Bondability Study of Chip-on-Film (COF) Inner Lead Bonding (ILB) Using Conventional Gang Bonder

Ching-I. Chen, Ching-Yu Ni, Chi-Min Chang, Shao-Chiun Wu, and De-Shin Liu

***Abstract*—Inner lead bonding (ILB) is used to thermomechanically join the Cu inner leads on a flexible film tape and Au bumps on a driver IC chip to form electrical paths. With the newly developed film carrier assembly technology, called chip on film (COF), the bumps are prepared separately on a film tape substrate and bonded on the finger lead ends beforehand; therefore, the assembly of IC chips can be made much simpler and cheaper. In this paper, three kinds of COF samples, namely forming, wrinkle, and flat samples, were prepared using conventional gang bonder. The peeling test was used to examine the bondability of ILB in terms of the adhesion strength between the inner leads and the bumps. According to the peeling test results, flat samples have competent strength, less variation, and better appearance than when using flip-chip bonder.**

***Index Terms*—Bondability, chip on film (COF), inner lead bonding (ILB), peeling test.**

TABLE I
ROADMAP FOR DISPLAY DRIVER

	2006	2008	2010	2012	2014	2016
Bonding metallurgy	Au-Sn bond Au-Au bond ACF, NCF				Au-Sn bond Au-Au bond ACF, NCF, NCP	
Max. number of pads	800	1200	1600	2000	2400	2800
Min. bump pitch (um)	30	25	20	15	10	10
Min. bump size (um)	20	15	12	10	6	6
Bump material	Au	Au	Au	Au	Au	Au

I. Introduction

HIGH-quality thin-film transistor (TFT) liquid crystal display (LCD) has become a mainstream display technology in recent years, with its features of light-weight, small out-of-plane dimension, low radiation, low power consumption, longer lifetime, and clear display. The packages which act as the LCD driver have been developed with an ever higher pin count and lower cost since the 1980s. Table I shows the roadmap of display driver IC packaging [1]. In order to place more I/Os in the same die size, the bump size and pitch have gotten finer and finer. Currently, there are three package types used in current TFT LCD products: tape carrier package (TCP), chip on glass (COG), and chip on film (COF) [2], [3]. The TCP was first introduced in the late 1980s, and was the major packaging method until 2005, because the bump pitch is limited to 40 μm. This limitation results from the three-layered film tape structure in TCP and the mechanical resolution of the ILB bonder. The COG is an alternative packaging method that can reach a finer pitch of less than 20 μm, because the driver IC is directly bonded onto the glass panel without a film tape substrate. However, the inherent problems of COG, such as stringent bump, bump surface coplanarity, difficult cumulative tolerance control, and poor reworkability, have restrained its application to large-area LCD products. Consequently, in 1998, COF was developed to overcome the bump pitch limitation by changing the film tape substrate from a three-layered to two-layered structure [6].

COF is a technology that uses adhesive-less metal foil as a flexible substrate, which is capable of visual transparency and irregular bending. As the LCD industry has developed and expanded so rapidly, COF has been a major technology, not only applied in large panel applications, such as flat-screen TVs, but also for small panel applications, such as PDAs and cell phones. Suter *et al.* [4] used the finite-element approach to study the thermomechanical bonding process of a chip on film. The residual stress distribution was determined with different bump arrangements and process parameters. Jang *et al.* [5] proposed a failure analysis study of fine-pitch COF. A verified/predictive finite-element method was developed and applied to figure out the more detailed phenomena that occurred at a miscellaneous area for a very short instant. A numerical approach was utilized along with tests and measurements to address the dominant factors as the root causes of the lead breakage. Jang *et al.* [6] also reviewed some of the current assembly issues of fine-pitch COF packages for LCD applications. Traditional underfill materials, anisotropic conductive adhesive (ACA), and nonconductive adhesive (NCA) were considered in conjuction with thermal and laser bonding. Numerical and subsequent testing results indicated that the NCA/laser bonding process can prevent both lead crack and excessive misalignment compared to conventional bonding processes. In this paper, the bondability of inner lead bonding (ILB) for a COF package was discussed through peeling test experiment to examine the adhesion status between the inner leads and the bumps. Three kinds of COF samples were prepared using gang bonder (where the bonding head is up, the IC is down, and interconnects are made using a

