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Development of Ultrasonic Flip Chip Bonding for Flexible Printed Circuit

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Abstract
Small form factor and high density of printed circuit boards (PCB) have been already realized by flip chip (FC) bonding technology. However, the requirement for finer pitch PCB is still increasing with shrinkage of die and wiring. Therefore, conventional FC bonding technology will not provide sufficient capability or productivity to meet future demands.

The authors have focused on flip chip bonding method utilizing ultrasonic vibration. Flip chip modules using flexible printed circuit (FPC) are strongly required for such as mobile phone applications. For that purpose, we investigated to assemble semiconductor devices with FPCs applying this method, particularly for large size die with multiple pads. In this report, we evaluated relationship between bonding parameters and reliability using several kinds of copper clad laminate (CCL) with different plating conditions. We show the correlation between formation of microscopic metallic bond and actual chip on flex (COF) module performance. As a result, we succeeded in realizing 35 micrometers pad pitch COF modules.

Introduction
Modern electronic devices are required to be thin, light weight, and functionally sophisticated. Therefore higher density mounting of electronic component is required on printed circuit board. Recently bare silicon dies are mounted directly onto the board.

In response to these trends, Fujikura has established chip on flex (COF) technology, mounting bare dies onto flexible printed circuit (FPC) board. Wire bonding (WB) method and flip chip (FC) bonding method has been already applied to mass production. Anisotropic conductive film (ACF) method[1] and solder bump connection method[2] have been realized.

Flip chip bonding on FPC is indispensable technology to miniaturized and/or sophisticated products such as mobile phones and so on.

However, more integrated semiconductor devices that equip more signal pins require narrower interval of input and output pads. Recently LSIs with 40 micrometers pin pitch such as liquid crystal display drivers has been appeared. Additionally, the demand of lead free products is increasing. Conventional flip chip bonding methods have difficulties to be adapted to these requirements. Therefore, we have focused novel ultrasonic flip chip bonding method.

Compared with ACF method, ultrasonic bonding method has two advantages. One is lower electronic resistance and the other is strong mechanical retention. These are obtained by metallic bond instead of physical contact in ACF method. The energy of ultrasonic vibration makes metallic bond between Au bumps on the LSI and Au plated pads on the FPC. It also reduces down force to the LSI, in result deformation or cracking of FPC pads are prevented compared with a solder bump connection method a finer pad pitch is achieved by the Au bump instead of solder bump. It is not necessary to control solder wetting and wash soldering flux using with Au bump.

Another advantage over both ACF and solder bump methods is lower temperature. Ultrasonic bonding method obtains metallic bond even in the room temperature. It is well known that the dimension of FPC is harmed with high temperature. Small dimension deviation of FPC in lower temperature realizes fine pitch bonding with high accuracy. Table 1 shows the comparison among three methods.

Table 1 - Bonding Method Comparison

Method	Solder bump	ACF	Ultrasonic
Mechanism	Solder wetting	Physical contact	Metallic bond
Available pitch	>100µm	>50µm	<40µm
Lead free	under study	OK	OK
Bonding force	no need	higher	lower
Process temperature	200~250°C	200~300°C	R.T.~200°C

Up to the present, ultrasonic flip chip bonding method has been only applied to small size dies with a few pins such as SAW (Surface Acoustic Wave) filters and TCXOs (Temperature Compensated X'tal Oscillator). The reason is that modified wire bonding machine is generally used as an ultrasonic flip chip-bonding machine. When large size dies with more pins are applied with the present machine, it is found the lack of vibration energy and harmful vertical vibrations. We have tried to evaluate new concept ultrasonic bonding machine adequate to the large size dies without those problems[3,4,5,6].

Experiments

The ultrasonic flip chip bonding process is shown in Figure 1. Firstly, Au bumps on bare die and Au plated FPC pads are aligned. Secondly, the bumps contact the pads with a low force. Then Au-Au metallic bond is generated by adequate force with ultrasonic vibration.

