

Development and Application of SiP Technology

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Abstract

Electronic products tend to be of smaller size, lighter weight, higher performance, while maintaining multiple functions, high reliability and low cost. In the last several years, MCM and SoC played important roles in the development of microelectronics. Today, SiP technology excels at design flexibility, high reliability and lower manufacturing cost, and it is attracting much attention in microelectronic field and becoming an ideal package solution as substitute for MCM and SoC.

This paper presents definition and features of SiP and compares it with SoC. In addition, we have also discussed its key technology issues and typical applications.

key words: System in Package technology application

1 Introduction

In recent years, semiconductor technology has developed following Moore's Law, producing finer lines and higher integration. As a result, IC can integrate more transistors and functional units, and this trend brings about the concept of SoC (System on Chip), which refers to integrate multiple ICs into a single chip to functionalize as a complete system or subsystem. Being limited by semiconductor process, SoC meets a series of unprecedented challenges from initial design to final test. Therefore, various rather new solutions are put forward in microelectronic field, in the hope of avoiding the difficulties of SoC and meanwhile realizing the same objectives and functions. In such background, SiP comes into being. SiP combines advanced technologies of IC, assembly, package and test, integrating IC chips, passive components and other functional elements into a single package structure to form a complete system or subsystem. SiP technology meets microelectronic products' requirements for miniaturization, high performance and low

cost and makes up SoC's defects. So, it is becoming the focus technology in the competing field of microelectronics.

2 Definition and features of SiP

SiP is characterized by any combination of more than one active electronic component of different functionally plus optionally passives and other devices like MENS or optical components assembled preferred into a single standard package that provides multiple functionals associated with a system or subsystem.

The concept of SiP has some similarities with MCM and MCP, but with more emphasis on the system integration. Compared with other integration or package technologies, SiP features in the following aspects:

SiP can integrate multiple packages into a single one, thereby significantly reducing its volume and weight, decreasing the number of I/O, shortening the interconnection of components and improving the performance of signal transmission.

SiP can integrate functional chips of

different process types, such as analog die, digital die and RF die, easy to realize the integration of mixed signals in an individual package structure.

SiP decreases package levels and processes, resulting in reduction of manufacturing cost and improvement of product reliability.

SiP product has a shorter developing cycle and better time to market.

3 SiP and SoC

SiP and SoC are two parallel technologies of system integration, in accordance with electronic products developing trend of miniaturization, light weight, high performance, multi-function and high reliability.

SoC concept was firstly initiated in 1990s, which integrated different functions like MPU, image processing, storing, logical inferring, DSP, signal mixing, RF and peripheral functions in an individual silicon chip to perform all functions of microelectronic end products. By using multiple aspects of Intelligence Patents (IP), SoC combines complex systems or subsystems into a single chip, having improved system performance and reduced cost of each functional unit. So it has a bright prospect of application and development.

SoC technology involves design tools, IP and its reusing, IP interconnection, programmable system chips, core chip developing and application, system design and manufacturing process, etc. SoC developed rapidly in the last decade, but it met many challenges and obstacles. Its design challenge lies in the reusability and interconnection of IP core, which is the design basis of SoC system. In addition, the manufacturing processes of analog, digital and RF functional units are not all the same, so it demands a universal semiconductor process with high feasibility to integrate all these different functions into a system. However, this puts forward a big challenge for worldwide semiconductor manufactures limited by the process complexity and cost factor. Up to now, there is still no ideal solution.

SiP has been developed on the basis of MCM, MCP and FCP for more than ten years. By altering integration technology, SiP can integrate various devices into a single electronic package structure, thereby decrease the package levels from 3 to 1 to achieve higher package density, system functionality and performance coupled with lighter weight,

higher reliability and lower cost. In contrast with SoC, SiP not only has no problem of IP, but also can integrate different types of IC chips like SiGe and GaAs. Therefore, SiP has a bigger flexibility of system design and occupies evident advantages in developing cost and time to market.

Strictly speaking, SiP and SoC are complementary rather than competing and they serve different market segments. SoC is targeted for high performance systems with rather long obsolescence cycle and wide market windows. SiP is mainly applied in wireless communications, consumer electronics and customized products, which have relatively harsh requirements for developing cycle and manufacturing cost, and sometimes for integration of mixed signals.

