CHALLENGES AND OPPORTUNITIES IN FLAT PANEL INDUSTRY

by

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Abstract

The Flexible Panel Display (FPD) business is rapidly growing in Asia. Many industrial companies not only from traditional coating industries but from others such as electronics, printing, and film manufacturing industries, are coming into this business in Japan, Korea, Taiwan and quite possibly in near future, China because of such a high growth opportunity. The total capital investment announced by several key companies, is several billion dollars for next one to two years. Due to the fact of the application to optical (quality) and consumer (cost) products, we have challenges in web handling technology besides coating and drying technologies. For example, the thin film precision coating, which is crucial for display products, requires the precision web handling, which means, for example, the technologies such as the uniform cross web tension of thin film and the scratch free web handling of wide film are essential.

The FPD business will be overviewed and the technological challenges in web handling in combination with coating process will be discussed briefly based on the current and future needs.

Nomenclature

K Constant value determined by the lip design of slot die
Q Coating flow rate
Q_1 Coating flow rate of fluid 1
Q_2 Coating flow rate of fluid 2

t Coating wet thickness
t_{min} Minimum coating wet thickness
T Web tension
V Line speed
W Coating width
η Coating fluid dynamic viscosity
η_1 Coating fluid 1 dynamic viscosity
η_2 Coating fluid 2 dynamic viscosity

Flat Panel Display Industry

<u>Product</u> [1]

There are two types of products in the flat panel display, which are, 1) "non-emissive" and 2) "emissive", based on the light source.
In the non-emissive type, which needs to have the light source, there are liquid crystal displays (LCD), MEMS (Micro-Electro-Mechanical Systems), and E-ink (Electronic Ink).
In the area of emissive type, there are plasma display panels (PDP), vacuum fluorescence displays (VFD), electroluminescence displays (ELD), light emitting diodes (LED), field emission displays (FED), and organic light emitting diodes displays (OLED).
Some of the displays are picked to discuss and shown in the schematic diagrams of the device structure.

The functionality of liquid crystal displays (LCD) is based on the controllable rotation of the polarization plane of incident light using a thin liquid crystal layer. LCD is non-emissive—the liquid crystals work like "light valves". (Fig.-1)
Light sources are either backlights like Cold Cathode Fluorescent lamps (trans-missive mode) or incident light reflected by a mirror foil behind the display (reflective mode). (Fig.-2)

The plasma display panel (PDP) has the benefits of a Cathode Ray Tube (CRT), but can be built in a much thinner structure. Plasma displays are typically filled with a gas such as neon, and driven in a row-column passive-matrix manner. They require high voltages to ignite the plasma, and careful current limiting to prevent display heating. Since the actuation mechanism ionizes gas at each pixel, PDPs create radio frequency emissions, which must be carefully controlled. (Fig.-3)

VFDs are an established technology still widely used as low information content displays in audio/video devices or household appliances. The VFD technology uses the fluorescence of phosphors under electron bombardment similar as in cathode ray tubes (CRT). However the device structure is quite different from CRTs and resembles the classical triode: Electrons evaporate from the metal cathode, a filament with around 50V. VSDs can be easily identified by honeycomb structure of that grid which is fabricated by etching a very thin steel foil. As soon as the electrons penetrate the anode at around 100V, light is being emitted. (Fig.-4)

Field emission displays (FEDs) resemble thin CRTs, but without the heating element in the cathode; in addition, they are organized in a one cathode per pixel passive matrix organization. Like the plasma display panels, FEDs typically require a high voltage to operate, anywhere between 200V and 6KV. These displays can be very thin, but thus far the production costs of manufacturing facilities have kept them out of mainstream commercial products. (Fig.-5)

An OLED is made from a stack of organic layers, forming a p-n junction, similar to an inorganic LED. When a voltage is applied in forward direction, light is emitted from the region where injected holes and electrons recombine. As the organic material is very susceptible to water vapor and oxygen, thorough encapsulation is indispensable.
OLEDs are self-emissive, highly efficient, and show excellent optical properties. They have high potential to be mass-produced on flexible substrates which enable processing in a roll-to-roll manner. Moreover, the possibility to simply print the organic material makes fabrication very inexpensive. (Fig.-6)

Product Technology Trend

Looking at LED, which is widely applied, PDP, which is growing, FED and OLED which are still in embryonic phase, the performance comparison was made in terms of image quality, response speed, product life, total thickness and weight (compactness), availability to large size, cost, and applicability to flexible substrates. Finally the companies are listed who are under technology development. (Table-1) The OLED has excellent performance in image quality and response speed and has also excellent compactness.

Comparing with LCD, the OLED seems to have better overall performance. The biggest challenge is how to make products and how to reduce the manufacturing cost.

The display industry has to meet the customers' interest in larger size and higher pixel numbers with lower price. There is a prototype of 40 inches size with 1 million pixels at moment. (Fig.-7)

As we discussed before, if you could reduce the manufacturing cost based on roll-to-roll process, the OLED has excellent potential to expand the application area from small size of audio, cellular phone, game machine, digital camera, automobile navigator, and PDA to desktop/note PC, indoor TV set, large size flat TV set, outdoor large screen, and projector within a decade. (Fig.-8), (Fig.-9)

If we could develop the wet coating technology successfully within a few years, the $ 10 billion business is expected in 2010 and the share of the wet coating OLED to the total OLED business is more than 90%. (Fig.-10)

Flat Panel Display Business Impact [2]

The CRT business seems to be in the maturity mode already but by having flat panel display (FPD) technology, the total business of CRT and FPD is being geared up from late 90's and it may reach over the \$100 billion business by the year of 2008. The 90% of the total market is basically FPD. (Fig.-11)

The figure 12 indicates that LCD is a key player and PDP is coming into the second player. The OLED may not be one of key players because there are technical challengers to be overcome although it has excellent potential performance. In other words, if we could develop the wet coating based OLED in the near future, the FPD business has a different growth story.