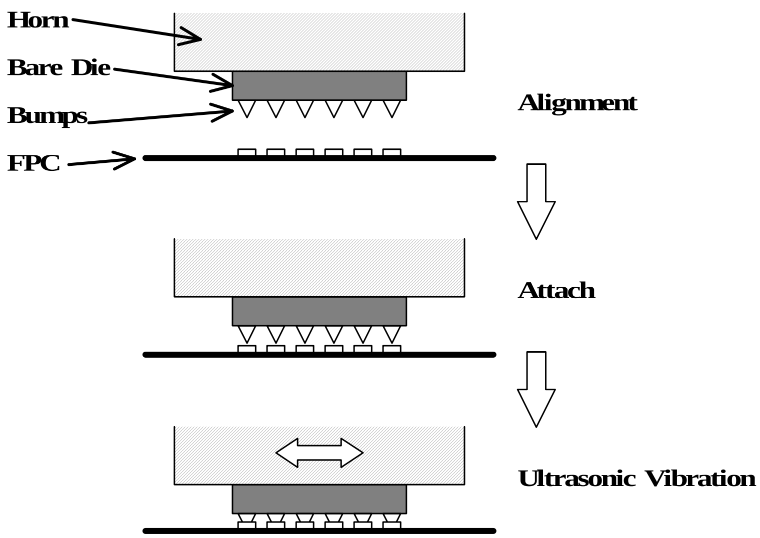

Figure 1 - Schematic Diagram of Ultrasonic Flip Chip Bonding Process

Two kinds of TEG (Test Elements Group) have been used for the evaluation of the ultrasonic bonding method. Table 2 shows specifications of each TEG. FPC pattern is designed in daisy chain manner to enable the measurement of series electric resistance of metallic bonds. The two TEGs have different types of copper clad laminate (CCL) and bump shape. TEG1 has no adhesive layer and plated bumps. TEG2 has 10 micrometers adhesive layer between copper foil and base polyimide film, and stud bumps. The TEG1 is intended to compare with ACF method, and the TEG2 with solder bump connection method. Each FPC pattern is made from 18 micrometers thickness copper foil, and plated with Ni-Au. We consider the performance of bonding depends on bonding force, temperature, amplitude of ultrasonic vibration and vibrating time. Changing these conditions, we have observed cross sectional shape of bonding part, electric resistance of daisy chain pattern, and the die shear strength.

The gap between the bare die and the FPC is filled by underfill resin in 150 degrees centigrade oven for 30 minutes.

Thermal cycle test is adopted to evaluate the reliability of bonding. The lower temperature is -40 degrees centigrade and the higher temperature is 125 degrees centigrade each for 30 minutes. Electric resistance of the daisy chain pattern is measured over the whole test cycles. The threshold is 20% rise of electric resistance to the initial value.

Table 2 - Bonding Sample Specifications

	TEG1	**TEG2**
Die size	2.0x7.2mm	3.0x2.7mm
I/O pad	179pins	48pins
Pad pitch	90µm	120µm
Bump shape	Plated bump	Stud bump
CCL type	adhesiveless	with adhesive

Evaluation of Bondability

Figure 2 and Figure 3 show cross sectional views of bonding points each for TEG1 and TEG2. We cannot find any voids between bump and pattern. We consider that the same power of ultrasonic vibration is distributed to all bumps because the cross sectional shapes of all bumps are almost same in one die.

