

Ultra-Thin Packaging Technology for Cell Phones

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Abstract

In the cell phone market in recent years, expanding user needs have led to increasing functionality and performance, and in order to ensure that cell phones remain portable, there has been an increasing emphasis on making the phones thinner. At NEC, we have taken initiative to develop technologies for creating ultra-thin cell phones that will surpass those from other manufacturers. In this paper, we describe the development of the hybrid case and the case-integrated thin key-switch technologies developed as a part of our ultra-thin cell phone packaging project. We also describe their packaging, and an example of integration into a commercial product.

Keywords: Packaging, Casing, Switch, Module, Structure

1. Introduction

Recently, there has been increasing demand from a variety of users for cellular terminal devices that can be used comfortably in a variety of scenarios. Functionality is expanding particularly with cell phones, which are becoming the core of the mobile Internet. High-speed communication, high-resolution cameras, e-money, GPS and OneSeg television reception are leading to this variety of users and usage scenarios. As can be seen in Figure 1, this has resulted in a temporary trend toward increasing device thicknesses. In anticipation of expected further diversification of users and usage scenarios, it is very important that cellular terminal devices retain real portability, with sizes and forms that allow these various functions to be used easily and comfortably.

We have developed our ultra-thin packaging technologies ahead of other manufactures, anticipating a downsizing movement in cell phones to maintain the core feature of the cell phone—portability.

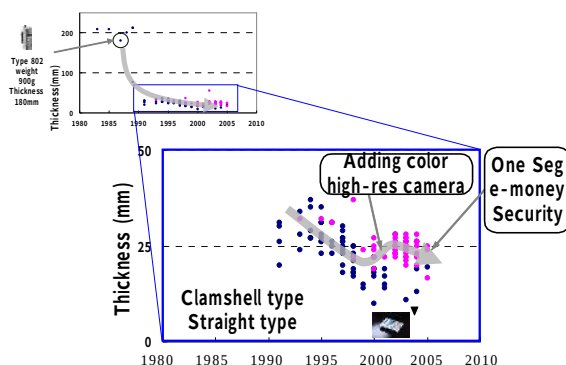


Figure 1: Trends in thickness of Cell phones

This research has undertaken to develop two case structural packaging technologies for ultra-thin mobile terminal devices, based on a space-management concept of placing required functionality where it is needed without waste. The ultra-thin packaging technology unites two functions which have conventionally been separate into a single module, using space optimally and reducing all waste. The first is a the hybrid case technology, and the second is the case-integrated thin key-switch technology: thin key-switch technology that is integrated into the case. As an example of commercialization of these technologies, we also describe an ultra-thin 3G cell phone that incorporates them, the NEC N702iD.

2. Overview of ultra-thin packaging technologies

As shown in Figure 2, cell phones are manufactured with five levels of packaging: "LSI-internal re-wiring", "Inter-LSI wiring", "LSI board packaging", "Board connections" and "Case structural packaging". Research and development on connection technology internal and external to the LSI, and on and between boards is quite advanced, designing for still finer LSI, finer wiring, and higher-density packaging.

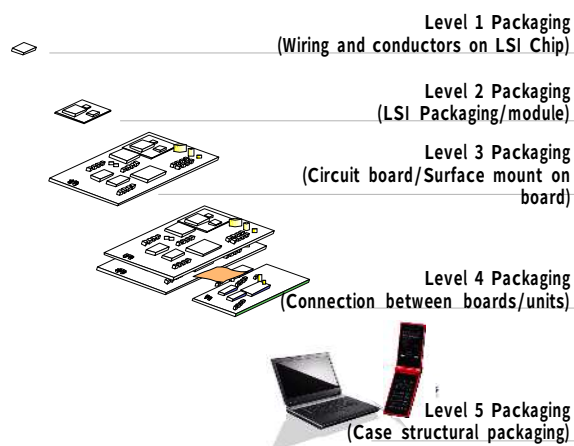


Figure 2: Five packaging levels

Figure 3 shows a classification of structural elements of a cell phone into circuit board, functional components, gaps, and casing, according to volume occupied. In the figure, the casing generally occupies about 40% of the total volume. The space taken by each of these elements can be divided into space that has functional value, and space that does not. In general, a device can be made thinner quite easily by making each of these components thinner, but there are obstacles between the development projects for the respective components, and even if each is optimized individually, optimization of the overall device is difficult. This suggests a promising approach to space management, in which functions in these elements are combined at a higher level, achieving thinner packaging through functional composition.

