Micropitch connection using anisotropic conductive materials for driver IC attachment to a liquid crystal display

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This paper reviews some of the past and current activities of the IBM Display Technology Division in the development of liquid crystal displays (LCDs), describing progress in the application of anisotropic electrically conductive film (ACF) to large LCD modules for notebook PCs, as well as the unique properties, advantages, and basic bonding mechanism of ACF. In addition, the status of the advanced chip-on-glass (COG) technique is reviewed.

Introduction

An LCD module is made up of an LCD glass panel device (called a cell), source and gate drivers, gate array(s), printed-circuit boards (PCBs), interface circuits, a backlight, connector(s), and a frame and cover(s). **Figure 1** shows the typical construction (cell with driver IC packages and PCBs) of a thin-film-transistor (TFT) color LCD 12.1-in. SVGA module in an IBM ThinkPad* 560 notebook personal computer (PC). The quality and reliability of the LCD module depend on the way in which the driver IC is attached to the glass panel. Anisotropic electrically conductive film (ACF) is the most popular material for attaching the tape-carrier packages (TCPs) of the driver IC to the LCD glass panel. Progress in bonding technologies using anisotropic electrically conductive materials has extended to the application area of flat-panel-display products. The connection pitch of the electrodes of the driver IC TCPs has been decreased from 160 μm to 60 μm, and the number of output terminal electrodes per IC has been increased from 200 points per IC to 400 points per IC, making it possible to realize high-

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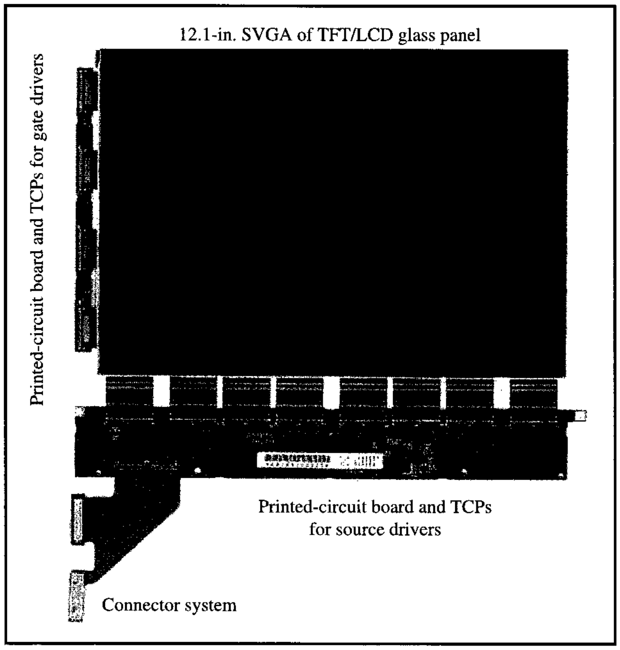

Figure 1

Part of a 12.1-in. SVGA TFT color LCD module for the IBM ThinkPad 560. Eight source-driver tape-carrier packages (TCPs), which provide a bending structure, and four gate-driver TCPs are attached by means of an anisotropic conductive film to the LCD glass panel. Printed-circuit boards are soldered to the input electrodes on the TCPs.

