Improvement of evaporating efficiency for OLED mass-fabrication

Eung-ki Lee, Seong Ho Jeong, Seok Heon Jeong,
Myung Soo Huh, Sung Ho Lee, Sung-jin Chung

Advanced Engineering Center, Samsung SDI Co. Ltd.,
Paldal-gu, Suwon-city, Gyeonggi-do, KOREA 442-391
Phone : +82-31-210-8039 , E-mail : eklee@samsung.co.kr

Abstract

For the evaporation process, thickness uniformity is of great practical importance. And, it is commercially significant to improve the efficiency of material of the evaporant which is deposited on the substrate because of high price of organic materials. To achieve the better thickness uniformity and the higher evaporating efficiency, Samsung SDI has introduced the new concept of the asymmetric evaporation technology for depositing evener and cheaper organic layers. Based on the developed method, the uniformity of the organic layer thickness can be successfully controlled. Furthermore, the very high efficiency may allow the OLED displays be manufactured with the lower cost.

1. Introduction

Organic electro-luminescence device (OLED) has been studied world-widely because of its simple structure, high resolution, large viewing angle and low driving voltage. Vacuum evaporation allows pure organic material deposition on a substrate without concern of contamination such as oxygen or solvents.[1] It is the most mature & common method already in production for OLED displays.

The trend of the display size has hauled the enlargement of the mother glass substrate. As the substrate size is enlarged, the thickness uniformity of the organic layer becomes more important. Now, here is another issue for fabricating OLED displays in existence. It is required to improve the evaporation efficiency because the organic material is expensive. Therefore, the improvement of evaporating efficiency can reduce the OLED manufacturing cost as much as that. Generally, the evaporation efficiency is in squarely inverse proportion to the distance between the glass substrate and the cell source. According to the evaporation efficiency, the closer is the better. But, in point of the thickness uniformity, the closer is the worse.

Samsung SDI has introduced the new evaporation methodology for depositing evener and cheaper organic layers. We have simulated the evaporating deposition for improving the thickness uniformity and evaporant consumption efficiency according to the various arrangements of cell sources. Based on the developed method, the user-specified thickness uniformity and the high evaporating efficiency was successfully achieved. Furthermore, the very high evaporating efficiency may allow the OLED displays be manufactured with the much lower cost. For instance, the double efficiency can reduce the half amount of the material consumption.

2. Evaporation modeling

Atoms or molecules evaporating from a cell have kinetic energies that are distributed according to their temperature.[2] The deposited layers should be as uniform as possible, and therefore it is important to know the directional distribution of the evaporating molecules. Many investigations have been done to optimize the thickness uniformity on the substrates. [3, 4] Figure 1 shows the geometrical arrangement of typical evaporation using a plane rotating substrate.

