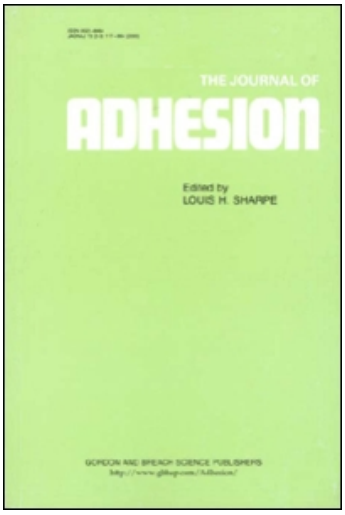

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Ultrasonic Bonding of Electrodes of Rigid and Flexible Printed Circuit Boards with Non-Conductive Film (NCF)

Jong-Bum Lee[1], Ja-Myeong Koo[2], Jong-Woong Kim[2], Bo-In Noh[1], Jong-Gun Lee[1], and Seung-Boo Jung[1]
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This study investigated the feasibility of ultrasonic bonding of a rigid printed circuit board (RPCB) to a flexible printed circuit board (FPCB) with a non-conductive film (NCF) for improving the long-term reliability and lowering the manufacturing cost. Peel tests of the joints were carried out with increasing bonding time to optimize the bonding condition. High-temperature storage and thermal cycling tests were carried out to evaluate the reliability. The RPCB was successfully bonded to the FPCB with NCF using a transverse ultrasonic bonding. The optimum time taken for bonding was 3 sec. The joints with NCF showed a good reliability after the high-temperature storage test at 125°C for 1,000 h and the thermal cycling test for 1,000 cycles.

Keywords: Flexible printed circuit board (FPCB); Non-conductive film; Peel test; Reliability test; Rigid printed circuit board (RPCB); Ultrasonic bonding

1. INTRODUCTION

Non-conductive adhesives (NCAs) bonding technology has been researched and applied as interconnect materials due to the fine pitch capability and simple process. Compared with anisotropic conductive adhesives (ACAs), NCAs do not contain conductive

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particles and require high bonding pressure with heat to bond the electrodes [1]. Electrical conduction is provided by direct and mechanical contact between the two surfaces of the electrodes when applying the heat and pressure. This joint contact is maintained by the bonding strength of the cured NCA resin. Nowadays, NCAs are being considered as an alternative material for ACAs, because they can achieve finer pitch of input/outputs (I/Os) due to the absence of any dispersion of conductive particles between I/Os, as well as better electrical properties.

The flexible printed circuit board (FPCB) and rigid printed circuit board (RPCB) have been broadly used in electronics because of their characteristics of flexibility, low cost, and high packaging density. As occasion demands, these printed circuit boards (PCBs) are needed to be used in an electronic package. Ultrasonic bonding at room temperature could be suitable for bonding the FPCB to the RPCB because of low bonding temperature, short bonding time, low-cost, and environmentally friendly operation [2,3]. Depending on the vibration direction of the horn, the ultrasonic bonding can be divided into longitudinal and transverse vibration systems. The transverse ultrasonic bonding is suitable for metal to metal and flip chip bonding because of the theoretically unlimited joint materials. However, the transverse ultrasonic systems need higher precision tools to control the amplitude of vibration and transmit the ultrasonic energy than the longitudinal system.

The ultrasonic electrode direct bonding showed low reliability without reinforcement as underfill in a previous study of the present authors [4]. Therefore, this study was focused on the optimization of processing time for the ultrasonic electrode bonding with a non-conductive film (NCF). It can be expected that the NCF keeps the electrodes connected and also improves the reliability as well as dispensing with the underfill. The surface finish of the FPCB and RPCB was fixed as electroless Ni/immersion Au (ENIG). Peel tests were carried out to measure the bonding strength between FPCB and RPCB with NCF and high-temperature storage and thermal cycling tests were carried out to evaluate the reliability.

2. EXPERIMENTAL PROCEDURE

Two different polymer substrates were employed for ultrasonic bonding: 1 mm-thick RPCB and 25 μm-thick FPCB. The electrodes on both PCBs were coated with 5 μm-thick electroless Ni/0.03 μm-thick immersion Au (ENIG). An epoxy-based NCF was employed for improving the long-term reliability of the joints. Table 1 shows the specifications of the PCBs used in this study.

