Development of Anisotropic Conductive Film for Narrow Pitch Circuits

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Anisotropic conductive film (ACF) is a film adhesive with conductive particles dispersed in thermosetting resin, and is mainly used for circuit board connection in the field of liquid crystal displays (LCDs), mobile phones, TVs, etc. High performance LCDs require advanced ACF that is applicable to the connection of circuit boards with narrow pitch electrodes. We have developed a new ACF for the connection of circuit boards using our nickel nano straight-chain-like particle technology. This paper describes the performance of the newly developed ACF.

Keywords: ACF, LCD, nickel, nano particle, circuit board

1. Introduction

Anisotropic conductive film (ACF) is an adhesive film with conductive particles dispersed uniformly in thermosetting resin. Because ACF can connect electrodes by one-shot pressing, it is widely used for circuit board connection in the field of flat panel display (FPD) manufacturing. Conventional ACF contains sphere-shaped nickel particles or Au-plated resin balls as conducting materials; in contrast, the new ACF we have developed is composed of original nickel nano straight-chain-like particles oriented vertically to the film[1]. In response to the increasing demand for higher resolution FPDs such as three-dimensional (3-D) image panels, an advanced connection technique for narrower pitch electrodes is increasingly required for flexible printed circuits (FPCs) with glass substrates (Film on Glass: FOG) or FPCs with PCB substrates (Film on Board: FOB). We have developed a new ACF for the connection of narrow pitch circuit boards by using our nickel nano straight-chain-like particles. The performance of this ACF is described in this paper.

2. Development Concept

Our nickel nano straight-chain-like particles were manufactured using our innovative liquid phase process based on the plating technology of Sumitomo Electric Industries, Ltd[2]. An adhesive resin was also designed to be applied to these nickel nano particles. More particularly, the resin is designed to have higher adhesiveness to a flat surface glass substrate in the FOG application while offering clean removability with the use of a general solvent in the FOB application so as to reuse the PCBs. We also aimed to reduce the content of conductive particles to one tenth of that of the conventional ACF by vertically orienting straight-chain-like particles of 3 μm in length. This simultaneously leads to higher connection and insulation performance than ever, and therefore connection of finer-pitch electrodes has become possible with our new ACF. Furthermore, lower pressure bonding has become possible because the new ACF does not need to crush the sphere-shaped conducting ball for bonding as the conventional ACF does.

3. ACF for FOG Connection (SFG130)

3-1 Connection reliability and pressure margin of bonding

Initial connection performance and environmental tests were performed to evaluate the FOG connection between an FPC and a glass substrate with 100 μm-pitch electrodes (**Table 1**). The bonding condition is shown in **Table 2**. Cu electrodes on the FPC and indium tin oxide (ITO) electrodes on the glass substrate formed a daisy chain. We measured the total resistance of the entire circuit including the daisy-chained FPC and ITO, and calculated resistance per electrode by dividing the total resistance value by the number of electrodes. Environmental tests

Table 1. Substrates for estimation (FOG)

FPC	Composition	Cu/PI = 9/25 μm (Double layer)
	Pitch	L/S = 50/50 μm
	Number of electrodes	124 lines
Glass substrate	Material	Non-alkali glass
	Thickness (ITO)	2000 Å
	Thickness (Glass)	0.7 mmt

Table 2. Bonding condition

Condition	Temperature	185 ~ 200°C × 8s
	Pressure	About 3MPa
	Heat tool	2.0 mm × 22 mm
	ACF width	1.5 mm
	Cushion	Silicone (200 μmt)

were performed by measuring the resistance change in a high-temperature (85°C) and high-humidity (85%RH) environment, and in a thermal cycle (−40°C ↔ 100°C) environment. The results are shown in **Fig. 1 and 2**. Initial resistance was very low (under 0.5 Ω including circuit resistance), and the resistance remained unchanged after being exposed to a high-temperature and high-humidity environment for 1000 hours or 1000 thermal cycles. This result has proven that the new ACF (SFG130) has excellent connecting reliability at 180 – 200°C. Moreover, bonding pressure dependence on connecting reliability was evaluated at a fixed bonding temperature of 190°C (for 8 sec.) as shown in **Fig. 3**. The new ACF, which does not require crushing conductive balls, enables low pressure bonding (at 1 MPa) and bonding of weak substrates such as thin glass. We expect that the wide pressure margin of the new ACF will facilitate quality control of products.