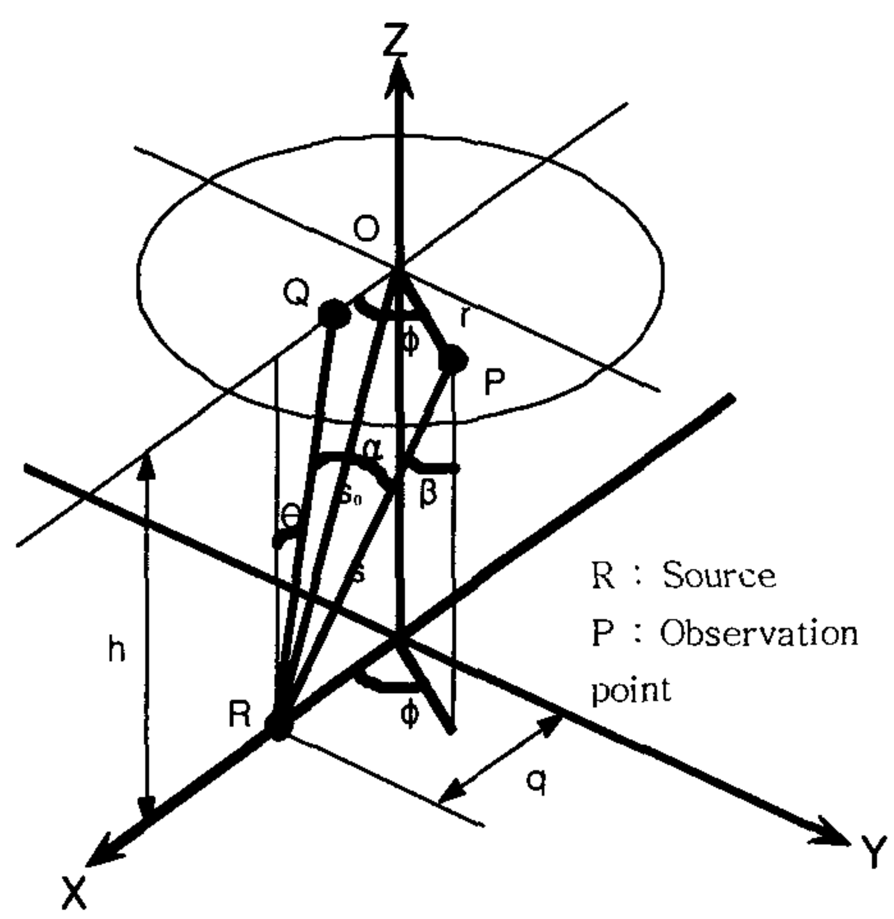

Figure 1 Evaporation geometry

The position of the evaporator is out of center by a section q. The substrates rotate with a radius r in a vertical distance h above the cell source. (Figure 1)

Generally, the mass *m* of material emitted from an evaporation source at a solid angle ω is:

$$dm = m(\omega)d\omega = m(\omega)\cos^n \alpha \, d\omega \qquad (1)$$

The evaporated material transported in the solid angle dω condenses on the substrate element dA. The relation existing between mass m, density ρ and thickness is:

$$dm = \rho \, d \, dA \qquad (2)$$

By substituting Eq. (2) into Eq. (1), the thickness on the substrate element of the distance *s* is:

$$d = \frac{m(n)}{\rho}\frac{\cos^n \alpha \cos \beta}{s^2} \qquad (3)$$

The substrate has a point, the center of rotation, whose relative position to the evaporation source remains unchanged during the rotational motion. This center of rotation is best suited as a normalization point for the thickness d_0.

In normalized representation is obtained:

$$\frac{d}{d_0} = \left(\frac{s_0}{s}\right)^2 \left(\frac{\cos^n \alpha \cos \beta}{\cos^n \alpha_0 \cos \beta_0}\right) \qquad (4)$$

For simplification of representation, introducing new parameters *c, e* and *f*, substitutes the parameters of Eq. (4) and yields:

$$c \equiv \sqrt{1 + \tan \theta}$$

$$e \equiv h + q \tan \theta$$

$$f \equiv \sqrt{h^2 + q^2}$$

$$\frac{d}{d_0} = \frac{f^{n+3}(e - r \tan \theta \cos \phi)^n}{\left(f^2 + r^2 - 2rq \cos \phi\right)^{\frac{n+3}{2}} \cdot e^n} \qquad (5)$$

Eq. (5) describes the relation of the thickness of a random point to the thickness of the point on the axis of rotation under stationary conditions. In practice, the glass substrate is rotated. This physical face is solved mathematically by forming the integral of Eq. (5) with the integration variable. The resulting thickness distribution on a rotating substrate is then:

$$\frac{D}{D_0} = \frac{1}{\pi}\frac{f^{n+3}}{e^n}\int_0^{\pi} \frac{(e - r \tan \theta \cos \phi)^n}{\left(f^2 + r^2 - 2rq \cos \phi\right)^{\frac{n+3}{2}}} d\phi \qquad (6)$$

