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Characteristic study of anisotropic-conductive film for chip-on-film packaging

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Abstract

Chip-on-film (COF) is a new technology after tape-automated bonding (TAB) and chip-on-glass (COG) in the interconnection of liquid crystal module (LCM). The thickness of the film, which is more flexible than TAB, can be as thin as 44 μm. It has pre-test capability, while COG does not have. It possesses great potential in many product fabrication applications.

In this study, we used anisotropic-conductive film (ACF) as the adhesive to bind the desired IC chip and polyimide (PI) film. The electric path was formed by connecting the bump on the IC and the electrode on the PI film via the conductive particles in the ACF. In the COF bonding process experimental-design method was applied based on the parameters, such as bonding temperature, bonding pressure and bonding time. After reliability tests of (1) 60 °C/95%RH/500 h and (2) −20 to 70 °C/500 cycles, contact resistance was measured and used as the quality inspection parameter. Correlation between the contact resistance and the three parameters was established and optimal processing condition was obtained. The COF samples analyzed were fabricated accordingly. The contact resistance of the COF samples was measured at varying temperature using the four points test method. The result helped us to realize the relationship between the contact resistance and the operation temperature of the COF technology. This yielded important information for circuit design. © 2001 Published by Elsevier Science Ltd.

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1. Introduction

Chip-on-film or chip-on-flex (COF) is the fabrication technology that is currently applied in liquid crystal module (LCM) of small panel. COF is developed after the surface mount technology (SMT), tape-automated bonding (TAB), and chip-on-glass (COG) technology. The geometry of the COF is similar to that of TAB. However, the substrate of COF is two-layer structure (Cu and polyimide (PI)), which is thinner, higher density, better flexibility and high-temperature durable; and the substrate of COF is not like TAB which is normally three-layer structure (Cu, adhesive, and PI). Compared with COG, COF has the features of lower contact resistance and available pre-test capability [1]. This technique has grown quickly and been applied on high-density, multi-functional LCM fabrication, such as mobile phone and personal digital assistance (PDA). In addition, it is also applied to chip scale package (CSP) [2–4] and multi-chip module [3].

There are many kinds of COF technologies using Flip Chip Bonding Technology, such as Au/Sn eutectic joining, solder joining, anisotropic-conductive film (ACF) joining [5,6], and non-conductive adhesive [7,8]. Among these COF technologies the ACF joining technology has been extensively applied in liquid crystal display (LCD) product as the interconnections for outer

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leaded bonding on glass (OLB-on-Glass), COG, and nowadays wildly used in COF as the main stream process. This method is based on the random conductive particle connections between IC bumps and electrodes on flex. The binder not only can be used as an adhesive but also can provide the necessary contractility to maintain the contact between the electrodes. Because COF process is similar to COG and TAB-on-Glass processes, many LCM fabricators have been developed in accordance with this trend.

Au/Sn eutectic bonding process is achieved by heating the joints of IC chip and flex to form the eutectic bonding between Au bump and Sn electrode, and followed by protecting the joints by underfill. In the past, tape carrier package (TCP) used eutectic process. However, because the mid layer (adhesive) in this three-layer structure is not high temperature durable, punching a window for bonding area is unavoidable and the bonding lead's support substrate (PI) is removed. Finally, the ILB joints are protected by encapsulation. On the other hand, COFs substrate (flex) is two-layer structure without adhesive layer. Hence, it can endure high-temperature process like eutectic bonding. Since the COF process is similar to TCP process, many manufacturers with TCP fabrication lines are moving towards this direction. This technology becomes another major manufacturing procedure of COF after ACF bonding.

Soldering is based on solder reflow. Connection is achieved by melting the joints on the electrodes of IC Solder bump and flex, and then fills the underfill. The disadvantage of this process is easy to form shortage resulted from melting connection so that it is not suitable for high-density connection.

NCA and ACF differ mainly in the use of conductive particles in the adhesive material between the chip and the substrate. Unlike ACF, the adhesive used in NCA method has no conductive particles. The contact force between the two opposing electrodes is created in NCA owing to the compression stress between the chip and the substrate when the adhesive is applied. Larger contact area and finer pitch are achieved when using NCA than when using ACF because the entire surfaces of the opposite electrodes, rather than random particles, come into contact. Many companies in the world are starting to develop this joining method, which could be a very important technology in the near future.

Among the aforementioned bonding methods in COF, the ACF joining was chosen in this study because it was a main stream process. We first searched for the optimal process parameters according to the results from reliability test. The COF samples were then fabricated accordingly. The contact resistance was measured under various different temperatures to understand the influence of the environmental temperatures on the COF contact resistance.

