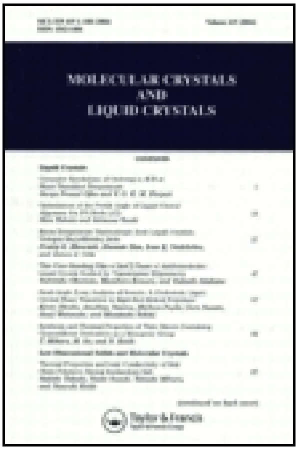

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According to the advent of ubiquitous world, the requirement for the mobile information devices with high display quality and compact device size is surprisingly increased. Among the diverse candidates for this mobile display system for mobile devices, Liquid Crystal on Silicon (LCoS) is the most competitive device due to the high aperture ratio and simple fabrication process. The inorganic liquid crystal (LC) alignment layers are widely used for LCoS devices because of the thermal and photochemical stability. In this work, the reactive sputtering was selected for the preparation method of inorganic LC alignment layers. The nitrogen (N_2) gas had the effect on the deposition process of SiO_2 and the surface morphology of SiO_2 thin layers were affected by the N_2 mixing ratio of sputtering gas. In addition, the LC alignment properties on SiO_2 thin layer were also closely related with the N_2 mixing ratio and other sputtering conditions. In the case of high RF power of reactive sputtering, the N_2 mixing ratio has little effect on the LC alignment on SiO_2 thin layers. However, in the case of low RF power of reactive sputtering, the LC alignment properties were enfeebled by increasing the N_2 mixing ratio. This result might be attributed to the change of the surface morphology of inorganic SiO_2 thin layers.

Keywords: inorganic thin film; liquid crystals alignment; reactive sputtering; SiO_2

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I. INTRODUCTION

Liquid Crystals on Silicon (LCoS) microdisplays are widely used for various projection and near-eye application systems [1]. The LCoS device requires higher thermal and photochemical stability due to the high power light source of projection system. Contrary to the conventional active matrix liquid crystal display (AMLCD), LCoS panel works under severe circumstances such as high temperature and intense light irradiation due to the higher power light source compared with conventional AMLCD. For conventional AMLCD, rubbed polyimide is generally used for the LC alignment layer due to the good LC alignment properties and the higher thermal stability. However, polyimide is well known for poor photochemical stability and therefore the polyimide LC alignment layer is not suitable for the LCoS panel. In order to overcome the photochemical stability problem of conventional polyimide LC alignment layer, an inorganic LC alignment layer was raised for the candidate for the LCoS panel and there are many reports on the LCoS system based on the inorganic LC alignment layer [2–5]. There are some publications on the phenomenon of LC orientation on the inorganic thin film [5,6]. However, there is little study on the effect of the processing condition of the RF-magnetron sputtering on the surface properties of an inorganic thin film and the relationship between the surface properties and the LC orientation of the inorganic thin film.

In our work, we have focused on the preparation method of SiO_2 inorganic thin layer. The reactive sputtering was well known for the deposition method for the modification of the surface properties of the inorganic layer. We deposited the SiO_2 inorganic thin layer by using the reactive sputtering method and evaluated the SiO_2 inorganic thin layer for the LC alignment layer. The surface characterization of the SiO_2 inorganic thin layer prepared by the reactive sputtering was performed. The LC orientation on the SiO_2 inorganic thin layer was also observed. Finally the relationship between the surface properties and the LC alignment properties of inorganic SiO_2 thin layer prepared by reactive sputtering was investigated.

II. EXPERIMENTAL DETAILS

SiO_2 thin layer was coated on the indium-tin-oxide (ITO) coated glass by RF-magnetron sputtering. Base pressure of chamber was around 10^{-6} Torr and the working pressure was 20 mTorr. Pure Ar (99.9999%) and N_2 gas mixture was used for the sputtering gas in the chamber. The RF power was controlled to 100 and 200 W.

