

Materials and Components for Flat Panel Display Applications

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OVERVIEW: As the networked ubiquitous information society continues to develop, we are seeing the emergence of an environment in which people can send and receive information practically anywhere and anytime. Obviously the display device has a singularly important role to play in this society as the exit where information emerges from the network infrastructure for us to see and act upon, and will become even more important as time goes on. For flat-screen TVs that are now emerging as one of the most coveted consumer electronics products, large-screen LCDs predominate for screen sizes up to about 30 inches while plasma displays have clear advantages for larger screen sizes exceeding 40 inches. Yet in order to provide stable high-quality products, a number of technical challenges must be overcome, most notably the reduction of material and component costs to facilitate the use and drive down costs of longer sheets of motherglass to create larger LCD screens. Hitachi is committed to R&D aimed at improving the performance and reducing the cost of LCDs, plasma displays, and other lightweight flat-screen display technologies, while at the same time bringing more advanced materials and components to market supporting Hitachi's high standard of display module craftsmanship.

INTRODUCTION

AS the ubiquitous network society continues to unfold, we are seeing the emergence of an environment that supports the ability of people to send and receive information at will anytime and anywhere. The display device has a singularly important role to play in this society as the exit where information emerges from

the network infrastructure for us to see and act upon. For flat-screen TVs that are now emerging as a hot consumer product, large-screen LCDs (liquid crystal displays) predominate for screen sizes up to about 30 inches while plasma displays have advantages for larger screens over 40 inches in size. Now that flat-screen TVs are poised for rapid market penetration,

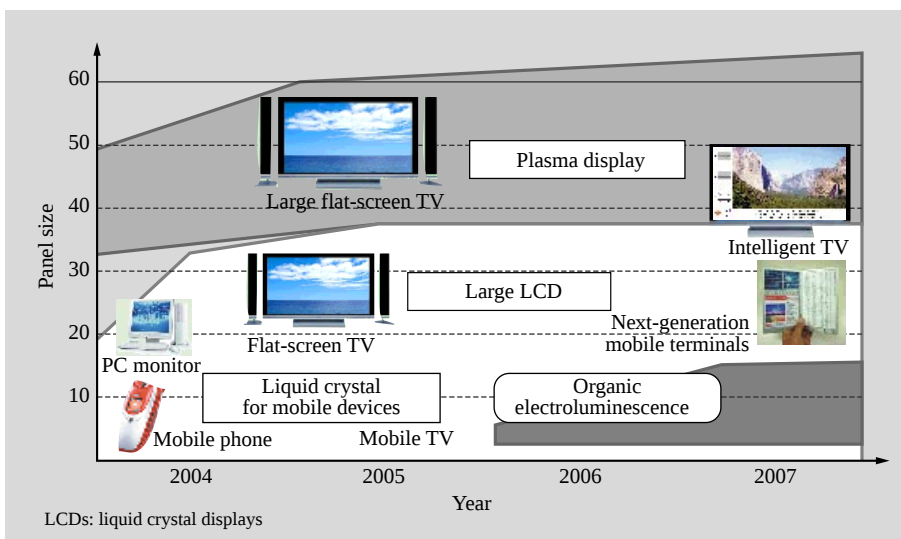


Fig. 1—Trends in Flat Panel Display Screen Sizes.

In the larger screen sizes greater than 30 inches, large-screen LCDs and plasma displays for thin-screen TVs are the main technologies. Currently smaller displays for mobile devices size are monopolized by liquid crystal, but there is a good chance that organic electroluminescence displays will become available for handheld devices in a few years.

the key R&D (research and development) issues are the deployment of processing equipment capable of handling longer sheets of motherglass and developing higher performance lower cost components and materials that can hold down the cost of flat-screen displays while perfecting displays that are intuitive and easy for the greatest number of people to operate (see Fig. 1).

While continuing its strong commitment to R&D on LCDs, plasma displays, and other flat-screen display technologies for digital consumer products and mobile devices, Hitachi is also dedicated to bringing more advanced materials and components to market that support Hitachi's high standard of display industrial craftsmanship.