2. Experiment

Fig. 1 schematically depicts the process flow of COF bonding by using ACF material, which includes (a) attaching the ACF on the flex substrate, (b) aligning the IC chip against the flex substrate, (c) applying high temperature and pressure on IC to cure ACF, and (d) removing pressure from the IC chip.

2.1. Materials used

1. Driver IC:
   - chip size: $X = 11.49$ mm, $Y = 2.44$ mm;
   - chip thickness: 400 ± 30 μm;
   - bump size: 50×110 μm;
   - bump pitch: 80 μm;
   - bump height: 25 μm;
   - bump material: Au.

2. Flex substrate:
   - base film (PI): 22 μm thick;
   - conductor (copper): 12 μm thick, coated with gold;
   - insulator (solder resistor): 10 μm thick.

3. ACF:
   - binder:
     30 μm thick, thermal set, epoxy resin;
     glass transition temperature, $T_g = 125$ °C;
     coefficient of thermal expansion, CTE = 63 ppm, for $T < T_g$;
     CTE = 130 ppm, for $T > T_g$;
     elasticity = 1.2 GPa, at 30 °C;
     elasticity = 0.02 GPa, at 150 °C;
     water absorption: 2.3 wt.%;
   - conductive particle (resin coated with gold): 5 μm.

2.2. ACF properties measurement

In order to improve the quality of connection and further investigate the characteristics of the connection, besides having the bonding parameters suggested by ACF maker, we measured the curing temperature and T_g value from differential scanning calorimeter (DSC) and thermo mechanical analyzer (TMA) to fully understand the characteristics of the ACF.

The ACF's DSC analysis is shown in Fig. 2. The curing reaction was started when temperature was higher than 124 °C. Bonding time had to be long enough for fully curing. Generally, the bonding temperature was set at 180–210 °C to increase the throughput.

The ACF's TMA analysis is shown in Fig. 3. The curing condition was set at 180 °C for 5 s. The resultant T_g was 131 °C. Some ACF samples were cured at various temperatures, i.e. 160, 170, 180, 190, 200 and 210 °C.

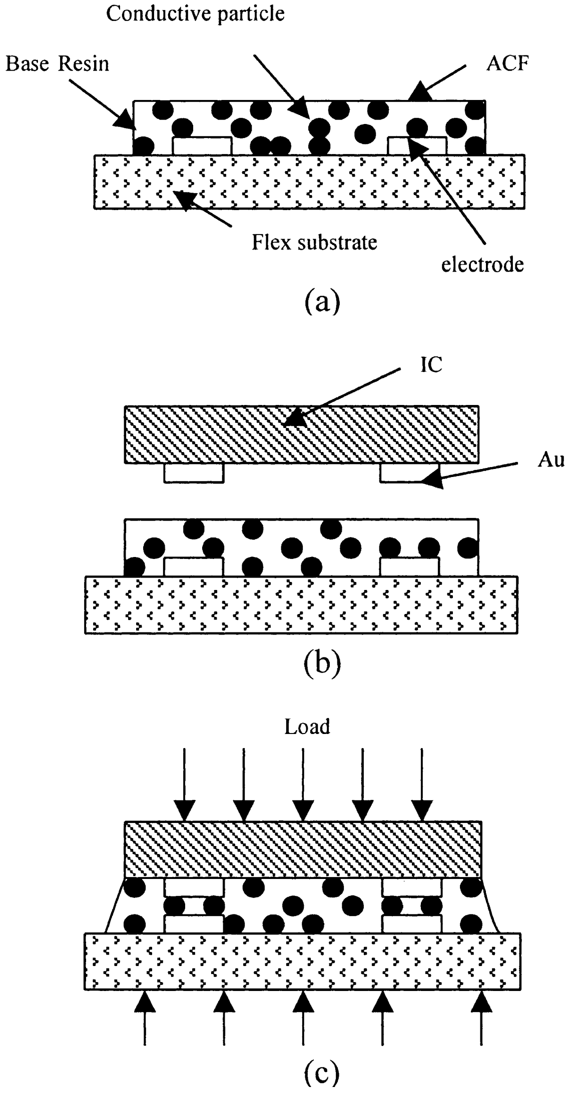

Fig. 1. ACF process: (a) lamination (temporary bonding): impose enough pressure and temperature to attach ACF on flex substrate, (b) alignment: align between IC and flex substrate, and (c) bonding: apply high temperature and pressure through IC to cure the ACF.

