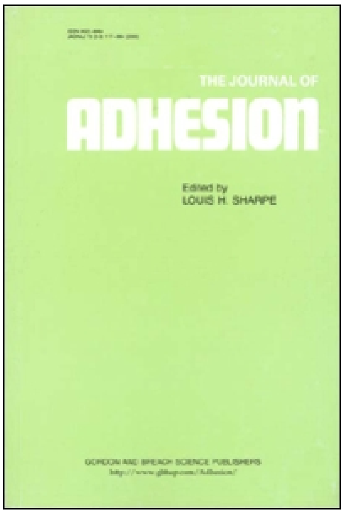

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Reliability of Fine-Pitch Flip-Chip (COG) Bonding with Non-Conductive Film Using Ultrasonic Energy

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This study evaluated the reliability of fine-pitch, flip-chip bonding with ultrasonic energy and non-conductive film (NCF). The surface treatment was carried out with H_2SO_4 *before flip-chip bonding (FCB). The electro-plated Cu bumps on the Si wafer and Cu-coated glass substrate were prepared for chip on glass (COG). The ultrasonic bonding was carried out, with and without NCF, under optimum bonding pressure and time. The mechanical properties were tested by die shear testing. The reliabilities of COG with and without NCF were evaluated with thermal shock testing, humidity and temperature (HT) testing, and high temperature storage (HTS) testing after FCB. The contact resistances of COG were evaluated for electrical reliability. To determine the variation in the initial value of the contact resistance of the flip-chip bumps according to the bonding method, the bonded interface of each sample was analyzed with scanning electron microscopy (SEM).*

Keywords: Chip on glass (COG); Copper bump; Die-shear-test; Flip-chip; Non-conductive film; Reliability test; Ultrasonic bonding

1. INTRODUCTION

Miniaturized, multifunctional, and portable electronics have been realized by the development of flip-chip bonding (FCB) technology using solders or adhesives. Solder bump connections show superior

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electrical and mechanical properties, while the excessive growth of intermetallic compounds at the joint interface significantly degrades the performance and reliability of the solder joint during manufacturing and system operation [1]. Furthermore, electronics may experience heat damage during manufacturing due to high processing temperature when conventional, lead-free solders are used [2]. Adhesive bonding methods using anisotropic conductive adhesive (ACA) or non-conductive adhesive (NCA) provide shorter bonding time, lower bonding temperature, and finer pitch than conventional solder bumps. However, they show poor electrical properties [3]. Additionally, the thin chip die can suffer breakage during bonding owing to the high bonding pressure.

Recently, ultrasonic FCB (UFCB) technology has attracted research attention owing to several advantages such as fast bonding time, low bonding temperature, low bonding pressure, low environmental impact, high electrical performance, and good reliability [4,5]. However, the joint strength of UFCB is no higher than that using adhesive bonding with methods such as NCA and ACA. Therefore, non-conductive film (NCF) is used in UFCB to complement the joint strength.

Copper is a typical material for interconnections and has been extensively used in microelectronics packaging because of its advantages of cost reduction, good electrical and thermal conductivity, good reliability, and mechanical stability. In this study, therefore, the reliability of FCB with and without NCF using ultrasonic energy was investigated. To measure the bondability, die shear testing of the flip-chip package was performed with different bonding conditions. In order to analyze after UFCB with and without NCF, the bonded interface was observed with scanning electron microscopy (SEM). To compare the reliabilities of chip on glass (COG) with and without NCF, the contact resistances before and after the reliability test were measured with a Kelvin structure.

2. EXPERIMENTAL PROCEDURES

A. Sample Preparation

Figure 1 shows the cross-sectional schematic structures of the upper flip-chip and lower glass substrate. Si and glass wafers were prepared to fabricate the upper and lower substrates. A 100-nm thick SiO_2 layer was deposited on a bare Si wafer, and then 100-nm thick Ti and 500-nm thick Cu layers were sputtered on top. The SiO_2, Ti, and Cu layers acted as the passivation, adhesion (between SiO_2 and Cu),