This paper highlights the functions and roles of some of the most elemental materials and components of displays, focusing on optical components, advanced film materials, and module packaging technology.

OPTICAL COMPONENTS

Holographic Waveguide

Along with advances in the information and communications sectors, mobile phones and other handheld devices have seen remarkable advances in speed and functionality. The LCDs used in these applications have also seen rapid improvement color intensity and resolution, and it is desirable that the constituent backlight provide better luminance to make up for reduced transmissivity with higher color purity and diminished luminance resulting from smaller pixels. Hitachi Chemical Co., Ltd. has addressed these problems with commercialization in August 2000 of a backlight that incorporates a holographic waveguide based on Hitachi's own proprietary elliptical diffusion technology.

White color LEDs (light emitting diodes) were used as the light source for backlights for small- to mid-sized LCDs, but produced problematic bright lines on the surface of the waveguide. This is generally prevented by forming various solid light dispersion patterns on the waveguide surface. However, it was found that the existing pattern caused the light emitted from the waveguide to largely disperse over a circular area, which had the disadvantage of diminishing the luminescence (see Fig. 2).

Our newly developed holographic waveguide forms a holographic pattern with the dispersion characteristics shown in Fig. 3, which mitigates the shadowy dark areas between LEDs which inevitably occur when LEDs are used as the light source. The

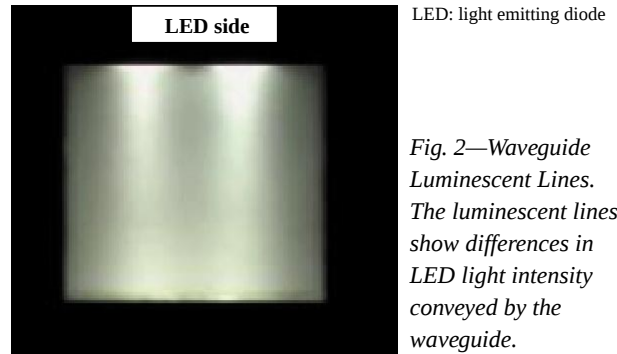


Fig. 2—Waveguide Luminescent Lines. The luminescent lines show differences in LED light intensity conveyed by the waveguide.

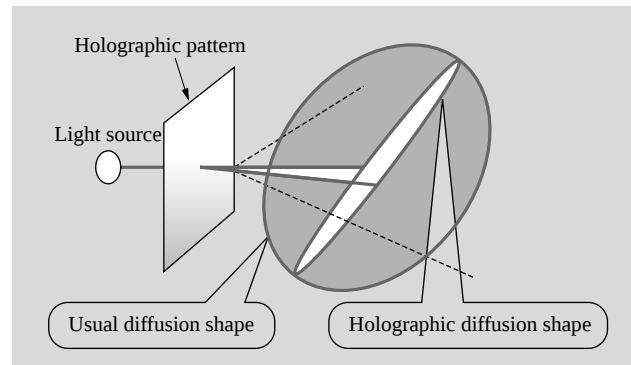


Fig. 3—Holographic Diffusion Pattern. Holographic patterns are unique in the linear diffusion pattern of the light.

TABLE 1. Comparison of Waveguide Characteristics
Backlight conditions: 2.2 inches, 15 mA input by four LEDs

Item	Conventional	New
Luminance	2,800 cd/m ²	3,600 cd/m ²
Uniformity	80%	82%
Convergence film	2 film layers	1 film layer
Dispersion film	1 film layer	Not needed

new waveguide also fixes another old problem of extremely weak vertical dispersion in the vertical direction between LEDs to prevent this source of reduced luminance. With development of this waveguide, we have already marketed a new backlight that uses only one prism-type convergence film instead of two films that are required by conventional backlights. Right now this backlight is being used primarily with LCDs for color mobile phones, but it should see extensive use in a diverse array of products that use LEDs as a light source (see Table 1).