The T_g, shown in Fig. 4, increases as the bonding temperature increases. In general, before a critical bonding temperature is reached, the T_g markedly increases as bonding temperature increases. When curing temperature was higher than 180 °C, the T_g achieved a stable value which was around 130 °C. This means that bonding temperature needs to be set at temperature higher than 180 °C to ensure enough curing degree. The higher curing degree yields a higher T_g as well as a higher modulus. It is also discovered that the COF product under an environmental temperature higher

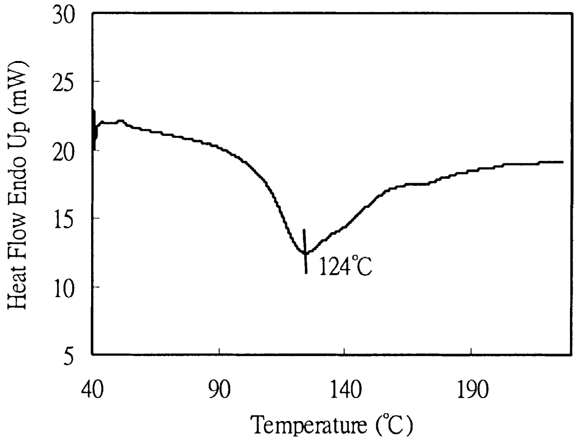

Fig. 2. DSC result of the ACF. The ramp rate is 10 °C/min.

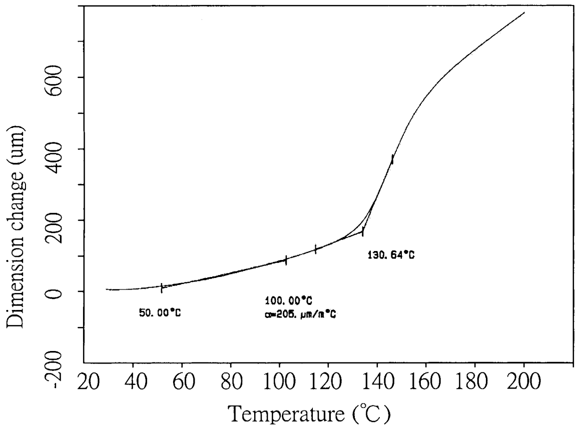

Fig. 3. TMA analysis of the ACF, which had been cured at 180 °C for 5 s.

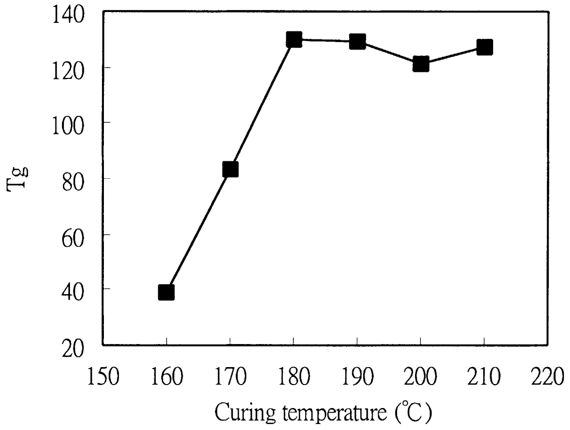

Fig. 4. Effect of curing temperature on the T_g of the studied ACF.

than T_g shows significant variation in its contact resistance.

2.3. Bonding accuracy measurement

Bonding accuracy affects the contact resistance of high-density connection. Poor accuracy causes random data and serious experimental deviation. It is difficult to check the accuracy due to poor transparency of the flex. Thus, X-ray or ultrasound measurement must be applied to check the connection. Fig. 5 shows the X-ray photograph of the bonding result of the COF sample from the backside. It is clear to see that the leads of the flex have been accurately bonded to the bumps of the chip.

2.4. Experimental design

The parameters in this experiment included bonding temperature, bonding pressure and bonding time. The temperature was set at 170, 190, and 210 °C, respectively. The pressure was set at 30, 50, and 70 g/bump, respectively. The time was set at 5, 10, and 15 s respectively. 27 combinations were obtained by all-factor experimental method. Six samples were made for each parameter set. These samples were tested to realize their reliability upon thermal cycling from −20 to 70 °C for 500 cycles and high temperature humidity at 60 °C, 95%RH for 500 h. All these reliability tests follow IEC 60068-2-3 standards. According to these optimal parameters, several COF samples were made and the contact resistance of each sample was measured under different temperature environments. The relationship between the contact resistance and the temperature variation was established. In the meantime, the *I–V* curve of the joints was determined.

