Development of Printed Circuit Board Technology Embedding Active and Passive Devices for e-Function Module

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Background

Higher functionality of today's portable devices demands smaller, lighter and thinner electronic components. Looking at the evolution of package miniaturization from the flat structure (System in Package: SiP) -> silicon chip stack structure (Chip on Chip: CoC) -> package stack structure (Package on Package: PoP) -> Si through chip contact structure, the technology has gone from two-dimensional to three-dimensional packaging achieving high density packages. The trends in printed circuit boards and their packaging are shown in **Figure 1**. Among the printed circuit boards, the three-dimensional integrated printed circuit board (hereafter referred to as "embedded component module board") is attracting great attention.

Component embedding enables passive components to be positioned directly beneath the LSI mounted on the surface providing electrical benefits such as shortening of signal wirings between circuits, reduction of damping resistors and elimination of characteristic impedance controls. Embedded component module boards have been adopted for higher functionality of video cameras and miniaturizing wireless communication devices. It is expected the use will spread to a wider range of areas including automotive, consumer products, industrial equipment and infrastructure equipment. To meet these needs, a technology to package and embed the various components and LSI will be required. This article discusses the method of embedding components, soldering technology, production method, reliability and case examples of the embedded component module board.

Integrating components into embedded component module boards

(1) Embedding active components

There are two methods of embedding active components. One is to embed the components in bear

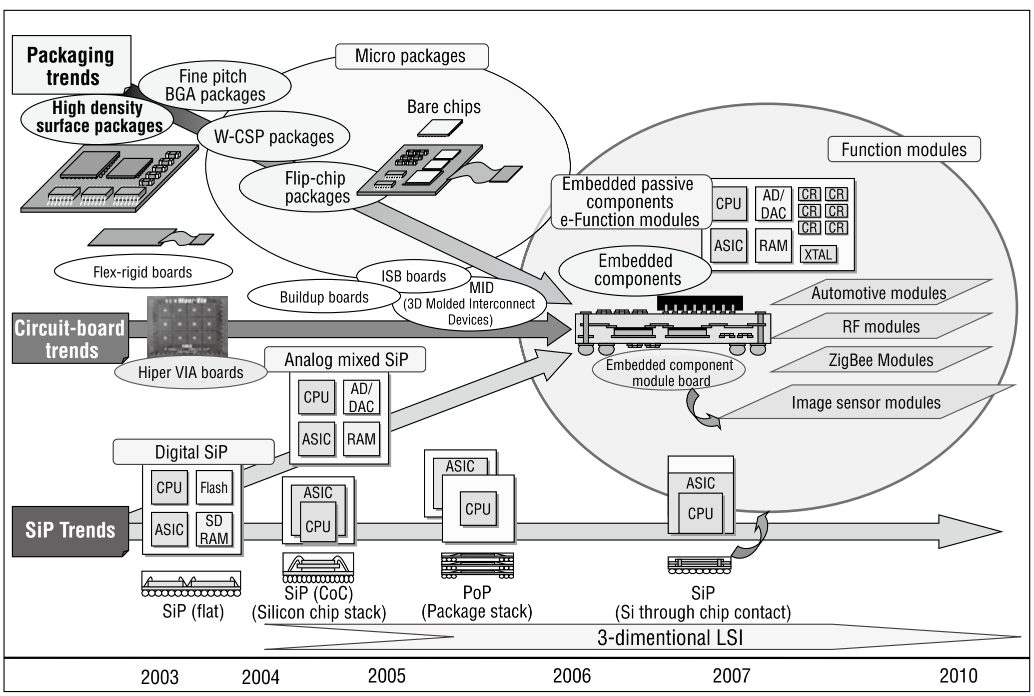

Figure 1. Trends in Printed circuit Boards and Packaging

chip form, and the other is to process components into a package prior to embedding. Considering the stability of quality and yield, we have decided on the latter method utilizing W-CSP (Wafer-Level Chip Size Package). Inspection guarantees the quality of W-CSP, and achieving KGD (Known Good Die) will not be an issue.