4 Common package structures of SiP

In a general way, SiP has two types of package structures. One type is 2-D package of chip horizontal mounting. And the other type is 3-D package of chip vertical stack.

In the 2-D structure, chips are mounted on a substrate surface side by side, without limitation of chip size. This process is rather simple and sophisticated, while the package area is relatively large and package efficiency is fairly low with the biggest theoretical value of 85%.

3-D package structure refers to stack package evolved on the basis of 2-D MCM technology. Stack package is further divided into stacked die package and stacked module package. The former directly stacks chip on chip, and connect them by wire bonding or flip chip. The latter vertically stacks multilayer substrates assembled with devices and components by means of spacer technology.

The efficiency of stack package can be up to 200%, exhibiting the advantages of SiP technology to the utmost extent. In this sense, stack package is the most efficient approach of system integration and represents the main trend of future SiP technology.

5 Critical technologies of SiP

SiP is a comprehensive technology of microelectronics, involving knowledge and approach of multiple subjects. Its critical technological issues include system design, materials of interconnecting substrate, integration of passive components and 3-D stacking package and so on.

5.1 System design technology

SiP is a newly developed technology of integration and package. The common EDA design software is targeted for a certain type of technology, either digital circuit or analog circuit, and it can not meet SiP design needs sufficiently. SiP design usually faces a series of new challenges like the absence of integrating tools and approaches, the obstacle of integrating IC, package and board, and the difficulty in simulating, verifying and analyzing the whole SiP design.

Currently, Cadence Company has developed the industry's first complete set of EDA design tools for SiP products, offering a whole set of automatic, integral and reliable SiP design flows and approaches, which overcomes the limitation of former design modes of over reliance on personal experience. This new set of design tools includes Cadence Radio Frequency SiP Methodology Kit, Cadence SiP RF framework, Cadence SiP RF format, Cadence SiP digital structure, Cadence SiP digital signal integrity and Cadence SiP digital format. This set of design tools can be used with Cadence's main design platforms with full compatibility, such as designing bare chips with Encounter, developing RF module with Cadence Virtuoso, and designing package and board with Cadence Allegro. By combining IC design and package technology elastically, it can help SiP manufacturers develop high-integrated products with great improvements in cost, size and performance.

Thermal design is an essential part in system design, for half of the packaged products failures are caused by thermal failure. In the process of SiP design, system power dissipation caused temperature distribution curve and thermal conducting process need to be simulated first. Then by simulated data, we predict the thermal conduction characteristics of devices, analyze its impact on the system, and study the corresponding dealing methods. For example, for a chip stack packaged SiP containing multiple LSIs, its chips upper and lower have different power consumption, but the operating temperature they withstand are very similar. In this case, thermal design must be made prudently, better to place the chips with higher power consumption into the lower layer for the purpose of improving heat dissipation of the whole SiP product.

5.2 Substrate material of SiP

Interconnecting substrate is an indispensable part of SiP products, which not only offers mechanical support and electrical interconnection, but also has the capacity of embedding passive elements and improving system integrity. Currently, the commonly used substrates in SiP are LTCC multilayer substrate and PCB, both of which have high wiring layers and wiring density, applicable for high density integration of various types of devices and components.

LTCC multilayer substrate combines various benefits including high-density multilayer interconnection, embedding passive components and hermetic ceramic package, with added benefits of high performance in microwave for hybrid design of high and low frequency, digital and analog signal. So it has unique advantages in applications of aviation, space, radar, wireless communications, automobile electronics, optoelectronics and MENS. At present, LTCC substrate of high frequency and low loss has already become preferential option for many manufacturers engaged in research and production of RF SiP products. Such commercial products mainly include A6 green tape serial products of Ferro Company and 943 green tape series of DuPont Company.

From the point of cost reduction, PCB are likely to become the mainstream substrate material of SiP products. The latest research focuses on the macromolecular PCB materials of high performance, particularly on the property optimization of dielectric constant, loss and thermal expansion coefficient.

