Advancing packaging solutions using 3D capabilities of ceramic multilayers

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Abstract

Semiconductors are running in Moore's beat bringing out impressively small processor, memory, amplifier and sensor chips. However, their packaging is more often the challenge for developers and system designers. The paper describes requirements and solutions for two advancing 3D chip packages.

The first application is a request for a magnetic field sensor in the narrow gap between rotor and stator of electric motors under the influence of temperature, axial and radial load. This LTCC multilayer providing twisted pair wiring and stepped cavities including a lowered bond shelf is 200 microns thin.

The second one is a challenging package for a space component with a 7 layer stepped cavity. It enables multi level wire bonding to the <50µm pitch of the detector chip. Beside the large chip the package is carrying multiple soldered or adhesive bonded chips and passive components, the flex and a robust LGA connector. Further reasons for the choice of LTCC were stiffness, high reliability expectations and thermos- mechanical matching to silicon under space conditions.

1. Introduction

Today’s leading edge in electronics demand more functionality in electronic devices, fast and tiny semiconductors, clever interfaces and economic production. Packaging is unfortunately not one of the first points that users and developers have in mind. Solutions must be smaller, lighter, more complex, operate at higher frequencies and accommodate more components per unit area. Nevertheless, everything has to competitive, rapidly available and flexible for revisions following trends on the market. But these facts are not only a challenge to the circuit designers and the Moore’s law driven chip industry, but also to packaging engineers and electronic materials suppliers.

LTCC- multilayers are known as RF- packages with advanced properties: 3-dimensional functionalities, good RF performance and integration of passives (buried components, waveguides and antenna functions). LTCC as a multilayer interconnection technology enables an increased circuit density. But LTCC-based packaging solutions are also well suitable for system in package integration. System in package integration capabilities, thermal management, temperature resistivity and heterogeneous system integration are the driving forces for the utilization of ceramic substrate technologies in microelectronics. Today LTCC is particularly capable for advanced packages and systems in package because of its electrical, functional, thermo-mechanical properties as well as its excellent long-term stability and reliability. LTCC combines the potential for miniaturization, low loss handling of higher frequencies and offers the opportunity to integrate additional features like passives, fluidics or cavities. Last but not least it is a package for the system with the opportunity of hermetic encapsulation.

Its thermal and mechanical matching to semiconductor materials together with reliability enables this glass ceramics to enter challenging functions in markets like sensors, automotive, medical engineering, oil/gas and avionics or emerging markets like MEMS, Biosensors, MOEMS and others.

Multilayer ceramic substrate technologies are produced in a sequential manner. The geometrical structuring of each single layer - by punching, machining or laser cutting - has to be completed by vertical and horizontal metallization steps –usually screen printing of metal pastes- , followed by stacking, lamination and cofiring. [1] But particularly this sequence is the point that offers exceptional preconditions and variances to build three dimensional carriers for electronic packaging.

2. LTCC technology – particularly features and challenges

2.1. LTCC – a technology for both high volume and niche products

Packaging solutions based on LTCC offer some advantages in comparison to other main packaging materials. They vary from organic multilayers by their higher reliability, from alumina and AlN thickfilm technology by a larger degree of miniaturization, from HTCC by reasons of functionality and availability and from silicon by cost for production run and tooling. LTCC offers superior reliability performance compared to organic technologies. So the high CTE of FRx materials in x/ y which leads to fatigue during thermal cycling and shock is often a reason not to use FRx. Also absorption of humidity, significant ageing and low mechanical strength or parasitics and larger loss tangents motivate people to ask for alternative materials if their applications require better characteristics. On the other hand they are only a fraction of the development cost required for monolithic semiconductor integration.

Speaking about examples LTCC is used for large quantities in automotive industry carrying electronics for gear control and engine management. The car electronics mainly need the thermal stability for COB/SMD assembly and passive integration. LTCC is used in medical applications, e.g. pacemakers or hearing aids. This medical units primary require the extreme design life in consequence of noble conductor metals and inorganic insulation.