The distance between a target and a substrate is 12 cm and the incidence angle of the sputtering is 67.5°. Figure 1 shows the schematic diagram of the RF-magnetron sputtering system. The deposition rate of reactive sputtering was known to be lower that that of normal sputtering [7]. Therefore the sputtering time of each SiO_2 thin layer was adjusted from 200s to 1200s in order to maintain the thickness of SiO_2 layers from 100 Å to 200 Å. The sample stage of sputter was not rotated during the sputtering process in order to generate the structural anisotropy of SiO_2 inorganic thin layer. The thickness of the SiO_2 thin layer was measured by using Alpah-Step IQ (KLA Tencor, USA) surface profiler. The surface morphology of SiO_2 thin layer was observed by using atomic force microscopy (AFM) NANOStation HD (SIS, Germany) combined with an image processor (SPIP, version 2.3, Image Metrology, Denmark) was used to determine the respective surface roughness.

The LC cell was prepared using two SiO_2 coated ITO glasses and LC was injected to the cell by capillary method. Nematic LC E7 (Merck, Germany) was used for LC cell preparation. LC cell was fabricated with anti-parallel configuration in order to measure the azimuthal anchoring energy of LC alignment layers and the order parameter of LC. Polarized microscope images were observed to measure the azimuthal anchoring energy of LC alignment layer. The polar plot was obtained by measuring the transmittance of light at 532 nm passing through the rotating LC cell between two cross polarizers.

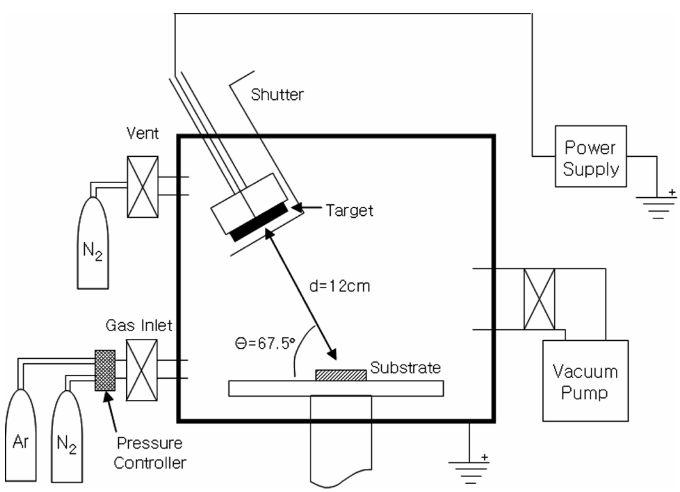

FIGURE 1 Schematic diagram of RF-magnetron sputtering system.

In order to compare the degree of LC ordering on the SiO_2 thin layer, the order parameter of LC was also calculated.

III. RESULTS AND DISCUSSION

For the reactive sputtering of SiO_2 thin layer, various gases, such as hydrogen (H_2), oxygen (O_2), N_2, are well known to be used for the sputtering gas mixed with argon gas. In our work, N_2 was selected for the sputtering gas for reactive sputtering. RF power of sputtering, sputtering pressure and time were selected for the major control factors for reactive sputtering. RF power is well known to be related with the plasma energy and the working pressure has the effect on both of the ion current density of plasma and the scattering behavior of activated target atoms. The sputtering condition was divided into two main groups according to the RF power, 100 W and 200 W. The sputtering pressure and time were controlled in each group. The detailed reactive sputtering condition of SiO_2 thin layer was summarized at Table 1.

The properties of the inorganic thin layer prepared by the reactive sputtering would be dominantly affected by the sputtering condition. First, the thickness of inorganic thin layer and the deposition rate were observed and the relationship between the deposition rate of the inorganic layer and the sputtering condition was investigated. Figure 2(a) shows the thickness of SiO_2 thin layer according to the sputtering condition. With increasing the N_2 mixing ratio of sputtering gas, the amount of deposited SiO_2 was decreased and the thickness of SiO_2 thin layer also would be decreased. The deposition rate of sputtered SiO_2 thin layer was shown in Figure 2(b). The deposition rate of SiO_2 thin layer by reactive sputtering was much lower that of normal sputtering. Regardless of RF power, the deposition rate of reactive sputtering was one third of that of normal sputtering.