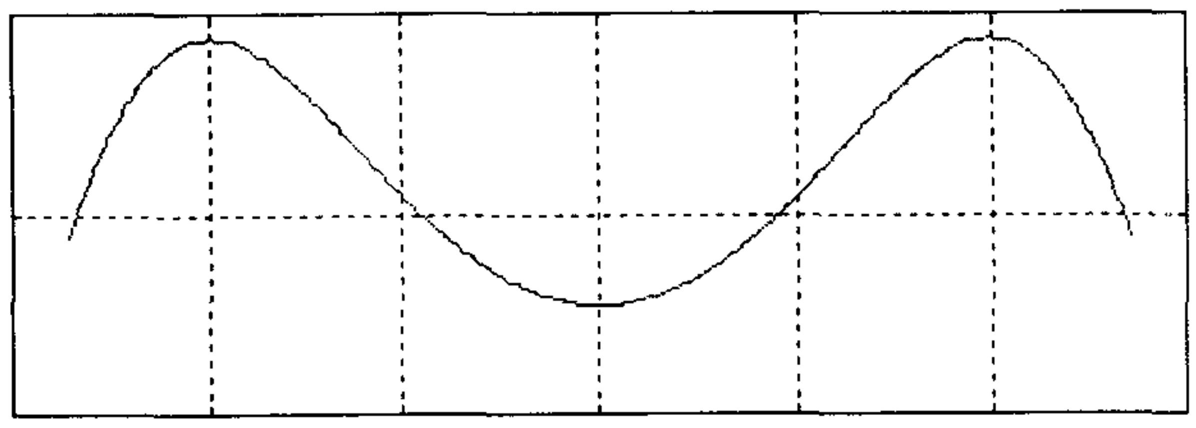

Figure 2 Thickness profile on a substrate

The shape of the thickness profile is strongly influenced by the geometrical position of the evaporation source and the exponent n. The solution of the Eq. (6) makes it possible to obtain quickly a survey of the thickness distribution which can be expected. Figure 2 shows the normalized thickness distribution with n=1 and the evaporation source of q/h=1.4 and θ=π/3.

In OLED production, the expense of organic material consumption is an importance factor. The efficiency of the evaporated material is determined by the mass effectiveness η.

$$\eta = \frac{m}{M} = \frac{\rho v}{\rho V} = \frac{v}{V}(\%) \qquad (7)$$

in which ρ is the film density. In Eq. (7), *M=(ρV)* is the total mass emission of evaporated material of the cell source, and *m=(ρv)* is the mass deposited on the area of the substrate. Only a portion of the evaporated material *M* is deposited on the substrate as effective material *m* for evaporation.

The mass effectiveness can be calculated by using Eq. (6), the determination of the normalized thickness profile along the glass. The deposited mass v on the substrate, of which the radius is *r*, is obtained by Eq. (8)

$$m = \rho v = \rho \int_0^r \oint_{2\pi} r \frac{D(r)}{D_0} d\phi \, dr \qquad (8)$$

The total mass deposited on the infinite substrate can be calculated with Eq. (8) by extending the substrate radius *r* to infinite.

3. Simulation & verification

According to Eq. (6), the shape of the thickness profile is strongly influenced by the geometrical position of the evaporation source and the n value. The geometrical position of the evaporation source is easy to establish, but the n-value characterizing the shape of the deposition profile, must be determined experimentally.