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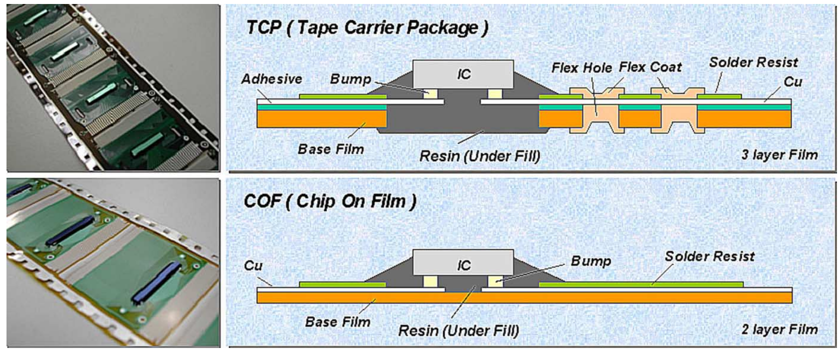


Fig. 1. TCP and COF.

hot bar soldering system) instead of flip-chip bonder to explore the machine limitation.

II. Review of COF ILB

ILB is used to thermomechanically join the Cu inner leads on a flexible film tape and the Au bumps on a driver IC to form electrical paths. In the past, TCP used a eutectic process. However, because the mid layer (adhesive) in this three-layer structure is not high-temperature durable, the bonding lead's support substrate (Polyimide) is delaminated. COF was developed in the late 1990s to overcome the limitations of the TCP. The TCP film has a device cavity in the center for the gang lead bonding. On the other hand, COF's substrate (flex) is a two-layer structure without an adhesive layer. Instead of the gang bonding, the flip-chip bonding method is used for the COF packaging [7]. There are two common bonding tools that can be combined to fulfill the COF ILB process. Fig. 1 shows the schematic diagrams of the bonding mechanisms. The gang bonder was originally designed for the TCP production, where the bumps and inner leads are aligned by a CCD camera from the top-view. The difficulty in the COF ILB process is that the visual interference through the polymer film degrades the alignment accuracy. Otherwise, the requirement of film transparency limits the materials that can be combined and constrains the thermomechanical properties such as the glass transition temperature of the film tape. The flip-chip bonder was modified based on the same framework of flip-chip packaging but with different loading and unloading system design. The film tape must be laid on the stage, which is different from the gang bonder. Moreover, a rubber tip picks up a driver IC flipping through 180° to transfer the driver IC onto the bonding head. A two-tunnel CCD, which camera aligns the bumps and inner leads in between the bonding head and stage is capable of excellent accuracy without film interference. The COF ILB performance illustrated the successful application of micro-bump interconnections in the COF system.

The bonding force, bonding head temperature, stage temperature, time and geometrical form are critical parameters for the eutectic bondability [8]. The bonding recipes used in the two bonders is shown in Fig. 2. Because the base material of the film tape is a polymer material which intrinsically has a large coefficient of thermal expansion, a high contact temperature will aggravate the misalignment between bumps and inner leads, especially at the edges of chip long side. The flip-chip bonder is thus able to satisfy the fine-pitch design owing to its advantages of lower contact temperature and zero forming. However, the drawbacks of the flip-chip bonder are that the silicon dust drop causes foreign contamination or electrical short without film tape shielding, and a slow throughput results from time-consuming flipping and alignment actions. As for the gang bonder, it has minor remodeling with a high-resolution CCD camera system to achieve better alignment capability, and fast production throughput and less foreign contamination are its significant advantages. However, the film tape suffers high-temperature contact with the bonding head, which induces severe thermal expansion. Inner lead fan-out design on the film tape must particularly consider the thermal compensation to increase the design complexity. An empirical value of thermal compensation ranges from 2% to 5% according to different device lengths. Moreover, the polymer film within the device area might be wrinkled during the thermal contact to influence the resin flowability in the next potting process. A forming height is able to recover the wrinkled area upon the tension force, but inner leads will have a certain tradeoff elongation or distortion. Table II summarizes the pros and cons of two ILB bonders.