The figure 13 indicates the LCD TV and the PDP TV are growing in terms of market by product and in particular the LCD TV grew from 0% level (Sale Amount) in 2000 to more than 10% level in 2005 and is expected to grow up to 25% by 2008. The figure 14 indicates unit based share between monitor, notebook PC, TV and others and it could be found that their growth is still high for next several years. It is also believed if the low cost OLED with flexible substrate is coming into market, the picture will be changed to grow more with different applications, including outdoor large screen.

Technological Challenges

Product Structure

The typical LCD product structure is shown in figure 15. The LCD has many functional layers such as anti-reflection/anti-glare layer, polarizing layer, retardation layer and so on. The total number of layers is for example more than 10, excluding a glass substrate and the total thickness is about 4-6mm, which makes the manufacturing cost high.

To the contrary, the total number of layers and also the total thickness of the possible OLED product are 4-5 layers and less than 2mm with a glass substrate. (Fig.-16) If we could develop the LCD or the OLED product with flexible substrate, the manufacturing cost will be reduced because of roll-to-roll process and the application area will be expanded as we discussed before.

Product Characteristics

It is translated into challenges from my knowledge and information collected from the plat panel display industry, based on possible idea of flexible panel display products. In the quality area, we have challenges such as,

1) thin film (less than 5μ wet thickness per layer),
2) uniform coating thickness (less than ± 1 %),
3) optically defect free (for example, the "rainbow" defect should be eliminated.),
4) functional multilayer structure, and
5) optically clear (for example, no scratch, no wrinkle, and no haze).

In the area of cost, we have other challenges such as,
1) roll-to-roll continuous process in stead of batch process of vacuum coating
2) high speed,
3) wide web, and
4) multilayer simultaneous solvent base coating.

Challenges to Coating Process

The coating process is to be defined as the replacement of the gas (air) with the liquid (coating fluid) in a very short period of time (microsecond). With this general definition, the printing is also a part of coating. The oldest coating method is "dip coating", which was used for more than 2,000 years and there are many different coating methods developed and available in these days.

Considering the quality and cost requirements of flat panel display products listed in previous section, there are only a few methods applicable, which are, for example, wire-rod and meniscus coating methods at relatively low speed, which are being widely used to coat a thin primer layer to the substrate in the film industry, reverse gravure and kiss roll coating methods, which are possibly applicable but have the low thickness limit, slot coating, which has also the thickness limit due to mechanical preciseness, and lastly tension web slot coating, which has a good potential but has a big challenge to develop the design of the slot with unique lips.
The table 2 gives us a rough idea that each coating method except the tension web coating has advantage and disadvantage from various aspects.
The figures 17 and 18 show the pictures of typical coating methods.

Although there are several technology issues to be solved, the tension web slot coating has a good potential from the standpoint of ultra thin film coating with relatively high speed and multi-layer simultaneous coating.
The figure 19 shows a sketch of tension web single layer slot coating.
The coating thickness t is calculated by

$$t = \left(\frac{Q}{WV} \right) \qquad \{1\}$$

and the minimum thickness t_{min} is determined by

$$t_{min} = K\left(\eta \frac{V}{T} \right)^{0.4 \sim 0.7} \qquad \{2\}$$

, where Q is the flow rate, W is the coating width, V is the line speed, η is the fluid dynamic viscosity, and T is the web tension. [3]

The two layer simultaneous slot die coating is more complex (Fig. 20) and requires a lot of fundamental research to determine the die lip configuration. The key parameters to achieve thin and streak free coating, are the land length and the angle depending on the coating thickness for each layer and fluid properties such as the viscosities at high share rate and the surface and interfacial tension at high extension rate. But this system has a potential to reduce the manufacturing cost dramatically by having an innovative multilayer simultaneous coating technology, same as what happened in the photographic industry for the last half century.

Challenges to Web Handling Process

As discussed several times already, the tension web slot die coating has a good potential to give high quality and low cost manufacturing but requires following challenges to the web handling experts.

1) Cross and Down Web Uniform Tension (Quality)
   Depending on required coating uniformity, which is less than ±1% in most cases for optical products, the tension needs to be controlled within ±1.6-1.7% in both the machine and the cross web directions. Oftentimes, the elongated edges of the film web due to the result of the film manufacturing process, could be seen and it is difficult to control the cross web tension within the number above. The wrinkle, bagginess and buckling of the thin film at the coating station also create serious problems.
2) Precision Web Speed Control at High Speed (Quality & Cost)
   Due to the pre-metering coating system, the slot die coating requires precise web speed control, which should be in less than ±0.5% for the precision coating products in general.
3) Online Tension Measurement and Control (Quality)
   In order to assure the uniformity of coating thickness, the online cross web and non contact tension measurement and control is preferable but at moment there exist only a few systems available. One system is coming from OSU, called Non Contact Tension Measurement System (NCTMS) and another one is the product of Bellmatic International Ltd., Japan. [4]
   The latter one is based on the back pressure measurement between the web and the air turn roll.
4) Web Registration Measurement and Control (Quality & Cost)
   The slot die coating needs to have precise registration or in other words, precise edge measurement and control at the coating station. Otherwise the coating fluid is coated onto the back side of the web, which causes serious coating problems.
5) Low Tension Handling of Soft Polymer Materials (Quality & Cost)
   This challenge is not coating process related but film casting process related.