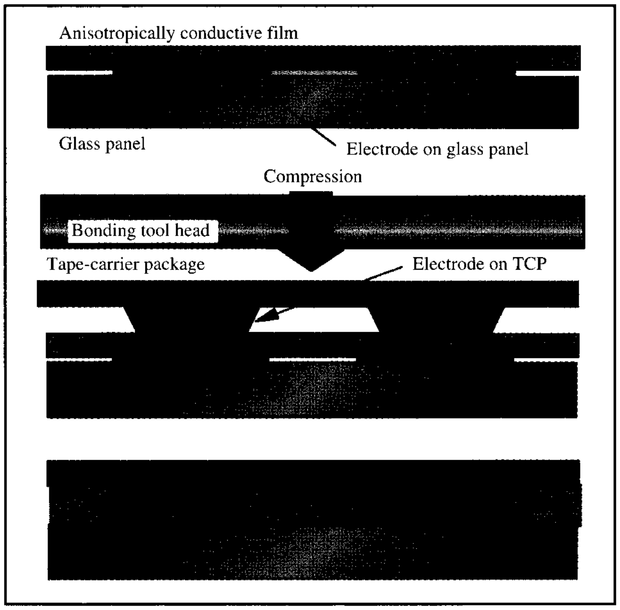

Figure 3

Bonding process for TCPs and LCD glass panels. An ACF is attached to the glass panel and a TCP is pre-attached, with accurate alignment. Final curing is then done. Adhesive fills the space between the electrodes, bonding the TCP and glass panel. Particles between the corresponding electrodes create an electrical contact, and insulation between adjacent electrodes is maintained.

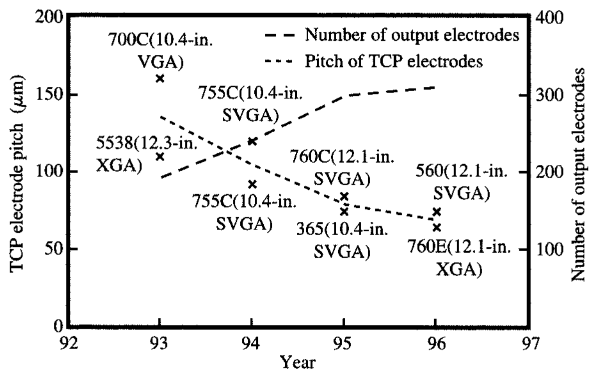

Figure 2

Progress of IBM notebook PCs, showing the increasing number of output electrodes on the driver IC and the decreasing pitch of the TCP electrodes.

resolution LCD modules such as XGA and SXGA for notebook PCs. Anisotropic electrically conductive materials have been developed in order to cope with the demands of LCD applications. A film-type material called ACF has become popular for bonding TCPs to LCDs because of its advantageous properties. Since the announcement of the IBM 5527 display, which was the first color TFT/LCD 10.4-in. VGA product made by IBM, ACF has been used in all IBM notebook PCs. Notebook PCs, in general, require higher resolution, larger displays (with a smaller outside frame), smaller modules, lighter weight, quicker response, lower power, and lower price than their competition. With the progress of the products, driver IC TCPs have been integrated and the electrode contact pitch has been significantly decreased. As a result, innovative improvements in the contact method are required. **Figure 2** shows the progress of IBM notebook PCs, with the number of output terminals of the driver IC increasing, and the electrode pitch of the TCP electrodes decreasing. This paper reviews the evolution of materials and processes that is reflected by that progress.

ACF and its bonding mechanism

ACF is an adhesive film consisting of dispersed, microscopic, electrically conductive particles 3–15 μm in diameter and an insulating adhesive film 15–35 μm thick.