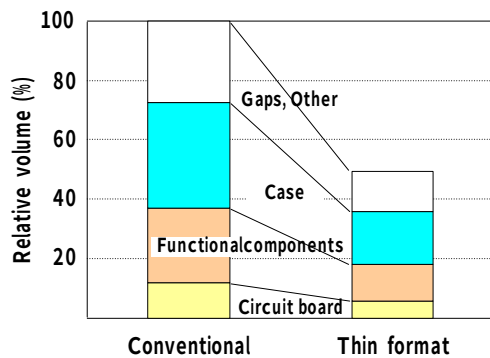


Figure 3: Comparison of structural elements

3. Merging of structural and packaging technologies

Conventionally, the structural technology, used to implement the case, is part of product-design, while board packaging is done by the production technology. To further optimize for thinness, high-level integration of packaging from level five, "Case structural packaging," to level three, "Board packaging," is important. Optimizing components in a complementary way, while maintaining reliability, can result in an optimized overall design. With thin designs, both the structural thickness, and the thickness of wiring tend to decrease. As a result, sturdiness and reliability can also tend to drop, creating many difficulties due to the trade-off between thinness and preserving reliability.

In this research, we have created two new case structural packaging technologies, taking two conventional technologies that have been optimized individually, and merging the structures to create a single module. The first is the hybrid case technology, which uses a combination of materials, embedding a metal frame within plastic, and resulting in a thin, rigid case that can hold components while providing design flexibility without waste. The second is a

technology for integrating thin key switches into the case itself. This is done by inverting the conventional key switch structure, placing part of the key switch structure in the case, and merging the case and key-switch structures into a single module. This case structural packaging technology makes optimum use of limited space by combining functionality.

4. Hybrid case technology

Conventionally, cell phone cases have been made using plastic or magnesium. These materials can be injection molded, allowing for the complex forms needed to meet requirements for external appearance and holding components.

When making a case thinner, either wall thickness or structural thickness can be reduced, but the second moment of area decreases proportionally proportional to thickness, resulting in a considerable decrease in rigidity. Also, with extremely thin shapes, there are many difficulties with molding plastics and magnesium due to changes in their flow properties. For these reasons, we began studying and prototyping hybrid case structures using both plastic and metal materials where needed to achieve flexible and sturdy structure.

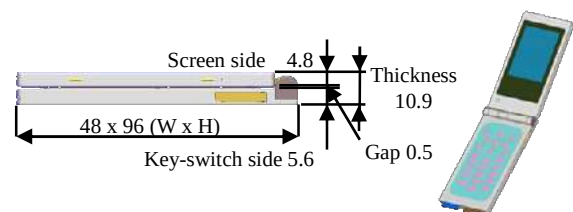


Figure 4: Prototype terminal dimensions

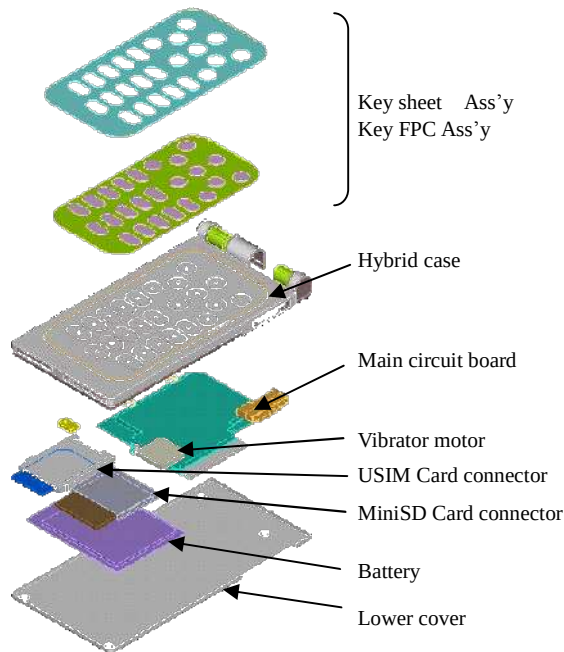


Figure 5: Overview of prototype terminal structure (key switch component)

