

Research on Patterned Cu Growth in Electrochemical Process of Large Glass Substrate

Jian Tian^{1,2}, Jie Wang^{1,2}, Lingyun Shi¹, Chunjian Liu^{1,2}, Xintao Wu^{1,2}, Jie Lei^{1,2}, Yajun Ma^{1,2}, Jiaying Zhang^{1,2}, Ting Zeng^{1,2}

1 BOE Technology Group Co., Beijing, China

2 Hefei BOE Rui Sheng Technology Co., Ltd., Hefei 230011, China

Abstract

This paper studies the growth of patterned Cu prepared by electrochemical process for the G6 large size glass substrate in the world firstly. The key parameters affecting electroplating uniformity were studied by simulation. After a series of trial runs, G6 glass substrate was prepared by electrochemical method based on the optimized parameters. The thickness of G6 electroplated Cu can meet 5~11um and the uniformity of the corresponding film layer can be reduced to less than 20%. The simulation model shows good performance to guide design and device modification.

Keywords

Glass-based; Mini-LED; Electroplated; Uniformity; Simulation

1. Introduction

Currently, Mini-LED BLU products can be roughly categorized into COB and COG [1]. Among them, COG products combine the advantages of high heat and humidity stability, strong warpage resistance, etc, and have a broad market prospect [2]. With the development of high HDR products, which puts forward higher requirements on the thickness of the Cu layer. Conventional coating processes (Sputter) cannot meet the demand for thicker Cu ($\geq 3.6 \mu\text{m}$), so the industry often uses electroplated Cu process for fabricating thicker Cu products. However, there is no relevant experience in the G6 generation line for the electroplating deposition of Cu on large-size glass substrate. The core point of the electroplating process is to control the uniformity of the deposition. Uneven thickness of the electroplated Cu will result in the uneven brightness of each light-control zone of the Mini-LED BLU. This paper simulates the transient Cu plating process on the glass substrate of G6 generation line, explores the influence trend of related factors, and obtains the optimized design and equipment process parameters. The G6 glass substrate is prepared by the electrochemical method, and the glass substrate electroplating Cu process can be combined with the array process of TFT to produce multi-film Mini LED display products. The related design has completed the patent application and authorization [3].

2. Uniformity problems and mechanism analysis

2.1 Influence of uneven plating thickness

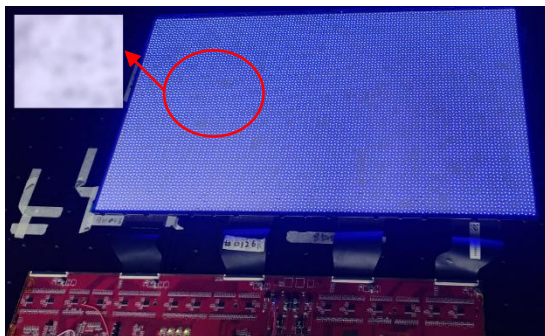


Figure 1. The picture of uneven brightness of light board

In the process of electroplating deposition of the Cu layer, uneven deposition of the Cu layer may occur due to the influence of circuit pattern design, equipment structure or parameters. Figure 1 shows the lighting screen of a glass-based Mini-LED BLU fabricated using the electroplating process, and the difference in brightness can be clearly observed after placing an optical film material on the bare light board.

2.2 Establishment of electroplating physical model

Faraday's law specifies that the thickness of the electroplated Cu layer and the amount of cathodic Cu deposited are directly proportional to the current density and current efficiency:

$$d = \frac{M_{cu}t}{Fn\rho_{cu}} \varepsilon_F i \quad (1)$$

M_{cu} is the molecular weight of copper, ρ_{cu} is the density of copper, F is Faraday's constant, i is the current density, t is plating time, ε_F is the cathode current efficiency, n is the number of electron transfers in electrode reactions. The electrode interface is described by the Butler-Volmer equation, and the cathode current density can be expressed as:

$$i_c = i_0 \left[\exp\left(\frac{\alpha_A n F}{RT} \eta_c\right) - \exp\left(-\frac{\alpha_c n F}{RT} \eta_c\right) \right] \quad (2)$$

$$\eta_c = \phi_s - \phi_l - E_{eq} \quad (3)$$

α_A and α_c are the anode and cathode charge transfer coefficients respectively, η_c is the cathodic overpotential, ϕ_s is the cathodic potential, ϕ_l is the solution potential, E_{eq} is the equilibrium potential, T is the thermodynamic temperature of the solution.