(2) Embedding passive components

Passive components (C, R, L) can be embedded either by building them in during the manufacturing process of the board or embedding commercially available chip components. Guaranteeing the properties with the former method is difficult. Additionally, required properties cannot be obtained due to manufacturing constraints. For example, a required capacitance can be achieved by expanding the area of the layered stack or increasing the number of stacked layers, however that would stray from the purpose of miniaturizing and thinning. In comparison, the latter method ensures reliability using general-purpose components that have guaranteed properties and are available commercially. We have chosen to use the latter method.

(3) Sizes of embedded components

Sizes of components that can be embedded are 0402, 0603 and 1005. However, if 0402, 0603 and 1005 are mixed in the same layer, internal board thickness will be the same as when 1005 is implemented. The cross-sectional view of a embedded component module board with 0603 and 1005-sized chips mixed in the same layer is shown in **Figure 2**.

Due to recent increase in product applications, 1005-sized components capable of handling capacitance greater than 1μF are increasingly being implemented.

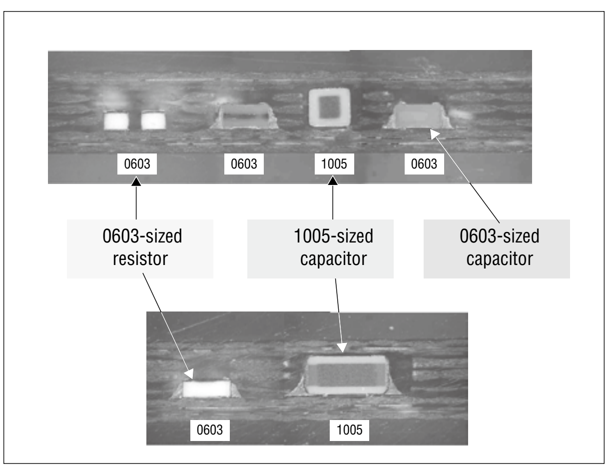

Figure 2. Mixing Chip Components with Different Sizes

Component thickness is an obstacle when it comes achieving thinner devices. Manufacturers are working to develop components that are both large capacity and low profile. Currently it is possible to manufacture 1005-sized components comparable in thickness with 0603-sized components.

Soldering technology for embedded component module boards

In order to simultaneously mount W-CSP and chip components, reflow soldering using lead-free solder was employed. The benefits of this soldering method are given below.

① It is an extension of an existing process and does not require a new facility.
② It can utilize exiting components.
③ LSI and passive components can be mounted simultaneously.

Our component mounting technology was acquired with the cooperation of Nagano OKI. An integrated line consisting of solder printing machine, mounter, reflow oven and inspection machine was built and a production

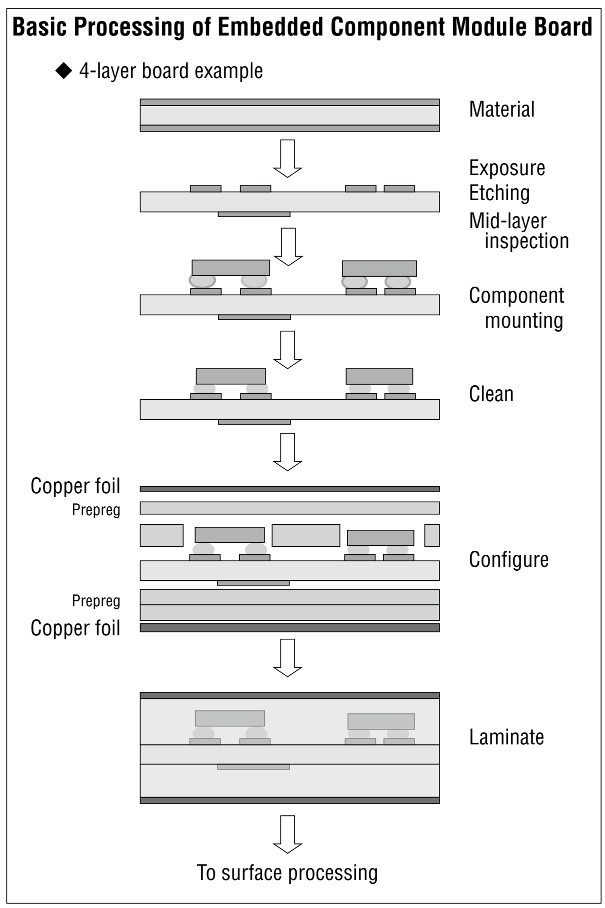

Figure 3. Embedded Component Module Board Manufacturing

system was established (line is capable of processing the same work size as circuit board manufacturing). Mounting density is at the same level as surface mounting.

