Next Generation AMLCD Production Technologies for Large Substrate

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Abstract

This paper will review the state of the latest development of AMLCD manufacturing facilities for large Substrate and discuss the future technologies. The trend of the display size enlargement of Note book PC has hauled the enlargement of the mother glass substrate in past 10 years. The enlargement of a substrate size has brought about the productivity improvement of the TFT panel with process innovation as yet.
Will this trend be continuing hereafter too? The issues of the processing and facilities related with the large square substrate and mask step reduction will be overviewed and the future processing and facilities will be discussed.

1. Introduction

The TFT-LCD Industry is in the deep valley of crystal cycle yet. Although there is a little symptom of recovery in the demand of notebook book PC and monitor the gait of the profits recovery is heavy, and it comes to be the subject that the cost reduction bet the survivor.
Seeing from the demand and supply, it is urgent business to develop new market with new product that fills the huge production ability that exists in Korea, Taiwan, and Japan for the healthy development of the industry. And it is also the urgent business to develop new production technologies that supports the new product within required cost.
As the means of new market reclamation and productivity up, TFT-LCD Industry has conducted the adoption, panel size expansion, mother glass base expansion, yield improvement, throughput improvement, more thin glass substrate heretofore. The performances of these guideline are in a high trend as the facility that was developed later in general. So it is the trend of the production line till today, the later the line generation the higher the productivity.
The 5th generation substrate line about to be constructed from the end of 2001 through 2002. Can this 5th generation line over come 4^{th} generation line in the productivity and the new product correspondence ability really? I review including the development activity of the product and the process what kind of thing it is the TFT-LCD process technology and facility that is expected to the next generation large substrate.[1][2][3][4]

2. Progress of Displays

The Display Industry, along with Information Society, supplying Information interface Device in each era, and has grown like Fig. 1. The market Driver of it was CRT-TV in the 1960, electric calculator in 1970, PC in 1980, Note book PC in 1990. Historically it is observed a new market driver had arisen in every 10 years. What can be the next 10 years market driver? In the new application market of TFT where the growth is expected by 2005 from now on, there are a color cellular phone and digital TV (D-TV). They are expected to become the market scale equivalent to the monitor market of 2000 for each in 2001.
In spite of a color cellular phone is expected, it does not reach for the purpose that supply ability excess is mitigated even if all the cellular phone are penetrated to collar, because of panel size is small. On the other hand, as for a D-TV, the panel size is big, it has a possibility that exceeds the prediction of Figure 2 considerably by the alternate of the huge market of CRT and mitigate supply ability excess.
Let's estimate these two markets by revenue. In the case of cellular phone, assuming that the market of the cellular phone will become one billion units inch 2005 and that TFT-LCD for it will be about 2,000 yen to every 1 unit, it becomes the market of one trillion yen as a whole in case 50% of them are colored. On the other hand in the case of TVs, it is said that eight billion Units CRT-TVs are on the earth at present. Supposing that these 50% are alternated to TFT-LCD TV and TFT-LCD for it is 50,000 yen in average, it becomes the market of 20 trillion yen as a whole. It is the market of 4 trillion yen in a year, if this alternate is carried out in the periods for 5 years. As a conclusion it can be said, TV application is the most likely candidate for the next driver.
Although TV is the most likely application for the next driver, every people are warring about the acceptable price is too cheep to TFT-TV. Is it possible to over come the cost issue?
In the past 10 years, Experience curve of TFT are changing like Figure 2 in receiving the influence of the crystal cycle of which period is almost 2.5 years due to the balance of the demand and supply. According to the Experience curve with the accumulated TFT-LCD area till today, the reasonable price of TFT is about 66 yen/cm2 in 1Q/01. On the contrary the sales price of TFT in 1Q/'01 was 40 yen/cm2 due to the over supply. We have to throw down the policy of the cost-down that should be done by 2003 in the present year, even in the market of PC.[5][6][7]

Therefore it can be said for TFT-LCD Industry that it is most important & urgent item to proceeds cost down with design and with manufacturing technology.

