Statistical Modeling of Pretilt Angle Control using Ion-beam Alignment on Nitrogen Doped Diamond-like Carbon Thin Film

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The response surface modeling of the pretilt angle control using ion-beam (IB) alignment on nitrogen doped diamond-like carbon (NDLC) thin film layer is investigated. This modeling is used to analyze the variation of the pretilt angle under various process conditions. IB exposure angle and IB exposure time are considered as input factors. The analysis of variance technique is settled to analyze the statistical significance, and effect plots are also investigated to examine the relationships between the process parameters and the response. The model can allow us to reliably predict the pretilt angle with respect to the varying process conditions.

Keywords : Response surface model, Pretilt angle, Nitrogen doped DLC (NDLC), Ion beam (IB) alignment, Nematic liquid crystal (NLC)

1. INTRODUCTION

Liquid crystals (LCs) are widely used in flat panel display (FPD) technology. The pretilt angle is the main factor that determines the alignment of the liquid crystal display (LCD). Rubbed polyimide surfaces have suitable characteristics such as uniform alignment and a high pretilt angle[1-4]. However, the rubbing method has some drawbacks. Thus a non-contact alignment technique would be highly desirable for future generations of large, high-resolution LCDs. A number of alternative alignment techniques have been reported, but none of these have so far been implemented in large-scale manufacturing. Nitrogen doped DLC (NDLC) thin films have properties of high mechanical hardness, high electrical resistivity, low friction coefficient, optical transparency and chemical inertness.

However, very few attempts have been made to statistically model the pretilt angle using ion-beam (IB) alignment. The statistical modeling will allow us to reliably predict the pretilt angle with respect to the varying process conditions. Therefore, the statistical modeling of the pretilt angle control will be very useful. The methodology of characterizing the process using the response surface model has been applied to various fields. May *et al.* used it to design plasma etch modeling experiments[5]. Garling and Woods applied the analysis of variance (ANOVA) technique to wafer processing[6]. Hu *et al.* optimized the hydrogen evolution activity on a zinc-nickel deposition using a statistical methodology[7].

In this study, the pretilt angle control using IB alignment on NDLC thin film layer is characterized by the response surface model. The relationships between the response and the input factors are statistically analyzed using ANOVA and effect plots.

2. EXPERIMENTAL

NDLC thin films are deposited on indium-tin-oxide (ITO)-coated glass substrates by plasma enhanced chemical vapor deposition. ITO coated glass substrates of dimensions 307 mm × 217 mm × 1.1 mm are used. The substrates are pre-sputtered for 10 minutes using the Ar plasma in the chamber. The NDLC thin film is deposited using C_2H_2 : He : N_2 gas for 30 seconds in order to settle the working pressure the total flux is 33 sccm. Namely, as the flow amount of N_2 is increased, that of He is correspondingly decreased as the same rate. However, the quantity of C_2H_2 is fixed.

The thickness of NDLC thin film layer is about 10 nm. We show a Kaufman type IB exposure system in Fig. 2. The NDLC thin films are bombarded by an Argon IB. The energy, integrated dose, and the angle of the substrate plane with respect to the IB are varied. After the NDLC deposited substrates are bombarded by the IB, cells are arranged in an anti-parallel configuration, which is used for pretilt angle measurements. Two substrates are assembled together and filled with a nematic liquid crystal (NLC) (T_c = 72°C, $\triangle\varepsilon$ =8.2, MJ001929 from

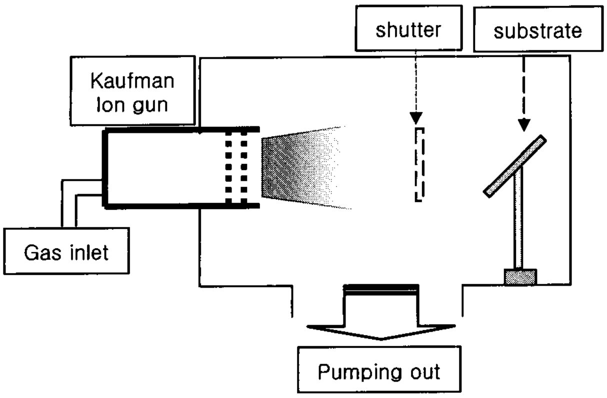

Fig. 1. The Kaufman Type Ar ion gun exposure system.

Merck Co.). The thickness of the LC cells for pretilt test sample is 60 μm. The pretilt angle of anti-parallel cell is measured by a crystal rotation method. LC alignment effects are observed using a polarized microscope.