Looking one more time at the product structure of LCD, there are four layers of polarizer protective films in total, which are made by TAC (Tri-acetic cellulose). (Fig.21)

In the manufacturing process of this film, there are tough challenges for the web handlers. The figure 22 indicates the TAC manufacturing process, where at least three critical technologies are identified. [5]

One is how to peal off the cast film from the metal belt or the metal drum, which depends on residual solvents in the film. The second one is how to handle soft polymer materials along with the long drying zone, which is known to have more than 500 meters long usually. The third one is how to increase the drying speed.

There is an interesting patent to solve the first and the third issues, which seems to apply the multilayer coating concept to the casting process. [6] The figure 23 explains this multilayer successive casting process. The bottom layer is "poor" solvent rich which helps to peal off the film at high speed and the top layer has "good" solvent rich to help the drying speed high. In this two layer casting process, the most innovative idea is to make the bottom layer thinner as possible and keep the top layer with as much good solvent as possible. The similar concept was developed before in coating area to make viscous fluid coating at high speed with the idea of splitting a single layer to two layers, where there are a low viscosity and thin bottom layer as carrier layer and a high viscosity and thick top layer. By applying this idea, the peel-off process could be kept in high speed and the drying process could be kept in high speed, too.

The third critical one is to develop the web handling process technology of soft TAC film, which is not dried completely yet, at relatively high speed. The high tension is not able to be applied and soft polymer web has to travel in a long path. This is another challenging research theme for us, web handlers.

Conclusion and Opportunity

The display product business has a big growth potential for next a couple of decades. The technology drivers are in US, Europe and Asia but the business drivers are at moment in Asia and looking at the breadth of applications, flexible display product is in main track. Many industrial companies in this area are new to this precision process technology and they want to learn a lot engineering fundamentals in this area. This is one of the good reasons for us to keep developing fundamental understanding of the process applied.

In order to make this future business opportunity of flexible display business realistic, the precision process technology in coating/drying/web handling is needed to develop in timely manner, which is very much essential to the success.

The coating, drying, and web handling researchers and engineers have to collaborate to give good solutions to the challenging issues discussed.

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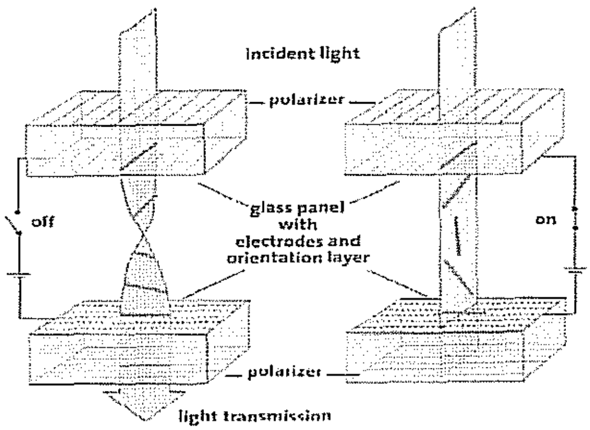
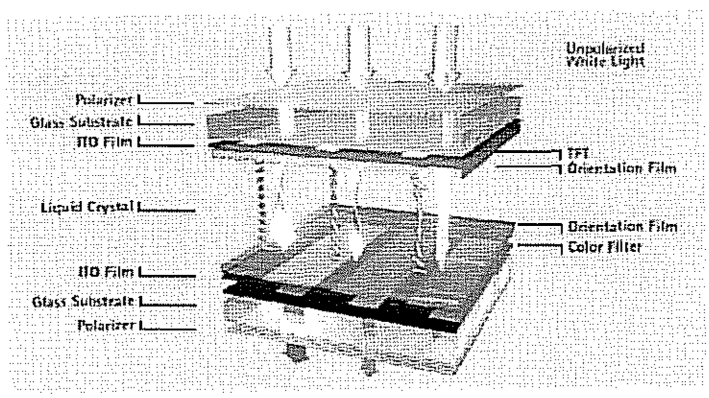
5. Tsujimoto, T., "Solution Film Casting Process," Industrial Coating Research, Vol. 5, 2004, pp.125-143.
6. Suzuki, Y., Ono, K., Saito, H., , "Preparation of Cellulose Triacetate Film," Japanese Patent JP6110413, 1986