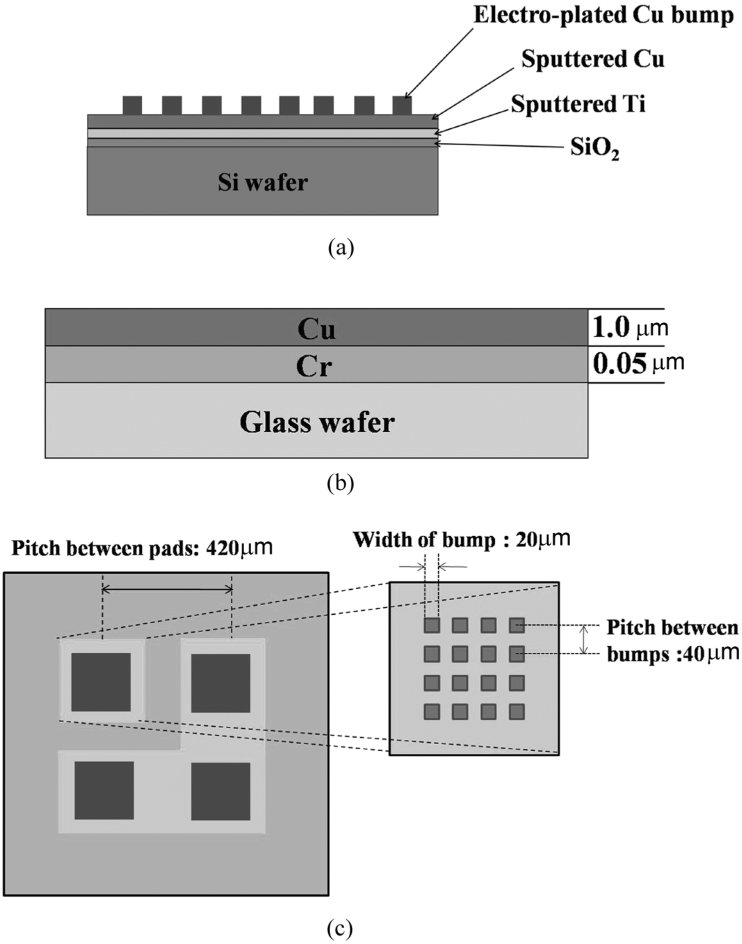


FIGURE 1 Cross-sectional schematic diagrams of the (a) upper and (b) lower substrates used in this study; (c) a top view of the upper Cu flip-chip.

and interconnection layers, respectively. After the photolithography process, 64 Cu bumps, of dimensions 20 (width) × 20 (length) × 14 (height) μm^3, were electroplated on the sputtered Cu surface, as shown in Fig. 1c. After another photolithography process, the Ti/Cu layers were selectively etched for the patterning of the Kelvin structure. Four bonding pads, each with 16 bumps, were formed in a package. The pitch size between two bumps was 40 μm. To fabricate the lower substrates, the glass wafer underwent photolithography for circuit formation and was then sputtered with 50-nm thick Cr and 1000-nm thick Cu layers to act as the adhesion layer between the glass wafer and the Cu layer, and between copper and the interconnection, respectively. After the Cu and Cr were sputtered, the Cr/Cu layers were selectively etched for circuit formation. Finally, the upper and lower substrates were diced to dimensions of $3 \times 3\,\mathrm{mm}^2$ and $9 \times 9\,\mathrm{mm}^2$, respectively.

B. Surface Treatment

The samples were rinsed with 5 vol. % (aqueous) H_2SO_4 for 10 s. In ultrasonic bonding technology, surface treatment is essential for successful bonding. The optimum surface treatment for UFCB with Cu flip-chip bumps and Cu-coated glass wafer was investigated in our previous study [6].

C. UFCB With and Without NCF

Figure 2 shows a schematic diagram of the ultrasonic bonding system. The upper and lower substrates were directly bonded using an ultrasonic bonder (Fine-placer-Lambda, FINETECH GmbH & Co. KG, Berlin, Germany). In the other process with NCF, the Cu flip-chips

