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Analysis of Pinhole Defects on Alignment Layer Surface for TFT-LCD

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Abstract: The pinholes on the surface of alignment layer was studied, which formed during the TFT-LCD manufacturing process and caused defects of the products. Herein, a vitally typical defect, black spot, was analyzed via FIB, SEM and OMS. The analysis results of statistical software BO (Business Objects) show that the pinhole is the main cause of the black spot. Based on theoretical analysis and further experimental results, it is found that the hydrodynamic instability of the solution may lead to the pinholes on the alignment layer surface, and the pre-cure time of the alignment film solution is significantly responsible for hydrodynamic instability. It is noteworthy that the instability needs times to grow full enough and then to influence the film structure. Therefore, the pinholes on the alignment layer surface will be reduced or eliminated if the pre-cure time is less than or equal to that time.

Key words: TFT-LCD; alignment; pinhole; pre-cure; failure analysis; hydrodynamic instability

TFT-LCD 取向层表面的针孔缺陷分析

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摘 要: 在 TFT-LCD 的生产过程中, 取向层表面针孔缺陷是造成产品不良的常见原因。应用聚焦离子束 (FIB)、扫描电子显微镜 (SEM) 和光学测量系统 (OMS) 工具, 并结合数据统计软件 Business Objects (BO) 对实际生产过程中的一种典型产品不良——黑点, 进行了测试和分析。结果表明, 取向层表面针孔缺陷是产生黑点不良的根本原因。在此基础上, 进一步通过理论分析和实验研究证明, 成膜过程中膜液的流体力学不稳定性是导致取向层表面针孔缺陷的重要原因, 而固化时间则是影响流体力学不稳定性的重要参数。膜液流体力学不稳定性充分发展并最终对膜结构产生影响需要一定时间, 当固化时间接近甚至小于不稳定性充分发展的时间时, 取向层表面产生针孔缺陷的机会将大大减小甚至消除。

关 键 词: TFT-LCD; 取向; 针孔; 预烘; 缺陷分析; 流体力学不稳定性

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1 Introduction

The alignment layer is an important component of TFT-LCD, and is the key to control the display quality. The process of the alignment layer is referred to as PI-Rubbing process, to form a TFT-LCD alignment layer on TFT and CF glass substrate by cleaning, coating, pre-cure, main-cure and rubbing steps. As a direct contact part with liquid crystal in TFT-LCD, it directly determines the arrangement of liquid crystal molecules. So, the defects of the alignment layers have a significant impact for the basic properties of TFT-LCD, such as uniformity, viewing angle, response speed, and threshold voltage and so on. In practical product line, it is widely noticed that pinhole defects cause a disc-shaped black spot in TFT-LCD, and that these defects are only formed during manufacture^[1-2].

Herein, the pinhole on the alignment layer surface was analyzed by FIB, SEM, OMS and statistical software BO (Business Objects). Theoretical analysis and experimental researches are made on the hydrodynamic instability conditions of the alignment layer solution during the pre-cure (evaporation) process. The results show that we can depress the formation of pinholes on the alignment layer surface via control of the pre-cure time.

2 Experiments

2.1 Material and Instrument

Polyimide solution, which is mixed with N-methyl pyrrolidone, γ -butyrolactone and ethylene glycol butyl ether, was used in experiments.

Scanning electron microscopy (SEM) images were obtained on a FEI Nova 200 Nanolab Dual Beam FIB-SEM. The semiconductor material was coated with Pt layer (<10 nm) to make them conducting. The sample was observed at the accelerative voltage of 10 kV. The optical measurement was achieved on an Optical Measuring System (OMS, LCD properties Evalua-

tion Device) from Japan CHUO Company.

2.2 Experimental Procedure

In this study, we produced the alignment layers by the phase transition. The experimental procedure includes 5 steps: cleaning, coating, pre-cure, main-cure and rubbing to form the alignment layer. Firstly, polymer material was coated on the cleaned glass substrate by Toppan Printing method. Then, the solvent of the coated polymer solution was evaporated under different pre-cure process conditions. After that, the film was cured at about 300 °C in oven, where the alignment layers with thickness of 60~90 nm were formed. Finally, the film was rubbed using nylon, fiber, lint or other materials by a certain direction on the directional orientation. The surface conditions of orientation layers changed, leading to uniform anchoring for liquid crystal molecules and orientation. The prepared sample was sent to the next fabrication process and finally for the cell test.

