The development of the highly efficient Circular Nozzle Source by using a study on the flux distributions of nozzle type thermal evaporation sources

Sungmoon Kim, Kwangho Jeong
R&D center of YAS co., Ltd, Goyang-si, Gyeongi-do, Korea
TEL:82-31-904-8591(ext 202), E-mail: smkim@yasoled.com

Keywords : evaporation source, flux distribution, film uniformity, material efficiency

Abstract

We studied the properties of vapor flux distributions of nozzle shaped thermal evaporation sources and the factors, which can change the flux distributions such as nozzle structure. We used a simulation and experiment methods for this study. By using the results of our study, we improved the Circular Nozzle Source, which can make uniform thin films without substrate rotation, into more efficient source.

1. Introduction

The vacuum thermal evaporation method has been generally used in many laboratories and thin film manufacturing systems. Recently, in OLED (organic light-emitting device) industry, a point source evaporator is widely used for organic and cathod layers. But there are many technical issues such as film uniformity in large size substrates and material efficiency.

Thus, we have made the circular nozzle source (CNS), which overcomes many of point source problems. But there remains problems that the material efficiency of CNS is not good enough. To improve the material efficiency of CNS, we must control the flux distribution of nozzle source accurately.

Therefore, in this study, we have studied the properties of vapor flux distributions and factors, which can change the flux distributions such as nozzle structure. We used simulation and experiment methods for this study. By using the results of our study, we improved the CNS into more efficient source.

2. Simulation of flux distribution

We made a simulation program by using Monte-Carlo methods. It can describe the trajectory of each particle in a nozzle of evaporation source.

For our modeling, we used collision probability related with pressure gradient in nozzle. Finding the pressure gradient, we discussed the number of particles emitted from nozzle, the conductance of nozzle and the mean free path. We use cosine shaped probability functions on deciding directions of incidence particles and the particles re-emitted from wall.

Finally, we made a simulation program by Labview programming tool. In figure 1 an algorism of the simulation program is displayed and in figure 2 the simulation program is displayed.

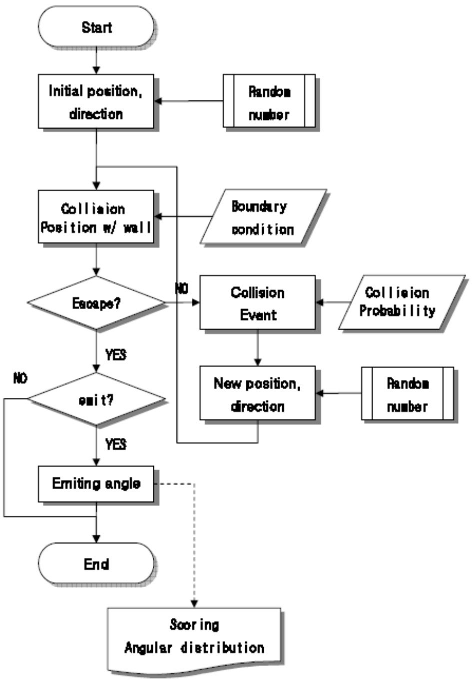
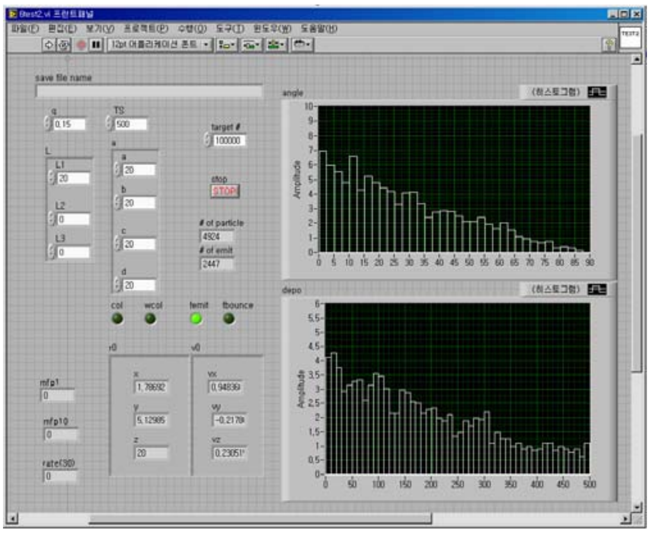


Fig. 1. Algorism of Monte-Carlo simulation.



q 0.15
TS 500
target # 100000
L1 20
L2 0
L3 0
a 20
b 20
c 20
d 20
stop
# of particle 4924
# of emit 2447
x 1.78692
y 5.12985
z 20
vx 0.94836
vy -0.2178
vz 0.23051
mfp1 0
mfp10 0
rate(30) 0

Fig. 2. Simulation program of flux distribution.

Now, let us compare the simulation result with real experiment result, as shown in figure 3. The cosine fitting of real experiment result is different from real data, contrary to our expectation. The real experiment data is sharper at center than cosine fitting and broader at each side than cosine fitting. We can find in our experiments that the difference of cosine fitting with experiment data grows up, as ‘n’ of cosine fitting increase (the flux distribution gets sharper). Our Monte-Carlo simulation result is more similar with real data by contrast with cosine fitting.