5.3 Passive components integration

For a typical microelectronic product, passive components makes up its 80%, covering a half of the surface area of its substrate, while pads covering a quarter of the substrate. In this sense, passive components play a significant role in system cost, size and reliability. So effective integration of passive components of a SiP product can greatly reduce size, shorten conduction pass, lower parasitic effect, reduce manufacturing cost and improve system reliability.

In a SiP product, integration of passive components can take three forms: discrete format, integral format and embedding format. Discrete format directly assemblies packaged components in the whole system with the lowest level of integration and very sophisticated process. Integral format assemblies passive element arrays/ networks

like resistor network, RC, LC or RLC circuits and others. Embedding integration directly manufactures passive elements inside multilayer substrate, with the shortest interconnection and the highest package efficiency.

Embedding integration format has bright developing prospect and has become the preference of many SiP manufacturers. CTS Company had developed a high density integrated SiP module for cell phone front through LTCC process, which embeds passive components including a doubler, a low-pass filter, a SAM filter and a transforming switch within a LTCC multilayer substrate.

5.4 3-D stacking package

3-D stack package consists of stacked die package and stacked module package.

Stacked die package refers to stacking a bare die directly on another bare die, then achieving electrical connection and package. This approach can integrate circuits of different types and improve packaging efficiency, for it realizes the shortest interconnection without increasing package size. The first step is thinning the patterned semiconductor wafer and dicing it into bare chips. The second step is adhering these bare chips in certain order, and interconnecting them by wire bonding or flip chip for the bottom chips. The last step is assembling these stacked chips to form an integral system.

Chip thinning has the merits of improving heat dissipation efficiency, improving mechanical properties and electrical performance, and reducing package size and working amount of dicing. For the wafer back thinning, the widely used methods include ultra precise grinding, milling, polishing and etching. The current thinning level for wafer of $\phi 200\text{mm}$ is $0.2\sim 0.5\text{mm}$. For such thinning level of $\phi 300\text{mm}$ wafer, it still needs chemical-mechanical polishing, plasma etching, dicing and milling. With the advance of processing technique, future wafer thinning is expected to be less than 0.05mm .

Interconnection of stacked chips is generally achieved by peripheral interconnection, firstly leading the pins to the edge of the chip, leaving pads during stack adhering, and then realizing interconnection by wire bonding. Nowadays, some SiP manufacturers are studying an ion etching via process, directly reaching electrical interconnection of stacked chips through wafer vias. This process is predicted to

achieve high density interconnection of more than 1×10^4 joints/ cm^2 .

Stacked die package is a fast developed SiP technology with a constant increasing rate of more than 10% in recent years. It has developed from stacking multiple storage chips at beginning stage to stacking different types of chips in a single package, extending to various stack types like digital signal processor with SRAM and flash memory, ASIC with memory, and digital with analog and RF microcontroller. With these improvements, SiP technology has occupied a huge market with applications in cell phones, digital cameras, notebooks and intelligent cards.

A complex electronic system not only contains active chips, but also needs a great amount of peripheral passive components. Correspondingly, stacked module package is an ideal solution for such complex system integration. This solution firstly divides the system into several functional sections, making them respective 2-D circuit modules by LTCC or others, and then stacks these modules vertically by BGA welding with the help of spacers, which not only provide mechanical support, but also establish electrical interconnection of these 2-D modules through metal vias. In this way, a complete functional system of SiP product is realized. In addition, packaging efficiency of SiP product can be further improved by integrating passive components such as resistors, capacitors and inductors inside LTCC multilayer substrate.

6 Applications of SiP

The developing demand of electronic product market and the emergence of new material and new process are driving SiP technology develop and progress constantly. Now, SiP has been widely used in wireless communications including cell phones, bluetooth, WLAN, network, automobile electronics and customer electronics. Although SiP technology has not occupied a very big share in such fields, it has become the fastest developed technology. In 2004, 1.89 billion pieces SiP products were assembled and manufactured worldwide. This number is predicted to increase to 3.25 billion in 2008, with the average annual growth rate of 12%. The output value of SiP products in 2007 is estimated to be \$ 8 billion. The market share of its typical products are as following: cell phones hold a share of 35%,

followed by digital electronics of 14%, then WLAN/Bluetooth 12%, power supply 12%, automobile electronics 9%, image/display 6%, optoelectronics 6% and others 6%.