Manufacturing embedded component module boards

The manufacturing process of embedded component module boards (4-layer board example) is shown in **Figure 3**. Using a photographic method, copper circuits are formed on both sides of a 2-layer board. After solder paste printing, reflow soldering is used to mount components, which is followed by flux residue cleaning. The mounted board is sandwiched and laminated between the prepregs and copper foils then heat bonded. To avoid stress on the components during pressure bonding, the height of the components are taken into consideration when selecting the prepreg thickness. Thereafter, the surface processing is the same as the manufacturing process of a normal printed circuit board.

We offer one-stop service including miniaturization suggestions, circuit board design, board fabrication, component assembly and product inspection based on specification and other information provided by the customer.

Reliability of embedded component module boards

(1) Comparing reliability of surface-mounted and embedded component boards

Result of the temperature cycle test has revealed the embedded W-CSP has more than twice the lifespan of a surface-mounted board 1). The following describes the result of the evaluation.

Using an exclusive TEG (Test Element Group), a board with embedded W-CSP and chip component was manufactured. The embedded W-CSP was 6mm square, 0.5mm pitch and had 112 terminals. The chip component was a 0603-sized resistor. Temperature was cycled -25°C/9min ⇔ room temperature ⇔ 125°C/9min for the evaluation. As a result, the time for the 50% failure rate to occur from W-CSP breakdown was more than twice the surface-mounted board.

Next, a board with surface-mounted chip resistors and another with embedded components were prepared. They were subjected to a push-bending test along 18% of their length. Number of 0603 chip resistors connected in series on each board was 312. Changes in resistance were observed and the result is shown in **Figure 4**.