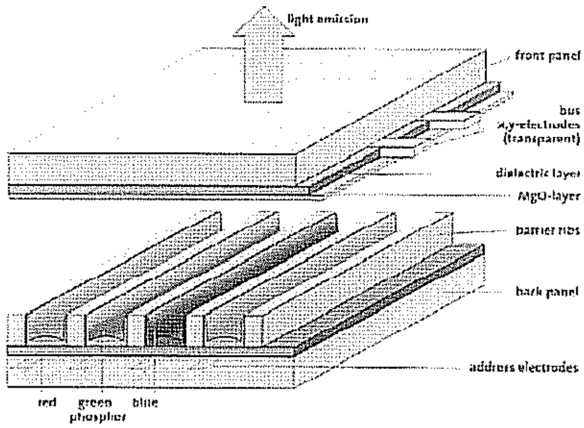
Courtesy of VDMA

Fig. 1 LCD (Liquid Crystal Displays) "Light Valve" Technology



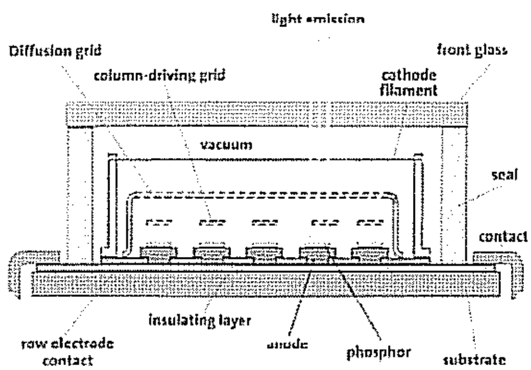
Courtesy of VDMA

Fig. 2 LCD Schematic Cross Sectional View



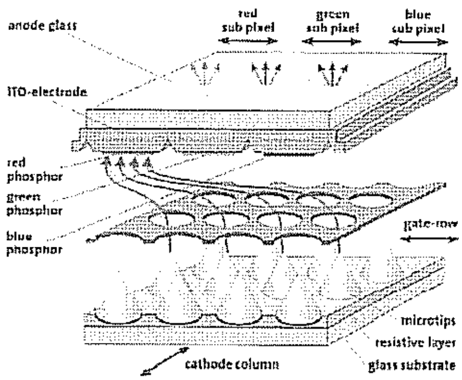
Courtesy of VDMA

Fig. 3 PDP (Plasma Display Panels) Schematic Cross Sectional View



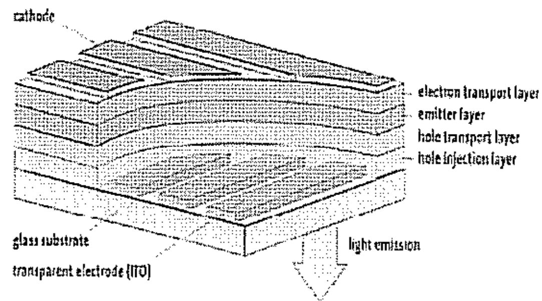
Courtesy of VDMA

Fig. 4 VFD (Vacuum Fluorescence Displays) Schematic Cross Sectional View



Courtesy of VDMA

Fig. 5 FED (Field Emission Displays) Schematic Cross Sectional View



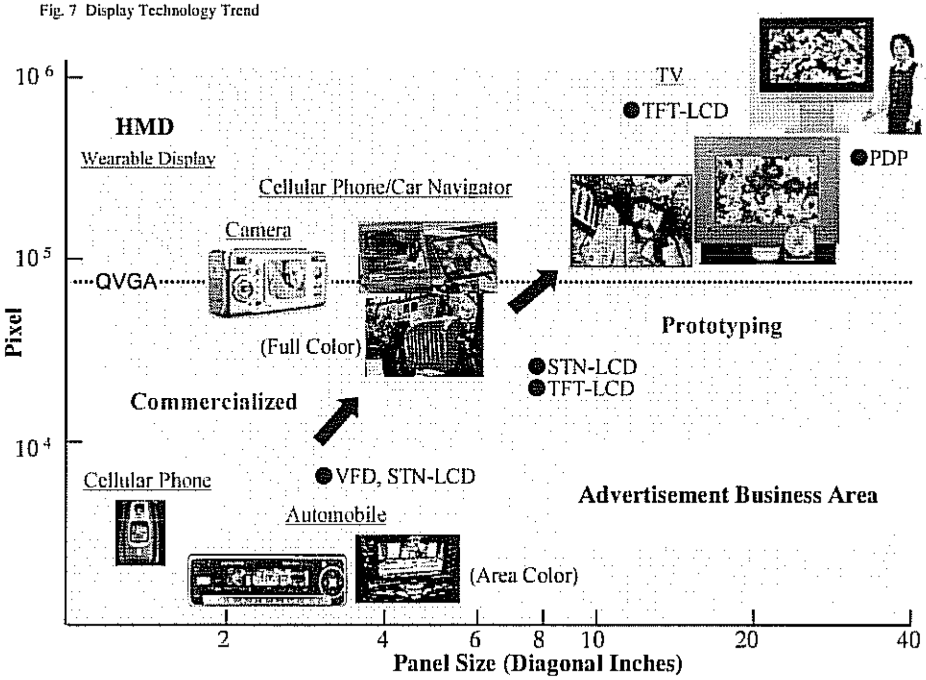
Courtesy of VDMA

Fig. 6 OLED (Organic Light Emitting Diodes) Display Schematic Cross Sectional View

Performance / Technology	Image Quality	Response Speed	Life	Thickness/ Weight	Large Size	Cost	Flexible Substrate	Companies Under Technology Development
LCD	Good	Fair	Excellent	Good	Good	Excellent except Large Size	Possible	Sharp, Samsung, Toshiba/Matsushita Display Tech
PDP	Good	Good	Good	Fair	Excellent	Fair	?	Fujitsu/Hitachi Plasma Display, Matsushita Plasma Display
FED	Excellent	Excellent	Good	Good	Good	Fair	?	Toshiba, Canon
OLED	Excellent	Excellent	Fair	Excellent	Fair	?	Possible	Sony, Sanyo, Seiko-Epson