Fig.1 Progress of Displays

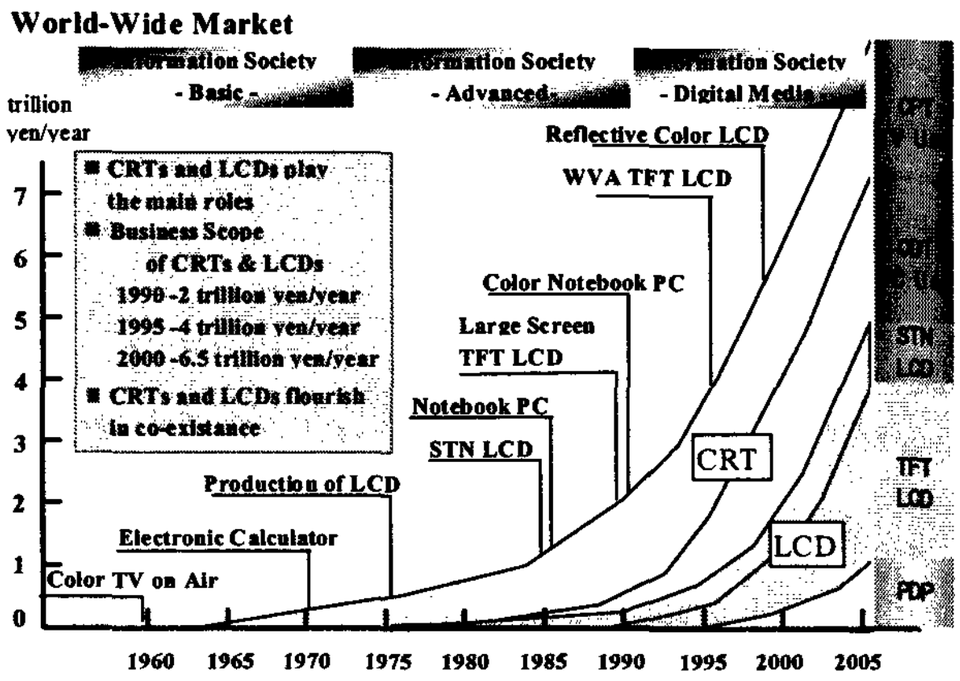
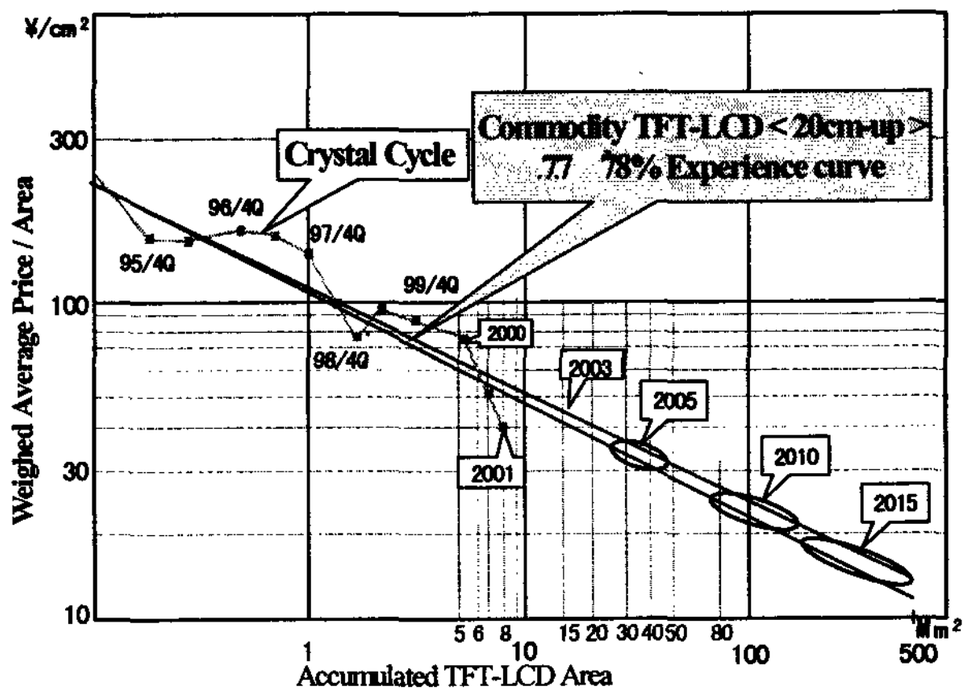


Fig.2 Experience Curve of TFT-LCD (20cm-up)



3. Enlargement of Mother Glass Size and Productivity up

When Mother Glass Substrate is selected, it is important firstly to be able to maintain fine productivity long time in the trend of panel size enlargement. Looking back the size trend of Note book PC it was 8.4" in 1991 and it becomes 9.4' and changed rapidly to 10.4', 11.3', 12.1', 13.3', 14.1' after that. It is new to a memory that along with the expansion of panel size, mother substrate size shifted up rapidly like Fig.3, and the equipment before the depreciation turned stereotyped in succession. And even in the present size shift from 14.1"to 15" is under way in Note book PC, and the size expansion is in the situation that does not permit foresee. The effective use rate of the glass in the same panel size becomes to secondary importance. It is requested that it is near equally whether higher efficiency than today.

