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Low-cost Flip Chip Technology for Organic Substrates

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This paper introduces a flip chip technology that is used on various kinds of substrates (glass-epoxy, flexible printed circuit board, and MCM-L/D).
In this technology, Au bumps are formed on the chip I/O pads by wire bonding and the bumps are pressed onto the substrate pads. The chip is bonded and encapsulated with a thermosetting adhesive, and conductive paste improves the mechanical and electrical connection between the Au bumps and the substrate in order to increase the connection reliability.
To apply this technology to different types of substrates, we investigated the deformation characteristics of the substrate pad and the adhesive strength and insulation of the adhesive for encapsulation.
This technology has been applied to some practical products and reduces the mounting areas of LSI to 1/10 or less that of LSI that use the existing SMD package approach.

1. Introduction

Flip chip technology was initially developed for large-scale computers to enhance their transmission speed. Recently, however, flip chip technology has begun to be applied to portable equipment such as notebook PCs, where improvements in terms of miniaturization and performance have become increasingly important.[1)]

When flip chip technology is applied to consumer products, there is a strong need to use commercially available chips and conventional organic substrates in order to reduce cost. From the perspective of cost, the Au wire bump method is preferable to solder bumps. Because wire bonding is mainly used as a packaging technology, most of the chips have I/O pads made with aluminum alloy, so it should be more straightforward to fabricate Au wire bumps than to employ other methods such as plating processes.

Figure 1 shows four methods for interconnections between Au bumps and substrate electrode pads. These methods are as follows:

a) A mechanical contact method. This is used on glass substrate LCD panels.[2)] In this case, a light-setting adhesive is used as an encapsulant.

b) A method by which conductive paste is used to connect Au wire bumps and substrate pads. In this method, underfill encapsulant is adopted to increase the fatigue life.[3)]

c) A soldering connection method. In this method, an underfill encapsulant is used for the same reason it is used in the conductive paste method.[4)]

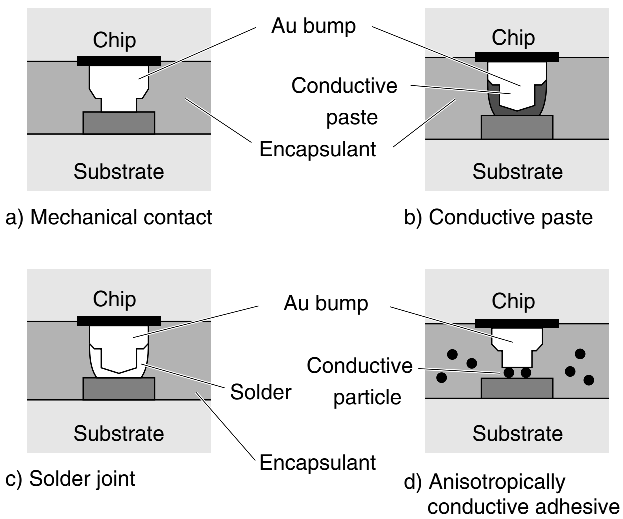

Figure 1.
Flip chip joint technologies using Au wire bumps.

d) A method that uses Anisotropically Conductive Film (ACF) or Anisotropically Conductive Adhesive (ACA) to form conductors in the vertical direction and insulators in the horizontal direction.[5),6)]

In 1989, we started development of the flip chip mounting technology with Au Bumps. After examining various methods, we found that by combining the mechanical contact and conductive paste methods we could achieve sufficient reliability in the glass epoxy substrate. In 1991 this technology was used for our Hand Held Word Processor.[(7)]

Since then, we have had two major problems with this technology:

1) The I/O pitch of the LSI has become finer (120 µm R 85 µm).
2) Because of increases in the demands of various applications such as notebook PCs and hard disk drives, this technology must now also be applicable to substrates such as MCM-L/D and flexible PCBs.

When the I/O pitch becomes finer, the gaps become narrower and therefore the insulating property of the adhesive must be improved to prevent short failures.

In the case of flexible PCBs, the circuit is formed on poly-imide film, but the adhesive strength of the bond between this adhesive and the poly-imide surface is inferior to the case for a glass-epoxy surface. We solved this problem by improving the characteristics of the adhesive and by optimizing the bonding pressure for each kind of substrate.