2.3 Establishment of electroplating simulation model

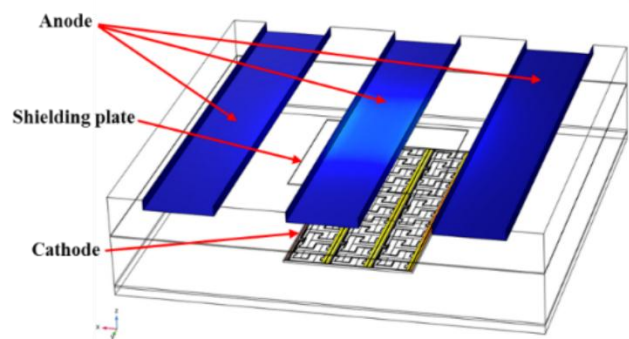


Figure 2. Electroplating simulation model

Keeping the plating time and electric field strength unchanged, the plating thickness is mainly affected by the cathode plate current density, which is determined by ϕ_s and ϕ_l . ϕ_s is related to the cathode pattern design, due to the current cluster effect, accompanying plating pattern design is usually used to reduce the influence of the uneven distribution of current. The equipment structure and parameter can also affect the cathode current density.

Based on the above analysis, an electroplating simulation model was established in simulation software, as shown in Figure 2.

3. Experiment and analysis

3.1 Uniformity evaluation index

After the simulation of electroplating on the glass substrate, the software obtains the Cu layer thickness information from the cloud image automatically. The Cu layer thickness at the simulation sampling point is X , and the average Cu layer thickness is \bar{X} . Uniform(Unif.) was calculated to evaluate the uniformity of Cu layer distribution:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (4)$$

$$\text{Unif.} = (\text{Max}_x - \text{Min}_x) / (2 * \bar{X}) \quad (5)$$

Max_x and Min_x are the maximum and minimum values of Cu layer thickness respectively. The smaller the Unif. value, the better the uniformity of electroplating.

3.2 Simulation study on the influencing factors of design parameters

There is irregularity of pattern distribution in backplane design, and the local current density in isolated area and edge area is too high, which ultimately leads to an excessively thick Cu layer in these areas, and affects the uniformity of electroplating. In order to reduce the influence of current cluster effect, dummy pattern is usually added in these areas to serve as an accompanying plating pattern (co-plating) of effective pattern. However, there are few relevant studies on co-plating pattern design. In this section, simulation studies are focused on influencing factors such as design style of the co-plating pattern, space and width of co-plating pattern.

3.2.1 The number of Equal divisions of co-plating patterns

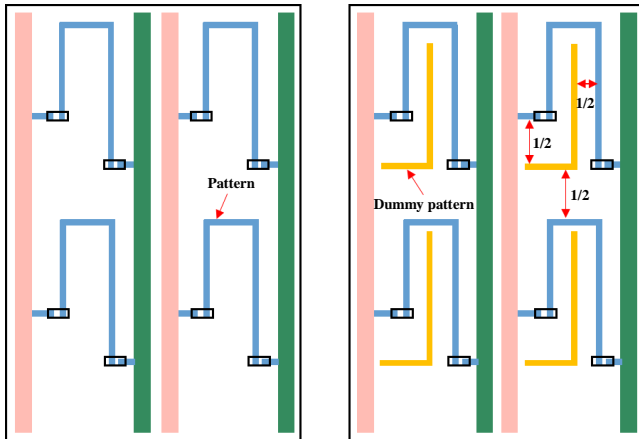


Figure 3. Schematic diagram of the number of equal divisions of co-plating patterns

Accompanying plating means that a floating pattern was designed in the uneven area of the line, and the connection logic of the line is not changed. At the same time, as part of the auxiliary cathode, it can absorb part of the cathode power line during electroplating to improve the uniformity of the coating [4]. The equal division of the co-plating pattern refers to the plating line where the blank distance between the metal wires in the panel is set according to the equal division rule. Figure 3 shows the design schematic diagram of the plating pattern without plating and 1/2 equal division. Figure 4 shows the uniformity data of the Cu layer with different co-plating

designs. It can be seen that co-plating design can significantly improve the uniformity of electroplating. However, the accompanying plating pattern equal division number, it's not that the more the better. With the increase in equalization times, the uniformity value shows an upward trend but the dispersion of the Cu layer's thickness increases. The design effect of 1/2 equal division plating pattern is the best.

