Statistical Modeling of the Pretilt Angle Control in Nematic Liquid Crystal using *In-situ* Photoalignment Method on Plastic Substrate

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In this study, the response surface modeling of the pretilt angle control using *in-situ* photoalignment method with oblique UV exposure on plastic substrate is investigated. The pretilt angle is the main factor to determine the alignment of the liquid crystal display. The response surface model is used to analyze the variation of the pretilt angle on the various process conditions. Heating temperature and UV exposure time are considered as input factors. The liquid crystal (LC) pretilt angle increased with increasing heating temperature and UV exposure time. The analysis of variance is used to analyze the statistical significance and the effect plots are also investigated to examine the relationship between the process parameters and the response.

Keywords : Response surface model, Pretilt angle, *In-situ* photoalignment method, Nematic liquid crystal, Effect plots

1. INTRODUCTION

Flexible displays based on polymer substrates for liquid crystal displays (LCDs) have several advantages compared to display using glass substrates[1]. Presently, most flexible LCDs with pretilted homogenous liquid crystal (LC) alignment are prepared using rubbed polyimide (PI) surfaces. However, rubbing causes electrostatic charges and dust. Thus, a rubbing-free method for LC alignment is required for the fabrication of LCDs. The *in-situ* photoalignment method produces a high thermal stability of LC alignment. Most recently, the LC alignment and pretilt angle generation using the *in-situ* photoalignment method on a PI surface for homogeneous alignment have been reported[2-7].

However, very few attempts have been made at the statistical modeling for the pretilt angle using photoalignment method. The statistical modeling will be able to allow us to predict the pretilt angle with respect to the varying process conditions. Therefore, the statistical modeling of the pretilt angle control can be very useful and give reliability to predict the pretilt angle.

The methodology to characterize process using the response surface model has been applied to various fields. May *et al.* used design of experiments plasma etch modeling[8]. Garling *et al.* presented enhancing the analysis of variance (ANOVA) technique to wafer processing[9]. Hu *et al.* optimized the hydrogen evolution activity on zinc-nickel deposition using statistical methodology[10].

In this paper, the pretilt angle control in the nematic liquid crystal (NLC) on the photopolymer surface is characterized by the response surface model. The input factors were explored via full factorial design with 3 levels for heating temperature and 4 levels for UV exposure time. The relationship between the response and the input factors is statistically analyzed by the ANOVA and the effect plots.

2. EXPERIMENTAL

The plastic substrates are prepared at room temperature (22 ℃). Figure 1 shows the chemical structure of the photopolymer used in this study with CH_3 moiety. The photopolymer is used as a homogeneous alignment layer and coated uniformly on the indium-tin-oxide (ITO) electrodes by a spin-coating machine. The thickness of the PI layer is set at 500 Å. The polymer surfaces are exposed to oblique UV that the energy density of UV used is 15.5 mW/cm^2. The UV exposure system is shown in Fig. 2. The UV source is a

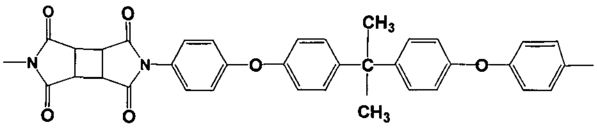

Fig. 1. The chemical structure of the photopolymer.

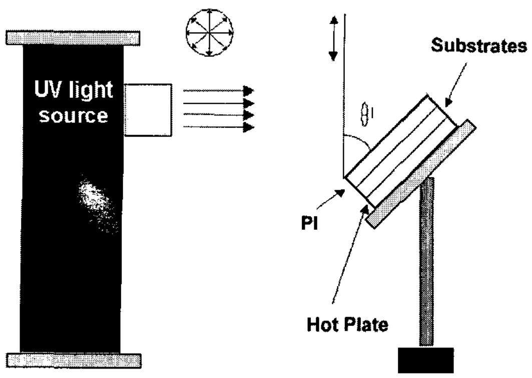

Fig. 2. The UV exposure system.

500 W Xe lamp. The polymers are exposed to obliquely polarized UV during imidization at 50~150 ℃. We use 3 levels for heating temperature and 4 levels for UV exposure time to generate different pretilt angle. A cell is fabricated as a sandwich type, and the thickness of the cell is 60 ㎛. After fabricating the cell, the NLC (T_C= 72 ℃, $\Delta\varepsilon$ = 8.2, from Merck Co.) is injected to the isotropic phase. LC cells are cooled to room temperature. The crystal rotation method is used to measure pretilt angle with TBA-701 made by autronic-MELCHERS GmbH.

3. MODELING SCHEME

Two input factors, such as heating temperature and UV exposure time, are used to analyze the variation of the pretilt angle. All experimental runs are made in random order. The experimental design matrix of input factors used in each run is summarized in Table 1.

In order to build the process model, the insignificant effects in this study are eliminated by backward elimination method under the statistical significance level is 0.1 (α = 0.1). The backward elimination method starts with the equation in which all effects are included and the insignificant effects in the model are eliminated one at a time. At any step, the variable with largest p-value, as computed from the current regression, is eliminated if this p-value exceeds a specified value[11].