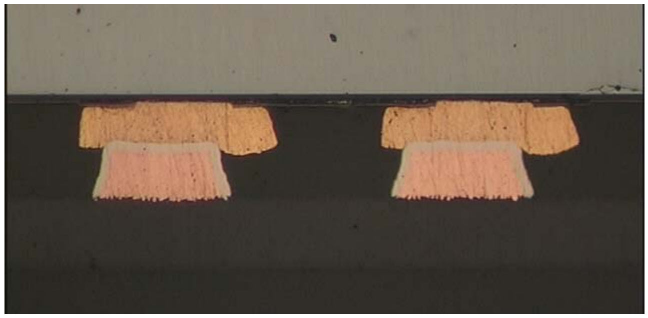

Figure 2 - Cross Sectional View of Plated Bump Bonding

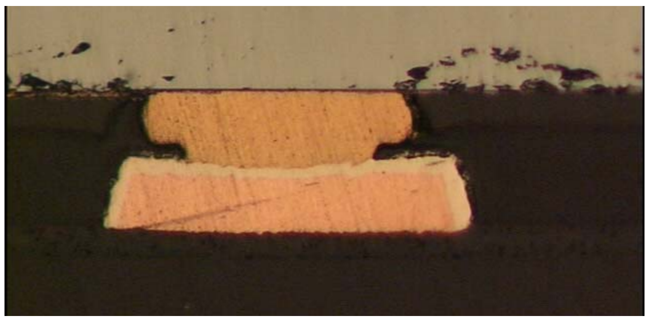

Figure 3 - Cross Sectional View of Stud Bump Bonding

It is observed the bumps are well collapsed by the bonding force and the ultrasonic vibration at the same time. The collapsed part of the plated bump is much more than that of the stud bump. Figure 4 and Figure 5 show the surfaces of bonding point intentionally broken, many dents are observed. We consider these dented sections are caused by the Au-Au bond between the bumps and the patterns. New pure Au surface appears at these sections while collapsing. When a bump is wider than a pattern, the Au-Au bond is formed mainly at the edge of the pattern as shown in Figure4. When a bump is narrower than a pattern, it is formed at edge of the bump as shown in Figure 5. Additionally we can recognize enough low initial electric resistance of the daisy chain.

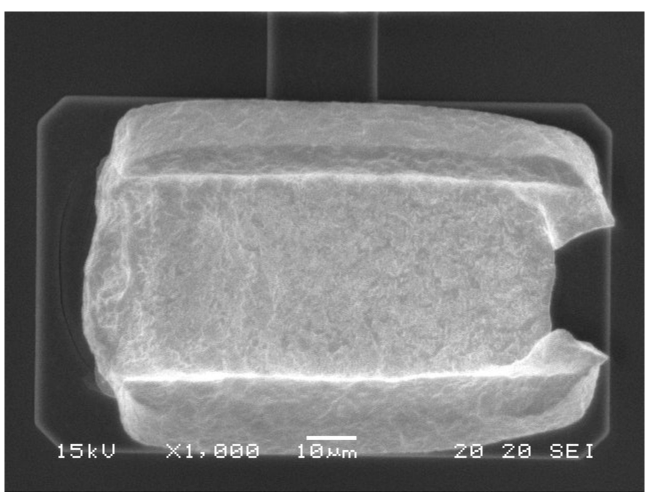

Figure 4 - Surface View of Plated Bump after Bonding

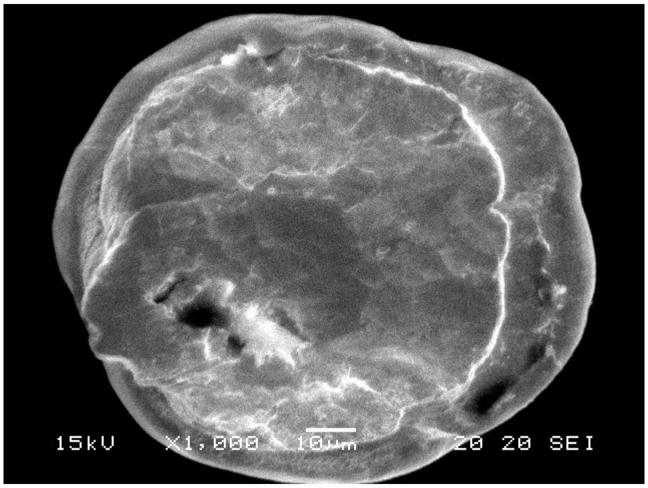

Figure 5 - Surface View of Stud Bump after Bonding

The bonding process takes less than one second and does not depend on number of pins or bump shapes or CCL types. Compared with 10-20 seconds of thermocompression in ACF method and 3-5 minutes of reflow soldering in solder bump method, the process time is greatly shortened.