Various kinds of conductive particles, such as carbon fiber, metal (Ni, solder), and metal (Ni/Au)-coated plastic balls, and types of adhesive materials, such as thermoplastic (SBR: styrene butadiene rubber, polyvinyl butylene), thermosetting (epoxy resin, polyurethane, acrylic resin), and mixed thermoplastic and thermosetting materials, have been proposed. Thermosetting adhesive film with metal-coated plastic particles is the most popular type. In general, the normal bonding conditions, as well as an adhesive temperature of about 180°C, a bonding time of about 20 seconds, and a bonding pressure of about 20 kg/cm^2 are recommended [1]. The latter three key parameters depend on the type of ACF, the capability of the process equipment, and the required process time. **Figure 3** shows the process of bonding between a TCP and a glass panel with ACF. ACF is first attached to the surface of the electrodes of the glass panel or TCP at 60–100°C and 3–5 kg/cm^2 for 1–3 seconds, and then the release film is removed. In the next step, the TCP electrodes are aligned with the electrodes on the glass panel and prebonded under the conditions described above, so that an accurate alignment can be achieved in response to the lower temperature and lower pressure. Finally, the ACF is completely cured at 170–230°C and 20–50 kg/cm^2 for 10–20 seconds. At around 90–100°C, the adhesive film displays fluid properties and flows easily into the space between the glass panel and the TCP. Electrically conductive particles between the electrodes of the glass panel and TCP are simultaneously compressed and mechanically contact individual pairs of electrodes. In this process, when the adhesive is cured, the glass panel and the TCP become firmly attached. The corresponding electrodes on the glass panel and the TCP are electrically connected with the compressed particles, while the insulation between adjacent electrodes is maintained. That is, ACF provides mechanical bonding, electrical conductivity between the TCP and the glass panel (vertical direction in the figure), and insulation between the adjacent electrodes (horizontal direction in the figure); and anisotropic electrical contact between the TCP and the glass panel is achieved [2]. **Figure 4** shows cross-sectional views of the interconnections created by conductive particles 5 μm in diameter. The particles are compressed and deformed between the copper lead electrode of the TCP and the aluminum/chromium electrode on the glass panel.

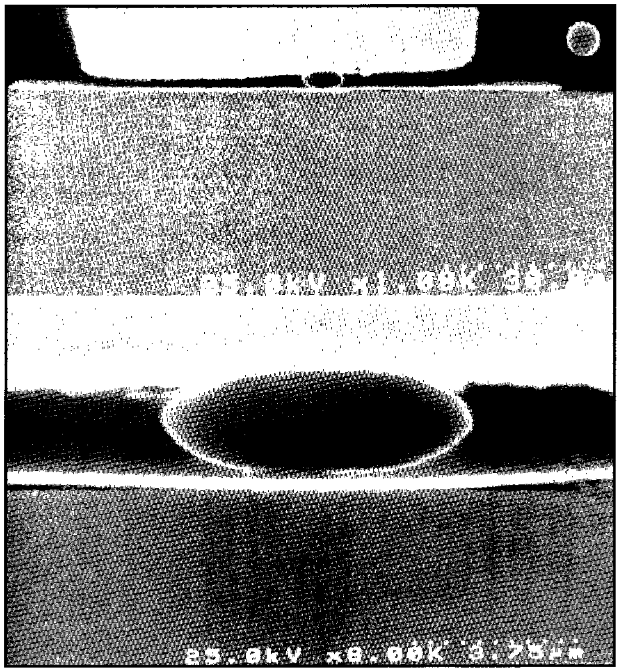

Figure 4

Cross-sectional view of interconnection by a 5-μm-diameter electrically conductive particle for the TCP sample. The particle is deformed between a copper lead electrode on the TCP and an aluminum/chromium electrode on the glass panel.

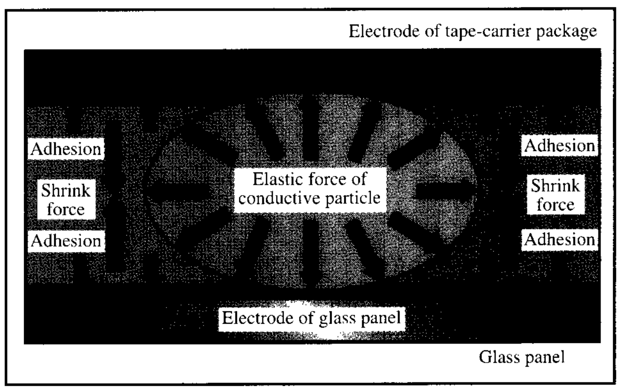

Figure 5

Concept of reliable bonding. A balance of opposing forces between the elasticity of the electrically conductive particles and the shrinkage of the adhesive achieves reliable electrical contact.