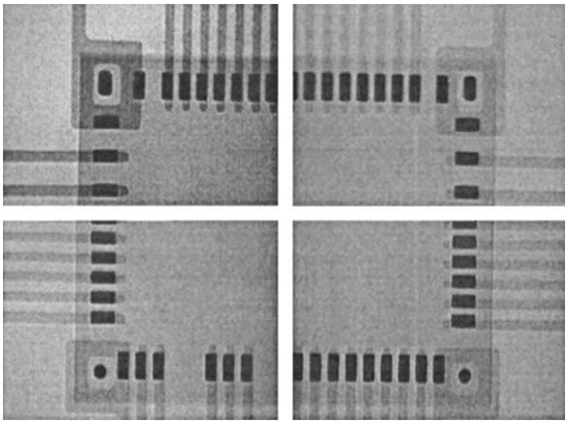

Fig. 5. X-ray inspection of the backside of COF sample.

2.5. Contact resistance measurement [9]

Fig. 6 shows the COFs circuit design for electrical measurement and the equivalent circuit. Since I_{sense} is negligible, one has

$$V/I = R_2,$$

where R_2 is the contact resistance from bump-2 to the electrode of flex through ACF. The electrical resistance of the copper electrode is relatively small when compared to the ACF contact resistance, so it can be neglected.

3. Results and discussion

3.1. Contact resistance after COF bonding

Fig. 7 shows bonding force effect on the contact resistance of the COF samples cured at three different temperatures (a) 170 °C, (b) 190 °C, and (c) 210 °C before reliability test. Obviously, the contact resistance is lower when the bonding force is larger, the bonding temperature higher, and the bonding time longer.

Fig. 8 shows SEM photographs of the COF samples cured under three different conditions (a) 170 °C/5 s/(30 g/bump), (b) 210 °C/5 s/(30 g/bump), and (c) 210 °C/15 s/(70 g/bump). The photographs obviously indicate the gap between the leads of flex and the bumps of IC chip to be the largest for condition (a), second largest for condition (b), and the smallest for condition (c). The corresponding contact resistance of the sample shown in Fig. 8 is the largest for condition (a) followed by condition (b). The condition (c) is the lowest. Comparing Fig. 8(a) with (b), it is learned that higher bonding temperature results in higher curing extent for the binder, the binder hence becomes stiffer with higher modulus. After the bonding process, the conductive particle only recoils a little. Thus the gap is small, and the contact resistance becomes relatively low. As learned from Fig. 8(a)–(c), the gap is smaller and the contact resistance lower, when the bonding force is larger, bonding temperature higher, and bonding time longer.

3.2. Contact resistance after thermal cycling test

Fig. 9 shows bonding force effect on the contact resistance of the COF samples cured at three different temperatures (a) 170 °C, (b) 190 °C, and (c) 210 °C after thermal cycling test (−20 to 70 °C/500 cycles). Markedly, the contact resistance is lower when the bonding force is larger, bonding temperature higher, and bonding time longer. The variation of contact resistance is relatively small after the thermal cycling when comparing

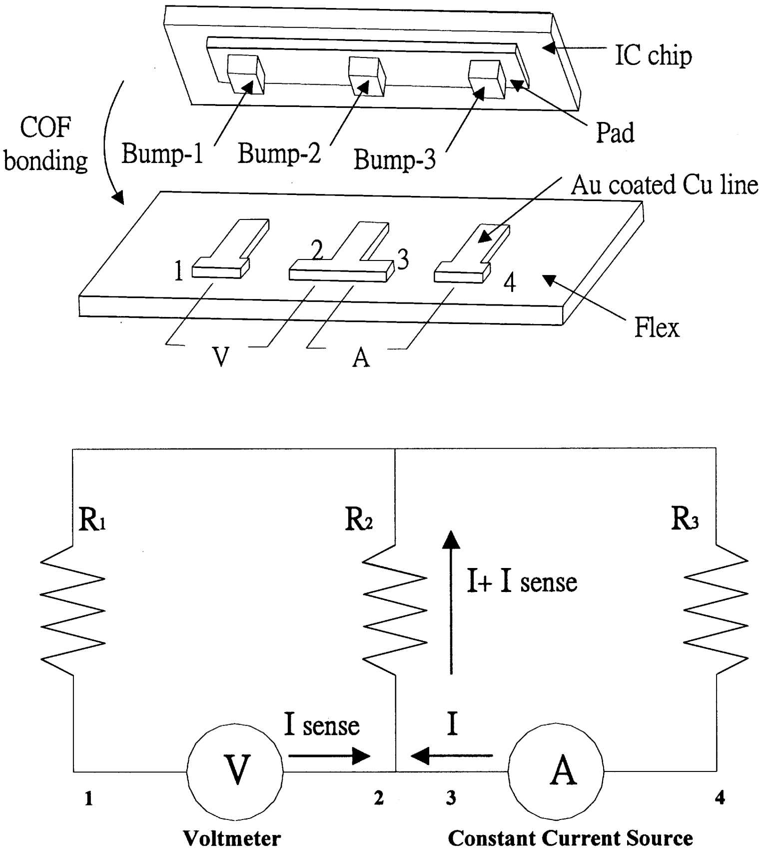

Fig. 6. Schematic illustration of the R_2 contact resistance measurement by using the four points test method and its corresponding circuitry.