Further fields of high-volume LTCC- applications are high-frequency assemblies - antennas, mobile components, transmit/receive modules, radio frequency filters, couplers and phase shifters. They use the excellent RF properties of ceramics.

But there are also applications for highly specialized niche products that combine usually many of the advantages of LTCC. Particularly the opportunity to create vertically structured carriers and leak tight sealings are extra features for these nonstandard areas of operation. Passive functions like resistive, capacitive and inductive elements can be integrated in a limited manner as well as fluidic structures such as channels, chambers and membranes. These features are suitable for sensing or acoustic functions, thermal coupling or decoupling. 3D enables also sophisticated stepped cutouts and cavities that allow pretty clever wire bonding of and between chips, allow specific styles of wire bonding, e.g. impedance controlled or just the shortest possible loop height or wire length. LTCC facilitates special routing like strip lines, waveguides or vertical shielding fences. Covering many of such special needs makes the multilayer ceramic technology unique and opens doors to enter these “specialties” of electronic microsystems. [2]

Some fancy applications use channels and hollow spaces as micro reactors, to apply chemicals to electrophoretic electrodes or for liquid cooling of hot spots in high power multi chip modules, both alongside the main task to serve as complex electronic packages. [3]

Additionally many of these applications require for small and medium volumes, high specialization and frequent adoptions to new functionalities. So NRE cost should be reasonable and amortization of high cost for full automation over years is less important than high flexibility, customization and most specific matching to the particular request. The high potential of integration and combination of functional properties makes LTCC to the core technology of module integration. Many active and passive components can be integrated and assembled into a multilayer subsystem with 10 to 15 or even more layers. They may contain integrated passives such as capacitors, inductors and impedance controlled transmission lines as well as additional surface mounted devices. Last but not least LTCC enables hermetic packaging, both locally or for the complete system as well as specialized electrical and other interfaces.

Other advantages of LTCC in highly specialized products are the good thermal conductivity compared to organic base materials e.g. Teflon and FR4, the resistance against thermal shock and a good matching of the thermal coefficient of expansion compared to usual chip materials like Silicon, SiGe, GaAs or Quartz. This enables numerous assembly opportunities including flip chip and micro-ball-bumping based chip-scale-packaging techniques.

Summing up one can say that LTCC is a technology platform for high volume production in major international groups as well as for small volume production of highly specialized products in mostly small and medium-sized companies.

2.1. Particular Challenges of LTCC package manufacturing

The challenge of manufacturing high quality LTCC package applications is the combination of highly dense structures, small vias, catch pads and clearances around them, high demand for extreme alignment accuracies in the stack, tiny bonding pads on stepped ceramic layers closely besides chip pockets and all this with the lowest possible electrical and dimensional tolerances.

The behavior of the laminated green ceramic stack under refiring conditions has to be investigated and firing conditions must be adapted to the specific situation, especially for laminates with large cavities / channels, unfavorable distribution over the substrate surface or high numbers of them. This is a complicated situation for the manufacturer. Through the use of very special tools and technologies the lateral shrinkage tolerances after sintering have to be reduced to less than +/- 0.1% maintaining very low substrate warpage at the same time.

Feasible accuracies depend highly on the specific situation. There are influences of the layout, e.g. type and number of dielectric layers, metallization material, covering ratio, density of via perforation and lateral metallization patterns, eventual cavities, cutouts or precuttings. Additionally all manufacturing steps have an impact on later characteristics, such as the sintering profile and the uniaxial or isostatic lamination.

Particularly these advanced packages combine several features with unfavorable impact on even and homogeneous shrinkage. Ceramic densification during cofiring follows radial, not orthogonal forces, while chip pockets and multiple patterns are expected square. The right choice of technological features, their fine tuning and the best fitting work flow is essential for a package that fulfils extreme expectations in terms of functionality, miniaturization and precision in details.

3. Applications

The examples described in the following chapters stand for highly specialized applications that use LTCC as the base material from a few different reasons. In both cases it was from our point of view the best decision in comparison to other technologies or packaging materials.