III. Testing Samples

Three types of COF samples namely 1) forming, 2) wrinkled, and 3) flat were prepared to investigate the quality of corresponding bondability using Shibaura TTI-810 TCP/COF gang bonder. Fig. 3 shows a reference flow to determine the bonding recipe and possible failures observed in extreme conditions. The driver IC adopted is a 17 $\times$ 1 mm gate device with 427 lead counts. The bonding force was 90 N, bonding head temperature was 180 °C, stage temperature was 400°C, and bonding time was 1 s. These parameters were fixed except for the forming height. The film tape does not consider the thermal compensation to the inner lead fan-out design.

A. Forming Sample

The forming samples were prepared following a similar machine operation mode for the TCP production. The steps of stage movements can be referred to in case (a) in Fig. 4. The driver IC was placed on the stage at the placing position. The stage, then moves upward and stops at a recognition position where a linear x-y motor horizontally adjusts the stage position through

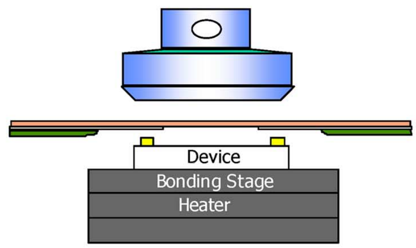
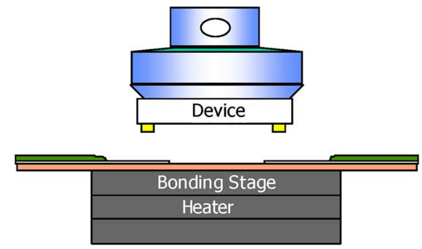
Description	Gang Bond	Flip Chip Bond
Process		
Parameter Design Window		
Head Temp	• 150 ~ 250°C	• 400 ~ 450°C
Stage Temp	• 350 ~ 450°C	• 100 ~ 150°C
Bond Time	• 1 ~ 1.5 sec	• 3 ~ 5 sec
Bond Force	• 80 ~ 150 N	• 50 ~ 90 N
Forming	• 15 ~ 20 um	• 0 um (zero forming)
Machine	• Shibaura TTI-810	• Shibaura TFC-2100

Fig. 2. Bonding mechanisms of gang bonder and flip-chip bonder.

TABLE II
PROS AND CONS OF ILB BONDERS

ILB tool	Pros	Cons
Gang bonder	1.Alternative for TCP or COF 2.Fast throughput 3.Low cost equipment	1.Limited film material resources due to transparent requirement 2.Low bonding accuracy
Flip-chip bonder	1.High bonding accuracy for fine pitch 2.Permit high Tg and dark film tape	1.Slow throughput 2.Expensive equipment cost

