P-62: OLED Deposition Characteristics for 4th Generation Mass-Production

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Abstract
The characteristics of the organic evaporation source and vapor distribution for 4^{th} generation mass production OLED system were investigated. We simulated the heat distribution of the organic material evaporation source for mass production which could run for more than 2 days and could control each deposition rate stably during the doping process. The velocity distribution of gas and vapor from the injection head to each nozzle was also simulated to get preferable film uniformity and the size and pitch of the each nozzle was designed from the simulation results. Finally the best length and shape of the injection head were fixed.

The film non-uniformity was about ±4.0% with only a short deposition distance of 200~300mm. During the process there was no thermal damage on the glass from heated injection head and its temperature variation was about Δ 3℃ as the main shutter opened and closed repeatedly.

1. Introduction
Many companies are now trying to change their mass production line from a small-sized passive matrix line to a large-sized active matrix one. Various active matrix panels already have been introduced at many conferences and in R&D studies. Now, mass production planning for manufacturing the large-sized panel is going faster. The present substrate for the mass production line is $370X470mm^2$, which are almost the largest possible dimensions of 2^{nd} generation glass, and 1~2-inch small-sized panels are fabricated in that line. But now there is much interest in manufacturing the large-sized panel, like for TVs or monitors, as the performance of the device gets improved. And the development of the OLED mass production system is the one of the most important things in setting the mass production for the 4^{th} generation or higher generation substrate.

As well known, a point source or modified one was used as a heating source for evaporating the organic material in the 2^{nd} generation OLED system. But it had a lot of limitations, like small capacity, lower material usage, difficulty in deposition rate control, long deposition distance as a larger substrate. So, there were a lot of efforts in developing a new type of evaporation source and several companies have introduced their newly developed evaporation sources. As mentioned above, the good uniformity of the film, high capacity, higher material usage are the important factors in the development of a new and better model.

In this paper, we introduce the simulation results of heat and vapor distribution of a new evaporation source for the 4^{th} generation glass and injection head. And we also show some results of the film uniformity, deposition rate stability and thermal effect on glass in our developed OLED mass production system.

2. Analysis of the heat distribution for the large capacity evaporation source
In order to simulate the heat distribution of the organic evaporation source, an analytical tool (as shown Figure 1) was used. In this tool, we assumed that the heat is transferred by conduction in all of the contact parts and exchanged by radiation on a opposite area. We introduced a potential difference at the end of the each heater instead of real electrical power to heat the evaporation source. After the potential difference was introduced to the heater, the heat distribution of the each part was observed at about 15-minute intervals.

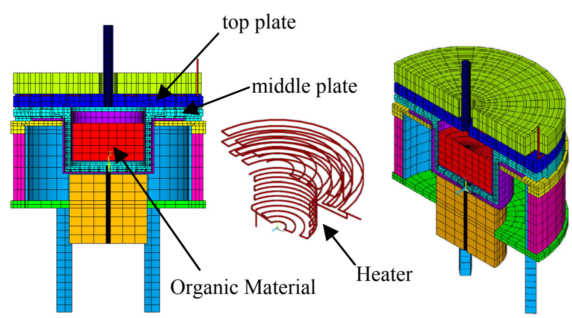

Figure 1. The schematic of the organic material evaporation source for heat distribution simulation

Figure 2 shows the temperature variation as heating time at each part of the organic evaporation source. In designing and manufacturing the organic evaporation source, the guarantee of the temperature distribution uniformity is a very important factor. However, it also gets more difficult when we need to use the larger point source because a large capacity is required. The good uniformity of the heat distribution inside the evaporation source

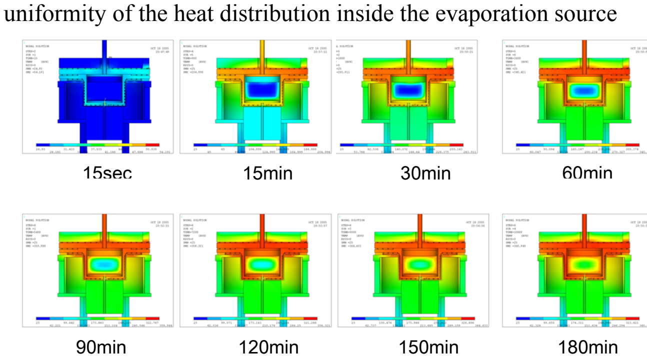

Figure 2. The simulated heat distribution inside organic vapor source as heating time

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after about 90 minutes of heating is shown in Figure 2. It reaches a stationary state of 350℃ but we can observe the temperature of the organic materials insides lower than that of the evaporation source or upper surface of the organic materials. We guess this is caused by lower thermal conductivity of the organic material and it rise slowly as time goes on.