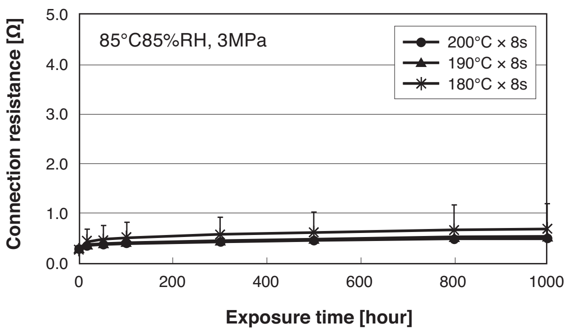

Fig. 1. Connection reliability at high temperature and humidity

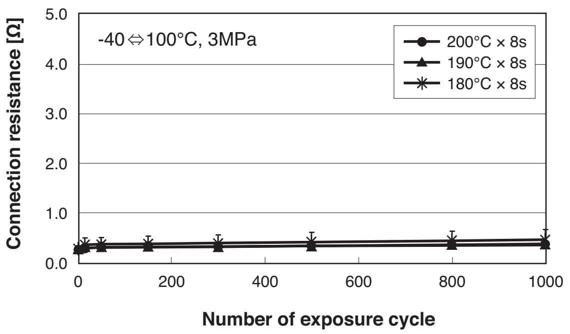

Fig. 2. Connection reliability in thermal cycle test

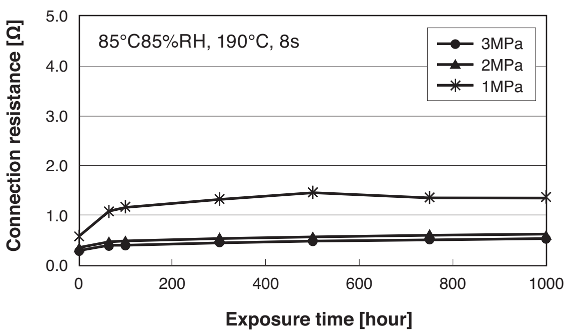

Fig. 3. Estimation of pressure dependence

3-2 Fine-pitch connection

The minimum connection area was evaluated. As mentioned above, FPDs have become increasingly functionalized, and the electrode pitch in the connection area has become narrow. Therefore, ACF that can connect electrodes in an area as small as 5000 μm^2 is required. In order to evaluate the connection performance of the new ACF in a narrow area, the test substrates shown in **Fig. 4** were designed. We tested the connection performance at a bonding temperature of 190°C (for 8 sec.), which is the standard condition of SFG130. The result is shown in **Fig. 5**. Initial resistance remained under 1.0 Ω at the electrode area over 2000 μm^2. This shows that SFG130 can connect electrodes in a small area like IC bumps. As the use of SFG130 enables smaller area and narrower pitch connection, it may contribute to the downsizing of electronic devices and the cost reduction of such devices.

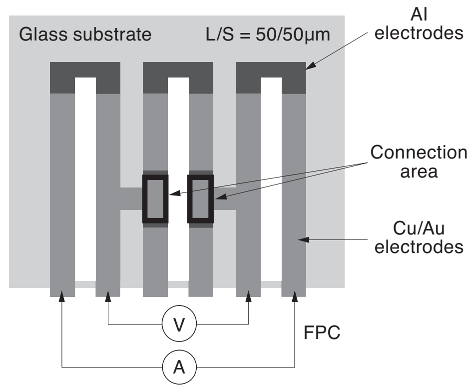

Fig. 4. Substrates for estimation

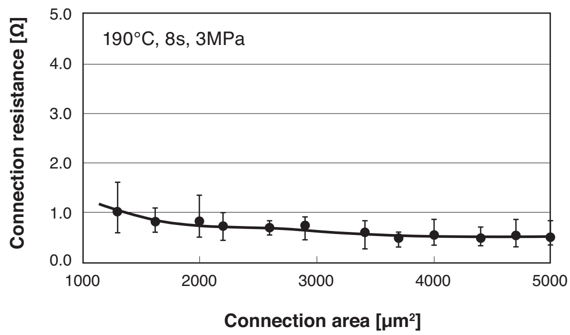

Fig. 5. Minimum connection area (FOG)

3-3 Evaluation for connection of large-size panel electrodes

In large-size panel bonding, multiple FPCs are bonded simultaneously with a large press machine using a long heating tool. However, it is difficult to ensure the flatness of the bonding surface, and microscopic inclination of the heating tool or foreign objects in the connection area can cause failure in bonding. Expecting that a wider range of bonding pressure margins of the new ACF can work effectively for a reliable connection, we have applied this ACF to the one-shot bonding of large-size electrodes for large panels. To evaluate the one-shot bonding process for wide panels, we used a new glass substrate on which five FPCs can be connected (**Fig. 6**). The bonding condition in the test was shown in **Table 3**, and the connection resistance of areas A ~ E was measured by the same method shown in 3-1 Furthermore, we evaluated the changes of resistance in a high-temperature (85°C) and high-humidity (85%RH) environment. The result shown in **Fig. 7** indicates that unevenness depending on the bonding position is trivial and resistance during the environmental test is stable. Thus, we confirmed that SFG130 has a superior connection performance for large-size panel bonding.