MLAs

MLAs (microlens arrays) are one- or two-dimensional arrays of minute lenses ranging from

several microns to several hundred microns in diameter, and are used in CCD (charge-coupled device) image sensors, 3D display elements, optical communications, and a host of other optical devices. Indeed, the MLA occupies a central place in Hitachi Maxell, Ltd.'s strategy to create more advanced optical devices, and the company is moving aggressively to develop MLAs by leveraging its expertise in optical disk manufacturing. For some time now, we have been offering a glass high-precision MLA for industrial optical equipment manufactured through a combination of resist reflow and dry etching processes.

More recently, there has been an intense effort to apply MLAs to LCDs. For example, by installing MLAs directly above a liquid-crystal backlight unit the optical path from the light source can be controlled, and by incorporating MLAs in the valve of a liquid-crystal projector, the light usage efficiency can be markedly improved by exploiting the focusing action of the lenses. Applying MLAs to semi-transmissive LCDs is also beneficial, for it not only improves efficiency by focusing the transmitted light but also boosts the reflectivity by expanding the reflecting area of the pixels. This has enormous advantages because it enhances luminosity while improving contrast in the presence of sunlight.

Hitachi Maxell is now developing a new method for fabricating MLAs for semi-transmissive LCDs based on earlier development of a new type of stamper and precision alignment technology. The key feature of this new method is that the alignment with liquid-crystal pixels can be precisely controlled to within $\pm 1 \mu\text{m}$ which allows lenses to be formed directly on the liquid-crystal substrate. Fig. 4 shows SEM (scanning electron microscope) and focused spot images of test lenses made by this process. As one can see, two types of lenses can be produced by the process: a hexagonal type and a rectilinear type. We verified that the fill-factor is over 95% and the focusing characteristics are also excellent.

This recent development of MLAs that exhibit such exceptional performance will have an enormous beneficial impact on the performance of LCDs in the years ahead.

Color Resists for LCD Color Filters

Color resists are liquefied resists in which negative UV (ultraviolet)-cured resists are doped with submicron organic pigments, and they are used in the manufacture of color filters for LCDs. Hitachi develops and markets a range of color resist products for LCDs for TVs and

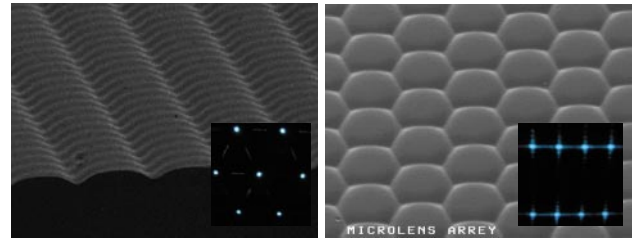


Fig. 4—SEM Images of Microlens Array Formed on Glass Substrate.

SEM (scanning electron microscope) image of hexagonal lenses with a diameter of $420 \mu\text{m}$ and a focal distances of 0.83 mm (right), and a rectilinear lenses measuring $150 \times 50 \mu\text{m}$ and with a focal distance of 0.35 mm (left) and their responding focused spot images. The curvature is isotropically formed, so the light converges at one point. This reduces the light transmitted portion of pixels while increasing the reflectivity, thus improving contrast in the presence of sunlight which makes a display easier to see.

for mobile phones and other handheld devices.

Large LCDs—particularly those used for TVs—require high contrast and excellent color purity in terms of the color characteristics, and demand uniform coating using a slit coater on large glass substrates measuring at least one meter square in terms of processing characteristics. Requirements for smaller to medium sized LCDs—including displays for mobile phones—are enhanced resolution in addition to good color purity⁽¹⁾.

In developing resists for LCD TVs and mobile phones, Hitachi achieved excellent pigment concentration and micro stabilization⁽²⁾ by optimizing the type and dose of resins and dispersing agents in the pigment to achieve color purity with an NTSC (National Television System Committee) ratio of 72% and excellent contrast (see Table 1). In developing resists for LCD TVs, we also improved the coating uniformity of the slit coater by optimizing the mix of solvents and leveling agents. We also improved the resolution of resists for smaller mobile phone LCDs by modifying the composition of the photoinitiator agent.