This takes part in the entire price, use energy, expense of equipment, the glass material and also color filter. And, it is requested that high ROI can be obtained thirdly. [8][9]

Table 1 shows the useful are of mother glass of different panel size. As for the utilization efficiency of glass 85% or more are desirable and 76-84% are good, although 75% or less there is not competitive power at all. On the other hand, Table 2 shows the comparison of ROI ratio of Mother Glass for different panel size. The tact/sheet and yield are assumed the same in this comparison. On the contrary, Table 3 shows the trial comparison of ROI in the case that Tact/sheet is prolonged with 850x1000 of Gen.4 and also with the substrate size of Gen.5.

Compared with 15"s that are expected to become main size of Note PC, Monitor, TV from now on, the ROI of 850x1000 and 1100x1250 become equal in the case of Table 3, and it becomes higher than of 1000x1200, although the ROI becomes higher in the order of 1100x1250, 1000x1200, 850x1000 in the case of Table 2. In other words, the process and facility for Gen.5 line are expected to develop breakthrough technology to shorten the tact time. For the yield it is the same thing.

Innovation is expected for Gen.5 line to make the productivity up really.

Fig.3 Trend of Substrate Size Expansion

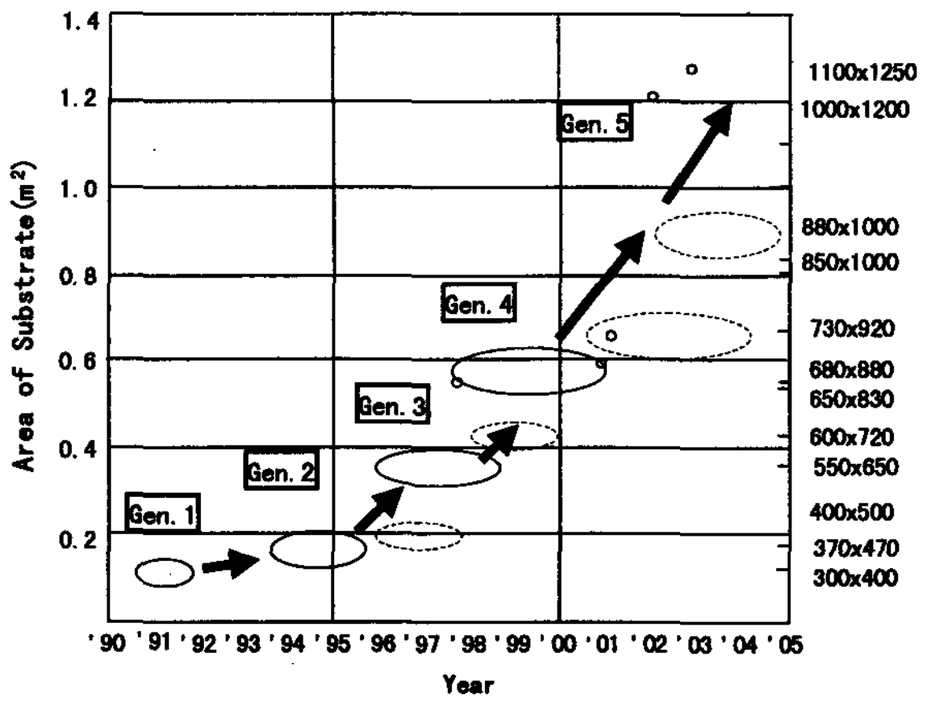


Table 1 Useful Area of Mother Glass of Different Panel Size(%)

Generation	Gen.3		Gen.4			Gen.5	
Width(mm)	550	600	680	730	850	1000	1100
Length(mm)	650	720	880	920	1000	1200	1250
W*L(Kmm2)	357.5	432	598.4	671.6	850	1200	1375
W*L Ratio	1	1.10	1.29	1.37	1.54	1.83	1.96
12.1"XGA	90	74	80	72		71	
13.3"XGA	70	84	93	83	66	83	72
14.1"XGA	80	97	72	92		89	83
15"XGA	91	76	82	73	93	82	87
17"SXGA	61	100	72	92		81	71
18"SXGA	68	56	81		93	91	80
20"UXGA	41	68	90	87		73	64
21.3"UXGA	46	76	55	90		82	72
25"STD(4:3)	63	52		67	53		99
24"W(16:10)	54	89	65	58	45	64	84
28"W(16:10)	73	60	87		61	65	57
32"W(16:10)			56	100	79	56	49
36"W(16:9)			67	60	95	67	58
Edge Area	10mm				15mm		