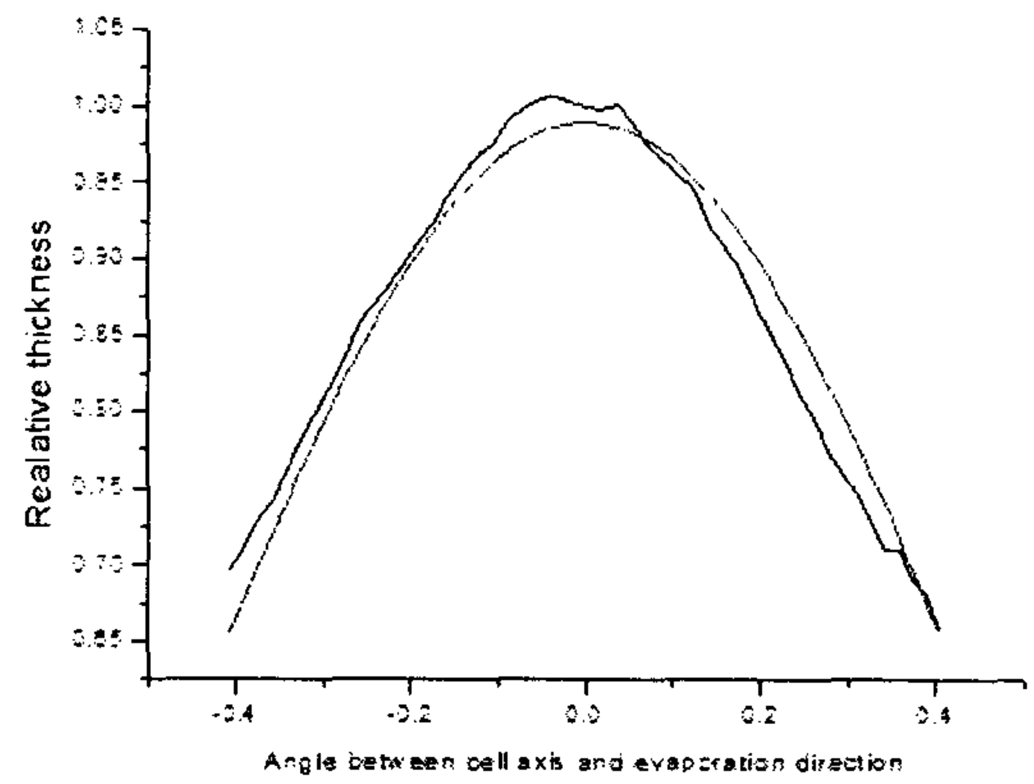

Figure 3 Curve fitting to determine n-value

The experimental determination of n is done by measuring the thickness profile on substrates and fitting the measured profiles with those calculated. (Figure 3) The least-square fitting method is applied for obtaining the best fit between experiment and calculation.

In the evaporation model, the molecules leave the vaporizing surface with direction defined by the cosine law. They travel to the substrate without any interactions in the residual atmosphere. The simplest events that may happen are collisions with residual gas atoms.[5] The usual consequences are changes in direction and velocity. For the case of the cell source and the chamber in use, the cosine law is decided to be appropriate for modeling the organic material evaporation by the n-value fitting result as Figure 3.

With the calculated n-value, the thickness distribution can be predicted. Analytic solution of the integral does exists for all possible n values of the evaporation; therefore numerical calculation methods were used. The geometrical parameters q, h are used and are allowed to vary in a computer simulation under defined geometrical boundary conditions, such as dimensions of the chamber and the glass area to be coated, etc. Figure 4 shows the trend of thickness uniformity as various positions of the evaporation source. The calculation had been performed with numerical methods.

One of the objects of this paper is to obtain uniform thickness distribution over the area of the substrate. The other is to increase the evaporating efficiency. Generally, the evaporation efficiency is in squarely inverse proportion to the distance between the glass substrate and the cell source. Moving the source into the axis of rotation increases the evaporating efficiency remarkably. But, in point of the thickness uniformity, the closer is the worse.