TABLE 1 Specifications of the FPCB and RPCB Used in this Study

Pitch size (mm)	0.3
Bonding area (mm^2)	0.12×2.5
Electrode number (ea)	38
Surface finish	
RPCB	Electroless Ni (5 μm)/immersion Au (0.03 μm)
FPCB	Electroless Ni (5 μm)/immersion Au (0.03 μm)
NCF thickness (μm)	45

Figure 1 shows the schematic diagram of the transverse ultrasonic bonder with a constant vibration frequency of 27 kHz for RPCB-to-FPCB bonding. Before bonding, the two PCBs were cleaned by immersion in 10 vol. % H_2SO_4 for 1 min to remove contaminants. The NCF was pre-bonded on the electrodes of the RPCB at 80°C for 3 s. The RPCB was fixed on the anvil by a fixture to prevent the movement of the RPCB during ultrasonic bonding. The electrodes of the FPCB were bonded to those of the RPCB with NCF with different bonding times from 1 to 4 s at a bonding pressure of 40 MPa at room temperature.

A thermogravimetric analyzer (TGA), (Seiko Exstar 6000, Seiko Instruments, Tokyo, Japan), was utilized to determine the thermal decomposition temperature of the NCF. The heating rate and temperature range were 10°C/min and 25 ~ 600°C. The curing degree and chemical structural change of the NCF were evaluated using Fourier transform infrared (FTIR) spectroscopy. The resolution and

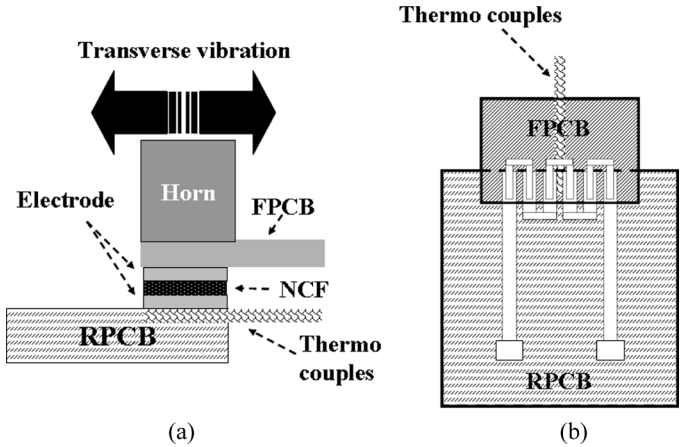

FIGURE 1 Schematic diagram of the transverse ultrasonic bonding system: (a) side view and (b) top view.

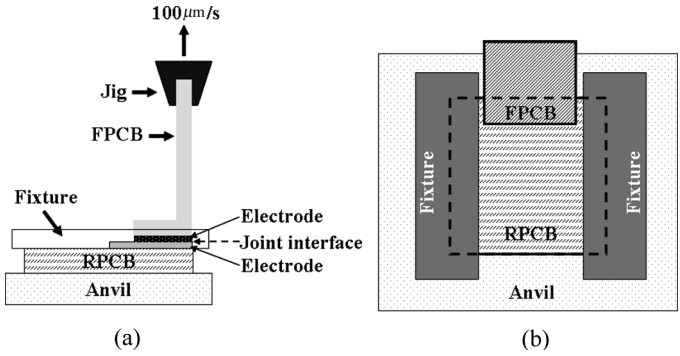

FIGURE 2 Schematic diagram of peel testing method: (a) side view and (b) top view.

spectral range were 4 and $4000 \sim 600\,\mathrm{cm}^{-1}$, respectively. To evaluate the effect of bonding time on the temperature variation of the joint, the surface temperature of the RPCB was measured using a 500 μm-thick k-type thermocouple during bonding. A space of 500 μm between the electrodes in the RPCB was cut off to place the thermocouple.

Figure 2 shows the schematic diagram of the peel test apparatus used in this study. To optimize the bonding condition, 90° peel tests were carried out with a displacement rate of 100 μm/s.

To investigate the reliability of the joints, high temperature storage (HTS) tests and thermal cycling (TC) tests were carried out using an oven and thermal shock chamber (TSA-101S, ESPEC, Osaka, Japan), respectively. For evaluating the circuit-opening and the joint reliability, the daisy-chain structure which consisted of 38 electrode joints connected in series as shown in Figure 1b, was fabricated to measure the electrical resistance. For the HTS test, the samples were isothermally aged at 125°C for 1,000 h. The TC test was performed in the range of −40°C to 125°C for 1,000 cycles. The dwell time at high and low temperatures was 15 min and the total time for one cycle was 30 min. During HTS and TC tests, the resistance of the daisy-chained circuit was measured every 200 cycles and 200 h, respectively. The resistance was obtained from the average of ten samples.