A prototype clamshell-type terminal using the prototype case is shown in Figure 4. Folded, it is 10.9 mm thick, and the key-switch side is 5.6 mm thick. Figure 5 shows an expanded view of the structure of the key-switch side. Use of the hybrid case is one of the measures taken to achieve this thinness. Specifically, fiberglass-reinforced plastic is used to resist elastic deformation and drop-impact, protecting internal components. A stainless plate is also used to resist static external torsion and bending stresses. A manufacturing method that fuses the plastic parts with the press-formed stainless plate is used, building the plate into the plastic part using insert molding. Insert molding allows the combined strength of the stainless plate and the plastic parts to be increased, and stresses in the stainless plate that tend to concentrate around through-holes can be distributed.

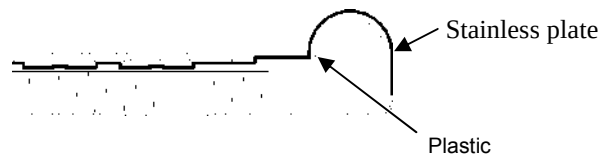


Figure 6: Theoretical prototype model for hybrid case structure

In order to ensure the sturdiness of the case, the product of the Young's modulus and the second moment of area must be large. Accordingly, the cross-section shape of the plate was optimized by increasing the vertical dimensions and curving the case surface to increase the second moment of area. Also the balance of thickness and shape of the metal and plastic parts was optimized to maintain sturdiness, distributing stresses that could concentrate and cause plastic deformation of the plate.

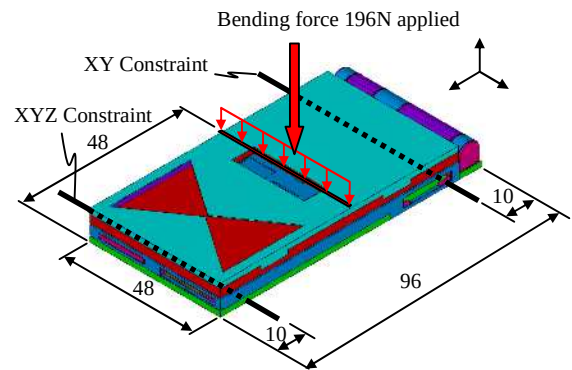


Figure 7: Stress analysis model

Table 1: Physical properties of case materials

	SUS304CSP	AC112 (special nylon, CF40%)
Young's modulus E [GPa]	197	35
Poisson ratio ν	0.3	0.34
Breaking strength [MPa]	-	310
Bending strength [MPa]	-	500
Yield strength [MPa]	205	-
Tensile strength [MPa]	520	-

Figure 7 shows a stress analysis model for a case with this basic construction. The dimensions are 48 by 96 mm, and the test conditions apply a bending force of 196 N in the center along the long dimension. The analysis was done with the metal frame for both the key switch and screen sides made from SUS304CSP stainless steel, and the plastic parts made from carbon-fiber reinforced nylon. As shown in Figure 8, the results showed a maximum stress of 139 MPa in the area around the external I/O connector, which is 63% of the yield strength of the SUS304CSP material. This confirms that the basic structure ensures adequate rigidity against static external forces with this shape.