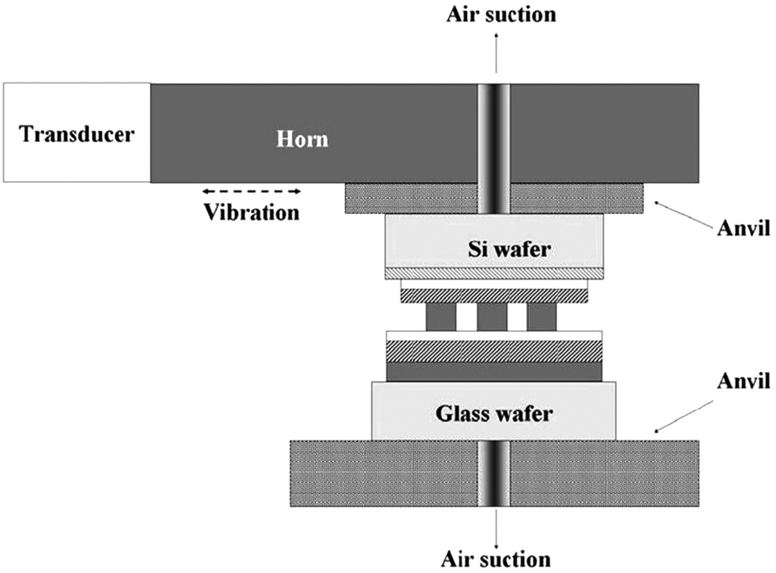


FIGURE 2 Schematic diagram of the ultrasonic bonding system used in this study.

TABLE 1 UFCB Conditions With and Without NCF for Chip on Glass (COG)

Vibration direction	Transverse
Power (W)	8
Frequency (kHz)	40
Pressure (N)	Without NCF 10; with NCF 20
Time (s)	Without NCF 0.5; with NCF 1.0
Temperature (°C)	Ambient temperature
Humidity (%RH)	40

and the lower glass substrates sticking to the NCF were bonded to the glass substrates using an ultrasonic bonder with variable temperature. The temperature of the bouder was varied from 65 to 110°C. Table 1 shows the experimental details of the UFCB. Figure 3 shows the top view of the upper Cu flip-chip and the lower glass substrate before UFCB.

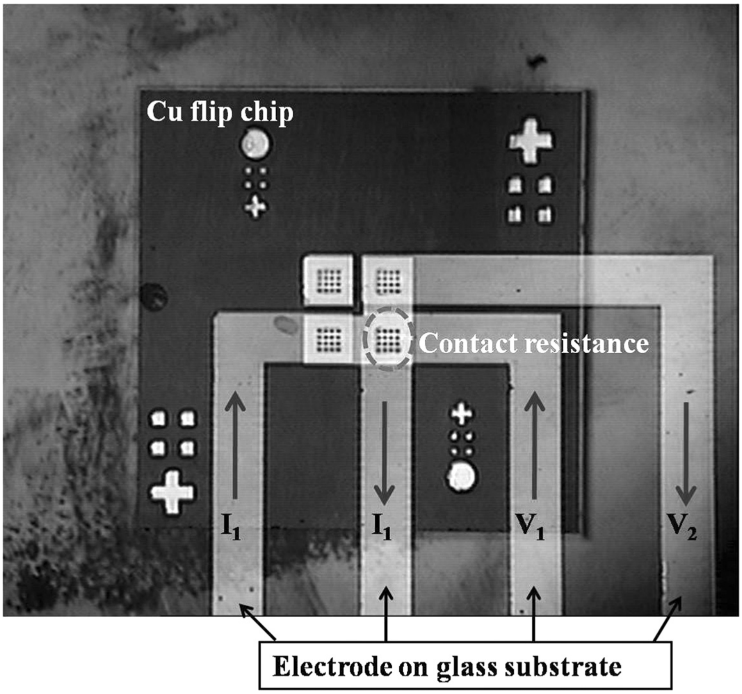


FIGURE 3 Overlap image of the upper Cu flip-chip and the lower Cu-coated glass substrate with a Kelvin structure before UFCB.

D. Microstructure Observations

After bonding, the samples were mounted in cold-cure epoxy and mechanically polished for microstructure observation. The microstructures of the samples were observed with SEM.

E. Die Shear Test

Die shear tests were carried out with the bonded samples using a die-shear tester, Rhesca PTR-1000 (Rhesca, Tokyo, Japan), and 5 kg.f and 30 kg.f load cells. The instrument was calibrated with a 1 kg.f standard weight. The displacement rate, probe height, and probe width were 200 μm/s, 5 μm, and 10 mm, respectively.

