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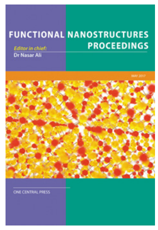

Further improvement of the unevenness of the edge portion of the coating film after drying by controlling the evaporation rate of the edge's side surface of the coating liquid film during drying

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ABSTRACT

The drying of polymer solutions coated on a flat substrate is very important in various industrial applications such as fabricating flat polymer resist thin films in resist coating process in semiconductor process and so on. We have proposed and modified a model of the drying process of a polymer solution coated on a flat substrate for uniform polymer film deposition. In this study, in order to further reduce the thickening of the edge of the thin film after drying, we tried to adequately control the evaporation rate on the side of the liquid film at the edge. As a result, it was found that appropriate management of the evaporation rate on the side of the liquid film at the edge during drying further reduces the thickening at the edge after drying.

I. INTRODUCTION

The drying of polymer solutions coated on a flat substrate is very important in various industrial applications such as fabricating flat polymer resist thin films in resist coating process in semiconductor process [1, 2] and so on. There are various studies of this process. Previous studies of the fabrication of flat polymer thin films have focused on the temporal variation in the thickness of polymer liquid films during drying [2, 3], without considering spatiotemporal variation in concentration distribution. Previous studies of inkjet printing have discussed drying of droplets of polymer solution [4, 5], and thus have a different scope from our study, which considers a large-area liquid film of polymer solution.

We have proposed and modified a model of the drying process of a polymer solution coated on a flat substrate for uniform polymer film deposition [6 - 11]. And we clarified the dependence of the distribution of polymer molecules on a flat substrate after drying on various parameters based on the analysis of many numerical simulations of the model.

However, the mechanism of the drying process in the previous studies does not allow problems with thin films after drying, such as thickening of the edges and depressions near the edge, to be avoided. We used the model to control the thickness of a thin film after drying through management of the temperature, evaporation, and concentration [12]. In addition, we applied the thermal, evaporative, and concentration management to the modified model incorporating the Marangoni effect [13]. As a result, we see that the thickening at the edge of the thin film after drying due to the Marangoni effect and so on can be improved through appropriate thermal, evaporative and solute concentration management.

However, on the other hand, it was also found that a certain degree of the thickening at the edge of the thin film after drying remained. In this study, in order to further reduce the thickening of the edge of the thin film after drying, we tried to adequately control the evaporation rate on the side of the liquid film at the edge. As a result, it was found that appropriate management of the evaporation rate on the side of the liquid film at the edge during drying further reduces the thickening at the edge after drying.

II. METHOD OF THIS ANALYSIS

As a mathematical model, we use the following model which has been proposed by Kagami et al. [14].

$$\frac{\partial N}{\partial t} = K_C \nabla^2 N + \frac{N}{V}(K_V - K_C)\nabla^2 V - \frac{2K_C}{V}\nabla N \cdot \nabla V \quad (1)$$

where N denotes the number of solute molecules included in a space, K_C is the diffusion coefficient of the solution, V is the volume of solvent containing solutes included in a space and K_v is the diffusion coefficient of the solvent. Marangoni effect is incorporated into the model and treated the effect as pseudo-negative diffusion at an upper gas-liquid interface [15]. Then we control the vaporization rate and the concentration diffusion coefficient of the solution by managing the temperature, evaporation, and solute concentration of a solution film on the substrate. In particular, in this research, as mentioned above, we adequately control the evaporation rate on the side of the liquid film at the edge.

First, the results of the control of the thickening at the edge of the thin film after drying so far are shown below. The control is done as follows. If the integrated number of solute polymer molecules at a point on the substrate is more than (less than) α_k times the initial average during drying, the temperature of the surface of the polymer solution film over the point is perturbed upward (downward) by β_k. In addition to raising or lowering the point temperature, if the integrated number of solute polymer molecules at a point on the substrate exceeds α_k times the initial average during drying, the vaporization rate constant γ over the point is perturbed downward by γ_k . Furthermore, if the integrated number of solute polymer molecules at a point on the substrate exceeds α_k times the initial average during drying, the solute concentration of the surface of the polymer solution film over the point is perturbed downward by ξ_k^{-1} . An example of the numerical simulation results is shown in Fig. 1(a) [13]. We can confirm reduction of the thickening of the edge of the thin film after drying.

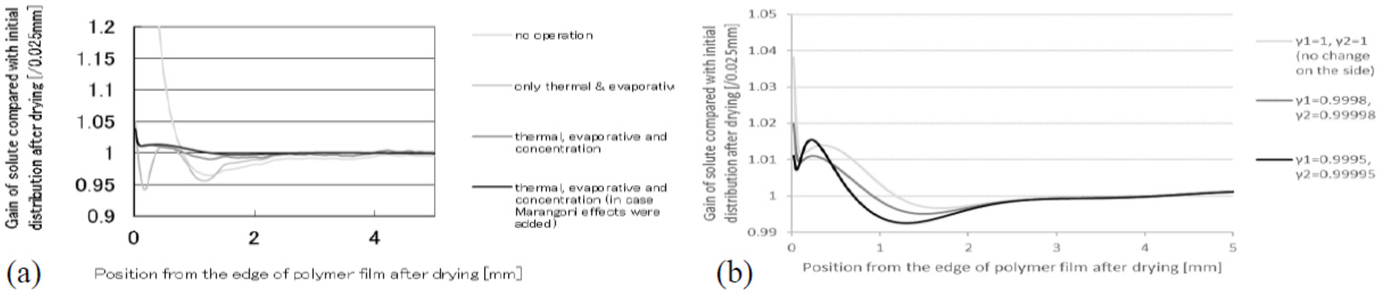

Figure 1 An example of the results of the control of the thickening at the edge of the thin film after drying by the numerical simulation of (a) the former model [13] and (b) the modified model.

III. RESULTS AND DISCUSSION

In this trial, if the integrated number of solute polymer molecules at a point on the substrate is more than 1.1 or 1.02 times the initial average during drying, the vaporization rate constant γ at the upper surface over the point is perturbed downward by 0.9999 or 0.99999 and the vaporization rate constant γ on the side of the liquid film at the edge is perturbed downward by γ_1 or γ_2 . An example of the numerical simulation results is shown in Fig. 1(b). We can confirm further reduction of the thickening of the edge of the thin film after drying.

IV. SUMMARY

In order to further reduce the thickening of the edge of the thin film after drying, we tried to adequately control the evaporation rate on the side of the liquid film at the edge. As a result, it was found that appropriate management of the evaporation rate on the side of the liquid film at the edge during drying further reduces the thickening at the edge after drying.

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