Fig. 9 with Fig. 7. This indicates that the ACF bonding has been barely affected by thermal cycling.

3.3. Contact resistance after high temperature humidity test

Fig. 10 shows bonding force effect on the contact resistance of the COF samples cured at three different temperatures (a) 170 °C, (b) 190 °C, and (c) 210 °C after the high temperature humidity test (60 °C/95%RH/500 h). For those samples cured at the higher temperatures or longer curing time, the contact resistance decreased with the increase of bonding force, except for the sample bonded at 170 °C for 5 s as shown in Fig. 10(a). This sample that was bonded at 170 °C for 5 s may be due to poor curing of the binder that results to weak structure with lower modulus and poor adhesion. Since larger bonding force induces larger bouncing force, larger gap could then be resulted after the high temperature humidity test. This in turn results to higher contact resistance.

Comparing Fig. 10 with Fig. 7, it can be seen that the contact resistance of all the COF samples became higher after the high temperature humidity test. This was especially true for that cured at 170 °C for 5 s. This clearly indicates high temperature humidity test to have great impact on the ACF bonding, especially when the resin is not fully cured which result to weak structure with lower modulus.

According to the 27 sets of experiment, it was realized that the COF sample fabricated at 210 °C for 15 s with a bonding force of 70 g/bump exhibited the lowest contact resistance. Its contact resistance was barely affected after the reliability test. Its fabrication conduction was then decided to be optimal. The subsequent COF samples were then prepared under this chosen condition. Their interconnection characteristics were investigated and given in the following section.

3.4. Contact resistance at various temperatures

Fig. 11 shows the contact resistance of the COF samples at different environmental temperatures. As

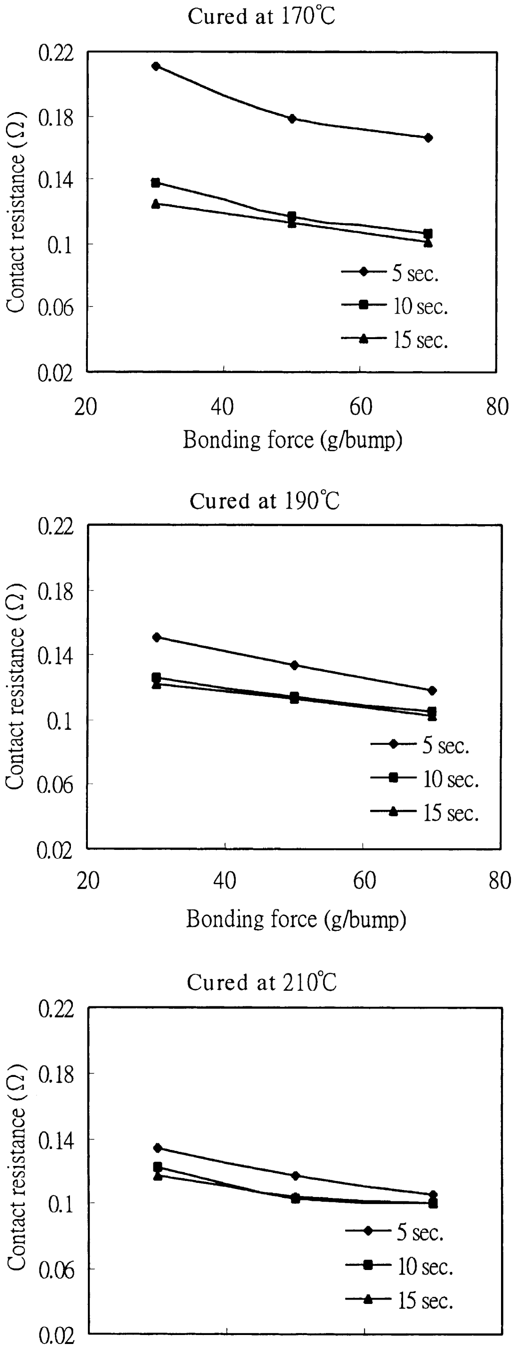

Fig. 7. Bonding force effect on the contact resistance of the COF samples cured at various different temperatures before the reliability test.