Hitachi's color resists targeting LCD TVs produces excellent uniformity with a film thickness variation of less than 3% in slit coating, and the company's color filters show a significant improvement in contrast of more than 30% over previous filters. And in color resists for mobile phones, we have achieved a color purity with an NTSC ratio exceeding 70%, and pixel patterns that precisely map to exposure mask dimensions (see Table 2 and Fig. 5).

Meanwhile, we are continuing efforts to further

TABLE 2. Color Resist Color and Contrast Values
Contrast value is based on glass cell reference calculated as 10,000.

Chromaticity	Brightness (cd/m ²)	Color (X-axis)	Color (Y-axis)	Contrast ratio
Red	18.7	0.654	0.324	3,000
Green	55.9	0.29	0.594	4,500
Blue	11.6	0.134	0.104	3,800
WB	28.7	0.304	0.327	—

WB: white balance



Fig. 5—Example of Coating by Slit Coater.
 Based on evaluation equipment, example shows coating onto smaller substrate. The system also provides sufficient film thickness uniformity for mass production and large substrates.

enhance the color purity of color filters that can be used with LED backlights for LCD TVs⁽³⁾, and in pursuit of better color resists for thin-film color filters that enhance the color purity of mobile phones and other handheld devices.

FUNCTIONAL FILMS

Anisotropic Conductive Films

LCDs must provide a way for the circuits deposited on the glass substrate to interconnect with the multitude of tiny outer leads on the driver chip that drives the display. Hitachi Chemical Co., Ltd.'s ACF (anisotropic conductivity film) ANISOLM is able to provide the mass connection to this multitude of minute dense circuitry. This section will consider Hitachi's recent advances in this area.

As shown in Fig. 6, ACF is essentially a tape adhesive that is filled with conductive particles. Fig. 7 illustrates that the ACF is inserted between the circuits

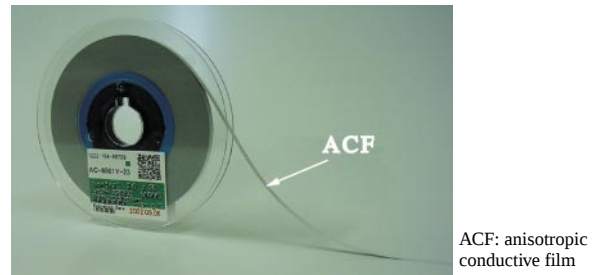


Fig. 6—Photo of ACF.

ACF is a tape adhesive that is doped with conductive particles and simplifies interconnection processing automation.

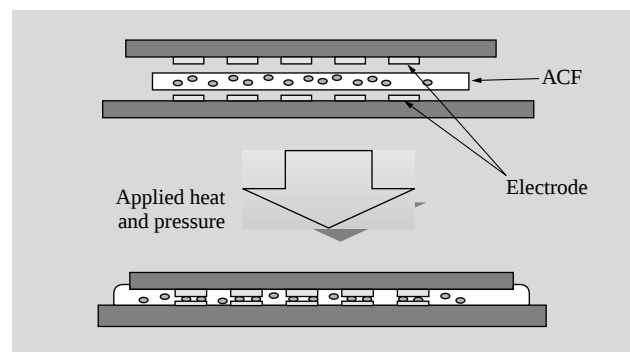


Fig. 7—Interconnecting Circuits by ACF.

The ACF is inserted between the circuits to be interconnected, and anisotropic conductive interconnection is achieved by the application of heat pressure.

to be interconnected, and the two substrates are then tightly bonded together by heat and pressure to provide conductivity between the facing circuits and insulation from other circuits. Two types of conductive particles are used on the film—nickel and other metallic particles and metal-coated resin particles—and the diameters of the particles range in size from 2 to 10 μm . The resolution was improved by carefully controlling the dispersion condition of particles on the film and by optimizing the composition of the film itself.