F. Electrical Resistance Measurement

The electrical resistance of the 16 bumps located on each bonding pad was evaluated using a Kelvin structure. The resistance was calculated by measuring the I-V curves, *i.e.,* the output voltage per input current, over the current range of 0.001 to 0.01 A using a four-point probe station. I_1, I_2, V_1, and V_2 show the current input, current output, voltage input, and voltage output, respectively, for measuring the contact resistance, as shown in Fig. 3.

3. RESULTS AND DISCUSSION

A. UFCB with NCF

Figures 4a and b show the optimum bonding temperature and time for the ultrasonic bonding: 95°C and 1.0 s, respectively. UFCB was carried out conventionally at ambient temperature. However, UFCB with NCF did not bond without additional heat energy because the ultrasonic energy at ambient temperature was too low to generate sufficient heat energy for deforming and curing the NCF.

B. Comparison of Mechanical Reliability

To investigate the mechanical properties of the two different bonding systems, die-shear testing was carried out. In the case of UFCB without NCF, the bonding strength peaked at 550 g.f after treatment with sulfuric acid, which demonstrated the effectiveness of the sulfuric acid treatment in increasing the mechanical reliability of the Cu flip-chip package compared with that before the treatment which peaked at

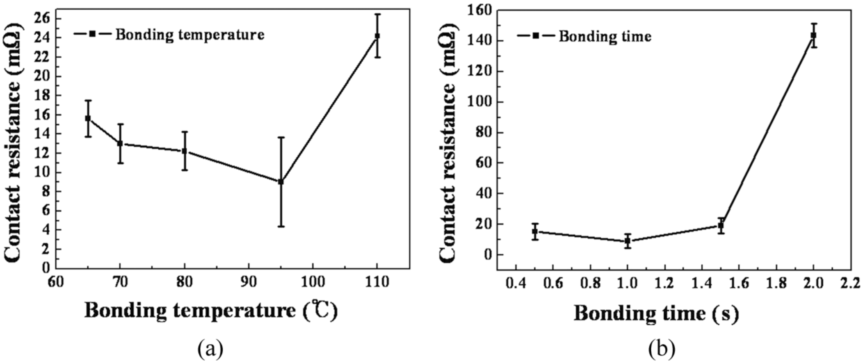


FIGURE 4 Optimum (a) temperature (with time fixed at 1.0 s) and (b) time (with temperature fixed at 95°C) conditions of Cu-to-Cu bonding using ultrasonic energy with NCF.

122 g.f [6]. In the case of UFCB with NCF, however, the die-shear test results could not be measured because the Si flip-chips were broken due to the high bonding strength between the Cu flip chips and the glass substrates after the NCF was cured. The Cu bumps and the Cu pad were bonded to the NCF after the Si chip was broken. Therefore, UFCB with NCF greatly improved the mechanical reliability of the Cu flip-chip package.

C. Contact Resistance

The initial contact resistances of UFCB with and without NCF were about 5.57 and 9.02 mΩ, respectively. Figures 5a and b are the cross