Table 1. The design matrix of input factors.

Run	UV exposure time (min)	Heating temperature (℃)
1	1	50
2	1	100
3	1	150
4	6	50
5	6	100
6	6	150
7	11	50
8	11	100
9	11	150
10	16	50
11	16	100
12	16	150

Table 2. The ANOVA for the pretilt angle.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	1.7738	1.773802	0.591267	293.98	0
Linear	2	1.66978	0.351344	0.175672	87.34	0
Square	1	0.10402	0.104017	0.104017	51.72	0
Residual Error	8	0.01609	0.01609	0.002011		
Total	11	1.78989				

S = 0.04485 R-Sq = 99.1 % R-Sq(adj) = 98.8 %

The analysis of variance for the response is summarized in Table 2. P-value of the model is 0.000. It indicates that the model can explain the variation of the pretilt angle. The adjusted R-square value is 0.988. It means that 98.8 % of variation is being explained by the model.

The regression model for the pretilt angle is the following expression:

$$Y = 0.2114 + 0.0166 * time + 0.02465 * temp - 0.000079 * time * temp \quad (1)$$

Where, *Y* is the pretilt angle, the *time* is the UV exposure time and the *temp* is the heating temperature.

The modeling result exhibit a good agreement with the values between the predicted and the measured response as shown in Fig. 3.

There are three assumptions to use ANOVA, which is independence, normally distributed, and homogeneity of variance. First assumption is that each of the group is independent. Second assumption is that the values in each group of the design are normally distributed. Last assumption is that the variances in each of the group are not different from each other. Those assumptions can be verified using the residual analysis. The residual plot is illustrated in Fig. 4. The residual plot for the response is randomly distributed and there are no special patterns and features indicating that the result is satisfied with the statistical assumption for the residuals.

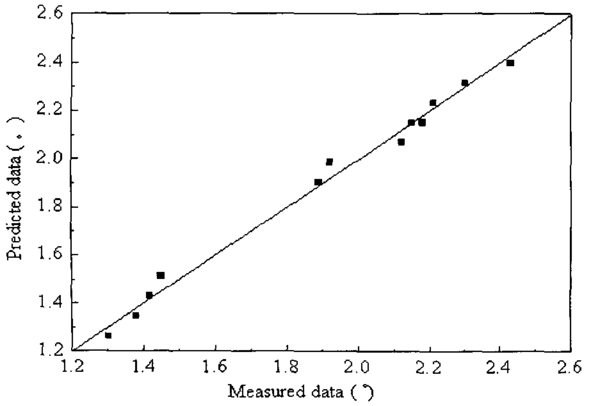

Fig. 3. The modeling result with the values between the predicted and the measured response.

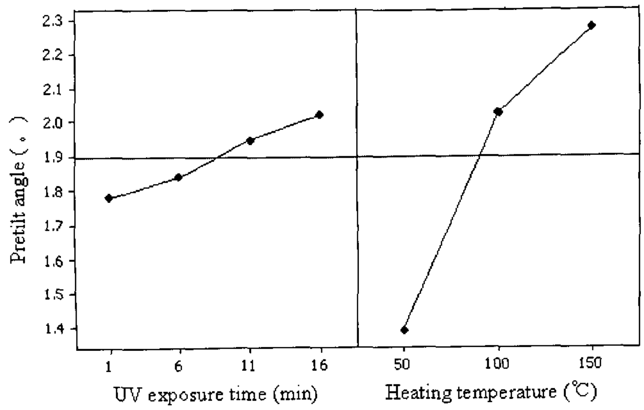

Fig. 5. The main effect plots for the UV exposure time and heating temperature.

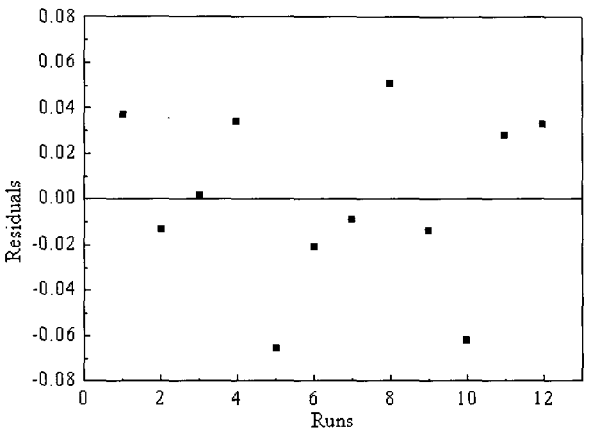

Fig. 4. The residual plot.

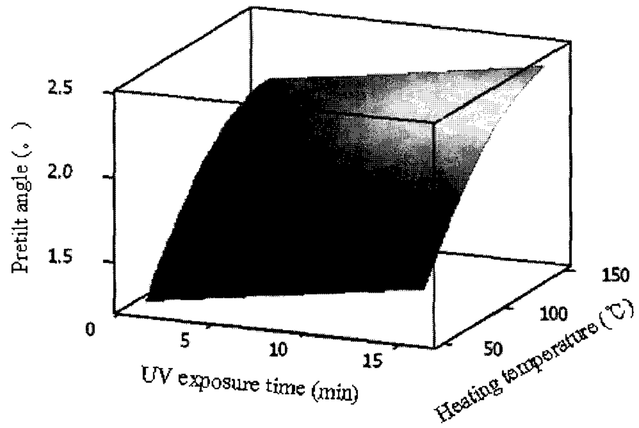

Fig. 6. The response surface plot for the pretilt angle.