2.3 Failure Analysis

For the analysis of the black spots observed during the TFT-LCD testing, the samples containing defects were retested by cell test equipment, and marked these defect areas. Then, the samples were made a comparison testing of pretilt angle using OMS with a 0.2 mm interval. After that, the samples with black spots were decaped and cleaned, and then analyzed by FIB and SEM.

2.4 Data Statistics

Defect ratio of black spot in the film which determined by TFT-LCD inspection process (Cell Test) were obtained by statistical software BO.

3 Results and Discussion

3.1 Failure Analysis Result

As shown in Fig. 1, the pretilt angle of the marked area of black spots fluctuates obviously, where it is smooth in normal area. It can prove that the liquid crystal molecule arrange unordered in

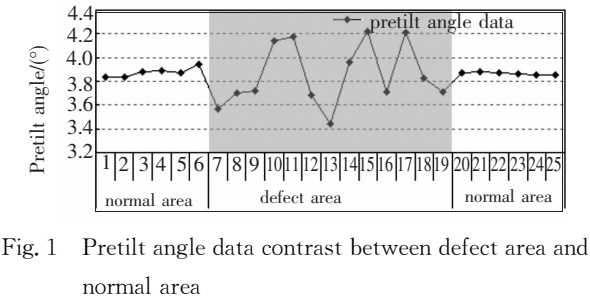


Fig. 1 Pretilt angle data contrast between defect area and normal area

these area.

From FIB picture (Fig. 2), we can see that the color in defect area is different with other areas before the alignment layer is removed, and that difference disappeared after the alignment layer is removed. So, there may be some difference structures in these areas. The cross section of the normal area and the defect area were tested on SEM and compared (Fig. 3). The results showed that the thickness of defect area was much thinner than the normal one. Therefore, we can conclude that the thickness of the alignment layer is the cause of the difference in the OMS and FIB testing. In general, this defect is called as pinhole on the alignment layer surface. Black spot observed in the TFT-LCD cell test is caused by the pinhole on the alignment layer surface which induces the liquid crystal molecule unordered arrangement.

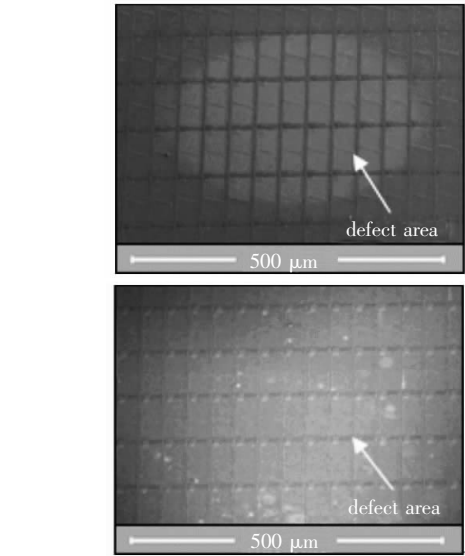


Fig. 2 FIB picture of defect area before/after the alignment layer is removed

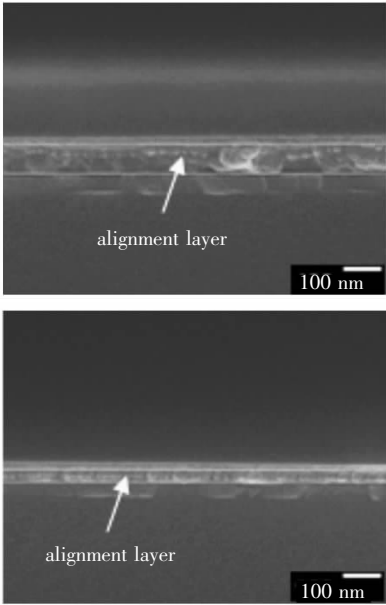


Fig. 3 SEM picture of normal area vs. defect area

3.2 Theoretical Analysis

In accordance with the hydrodynamic stability theory^[3], the film liquid in the gas-liquid interface will inevitably be subject to some random disturbance in a fluid system during the evaporation process (Fig. 4).