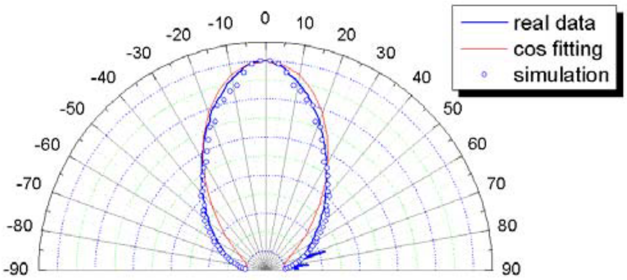


Fig. 3. Simulation result and experimental result.

3. Experimental results

Next, we analyzed the experiment data of vapor flux distribution of various nozzles. For nozzle experiment, we installed the nozzle test system, which can measure in-situ the angular flux distributions and linear flux distributions of nozzles (as shown in figure 4).

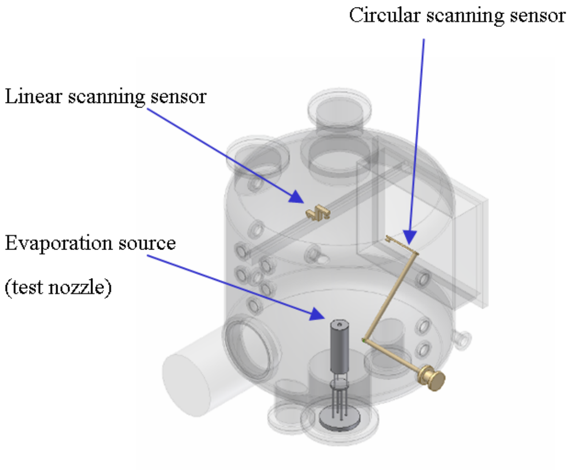


Fig. 4. Experimental equipment.

We analyzed the simple cylindrical nozzles, which have various lengths and diameters. We found that there are five factors, which have influence on the flux distributions of nozzles; the nozzle length, the nozzle diameter, the aspect ratio of nozzle, the deposition rate, and inner situation of nozzle. As the nozzle length grows up, the ‘n’ of cosine fitting of flux distribution increases, but stops increasing after optimum aspect ratio. As the diameter grows up, the ‘n’ value increases, but decreases after optimum aspect ratio. The ‘n’ value maximize at optimum aspect ratio. And as deposition rate increase, the ‘n’ value decreases. The experimental results are shown in figure 5 and the optimum ratio in the results is 1:2.

In addition, five factors relate with two principle factors, the collision and the geometry. Thus we can understand physical phenomena about the flux distribution of the nozzle by the collision effect and geometric effect.

And we checked the flux distributions of special shaped nozzles either; 3-zone conical nozzles, multi-hole nozzles and composite nozzles. The 3-zone conical nozzles make distorted distributions in contrast to simple cylindrical nozzles. It can be used to control a flux distribution accurately. The multi-hole nozzles, which consist of many of small cylindrical nozzles, make highly directional distributions in contracts with simple cylindrical nozzles. It is very useful to control a flux distribution, either.

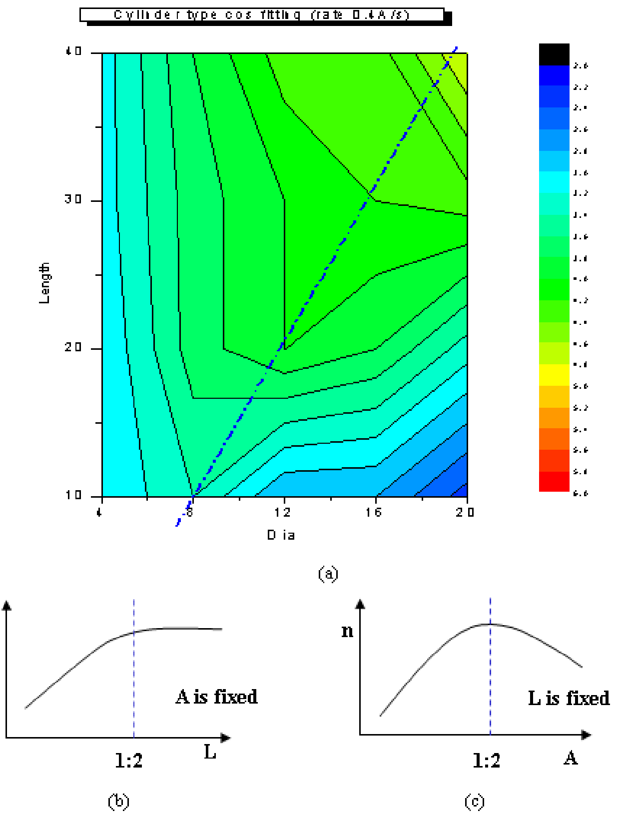


Fig. 5. (a) the contour graph of the 'n' of flux distributions with variables – length and diameter of nozzles, (b) schematic illustration of change 'n' before and after optimum ratio, (c) schematic illustratio of change 'n' before and after optimum ratio

4. Application ; Efficient circular nozzle source

The flux distribution of a point source is given as ;

$$F(\theta)=I(\theta)\frac{\cos\theta}{r^2}, I(\theta)=\cos^n\theta \quad (1)$$

$F(\theta)$ is a flux distribution at substrate position with anonymous unit. $I(\theta)$ is a angular flux distribution of a point source.