4. RESULTS AND DISCUSSION

The main effect plots for the response are illustrated in Fig. 5. When the heating temperature factor is fixed in middle point, the effect of the UV exposure time plot for the pretilt angle is illustrated at the left. When the UV exposure time factor is fixed in middle point, the effect of the heating temperature plots for the pretilt angle is illustrated at the right. The main effect plots show that the pretilt angle is increased when the UV exposure time or the heating temperature is increased.

The response surface plot of the pretilt angle according to the change of the UV exposure time and the heating temperature is illustrated in Fig. 6. The smallest pretilt angle is generated applying the shortest UV exposure time and the lowest heating temperature on the PI surfaces. In a similar fashion, the largest pretilt angle is generated applying the longest UV exposure time and the highest heating temperature on the PI surfaces. As a consequence, it is very informative for the control of the pretilt angle. The response surface plot of the pretilt angle can give the solution to make wanted pretilt angle.

5. CONCLUSION

The control of the pretilt angle in NLC on the photopolymer surface as a function of the heating temperature and UV exposure time is investigated via the response surface modeling. The statistical significance factors are determined by ANOVA and those effects are compared with that of the varying process conditions, and are analyzed by the effect plots.

The response surface modeling is in an agreement with the experimental data and represents a comprehensive characterization of the pretilt angle. The *in-situ* photoalignment method was obtained better LC aligning capability than conventional photoalignment method without heating temperature. It is considered that the heating temperature of substrate is attributed to generate pretilt angle. Also, the LC pretilt angle increased with increasing heating temperature and UV exposure time.

From the results, the model will be able to allow us to predict the pretilt angle with respect to the varying process conditions. As a result, the statistical modeling of the pretilt angle control is very useful and gives reliability to predict the pretilt angle.

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REFERENCES

[1] J.-Y. Hwang, K.-H. Nam, J.-H. Kim, D.-S. Seo, and D.-H. Suh, "Characterization and alignment properties on polyimide surface using polymer films for flexible liquid crystal displays", Jpn. J. Appl. Phys., Vol. 43, No. 12, p. 8179, 2004.

[2] J.-Y. Hwang, D.-S. Seo, J.-Y. Kim, and T.-H. Kim, "Aligning capabilities of nematic liquid crystal on photopolymer-based N-(phenyl)maleimide homo-polymers", Jpn. J. Appl. Phys., Vol. 42, No. 1, 2003.

[3] J.-Y. Kim, J.-Y. Hwang, T.-H. Kim, D.-S. Seo, and J.-U. Lee, "Liquid crystal alignment effect on the photopolymer surface using an acrylate unit photopolymerized by a photo-inititor", Jpn. J. Appl. Phys., Vol. 42, No. 1AB, p. L54, 2003.

[4] J.-Y. Hwang, Y.-M. Jo, D.-S. Seo, and J. Jang, "Liquid crystal alignment capability by the UV alignment method on a-C:H thin films", Jpn. J. Appl. Phys., Vol. 42, No. 2A, p. L114, 2003.

[5] J.-Y. Hwang, D.-S. Seo, J.-Y. Kim, and T.-H. Kim, "Liquid crystal alignment and pretilt angle generation on a photopolymer layer based on N-(phenyl)maleimide", Liquid Crystals, Vol. 29, No. 8, p. 1047, 2002.

[6] J.-Y. Hwang, D.-S. Seo, and E.-J. Hahn, "Electro-optical characteristics of photo-aligned vertical-alignment cells on photo-crosslinkable copolymer surfaces containing cholesteryl moiety", Liquid Crystals, Vol. 29, No. 4, p. 567, 2002.

[7] J.-Y. Hwang, Y.-B. Kim, and D.-S. Seo, "Liquid crystal aligning capabilities on new photo-crosslinkable polyimide based polymer by the photodimerization method", Ferroelectrics, Vol. 278, p. 127, 2002.

[8] G. S. may, J. Huang, and C. J. Spanos, "Statistical experimental design in plasma etch modeling", IEEE Trans. Semiconduct. Manufact., Vol. 4, p. 83, 1991.

[9] L. K. Garling and G. P. Woods, "Enhancing the analysis of variance (ANOVA) technique with graphical analysis and its application to wafer processing equipment", IEEE Trans. Comp., Hybrids, Manufact. Technol., Vol. 17, p. 149, 1994.

[10] C. Hu, C. Tsay, and A. Bai, "Optimization of the hydrogen evolution activity on zinc-nickel deposits using experimental strategies", Electrochimica Acta, Vol. 48, p. 907, 2003.

[11] R. R. Hocking, "The analysis and selection of variables in linear regression", Biometrics, Vol. 32, p. 1, 1976.