DEVELOPMENT OF POWER KEYS MICRO-ASSEMBLY

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ABSTRACT

The article describes the results of developing a power keys micro-assembly based on the specialized technology of three-dimensional integration obtained by SMC "Technological Center". The applied technology of partitioning the device into stacks and a typical series of technological operations is described. The article also shows the comparison of the technology used with the perspective 3D SIP technology. A constructive-circuit solution for micro-assembly is described that includes the use of the specialized control integrated circuits and galvanically isolated semiconductor power transistors. The test bench for electrical characteristics measurements is considered which provides the automatic test and control of the created samples to detect defects during manufacture.

Key words: 3D SIP, micro-assembly, power electronics, power keys, sealing.

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1. INTRODUCTION

Nowadays the traditional planar technology based on individual crystals or electronic components placement on printed circuit boards (PCBs) remains the most commonly used. Due to this the finished electronic products have significant dimensions. The technology of three-dimensional integration is practically not used and is in the initial stage of its development. This is especially true in the area of power electronics, where the implementation of elements dense arrangement and dimensions reduction of the product is associated with obvious problems. They are the size of the electronic components, the problems of heat removal, the limited choice of materials. For such applications as aero and space technology, the task of miniaturization solved without losing the necessary reliability level remains extremely urgent.

Modern production of electronic equipment as a whole is characterized by tendencies towards miniaturization and increase in the density of functional elements [1]. The tasks of miniaturization, density increasing and functionality widening of power electronics elements are solved due to the use of modern technologies for semiconductor devices manufacturing,
installation and casing technologies, and also through the development and use of new materials.

2. THREE-DIMENSIONAL INTEGRATION

Under this research project it is proposed to develop a miniature micro-assembly of power keys using the advanced technology of three-dimensional volumetric integration, which was developed at the SMC “Technological Center”.

The proposed technology is based on partitioning the device into separate technological substrates for the purpose of their stacking and subsequent sealing with a compound to ensure the mechanical strength of the micro-assembly. The main idea of the technology is to create interlayer connection on the lateral surface of the micro-assembly by covering the micro-assembly with conductive metal and then forming a topological pattern. The device assembled for this technology has smaller dimensions, as well as higher protection against external influences of various types such as vibrations, impacts, moisture, friction, chemically active substances, pollution, explosion protection. When the device is divided into separate technological substrates, it becomes possible to check each functional part of the device separately, which positively affects the yield coefficient of the production process.

This technology is similar to the perspective 3D-SiP (Three-dimensional System-In-A-Package) miniaturization technology. The 3D SIP technology is a set of electronic subsystems packaged into one functional highly integrated system [2-5]. An example of volumetric and multi-crystal packaging using 3D-SiP technology is shown in Figure 1. Such a system contains two or more levels. In the role of these levels are technological substrates, on which various electronic components and chips are mounted. For connecting the subsystems this technology [6] uses BGA solder balls (Ball grid array), thermos-compression welding, flip-chip mounting, Tape automated bonding (TAB), and vertical interconnect pillar (VIP).

![Figure 1 Example of three-dimensional SIP technology](image)

The project for power keys device miniaturization uses the developed technology based on interconnection vertical columns with technological substrates made of conventional PCBs. The technology is based on the use of already known technological processes. The main stages of manufacturing are as follows:

1. Manufacturing the PCBs taking into account the requirements of assembly stack units.
2. Input quality control of stack metal-core PCBs (with metal base).
3. Electronic components surface mounting on PCBs.
4. Programming and testing the functional parts.
5. Assembly of the stacks with the use of specialized rigid frame, designed for filling a multilevel assembly with a molding compound.
6. Molding the micro-assembly with a compound through a specialized rigid frame, polymerization of the compound.
7. Cutting the molded module to the required shape, cleaning and grinding the surface.
8. Surface preparation for metal deposition.
9. Metal deposition of the necessary thickness on the surface of the micro-assembly by the chemical or galvanic technology.
10. Forming on top of a micro-assembly the topology of interlayer commutation.

3. DEVELOPMENT OF POWER KEYS MICRO-ASSEMBLY

Within the work project, a prototype of a multilevel micro-assembly consisting of two technological substrates was developed. 3D micro-assembly has the following technical characteristics: 8 commutated switching power lines up to 100V, parallel digital control interface, operating temperature range from -60 to +125°C, logic voltage 5V.

The composition of the power keys micro-assemblies includes: control integrated circuits (CIC), semiconductor power transistors, miniature transformers, temperature sensors, radiators. The structure of the micro-assembly [8] of power keys is shown in Figure 2.

![Figure 2 Internal structure of power keys micro-assembly](image)

In the micro-assembly design power transistors are located on the lower technological substrate, and a control circuit is located on the upper level. The space between the boards and the entire micro assembly is hermetically molded with an insulating heat-conducting compound, which provides the mechanical strength of the assembled structure, its final shape. Also it is used as a working surface to form conductors topology of the micro-assembly lavers interconnects. To ensure the effective heat dissipation, the micro-assembly is installed on the metal base with a heat-conducting paste.

The design and circuit solution for power key micro-assembly offers the use of MOS transistors and an additional circuit that improves the reliability of the system. Usually, the power switch is implemented on the MOSFET switch with various switching circuits, depending on the practical application. The weakest point of such a control scheme is the exclusion of false triggering when power is applied to the microcontroller or VLSI, since the control outputs of the ports are in an uncertain state at the moment of supply voltage increase. Since the speed of MOS keys is tens of nanoseconds, and the start time of the microcontroller program can reach several microseconds, there is a high probability of false triggering that exclude the use of this circuitry or require additional circuitry solutions (for example, "tightening" the control inputs to zero potential), which increase consumption of the circuit or increase the switching time of the keys.