3. RESULTS AND DISCUSSION

Two input factors, IB exposure angle and IB exposure time, are used to analyze the variation of the pretilt angle. The input factors are explored via full factorial design with five levels for IB exposure angle and three levels for IB exposure time. Three more center points were added. These replications can be used for the "lack of fit" test, which determine whether the selected region is too large to be approximated by a quadratic equation. All experimental runs are made in random order. The experimental design matrix of the input factors used in each run is shown in Table 1.

A quadratic model is used as the basic model. The quadratic model, having an intercept, two main effects, two square effects, and one two-factor interaction, is defined as

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1^2 + \beta_4 X_2^2 + \beta_5 X_1 X_2 \qquad (1)$$

where Y is the response value, β_i are the model coefficients, and X_i are the process factor values.

To build the process model, the insignificant effects in this study are eliminated by backward elimination method under the statistical significance level of 0.01 (= 0.01). Significant factors are listed in Table 2. P-values of each factor are 0.000. It indicated that significant factors are very significant. The backward elimination 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 the largest p-value, as computed from the current regression, is eliminated if this p-value exceeds a specified value[8].

Table 1. Design matrix of input factors.

Run	IB exposure time (s)	IB exposure angle (°)
1	60	15
2	60	30
3	60	45
4	60	60
5	60	75
6	120	15
7	120	30
8	120	45
9	120	60
10	120	75
11	120	45
12	120	45
13	180	45
14	180	15
15	180	30
16	180	45
17	180	60
18	180	75

Table 2. The summary of the statistical significance.

Term	Coef	SE Coef	T	P
constant	2.61462	0.508733	5.139	0.000
time	-0.01858	0.002004	-9.272	0.000
angle	0.34016	0.021596	15.752	0.000
angle*angle	-0.00375	0.000234	-15.995	0.000

The analysis of variance of the response is summarized in Table 3. The p-value of the model is 0.000. This indicates that the model can explain the variation of the pretilt angle. The adjusted R-square value is 0.952. This means that 95.2 % of the variation is explained by the model.

The regression model for the pretilt angle is

$$Y = 2.61462 - 0.01858 * time + 0.34016 * angle - 0.00375 * angle * angle \qquad (2)$$

Where *Y* is the pretilt angle, *time* is IB exposure time and *angle* is IB exposure angle.

There are three assumptions made using ANOVA, which are independence, a normally distribution, and the homogeneity of variance. The first assumption is that the groups are mutually independent. The second assumption is that the values in each group of the design are normally distributed. The last assumption is that the variances in each of the groups are equal. These assumptions can be verified using residual analysis. The residual plot is shown in Fig. 2. The residual plot of the

Table 3. ANOVA for pretilt angle.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	49.4786	49.4786	16.4929	114.05	0.000
Linear	2	12.4843	48.3107	24.1553	167.04	0.000
Square	1	36.9942	36.9942	36.9942	255.83	0.000
Residual Error	14	2.0245	2.0245	0.1446		
Lack-of-Fit	11	2.017	2.017	0.1834	73.59	0.002
Pure Error	3	0.0075	0.0075	0.0025		
Total	17	51.5031				

response is randomly distributed and there are no special patterns or features, indicating that the result satisfies the statistical assumptions for the residuals. The modeling result exhibits a good agreement between the predicted and the measured response values, as shown in Fig. 3.

Figure 4 shows microphotograph of the aligned NLC using IB alignment on NDLC thin film layer, when the quantity of C_2H_2, He and N_2 gas is 3 sccm, 0 sccm and 30 sccm. This sample is exposed to 200 eV ion beams at 45° of exposure angle for 120 second of exposure time. Good LC alignment of the NDLC thin film is achieved.

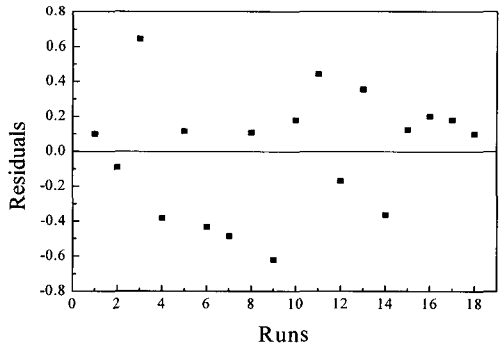

Fig. 2. Residual plot.

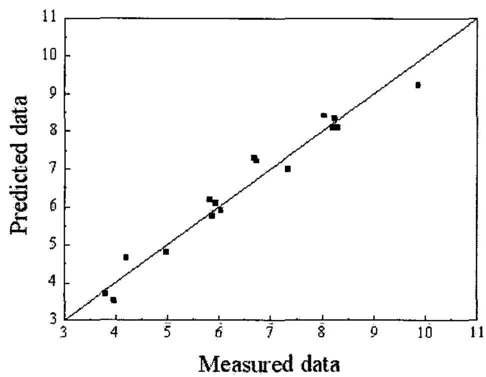

Fig. 3. Modeling result showing predicted and measured response values.

