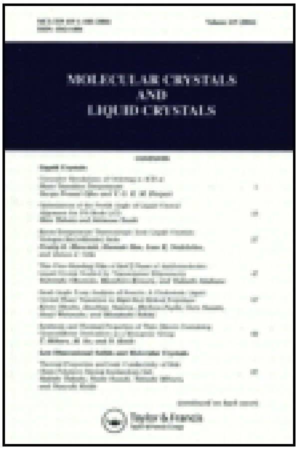


## Molecular Crystals and Liquid Crystals

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# Alignment and Electro-Optic Properties of SSFLC Cells Aligned by Obliquely Evaporated SiO Films

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# Alignment and Electro-Optic Properties of SSFLC Cells Aligned by Obliquely Evaporated SiO Films

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Alignment and electro-optic properties of SSFLC cells aligned by 85° obliquely evaporated SiO films are investigated. The vacuum condition of the SiO evaporation was found to have a great effect on the alignment. The SiO film evaporated in a high vacuum gives a poly-domain alignment which is reformable into a mono-domain by the application of a strong electric field. The cell with the reformed alignment shows an almost perfect memory and a high contrast in a specific temperature range, which suggests that the cell is aligned in the so-called "uniform" state. A cell with the SiO film by low vacuum evaporation shows an imperfect memory and a very low contrast. The alignment of this cell is confirmed to be in the "twisted" state. The strong electric field gives no influence on the alignment of this cell. Possible relation between the obtained alignment and the observed SiO columnar structure is discussed.

*Keywords: ferroelectric, alignment, SiO films, display*

## INTRODUCTION

The zig-zag defect in SSFLC cells is still one of the serious obstacles for SSFLCD to be commercialized. It has been revealed that the defect originates in the so-called Chevron structure through many investigations on the layer structure[1] and switching process[2] of SSFLC cells. Recently, two kinds of methods have been attempted to eliminate such a defect. Yamamoto[3] rubbed newly developed polyimide which gives a high pre-tilt to FLC molecules and obtained the defect-free cells. He concluded that a splayed state of *n*-director in a chiral nematic phase by the high pre-tilt brings about the sole direction of the Chevron in a chiral smectic C phase. Sato[4] and Bawa[5] eliminated the defect by applying a strong electric field to the cells aligned by rubbed aminosilane and polyamide, respectively. They suggested that the layer structure can be reformed by strong electric field application.

It is known that 85° obliquely evaporated SiO films give a high pre-tilt to FLC molecules. We investigated the alignment and electro-optic properties of SSFLC cells aligned by the SiO films and studied the effect of strong electric field application on the alignment. It is also discussed in this paper that the above-mentioned effect depends on the vacuum condition of SiO evaporation.

## EXPERIMENTAL

Figure 1 shows the set up of cell fabrication process. We used 1.1 mm thick glass substrates with sputtered and patterned ITO transparent electrodes. SiO was evaporated obliquely on the glass substrates at an incident angle of 85° to the substrate normal. Thickness of obliquely evaporated SiO films was about 200 nm parallel to the incidence direction. Therefore the thickness normal to the substrate surface lies between 20 and 30 nm. The vacuum condition of SiO evaporation was varied; A high vacuum (2 to 4 $\times$ $10^{-6}$ Torr), and a low vacuum (2.4 $\times$ $10^{-4}$ Torr).

The cells were assembled with the evaporation direction of the two substrates in antiparallel arrangement. The cell gap was measured to be 1.7 to 1.8 μm by the capacitance method. The cells were filled with CS-1014 FLC by Chisso in an isotropic phase, then were slowly (−5°C/min) cooled down into liquid crystalline phases.

Extinction angle measurement and phase texture observation were performed under cross Nicol of a Nikon OPTIPHOT-POL™ microscope equipped with a Mettler FP800 hot stage. An apparent tilt angle is defined as a half of the angle difference between the two extinction angles. The application of electric fields to the cells was carried out using a Wavetek model 275 function generator and a conventional DC amplifier. The electro-optic properties of the cells were measured with a photo-diode and an HP 94501 digitizing oscilloscope.

Transmittance spectra of the cells were obtained with the combination of the above-mentioned microscope and an Otsuka Electronics MCPD-110 spectro multi channel photo detector. The X-ray scattering measurement was performed using a Rigaku RAD-RC X-ray diffraction system with an RU-300 X-ray source (60 KV, 300 mA). For this measurement, special cells assembled with 150 μm thick substrates were used in order to keep X-ray absorption low. SEM images of obliquely evapoarated SiO film surfaces were taken with a JEOL S-890 scanning electron microscope, and 3-D profiles of the SEM images were obtained by a Nippon Avionics SPICCA-2 image processing system.