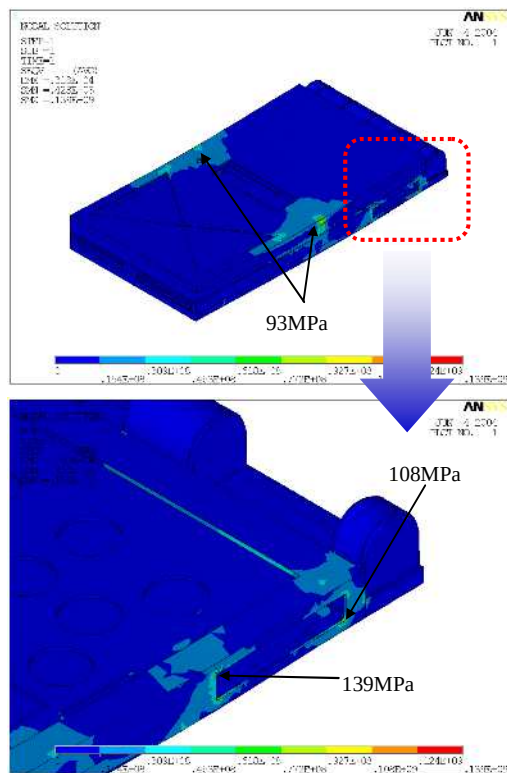


Figure 8: Analysis results

A series of reliability tests on the prototype were conducted, including bending, key-stroke and drop-shock tests, verifying the effectiveness of the

hybrid case and confirming that it is as-strong or stronger than conventional cases made with a single material.

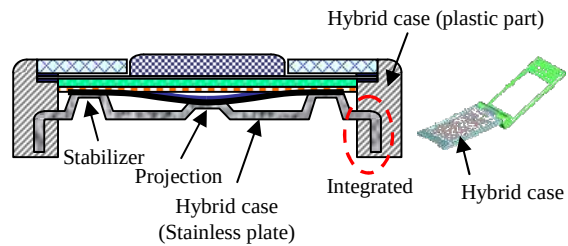


Figure 9: Hybrid case construction

This technology was first used for NEC's domestic N702iD and overseas e949/L1 thin, 3G cell-phone models, allowing further thickness reductions. Figure 9 shows the cross-sectional structure of the hybrid cases used in practical packaging technology. For cell phones it is important to ensure a good design sense and "feel", in addition to sturdiness, so the composition of materials uses a plastic that allows application of various external coatings, and the internal stainless plate is positioned to maintain utility.

5. Case-integrated thin key-switch technology

5-1. Basic structure

The conventional structure of key switches used in cell phones is shown in Figure 10. A bowl-shaped dish spring called a metal dome with conductivity is placed over the switch circuit on the circuit board, protruding toward the key button side. By pushing key buttons on a key sheet that is placed over these, a tactile click is produced. The key buttons protrude through holes in the case, which covers the surrounding area.

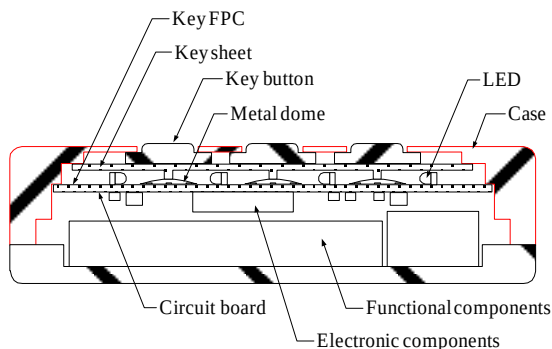


Figure 10: Conventional key-switch structure

With this structure, keystroke stresses from the key switches are felt directly by the circuit board, the case is only required to protect internal parts from external stresses, and the case thickness tends to be larger. Also, the circuit board is repeatedly stressed due to keystrokes, which can cause a drop in reliability of the soldered connections of LSI and tiny components on the board. Design changes and development cost increases related to the need to re-position LSI to distribute these bending stresses have been an issue. We have created and prototyped an original structure which inverts the traditional switch structure and combines the upper surface of the case with the key-switch base.