The ACF adhesive hardens quickly in under 20 seconds, but until the thermal pressure is applied, the ACF can be used even after exposed to the ambient room temperature for up to two weeks. Moreover, in light of recent trends toward larger LCDs and narrower frames, warpage of printed circuits boards and increased thermal effects on LCD panels at the time of interconnection has become more problematic. This

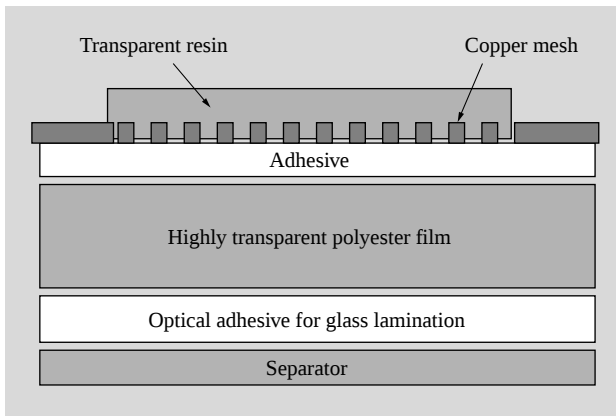


Fig. 8—Structure of Electromagnetic Wave Shielding Film. Copper mesh is bonded onto polyester film. The line-width of the copper is $10\text{ }\mu\text{m}$, which is practically invisible to the naked eye.

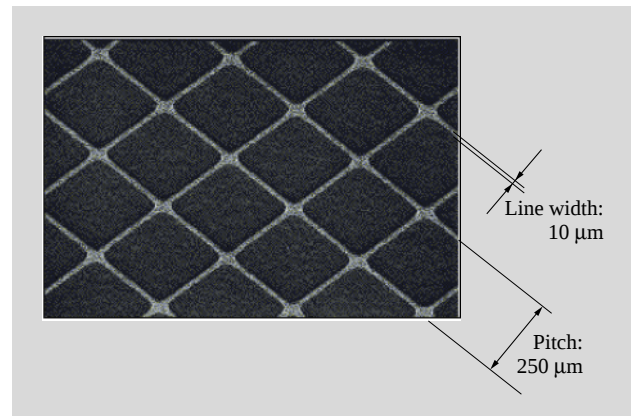


Fig. 9—SEM Photograph of Copper Mesh Embedded in Electromagnetic Wave Shielding Film. The copper mesh is covered with transparent resin to increase its transparency.

has led to an even more urgent need for the quick low-temperature interconnection provided by ACF to counter these adverse effects. Our new adhesive system works at the low temperature of 150°C , much lower than earlier systems, sets up quickly (10 seconds at 150°C), and is now widely available on the market.

While there are various practical packaging solutions using ACF, the COF (chip-on-film) substrate package is a new approach that achieves good adhesion for two-layer FPCs (flexible printed circuits) and provides excellent adhesion reliability against stress and absorption for different chip-film interconnect structures. In addition, there are many cases where the top of the package is sealed in a reflow oven after the driver chip is mounted in the package, and this requires reflow process ability at a higher temperature than the ACF connection temperature, which is about 260°C . This led us to develop a practical new ACF adhesive product specifically tailored for use with COF packages.

In the last few years, ACF is starting to be used on other kinds of devices besides LCDs including interconnecting of new types of displays and interconnecting the IC chip and substrate in flip-chips. This technology is attracting widespread interest as a lead-free environmentally-friendly material enabling low-temperature interconnection. ACF technology has already led to a transformation in packaging methodology. It is certain to have other major benefits—sustained reliability, better resolution, and improved manufacturability—and Hitachi is now working on a new generation of ACF products that incorporate these features.