This paper outlines this technology and describes our experimental method and results. Lastly, we describe the effects of miniaturization for some practical applications.

2. Outline of the technology

2.1 Structure

In this technology, as shown in **Figure 2**, an electrical connection between the Au wire bump and the substrate electrode pad is obtained mainly by mechanical contact. Conductive paste supports the mechanical and electrical connection. A bare chip is fixed and encapsulated by using a nonconductive, thermosetting adhesive. The technology requires a highly reliable adhesive because the adhesive is used not only to fix and protect the chip but also to prevent a short between bumps. Specifically, the concentrations of impurity ions such as Na+, Cl-, and K+ in the adhesive must be minimized to prevent Ag migration.

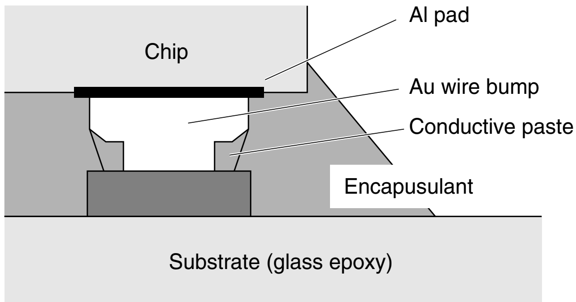

Figure 2.
Cross section of Fujitsu's flip chip technology.

2.2 Process

First, Au bumps are formed on Al pads on the circuit side of a bare chip (**Figure 3a**). Next, the bumps are pushed against a glass plate to make them the same height (b). Ag paste is then applied to the top of each Au bump (c). Then, a nonconductive, thermosetting adhesive is applied to the substrate (d) and positioning is performed (e). Finally, the bare chip is pushed against the substrate to connect the chip's electrodes to the substrate electrodes and heat is applied to harden the thermosetting adhesive (f).

3. Experiments

3.1 Insulating property of adhesive

We improved the insulating property of the adhesive by reducing the density of impurity ions (e.g., Na+, K+, Cl-). **Table 1** shows a comparison of ion densities of the current adhesive for glass epoxy substrates (adhesive A) and the improved adhesive (adhesive B).

We performed a high-temperature, high-hu-

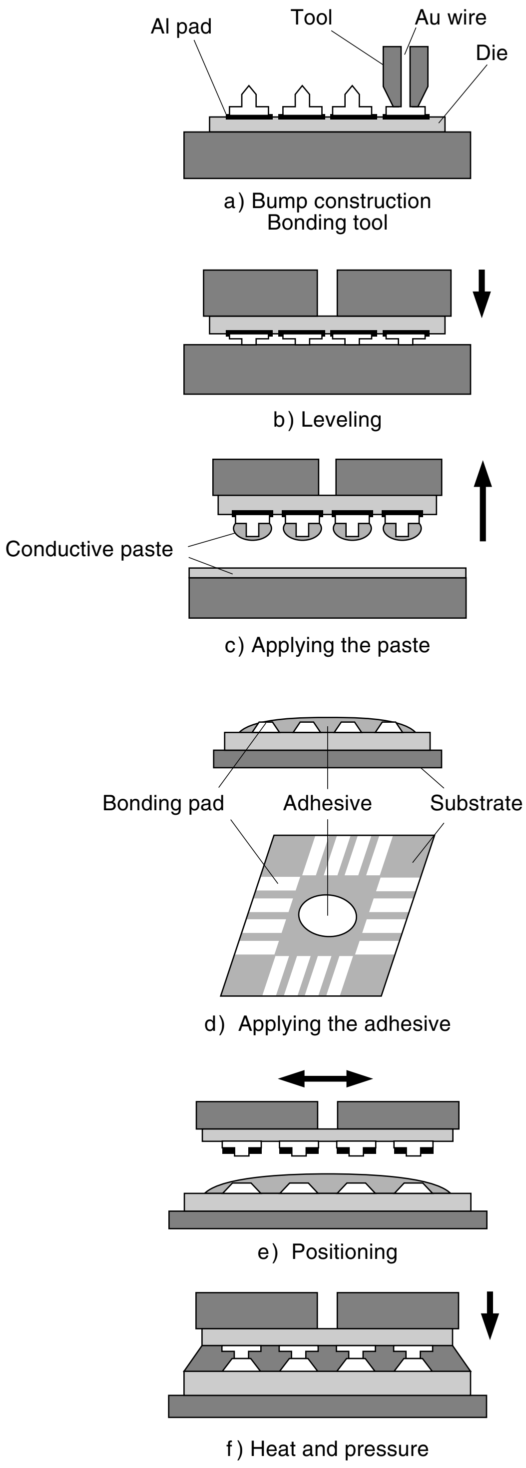

Figure 3.
Bonding process.

