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Development of Ultrathin Bonding Wire for Fine Pitch Bonding

Yasuhide Ohno[*1] Yoshio Ohzeki[*1]

Abstract:

In the conventional wire bonding technologies, the bonding pitch was limited to a minimum of about 120 μm. A 40 μm pitch wire bonding technology was investigated with the aim of developing 600 DPI print heads. First, a ultrathin and high-strength gold-base alloy wire of 10 μm diameter was developed. Bonding technology was established to make wedge bonds at the bonding pitch of 40 μm by using the ultrathin wire developed. Trially manufactured 600 DPI LED print heads demonstrated the reliability of the 10 μm bonding wire. After extensive study on various manufacturing technologies, a process was finally established for the production of long wire with a fine metallic structure.

1. Introduction

As electronic equipment has decreased weight and size while increasing functionality, integrated circuits (IC) used in them are faced with growing demands for reduced size and increased pins. In recent years, IC mounting technology has made remarkable progress in response to the current tendency toward increased pins. Pads provided around the IC for information exchange between its inside and outside must be reduced in spacing to accommodate the increased number of pins. With the present mounting technology, however, the shortest pad spacing is said to be 120 μm by the conventional wire bonding process and 80 μm by the tape automated bonding (TAB) process.

There is mounting need for higher resolution of terminal printers, calling for the development of 600 DPI (dots per inch) LED (light emitting diode) printers in place of the existing 400 DPI LED printers[1]. To realize a 600 DPI print head, precision wire bonding technology with a bonding pitch of 40 μm must be developed. The wire bonding process is most advantageous from the point of view of mounting cost. The authors undertook the difficult task of developing new wire bonding technology to make the 40 μm pitch possible instead of the conventional minimum pitch of 120 μm, the limit so far. **Fig. 1** schematically illustrates 40 μm pitch wire bonds formed on an LED print head. The LED chips and the driver IC chips are connected by ultrathin wire. This development has been made jointly with Oki Electric Industry Co., Ltd.

2. Experimental

2.1 Wires used in experiments

Gold wires used for the wire bonding process are commonly made of 4N (99.99%) pure gold and measure 25 to 30 μm in diameter. With a view to establishing the 40 μm pitch wire bonding technology, however, ultrathin gold-base-alloy wires with high

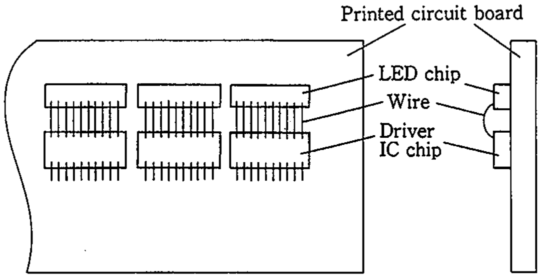

Fig. 1 Schematic illustration of LED print head

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*1 Technical Development Bureau

strength were trially manufactured.

The wire bonding process is conventionally divided into ball bonding process and wedge bonding process, each of which is adopted in specific fields where its meritorious characteristics can be best exploited. **Photo 1** compares in appearance the ball bond and wedge bond, each using gold wire. As evident from the photo, the wedge bonding process that exhibits a smaller deformation width after bonding is advantageous in accomplishing the 40 μm pitch, which is very difficult for the ball bonding process to achieve.

Fig. 2 shows two short-circuit conditions considered to occur when wire bonds are formed at the 40 μm pitch. The conditions (a) and (b) can be expressed respectively by the following relational expressions (1) and (2) of boundary condition:

$$P>2\times\frac{W}{2}+\sqrt{2(T^2+M^2+F^2)}\qquad\cdots\cdots(1)$$

$$P>\left(\frac{W}{2}+\frac{B}{2}\right)+\sqrt{(T^2+M^2+R^2+F^2)}\qquad\cdots\cdots(2)$$

where P is wire bonding pitch; W is wire deformation width; F is deformation width variation; T is bonder teaching accuracy; M is bonder mechanical accuracy; R is pattern recognition accuracy; and B is pad width. The two relational expressions are graphed in **Fig. 3**. The region where wire bonds can be made at the 40 μm pitch is shaded in the figure.