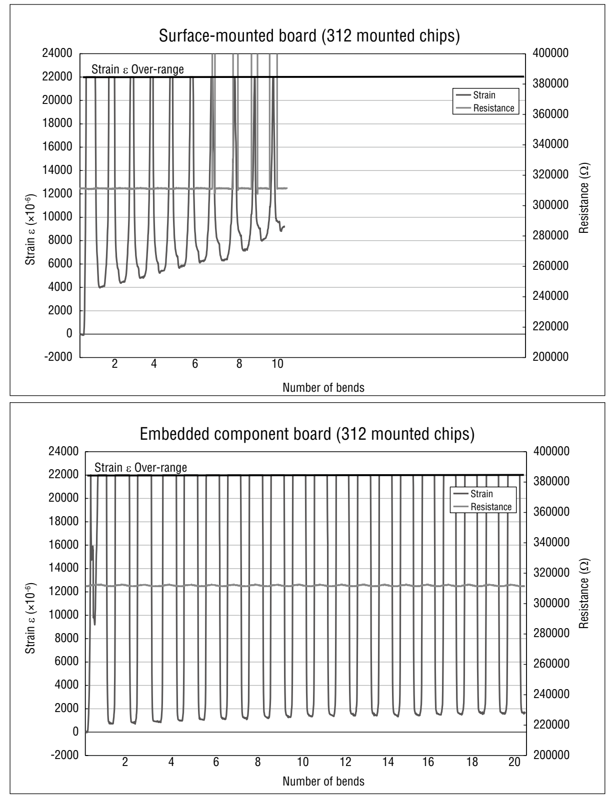

Figure 4. Bending Reliability of Surface-Mounted and Embedded Component Boards

Table 1. Reliability Test Results of Embedded Component Module Board

Test	Test Condition and Result	Remarks
Drop test	Board dropped on its X, Y and Z-axis. No resistance change after 150 drops.	
Repeated reflow test	After moisture absorption, reflow profile repeated 20 times. No change in resistance. No blistering or peeling.	Cross-section observed with SAT, and no problems found.
Temperature cycle test	-65°C (30min) ⇔ 125°C (30min) No resistance change after 3,000 cycles.	
HAST test	110°C, 85%RH, DC25V bias Passed 500 hour test	
Static electricity test IEC-61000-4-2	Discharged ten times for max. 8KV at 5s. Resistance and capacitance measured before and after were found to be within normal values.	No peeling observed with SAT
Vibration test JIS C 60068-2-6 (IEC60068-2-6)	10 ~ 2000Hz applied for 20 cycles each in X, Y, Z directions. Resistance and capacitance measured before and after were found to be within normal values.	
Repair tolerance	After mounting BGA to the surface, post-rework connection was verified. . Resistance and capacitance measured before and after were found to be within normal values.	No peeling observed with SAT
Bending test	Amount of bending changed (5, 10, 20% of length) and breakage was observed. Breakage occurred after 14 bends at 10%, after 4 bends at 20%.	Reference test

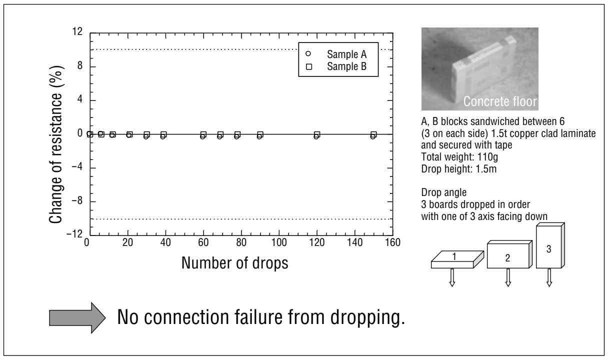

Figure 5. Result of Drop Test

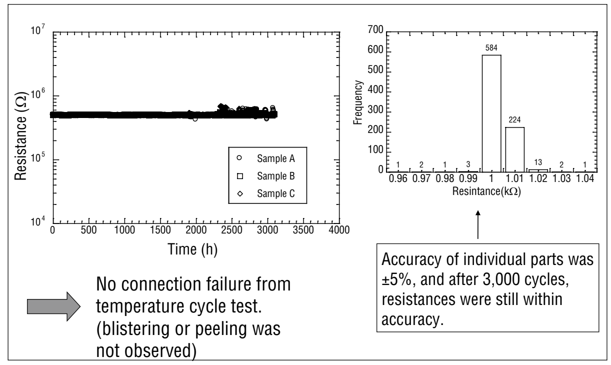

Figure 6. Result of Temperature Cycle Test

The surface-mounted board began to show an increase in resistance at the seventh bending and completely broke at the tenth. The embedded board showed no change in resistance even after twenty bends. This confirms the embedded board has a higher mounting reliability against bending than the surface-mounted board. It is speculated that the reliability is higher with the embedded board because the resins surrounding the component junctions help to distribute stress.

(2) Reliability test results of the embedded component module board

Results of the reliability tests are shown in **Table 1**.

In the drop test, there were no changes in resistance even after 150 drop, and it was confirmed that there were no problems with the connection of the internal components from drop impact.

Figure 5 shows the details of drop test.

To determine if temperature cycling has any effect on the properties of embedded components, the board was subjected to a cycling test condition of -65°C × 30min ⇔ 125°C × 30min. Resistance variation was continuously measured as a sign of change in electrical properties. Result of the temperature cycle test is shown in **Figure 6**.

There were no changes in resistance for 3,000 cycles and problems with electrical properties were not observed.

Moreover, after the temperature cycle test, chip components in the sample board were checked individually and resistances were all found to be within the tolerance guaranteed by the component manufacturer.

Other tests including repeated reflow, HAST, static, vibration and repair tolerance were performed, but no problem with reliability of the embedded component module board could be found.

As shown above, results of the various reliability tests conducted on the embedded component module board equal or surpass that of the surface-mounted board. This confirms that embedding existing components does not degrade connection reliability.