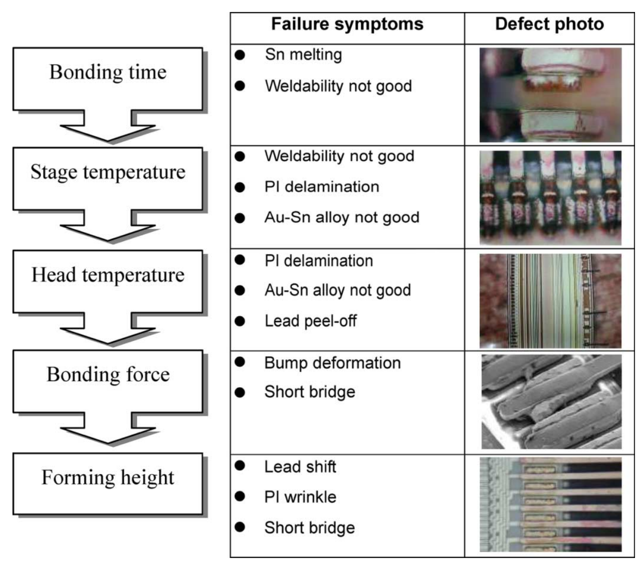


Fig. 3. Reference flow to determine bonding recipe and associated failures.

the CCD monitoring to catch an alignment mark. After completing the alignment, the stage moves to a standby position and waits for the bonding. The bonding head moves downward with a constant speed to compress the film tape. Meanwhile, the stage moves downward and stops at a bonding position to generate a forming height. The molten Sn metal reacts with Au metal to join the bumps and inner leads until the bonding head rises up. Fig. 5(a) shows the examination pictures of a forming sample. During the sampling, it was impossible to set a large forming height because of the inner lead fan-out without thermal compensation design. The forming height was nearly 15 μm to diminish the shifting. However, it still can be found that the forming sample has lead shifting near the corner. Inner lead delamination can also be observed at the extension tip.

B. Wrinkled and Flat Samples

Considering stage movements with reference to case (b) in Fig. 4, the second machine operation mode is to setup the standby position as close to the film tape as possible and give an above bonding position (negative value in the programming code) to approach zero forming condition, which means that the forming height is identical to the bump height after the bonding. This methodology is able to solve the lead shift issue. However, thermal convection and radiation transfer the heat from the stage to soften the film tape. Fig. 5(b) shows the examination pictures of a wrinkled sample. Irregular wrinkles can be observed around the outer boundary of the bonding head on the film tape and irregular also can be found within the device area after the ILB. As a consequence of this, it can be found that the inner lead waves accompany the film tape wrinkles. The stage stops at the standby position of around 100–300 μm, and slightly lowering the standby altitude can to reduce the surface temperature to eliminate the occurrence of film tape

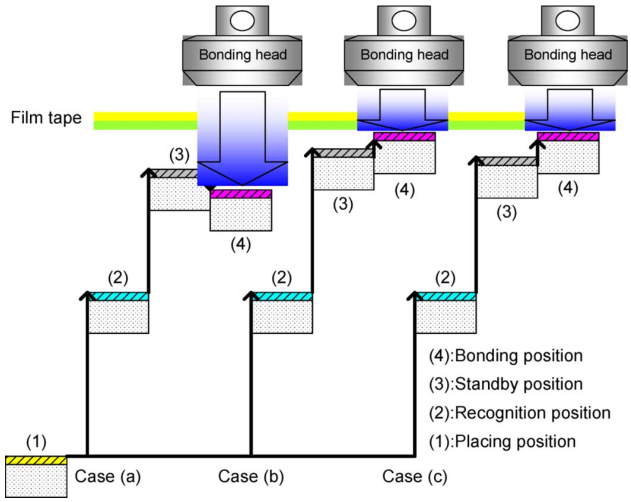


Fig. 4. Stage movements of TCP/COF gang bonder.