The result of the die shear strength measurement shows more than 0.2N per bump in either bump shape. When some bumps are broken with die shear test, some Au parts of the bumps still remain on the patterns as shown in Figure 6. This means the strength of the bonding is as same as Au original metal strength.

More bonding force, higher temperature, more amplitude of ultrasonic vibration, more vibrating time make the collapsed bump area more. As a result, higher strength is obtained. However, we have to recognize the risk of the electric short between adjacent bumps, in addition, the breakage of the silicon die.

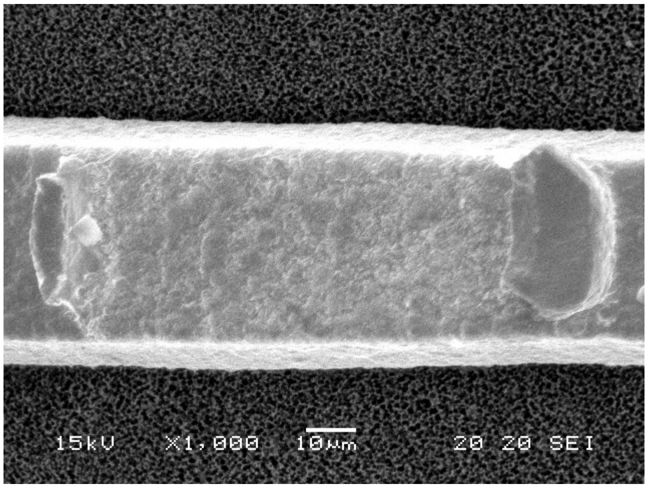

Figure 6 - Piece of Bump Remaining Bonded on Pattern

Underfill Process

Open circuit failures shown in Figure 7 have occurred during the underfill cure process. We consider that the root cause is the shear stress between the silicon die and the polyimide base film, because they have different coefficients of thermal expansion. During the high cure temperature, the stress concentrates on the bonding points and breaks the metallic bond. We also find that the bonding conditions correlate with the frequency of the open circuit failure. It is very important to adjust bonding conditions suitable for each application in order to get the enough bonding strength.

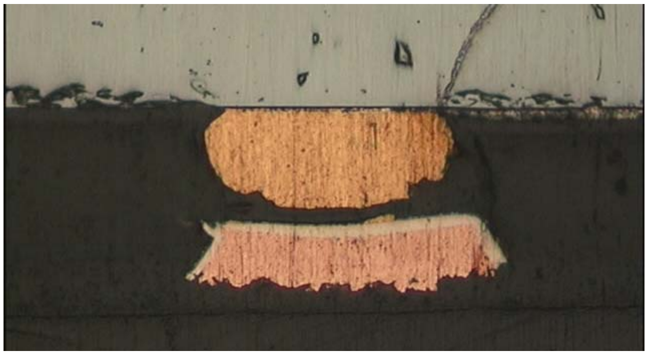

Figure 7 - Cross Sectional View of Open Circuit Failure after Underfill Resin Cure

Bonding Reliability
Figure 8 shows the result of thermal cycle test. The horizontal scale indicates number of the test cycle and the vertical scale indicates the ratio of the resistance to the initial value.

The resistances of both TEG1 and TEG2 do not rise during the 1000 cycles. Once underfill cure process is completed successfully, enough reliability is obtained by the stress relaxation of the underfill.