The bonding strength of wire bonds is another important factor. **Fig. 4** shows the experimentally determined deformation width and pull strength of bonds by wedge bonding formed by using 10, 13, and 18 μm diameter wires. From the figure, the 10 μm wire provides the highest bonding strength in the deformation width range of 19 to 21 μm. **Fig. 5** shows the variation of deformation width when the 10 μm wire was deformed to 20 μm. The 3σ variability is 6.4 μm. When the data of **Fig. 5** are consolidated with those of **Fig. 3**, it is known that 40 μm wire bonding is feasible on condition that the 10 μm wire is bonded to achieve the deformation with of 20 μm.

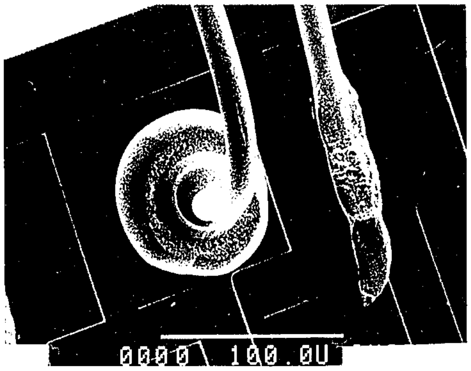


Photo 1 Comparison of wire bonds by ball bonding and wedge bonding processes

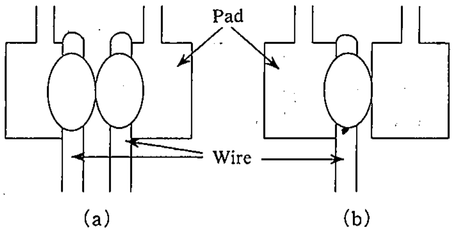


Fig. 2 Short-circuit modes of wire bonds

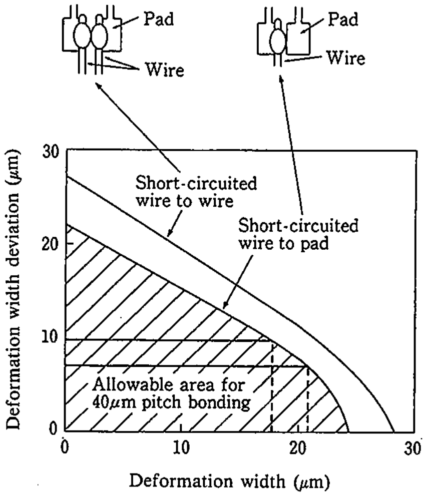


Fig. 3 Effects of deformation width and positional accuracy on short-circuit conditions of wire bonds formed at 40 μm pitch

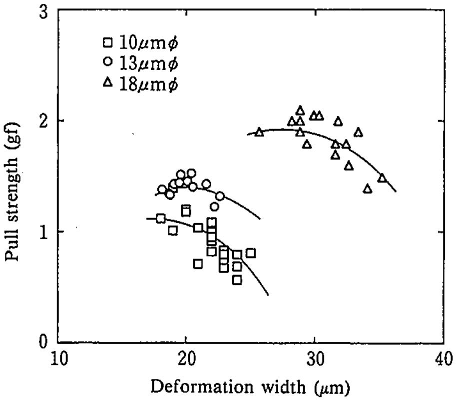


Fig. 4 Deformation width versus pull strength of wire bonds

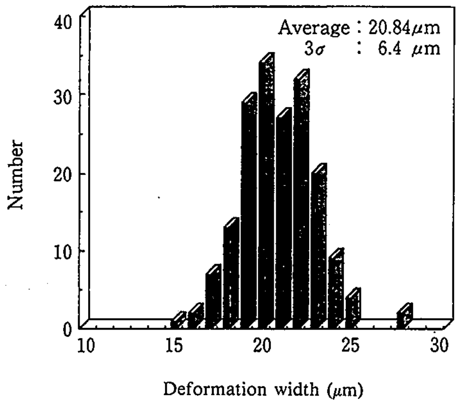


Fig. 5 Deformation width distribution

A 10 μm wire must be developed as noted above. When the conventional 4N gold wire is reduced to the diameter of 10 μm, the following problems occur:

(1) The wire strength is too low to handle.
(2) The resultant wire bond is low in pull strength.
(3) The wire is difficult to draw to such a small diameter.
(4) Tailing tends to occur in the second bond.