midity, bias-voltage test and compared the insulating resistance changes in adhesives A and B. **Figure 4** shows the outline of the test substrate we used for the insulating tests. The comb-like

Table 1. Comparison of impurity ion densities.

	Adhesive A	Adhesive B
Na^+	< 10 ppm	< 1 ppm
K^+	< 10 ppm	< 1 ppm
Cl^-	< 80 ppm	< 10 ppm

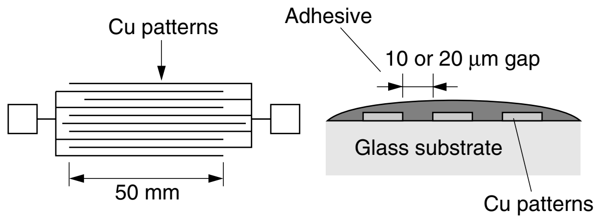

Figure 4.
Outline of the test substrate.

patterns of Cu were formed on the glass substrate, and the pattern was potted with adhesive. We evaluated the insulating properties of the adhesive by measuring the insulating resistance change during the test. The test conditions were 85°C, 85%RH, and a 5.5-volt bias.

3.2 Shear strength improvement on poly-imide film surface

We developed a new adhesive (adhesive C) which improves the adhesive strength with the poly-imide surface. Also, we measured the change in the shear strength of the adhesive part after subjecting the samples to high-temperature, high-humidity (85°C, 85%) storage. We also measured the change in the shear strength during high-temperature storage at 130°C. **Figure 5** shows the measurement method.

3.3 Examination of bonding pressure

In the case of the flip chip technology with the solder joint, displacement in the horizontal direction due to thermal expansion mismatch between the chip and the substrate causes a reliability problem. However, in the case of the mechanical contact method, displacement in the vertical direction produced by thermal expansion

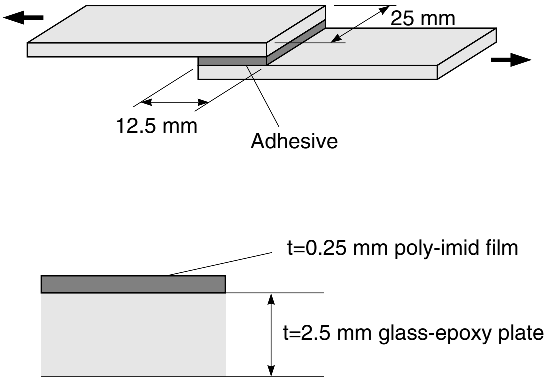

Figure 5.
Test piece for shear strength measurement.

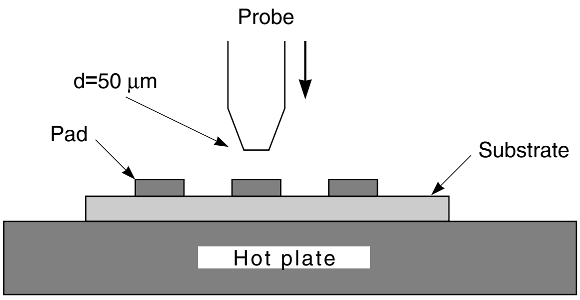

Figure 6.
Outline of measurement method for substrate pad deformation.

of the adhesive generates a problem; namely, this displacement causes an electrical open failure at the interface between the bump and the substrate pad. We considered that this problem could be solved by controlling the thickness of the insulating layer by controlling the bonding pressure. Because the bonding pressure must be optimized for each kind of substrate, we examined the correlation between the deformation in the insulating layer of each kind of substrate and the bonding pressure.