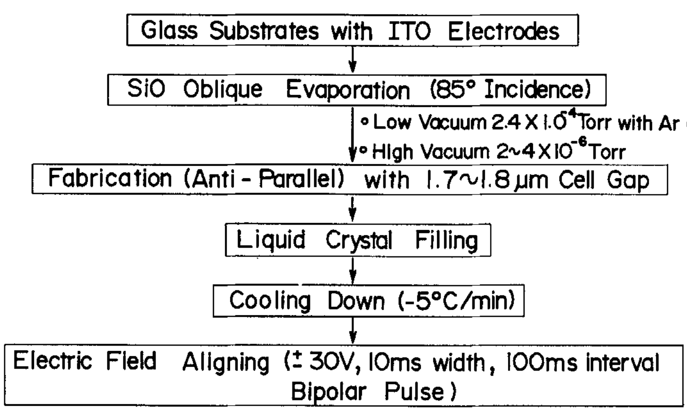


FIGURE 1 Cell fabrication process and electric field aligning.

## RESULTS AND DISCUSSION

The cell with the high vacuum SiO evaporation changed its extinction angle and texture when it was cooled down slowly from an isotropic phase, as shown in Figure 2. While the director of the FLC in a chiral nematic phase lies parallel to the incident direction of SiO vapor, the director in a smectic A phase is tilted a little to the incident direction. In a chiral smectic C phase, the texture which looks like a poly-domain appears, the extinction becomes blurred, and the director is tilted more to the incident direction. The electric field aligning was carried out on the cells with the poly-domain like texture in the chiral smectic C phase. Applied bipolar pulses had greater height (30 $V_{0-p}$) and width (10 ms) than usual driving pulses (10 to 15 $V_{0-p}$, several hundreds μs, respectively). The texture in the cell disappears immediately after the electric field application and the cell starts to show a sharp extinction. However this drastic change happens only in a limited temperature range near the smectic A–chiral smectic C transition such as between 46.5°C and 50.2°C. The cell with the low vacuum SiO evaporation behaves in a different manner during the cooling process. Through chiral nematic and smectic A phases, the director always lies in a direction perpendicular to the incident direction, judging from the cross Nicol observation. Moreover, typical zig-zag defects appear in the chiral smectic C phase as shown in Figure 3. The application of the strong electric field gives no influence on this alignment.

Figure 3 also shows the electro-optic responses of the cells with the high and low vacuum SiO evaporation. They were observed at 50°C. The height and width of the bipolar pulses applied to the cells are 10 $V_{0-p}$, 1 ms, respectively. Apparent tilt angles measured at 50°C are also shown in this figure. Apparent tilt angles in a "switched" state were measured under application of 10 $V_{0-p}$, 10 Hz rectangular pulses to the cell; a "memory" state measured under no electric field subsequent to 10 $V_{0-p}$, 10 ms bipolar pulse application. The cell of the low vacuum SiO has an imperfect memory and shows a low contrast ratio of 4:1. The large difference between the two apparent tilt angles also indicates the imperfect memory. On the other hand, the cell of the high vacuum SiO has a more perfect memory with a high contrast ratio of 50:1. For this cell, the apparent tilt angle in the switched state is nearly equal to that of the memory state, and also to a half of the cone angle (28.0° at 50°C) of this FLC. This means not only that the cell has an excellent memory but also that the smectic layers in the cell have been made to stand perpendicular to the substrate surface by the electric field aligning, as illustrated in Figure 4. It is thought that the layer reformation is caused by the coupling of the applied electric field and the spontaneous polarization of the FLC.