Properties of ACF

ACF and its unique properties have been accepted because of the requirements of LCD applications, such as electrical contact resistance and usage temperature. LCD devices cannot be exposed to high temperatures because of concern about the thermal stability of their materials as well as the thermal instability of the liquid crystal and polarizers ($T < 120$°C is required); however, high contact resistance is allowed because of the low electrical current requirement (30–100 Ω is allowed). In order to attach

Bonding technology	ACF	Wire bonding	Ag–Pd paste	Ball bump–Ag paste
Maker	Hitachi/Sharp	Kyocera	Citizen	Panasonic
Products	TFT/LCD note PC/PHS	STN/LCD note PC	STN/LCD IBM-110/230	
LSI electrode pitch (μm)	70		150	(60)–120
LSI electrode size (μm)	40 × 120		100 ϕ	(35)–70
Contact resistance	1–a few (Ω)	a few (mΩ)	$\leqq$10 (Ω)	1–50 ($\times 10^{-6}$) Ω/cm^2
Allowable temperature (°C)	110–120 ($\leqq T_g$)	250	−45/125	−45/100
Bonding temperature (°C)	170–180 (220–250)	250	80–120	100–120
Bonding time (s/chip)	15–20 (5–10)	Ball bond; 70–75	7–8	10–20
Bonding pressure	10 g/bump	30 g/bonding	1.4 g/bump	0.1 g/bump
Bump height	15–20		30–50	40–80
Contact material	Au/Ni	Au wire	Au–Pd	Ag paste
Electrode material	ITO/Al	Al	ITO/Al	ITO/Al
Encapsulant	Epoxy	Epoxy	Epoxy	Epoxy
Thermal expansion (ppm)	45–50		40–60	
High-temperature storage			70°C 1000 hr	85°C 1000 hr
Temperature/humidity	85°C, 85% RH 1000 hr		65°C, 90% RH 1000 hr	85°C, 85% RH 1000 hr
Thermal cycle	−40/100°C 1000∞			
Thermal shock			−20/80°C 1000∞	−40/85°C 500∞
Repair method	Thermal tensile/solvent	Remove, shift, and bond	Thermal remove	Before curing
Advantages	High density Automation Quick bonding Infrastructure	Low contact resistance Easy inspection Easy to repair Infrastructure	Height controllable Electrode on active area	Height controllable No bump required
Disadvantages	Tape-width control	Difficult micropitch More bonding space Total bonding time Terminal material (Al)	Difficult micropitch High contact resist Under-fill required No infrastructure	Difficult micropitch Total bonding time Under-fill required No infrastructure

Figure 6

Major structures and specifications of chip attachment methods for COG.

the driver IC TCPs to the glass panel, for 10–12-in. SVGA/XGA, about 280–330 electrodes per TCP with 70–90-μm pitch are required for a productive connection process. ACF provides the following suitable properties for LCD applications: 1) many electrodes with micropitch (10–15 electrodes per mm) can be connected simultaneously; 2) acceptable bonding conditions (180°C, 20 kg/cm^2, 20 s) are provided for TCPs and LCD glass panels; and 3) mechanical and electrical contact and the reliability of contact required for the LCD application (1–30 Ω per electrode of contact resistance) are obtained. **Figure 5** illustrates the concept of reliable mechanical and electrical contact, focused on a compressed particle providing ideal connection. The required deformation ratio of the particle is approximately 25–30% of the diameter, and this ratio is controlled by bonding conditions and tool accuracy. The deformed particle tends to revert to the original state. This elasticity depends on the material properties of the particle. The cured adhesive shrinks, whereas the conductive particles have elasticity. These two opposing forces balance in the binder, and stable electrical contacts and adhesion at the bonding of the glass panel and TCP can be achieved. Water absorption by the epoxy adhesive may reduce adhesion in humid conditions, but the elasticity and proper deformation of the conductive particle can maintain the required electrical contact in this situation. The adhesive material should be sufficiently cured to ensure adhesion of the glass panel and the TCP. The reactivity of the adhesive material can be described as the ratio of the epoxy group to the methyl group, and can be measured by Fourier-transform infrared spectroscopy (FTIR) [3, 4]. The epoxy group forms a methyl group as a result of heating for the thermosetting type; thus, the reactivity can be described by the formula

$$Reactivity = 100 - (a - b)/(A - B) \times 100\ (\%), \quad (1)$$

where

A = epoxy group absorbance = 914 cm^{-1} before curing;
B = methyl group absorbance = 2950 cm^{-1} before curing;
a = epoxy group absorbance = 914 cm^{-1} after curing;
b = methyl group absorbance = 2950 cm^{-1} after curing.