TABLE 1 Sputtering Conditions of SiO_2 Thin Layer

No.	RF power (W)	Working pressure (mTorr)	N_2 ratio (Vol.%)	Sput. time (sec)
1	200	20	0	200
2	200	20	10	600
3	200	20	20	600
4	200	20	30	600
5	100	20	0	400
6	100	20	10	1200
7	100	20	20	1200
8	100	20	30	1200

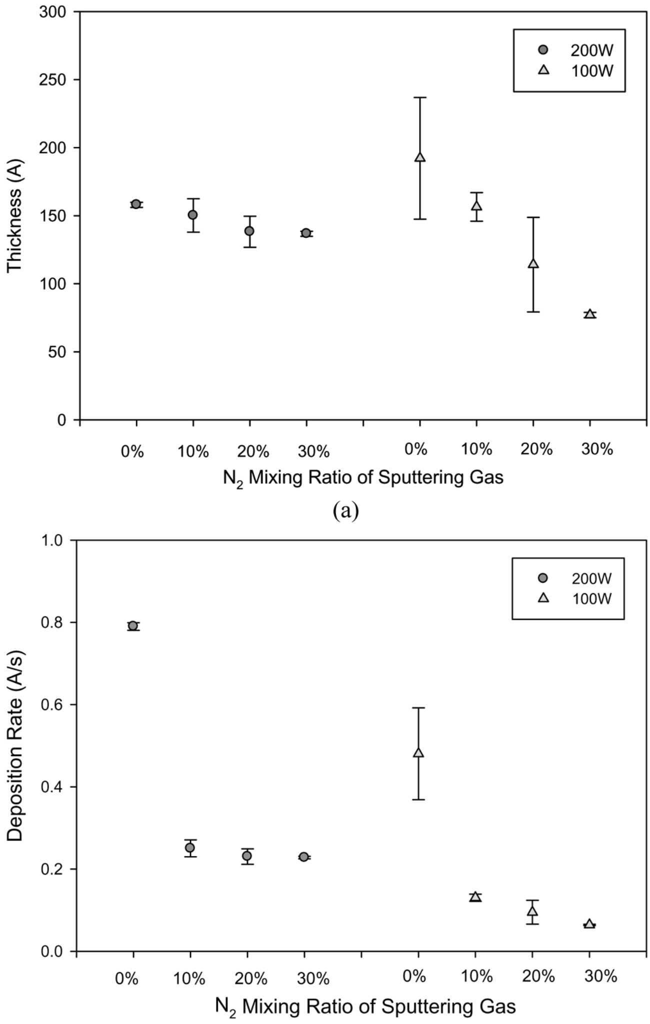

FIGURE 2 (a) Thickness of SiO_2 thin layer, (b) deposition rate of SiO_2 thin layer as a function of N_2 mixing ratio of sputtering gas.

The decrease in the deposition rate is due to a chemisorbed layer of reactive gases formed on the target surface during sputtering and to the change in plasma characteristics caused by mixing the reactive gas with sputtering gas [8].

The ordering of LC molecules on the LC alignment layer is the result of the interaction between the LC molecules and the LC alignment layer. Therefore the surface morphology of the LC alignment layer could be the considerable factor for LC ordering. In our work, the SiO_2 thin layers deposited by reactive sputtering with various sputtering condition were prepared and the surface morphology of SiO_2 thin layers was investigated. First, the surface morphology of SiO_2 thin layer was observed by AFM. Figure 3 shows the surface