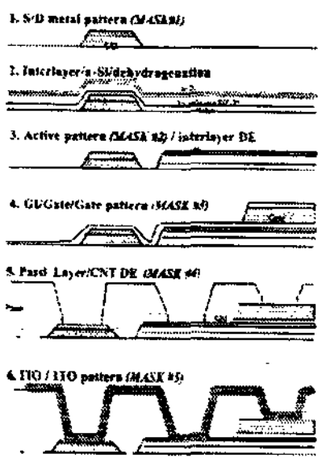
>85% Good
75-84% Accepta
<75% Fair

4. Trend of Mask Step Reduction

There are 3 kind of movement that simplify structure from the product design other than substrate enlargement due to the cost-down of TFT. As for the 1st, the mask number reduction, as for the 2nd, the peripheral circuit reduction by LTPS, as for the 3rd, the material cost reduction by color filter on array (COA) process or array on color filter (AOC) process adoption or the dramatically parts reduction by OLED adoption. [10][11][12] Although it seems that it takes the time for a while as OLED adoption is linked to material development, the others are under way at present. The attempt of the mask reduction is observed in both cases a-Si-TFT & LTPS. LG-PHILLIPS announces the production method of p-ch LTPS by 5-mask process, as shown in Fig. 4 (a) and Samsung is announcing the method that makes LDD/offset structure with 3-mask process which requires at least 5 masks by conventional process as shown in Fig. 4 (b) in SID'01. As p-ch LPTS requires 7 masks by conventional process. It is also possible to make p-ch LTPS with 5 masks by the method of Samsung. As the whole trend, it seems that LTPS is aiming for the joining to a large panel by 5 masks.[13][14][15][16]

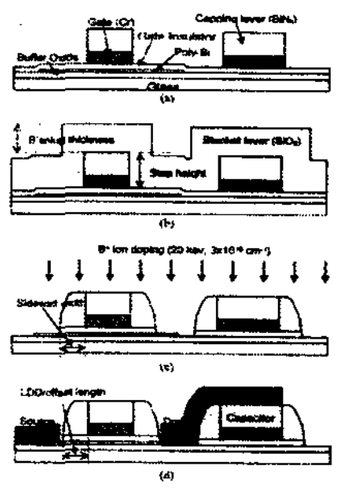
On the other hand, in the production of a-Si TFT, 4-mask fabrication process is going on. LG PHILLIPS and Samsung announced 4-mask fabrication process like Fig.5(a) in 1998, and like Fig.5(b) last year. Although these 2 process differ they are using a Half Exposure Technique for Photolithography in common.

Fig.4 Mask Step Reduction for LTPS Fabrication



(a) 5 Mask Process for P type LTPS

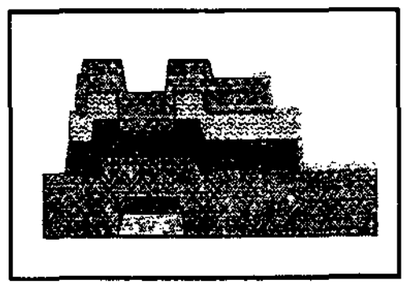
Source:D.G.Kim/LG-PHILIPS/IDMC2000



(b) 5 Mask Process for LDD/offset

Source:Y.W.So et al./Samsung/SID'01

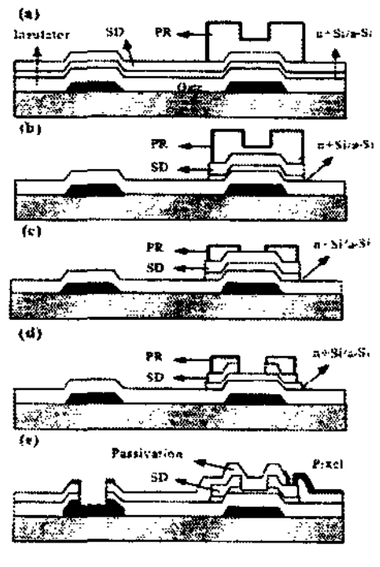
Fig.5 4-Mask Step Process for a-Si Fabrication



MASK	DEPO/PHOTO	ETCH/STRIP
1. GATE	Mo/Al-α	Mo/Al-α
2. S/D	Cr.Mo/N+	Cr.Mo/n+
3. PAS	SiN	SiN/a-Si/SiN
4. PXL	ITO	ITO

(a) 4-Mask Process with Half Exposing (1)

Source : Chan Hee Hong / LG.Philips



( )"4-Mask Process with Half Exposing (2)

Source E.W.Kim / Samsung / SID'00

It is required more improvement of process uniformity up whichever in these process, and It becomes an important item that it corresponds to these in the process development for the next generation substrate.