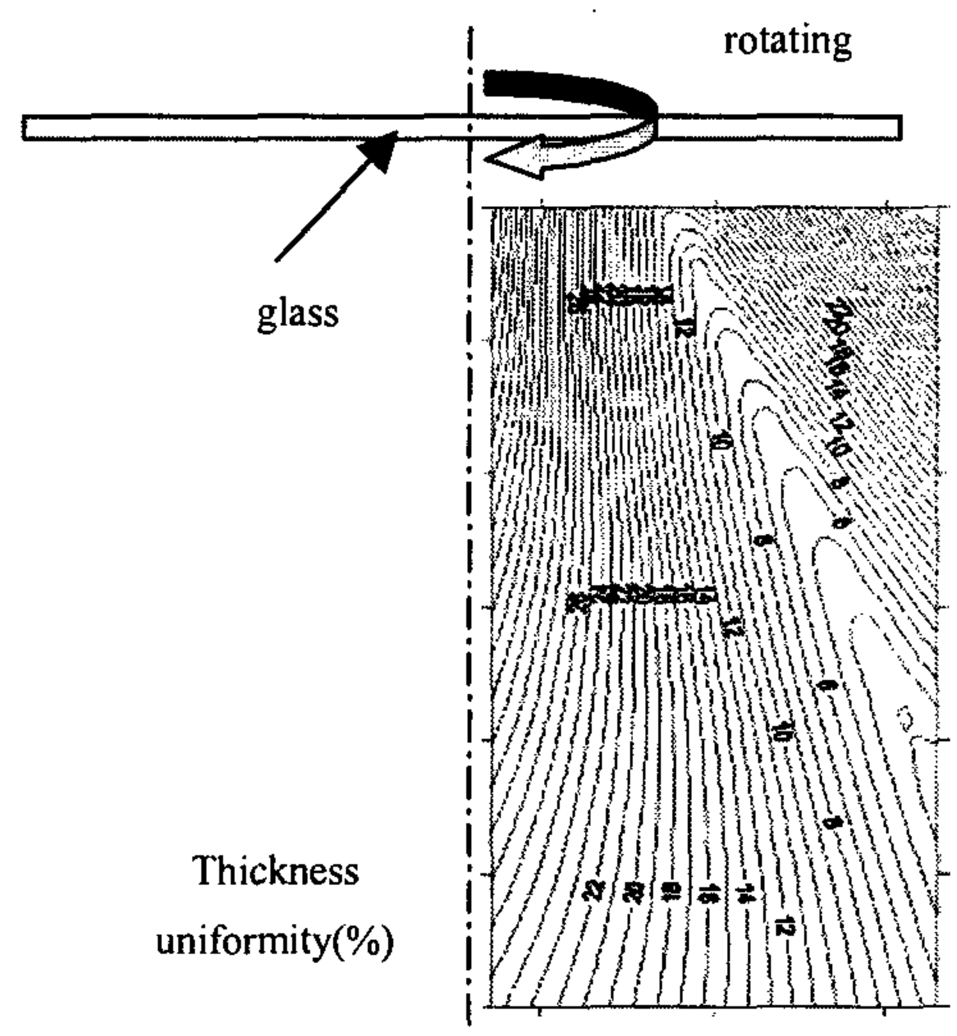

Figure 4 Thickness uniformity as function of the source position

Usually two evaporation sources are used to be located in the mirror position in conventional symmetric evaporation method. (Figure 5) To achieve the better thickness uniformity and the higher evaporating efficiency, Samsung SDI has introduced the new concept of the asymmetric evaporation technology. The asymmetric evaporation method adopts to use two cell sources and arranges them asymmetrically against the rotation center.

Optimization of the evaporation sources position is done by evaluating the thickness uniformity and evaporation efficiency as variation of the sources position.