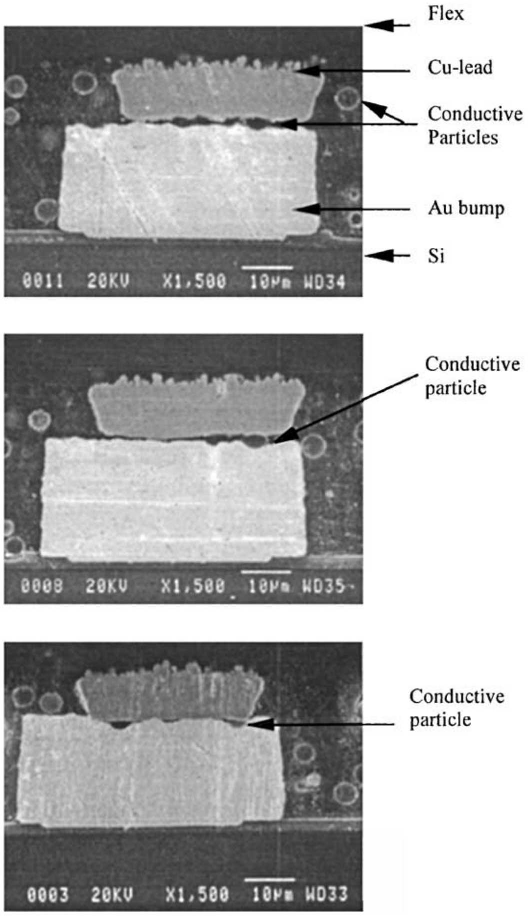

Fig. 8. SEM photographs of the COF samples cured under these different condition (a) 170 °C/5 s/(30 g/bump), (b) 210 °C/5 s/(30 g/bump) and (c) 210 °C/15 s/(70 g/bump).

seen in Fig. 11, the contact resistance increased with the increase of temperature. This may be attributed to the fact that the CTE of the ACF binder is smaller than that of the Au bump and conductive particle. This CTE mismatch caused reduction of the contact area between the IC bump and particles or between the electrode and particles, which would increase the contact resistance.

When the temperature was higher than 130 °C, the contact resistance increased with the increase of temperature at a higher rate. This is because the binder was softened at temperature above its T_g. The softened structure, with low modulus, would be more difficult to hold the conducting parts in good contact. Furthermore, the CTE value of the binder increased with the increase of temperature at a higher rate. Larger thermal mismatch for the binder with the conducting parts caused more serious reduction in their contact area. This, in turn, resulted in a rapid increase in the contact resistance.