5. Required Process & Uniformity for Half Exposing

Here, I would like to check the process uniformity and performance of the facility, and estimate whether it meets to the requirement of Half Exposing process or not, and make it clear the developing target of the Gen.5 facility. As Hitachi doesn't have the experience of the mass production of Half exposing process, following requirements are the author's estimation by the simulation and from the other information.[17]

First of all, the thickness uniformity of the photo resist film becomes important. It is required at least +/- 2-3% in general, and slit & spin coating will meet it.

For Exposure, the uniformity of illumination in the substrate surface and the uniformity of the depth of defocus. For the illumination uniformity, it is required with in +/- 1%, and is possible to achieve by the adjustment. For the depth of defocus, it is required with in +/- 3E-5m(30micro m), and is possible if the plate chuck of Exposure was made within that accuracy.

For the development there is the dispense time lag between front and end edge of the substrate in the paddle forming. It makes about 10-20% of the process time difference, and is expected to shorten.

After development, the thickness of the photo resist is about 1.3-1.5micro m in the area where wasn't exposed, and the photo resist thickness of half exposed area becomes 0.3-0.5micro m by the mask choice. After the etching, the half exposed photo resist is removed by O2 asher in this process. As the O2 asher takes the roll of Exposure in this process, it is required high uniformity. The asher which is used in common in TFT line, has poor uniformity of +/- 20-30% for the reason of process roll difference. As it is impossible to expect good result by that equipment, plasma etcher should be used as O2 asher. But it has also only +/- 10% uniformity or so and it seems that it can not meet the requirement the process. In other words there is the demand of new facility development here.

Now, here is another issue in existence. It is difficult to remove resist from substrate surface. This is because the resist changes to an inactivated polymer hardened with small hydrogen component. The resist surface is considerably hardened, and it becomes difficult to remove completely by wet resist remover.

As the existence of residue is reported even after full ashing, it is expected the new technology and facility is developed to make the yield ratio high in this process.

As the total, it seems that it is in the need in the 4-mask process to improve the process uniformity in photo resist coating, exposing, developing, ashing and that the development new photo resist removing technology & facility for the purpose to get the high yield ratio with high stability.

6. Status of facility development and view of the next generation

The trend of the development of the facility of the next generation as the counter proposal over and from the demand items other than 4-mask process comes as follows.

(1) Exposure

The Exposure is one of the most difficult facility to achieve the productivity up with required accuracy for the next generation.

Fig.6 Relation between DOF and Resolution

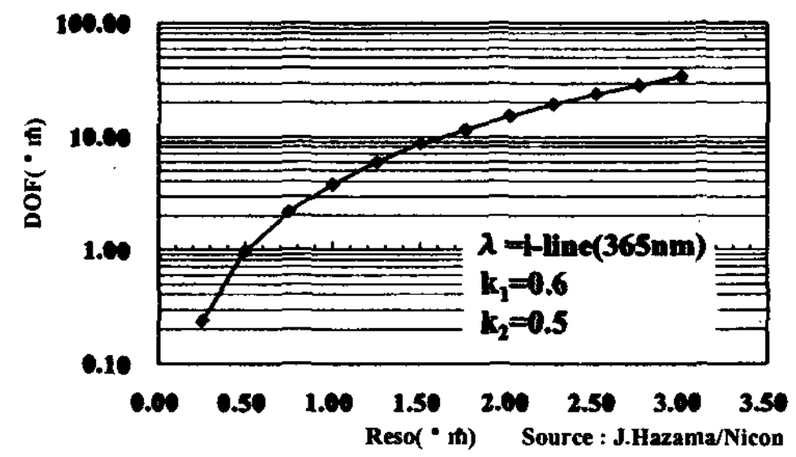
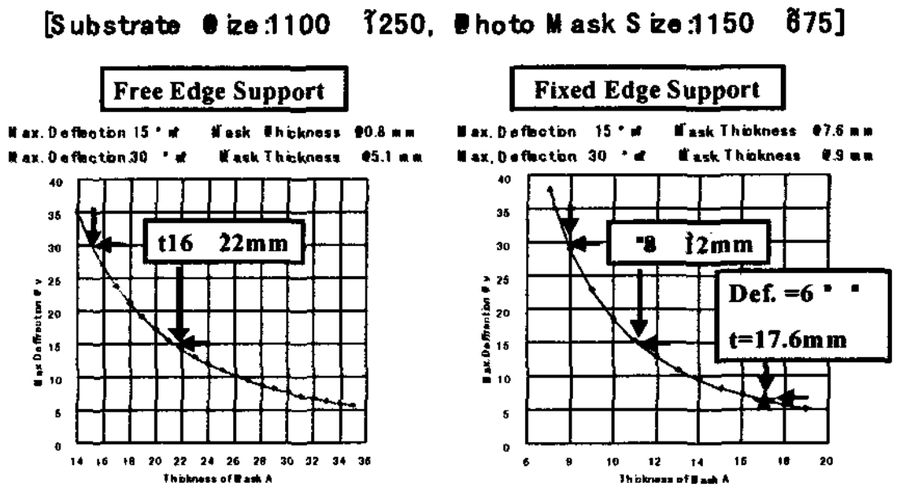