3. RESULTS AND DISCUSSION

Figure 3 shows the changes of the temperature at the interface between the FPCB and the RPCB during ultrasonic bonding. A narrow groove in the RPCB was gouged out to place the thermocouple. During ultrasonic bonding at room temperature, the temperature

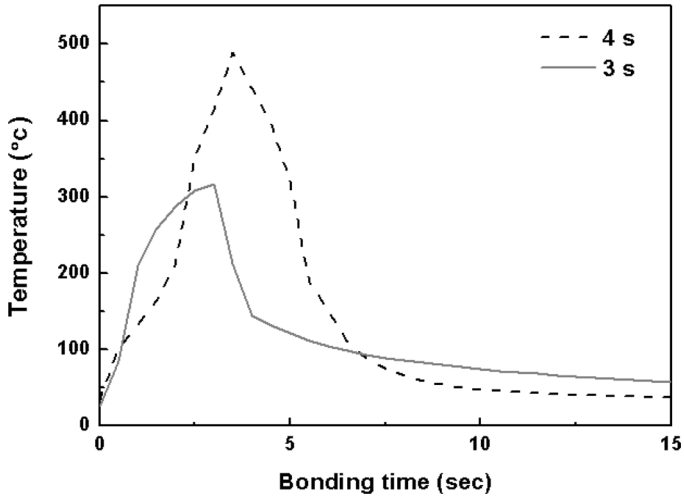

FIGURE 3 Temperature rise at the interface between the eletrodes during 3 and 4 sec of ultrasonic bonding.

reached 317.4°C and 489.3°C within 3 and 4 s, respectively. The NCFs can be rapidly heated and cured by applying ultrasonic vibration. The curing degrees and chemical structural changes in the NCF with different bonding times were determined by using FTIR spectroscopy. The epoxy functional group at the absorbance of 915 cm^{-1} decreased according to the progress of the bonding time, as shown in Fig. 4. This result shows that the curing degree of NCF increases as the bonding time increases. The heat was transferred to the monomers in the NCF during ultrasonic bonding and provided sufficient energy to the epoxy functional groups in the monomers to create polymer networks [5].

The thermal degradation of the NCF obtained by TGA is shown in Fig. 5. The figure shows the weight loss in percentage as the temperature increases. TGA is a method used to measure the weight loss of the samples due to formation of volatile products [6]. There are quite a number of interaction forces in the epoxy polymer networks. Covalent bonds in the polymer networks control the thermal and photochemical stability of polymers [7]. The polymer networks are fragmented at a certain temperature that causes the decomposition. For this reason, TGA was used to measure the thermal stability performances of the NCF. The NCF used in the TGA test was the original NCF material prior to the curing process. The weight dropped significantly when the temperature was above 320°C. This means that NCF is thermally

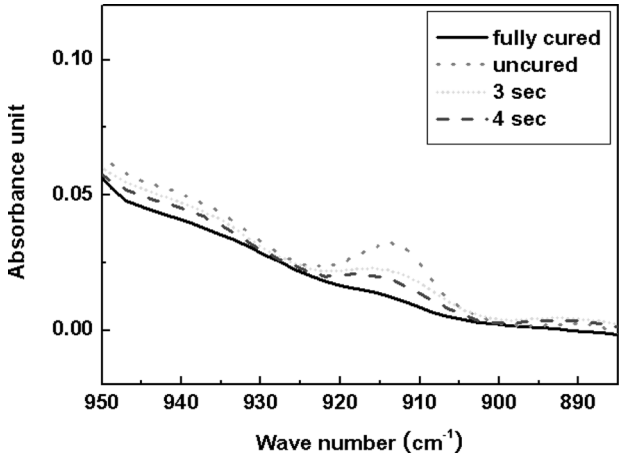

FIGURE 4 FTIR results showing epoxy group peaks at 915 cm^{-1} of uncured and fully-cured NCF and of NCF cured during 3 and 4 sec.

unstable and produced a great deal of volatile products at a temperature over 320°C.