More than 75–80% of the reactivity value is suggested.

Recent ACF development activities

TCPs for higher-resolution LCDs require smaller pitch connections (around 50–60 μm), which may have electrodes about 10–30 μm in width because of the requirements of the fabrication process for the tape automated bonding (TAB) tape. Accordingly, the bonding space on the glass panel has been decreased. Some reports [5, 6] state that densities of more than five particles per electrode with 50-μm pitch show stable contact resistance during testing at high temperature (85°C) and a relative humidity of 85%. The number of effective particles on the electrode depends on the thickness of the adhesive film. Most particles (about 60–75%) in the contact area between corresponding electrodes are flushed out to the noncontact area by the fluid adhesive. This phenomenon depends on the volume of adhesive. In the case of ACF with the same dispersed volume of particles, a thinner film provides a larger number of effective particles on the electrode, but the adhesion is reduced. A larger number of dispersed particles in the adhesive film may cause electrical short circuits. A mixture of particles (where the ratio of conductive particles to insulation particles is 3:1) has been offered as a solution. Further improvement is needed for the following elements: smaller pitch contact (50 μm); lower bonding temperature (130–150°C); lower bonding pressure (5–10 kg/cm^2); shorter bonding time (5–10 s); lower contact resistance ($R > 1\ \Omega$); greater ease of repair, lower rate of water absorption, longer shelf life, and lower cost. These will contribute to the improvement of bonding quality and reliability, process throughput, manufacturing productivity, and so on, and will make possible high-resolution products through the use of advanced techniques such as COG.

COG and its industry status

The attachment of a bare die to a glass panel (called COG: chip-on-glass) is one advanced application that has been developed, and many bonding methods have been presented [7]. **Figure 6** shows the major structures and specifications of the chip-attachment method for COG. ACF has been adopted as a practical and profitable way of attaching an IC chip to a glass panel by using automatic bonding equipment. COG has been successfully adopted for small (less than 4 in.) products, such as display panels for telephones and copiers, which have one or two chips. Medium-size (4–7 in.) products, such as video cameras and navigation systems, which require 3–8 chips, and large (8–12 in.) products for notebook PCs, have also begun to introduce COG. **Figure 7** compares the structures of COG and TCP applications. The advantages of COG are as follows. TAB tape and TCP packaging processes can be eliminated. The current resolution limit of the TAB carrier is approximately 50 μm of inner-lead bonding (ILB) pitch, and the practical limit of the outer-lead bonding (OLB; used for bonding TCPs to a glass panel with ACF) is about 60–70 μm. To ensure accurate alignment in the OLB process, the unique shrinkage factors of the TCP must be accounted for at the TAB carrier fabrication step. Because of the mismatch between the coefficient of thermal expansion (CTE) of glass and that of a TCP (5–6 ppm/°C vs. 20 ppm/°C), the bonding process for wider TCPs with smaller pitch has become more and more difficult. On the other hand, LCD products have come to require higher resolution and a