Generally, there is difficulty in deposition rate control because of these temperature differences, in the case of using the point source for evaporating the material and the spitting of the organic material inside the crucible often happens. As we can see in Figure 2 there is also a temperature difference between the inside of the organic material and our evaporation source or surface of the organic material. But we could get good deposition rate stability during the process by adding the heat to the top plate of the evaporation source. We found out that heating the top of the evaporation source could solve the non-uniformity problems for heat distribution.

3. Organic vapor distribution and film uniformity

The uniformity of the deposited organic material film is more important in the fabrication of a large-sized panel like that of a T.V or of a monitor. If the film uniformity isn't guaranteed, emitting performance and characteristics of the each device will be different from time to time. Figure 3 shows the simulation result about the vapor flow from both ends of the transfer pipe into injection head. It analogized the distribution of the vapor velocity at each nozzle. And it could expect film uniformity which promises tolerance. In Figure 3, we found out if we could expect the velocity of the injected vapor at each nozzle, the thickness uniformity by vapor distribution in 4th generation substrate could be expected. The organic vapor injected from a new evaporation source to injection head has different vapor distribution as volume of the injection head, nozzle size and its pitch and deposition distance between substrate and injection head. And we need to find best condition from all of results to expect the best uniformity.

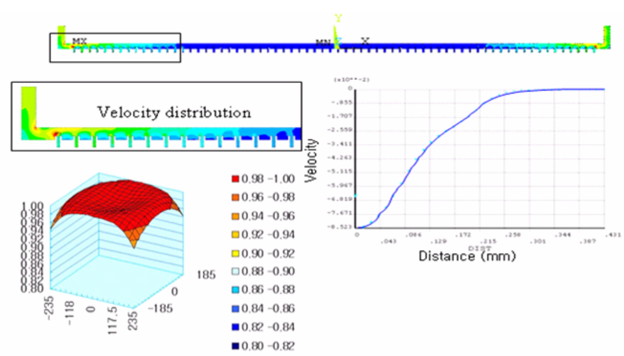

Figure 3. The simulated velocity distribution of the organic vapor from each nozzle of the injection head

Figure 4 is one of simulated thickness distribution results to seek best uniformity with shortest deposition distance and small volume of the injection head. As we can see each uniformity is variable according to many conditions and we could get film non-uniformity less than ±5% by much trying which varied nozzle size and pitch, distance between evaporation source and injection head and volume of the injection head. In Figure 4, we also could approximate our real model about injection head.

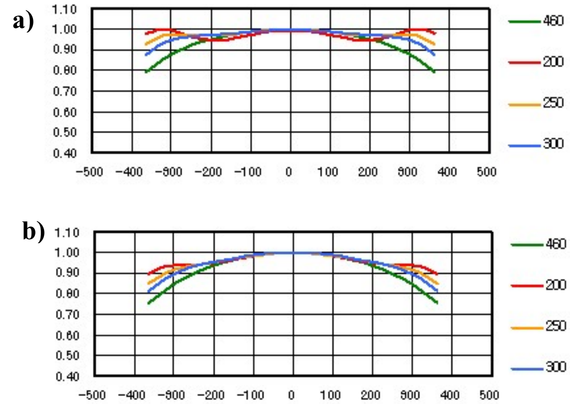

Figure 4. The thickness uniformity as distance between the substrate and injection head, a) injection head of 2/3inch diameter and Φ1.5 nozzle b) injection head of 1 inch diameter and Φ1.5 nozzle