Fig.7 Deflection analysis of photo-mask



The relation between DOF and Resolution is shown in Fig.6. We can see to get the 3 micro m resolution at least 30 micro m DOF is required. This means that the all the parts of the Exposure related DOF should be within 30 micro m plate surface. As there are many factor in existence usable DOF(UDOF) is used in common. It is about the half of DOF. In other word it is required for the LTPS of 1 micro m resolution that the flatness with sag of the photo mask and chuck plate should be within 2 micro m in the same time exposing area.

On the other hand the more increase dividing number of the exposing area to get the surface accuracy, the later the total exposing time. Therefore it is very important to make the flat plane in large area.

The status of the development for them is as follows.

(a) Photo mask

The allowance of the deflection of the photo-mask is at least 3E-5m(30micro m). Practically it is used 6E-6m(6 micro m) for today. It is known by simulation that the number of exposure division should be under 4 to expose 1100x1250 substrate within 60 second or so and photo-mask for it is required 1150x675 large.

Fig.7 shows the relation between the thickness and deflection of the 1150x675 mask. It suggest at least 18 mm thickness is required to get the maximum deflection under 6E-6m(6micro m) in this mask size.

As this size and the thickness are exceeding mask maker's production ability for today, it becomes one of the bottlenecks.

(b) Chuck plate flatness

It is required as the flatness of chuck plate under 1.5E-6m(15micro m) for a-Si and 2E-6m(2micro m) for LTPS.

As the material of the chuck plate, aluminum is commonly used due to the need of making the surface anti-reflection with black processing. But it is impossible to make mechanical processing in the above mentioned accuracy for entire surface of 1100x1250 with the aluminum material. So, it is expected to develop the ceramics chuck plate, but the way of weight reduction and surface anti-reflection is the subject for development. As for the today's status, the ceramics chuck plate for Pai 300 with anti-reflection surface has hardly developed this July and the development for large substrate is going to start just now.

(c) Others

Other than the above issue, there are many other subjects to be solved in the light source power up and in making sure the long span dimension. Some of them are under development and some of them are not started yet.

(2) CVD, Dry-Etcher and Asher

(a) CVD for today

AKT announced they had developed the CVD for Gen.5 with 5 process chamber and 1 load lock chamber in clustered type in SID'01. Generally speaking it is the scale up of conventional CVD, cut down a process and load lock chamber 1 chamber each, and prevented to be huge of a center cluster. It is keeping the through put in the tact time 120sec./sheet by the system optimization.[16]

The diode parallel plate plasma enhanced CVD forms the electric field with the span between upper electrode

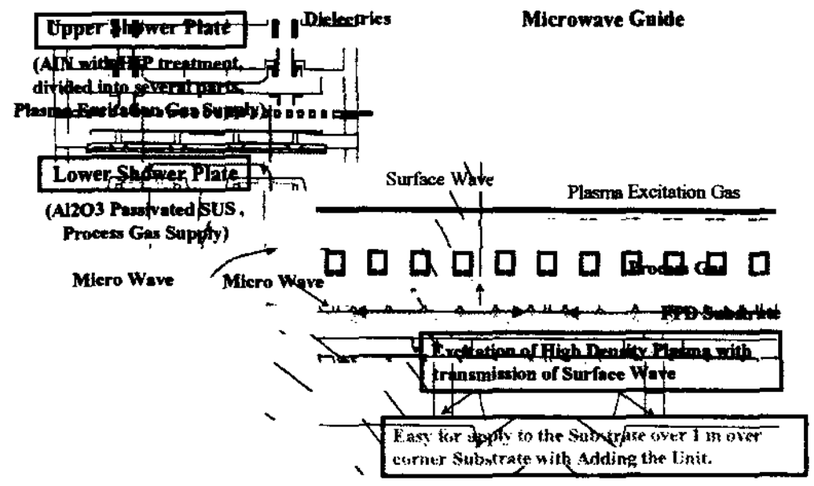
And lower electrode. Assuming that this span as 20 mm, it is said that the electric field changes 5% and performance of CVD or Dry-Etching changes 10% by the 1mm change of the parallel degree.[19]