Figure 6 illustrates the effect of the bonding time on the peel strength of the FPCB-to-RPCB joint. The peel strength of the PCBs bonded with NCF increased from 0.6 to 2.0 kgf/cm as the bonding time was increased from 1 to 4 s, while the peel strength of the PCBs with

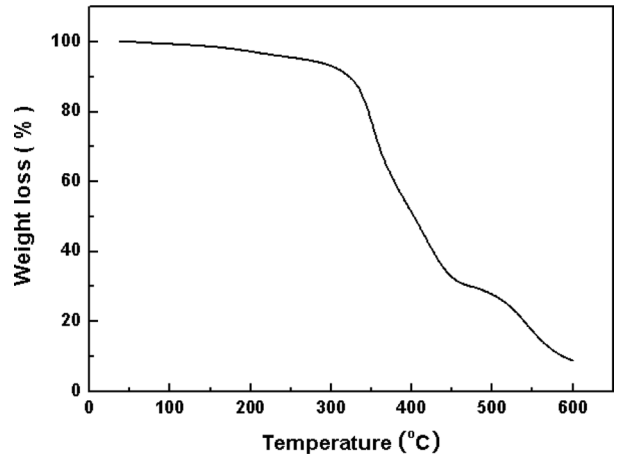

FIGURE 5 TGA results showing the weight loss of the NCF as a function of temperature.

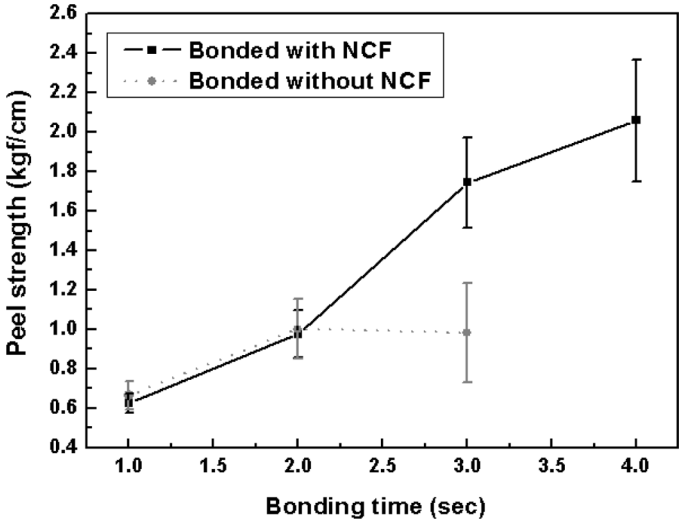

FIGURE 6 Peel strength variation of FPCB-to-RPCB joints bonded with increasing bonding time using transverse ultrasonic vibration.

no NCF peaked at 1.1 kgf/cm at 2 s. Longer bonding times led to higher temperature at the joint interface bonded with NCF during ultrasonic bonding. The PCBs bonded during 1 and 2 s with and without NCF had a similar peel strength increase. This was due to the strength of interfacial bonding between electrodes, which meant the curing degree of NCF before 2 s was not enough for mechanical bonding. For the PCBs bonded at 4 s, the NCF left some residuals on the electrodes consisting of carbonized material by degradation of the NCF at a high temperature of almost 500°C. As a result, the values of the electrical resistance were higher than for the PCBs which were bonded during 1, 2, and 3 s. The optimum bonding time for the PCBs with NCF was 3 s, because the PCBs bonded with NCF during 3 s were sufficiently mechanically and electrically stabilized.

Figure 7a shows the fracture surfaces obtained by scanning electron microscopy (SEM) (JEOL JSM7000 F, JEOL, Tokyo, Japan) of the joints bonded for 3 s of the bonding time. The chemical composition of each region cannot be analyzed exactly due to the spatial resolution limitation of SEM and the very thin immersion Au-plated layer. Dark Ni-rich regions and bright Au regions analyzed by energy dispersive X-ray spectroscopy (EDS) were observed on the surface which meant that the electrodes were successfully bonded during 3 s of bonding time using the transverse ultrasonic vibration. Unbonded regions

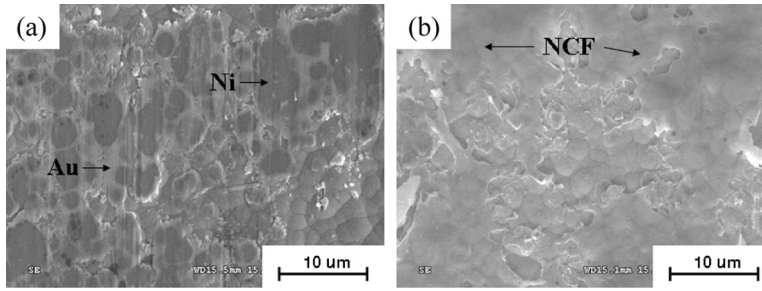

FIGURE 7 Fracture surfaces viewed by SEM of the RPCB side after the peel test. (a) Joint bonded for 3 sec with NCF (optimum condition); (b) Cured NCF on electrodes bonded for 4 sec.