Figure 11: Prototype

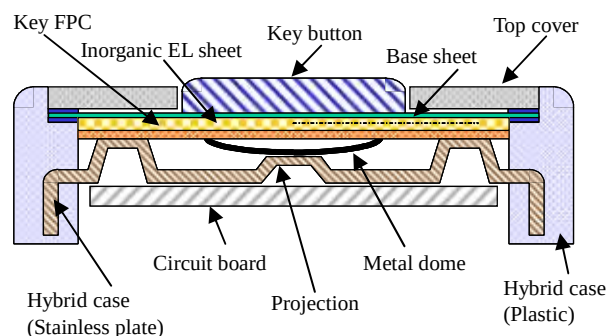


Figure 12: Structure of case-integrated thin key-switch

This architecture is shown in Figure 12. The key stroke pressure is absorbed by the case, which has the hybrid case structure. It has a layered constitution, with the metal dome placed facing downward on the upper side of the stainless frame, and the key Flexible Printed Circuit (Key FPC) for the key circuit placed on top of this. An inorganic electroluminescent sheet and a key sheet, with keys attached to a base sheet, are placed on top of this. The thickness from the bottom of the stainless plate to the top of the key buttons is 1.6 mm. The stainless plate in the hybrid case structure discussed above is also used as the key-switch base and, as suggested by the inversion of the metal dome, the projection and stabilizer protuberances, which were previously separate parts, are formed in the base surface by pressing. Previously, an illumination method with LEDs dotting the switch circuit surface was used, but the vertical inversion structure allowed use of a surface-emitting inorganic EL sheet positioned between the switch circuit FPC and the key sheet. This provides uniform, beautiful illumination for good visibility in dark environments.

5-2. Key switch characteristic and module development

Figure 13 shows the relationship between force and displacement when operating the switch circuit. Here the maximum force, P1, is called the operating force, and the minimum force, P2, is called the click force. The ratio $(P1-P2)/P1 \times 100$, or P (%), is called the click ratio.

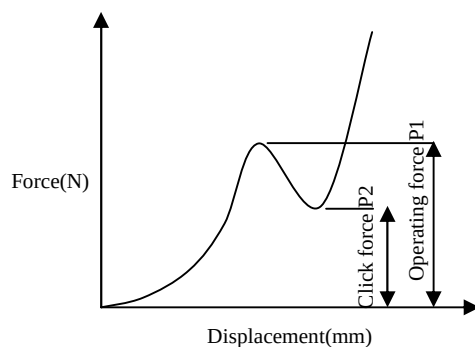


Figure 13: Click characteristic

The click characteristic depends on the sheet structure, the materials and thicknesses, as well as the key switch bending mode, all of which are different than conventional designs. Because of this, the materials, thickness, shape and positioning of each part had to be finely optimized. Figure 14 shows the relationship between click ratio and operating force, with click ratio on the vertical axis, and operating force on the horizontal axis.

As the click ratio increases, lower operating force gives a clearer operational feel, which was an objective of this design. For the sheet used to join the buttons together, we selected a material that would be flexible and of low tensile strength, not to interfere

with click-operation, and resistant in environmental testing. In order to reduce any obstruction to click operation by the wiring part of the switch circuit, called the Key FPC, slits of an experimentally-determined size are created in the Key FPC. The relationships between click ratio and height and shape of the projection, height, shape and positioning of the stabilizer, and combinations such as the offset measurements between projection and stabilizer were all determined experimentally. From these, an optimum design was found that achieved a click characteristic similar to conventional designs using the thin design. The switches were evaluated on four prototype terminals, with each of 24 key switches were pressed repeatedly 100,000 times. The results were favorable, showing no deformation of parts, or switch-operation irregularities. Also, the click ratio stayed in the range of 20 to 37.7 % from beginning to end, verifying that the design is usable practically.