Thus we could obtain an excellent mono-domain alignment showing an almost perfect memory and a high contrast in a temperature range of 46.5°C to 50.2°C. The alignment, however, starts to show small domains as the cell temperature decreases below the lower limit of the range. Most of the domains have no memory and show extremely low contrast ratios. At room temperature (31.0°C), the alignment gives a poly-domain which is an aggregate of the small domains as shown in the lower part of Figure 2. Consequently, this poly-domain shows only a low

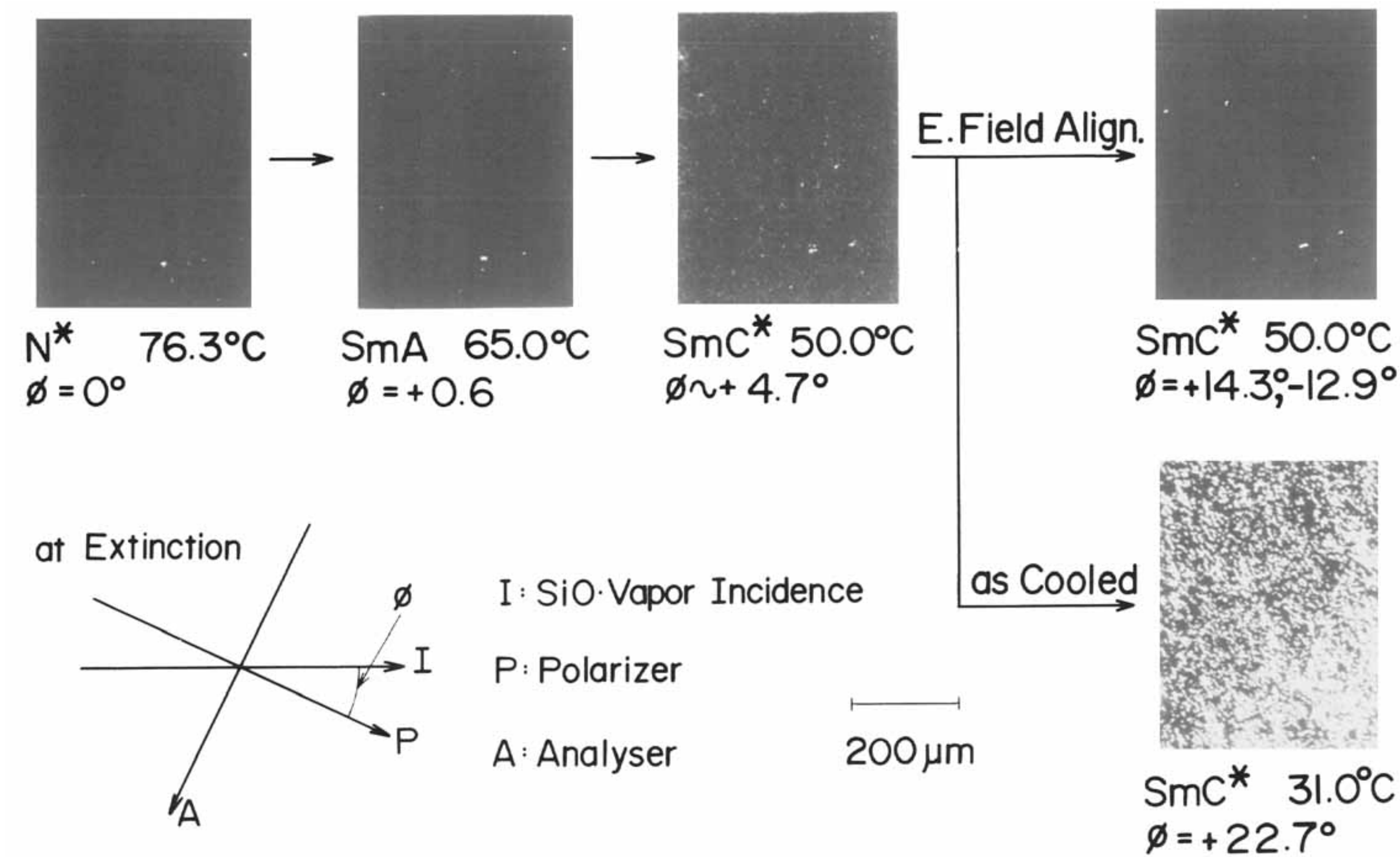


FIGURE 2 Changes in extinction angle and texture. The cell was aligned by obliquely evaporated SiO in the high vacuum. See Color Plate III.