To solve these problems, three types of high-strength gold-base alloy wires were trially made as shown in **Table 1**. The wire diameter is 10 μm. **Fig. 6** shows the relationship between the diameter and breaking strength of the prototype gold-base alloy wires as compared with the commercial 4N gold wire. The strength of the prototype wire III having a 10 μm diameter is approximately equal to the strength of the commercial 4N gold wire having a 25 μm diameter. The gold-base alloy III is a high-strength material with a breaking strength of 115 kgf/mm^2. These three types of bonding wires have gold substrate doped with a few weight percentage of other elements.

2.2 Bonding method

The above-mentioned prototype gold-base wires were bonded to aluminum electrode pads at the 40 μm pitch simulating the 600 DPI print head, and appropriate wire bonding conditions were researched into. The deformation width and bonding positional accuracy were investigated for first bonds, and the tail occurrence was investigated for second bonds. Pull strength was measured as an overall index. As bonding conditions, the bonding tool force was 15 to 100 gf, the ultrasonic power was 2.5 to 10 mW, and the ultrasonic time was 10 to 150 ms. Detailed data were collected as to conditions that permit uninterrupted bonding.

Table 1 Mechanical properties of prototype gold-base alloy wires

Bonding wire	Wire diameter (μm)	Breaking load (gf)	Elongation (%)
Au-base alloy I	10	1.7 - 3.4	0.1 - 2.6
Au-base alloy II	10	2.3 - 4.4	0.1 - 6.4
Au-base alloy III	10	9.1	1.1
Commercial grade Au (99.99%)	15	4	1

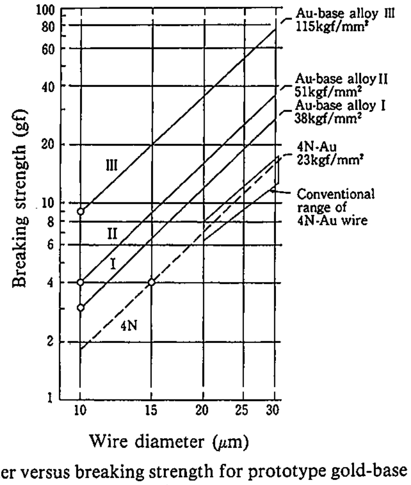


Fig. 6 Diameter versus breaking strength for prototype gold-base alloy wires and commercial 4N gold wire

2.3 Reliability tests

Thermal and humidity cycling test and thermal shock test were conducted using print heads having wire bonds formed under optimum conditions as described above.

3. Results of Experiments

3.1 Bond properties

Bond properties were evaluated using the gold-base alloys I to III shown in **Table 1**. Wire of the gold-base alloy I produced bonds with good properties at the 40 μm pitch. The gold-base alloy II provided bonds with a small deformation width and high strength, but tailing in second bonds made it impossible to make continuous bonding using the gold-base alloy II. The gold-base alloy III was high in strength and easy to handle, but revealed serious electrode damages. **Photo 2** shows examples of electrode damage arising from the use of the gold-base alloy III. The photo reveals a slight the wire deformation, and extensive electrode depression.

Continuous bonding is hampered by a decline in the bonding strength and tailing in the second bond. The tail refers to a wire break that occurs off the second bond site when the clamp is closed and the wire is cut after second bonding. The occurrence of such tail makes it impossible to form the first bonding in the next cycle, stopping the continuous bonding operation.

Fig. 7 shows the properties of wire bonds formed with wires of the gold-base alloy I. Wire bonds with optimum deformation width and high strength were obtained with the ultrasonic power of 3 mW, ultrasonic time of 60 to 80 ms, and tool force of 15 gf.

Fig. 8 shows the optimum range of bonding conditions in terms of wire breaking load and elongation for the prototype gold-base alloys I to III as compared with the commercial 4N gold wire. The optimum mechanical properties of 10 μm wires to produce bonds at the 40 μm pitch are the breaking strength of 2.5 to 3.5 gf and the elongation of 0.5 to 2%.