existed on the fracture surfaces because of the surface roughness of the electrodes. Residuals of NCF remained on the fracture surfaces due to the non-coplanarity between the FPCB and the RPCB, and the excessive vibrations applied for 4 s of the bonding time. Too much applied energy led to a change in the shape of the electrodes on the RPCB. The PCBs are heated, softened, and deformed during ultrasonic bonding, due to the viscoelasticity of the PCBs [8].

Figure 8 shows the cross-sectional SEM images of the FPCB-to-RPCB joints bonded under the optimum bonding conditions. The two electrodes were nearly bonded and the spaces between the electrodes were filled with the NCFs.

Two reliability tests (thermal cycling test and high temperature storage test) were carried out on the joint bonded under optimum conditions. Figure 9 shows the electrical resistance of ultrasonic

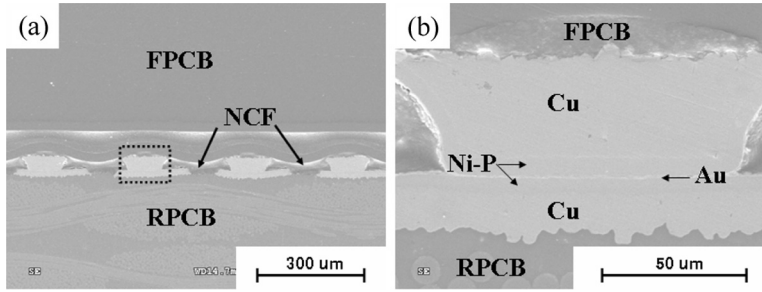

FIGURE 8 (a) Overall cross-sectional SEM image of FPCB/RPCB interfaces bonded for 3 sec with NCF (optimum condition). (b) Close-up showing well-bonded interface between FPCB and RPCB.

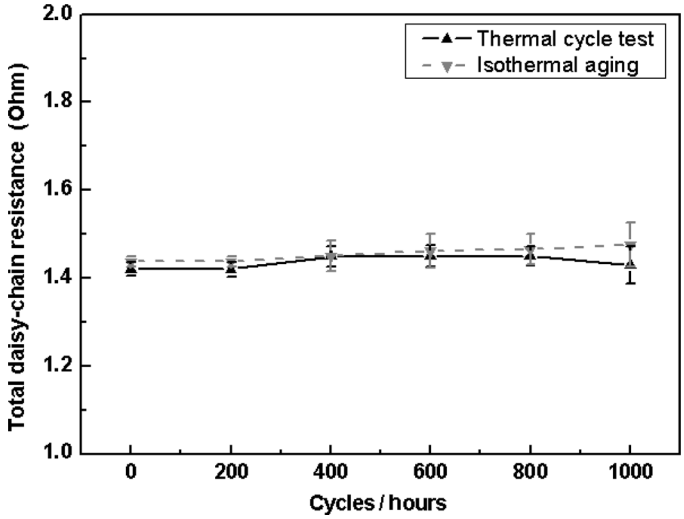

FIGURE 9 Variation of electrical resistances during reliability tests (thermal cycle and high temperature storage test) of joints bonded for 3 sec with NCF (optimum condition).

bonded electrodes during the reliability tests. No significant change of electrical resistance was observed for adhesive ultrasonic bonding of electrodes between the RPCB and the FPCB even though the electrical resistance of the bonded joints slightly increased during both reliability tests.

4. CONCLUSION

In this study, the electrode bonding process with NCF between FPCB and RPCB, which was focused on improving the long-term reliability, was investigated using a transverse ultrasonic system.

Two electrodes bonded with NCF between RPCB and FPCB could be bonded within 3 s at ambient temperature. FTIR specta showed that the epoxy group at the absorbance of 915 cm^{-1} decreased with increasing bonding time. For adhesive ultrasonic bonding of ENIG-finished electrodes between the RPCB and FPCB, the recommended bonding time was 3 s. However, the warpage of the RPCB by excessive vibrations caused the NCF to be cured on the electrodes at bonding times over 4 s. The joints ultrasonically bonded with NCF showed stable contact resistance during thermal cycle tests and isothermal aging tests, which showed that the joints had a good reliability.

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