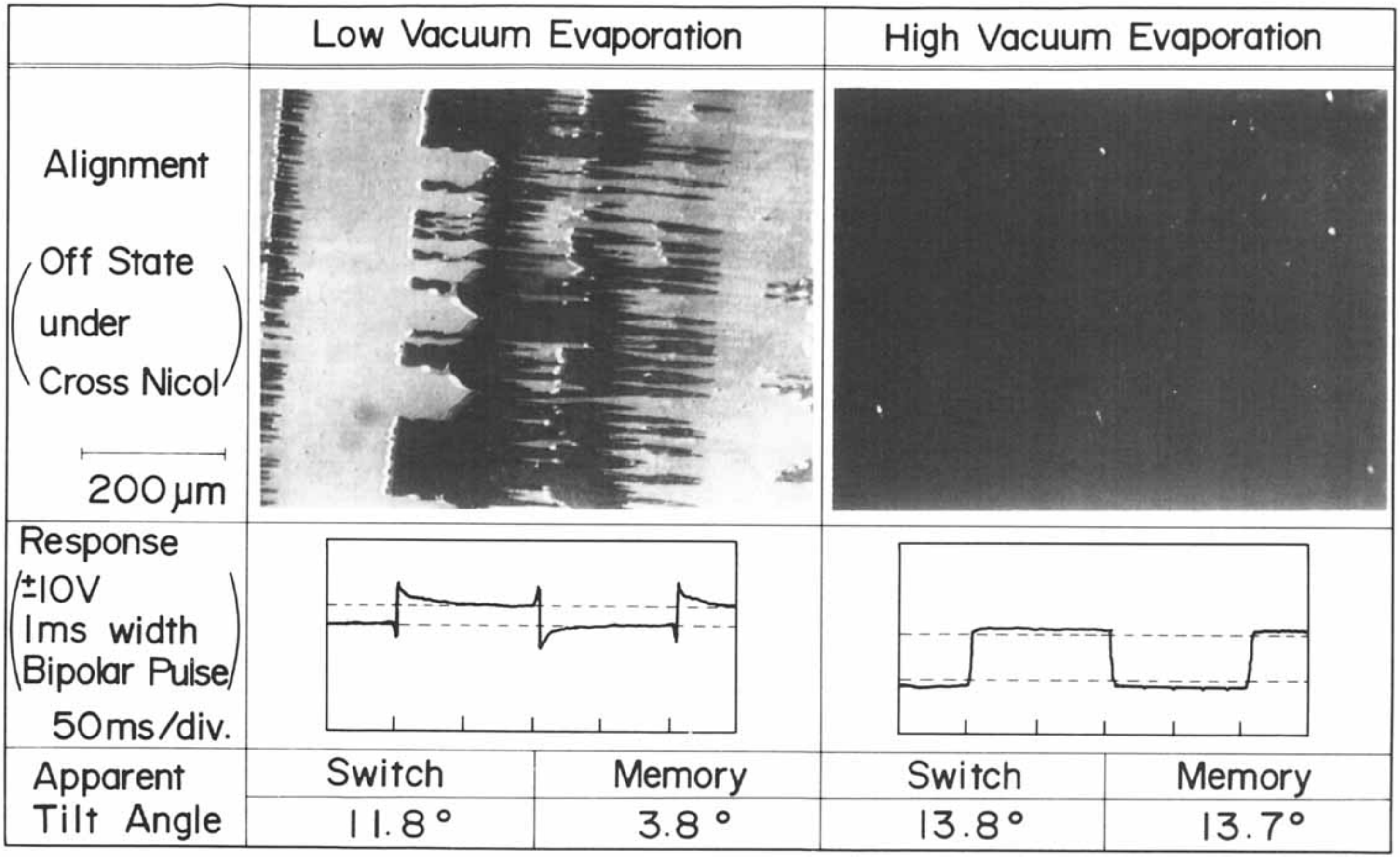


FIGURE 3 Alignment under cross Nicol, electro-optic response and apparent tilt angle, observed at 50°C, after the electric field aligning. See Color Plate IV.

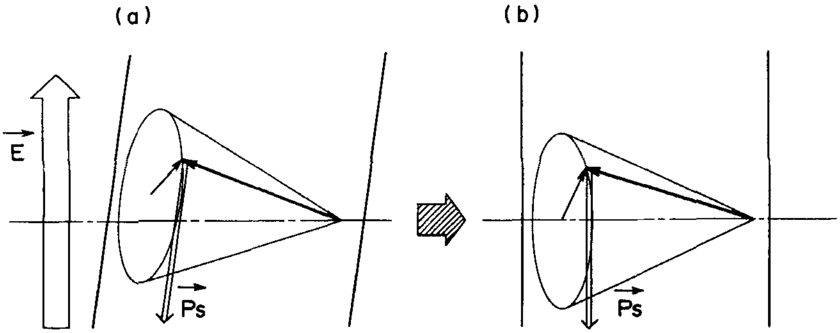


FIGURE 4 Layer reformation by strong electric field application.