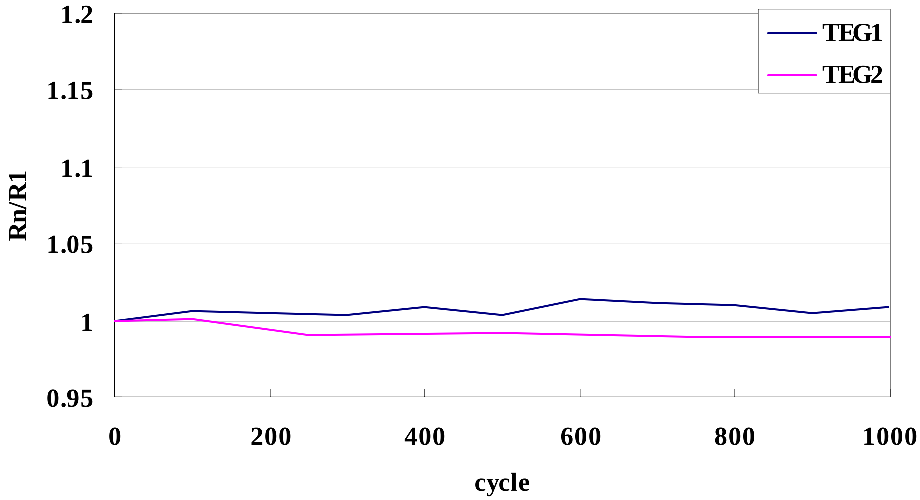

Figure 8 - Result of Thermal Cycle Test

Bonding on Liquid Crystal Polymer Based CCL
Liquid crystal polymer (LCP) based CCL is regarded as superior to polyimide based CCL in moisture absorption, dimensional stability and dielectric constant. Because these properties are useful in controlling impedance characteristics, we think LCP based CCL will be suitable for recent fine pin pitch LSIs which treat faster signals. Thus we have also evaluated the bondability of the ultrasonic flip chip method on the LCP based CCL. We have used samples that have the same pattern and the same die as TEG1.

Figure 9 shows the cross sectional view of bonding points. We can find no void between the bumps and the patterns, and well-collapsed bumps. And low initial electric resistances are observed. Therefore we consider that LCP based CCL has enough performance with the ultrasonic flip chip bonding method.

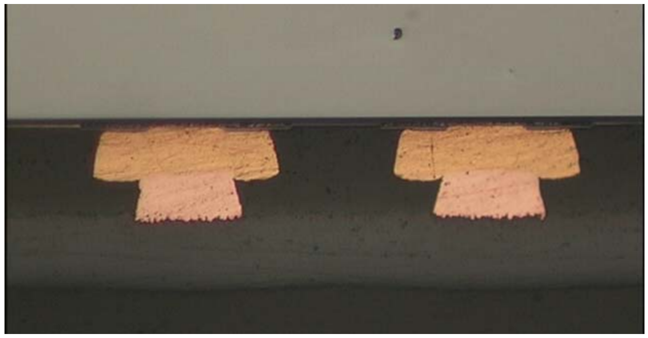

Figure 9 - Cross Sectional View of Ultrasonic FC Bonding on LCP Based CCL

For comparison, we have tried the ACF method to the LCP based CCL. Figure 10 shows cross sectional view of bonding points. We find that the patterns sink down into the LCP base film. The ACF method requires higher bonding temperature and longer process time than the ultrasonic method. As a result, the thermoplastic property of LCP occurs the deformation of itself. Silicon die also moves down with the patterns sunk down and the edge of the die touches to the copper patterns.

The ultrasonic method has indicated advantages of lower force, lower temperature and shorter process time, and we think these are effective especially to the LCP based CCL.

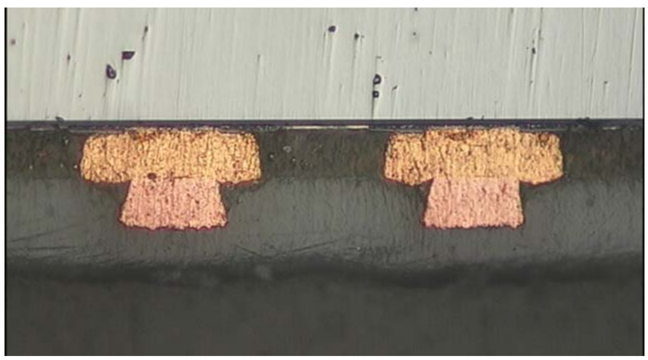

Figure 10 - Cross Sectional View of ACF FC Bonding on LCP Based CCL

35 Micrometers Pin/Pad Pitch Flip Chip Bonding

We have tried to assemble 35 micrometers pad pitch COF module that we name TEG3 shown in Table 3. FPC patterns are also designed in daisy chain manner. The TEG3 is made of the Polyimide based CCL with 5 micrometers thickness copper foil.