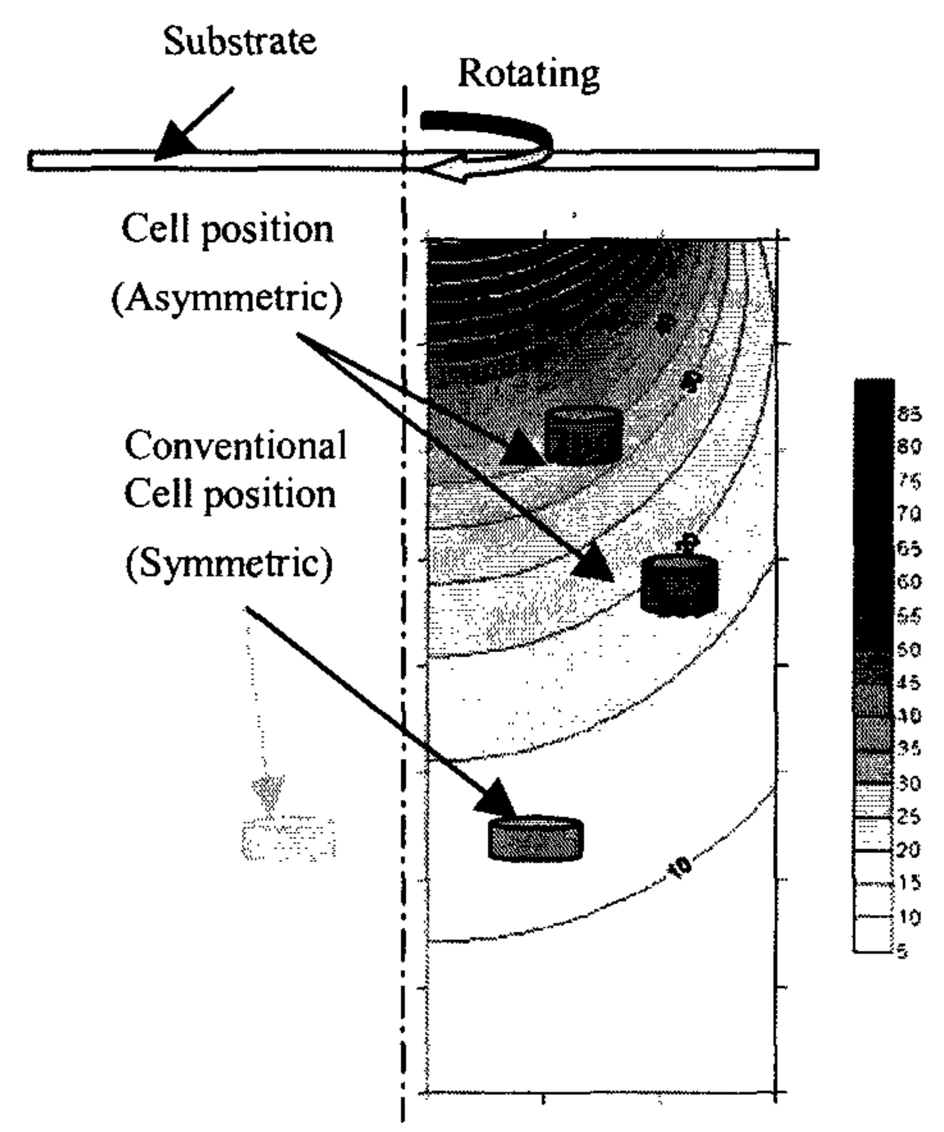

Figure 5 Evaporating efficiency as variation of the source arrangement

As in Figure 5, the positions of the cell sources are closer and asymmetrically to the substrate than those of the conventional method. The positions of the two sources are decided in order to compensate and control the thickness distribution.

No	Uniformity (%)
1	4.9
2	4.3
3	3.9
4	3.1
5	4.9
Mean	4.22

Table 1 Measured thickness uniformities

Based on the developed simulation method, the evaporation experiments had been done with two cell sources of the optimized positions. Table 1 shows the measured uniformities of the organic material Alq_3 evaporation experiments on glass substrates. The thickness profiles were measured by an ellipsometer. In experiments, the thickness uniformities are reproduced from 3% to 5%. The variations of the measured thickness uniformities are induced by instantaneous difference between the evaporating rates of two sources.

The evaporation sources with the optimal positions yields the calculated material consumption efficiency of 34%. This value is clearly superior to that obtained with the symmetric evaporation method.

4. Conclusion

Samsung SDI has introduced the new concept of the asymmetric evaporation method for improving the thickness uniformity and the evaporating efficient. We have simulated the evaporation process as the various arrangements of cell sources. The developed method was verified by the evaporation experiments and the measurements. The thickness uniformity of 3-5% and the evaporating efficiency of 34% were achieved.

With the developed method, OLED displays can be manufactured with the much lower cost.

5. References

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