3.1. Application 1 – Thin sensor package

3.1.1. Technical Description

Due to proceeding miniaturization for geometrical scaling of electronic circuits new areas for sensor application become available. One example for such a sensor application is the integration of a magnetic field sensor into the motor of an e.g. artificial knee. The increased effectiveness that can be achieved by measuring the magnetic field inside of the gap between rotor and stator has a direct influence on patient's health-related quality of life. More in detail the application wants to detect the quantity and changes in polarity of magnetic field in radial and tangential direction. Nevertheless, the integration has to be done in a way that functionality of the motor is kept. That is why the available space is limited in width and height.

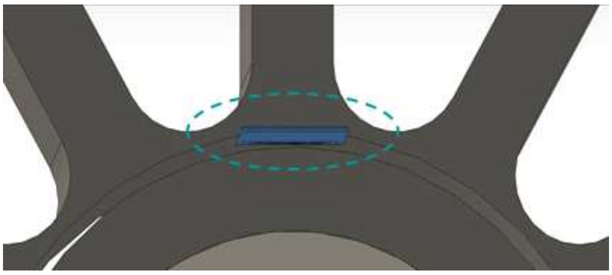

Figure 1: Rough sketch of mounting location

Especially the height must not exceed 220 microns. The whole package has to be capable to handle occurring vibrations and has to have enough stability to protect the embedded silicon die. Also electromagnetic noise on the circuit path due to external magnetic fields should be minimized.

Advantages of using LTCC as package material for this application is the possibility to integrate a twisted pair solution for circuit paths to eliminate interfering signals. Furthermore, a cavity to assemble and interconnect the sensor die, enables the possibility to use more or less standard technologies for interconnection and assembly. The ceramic base material and the gold and silver conductors withstand the hot air environment inside the stator block without problems for years. Last but not least the bottom of the cavity is suitable to protect the thinned bare die with a thickness of 40 microns against mechanical stress.

3.1.2. LTCC-substrate

This application requires a very thin ceramic board. The basic material system of that package is DuPont 951. Usually this material is used in thicknesses of approximately 90µm, 135µm and 200µm. But for special applications like buried capacitors or insulating layer on top on substrate surface a 50µm (fired thickness 40µm) raw tape is also available. This tape was chosen to build a board with a sintered thickness of ca. 210 µm. The sensor chip has to be placed into a cavity to achieve the required overall height. The thickness of the chip is 40 µm and the thickness of the cavity floor is only 80 µm. Five layers of tape with fired thickness of 40µm are used to fabricate that thin structure. The cavity is a laser- structured geometry in three of those five layers. A gold system is used for screen-printed metallization. Three inner layers are structured in a cofire thick film process to accomplish the bonding pads for chip and connection lines which are done partly as twisted pair. Soldering pads are made on top side using a postfire process. Stacking of that thin LTCC sheets requires a special equipment to handle the thin tapes.

The lamination process is a sequential process using both uniaxial and isostatic lamination. It has to be taken care for the shape of the cavities because lamination pressure values of more than 100bar is applied. An improper set-up of the stack or insufficient fixing may lead to deformations, cracks or incomplete lamination. This would cause defects in the following cofiring process. Special challenges are also the very thin raw tape compared to the dried thick film paste. The 50µm raw material of each layer has to assimilate additional 10 to 15µm of dried metal paste by its thermo-plastic behavior in the lamination process.

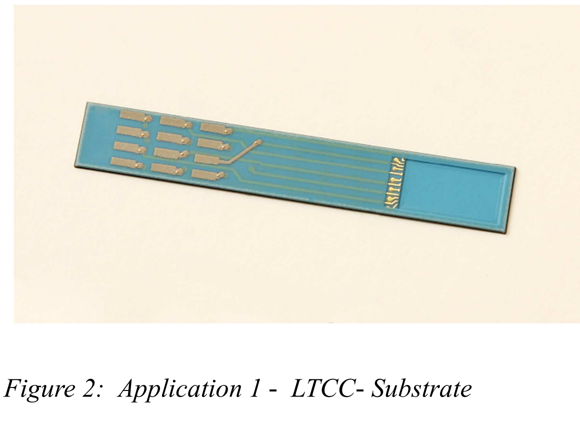

Figure 2: Application 1 - LTCC- Substrate

3.1.3. Assembly and packaging

For die attach an insulated epoxy based adhesive is used. To achieve a thin and areal amount of adhesive beneath the silicon die the adhesive can be applied with a stamp. Pick and place of the thinned dies is done with special tools. The tools are designed in a way that mechanical stress during pick and place is kept very low. Automated image recognition of the cavity for die placement is realized with transmitted light.