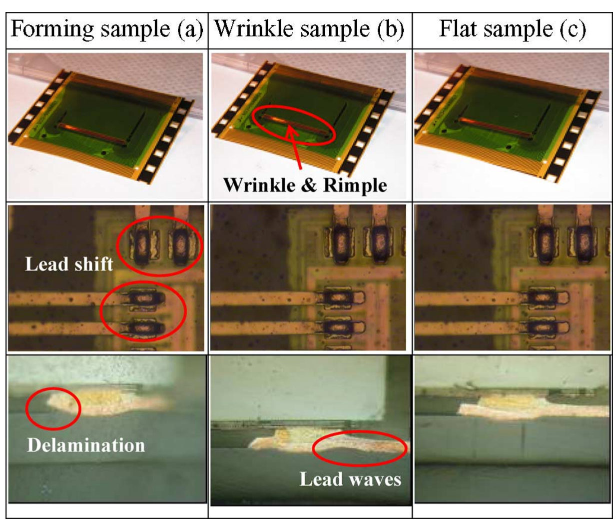


Fig. 5. Visual examination of COF samples.

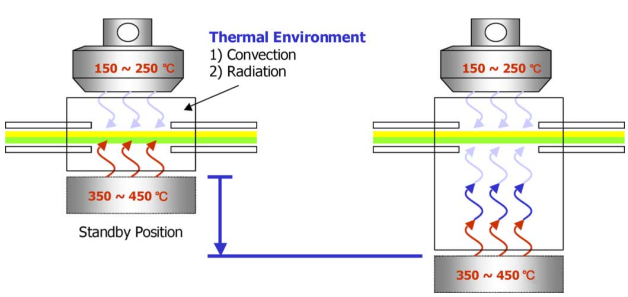


Fig. 6. Sketch of thermal analysis at the standby position.

wrinkles. Fig. 6 demonstrates the sketch of thermal analysis. Therefore, flat samples can be obtained following the proposed machine operation mode of case (c) in Fig. 5. Fig. 5(c) shows the examination pictures of a flat sample in which lead shifting and tape wrinkle were successfully eliminated.

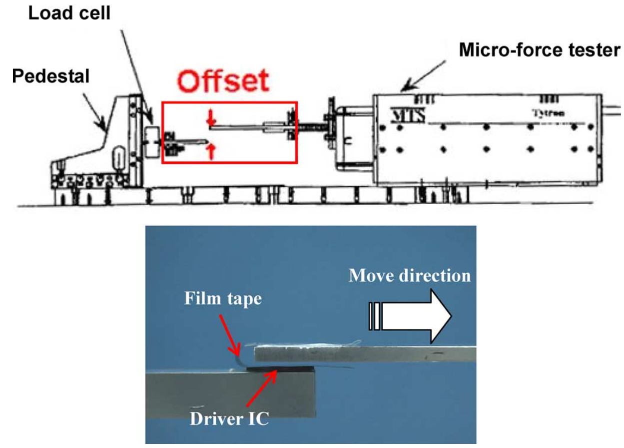


Fig. 7. Schematic diagram of microforce tester and picture of fixture for peeling test.

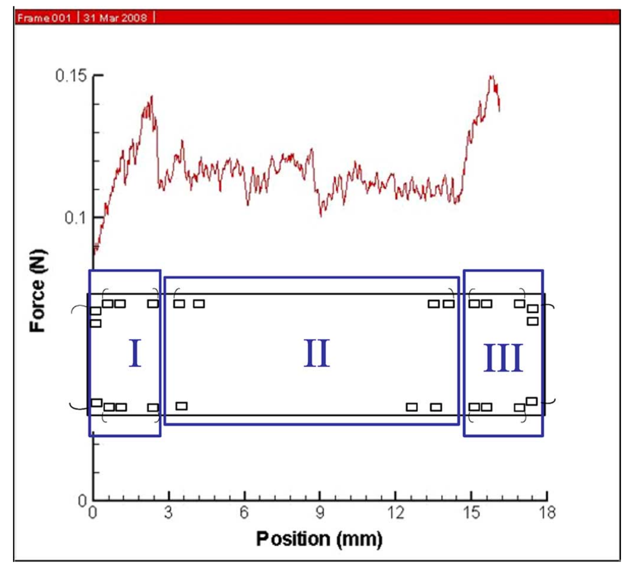


Fig. 8. Representative force data registered across the IC length.