Figure 6 shows the measurement method. We used a very fine probe (diameter=50 μm) to push the substrate's pads. The substrate was mounted on a hot plate, then the pressure and deformation in the vertical direction were measured simultaneously. The substrate was heated to 200°C during the test to simulate the actual bonding condition.

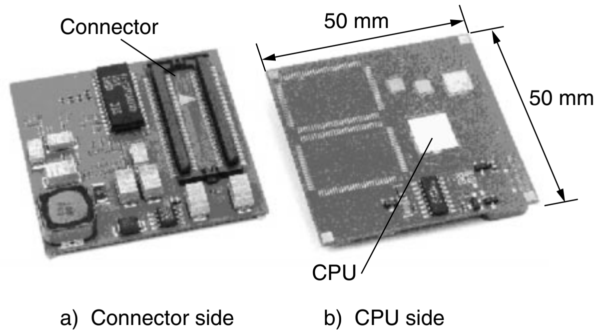

Figure 7.
Practical MCM–L/D sample.

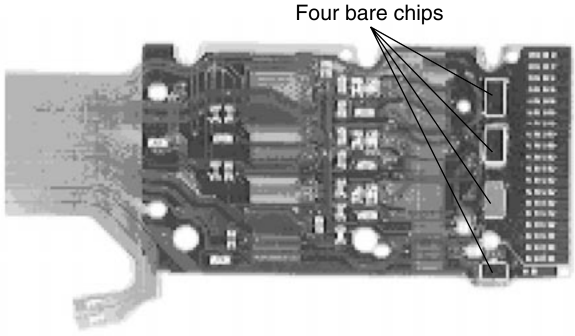

Figure 8.
Practical sample (head ICs of a hard disk drive).

3.4 Reliability testing of test and practical samples

1) Flip chip on an MCM-L/D substrate

Before adopting this technology for practical use, we evaluated the flip chip connection reliability using a test chip and substrate. The test chip had an 80 μm I/O pitch. We made a test substrate having two deposition layers (one layer for each side). This substrate had a daisy chain test pattern to test the connection reliability and insulating resistance. Also, we evaluated the reliability of MCM-L/D with practical samples (**Figure 7**). The reliability test conditions are summarized in **Table 2**. The reliability tests for the test sample and practical sample were done under the same conditions.

2) Flip chip on a flexible PCB

We evaluated the reliability of flip chips on a flexible PCB in the same way as for MCM-L/D. We used a test chip which had a 120 μm I/O pitch

Table 2. Reliability test conditions.

Test	Conditions	Number of samples tested
Thermal cycles	-65°C to 125°C 1,000 cycles	25
High-temperature, high-humidity, bias-voltage	85°C, 85% 5.5 V bias 1,000 hours	25
High-temperature storage	135°C 1,000 hours	25

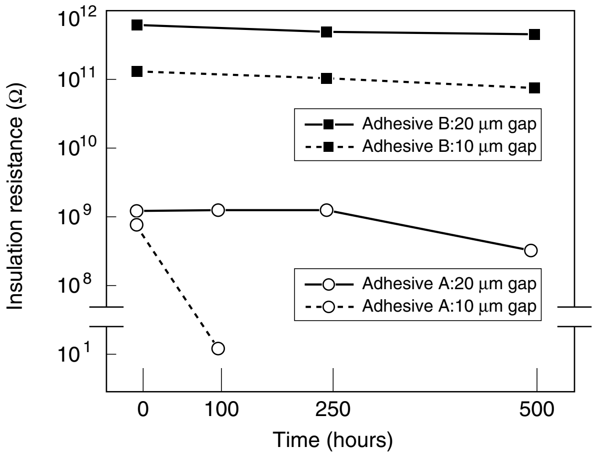

Figure 9.
Changes in insulation resistance of adhesives A and B during high-temperature, high-humidity, bias-voltage test (85°C,85%RH,5.5volts).