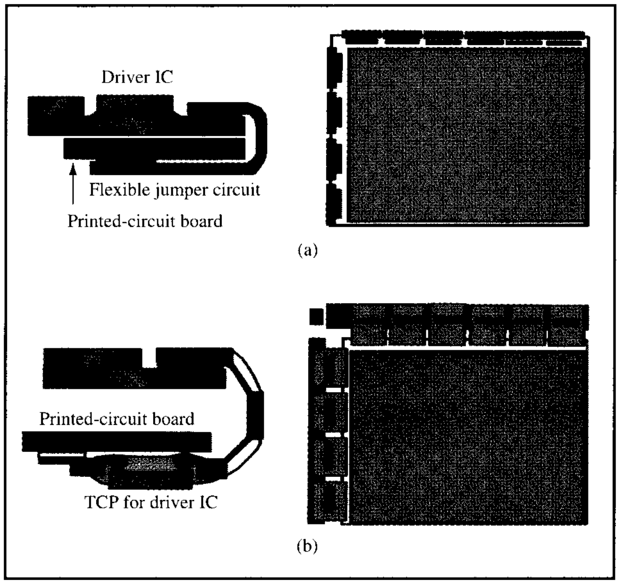

Figure 7

Comparison of the structures of (a) COG and (b) TCP applications. In the COG application, a bare die is directly attached to the glass panel.

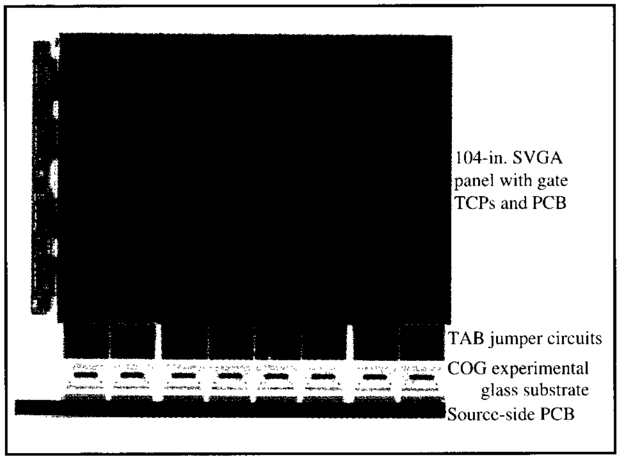

Figure 8

Test vehicle for COG demonstration. The hardware of the 10.4-in. SVGA module was selected, and an experimental glass substrate providing the COG pattern was prepared.

larger number of contact points. The array process of the glass panel and the driver IC (semiconductor) process provide the capability for higher resolution. COG is one way of achieving the higher resolution demanded in LCD products. The difference between the CTE of glass and that of silicon (5–6 ppm/°C vs. 3.5 ppm/°C) is quite small compared with that in TCP applications. Display products for use in mobile vehicles use COG, since the closer CTE gives more reliable connections.

COG demonstration on 10.4-in. SVGA

In a study of the COG process, various requirements such as accurate equipment for chip mounting and bonding, suitable ACF types, bonding reliability, repair methods, the design of input circuits for driver ICs, and bare-die availability were investigated.

- *Test vehicles and pilot line*

A 10.4-in. SVGA module was selected as a test vehicle for COG demonstration. **Figure 8** shows the test vehicle. Because of the unavailability of COG cells, an experimental glass substrate was prepared; this is a glass panel which has the same patterns as the TABs used for the 10.4-in. SVGA module. The ILB part of the TAB pattern can be used for the COG application. Eight bare dies of the driver IC were attached to the experimental glass substrate, and the substrate was electrically connected by eight TAB jumper circuits. A source-side PCB was also attached to the glass substrate. All of these connections were achieved by means of ACF bonding. Functional hardware was used for display demonstration and product-level environmental testing. A pilot COG assembly line consisting of an ACF-bonding machine, a chip-mounting machine, and a final bonding machine was developed and installed.