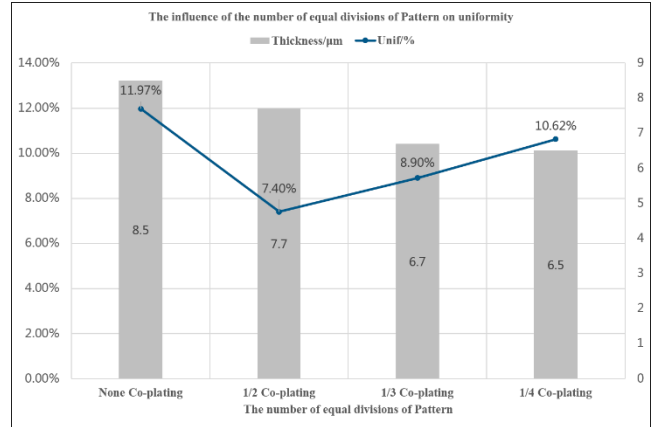


Figure 4. The variation trend of Cu layer thickness and uniformity with the number of equal divisions of co-plating patterns

3.2.2 Co-plating pattern space

The space between the co-plating pattern and signal wire also affects the uniformity of plating. Figure 5 shows the variation trend of the Cu layer thickness and uniformity when the 1/2 equal division plating pattern increases with the gradient of the metal line space. It can be found that uniformity is positively correlated with the space, and the smaller the space, the better the uniformity. With the increase in the space between the co-plating pattern and the metal wire, the thickness of the Cu layer also increases. However, there is an ESD and EMI risk if the distance is too small [5]. Generally, the space between the co-plating pattern and the metal wire will be set to $\geq 200\mu\text{m}$. Therefore, it is more appropriate to set the space between the co-plating patterns to $200\mu\text{m}$.

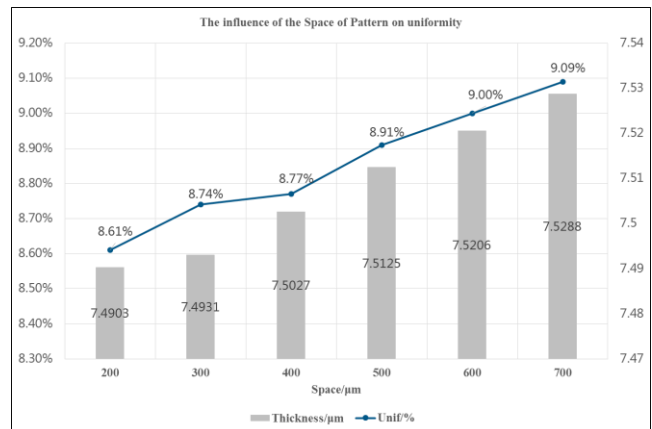


Figure 5. The variation trend of Cu layer thickness and uniformity with the space of co-plating pattern

3.2.3 Co-plating pattern width

The width of the accompanying plating pattern is also an important factor. The larger the area of the co-plating pattern, the more power lines are attracted to the cathode area, and the more obvious the

uniformity improvement effect. The 1/2 co-plating pattern design was selected, and the space was set to 200 μm . Figure 6 shows the simulation results of Cu thickness for plating patterns with different width designs. The variation trend of Cu layer thickness and uniformity with width is shown in Figure 7. It shows that uniformity improves with the increase of the line width, compared with the scheme without accompanied plating. When the line width of pattern for co-plating is 300 μm , the uniformity increases by 23.8%. With the increase of width, the average value of Cu layer thickness tends to approach the theoretical set value, and when the line width exceeds 300 μm , the change of the average value of the Cu layer thickness tends to stabilize. Therefore, the recommended value of the pattern width for accompanying plating is 300 μm .