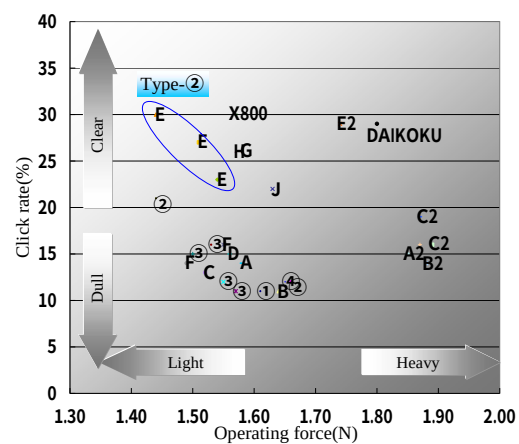


Figure 14: Relation between click ratio and operating force

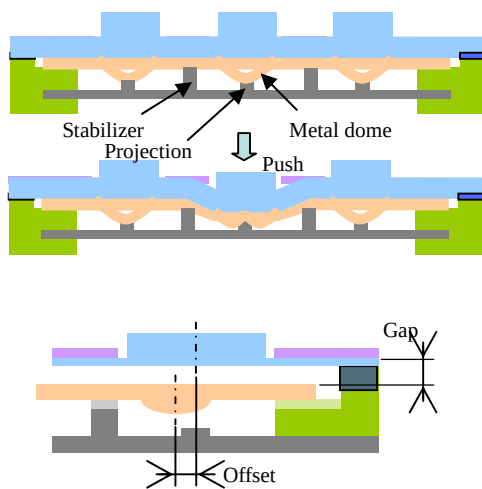


Figure 15: Relationships between stabilizer, projection and metal dome

Also, as shown in the cross-sections in Figure 15, the precision of the relative positioning of the metal dome, the projection and the stabilizer is also very important. In particular, if the horizontal offset in the position of the metal dome relative to the projection and the gap between the base sheet and the layer beneath it are within prescribed values, a good click ratio is obtained.

This structure consists of layering parts over a thin sheet. Each layer is bonded to the next with a 10 to 50 μm layer of adhesive, giving it a flexibility that does not interfere with click operation. Also, a voltage is supplied to the inorganic EL sheet through the Key FPC from the main circuit board power line. For this, an electrical connection is necessary between the Key FPC and the inorganic EL sheet. This is achieved with a thin electrical connection, made by screen printing an anisotropic conductive paste onto the electrode area of the inorganic EL sheet, overlapping it with the Key FPC and thermo-bonding them together at low temperature. In order to prevent electrical disconnection due to

keystroke stresses from key operation, the electrical connection is positioned at the edge of the sheet.

We verified the prototype's suitability for commercial application by clearing a series of tests, including evaluation of the click characteristic, continuous repeated key presses, and resistance to harsh conditions such as high-temperature, high-humidity and low-temperature, high-humidity environments.

This technology was first used in NEC's N702iD thin cell phones. Figure 16 shows the basic architecture of this structure, with key sheet assembly above, the Key FPC assembly in the middle, and the key base on the bottom, forming a single case and key-switch module. In order to make the technology practical, additional development was done, such as selecting suitable materials for volume production, creating a precision form for molding hybrid case key base plate, and ensuring the brightness and lifetime of the inorganic EL sheet. This greatly contributed to making a thinner and stronger product.

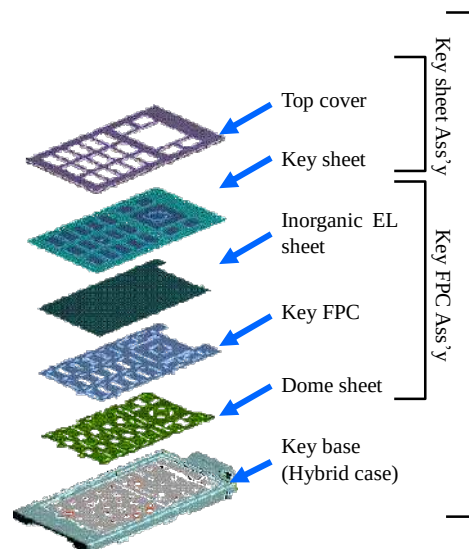


Figure 16: Layer constitution of case-integrated thin key-switches

6. Conclusion

As examples of ultra-thin packaging technology, we have described the hybrid case technology and the case-integrated thin key-switch technology created by merging manufacturing and packaging technologies at a high level. By using these technologies in a cell phone product, we were able to reduce the thickness by 4.3 to 6.3 mm relative to previous cell phones. In the cellular terminal market, represented by cell phones, we expect further advances in functionality, performance, form and design. We intend to continue to contribute to creating new terminal devices by further advancing case structural packaging technologies, combining functionalities and making optimal use of the limited space available.

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