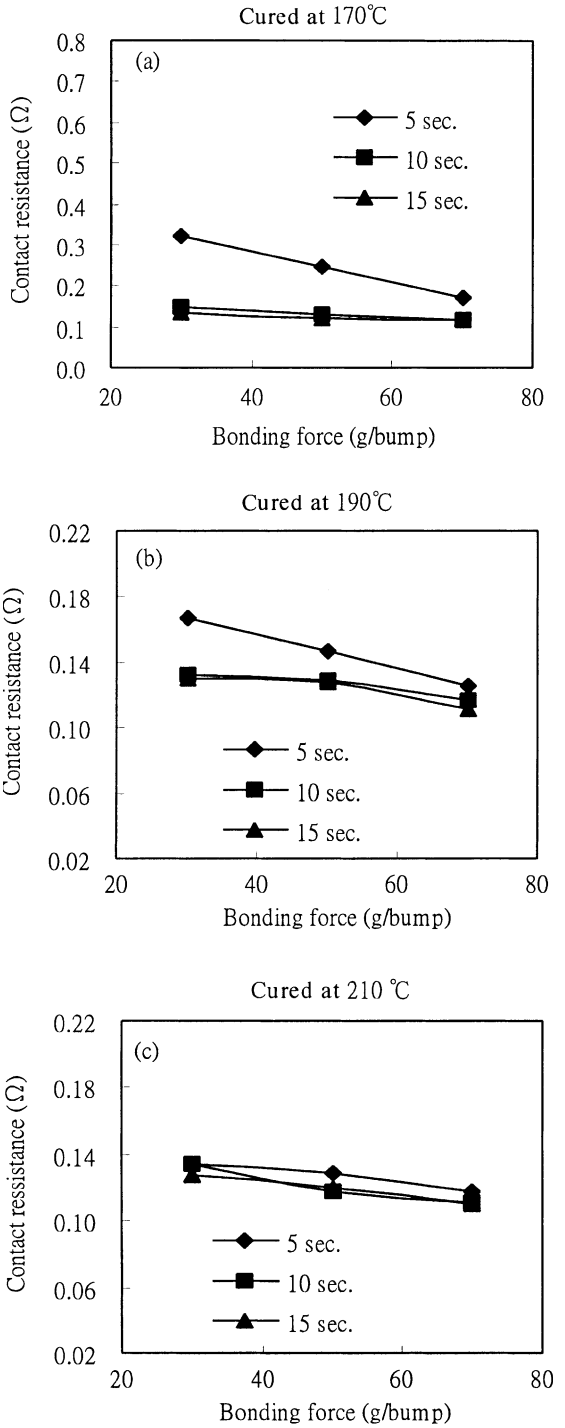

Fig. 9. Bonding force effect on the contact resistance of the COF samples cured at various different temperatures after the thermal cycling test from −20 to 70 °C for 500 cycles.

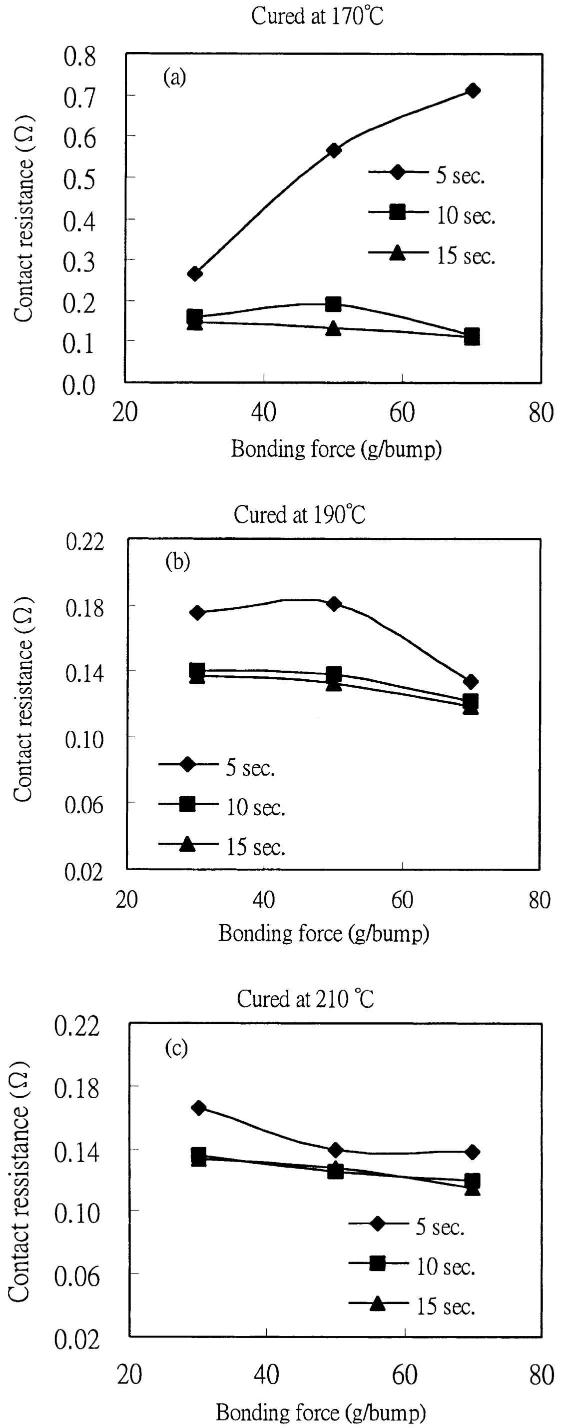

Fig. 10. Bonding force effect on the contact resistance of the COF samples cured at various different temperatures after the high temperature humidity test at 60 °C, 95%RH for 500 h.

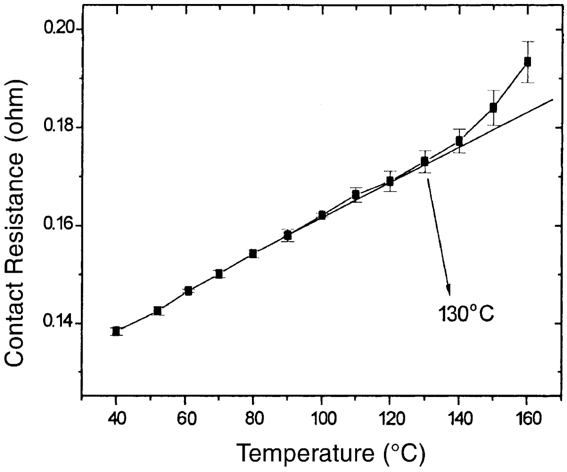

Fig. 11. Contact resistance measured at various different temperatures.