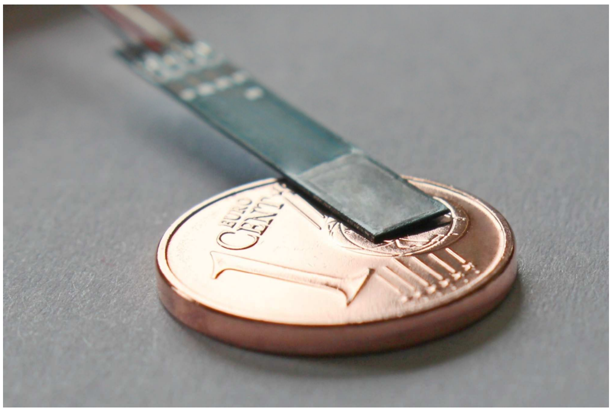

Figure 3: Sensor vs. Cent

Wire bonding is done with ultrasonic wedge-wedge technology and a 25µm diameter bonding wire out of AlSi1 alloy. To achieve very flat wires the clamp of the wire-bonder, that fixate the wire, stays opened while loop is forming. The connector cable is soldered to the solder pads. These cables have a thin diameter to avoid mechanical stress on the sensor package in operation. For encapsulation a material with low viscosity (below 1500 cPs) is used. For all chip on board processes fixation is done with suction to avoid damage due to mechanical stress.

3.2. Application 2 – Radiation Sensor Package

3.2.1. Technical Description

Another interesting application is an electronic unit for special space application. All assembly materials and components had to be selected generally concerning high vacuum stability and low outgassing level. A construction of stacked sensor element and electronic unit, which are placed in a sealed box, should be done.

Principal electrical function of described electronic unit is the processing of 128 signals of a special sensor element. DAC and communications complete the functionality.

Main component is a silicon chip with dimensions of 5.4 x 6.1mm, which has to be complemented with additional components like amplifiers, capacitors and resistors.

3.2.2. LTCC-substrate

This LTCC substrate application is a challenging package made of 10 layers. This package is also made with the DuPont 951 tape material and gold system for metallization. Main reason for design and manufacture these comparatively large numbers of layers are the requirements of the detector chip. It is a special design for space applications and has among other things 140 bonding pads in four rows with an effective pitch of 40 µm on the most challenging edge of the chip. Therefore a design with staggered bond pads in a 7 layer cavity is used. The bonding pads made of cofire gold are distributed on 6 shelves.