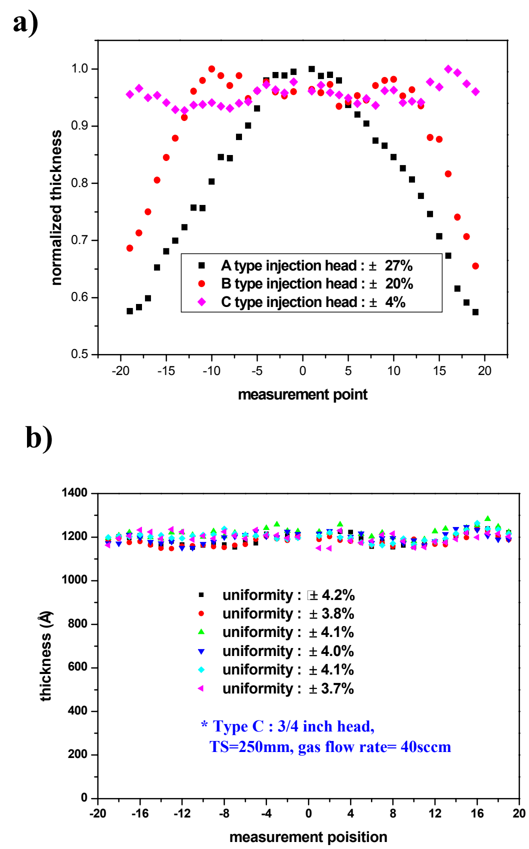

Figure 5. a) The thickness uniformity as injection head type, deposited organic material for measurement was Alq3 and film thickness was 1,000Å. b) The repeated thickness distribution result by injection head type C

Now we designed and installed the injection head in our system and measured real film uniformity for 4th generation substrate. Figure 5 a) shows the film thickness distribution according to injection head type after deposited to 1,000Å on 730mm direction of the glass. In injection head type of A and B, we just got each ±27% and ±20% non-film uniformity. But after rearranging the nozzle and pitch we could get better results as shown in Figure 5. In type C, the film non-uniformity is about ±4% and we deposited and measured the film several times for its repeatability as shown in Figure 5 b). The deposition distance is about 200~300mm and nozzle size is from 0.5mm to 3mm. we could get good uniformity with precise arranging the different nozzles and its pitch. Although there is a little difference with distribution results of simulations and real thickness we could reduce our trial and error for obtaining the good uniformity in large substrate and expect the vapor distribution result for 5th generation or higher one.

4. Deposition rate and doping control

Figure 6 shows deposition rate control of organic material using gas like nitrogen or Argon through the heated injection head. α -NPD was used for organic material in the deposition process and target deposition rate was 1Å /s.

During the process the stable deposition rate was maintained by gas flow control. The range of gas flow into the evaporation source was from 0 to 10sccm and we convert it to direct current signal for rate control. The mean deposition rate and standard deviation were 1.00402Å /s and 0.01537. The range of injected gas flow is changeable as deposition condition or system environment and high deposition rate can be obtained by controlling gas flow rate. If we can get high deposition rate and also good quality of the films, we may shorten the tact time in running the mass production system.

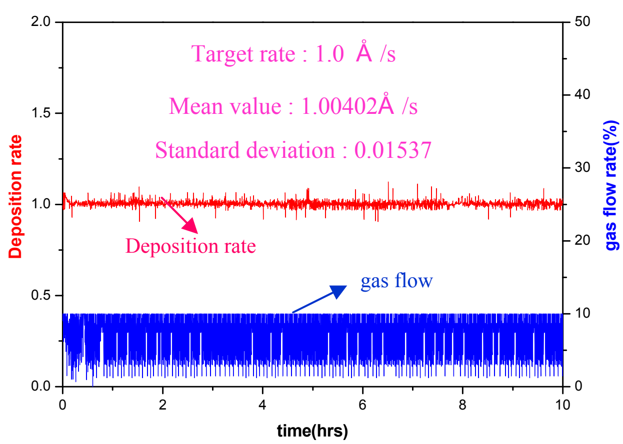

Figure 6. The deposition rate control of the α -NPD by gas flow rate of organic evaporation source

The doping rate control by gas flow is shown in Figure 7. Alq3 and C545T were used as the host and the dopant material, respectively. When we deposited each material we used Ar gas from 0 to 10 sccm for control of the deposition rate of the host and from 0 to 2 sccm for that of the dopant. The deposition rate of the host material was 1Å /s and we doped 1% C545T with host. If we intend to dope with 1% ratio at 1Å /s, deposition rate of the dopant has to be maintained 0.01Å /s stably. But in a real process, it is very difficult to maintain its deposition rate because there is much signal noise from the thickness sensor and signal wire. So we magnified its resolution 10 times or more in order to more easily monitor the deposition rate of the dopant. Now we could get the stable deposition rate of dopant during the process. As we can see in Figure 7, the mean of deposition rate of each host and dopant is 0.9647Å /s, 0.10306Å /s and their standard deviation are less than 0.05.