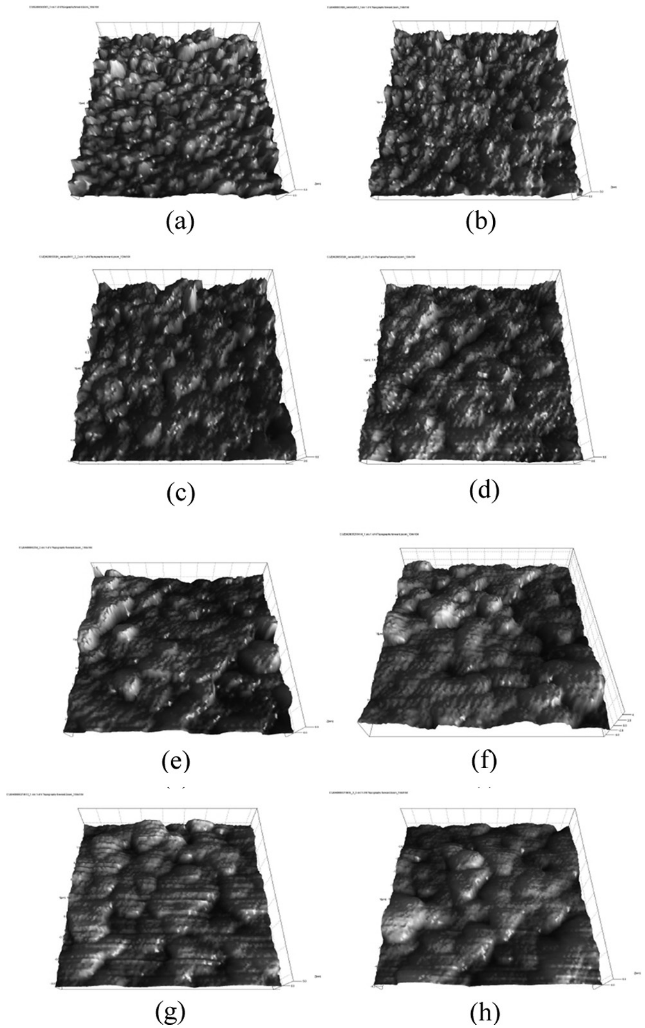

FIGURE 3 AFM images of SiO_2 thin layer prepared by reactive sputtering: a–h correspond to samples 1–8, respectively (Table 1).

morphology of sputtered SiO_2 thin layer. First of all, it could be seen that the grain structure of the surface of SiO_2 thin layer was definitely different for each case of RF power of reactive sputtering. The grain structure of SiO_2 thin layer sputtered by 200 W RF power showed smaller grain size compared with that of 100 W RF power. The smaller grain size of SiO_2 thin layer sputtered by 200 W RF power might be attributed to the higher ion bombardment due to the high RF power of sputtering. In the case of SiO_2 thin layer sputtered by the same RF power, the grain size of SiO_2 thin layer was increased by increasing the N_2 mixing ratio of sputtering gas. The N_2 molecules in the sputtering gas might be the hindrance for the bombardment of activated target atoms on substrate. Therefore the ordering of target atoms on substrate might be diminished and the grain size might be increased. In addition, the increase of the grain size of SiO_2 was observed regardless of RF sputtering power.

In order to investigate the surface roughness of SiO_2 thin layer, the respective surface roughness of SiO_2 thin layer was obtained by using image processing software, SPIP. Figure 4 shows the surface roughness of the reactively sputtered SiO_2 thin layer. The surface roughness of SiO_2 thin layer was increased with increasing the N_2 mixing ratio of sputtering gas. This result is in accordance with the previous work on the reactive sputtering of SiO_2 thin layer for semiconductor devices [7]. By the way, unlike the grain structure of the surface of SiO_2 thin

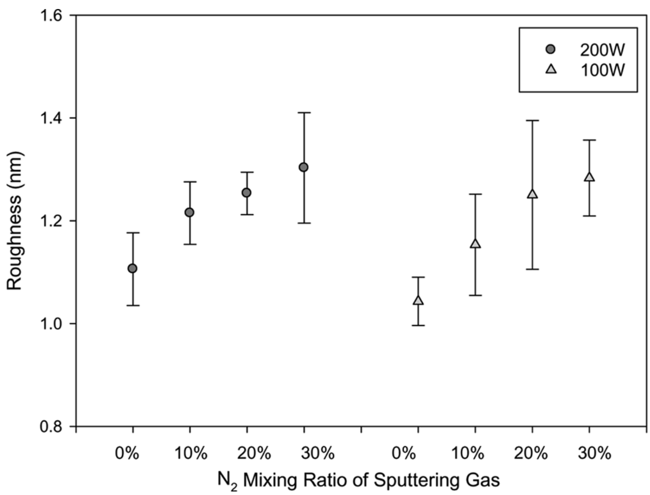

FIGURE 4 Surface roughness of SiO_2 thin layer as a function of N_2 mixing ratio of sputtering gas.

layer, the surface roughness of SiO_2 thin layer was irrelevant to the RF power of reactive sputtering. From the study on the surface morphology of reactively sputtered SiO_2, it would be concluded that the surface morphology could be controlled by modifying the RF power and N_2 mixing ratio of sputtering gas.