A common view of this industry is that a complete integrated system is hardly to achieve within a single chip, although there have been some progress in the research of integrating RF and mixed signals in a single chip by CMOS process. The first reason is that a system inevitably needs many peripheral elements including the matching inductors, antenna switches, power amplifiers, balanced/non-balanced converters and RF bandpass filters. The second reason lies in signal crosstalk when integrating analog/RF circuit with digital circuit. It demands isolation between signal and noise, increasing the chip size and demanding for additional process, unavoidably causing higher manufacturing cost. The last challenge comes from the integration of DRAM and logic circuit, which are made by totally different semiconductor processes. Consequently, additional manufacturing process is needed and cost is increased.

In contrast, SiP is an ideal solution for integrating RF signal and mixed signal. SiP technology not only is capable of integrate analog/RF signal, digital signal with storage chips, but also can embed passive elements of high performance like resistors, capacitors and inductors within substrate. Moreover, SiP can integrate nearly all the peripheral components, including balanced/non-balanced transformer, filter and antenna.

Automobile electronic system puts a developing challenge for SiP technology, for its operating environment is very harsh, which is different from customer electronics. Concretely speaking, the electronic system in engine and transforming devices must withstand operating temperature of higher than 125°C, accelerated gravity of 30G and random vibration of 10G, with the additional requirement for more than 10 years of life.

Up to now, SiP technology has been used widely in automobile electronics, such as Engine Control Unit (ECU), antilock brake system (ABS), fuel jetting control system, gasbag electronic system, steering wheel control system, tyre low-pressure alarming system and so on. SiP technology is also successfully applied in fast growing vehicle office system and entertainment system.

Medical electronics attach great importance to products' reliability, size, function and

life, and are always in pursuit of more functions and better performance within more compact structure. In this field, the typical applications of SiP are mainly embeddable medical devices such as cardiac pacemaker, heart shake remover, infusion pipe and audiphone.

By definition, shake remover can stop heart fiber shaking and make heart beat at a normal rate again. Its working principle is generating high-voltage pulse to shock heart when heart beats fast constantly or its electronic pulse comes into disorder.

Cardiac pacemaker is also a successful application of SiP. Essentially, it is a pulse generator to provide additional electronic pulse in the case of heart beats too slowly even stops beating.

Consumer electronics are the leading products of SiP, with typical examples of digital camera, digital camcorder, notebook computer, PDA, palm game player, MP3, MP4 and various sorts of entertaining toys.

SiP is also an ideal package solution for image sensors, which are core elements of digital cameras, scanners, video camcorders, and electronic toys and include a series of different types of devices such as CCD, COMS, touching image sensors, electron carrier component, optical diode array and non-silicon sensors. The working principle of image sensor is optoelectronic transformation, transforming optical signals into digital signals, and then performing the functions of image dealing, showing and storage.

SiP technology conforms to military applications, which are featured with high performance, miniaturization, multiple sorts and low volume. Therefore, SiP has great developing potential in military field, with various appliances like satellites, launch vehicles, aircrafts, missiles, radars and super computers. The most typical products are T/R modules for active phased array radars.

7 Conclusion

SiP is an advanced system integration and packaging technology, which has its unique merits not shared by other package approaches. It meets the lighter, smaller and thinner developing trend of electronic products, so it has wide applications and bright prospect in the field of microelectronics. However, SiP design meets more challenges than SoC design, for it involves both electrical design and mechanical design. SiP calls for more and more excellent design softwares to

yield more competitive products. Moreover, SiP technology is looking forward to a comprehensive industrial chain to smooth the purchasing channels of KGD, new materials and new test means. Lastly, there is still no international standard of SiP technology, which obstructs the popularity and application

of it.

To conclude, SiP technology still faces a series of challenges and difficulties. Its future development relies on close cooperation and joint efforts of manufacturers of software, IC, package, material and equipment.

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