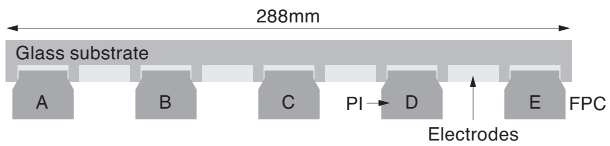

Fig. 6. Substrates for estimation of large size panel

Table 3. Bonding condition

Pre bonding	Temperature	75°C × 1s
	Pressure	About 1MPa
	Heat tool	2.0 mm × 30 mm
	ACF width	1.2 mm
	Cushion	Silicone (200 μmt)
Main bonding	Temperature	190°C × 8s
	Pressure	About 3.5MPa
	Heat tool	1.5 mm × 530 mm
	Cushion	Silicone (200 μmt)

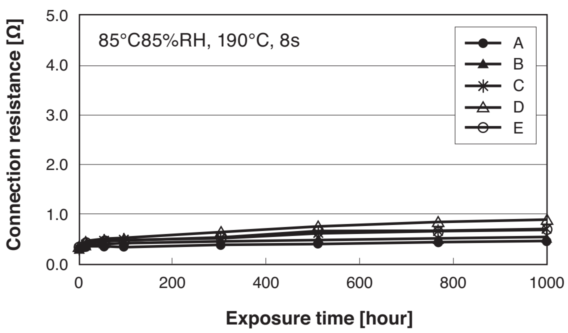

Fig. 7. Result of estimation with long heat tool

4. ACF for FOB Connection (SFB130R)

4-1. Connection reliability and pressure margin of bonding

We evaluated connection reliability of the ACF for FOB connection (SFB130R) by the same method used in the SFG130 evaluation test. A PCB substrate and an FPC, on which 200 μm-pitch electrodes were formed, were prepared (**Table 4**). Initial resistance at the bonding condition (**Table 5**) and changes of resistance in a high-temperature (85°C) and high-humidity (85%RH) environment were evaluated. The result shown in **Fig. 8** indicates that resistance remained low throughout a wide range of bonding pressure between 1 and 5 MPa. Thus, we have confirmed that SFB130R has a wide pressure margin in the same manner with SFG130. It is expected that SFB130R's wide bonding margin will improve productivity by enabling low pressure bonding in connecting thin or weak substrates.

Table 4. Substrates for estimation (FOB)

FPC	Composition	Cu/PI/ = 18/25 μmt (Double layer)
	Pitch	L/S = 100/100 μm
	Number of electrodes	80 lines
PCB	Material	Glass fiber reinforced epoxy
	Composition	Cu/FR-4 = 25/600 μm

Table 5. Bonding condition

Condition	Temperature	180°C × 10s
	Pressure	1 ~ 5 MPa
	Heat tool	2.0 mm × 22 mm
	ACF width	1.5 mm
	Cushion	Silicone (200 μmt)

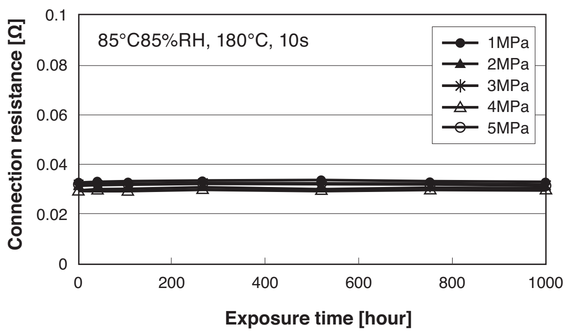

Fig. 8. Connection reliability at high temperature and humidity

4-2 Fine-pitch connection

The target connection area in FOB applications is larger than that in FOG applications. We measured the resistance of the minimum connection area by shifting the FPC intentionally. We used the same substrates described in 4-1 in the condition of 180°C and 3 MPa for 10 sec. as the SFB130R standard condition. Although the connection area is limited to 27,000 μm^2 due to the influence of substrate size and machine performance, connection resistance was maintained sufficiently low in the area over 27,000 μm^2. Therefore, we believe that SFB130R has a great potential for pine-pitch connection, just as SFG130 does.