From above results, it was possible to prepare the SiO_2 thin layers with various surface morphologies by controlling the sputtering condition. Following the preparation of SiO_2 thin layer, the behavior of LC orientation on the SiO_2 thin layer was studied. First, the azimuthal anchoring of SiO_2 thin layer was investigated. In order to measure the azimuthal anchoring energy of SiO_2 thin layer, the polarized optical microscope image of LC cell were observed. The width of Neel wall was measured and the azimuthal anchoring energy was calculated by the physical theory [9]. Figure 5 shows the azimuthal anchoring energy of SiO_2 thin layer according to the N_2 mixing ratio of sputtering gas. The azimuthal anchoring energy of SiO_2 thin layer sputtered by 200 W RF power was higher than that of 100 W RF power, which means that the smaller grain size of the SiO_2 thin layer would be suitable for the strong azimuthal anchoring of nematic LC. Regardless of RF power of reactive sputtering, the azimuthal anchoring energy was decreased with increasing the N_2 mixing ratio of sputtering gas. The more the grain size of SiO_2 thin layer becomes smaller, the more the azimuthal anchoring energy of nematic LC on the SiO_2 thin layer

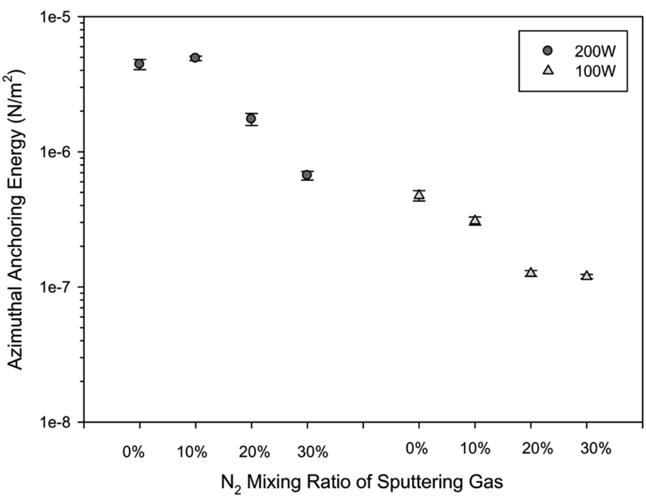

FIGURE 5 Azimuthal anchoring energy of SiO_2 thin layer as a function of N_2 mixing ratio of sputtering gas.

increases. The primary driving force of LC alignment on the deposited SiO_2 thin layer might be the orientation of LC molecules by the surface groove structure of SiO_2 thin layer. In the case of the SiO_2 thin layer with smaller grain size, the LC molecules could be anchored on the surface of SiO_2 thin layer more easily and the azimuthal anchoring energy might be higher. On the other hand, the surface roughness of SiO_2 thin layer showed the contrary relationship with the azimuthal anchoring energy according to the RF power of reactive sputtering. From the result of azimuthal anchoring energy, it was found that