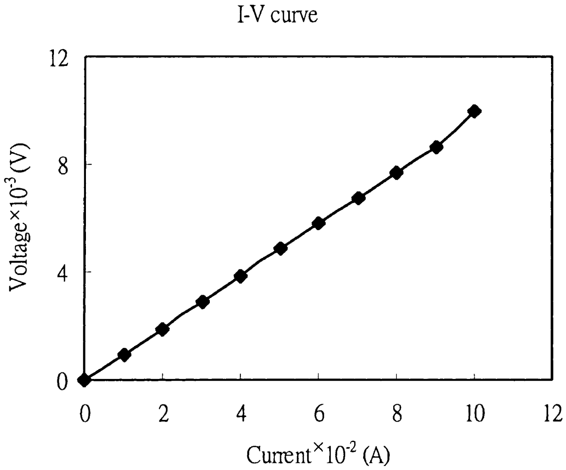

Fig. 12. *I–V* curve of the resultant COF sample. The nearly straight line clearly indicates its ohmic contact characteristic.

3.5. *I–V curve measurement*

Fig. 12 shows the *I–V* curve result of the COF joints. The *I–V* curve shows a linear relationship as the current is smaller than 0.09 A, indicating that the joint is an ohmic contact.

4. Conclusions

The impact of thermal cycling test on the contact resistance of COF joint was quite small. Nevertheless, the impact of high temperature humidity was significantly large.

Optimal process parameters were determined according to the results from high temperature humidity test. When bonding temperature ($\geqslant 190$ °C) and bonding time ($\geqslant 5$ s) were fixed, or bonding temperature at 170 °C and bonding time ($\geqslant 10$ s) were chosen, the contact resistance become smaller when the bonding force increased. Either higher bonding temperature or longer bonding time can result in higher degree of curing with higher modulus for the resin. In order to have a high throughput, bonding temperature can be increased to shorten the bonding time. To prevent resin damage, bonding time can be increased to improve the desired extent of curing even at lower bonding temperature.

The contact resistance of the COF sample obtained according to the optimal process parameters was quite low (around 0.1 Ω) and it was ohmic contact. The variation of the contact resistance after reliability test was quite small (below 0.02 Ω). Even when the operation temperature is as high as 140 °C, the contact resistance is still small (around 0.18 Ω). The electrical characteristics of the COF samples were stable and excellent.

References

[1] Clot P, Zeberli JF, Chenuz JM, Ferrando F, Styblo D. Flip-chip on flex for 3D packaging. Electronics Manufacturing Technology Symposium, Twenty-Fourth IEEE/CPMT, 1999. p. 36–41.

[2] Tjandra J, Wong CL, How J, Peana S. Au-Sn microsoldering on flexible circuit. IEEE/CPMT Electronic Packaging Technology Conference, 1997. p. 52–7.

[3] Kallmayer C, Oppermann H, Anhock S, Azadeh R, Aschenbrenner R, Reichl H. Reliability investigation for flip-chip on flex using different solder materials. Electronic Components and Technology Conference, 1998. p. 303–10.

[4] Fillion R, Burdick B, Piacente P, Douglas L, Shaddock D. Reliability evaluation of chip-on-flex CSP devices. International Conference on Multichip Modules and High Density Packaging, 1998. p. 242–46.

[5] Li L, Fang T. Anisotropic conductive adhesive films for flip chip on flex packages. Adhesive Joining and Coating Technology in Electronics Manufacturing Proceedings. 4th International Conference, 2000. p. 129–35.

[6] Chan YC, Hung KC, Tang CW, Wu CML. Degradation mechanisms of anisotropic conductive adhesive joints for flip chip on flex applications. Adhesive Joining and Coating Technology in Electronics Manufacturing Proceedings. 4th International Conference, 2000. p. 141–46.

[7] Ferrando F, Zeberli JF, Clot P, Chenuz JM. Industrial approach of a flip-chip method using the stud-bumps with a non-conductive paste. Adhesive Joining and Coating Technology in Electronics Manufacturing Proceedings. 4th International Conference, 2000. p. 205–11.

[8] Aschenbrenner R, Miessner R, Reichl H. Adhesive flip chip bonding on flexible substrates. The Proceeding of the First IEEE International Symposium on Polymeric Electronics Packaging, 1997. p. 86–94.

[9] Chang SM, Jou JH, Hsieh A, Chen TH, Chang CY, Wang YH, Lin HY, Huang CM. Characteristic study of chip-on-film interconnection. International Optoelectronics Symposium Photonics Taiwan, SPIE, July 2000. p. 228–39.