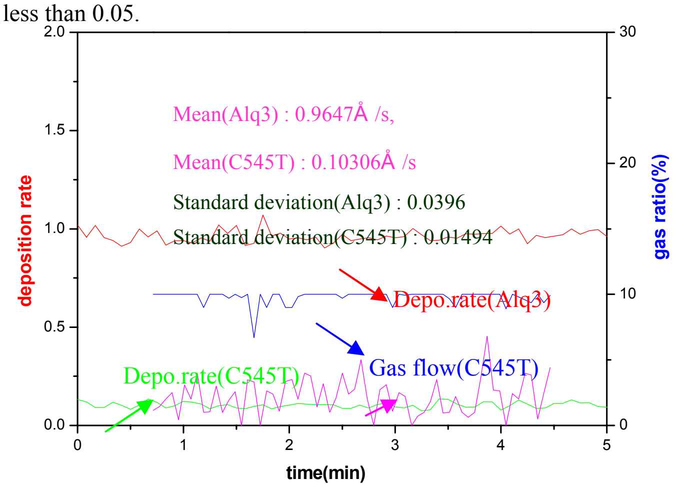

Figure 7. Doping control of the large capacity evaporation source using a gas flow control, Host & Dopant materials were each Alq3 and C545T, doping ratio was 1%.

5. Thermal damage on the glass

In order to prevent condensation of the organic material, it is necessary to heat the injection head and transference line which moves the vapor from evaporation source to injection head . But it also is a cause of the thermal damage on the glass or metal shadow mask with short deposition distance. Figure 8 shows

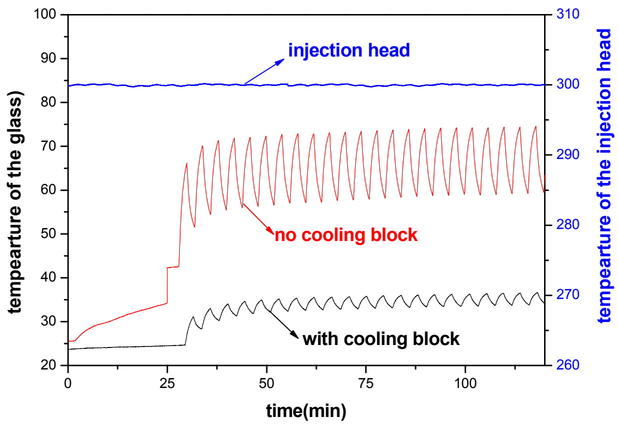

Figure 8. The temperature variation on the glass substrate during shadow mask with short deposition distance.

Figure 8 shows the process temperature rising was up to more than 70℃ without cooling block. But using the cooling block which flow water or refrigerant, we found it was lower than 32 ℃ and temperature variation as the main shutter opened and closed repeatedly was only about 3℃. We assumed that the tact time of the system was about 4minutes in mass production and it cost about 2 minutes for deposition of organic material and then main shutter was closed for 2 minutes. So we set auto close and open mode of the main shutter at 2 minutes intervals in our system. If we install more effective cooling block and cool the outside of the process chamber, temperature rising will be less than 30℃.

6. Summary

The heat distribution of the evaporation source for mass production of OLED was uniform after introducing the electrical power to the heater in 90 minutes. Less than 5% film non-uniformity could be expected by simulation with variables like nozzle size and pitch of the injection head, deposition distance, etc. And we got film which had non-uniformity of ±4% in real deposition process and there is no thermal damage on the glass during the real deposition process.

Since we made sure main parameters for guarantee of the uniformity for 4th generation substrate, we can also expect them which guarantee the uniformity for next 5th generation substrate or larger one. We are now developing the mass production system for 5th generation substrate and our next presentation will be results about uniformity, device performances and deposition characteristics of the evaporation source.

7. References

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