Figure 11 and Figure 12 show the views of 35 micrometers pad pitch bonding points. The bumps and the patterns are well aligned without misalignment by ultrasonic vibration. All the bumps are collapsed in the same shape with no void and no short circuit failure. Breaking of thin copper patterns by ultrasonic vibration energy has not occurred, and we can see appropriate values of daisy chain resistance. Therefore we believe the ultrasonic flip chip bonding method has enough performance to assemble fine pitch COF modules less than 35mictrometers pin pitch.

Table 3 - Specifications of TEG3

Die size	1.5x15mm
I/O pad	650pins
Pad pitch	35μm
Bump shape	Plated bump
CCL type	adhesiveless

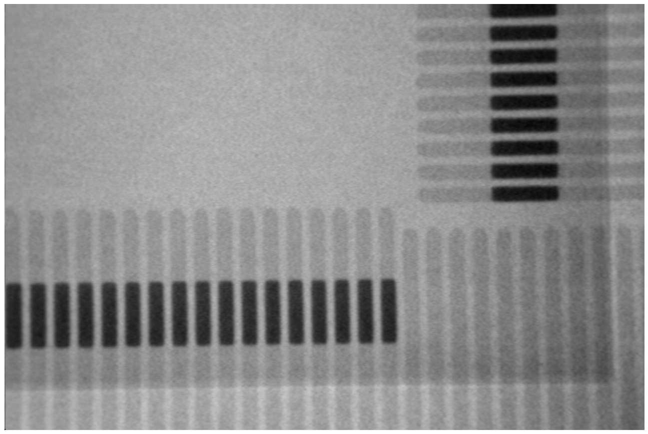

Figure 11 - X-ray Image of 35micrometers Pad Pitch Bonding

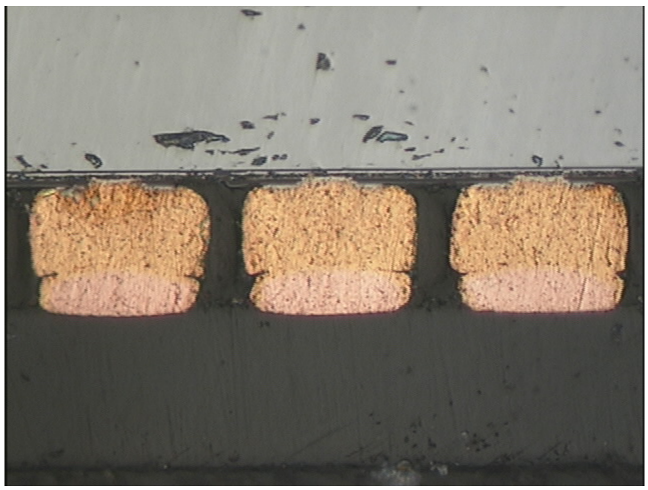

Figure 12 - Cross Sectional View of 35mcrometers Pad Pitch Bonding

Conclusions

We have focused on the ultrasonic flip chip method for fine pad pitch COF modules. We have found that the ultrasonic method has enough performance to obtain metallic bonds between Au bumps and Au plated patterns. This method makes the process time very short and greatly improves productivity. However, we still have to find appropriate conditions of the underfill cure process. We also have confirmed enough reliability in the thermal cycle test. We have found ultrasonic method has significant advantages in LCP based CCL bonding over the other methods. And we have succeeded to make the prototype of 35 micrometers pad pitch COF assembly with the ultrasonic method. As a next step, we will try to apply this method to actual modules and mass production.

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