- *Design of COG pattern on glass*

In the mass-production phase, the original glass panel before scribing (in the array and cell processes) has shorting rings on the outsides of the electrodes to protect them from electrostatic discharge (ESD) influence. In the TCP application, the electrodes on the glass panel are connected to shorting rings, and are cut during the scribing process. In the case of COG, shorting rings must be designed between the input and output electrodes for driver ICs on the glass panel. Since the shorting rings are designed on the insides of the input electrodes for driver ICs, ring cutting during the scribing process is not allowed. Laser trimming has been suggested for cutting shorting rings. The COG pattern (the layout of the electrodes) should be carefully designed to take account of key items such as the bump (electrode) size and layout of the driver ICs, and the layout of the cell on the original glass panel during array/cell production. A large quantity of driver ICs on a glass panel provides easy fanning-out of the circuits between array circuits and COG electrodes and of the circuits between COG electrodes and PCB electrodes, but increases the cost. A small quantity of ICs reduces the cost but does not meet the requirement for a wider fanning-out area of the circuits. A chip and PCB attachment area with a width of 3.5–4.5 mm at the edge of the glass panel appears to be the most advantageous in terms of size.

- *Equipment and process*

The design of the COG bonding machine is affected by the properties of the ACF and the specifications of the IC chips. The first COG bonding machine for industrial use was developed mainly for small products. Since equipment for such products is required to provide high throughput, a short cycle time is essential, and the bonding time for the final curing should be reduced. COG allows a higher bonding temperature than TCP, because the mismatch between the CTE of silicon and that of glass is less and the dimensional stability is higher. The higher temperature makes it possible to reduce the bonding time. On the other hand, medium-size products require a high bonding-process yield because of the larger number of IC chips. The requirement for high yield in large products is much more severe. Yield control for the chip attachment process becomes more difficult as the number of chips mounted on the product is increased. If the equipment provides a 99% process yield, the same product yield can be expected for single products. Hence, large products such as the 12.1-in. SVGA for the IBM ThinkPad 560 notebook PC, which has 12 chips, require a yield of more than 99.95% for each individual chip bonding, if a 99% product yield is required. A study of the specifications and availability of the ICs and the ACFs showed that an accuracy at least 10 μm ($\pm 3\sigma$) for the alignment is required. **Figure 9** summarizes the measurement results for bonding alignment performed with the developed equipment. The x-axis shows the measurement location on the test vehicle (COG experimental glass substrate), and the y-axis shows the positions of the alignment marks. The values of all of the measurement data were acceptable, and the deviation was within a permissible range.

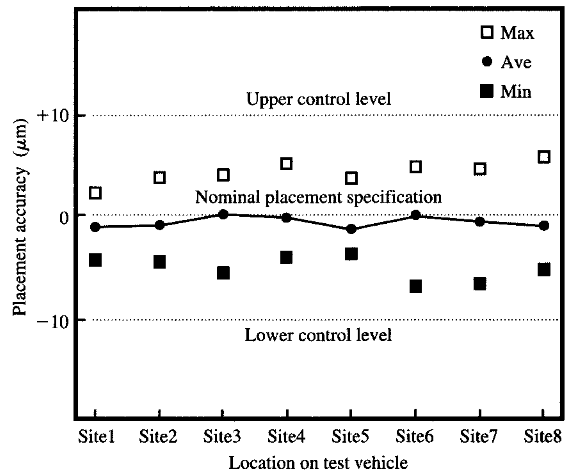

Figure 9

Alignment data for the test vehicle fabricated by means of the COG equipment.

- *Bare-die availability*

Infrastructures for bare-die application have recently been promoted by IC and tool makers. The specifications and quality of the electrode bumps, such as layout, dimension, shape, hardness, and coplanarity, are important for achieving high yield. Contact area of 3000–5000 μm^2, height of 15–25 $\pm$ 2 μm, bump pitch of 50–70 μm, gap of 20 μm, hardness of 40–50 Hv, and chip size of (1–1.5) $\times$ (16–18) mm are assumed.