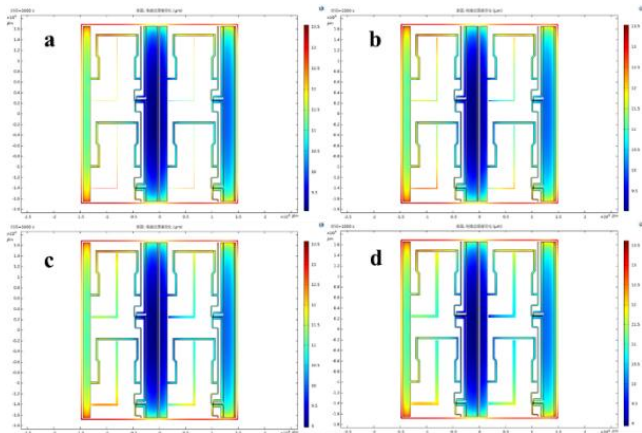


Figure 6. Cu layer thickness simulation distribution cloud image (a=50 μm , b=200 μm , c=400 μm , d=600 μm)

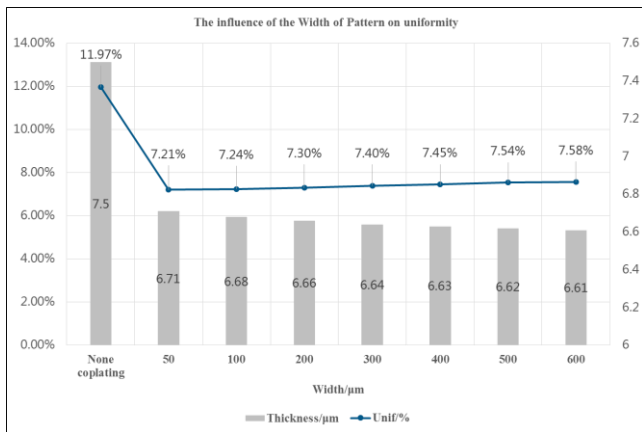


Figure 7. The variation trend of Cu layer thickness and uniformity with the width of co-plating pattern

3.3 Simulation study on the influencing factors of equipment parameters

In actual production, due to the influence of the spatial structure of electroplating bath, the current density distribution on the cathode substrate is uneven. Only increasing the current density to bring about the improvement of uniformity is not ideal, and changing the distribution of power lines on the substrate is the key means to improve the uniformity of electroplating Cu thickness. In this section, the influence factors of power line shielding area, anode and cathode plate space, and the current density were studied by simulation.

3.3.1 Shielded area of power line

The electroplating anode can change the spatial electric field distribution by increasing the insulation shielding, and then affect the Cu layer distribution on the cathode surface. The effect of different anode shading areas on plating uniformity was simulated by adding shielding plates in the simulation model, with the variation of shielding plate aperture size. The depth of the plating bath model is 100 mm, and the shielding plate was set 70 mm away from the cathode surface to simulate the influence of the change of shielding aperture on the thickness and uniformity, as shown in Figure 8. Increasing the shielding plate has little effect on the thickness of the Cu layer, while the uniformity value of the Cu layer shows a decreasing trend as the aperture of the shielding plate decreases. Combined with Fig 9, it can be seen that, after the shielding plate is set, the distribution of power lines will bypass the shielding plate. When the aperture size drops to 10*10 mm, the distribution of power lines is the most uniform and the uniformity is the best in the isolated fine line area. Continuing to reduce the aperture of the shielding plate, the uniformity value shows a fluctuating state. The above analysis indicates that the uniformity of cathode deposition can be improved by adding anode shielding plate, but in actual production, the anode shielding area should be adjusted according to the distribution of the pattern to be plated.