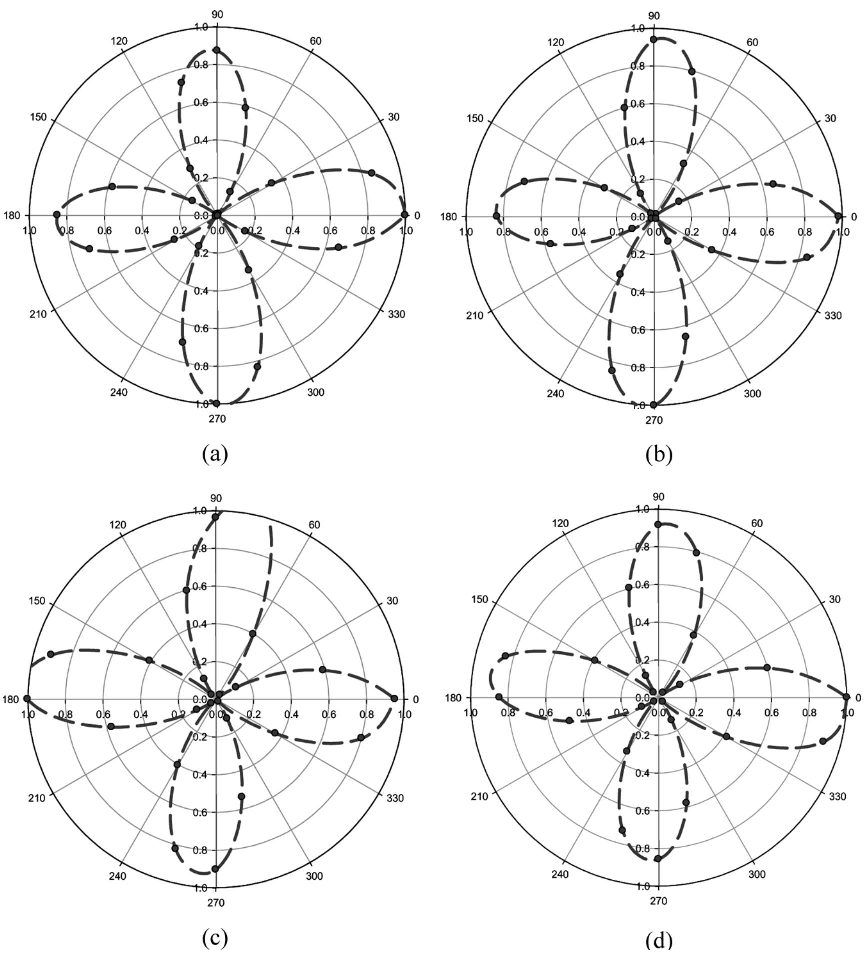

FIGURE 6 Polar plot of transmittance of LC cell made of SiO_2 thin layer sputtered by 200 W RF power: (a) 1, (b) 2, (c) 3, (d) 4.

the azimuthal anchoring of nematic LC on SiO_2 thin layer is closely related with the grain structure of SiO_2 thin layer. The smaller grain is preferable for the strong azimuthal anchoring of nematic LC on SiO_2 thin layer.

In order to investigate the LC ordering on the SiO_2 thin layer, the polar plot of light transmittance with cross-polarizer was obtained. Figure 6 shows the polar plot of the transmittance of light at 542 nm passing through the LC cell placed between polarizers. The transmittance was divided by the maximum transmittance value for the

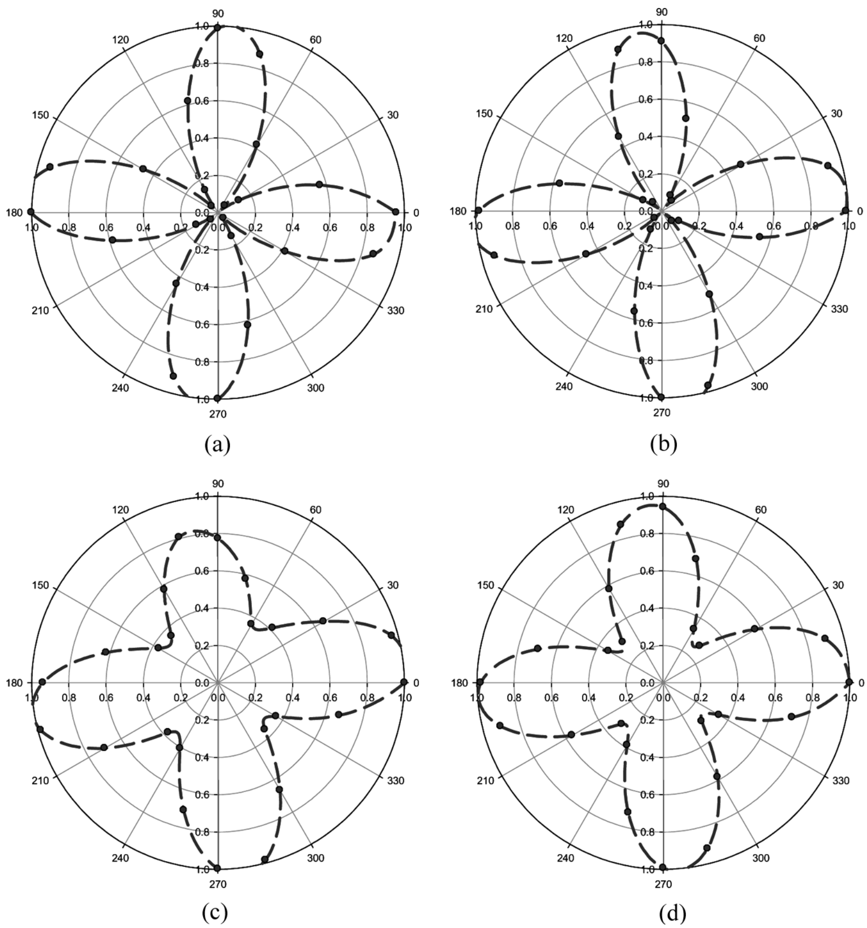

FIGURE 7 Polar plot of transmittance of LC cell made of SiO_2 thin layer sputtered by 100 W RF power: (a) 5, (b) 6, (c) 7, (d) 8.