Electromagnetic Wave Shielding Films

PDPs (plasma display panels) are large thin self-luminous displays that are capable of remarkably sharp resolution, and are now beginning to see rapid market penetration. The only downside of this technology is that, because of the luminous principle by which they operate, PDPs tend to emit electromagnetic waves triggered by noise emanating from other equipment in the vicinity. This means that PDPs require a filter shielding them from electromagnetic waves. The amount of permissible emissions is regulated by law (in Japan through the voluntary restrictions of the VCCI: Voluntary Control Council for Interference by Data Processing Electric Office Machines) and is divided into two classes: Class A for industrial applications, and a stricter Class B for consumer applications.

Hitachi Chemical's ES Series electromagnetic wave shielding film products for PDPs satisfy the VCCI's stricter Class B requirements for filters, and have now seen widespread acceptance among domestic and global filter manufacturers. Accounting for the favorable reception of these products⁽¹⁾ the ES Series films provide:

- (1) excellent electromagnetic wave shielding properties,
- (2) very high visual transparency (above 80%),
- (3) flexible design (pitch, bias angle, etc.), and
- (4) the ability to accommodate large sizes (up to $80\text{ inch} \approx 1.0\text{ m} \times 1.9\text{ m}$).

As shown in Figs. 8 and 9, the electromagnetic wave shielding film consists of a copper mesh with a pitch of 250 to $300\text{ }\mu\text{m}$ and a line width of $10\text{ }\mu\text{m}$ that

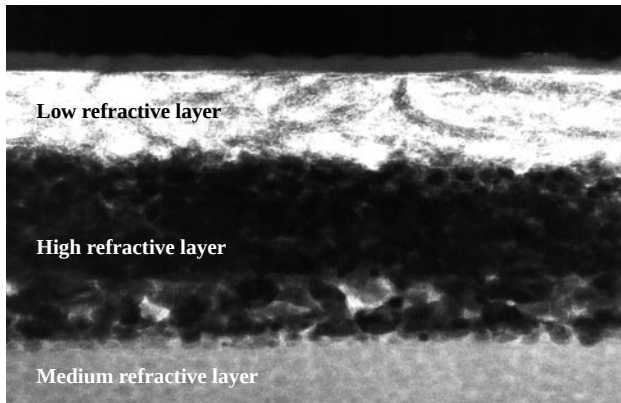


Fig. 10—TEM (transmission electron microscope) Cross-sectional Photograph of Three-layer Antireflection Film. A 4- μm hard coat layer, a 0.1- μm medium refractive layer, a 0.15- μm high refractive layer, and a 0.1- μm low refractive layer are deposited on a PET (polyethylene terephthalate) film substrate. Each layer is formed from UV (ultraviolet)-hardened coating dispersed nano particles having different refractive indexes.

is practically invisible to the eye, and is overlaid and bonded to a polyester film. To make the mesh even more transparent, it is covered with a transparent resin. Then, on another sheet of polyester film an optical adhesive layer is deposited to laminate the ES film to the filter glass.

Continuing this work, we plan to develop films with near-infrared absorption capability and other functionally enhanced film products.

Anti-reflection Films for Displays

PDPs and LCDs must be provided with anti-reflection films in order to minimize reflections and glare caused by outside light. In order to satisfy the dual demands of larger display areas and lower costs, these films are usually deposited today using the wet coating method⁽²⁾.

Hitachi Maxell has developed a high-performance three-layer antireflection film that reduces reflection for wide visible-light region and pale reflected light colors. Fig. 10 shows a TEM (transmission electron microscope) cross-sectional photograph of the film. The structure consists of a hard coat layer, a medium refractive layer, a high refractive layer, and a low refractive layer that are deposited onto a PET (polyethylene terephthalate) film substrate by the wet coating method. By depositing these thin layers that have different refractive indexes at just the right thicknesses, the resulting optical interference acts to effectively reduce reflected light.