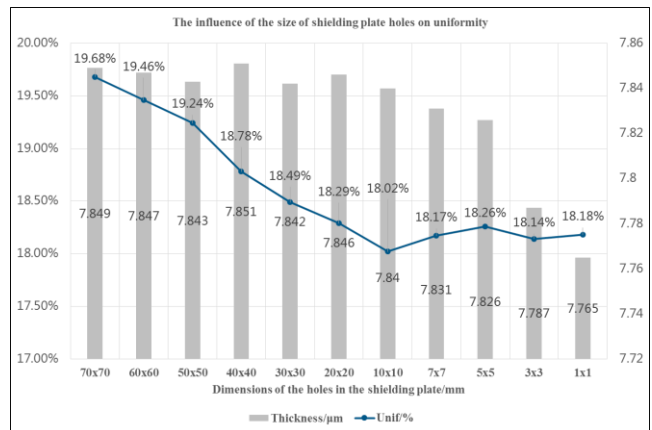


Figure 8. Effect of shielding plate aperture on thickness and uniformity of Cu layer

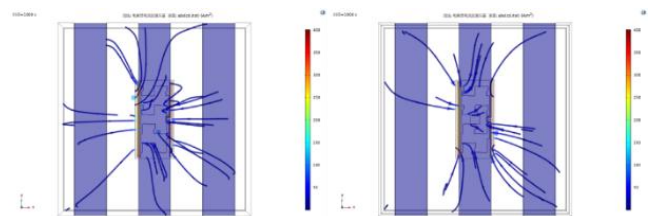


Figure 9. Effect of aperture of shielding plate on power line distribution during electroplating

3.3.2 The space of anode and cathode plate

The variation range of the anode and cathode plate space was set to be 60-100 mm. From Figure 10, it can be seen that the electric field linear density received by the cathode plate increases with the decrease of space. The deposition rate of metal ions in the electrolytic cell at the cathode increases within the same time, and the thickness of the Cu layer of the cathode gradually increases with the decrease of space. The smaller the space, the better the uniformity (60mm plate space compared with 100 mm plate space, the uniformity increased by 16.2%). Theoretically, when the plate space is zero, the uniformity of the Cu layer is the best. But when the anode and cathode plate space is zero, there is structural interference and collision risk, and it

is easy to cause the surface copper layer to strip. For equipment safety considerations, in order to obtain more even cathode deposition, the anode and cathode plate space should be ≥ 25 mm.

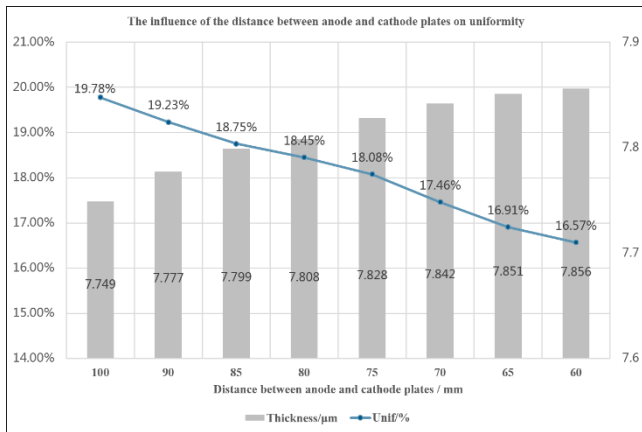


Figure 10. Effect of anode and cathode plate spacing on the thickness and uniformity of Cu layer

3.3.3 Current density

The increase in current density will speed up the plating reaction rate and shorten the plating time. However, increasing the current density without other uniformity improvement measures will amplify the current cluster effect, which is not conducive to the formation of uniform deposition. As can be seen from Figure 11, with the increase of current density, the uniformity value of electroplating tends to rise, which indicates that excessive current density will disrupt the uniformity of metal ion deposition. In actual production, it is necessary to set an appropriate current density after considering factors such as the coating thickness target and auxiliary uniformity improvement measures.