- *ACF for COG application*

Two types of ACF have been proposed. One has conductive particles covered with a very thin insulation layer. This type of ACF provides approximately four times as many particles as the regular type. The particles are 5 μm in diameter and are covered with a thin insulating layer, so that electrical shorts between the electrode bumps, which are separated by a 10-μm gap, can be avoided. The thin insulation layer is broken when the particles are deformed. The other type of ACF is the double-layer type, which consists of a layer filled with conductive particles and one with no particles, so that the functions of conduction and adhesion are separated. The particles are 3 μm in diameter. The quality and reliability of the bonding depend on the uniformity of the particle distribution. It has been reported [5, 6] that the distribution of the particles on the electrodes that can provide electrically effective contact closely resembles a binomial distribution. On the other hand, a density of more than five particles per electrode is required in order to ensure reliable contact, as mentioned above (in the section on recent development activities); in other words, a density of fewer than five particles per electrode is unacceptable. A defect (less than five particles per electrode) occurrence probability of less than 10^{-9} gives a stable quality level. Studies show that densities of more than 5100 particles per mm^2 for an electrode pitch of 100 μm and more than 9000 particles per mm^2 for an electrode pitch of 50 μm are required [5, 6]. The bump size of 3000 μm^2 mentioned above can be assumed to be the minimum size for currently available ACFs. In this case, an ACF with 5-μm particles can provide a density of 15 particles per bump on average. Reliable electrical contact can be achieved according to the simulation result (the probability of fewer than five particles per bump is 10^{-9}). Both ACFs can satisfy the electrical reliability requirement.

- *Repair method*

Cured adhesive material has viscous properties beyond the glass-transition temperature (T_g) around 120°C. Therefore, a bonded chip can be removed by a thermal tensile operation. The residue of the adhesive is wiped off, and the chip is cleaned with a solvent such as acetone or MEK. The difficulty of chip removal and solvent cleaning depends on the properties of the adhesive and its reactive values. Semicured adhesive (prebonding level) can be removed easily with ethanol or isopropanol. Electrical testing at the semicured level has to be studied.

- *Reliability demonstration*

Figure 10 shows the reliability test results under stress at 85°C and 85% relative humidity. The x-axis shows the measurement point on the driver IC, while the y-axis shows the average values of increase in resistance from the initial level for the eight samples. The experimental glass substrate mentioned previously was used for this measurement. Two types of ACF were used, one with the insulating conductive particles 5 μm in diameter, and the other a double-layer ACF with conductive particles 3 μm in diameter. The contact resistance was measured for 1000

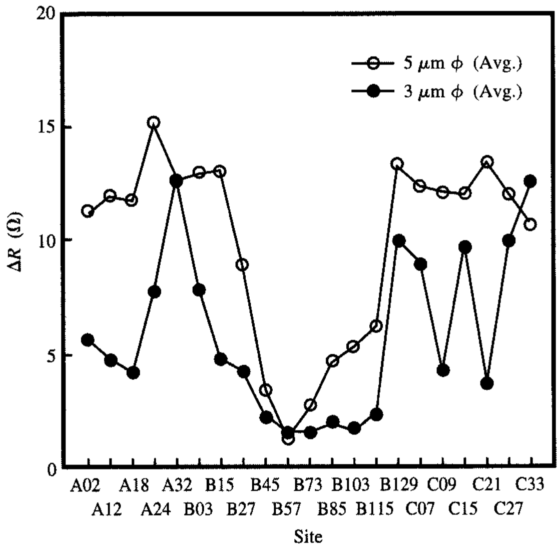

Figure 10

Acceleration test results for the COG test vehicle at 85°C and 85% relative humidity after 1000 hours. Two kinds of ACF were tested.

hours under the above conditions. The ACF with particles 5 μm in diameter showed slightly higher average values but a slightly smaller variance, while the ACF with particles 3 μm in diameter showed slightly lower average values but a slightly larger variance. Small particles may require stricter controls for the bonding process and equipment, and a small variation in the bump height on the driver IC. In summary, no major difference between these two types of ACF was observed. In addition, functional modules were fabricated with the experimental glass substrates and subjected to environmental tests. No major degradation of the image quality was observed.

Conclusions

Technology for micropitch connections using ACF has been established, with a focus on the requirements of LCD technologies and portable products. The density, reliability, and productivity of the technology have been improved to cope with these requirements. COG was successfully demonstrated as an example of an advanced technology.

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