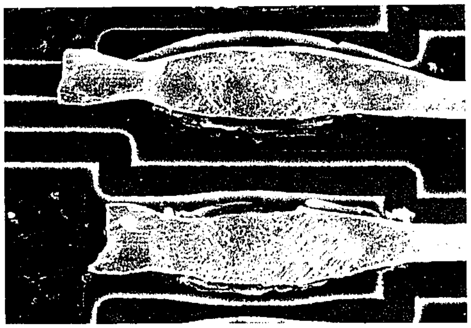
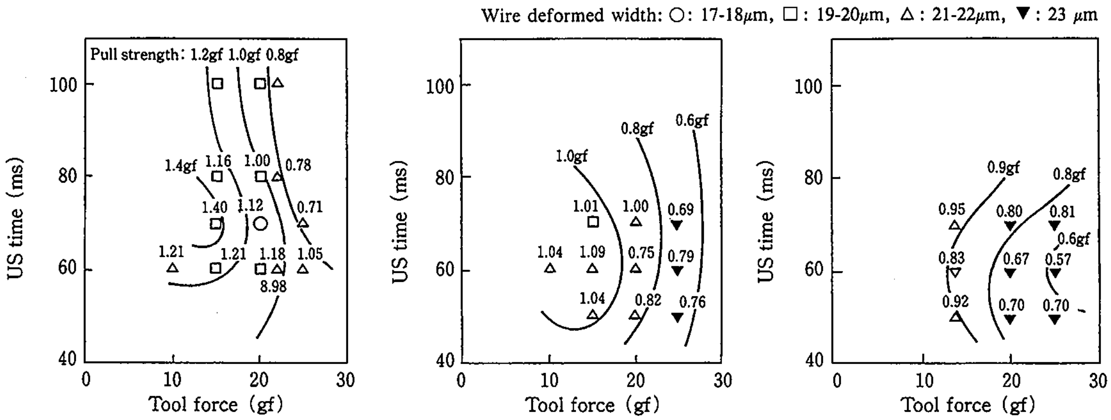


Photo 2 Examples of aluminum electrode damages



US power 3mW

US power 4mW

US power 5mW

Fig. 7 Experimental results showing effects of bonding conditions on deformation width and pull strength of wire bonds

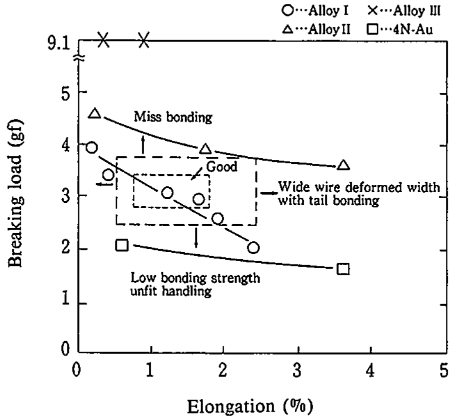


Fig. 8 Optimum range of elongation and breaking load for wire with good bondability

Fig. 9 shows the cross sections of bonding tools used in the experiments. The standard type has the wire threaded through the hole from the heel at the rear and guides the wire to the bond site. The guide type threads the wire from the rear and directly guides it to the bond site. The relationship between the tool hole diameter and the bonding positional accuracy was investigated. The results are as shown in **Fig. 10**. For the bonding positional accuracy, the guide type with a small hole is shown to be preferable.

3.2 Results of reliability tests

Wire bonds were formed on the LED print head under the optimum bonding conditions established as described in the preceding section, and were subjected to the thermal and humidity cycling test (repeated cycling at a temperature between −10°C and 65°C, 95%RH, 24-h cycles). The resultant change in electrical resistance is shown in **Fig. 11**. **Fig. 12** shows the change in the pull strength of wire bonds in the thermal shock test (−55°C, 0.5 h-125°C, 0.5-h cycles). A 4N gold wire of 15 μm diameter was used as comparison specimen. The gold-base alloy wire was finer than the 4N gold wire, but produced good results in each reliability test. **Photo 3** shows the appearance of 40 μm pitch wire bonds formed on the LED chip.