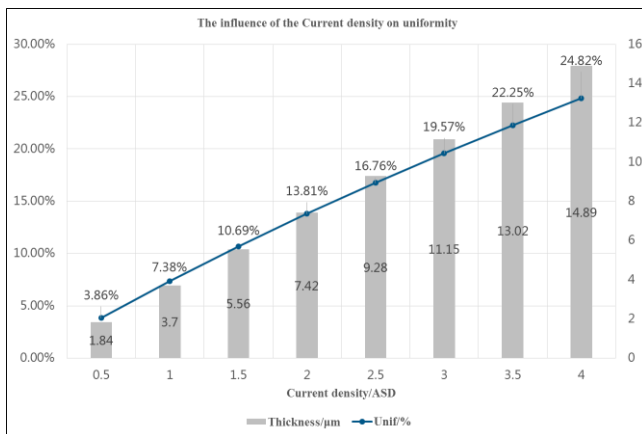


Figure 11. Effect of current density on thickness and uniformity of Cu layer

3.4 Experimental verification

According to the above simulation optimization parameters, the glass-based electroplated Cu backplane was prepared. Relatively uniform samples were taken on the surface of the substrate and the Cu layer thickness at the sampling points were measured using SEM, as shown in Figure 12. The average thickness of the measured Cu layer is 8.39 μm, and the error from the target value is less than 5%. The thickness distribution of the Cu layer is shown in Figure 13. The uniformity of the measured Cu layer is 18.6%, while the simulation result is 16.8%. The relative deviation from the measured uniformity

is 9.7%, but the relative error $\leq 10\%$, which shows that the parameters of the simulation model can reflect the distribution trend of the thickness and uniformity of electroplating Cu layer and can provide reference for actual production parameter control and design optimization.

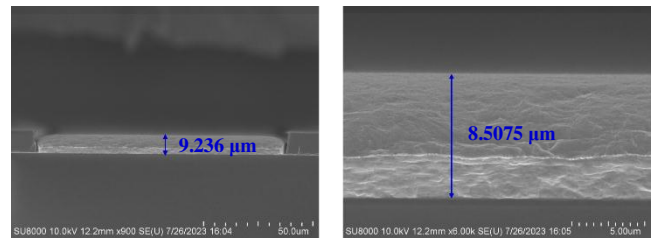


Figure 12. SEM image of Cu layer thickness

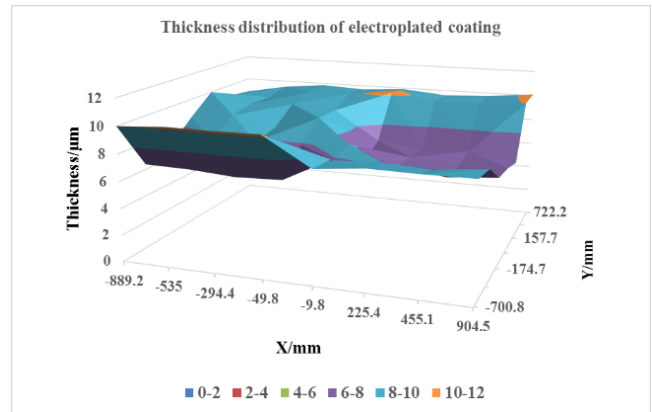


Figure 13. Thickness distribution of electroplated Cu layer

4. Conclusion

Based on the analysis of the electroplating reaction mechanism, this paper established a simulation model, and studied the influencing factors of Cu uniformity in electroplating on G6 glass substrate. The optimized design and process parameters were output, and the electroplating Cu backplane was manufactured. The uniformity of Cu coating thickness was 18.6%, which met the expected target, and provides experience and reference for the subsequent uniform debugging of electroplating products.

5. References

- [1] Tiankuo S ,Chenxi Z ,Kun L , et al.P - 7:11: A Study on Local Dimming Algorithm Design for MINI LED Backlight Display Quality Improvement [J]. SID Symposium Digest of Technical Papers,2022,53(S1):843-845.
- [2] Jiawei X ,Haiwei S ,Zongjie G , et al.P - 54: Research On DGS Character Of Glass Based Mini LED BLU [J]. SID Symposium Digest of Technical Papers,2023,54(1):1609-1612.
- [3] Substrate carrier and electrodeposition apparatus [P]. CN202021649802.2 2021-03-16.
- [4] Cong Peng, Han Luo, Yilan Luo, Shigen Zhu. Optimization of jig for electroplating based on finite element simulation [J]. Electroplating & Finishing, 2022,41(15):1053-1058.DOI:10.19289/j.1004-227x.2022.15.002.
- [5] Hong Zheng. The Harms of ESD on Electronic Products and Anti-static Design [J]. Sci-Tech & Development of Enterprise, 2010, (22): 47-49.