IV. Experiment Setup

A peeling test is a standard method to check the bondability of COF ILB, and is performed at the device site after peeling off the film tape to inspect the adhesion status between the inner leads and the bumps with an optical microscope. Because it is impossible to conduct traditional lead pull test to examine the bonding strength of an arbitrary inner lead, no separation between the leads and the tape film is the only acceptance criterion and this is mostly a qualitative judgment. In addition, the peeling result is very human-dependent, with possible variations from handling such as grip angle, peeling speed, and peeling orientation. For the sake of standardizing and quantifying, the peeling test, a microforce tester with a specially designed fixture, was implemented instead of manual peeling following the same inspection principle. Fig. 7 shows the schematic diagram of the experimental setup and a picture of a testing specimen. The specimen must be trimmed moderately to correspond with

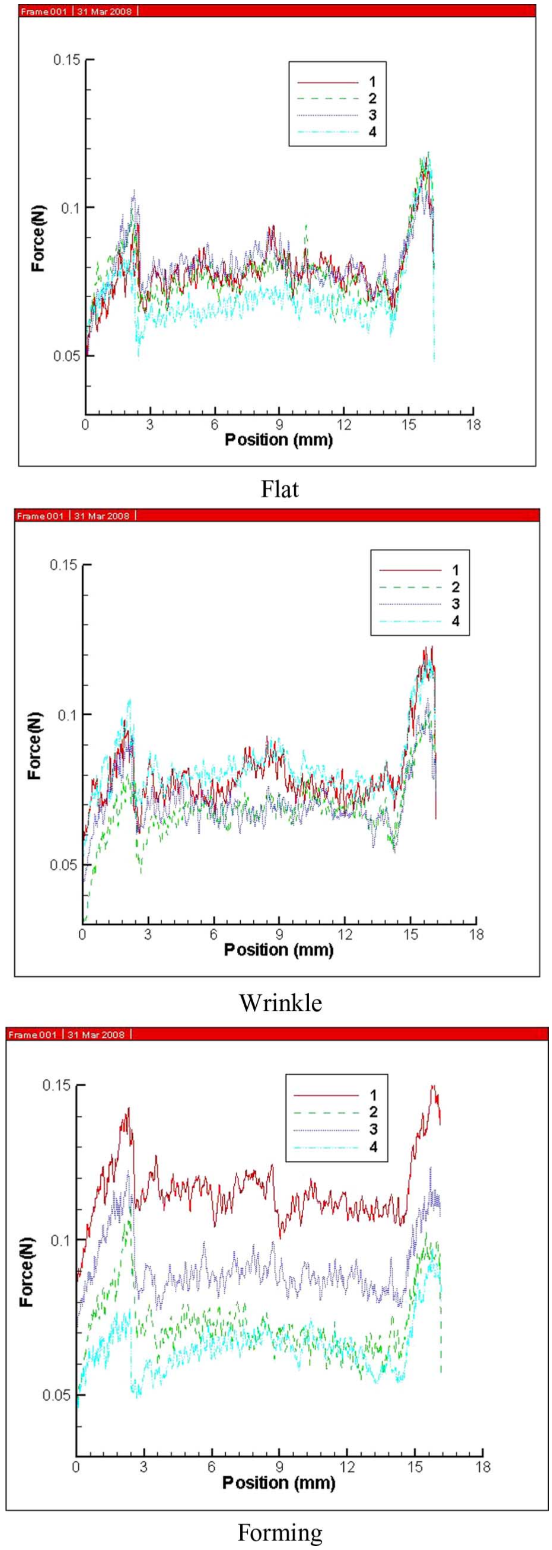


Fig. 9. Peeling test results of three kinds of COF samples.

