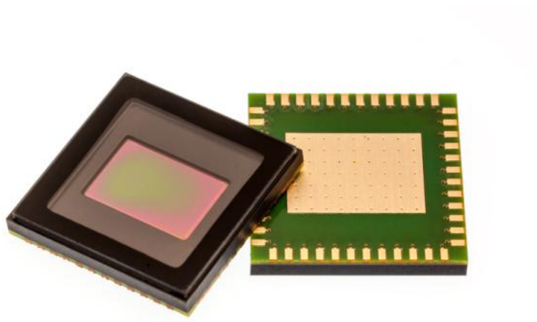

Fig. 5: Image sensor package. The soft compression of the ETFE foil enables to create clearances without damaging the image sensor.

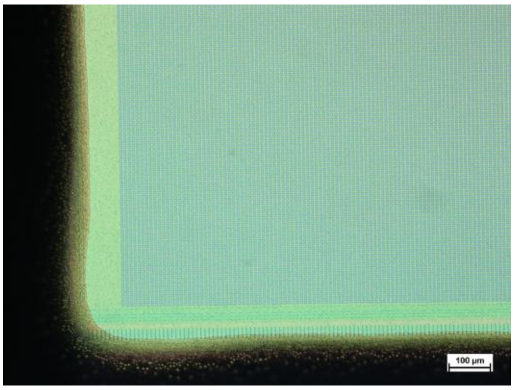

Fig. 6: Sealing edge of the ETFE foil at the sensor area. The soft seal of the ETFE foil in combination with precise alignment leads to well defined clearances.

than 50 µm. The task to align the FAM tool insert to the pixel array requires fiducial marks and a relative alignment of the sensors to the marks as well as of the sensors to themselves. This could be achieved by using the same pin adapter for both processes, the die attach process and the FAM process, whereas the orientation for the position of the tool was the theoretical position of the image sensor. To attach the image sensor on the PCB panel, the fiducial marks were placed outside the PCB on the adapter. With coordinate measurements using the Werth machine, the distance of the fiducials to the adaptor pin was defined, avoiding any deviations caused by the PCB tolerances.

To avoid bleeding of EMC onto the sensor area as well as excess pressure on the sensor, thereby causing chip cracking, it was of uttermost importance that the tool setting was planar. This commonly simple setting proved to be a challenge, because the z-axis tolerance of a PCB is typically between 5 % until 10 % of the PCB thickness, leading to variations of the sensor height compared to the tool setting of up to ± 0,055 mm for the given PCB design, enough to cause bleeding on the pixel array or to break the image sensor. Therefore, all PCBs were measured and sorted in order to minimize variations of thickness within each batch of production. Alternatively, for a large scale production height adaptive tooling should be employed. The height was set to the smallest thickness of the PCB within each batch to achieve sufficient sealing of the pixel arrays of each image sensor. Despite of the sorting procedure, the effect of bleeding could not be stopped entirely for each sensor due to the tolerances in z-direction. Several technological problems were identified as possible sources: the gap from chip to PCB could vary by the adhesive attachment process, the pads of the PCB carry a certain tolerance and therefore height differences, variations of the thickness of the PCB panel throughout the entire area, and of cause deviations of the planarity of the tool setting. The effect of bleeding of EMC on the pixel array generates shadows in this region by each image. Consequently, an optimized optimize tool concept with adaptive tooling should be employed to avoid the bleeding problem. Nonetheless, most of the packaged image sensors were free from bleeding.

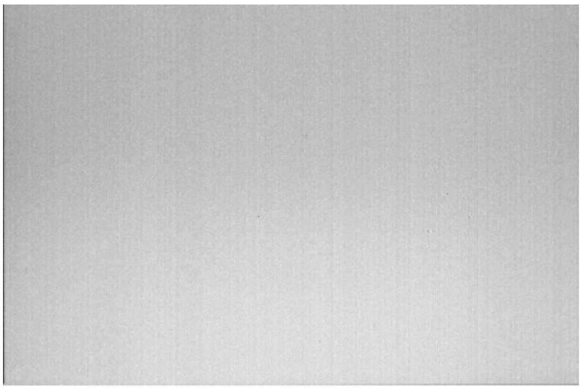

Fig. 7: Functional test image. The gray values were analyzed and pixel failures, if applicable, could be detected.

Fig. 8: Demo image using the image sensor packaged by the FlexPac process.

Subsequent to electrical testing, a glass lid was mounted onto the package and the functional testing was performed. Therefore, a gray image was recorded whereas gray value was analyzed and pixel failures could be detected (Fig. 7). In some cases dirty region due to bleeding or dust due to the non-optimized FAM process could be detected. Passing the functional test, the image quality could be valued (Fig. 8). The demo image is taking using the image sensor packaged by the FlexPac process.
Reliability testing was performed and showed the same good results as for QFN-FlexPacs (Tab. 2). In this test the PCB based image sensors package were compared with reference ceramic packages. No failures could be detected after reliability testing.

Tab. 1: Parameters and results of the reliability tests.

Procedure	**K**	**TL**
Condition	1000 h @ 85 °C / 85 %rH	1000 h @ 150 °C
Failure/Samples	0/10	0/10
Reference	0/10	0/10

4.4 Inertia sensor package

Packaging of the inertia sensor was done using the QFN tool. These sensors incorporate a membrane which is sensitive to pressure. Therefore it was important to test if the FAM process is sensitive enough to package such membrane based sensors without destruction of the membrane. Within the FAM process the cure pressure is the most important factor which could be destructive for the membrane. In a simple test sequence, the cure pressure was varied from 10 kg/mm² to 40 kg/mm² in steps of 10 kg/mm². The results did not determine any trend. In each case there were functional and dysfunctional inertia sensors which could not be linked to the FAM process. Consequently, the FAM process can be considered as a method to package the inertia sensor. Further investigations will package the inertia sensor based on PCB to build a functional demonstrator.
In order to validate the stress of the package, stress sensors were included in the PCB panel for the inertia sensor. The stress sensor is an ASIC structure which

measures the surface stress by current mirroring of p- and n-MOS transistors, whereas the electron mobility is influenced by mechanical deformation. The transistors were positioned in different angles. After die attach and after molding the stress of the sensors were recorded and compared to each other. A significant trend could be observed, that the FAM package decreases the stress. It is thought that CTE mismatch between ASIC and PCB and respectively mechanical deformations in the chip are equalized by the packaging at temperatures comparable to chip mounting.

5 Conclusion

The results of this investigation show a successful process development to package microelectronics systems based on PCB by FAM including the development of tolerance independent positioning and assembly processes. Adhesion testing and characterization of long-term reliability was performed, showing that PCB based packages are competitive to state-of-the-art reference packages and present a cost efficient alternative, which can be applied to a large variety of applications, even for small and medium sized production.

QFN-FlexPacs could be produced and standard design and process parameters were developed. Inertia sensors have shown that the FAM process is sensitive enough to package membrane based sensors, rendering the process a viable option for ASIC and sensor packaging. With the realization of clearances in the package with very precise positioning, optical sensors and optoelectronic applications can be processed. The demonstrator application of an image sensor proved, that the employment of the FAM process allows for damage-free processing of pixel arrays.

The tool concept developed for the investigations was reliable and functional. Further investigations should focus on equalization of z-axis tolerances to compensate for variations in PCB height and variations in z-direction due to the assembly process. Further results are required to determine the significance of the observed trends, especially for the results of the stress tests.

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