4-3 Insulation performance

In the use of electronic devices, short circuits may occur due to the isolation of metal ions from the electrodes of substrates caused by ACF impurities. With the aim of preventing this problem, we tested the insulation performance between the electrodes. We prepared an FPC and a PCB on which comb-shaped electrodes were formed. In the condition of 180°C and 3MPa (for 10 sec), they were bonded to each other with the FPC shifted 50 μm from the PCB. Then we noted any changes in insulation resistance while continuously applying a DC voltage of 15 V to the neighboring electrodes in a high-temperature (85°C) and high-humidity (85%RH) environment. The result is shown in **Fig. 9**. Although the condition was too harsh for the conventional ACF to clear, with the new ACF no ion-migration occurred, and its insulation resistance remained over 1G Ω for 500 hours. This result means that our ACF has superior insulation reliability.

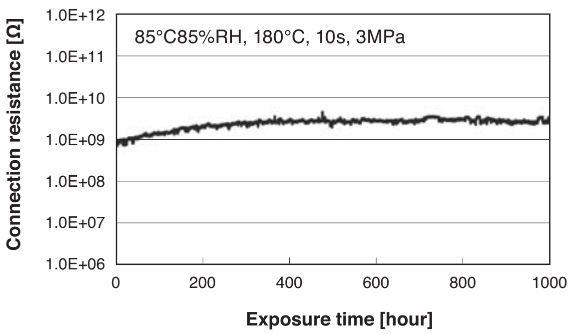

Fig. 9. Insulation reliability at high temperature and humidity

4-4. Repair performance

In general, PCB substrates use expensive electronic parts, and therefore, re-usability of these parts is desired in case of bonding failure. In light of this, we evaluated the repairability of the new ACF and the connection reliability of substrates to be reused. After bonding the substrates (described in 4-1) in the condition of 180°C and 3MPa (for 10 sec.), the FPC was peeled off by using heat from a fan heater, and then the residue of ACF resin on the substrates was removed with a solvent-impregnated wiper (**Table 6**). It took only 3 minutes to completely remove the residue.

Table 6. Repair method

Peeling off	Equipment	Fan heater
Residue removal	Solvent	Acetone
	Tool	Non-woven textile fabrics
	Temperature	Room temp.
	Time	About 3min.

In order to evaluate the reusability of the cleaned PCB, the FPC was bonded again by using the ACF in the same condition as shown above and its initial connection resistance and changes in connection resistance were measured in a high-temperature (85°C) and high-humidity (85%RH) environment. The result shown in **Fig. 10** indicates that the resistance of the repaired ACF remained almost unchanged. Thus, we confirmed that this substrate can be reused after some simple repair work and SFB130R is environment-friendly.

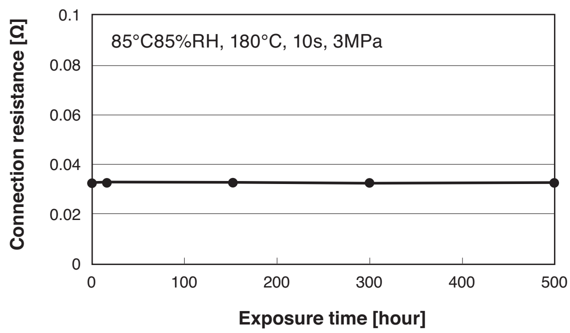

Fig. 10. Connection reliability of recycle substrates

5. Conclusion

We have developed a new ACF for substrate connection by applying our specialized techniques for manufacturing of nickel nano particles, vertical orientation and resin design. We confirmed that SFG130 can effectively work for small area bonding (about 2,000 μm^2) and low pressure bonding (1 MPa), and that it offers a stable connection for panels in various sizes. We also confirmed that SFB130R can be used for bonding at a wide range of pressure and that it enables substrates to be reused after some simple repair work.

We are currently producing fine substrates with a pitch of less than 30 μm. We are also planning to investigate the performance limitations of SFG130 and nickel nano straight-chain-like particles.

Technical Term

*1 FPC (Flexible printed circuit): An FPC is a flexible circuit on which metal electrodes are formed. It can be easily bent.

*2 PCB (Printed circuit board): In contrast to an FPC, a PCB is a rigid circuit board on which metal electrodes are formed. It is also called a rigid substrate.

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