Actual examples of embedded component module boards

(1) ZigBee®*1) module

ZigBee module is a type of low power RF module that is capable of linking together with other modules to establish networks. It is expected to be one of the networks in the upcoming ubiquitous society. With the use of embedded component technology, the module that was once 52mm×35mm in size has been reduced to 15mm×15mm (about 1/8 the area). **Figure 7** shows the development of the ZigBee wireless network module.

(2) Fingerprint authentication module

The fingerprint authentication module was developed (for OKI Semiconductor) based on the goal of achieving an ultra-compact, high-speed, high-precision, low-power, high-security, all-in-one module. An ultra-compact size of 25mm×23mm was achieved by embedding 0603 passive components. Product summary is shown in **Figure 8**.

(3) Compact IP camera

Through the embedding of passive components, the size was reduced from 96mm×50mm down to 64mm×50mm. This is approximately 33% smaller in area.

Figure 9 shows the example of the developed compact IP camera.

*1 : ZigBee is a registered trademark of ZigBee Alliance Inc.

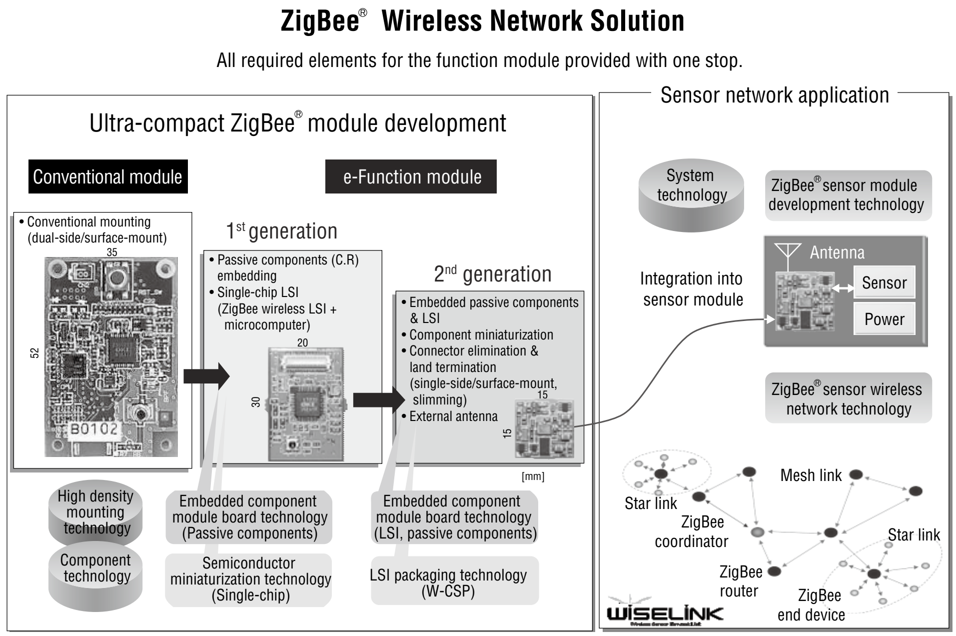

Figure 7. ZigBee® Module

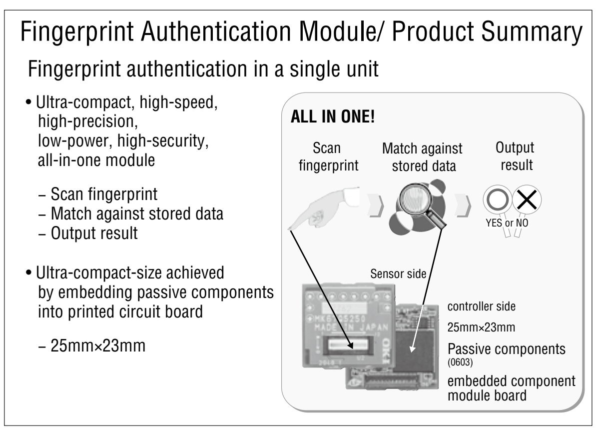

Figure 8. Fingerprint Authentication Module Board

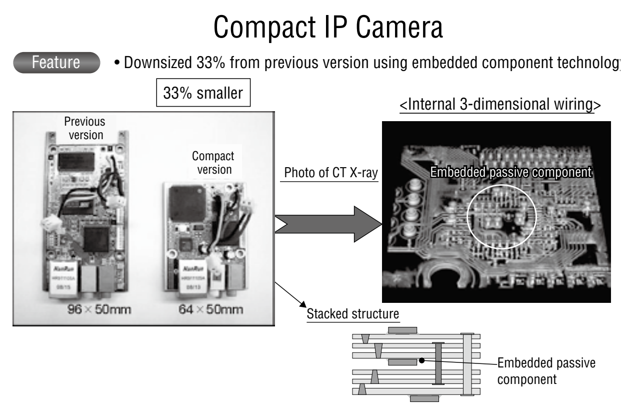

Figure 9. Compact IP Camera

Conclusion

Until now, existing components were not manufactured with purpose of embedding into printed circuit boards, and there have been very few reports confirming the reliability of embedded components. The results of our reliability tests performed on boards embedded with existing components confirm the technology to be fully viable. Furthermore, it was demonstrated that the technology could be utilized to reduce the size of products.

In order to manufacture embedded component module boards requested by customers, a wide variety of LSI packaging technology is required. Putting existing components into W-CSP is difficult, and there are times when customers directly supply the components.

It is becoming increasingly more difficult to realize new applications using only conventional soldering technologies. Therefore, technology to support ultrasonic bonding, ACF, ACP and other various bonding methods is necessary. Application development using embedded component technology has only just begun, however market and customer needs are very high. In response, we are considering to further advance technical development and make improvements to the embedded component module boards. ◆◆

References

1) Y. Shizuno, "Development of LSI-embedded Board Technology", OKI Technical Review No. 211, Vol.74 No.3, pp.62-65, 2007