Table 1 LCD/PDP/FED/OLED Performance Comparison

Fig. 7 Display Technology Trend



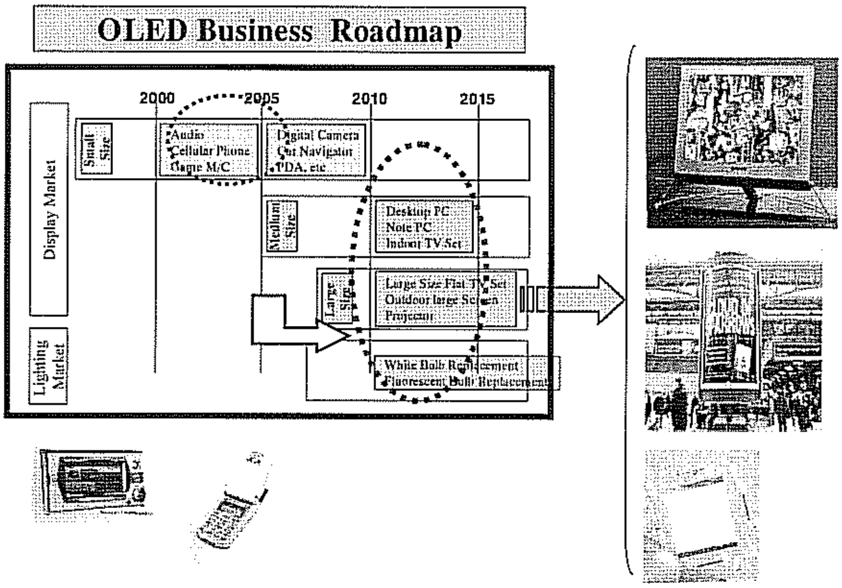


Fig. 8 OLED Display Market Potential

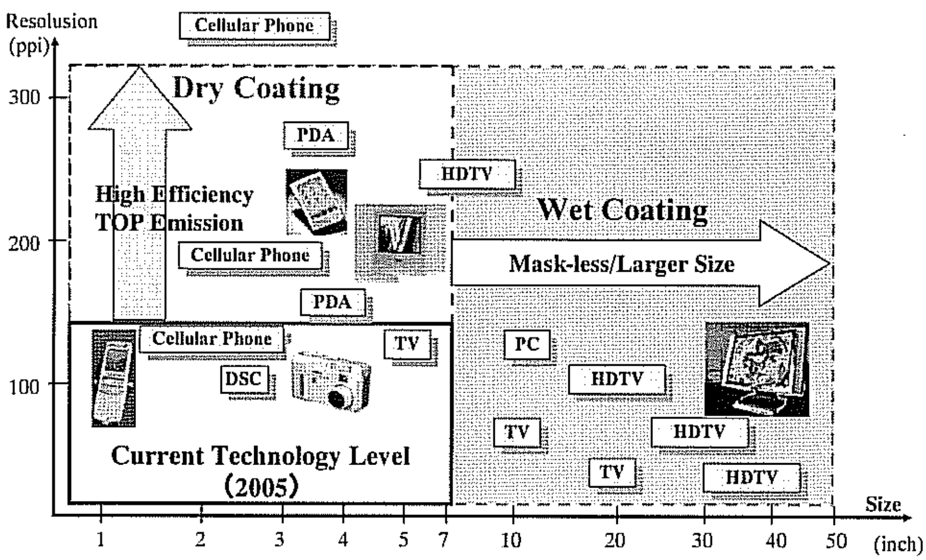


Fig. 9 OLED Display Product Roadmap

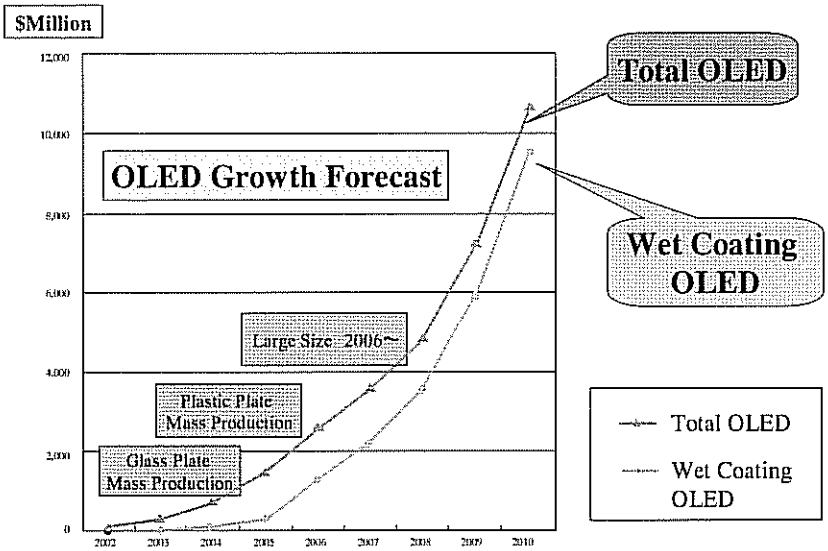


Fig. 10 Wet Coating OLED Market Forecast

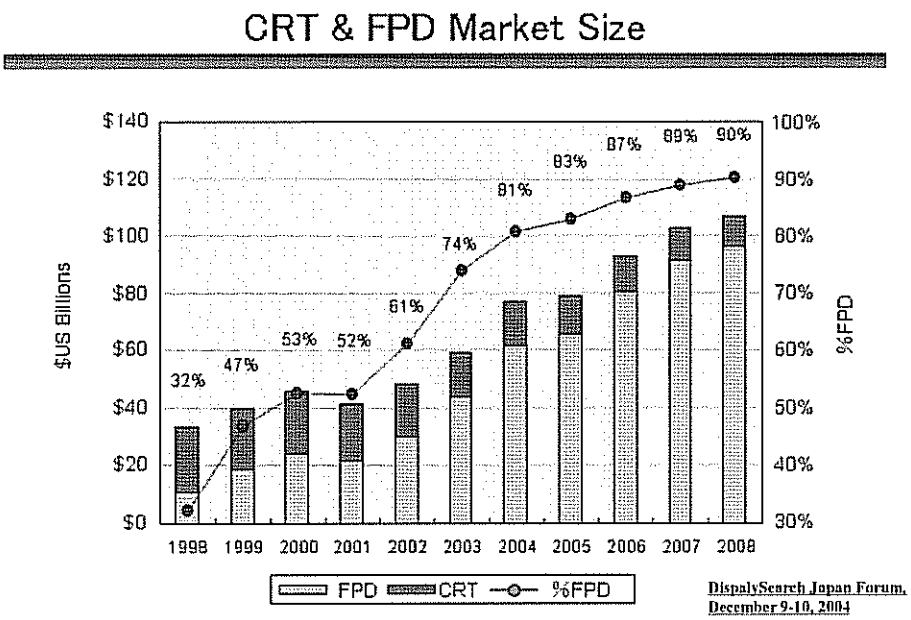


Fig. 11 CRT & FPD Market Size

Market Size by FPD Products

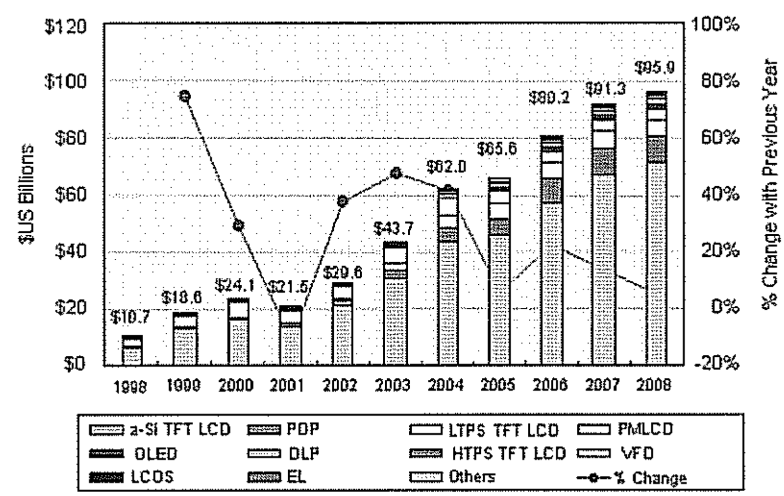


Fig. 12 Market Size by FPD Products

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FPD Market by Product (Sale Amount Based)