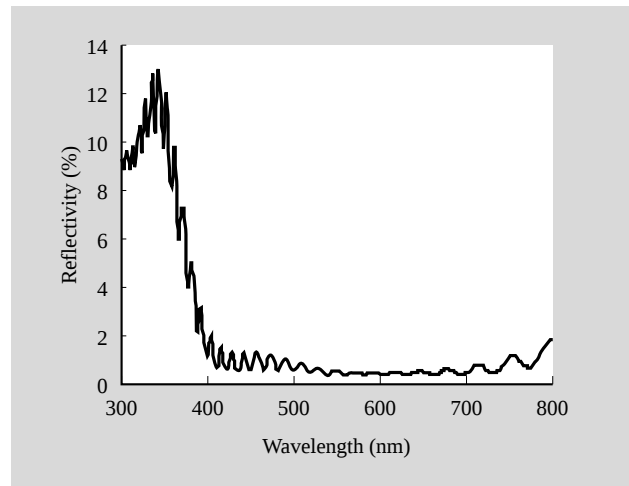


Fig. 11—Reflection Spectrum of Three-layer Antireflection Film. The back side of PET film without any antireflective coatings was roughened with sandpaper, completely blacked with a black marker pen, then the reflectance was measured with a spectrophotometer on the condition of 2° in angle of incidence of the light source.

Fig. 11 shows the reflection spectrum from the three-layer antireflection film. One can see that the luminous reflectance is 0.5%, which nearly matches the performance of anti-reflection films deposited by the dry coating method. Since the reflectivity of reflected light is reduced for wide visible-light region, the reflected light color is manifested as a pale blue, and the durability of the films is also quite sufficient for practical applications.

Trends in the coming years will focus on identifying simple layer compositions for anti-reflection films that strike a good balance between cost and functionality, and on developing complex anti-reflection films that incorporate other functions (such as film layers that provide an near-infrared radiation absorption function and electromagnetic interference shielding function for PDP optical filters).

MATERIALS AND COMPONENTS FOR PACKAGING

COF Tape Carrier for Large LCDs

As large LCD TVs become increasingly popular, we are seeing increased production of TAB (tape automated bonding) tape for mounting the driver IC (integrated circuit) that drives the liquid-crystal circuits. The conventional TAB method, called the flying lead structure, is illustrated in Fig. 12. An opening (device hole) is opened at the place where the chip is to be mounted, and an inner lead providing the interconnect with the chip electrode sticks out into

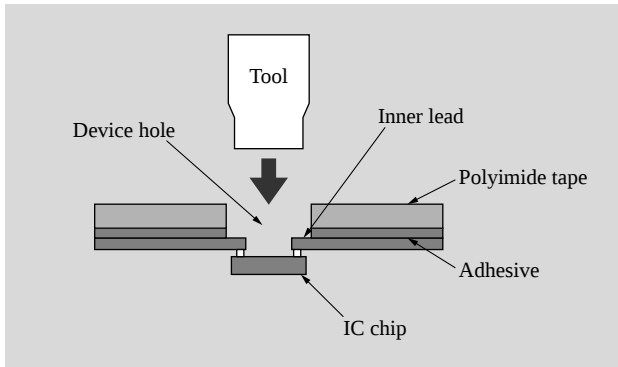


Fig. 12—Schematic of TAB Interconnect Method. TAB (tape automated bonding) tape and a driver IC are connected by electroless tin plated inner lead using the IC electrode pad bump and image recognition for alignment.

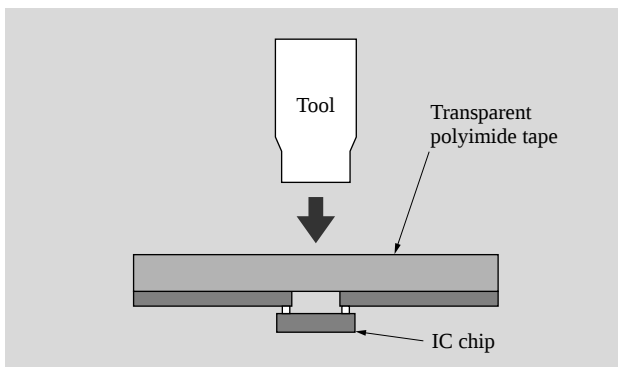


Fig. 13—Schematic of COF Interconnect Method. Using COF (chip-on-film) tape to connect the inner lead and IC chip electrode, bonding is usually done by looking through the lead and IC chip from the polyimide tape side.

the hole from around the hole.