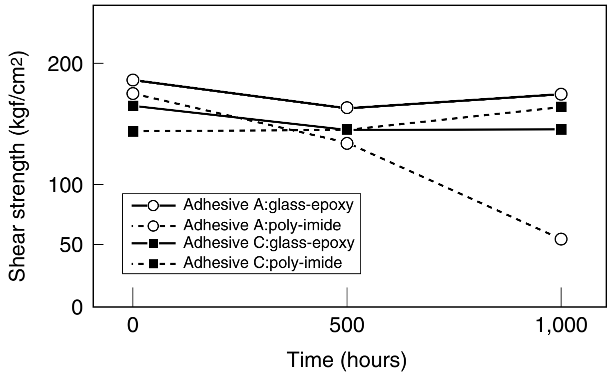

Figure 10.
Change in shear strength during high-temperature, high-humidity (85°C,85%) storage.

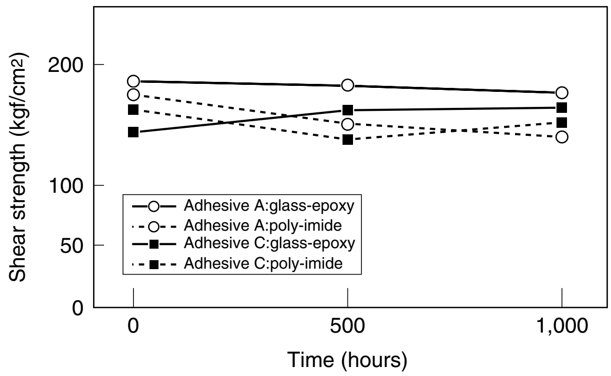

Figure 11.
Change in shear strength during high-temperature storage (130°C).

and a double-sided flexible PCB test substrate. We also did a reliability test for a practical sample (head IC of a hard disk drive; **Figure 8**). The reliability test was done under the same conditions as the test for MCM-L/D (Table 2).

4. Results and discussion

4.1 Insulating property of adhesive

As shown in **Figure 9**, the insulating resistance dropped rapidly in the case of adhesive A with a 10 µm gap. We estimated that if the I/O pitch is less than 100 µm, the minimum gap is 20 µm. Therefore, we decided to use adhesive B for MCM-L/D substrates that have a lower I/O pitch (80 to 100 µm) than glass-epoxy substrates (120 µm minimum).

4.2 Shear strength improvement on poly-imide film surface

As shown in **Figure 10**, the shear strength of adhesive A on a poly-imide film surface is degraded by humidity.

Next, we measured the shear strength change during high-temperature storage by using the same test piece because we considered that not only humidity but also high-temperature stress would affect the shear strength.

Figure 11 shows the measured changes in shear strength during high-temperature storage at 130°C. The shear strength did not change for adhesives A or C. We therefore concluded that adhesive C has sufficient reliability for flexible PCBs.

4.3 Examination of bonding pressure

Because the insulating layer is made from a

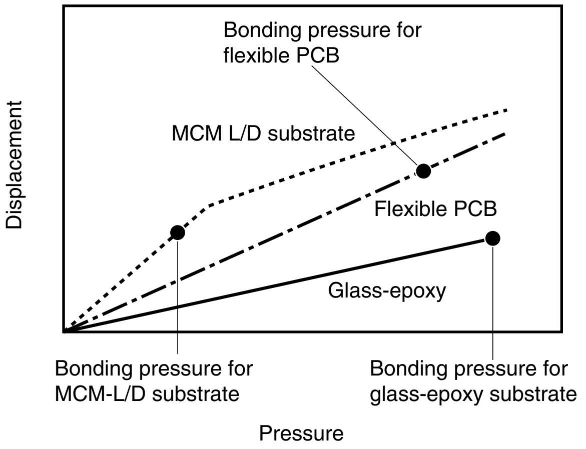

Figure 12.
Typical measured curves of MCM-L/D substrate pad, flexible PCB pad, and glass-epoxy substrate pad.