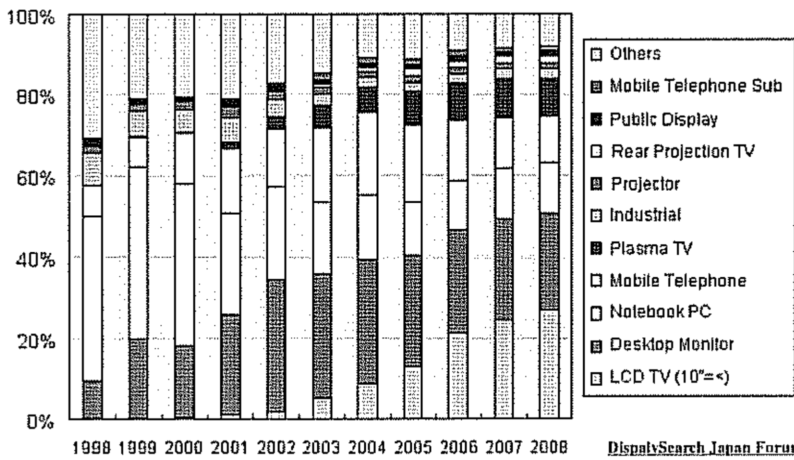

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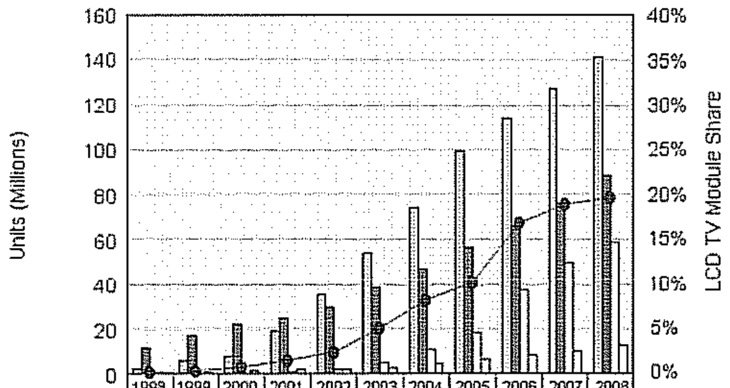
Fig. 13 FPD market by Product (Sale Amount Based)

Large Size TFT-LCD by Product(#Set)



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Monitor	1.9	5.4	7.3	18.4	35.5	53.7	74.1	99.3	113.9	126.9	140.5
Notebook PC	11.5	16.7	21.7	24.8	29.7	38.6	46.7	56.1	65.8	75.9	88.2
TV	0.0	0.0	0.2	0.6	1.5	5.0	11.6	16.2	37.4	49.2	58.9
Others	0.6	0.9	1.5	1.6	1.9	2.5	4.6	5.8	7.5	9.7	12.8
%TV	0.0%	0.1%	0.6%	1.4%	2.3%	5.0%	8.5%	10.1%	16.6%	18.8%	19.6%

Fig. 14 Large Size TFT-LCD by Product (#Set)