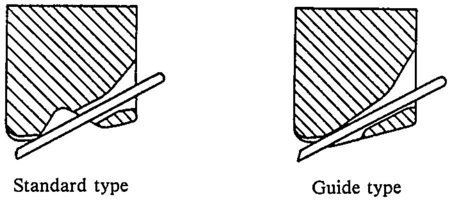


Fig. 9 Bonding tools

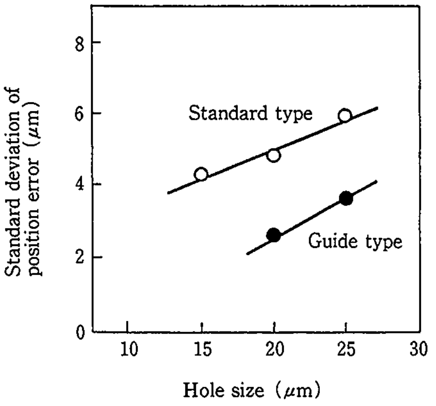


Fig. 10 Bonding positional accuracy and tool type

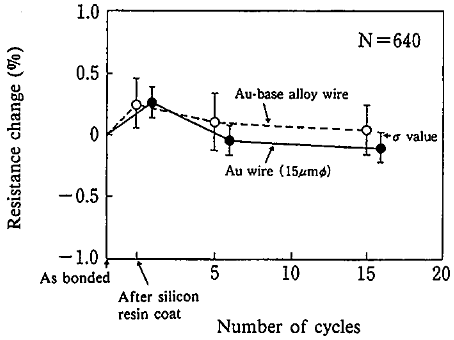


Fig. 11 Change in electrical resistance of bonding wire in thermal and humidity cycling test

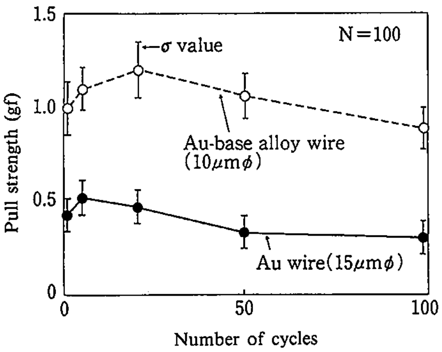


Fig. 12 Change in pull strength of bonding wire in thermal shock test

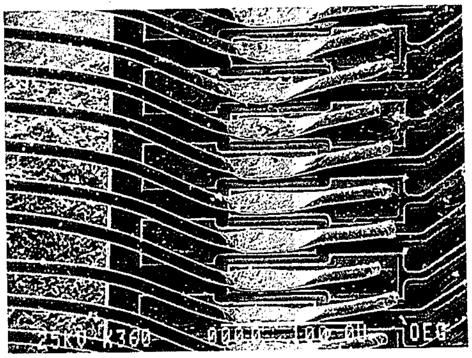


Photo 3 Scanning electron micrograph of 40 μm pitch wire bonds

4. Discussion on Ultrathin Wire Manufacturing Technology

High-strength gold-base alloy wire of 10 μm diameter was developed to establish technology for wire bonding at the pitch of 40 μm. The metallic structure of the wire is as shown in **Photo 4**. The wire diameter being 10 μm, the crystal grain size is a few micrometers, and the microstructure is dense and homogeneous.

The manufacture of bonding wire involves die drawing to the aimed diameter at room temperature and then annealing to the specified mechanical properties. One challenge in the development of the wire manufacturing technology was the establishment of drawing and annealing conditions for long 10 μm wire. Various measures, including highest-ever annealing temperature, were taken to draw 10 μm wire without breakage, which resulted in success in drawing practically long enough bonding wire. The annealing conditions are as schematically shown in curves in **Fig. 13**. The 10 μm wire exhibits characteristic elongation in the high-temperature region as compared with the conventional wire. As the annealing temperature rises, the 10 μm wire passes through the drawn structure recovery process, increases in elongation, and decreases in strength. As the annealing temperature rises further, the conventional wire decreases in strength and increases in elongation owing to recrystallization, whereas the ultrathin wire decreases in both strength and elongation.

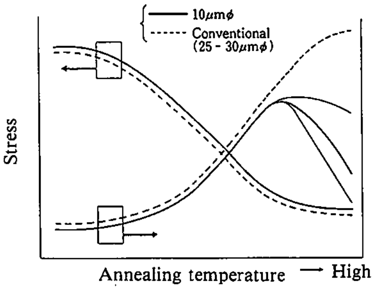


Fig. 13 Schematic diagram of annealing curves

The reason for the decrease of elongation in the ultrathin wire with further increasing annealing temperature is that recrystallized grains soon grow into the wire diameter to form the so-called bamboo node-like structure. This behavior resembles that of the heat-affected zone in ball bonding[2]. The optimum annealing conditions for the ultrathin wire are therefore narrower in range than for the conventional wire. This should be taken into account when manufacturing the ultrathin wire.