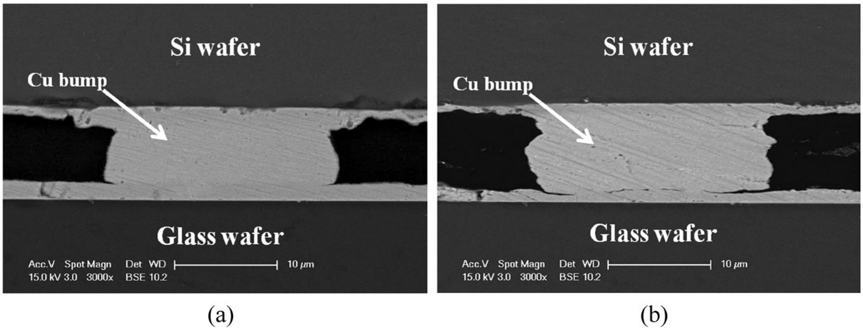
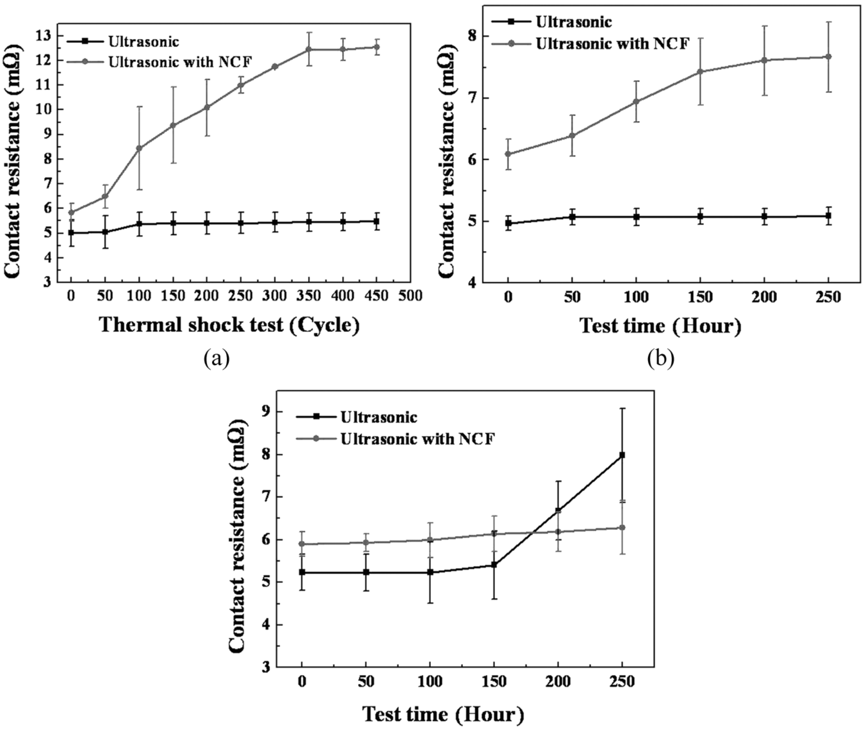


FIGURE 5 Cross-sectional images (a) after UFCB and (b) after UFCB with NCF.

sectional images after UFCB without and with NCF, respectively. Figure 5a shows the successful bonding between the Cu bump and Cu pad, whereas, epoxy resins remained after UFCB with NCF processing, shown in Figure 5b. The epoxy resins in the bonding interface interrupted the electrical path between the Cu bump and Cu pad, indicating that the initial values of contact resistance were different.

D. Thermal Cycling (TC) and High Temperature Storage (HTS) Tests

Figure 6a shows the TC test results with the two different specimens. The test temperature was increased from −40 to 125°C over 15 min using a thermal shock chamber (TSA-101S, ESPEC, Osaka,



(a) (b)

(c)

FIGURE 6 Contact resistance results after the (a) TC test, (b) HTS test, and (c) HT test measured by using a Kelvin structure.

Japan). The contact resistance of UFCB barely changed even after 450 cycles. However, the contact resistance of UFCB with NCF steadily increased with increasing TC. During UFCB with NCF, not all of the epoxy resins could flow out from the bonding interfaces due to the morphology of the Cu bumps. The different coefficients of thermal expansion between the Cu and epoxy resin degraded the electrical reliability. During the TC test, the shrinkage and expansion of UFCB with NCF were higher than those of UFCB. With increasing TC, the contact area between the Cu bumps and Cu pad decreased. The HTS test results were consistent with those of the TC test, as shown in Fig. 6b. The HTS test was conducted at 125°C using an oven.

E. Humidity and Temperature (HT) Test

For the HT test, the samples were placed in a temperature humidity chamber at 85% RH and 85°C. Fig. 6c shows the results of the HT test. The reliability of UFCB with NCF was higher than that of UFCB without NCF. After UFCB with NCF, the Cu flip-chip package was filled with epoxy resins that preserved the joint area from high humidity. However, the joint strength of the Cu bumps and Cu pad without NCF was weakened due to the high moisture. The cured NCF between the Cu flip-chip bumps and the Cu pads effectively blocked off the moisture and oxidation.

4. CONCLUSION

This study investigated the reliability of 40-μm pitch Cu FCB with and without NCF using ultrasonic energy. Cu flip-chip bumps and Cu-coated glass substrates were ultrasonically bonded with additional heat energy. The mechanical reliability of the joint strength between the Cu flip-chip and the glass substrate was greatly improved using NCF. However, the initial contact resistance of UFCB with NCF was higher than that of UFCB without NCF. UFCB exhibited excellent reliability in the TC and HTS tests, whereas UFCB with NCF showed good reliability in the HT test.

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