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LCD Total Thickness: 4～6mm

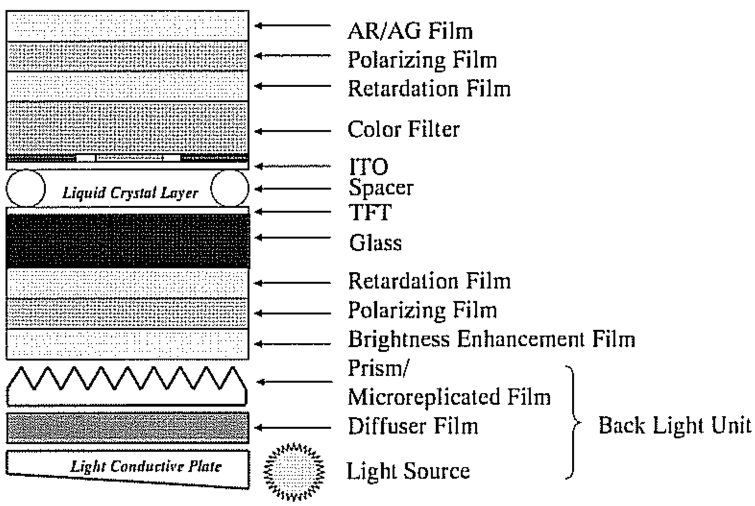

Fig. 15 LCD Product Structure

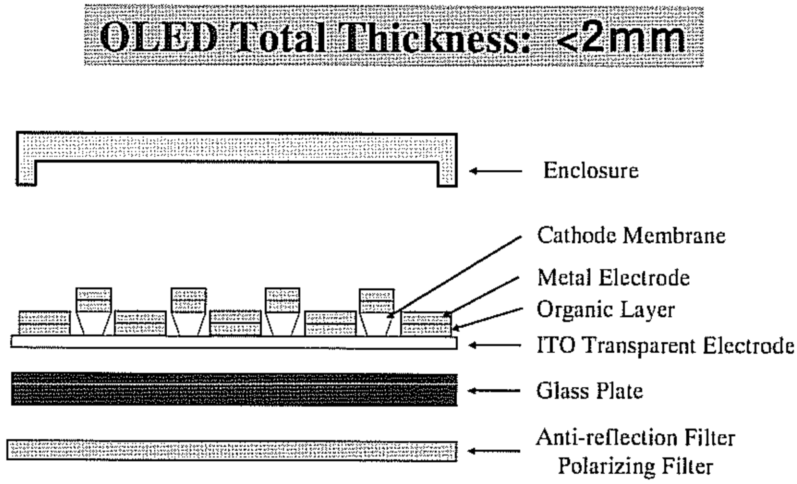

Fig. 16 OLED Product Structure

Process	Pre or Post Metering	Viscosity mPa*s	Wet Thickness μ	Uniformity %	Max Speed mpm
		Single Layer Coating			
Rod (Wire Wound) Coating	Post	20-1,000	5-50	10	250
Reverse Roll Coating	Post	100-50,000	5-400	5	300
Forward Roll Coating	Post	20-1,000	10-200	8	150
Air Knife Coating	Post	5-500	2-40	5	500
Knife Over Roll Coating	Post	100-50,000	25-750	10	150
Extrusion Die Coating	Pre	50,000-5,000,000	15-750	5	700
Balde Coating	Post	500-40,000	1-30	10	1,500
Gravure Coating	Post	1-5000	1-25	2	700
Slot Die Coating	Pre	5-20,000	15-250	2	400
		Multiple Layer Coating			
Slide Hopper Coating	Pre	5-500	15-250	2	300
Curtain Coating	Pre	5-500	2-500	2	600

Table 2 Coating Method Capabilities

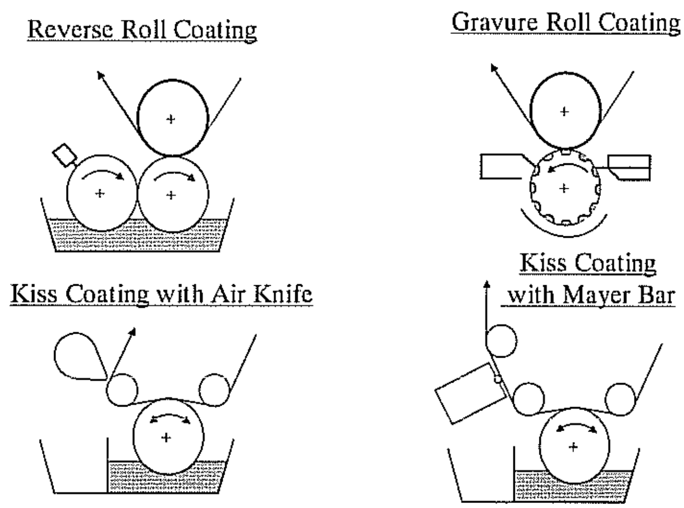

Fig. 17 Coating Method-1 (Roll Coating)

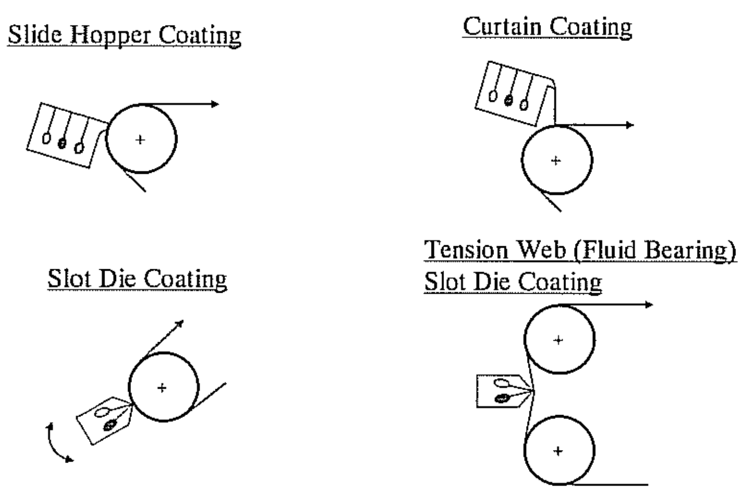

Fig. 18 Coating Method-2 (Die Coating)