relative comparison of the LC ordering for each cell. Figures 6 and 7 shows the polar plot of transmittance of LC cells of 200 W and 100 W RF power placed between polarizers. All of sample show the typical polar plot of transmittance of nematic LC cell, which shows the highest transmittance at 0° and 90°, the lowest transmittance at 45°. From this result, it was found that the SiO_2 thin layer induces the LC ordering regardless of the reactive sputtering condition of SiO_2 layer. However, the value of minimum transmittance was different according to the sputtering conditions and this might be closely related with the degree of LC ordering. The LC cell sputtered by 200 W RF power showed the lower transmittance compared with that of 100 W RF power, which means that the LC ordering on the SiO_2 thin layer sputtered by 200 W RF power is higher than that of 100 W RF power.

In order to compare the LC ordering on SiO_2 thin layer more precisely, the parameter of Lc quality was calculated. The equation of parameter of LC quality S is

$$S = (1 - T_{\min})/(1 + T_{\min})$$

where $T_{\min}$ means the minimum relative transmittance. Figure 8 shows the parameter of LC quality of the LC cell prepared by using the SiO_2 thin layer. In accordance with the result of azimuthal

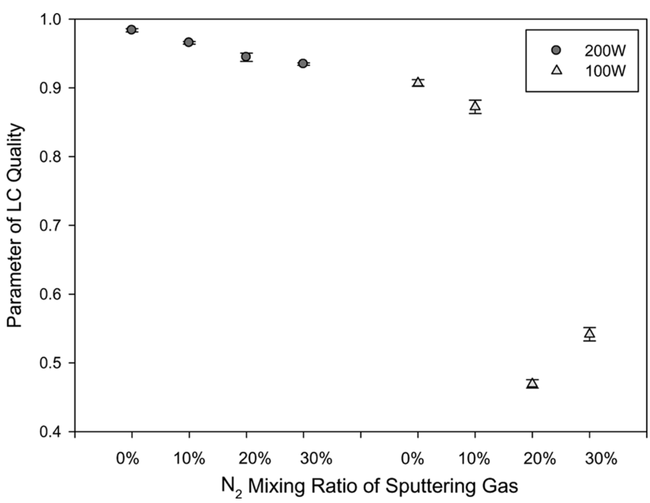

FIGURE 8 Parameter of LC quality of SiO_2 thin layer as a function of N_2 mixing ratio of sputtering gas.

anchoring energy, 200 W RF power series shows the higher parameter of LC quality compared with 100 W RF power series. In addition, the parameter of LC quality was decreased by increasing the N_2 mixing ratio of sputtering gas. Especially, the parameter of LC quality of SiO_2 thin layer Nos. 7 and 8 was remarkably lower that that of others. From the surface morphology image of the SiO_2 thin layer, it was found that the grain size of the SiO_2 thin layer Nos. 7 and 8 was extraordinarily larger than that of others. The decreased LC ordering of the SiO_2 thin layer Nos. 7 and 8 might be attributed to the large grain size of SiO_2.

From the results of azimuthal anchoring energy and the parameter of LC quality of SiO_2 thin layer, it could be concluded that the RF power of reactive sputtering and N_2 mixing ratio of sputtering gas might be closely related with the LC ordering on the SiO_2 thin layer. The surface morphology of SiO_2 thin layer was affected by the reactive sputtering condition and the difference of surface morphology could induce the change of LC alignment properties on the SiO_2 thin layer.

IV. CONCLUSION

In our work, the detailed study on the relationship between the reactive sputtering condition of SiO_2 thin layer and the orientation of LC molecules on the SiO_2 thin layer was carried out. It was found that the reactive sputtering condition of an inorganic thin layer was the important factor for the control of the surface morphology of the inorganic thin layer and the surface morphology was also closely related with the azimuthal anchoring and the ordering of LC molecules. Our work might be very helpful for the practical application of an inorganic thin film for the LC alignment layer to LCoS applications and also could be helpful for the study on the behavior of LC molecules on the inorganic thin layer.

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