Aluminum is used as electrode material in common in the CVD due to the needs of NF3 cleaning, it is hard work to maintain this parallel degree in the area over a corner 1 m in the process temperature over 300 degrees.
It causes the uneven plasma with an abnormal electric discharge. In addition above the plasma power increase du to the increase of the substrate size does harm the potential of the abnormal electric discharge.
AKT is announcing that they made lid design to provide thermally-isolated, flat shower head for Gen.5 as the counter proposal of this problem.
Although AKT CVD machine is developed, there is the strong demand of tact up. And it is high possibility of these counter proposal aren't enough for that.

(b) New Plasma Source for CVD, Dry-Etcher and Asher

Tohoku University is proposing microwave-excitation high-density plasma equipment as shown in Fig.8.[20]
This plasma source can excite plasma which keeps uniformity even 1m over corner area. It has futures of creating plasma with with high-density (>10^{12}cm^{-3}) and low electron temperature (-1eV). There is no metal contamination sputtered from a chamber wall due to low plasma potential. Besides, damages are not created into growing film, since ion bombardment energy is lower than 7eV. Because of the future of high density plasma, film formation and etching rate become fairly rapid, and processing time can be drastically shortened. This plasma source can be applied to all plasma process except sputtering process. As this plasma has self matching function plasma uniformity is very fine in entire surface. Therefore it is also ideal for the asher of Half-Exposure processing.

Fig.8 Microwave-Excitation System with RLSA



Source : T.Ohmi / Tohoku Univ.

(c) Cat-CVD(Hot-Wire CVD)

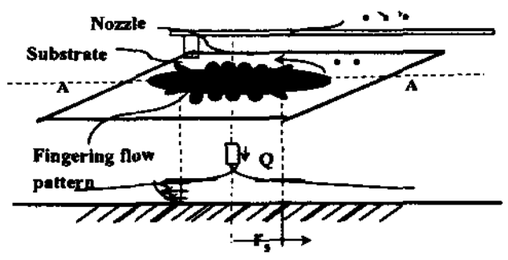
Cat-CVD(Hot-Wire CVD) is another CVD source that it suit for high speed deposition in large area. There is no need of preheating inch this equipment due to the wire temperature around 2,000 degrees and has the ability of deposition speed 400nm/min for Si3N4 without electrical abnormal discharge. As for this method, there is the week point that the metal ion density in the membrane becomes little bit higher than other CVD from necessity of tungsten heater adoption but it is in the allowable margin for a-Si TFT fabrication. [21]

(3) Wet process equipment

(a) Wet cleaner

It is well known that Fingering flow pattern appear on the surface of 1m over corner class substrate when one increase the rotating speed in supplying the water in the center. This Fingering flow is the function of the viscosity, density, flow rate of liquid, fluid surface tension coefficient, and the function of angular velocity of substrate, air flow pressure caused the square substrate rotation. And the relations of them are revealed by theoretically and experimentally. Fig.9 shows the predicting equation of on set point of fingering flow pattern. [22][23][24] [25]
On the other hand, the necessary flow speed of liquid to move the particle adhering with Van der Waals force on a substrate face, has been made clear by an experiment and also calculation.
When gathering above, it can conclude that it is impossible to remove the particle by a simple spin washing in the substrate of the over meter corner.
In another words, it becomes as main stream of wet cleaning and drying without rotating a substrate in the next generation.