As you see in eq. (1), even if a ideal point source case ($n=0$), the flux distribution has swollen shape and film thickness uniformity of substrate is bad. Because the distance from source to substrate (r) and projection ($\cos\theta$) make the flux distribution be swollen shape. Therefore, to make a uniform flux distribution, non-uniform factor ($\frac{\cos\theta}{r^2}$) must be canceled out by proper $I(\theta)$. The calculated $I_c(\theta)$, which can be counterbalance is

$$I_c(\theta)\propto\frac{r^2}{\cos\theta}\propto\frac{1}{\cos^3\theta} \quad (2)$$

If angular distribution $I(\theta)$ follows $I_c(\theta)$, the flux distribution $F(\theta)$ is constant and uniform. The ideal $I_c(\theta)$ and proper $I(\theta)$ are shown in figure 1-10.

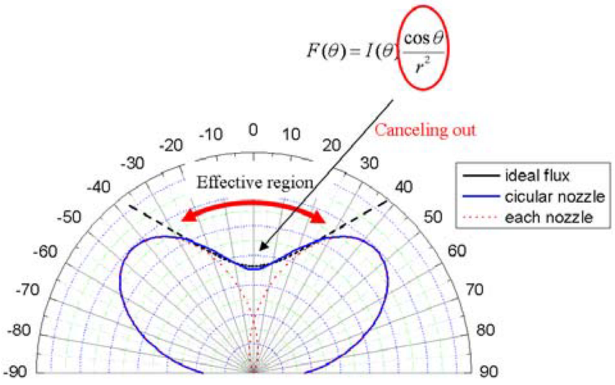


Fig. 6. Ideal uniform flux distribution.

Now we improve the nozzle of CNS by using the results of our study written in this paper. To make more efficient flux distribution, we apply the multi-hole nozzle structure. The key reason of inefficiency is the flux within outside of effective angle. For reduction the outside flux, we need highly directional flux distribution, such as the flux made by multi-hole nozzles. And, to prevent flux distortion at center, we apply guided nozzle structure at the end of CNS nozzle.

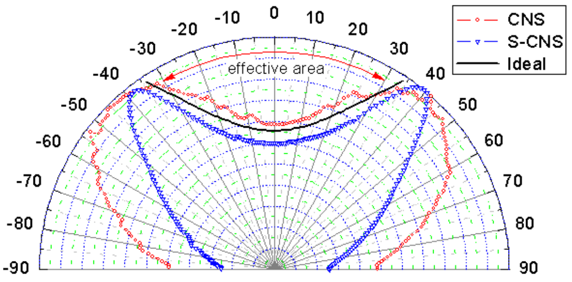


Fig. 7. Efficient CNS(S-CNS) flux distribution.

5. Conclusion

The graph of the angular flux distributions of CNS and improved CNS (we call it S-CNS or Super CNS) are shown in figure 7. As shown in graph, the angular flux distribution of S-CNS follows ideal uniform line within effective area like original CNS. But the flux of S-CNS decrease more rapidly than original CNS in outside of effective area. That such difference makes more efficient flux distribution.

We had run the S-CNS for 11 hrs. And we measured the change of mass of material in crucible and of deposited substrate. We obtain 19% as S-CNS efficiency, as shown in figure 8. This result is as best as we can get.

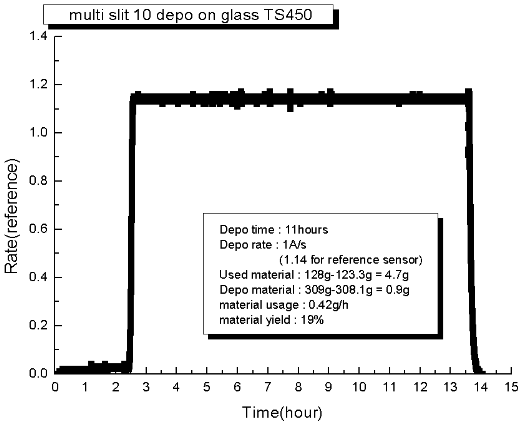


Fig. 8. material efficiency of S-CNS

5. References

1. J. A. Giordmaine and T. C. Wang, 31, 463, J. Appl. Phys., (1960)
2. S. C. Jackson, B. N. Baron, R. E. Rocheleau, and T. W. F. Russell, A , 3, 1916, J. Vac. Sci. Technol., (1985)
3. John E. Mahan, “Physical Vapor Deposition of Thin Films”, John Willey & Sons, New York, (2000)
4. Goerge S. Fishman, “Monte Carlo – concepts, algorithms, and applications”, Springer, (1996)