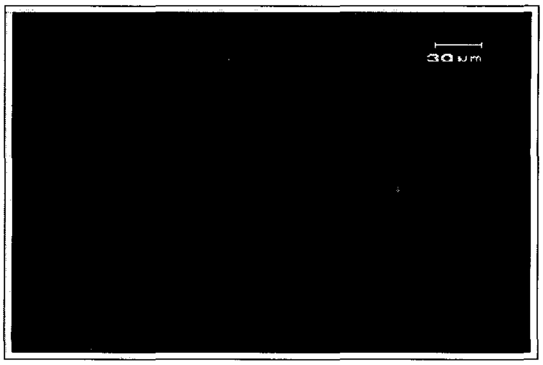

Fig. 4. Microphotograph of IB-aligned LC cell on NDLC thin film.

The effect plots of the response are shown in Fig. 5. The effect of the IB exposure time on the pretilt angle is shown on the left. The effect of the IB exposure angle on the pretilt angle is shown on the right. As the IB exposure time is increased, the pretilt angle is decreased and stabilized in Fig. 5(a). IB irradiation contributes to the generation of the pretilt angle. Because IB irradiation causes the increase of surface roughness and the decrease of the thickness of the NDLC thin film[9]. Figure 5(b) shows a plot of the pretilt angle variation as a function of incident angle of IB. The pretilt angle is maximum at 45° . The pretilt angle gradually decreased with becoming more distant from 45° .

The response surface plot of the pretilt angle as a function of the IB exposure angle and IB exposure time is shown in Fig. 6. The smallest pretilt angle is generated applying the longest IB exposure time, and the lowest or largest IB exposure angle. Similarly, the largest pretilt angle is generated by applying the shortest IB exposure time and the middle IB exposure angle. As a consequence, this is very informative for the control of the pretilt angle. The response surface plot of the pretilt angle can provide the conditions for setting the desired pretilt angle.

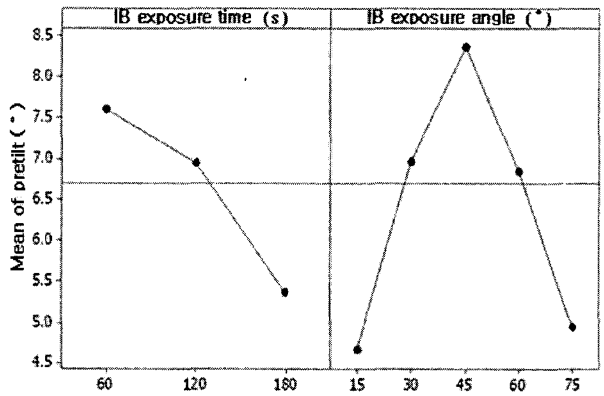

Fig. 5. Main effect plots of IB exposure time and IB exposure angle.

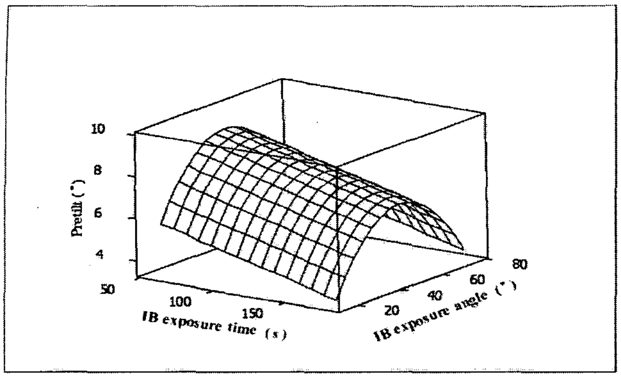

Fig. 6. Response surface plot of pretilt angle.

4. CONCLURION

In conclusion, the control of the pretilt angle using IB alignment on NDLC thin film layer as a function of the IB exposure angle and IB exposure time is investigated via response surface modeling. The statistically significant factors are determined by ANOVA and these factors are compared with those of the varying process conditions, and are analyzed using effect plots. The response surface modeling is in agreement with the experimental data and represents a comprehensive characterization of the pretilt angle. LC pretilt angle decreased with getting away from 45 ° of IB exposure angle. Also, LC pretilt angle decreased with increasing IB exposure time. From the results, the model allows us to reliably predict the pretilt angle with respect to the varying process conditions. As a result, the statistical modeling of the control of the pretilt angle is very useful.

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