As LCDs get smarter, the electrode count continues to multiply. But in order to hold down the cost of the overall package, the IC chip is continuing to shrink and the layout pitch of the electrode pad on the chip is getting increasingly narrow. This then creates a strong demand to reduce the size of the TAB tape inner lead pitch in order to match this decrease in device dimensions. We have been reducing the size of the lead pitch at a rate of about 5 μm a year, but when wire interconnects are miniaturized below a pitch of 40 μm , it becomes exceedingly difficult to implement the aforementioned flying lead structure.

As an alternative to the structure with the lead protruding into the device hole, we have conceived the flip-COF package for connecting the IC chip to

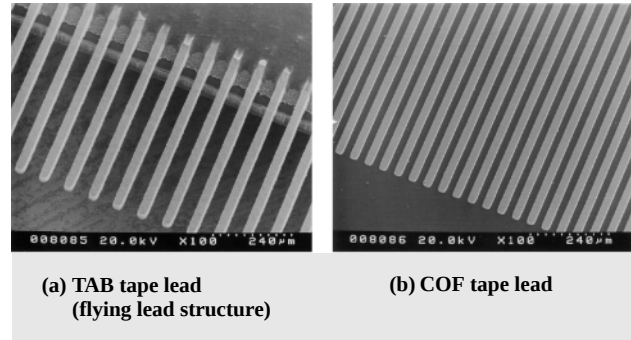


Fig. 14—SEM Photographs of Inner Lead Using TAB Method and COF Method.

The COF method is capable of forming fine-featured interconnects with a pitch of less than 40 μm .

the lead forms on polyimide. Corresponding to this design, Hitachi developed and is now manufacturing fine-featured interconnects with a pitch of less than 40 μm ⁽³⁾. Fig. 13 shows a schematic overview of IC chip bonding by the COF tape method. In connecting the inner lead and IC chip electrode using COF tape, the bonding is generally done by looking through the lead and IC chip from the polyimide tape side to achieve proper alignment, so to aid in this process we adopted a new polyimide tape material that is transparent.

Because the COF tape with such a narrow pitch lead raises concern about electromigration, we made a number of enhancements: naturally the etching process itself was improved, but we became more discriminating in our selection of materials and chemicals, implemented more stringent cleaning processes, and improved the tolerance of the process. As a result of these improvements, Hitachi Cable, Ltd. is now able to mass produce COF tape with a minimum lead pitch of 30 μm .

The ability to produce even smaller feature, high-performance, high-pin-count liquid-crystal drivers in the future will require not only the mass production of narrow-pitch COF tape, but also require comprehensive verification of a number of interrelated technologies including the continued reduction of the IC chip dimensions and the development of new bonding technologies. It is thus becoming increasingly important that all of the relevant players involved in this business—chip manufacturers, package manufacturers, materials manufacturers, and tape manufactures—work together and collaborate.

CONCLUSIONS

In this paper we surveyed the current development status and product specifications for many of the materials and components that are needed to produce state-of-the-art flat-screen display modules. Among optical components, we highlighted holographic optical waveguides, microlens arrays, color resists for LCD color filters, high-performance ACFs, electromagnetic wave shielding films, antireflection films, and new module packaging COF technology.

In the manufacturing of display devices, reconciling differences among basic materials is an essential area of technology, and overseas manufacturing that has made such excellent use of Japan's technical prowess in materials and components is now returning to Japan's own domestic manufacturing.

Hitachi remains committed to R&D on high-functionality components and materials that support a high standard of display craftsmanship that will further contribute to digital consumer electronics and mobile devices in the years ahead.

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