Fig.9 Predicting Equation of Onset Point of Fingering Flow Pattern



Predicting Equation

r_s : Onset point of striped flow
μ : Viscosity
ρ : Density
Q : Flow rate
ω : Angular velocity

$$r_s = 93.6\left(\frac{\mu Q}{\rho\omega^2}\right)^{1/5}$$

M.Togashi, T.Ohta, "A Study on Patterns of a Liquid Film on a Rotating Substrate", Transaction of JSME vol.66,No.650B, (2000.10)

(b) Resist Remover

The conveyer type resist remover should be used in common by the above reason. There are some issues in conveyer type resist remover of today. The 1st of it is the removing liquid consumption increase. The 2nd is the residue existence issue after O2 ashing or after ion doping.
As the counter proposal of them, Tohoku University is proposing Wet-Vapor Resist Striping (RS) technology. This is the method that the mixture liquid mist of the 0.1wt.% remover and the steam of 85-100 degree, are blown with the distance of 10-15 mm with the pressure of 1-2kg/cm2 to the substrate surface. The removing mechanism is as follows. 1) It cut the cluster of water, 2) The resist is expanded with steam, 3) It removes the peeling thing with steam cleaning.
By this process, for the resist after O2 ashing, the residue cannot be observed on the metal edge like Fig.10. Therefore it can be said that it solves the issue in the Half-Exposing process and LTPS process. As for TFT this equipment is an idea stage, it is expected the early development.

(c) Coater & Developer

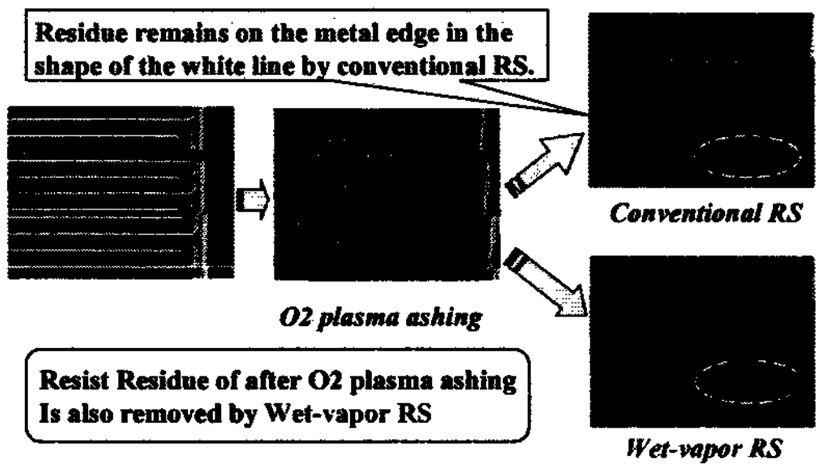
Slit & Spin coating or slit plus spin coating will become major from the same reason of wet cleaning. It is recommended to add reverse rotation in the spinner for the uniformity up. As for the developer the spin process can not be in existence in the same reason. Conveyer developing with paddle forming will become major.

The process time difference in the paddle forming is unsolved problem even now. The innovation is expected.

(d) Transfer Systems

Along with the substrate size enlargement, thickness reduction of the substrate is going on. It is also coming its limitation to transfer the over meter corner substrate with these thickness in under 60 second. There is another issue is in existence, that it takes large part of the time in the total process time. As the counter proposal of them an air levitation transfer system like Fig.11 is under development. It is expected to the process equipment to shorten the tact time by the adoption conveyer go through system. [26][27]

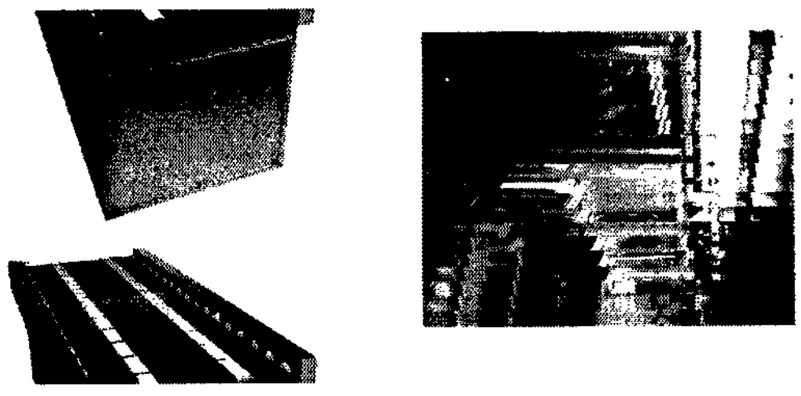
Fig.10 Residue Remove by Wet-vapor RS



RS : Resist Stripper

Source : T.Ohmi / Tohoku Univ.

Fig.11 Air Levitation Conveyor System for TFT



Source:DAIICHI INSTITUTION INDUSTRY Source:M.WATANABE & CO., LTD.

Summary

When we observe the present condition of a Crystal Cycle, it us necessary by all means to make the drastic cost reduction and to create a new market creation about TFT-LCD. All the effort should be focused on this matter. The direction of effort has revealed in this paper. The acceleration of the innovated development is expected.

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