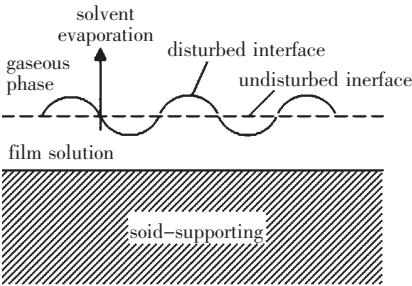


Fig. 4 Stability analysis of alignment layer solution in vaporation process

If the system is stable, the disturbance will naturally disappear, and the gas-liquid interface will remain flat. If the system is unstable, the disturbance will increase which results uneven area of the surface. Once the disturbance reaches a certain level, the uneven structure will form pinholes in the gas-liquid interface. After the curing of the film, the above structure will be solidified and kept on the film surface^[4-6]. Therefore, the control of the random disturbance of

the coating film is the key to prevent forming the pinhole on the surface during the evaporation process.

If the pinholes are caused by the instability of the hydrodynamic disturbance, the growth of the pinholes will need times because the hydrodynamic disturbance requires times to have enough strength to influence the structure of the film. Therefore, the pinholes may be depressed or eliminated if the evaporation rate is fast enough^[7].

3.3 Defect Ratio of Pinhole on Alignment Layer Surface vs. Pre-Cure Time

The relevant relation between the defect ratio of the pinhole on the alignment layer surface and pre-cure time of PI process was obtained by statistical software BO, as shown in Fig. 5. The results show that the defect ratio of the pinhole

on the alignment layer surface (correspond to defect ratio of black spot) gradually decreased following the shortening of the pre-cure time. It is noteworthy that the defect ratio is very low when the pre-cure time is about 100 s. Therefore, it is useful to avoid the formation of pinholes by control the pre-cure time of the film.

In the alignment layer forming process, the hydrodynamic instability of the film solution is one of important reasons of forming pinholes on the alignment layer surface. The hydrodynamic instability need time to get enough vibration to influence the film structure. In our experiment, 100 s is the critical point. So, if the pre-curing time is shortened to a certain level, the influence of the hydrodynamic instability will be depressed or eliminated. Then, the formation of pinhole ratio will be reduced and the corresponding defect

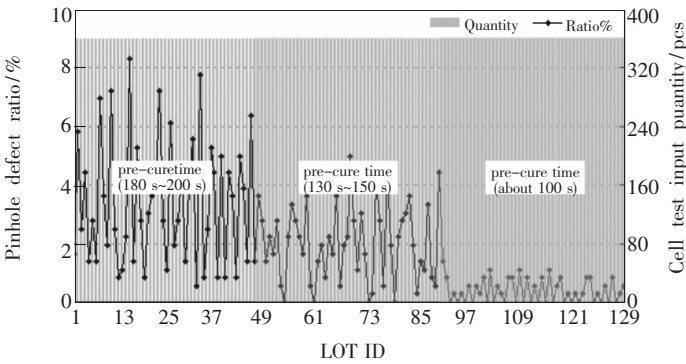


Fig. 5 Defect ratio of the pinhole on the alignment layer surface vs. pre-cure time

will be reduced or even eliminated.

4 Conclusion

The formation of pinholes on the alignment layer surface is the main cause of the black spots, which means the detection of black spots on the TFT-LCD cell test directly reflect the exist of pinholes.

In alignment layer forming process, the hydrodynamic instability of the film solution is one of important reasons of forming pinhole on the alignment layer surface, and the pre-cure time of the alignment film solution is significantly responsible for hydrodynamic instability. It needs

some time that the instability grows full enough to ultimately influence the film structure. If the pre-cure time is less than or equal to that time, the pinhole on the alignment layer surface will be reduced or even eliminated.

In our experiment, we found out that it needs at least 100 s that the hydrodynamic instability of the alignment film solution grows full enough to ultimately influence the film structure. So, the pinhole on the alignment layer surface will be well controlled when the pre-cure time is less than 100 s. And black spot defects observed in TFT-LCD cell test can be reduced very well.

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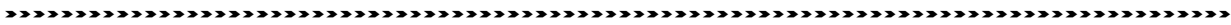
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