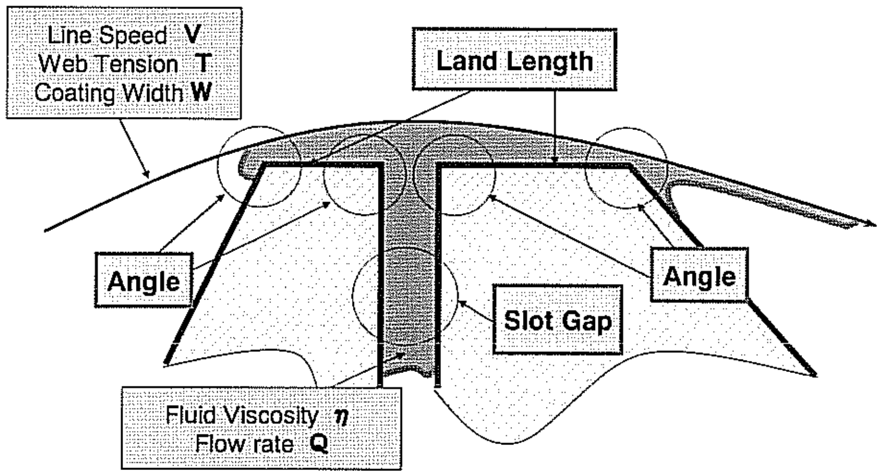

Fig. 19 Tension Web Single Layer Slot Die Coating

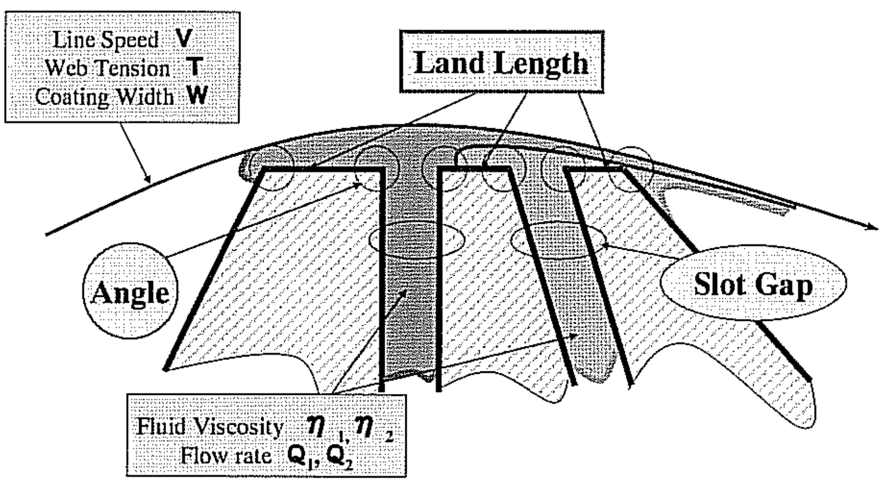

Fig. 20 Tension Web Multilayer Slot Die Coating

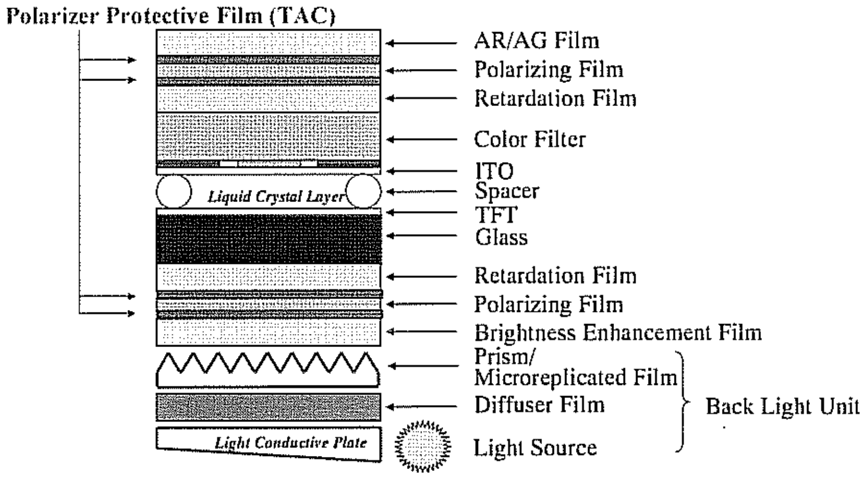

Fig. 21 TAC Film is a Key Component for LCD

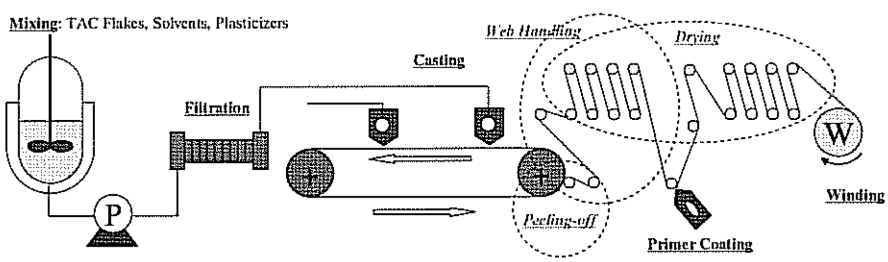

Fig. 22 TAC Film Casting & Forming

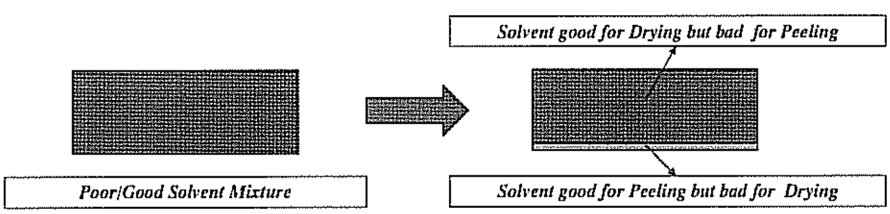

Fig. 23 TAC Multilayer Film Casting Principle