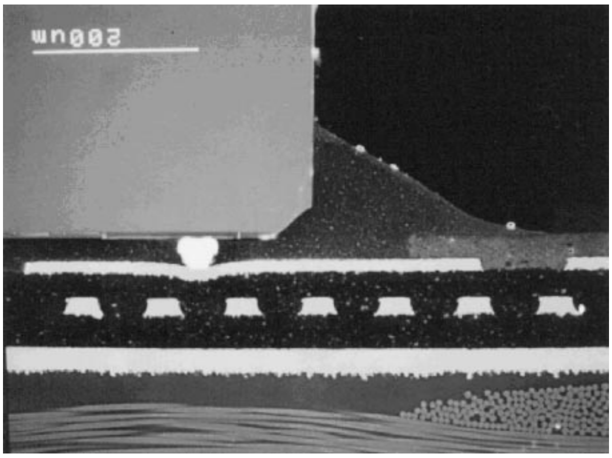

Figure 13.
Cross section of typical flip chip joint on MCM-L/D substrate.

different material, we measured the displacement characteristic of the substrate pad. As shown in **Figure 12**, on the flexible PCB, where poly-imide film is used as an insulating layer, the displacement is less than on the MCM-L/D substrate. We therefore set the initial bonding pressure for a flexible PCB somewhere between the MCM-L/D substrate and glass-epoxy conditions.

However, because the insulating layer of an MCM-L/D substrate does not contain glass-fibers, the insulating layer is easily transformed and the thickness of the encapsulant could be reduced,

Table 3. Reliability test results of test samples(80 μm I/O pitch, adhesive B).

Test	Conditions	Passes/samples tested
Thermal cycles	-65°C to 125°C 1,000 cycles	25/25
High-temperature, high-humidity, bias-voltage	85°C, 85% 5.5 V 1,000 hours	25/25
High-temperature storage	135 °C 1,000 hours	25/25

Table 4. Practical MCM-L/D reliability test results (Adhesive B).

Test	Conditions	Passes/samples tested
Thermal cycles	-65°C to 125°C 1,000 cycles	25/25
High-temperature, high-humidity, bias-voltage	85°C, 85% 5.5 V 1,000 hours	25/25
High-temperature storage	135°C 1,000 hours	25/25

thereby reducing the displacement in the vertical direction. If too much force is applied to the MCM-L/D pad, the distortion in the insulating layer may be sufficient to cause the substrate pattern to contact and damage the circuit surface of the chip. Therefore, the initial bonding pressure must be carefully determined and controlled. For this reason,we measured the pressure-displacement characteristics of substrate pads of each kind of substrate.

As shown in **Figure 13**, the MCM-L/D substrate pad is deformed more than the glass-epoxy substrate and flexible PCB. This is because the MCM-L/D substrate has no glass fibers and because the MCM-L/D substrate pad is narrower and thinner (the glass-epoxy and flexible PCBs have a 120 μm I/O pitch, and the MCM-L/D substrates have an 85 μm I/O pitch). Sufficient theoretical work has yet to be done regarding the correlation between the deformation of this substrate pad and the connection reliability. However, according to our experience, an open failure occurs during thermal cycle testing if the initial bonding pressure is too low. A more detailed investigation into the relation between the initial bonding pressure and the reliability will be made at a later date.

4.4 Reliability test results

1) Flip chip on an MCM-L/D substrate

The reliability test results of test samples are summarized in **Table 3**, and the results for practical samples are summarized in **Table 4**. We estimated that if the I/O is less than 100 µm, the minimum gap will be less than 20 µm. However, there were no failures after a high-humidity, high-temperature, bias-voltage test because we used adhesive B, which, as mentioned in Section 4.1, has a sufficient insulating property.

2) Flip chip on a flexible PCB

The reliability test results of the test samples are summarized in **Table 5**. Open failures occurred with the combination of adhesive A and a flexible PCB. We attributed these failures to flake-offs occurring at the interface between the poly-imide and the adhesive due to the humidity degradation of the adhesive on the poly-imide surface (Fig.10). On the other hand, there were no failures in the case of adhesive C, which had a high shear strength on the poly-imide surface.

Table 5. Connection reliability test results(120 µm test chip : Passes/samples tested).

	T/C -55°C to 125°C 1,000 cycles	HHB 85°C, 85% 5.5 V 1,000 h	HTS 130°C 1,000 h
Adhesive A, glass-epoxy	25/25	25/25	25/25
Adhesive A, flex. PCB	25/25	17/25	25/25
Adhesive C, glass-epoxy	25/25	25/25	25/25
Adhesive C, flex. PCB	25/25	25/25	25/25

Table 6 shows the reliability test results of practical samples. We used adhesive C in this case, and there were no failures.