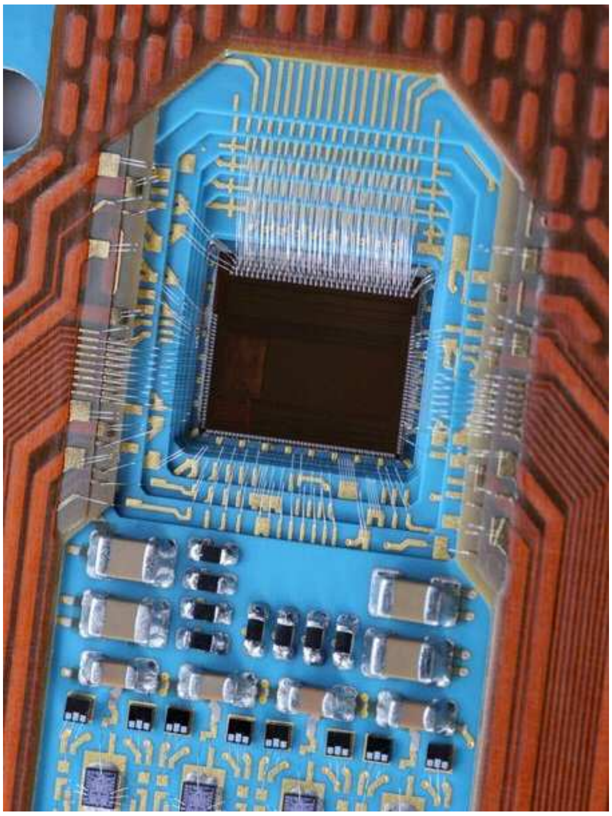

Figure 4: Application 2 – sensor chip - placed in LTCC cavity

This allows a pad pitch from 220µm to locally 300µm on each shelf to achieve the same effective pitch on chip level. The cavity is made by laser structuring of single tapes. It is laminated using an isostatic process to support the cavity geometry and the bottom evenness. A flat cavity floor is not only necessary for the chip assembly but also for the LGA style connector on the back of the package. On the topmost layer SMD pads and additional bond areas are printed to assemble passive components by soldering and chips as well as a large multilayer flex connector by wire bonding. Finally the package is equipped with mechanical fiducials for the alignment of the package to its connectors and the external housing.

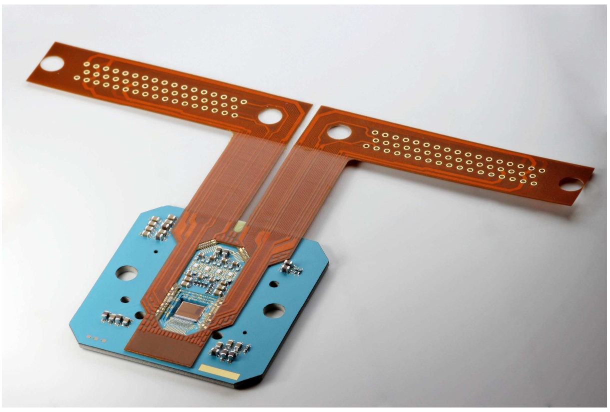

Figure 5: Application 2 – general view

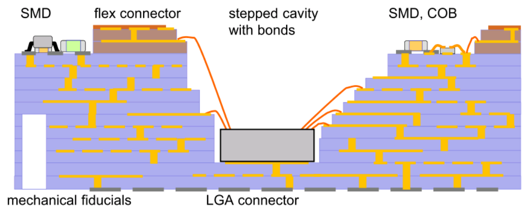

Figure 6: Application 2 – cross section

3.2.3. Assembly and packaging

The die has to be connected both to the sensor element and also to the controlling unit of the instrument with more than 240 lines. So the die has 248 bond pads with dimension of 95µm x 95µm, whereof 138 pads of the input signals were placed with an effective pitch of about 40µm (strung in 4 staggered rows). The others come with a pitch of 115µm. Wire bonding is required for connection of chip to the substrate. Wedge-wedge-bonding of Al wire with diameter of 17.5µm is selected. The low diameter reduces interconnection between input lines and the Al material prevents additional thermal processing.

The construction was completed by an additional flex-rigid multilayer printed board to connect the electronic unit to the controlling unit of the instrument. Therefor a special single sided multilayer design allows wire bonds in 2 additional bonding layers.

4. Conclusions

Many weaknesses of organic PCBs as well as ceramic thick film technology both on alumina or aluminum-nitride can be overcome with LTCC.

Ceramics are well known for use in harsh environment such as in automotive, long life outdoor, deep- hole drilling, aerospace or industrial sensors with advanced reliability conditions. The main advantages of LTCC compared to the other ceramic technologies are better opportunities for miniaturization, but most important the possibility to structure them three dimensionally. These options help LTCC to open doors into application in harsh environments under the need for miniaturization, hermeticity and very flexible metallizations for several packaging techniques.

The applications shown in the paper are examples for packages, where no competing technology would have potential to achieve the same grade of functionality, reliability and performance under comparable cost, explicitly relating to small and medium numbers of units. The combination of multilayer ceramics processed in a special manner and completed by an individual packaging technology leads to successful solution for these applications.

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