TABLE III
EXAMINATION RESULTS FROM PEELING TESTS

	Region I		Region II		Region III	
	Slope (N/mm)	Max. (N)	Slope (N/mm)	Max. (N)	Slope (N/mm)	Max. (N)
Forming sample	0.0205	0.146	-	0.113	0.0275	0.155
	0.0195	0.114	-	0.069	0.0269	0.106
	0.0174	0.129	-	0.088	0.0265	0.126
	0.0075	0.080	-	0.064	0.0280	0.101
Average	0.0162	0.117	-	0.084	0.0273	0.122
Wrinkle sample	0.0093	0.102	-	0.0769	0.0354	0.127
	0.0171	0.084	-	0.0674	0.0274	0.106
	0.0137	0.099	-	0.0683	0.0321	0.108
	0.0130	0.107	-	0.0804	0.0322	0.126
Average	0.0133	0.098	-	0.0733	0.0318	0.117
Flat sample	0.0115	0.096	-	0.0774	0.0317	0.118
	0.0108	0.104	-	0.0748	0.0375	0.123
	0.0191	0.108	-	0.0795	0.0241	0.115
	0.0042	0.091	-	0.0667	0.0386	0.121
Average	0.0114	0.0998	-	0.0746	0.0330	0.120

the fixture size; the driver IC was adhered onto the lower beam, and the specimen edge was connected to the upper beam by an adhesive tape. The offset gap between the upper beam and lower beam was 5 mm. The microtester peels off the film tape from the short side of the device with a constant speed of 0.1 mm/s.

V. Peeling Test Results

Fig. 8 shows a representative force data registered across the IC length where the force curve can be distinguished into three characteristic regions. The force data linearly increases in the first region with a sharp force drop when traveling into the second region. Therefore, it can be deduced that the slope of the force curve and the peak value are the bondability indices for the first region. For the second region, the force data transforms to be steady state, and the associated bondability index is the average force value across 11.7-mm length. The first and the third regions have higher peak values but shorter durations resulting from multiple bond peeling characterization compared to pair bond peeling characterization in the second region. Fig. 9 shows the peeling examination results of three kinds of COF samples. The sample size is four, and a mathematical filter was used to eliminate the fluctuations of raw data curves to have objective comparisons. It can be found that forming samples have larger force-displacement variation due to lead shift. Table III lists the examination results of the COF samples. Forming samples have higher strength but larger variations, which flat samples have competent strength and better appearance than wrinkled samples. Fig. 10 shows representative photos after the test.

VI. Conclusion

As the LCD industry develops and expands rapidly, the current TCP products are being replaced with finer pitch COF products to meet cost and size reduction requirements. Based on this premise, the COF ILB process was reviewed. In this research, the peeling test and examination results of three kinds of COF ILB processes were presented and investigated. In order to preserve high throughput and reduce new tool investment, conventional gang bonder was used to prepare three kinds of COF sam-

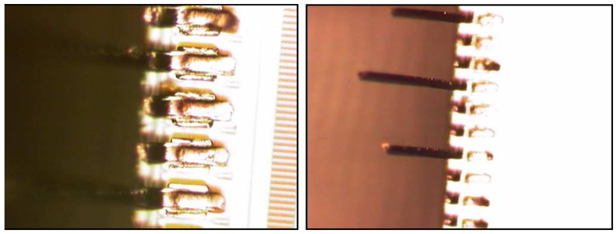


Fig. 10. Optical examination after peeling test.

ples with different machine operation methodologies. A microforce tester was used to standardize the peeling test instead of a manual check and to obtain the force-displacement curve to conduct further examination of ILB bondability. According to the peeling test, it can be observed that forming samples have large variation due to lead shift and flat samples have competent strength and better appearance than wrinkled samples. Therefore, the gang bonder can be combined for the COF ILB process as long as machine operation methodology is altered. Through this research, we explore an alternative way of using a conventional gang bonder without new tool investment that will also maintain high throughput and provide reliable bonding quality similar to a flip-chip bonder toward finer pitch COF products.

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