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TIPS

【Glossary】

e-Function module
e-Function module is a short TAT, high value-added module combining "high-density packaging technologies" , "system technologies" and "component technologies" held by the OKI Group.

SiP (System in Package)
SiP is a package containing multiple chips and LSI. From the exterior, it looks like an electronics system on a single chip.

CoC(Chip on Chip)
CoC is a package with multiple chips stacked inside and designed to enable complex features. Wiring bonding or flip-chip bonding is used between the chips.

PoP (Package on Package)
PoP is a technology to increase the density by stacking multiple packages. Utilizing BGA (Ball Grid Array), connection is often made by connecting the interposer electrodes on the bottom package with the solder ball on the top package.

W-CSP (Wafer-Level Chip Size Package)
W-CSP is a form of semiconductor component packaging. External terminals, resin molding and other processing on the bare chips are done at the wafer level before chips are cut out. Internal wiring with bonding wire is not performed, and it is a big bear chip package with part of the semiconductor is exposed.

RF module
RF is an abbreviation for Radio Frequency and refers to high-frequency signals. It is a general term for modules utilizing high-frequency signals.

ACF (Anisotropic Conductive Film)
A film-like insulating resin material containing fine conductive particles dispersed inside. By applying heat and pressure, bonding will take place and at the same time an electrical connection is make through the conductive material between the electrodes while maintaining isolation with the adjacent electrode.

ACP (Anisotropic Conductive Paste)
A bonding paste with particle-like conductor material dispersed inside. It is transcribed into a printed circuit board using screen-printing then dried. It serves the same function as ACF.

Prepreg
A sheet of glass fiber pulled and arranged in one direction or a fabric impregnated with thermosetting resin (mainly epoxy resin) then dried.

VIA
VIA is a region for electronically connecting the lower and upper layers in a multi-layer wiring. Conductivity is usually achieved by drilling a VIA hole in the dielectric then filling the hole with metallic material or metallic plating.

ZigBee
ZigBee is one of the short-range wireless standards for consumer electronics. It is slower and has shorter range than the similar Bluetooth technology, but has the advantage of low power and low cost. Two AA-size alkaline batteries can drive a ZigBee device for about two years.