5. Practical use

5.1 MCM-L/D

This technology was successfully applied to the CPU module of a notebook PC to reduce its size and weight. **Figure 14** shows the MCM-L/D and the MCM-L/D on the motherboard. **Table 7** compares data for the MCM-L/D notebook PC and one made using conventional SMD mounting technology.

5.2 Hard disk drive

We have applied this technology to the head ICs of a 1.8-inch hard disk drive. The mounting area of each chip on the new head that was made is 3/4 the mounting area on the same head made using the wire bonding method. Since there are

Table 6. HDD head unit reliability test results (Adhesive C).

Test	Conditions	Passes/samples tested
Thermal cycles	-65°C to 125°C 1,500 cycles	25/25
High-temperature, high-humidity, bias-voltage	85°C, 85% 5.5 V 1,000 hours	25/25
High-temperature storage	135°C 1,000 hours	25/25

Table 7. Comparison with SMD technology.

Module size weight	100 mm × 100 mm 104 g	50 mm × 50 mm 26 g
Substrate : Layers Thickness Line width/gap Via halls	8 laminated t = 1.2 mm 100/154 µm d = 0.35 mm : PTH	4 laminated and 4 deposited t = 0.75 mm 50/50 µm d = 0.2 mm : PTH d = 0.1 mm Photo via
LSI minimum I/O pitch	0.25 mm : TCP	85 µm : Flip chip

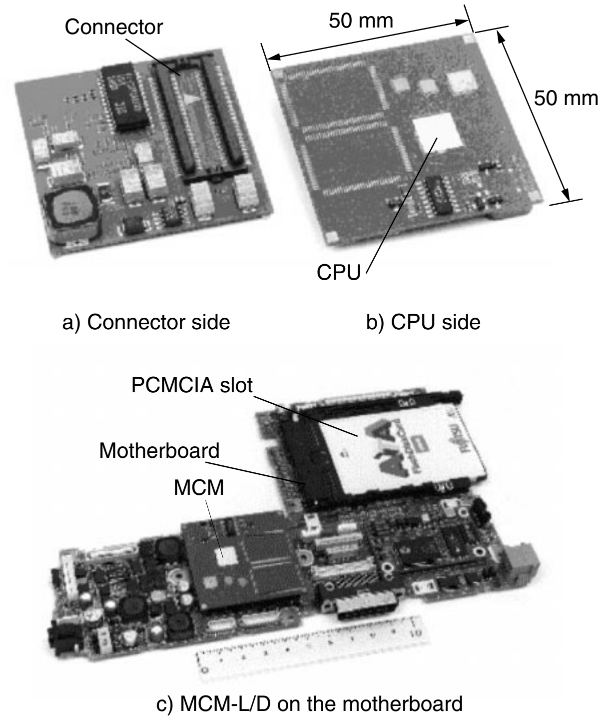

Figure 14.
MCM-L/D on the motherboard.

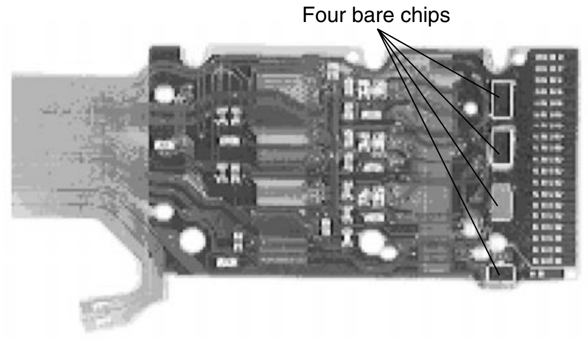

Figure 15.
Four flip chips on a flexible PCB
(Head ICs of 1.8-inch hard disk drive).

four chips on this PCB unit, the new head is less than 2/3 the size of the wire bonded head. **Figure 15** shows a photograph of this head.

6. Conclusion

We have developed a flip chip technology for MCM-L/D and flexible PCBs by optimizing the characteristics of the adhesive and the initial bonding pressure. This technology has been applied to several practical products with satisfactory reliability.

For the next step, we are trying to develop a reparable adhesive to make this technology more practical. Finally, more theoretical study about interconnection reliability that includes horizontal and vertical stresses is necessary.

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