5. Discussion on Fine-Pitch Wire Bonding Technology

With a view to finding optimum wire bonding conditions, experiments were performed using three types of gold-base alloy wires, by varying the tool force, ultrasonic power and ultrasonic time in the bonding conditions. Some of the experimental results are shown in **Fig. 7**. These bonding conditions were investigated for correlation with pull strength and deformation width. The bonding conditions most closely correlated with the pull strength and deformation width of the wire bonds are shown in **Figs. 14** and **15**. The experimental results of **Figs. 14** and **15** are for the alloys I and II, respectively. Wedge bonding is essentially pressure welding by ultrasonic vibration. Its bonding mechanism is not fully clear yet and must be discussed in relation not only to the properties of the wire itself but also to the properties of the mating aluminum electrode pads.

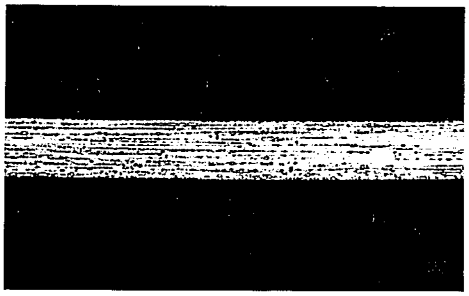


Photo 4 Cross-sectional microstructure of ultrathin wire

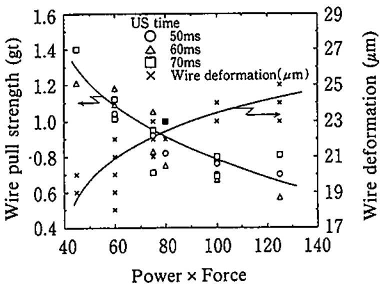


Fig. 14 Wire bonding conditions versus pull strength of gold-base alloy I

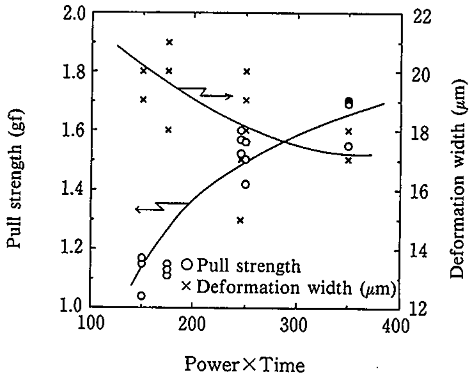


Fig. 15 Wire bonding conditions versus pull strength of gold-base alloy II

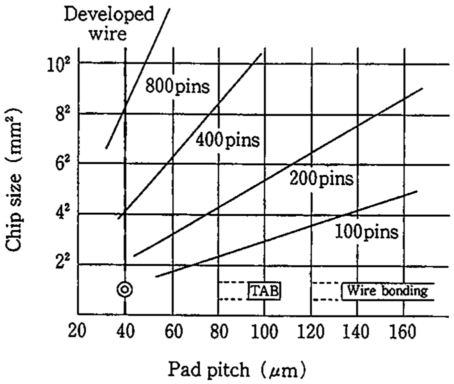


Fig. 16 Newly developed wire bonding technology as compared with conventional bonding technologies

6. Conclusions

The foregoing may be summarized as follows:

(1) Ultrathin and high-strength gold-base alloy bonding wire of 10 μm diameter was developed.
(2) Wire bonding technology was developed to form wire bonds at the pitch of 40 μm using the new wire.
(3) These technologies were used in the manufacture of 600 DPI prototype LED print heads, with good reliability.

The newly developed technology is compared with the conventional bonding technologies in **Fig. 16**. Through the application of the new 40 μm pitch wire bonding technology to other devices, the limits of the IC mounting technology are expected to be drastically expanded.

Acknowledgments

The authors express deep gratitude to the staff of Oki Electric Industry Co., Ltd. who have jointly developed the ultrathin bonding wire.

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