Figure 3 shows a scheme for implementing a more reliable power key, from the point of view of false triggering. The use of a transformer for galvanic isolation and as a control...
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voltage on the key makes it possible to build up this chain to the required number of links, which, however, multiplies the resistance of the channel and, accordingly, the power allocated to the switches.

![Figure 3 High reliability power key schematic](image)

The principle thing here is the possibility of generating an EMF in the secondary winding of a transformer sufficient to open the MOSFET switch. In this case, it is not necessary to power up the module itself, thereby reducing the number of terminals to two. The control principle also changes as the control becomes dynamic, which eliminates false triggering and "sticking" in case of any control circuit failures. The control frequency can be increased to several megahertz, which will reduce the size of the transformer to the lowest possible. The key scheme shown in Figure 3 uses a half-wave rectifier for static control of the transistor. If a pulse mode of keys operation is required, the capacitor can be used.

The technological substrate which contains the control scheme the specialized CICs is used. CICs are designed to generate key control signals in accordance with the galvanic decoupling time diagram and the logic for generating the output channel switching sequence. The control command is recorded by supplying an information word to the inputs of the microcircuit. After recording the command at the corresponding CIC outputs a frequency grid is formed which is necessary to create current pulses in the primary windings of the transformers. In this case, in the secondary windings, an EMF is induced, which is necessary to create a gate voltage on the gates of the corresponding keys. Windings are connected so that the half-periods of the frequency grid come in antiphase and fold on the diode rectifier, forming a constant voltage with a low level of ripple.

The micro-assembly consists of two technological substrates: the control board (Figure 4) and the power keys board (Figure 5). The photo of the produced power keys micro-assembly is shown in Figure 6.

To ensure effective heat removal, a prototype of power keys micro-assembly has a metal base - a radiator. The micro assembly is designed for direct mounting on the PCB to the control unit, by means of lateral fastenings and subsequent soldering of the pin terminals. The power output on power transistors is an important factor affecting both the reliability of the product and its design. Moreover, the power drain can impose certain limitations on the technologies used in the assembly manufacture.

To solve the problem of effective heat sink in a three-dimensional assembly, a multilayer PCB manufactured with a metal base is used (metal core PCB). It is also recommended to use
methods for increasing the efficiency of the heat sink through the use of "via-in-pad" technologies and "filling-via" [9-10] - the technology of filled holes. This technology allows additional removal of heat from the 3D micro-assembly [11].

Figure 4 Control board for micro-assembly test samples

Figure 5 Power keys board for micro-assembly test samples

Figure 6 Produced power keys micro-assembly
4. INVESTIGATION OF MICRO-ASSEMBLY CHARACTERISTICS

After all technological operations for the manufacture of power key micro-assembly, electrical parameters verification is required: power supply voltage, open key resistance, current consumption, leakage current at the output, input current of low and high levels, delay time for power channels switching on and off. Laboratory studies of such a micro-assembly include sequential switching of different channels for different types of load, as well as simultaneous measurement of all electrical parameters. These laboratory tests can take a very long time. Because of this it was decided to create an automated test bench for electrical characteristics verification.

Within the work project, an automated test bench was developed to study the electrical characteristics of 3D micro-assembly. It includes control and measurement equipment which is a programmable power source, a programmable electronic load, a controlled switching unit, an instrumental computer, special measuring equipment and a heat and cold chamber. To manage the components of the test bench, specialized software was developed in the LabVIEW environment, which is installed on the instrumental computer as a part of the test bench. The developed software works with instrumentation equipment through the GPIB interface, USB, RS232. To simulate the various modes of micro-assembly, the test bench uses an electronic programmable load. Electronic programmable load provides the simulation of various operation modes: direct current mode, constant voltage, constant resistance, constant power, dynamic mode. Special measuring equipment switches switching inputs and outputs of power keys micro-assembly, as well as their connection to the programmable power supply and programmable electronic load. In the developed test bench a 4-wire circuit is used for measuring resistance less than 100 ohms. It allows measuring resistance with error less than obtained while using a 2-wire circuit. When measuring resistance by this method, one pair of conductors serves to create a current flow path of excitation current, and the other pair is used to remove the voltage from the resistance being investigated.

Laboratory studies of the manufactured micro-assembly at different temperatures were performed in accordance with Russian legislation. Experimental studies were carried out to check the ability of samples to remain operational after exposure to the high and lower ambient temperature values. The experiment was carried out in two hot and cold chambers, each of which provided a test mode with minimal deviations. The influencing factors in the experiment were maximum and minimum ambient temperature of +125°C and 60 °C respectively.

The developed automated test bench for verification the electrical characteristics of micro-assemblies allows test and control of created samples for defects detection during manufacturing. Automation of the process of electrical characteristics measurements made it possible to significantly reduce the time for laboratory tests of prototypes of highly integrated 3D power keys micro-assemblies.

5. CONCLUSIONS

The developed by SMC "Technological Center" technology of three-dimensional integration of electronics allows producing the miniature 3D modules. The use of existing technologies operations in some stages of manufacture process, leads to higher reliability level and yield production coefficient increase. The manufacturing process does not require the use of specific materials or unique expensive equipment.

With the help of this technology, a miniature micro-assembly of power keys was made, which results in final device dimensions shrinkage by factor of 2.
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