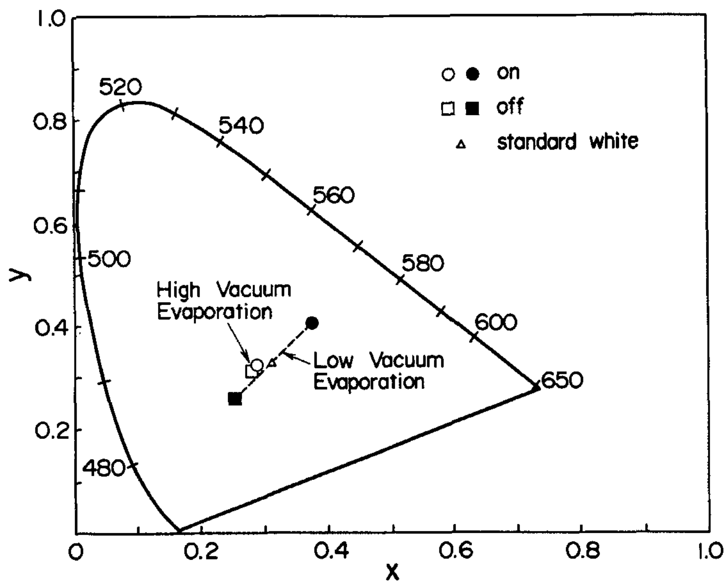


FIGURE 5 Chromaticity diagram of transmittance spectra, observed at 50°C.

contrast ratio and has almost no memory. But, this cell restores the ideal switching mentioned above when it is heated to that specific temperature range again.

Figure 5 shows the chromaticity diagram of the transmittance spectra of the cells which are prepared in the high and low vacuums. The spectra were obtained when the cells were both in a "on" state and in a "off" state (at 50°C). These states are acquired by applying electric fields which have the opposite signs each other. The cell of the low vacuum shows a remarkable color difference between its "on" and "off" states, as shown in the Figure. Shingu *et al.* calculated transmission spectra and chromaticities of SSFLC cells numerically.[6] They found that a molecular selective pre-tilt on both substrate surfaces causes a color difference observed in switching between the two "twisted" states distinguished by the sense of C-director rotation. So it is thought that the cell prepared in the low vacuum is aligned in the "twisted" states and that the molecular selective pre-tilt exists on the substrate surfaces of the cell. On the other hand, almost no color difference by switching is observed in the case of the cell prepared in the high vacuum. The fact that the cell of the high vacuum SiO evaporation has a nearly perfect memory and a very high contrast leads one to assume that the alignment of the cell is in the so-called "uniform" state.

The results of the X-ray scattering measurement at room temperature (25°C) are shown in Figure 6. The arrangement of instruments is the same as Rieker's.[1] The cell prepared by the low vacuum evaporation gives two sharp peaks as can be seen in Figure 6. This indicates that the cell has the Chevron structure in its smectic layers. The layer tilt angle of the cell is about 20° because the two $\alpha$'s as mentioned by Rieker are about 70° and 110°. By the cell rotation in the $\chi$ direction also mentioned by Rieker, it was confirmed that the layers in this cell lie parallel to the incident direction of SiO vapor. We, however, could not find any peak with the cell of the high vacuum SiO evaporation as shown in Figure 6. It is possibly because the alignment with the above-mentioned poly-domain has regularity neither in the direction of the layers nor in the distance between the layers. The effort to measure the X-ray scattering from the cell in the temperature range in which the alignment gives the mono-domain and ideal switching is under way.

As mentioned thus far, the alignment and electro-optic properties of SSFLC cells aligned by obliquely evaporated SiO films are dramatically influenced by the vacuum condition of the SiO evaporation. We observed the surfaces of obliquely evaporated SiO films by a SEM. The SiO films are evaporated in the high and low vacuums as stated earlier in this paper. SEM images and the corresponding 3-D profiles of them are shown in Figure 7. The incidence of the SEM electron beam was normal to the substrate surface coated by SiO. Steep columnar structure are seen to grow on the surface of the SiO film evaporated in the high vacuum. It was also revealed that the columns on this surface are rather deeply tilted to the substrate normal. Whereas, much more flattened structure is obtained with the SiO film by

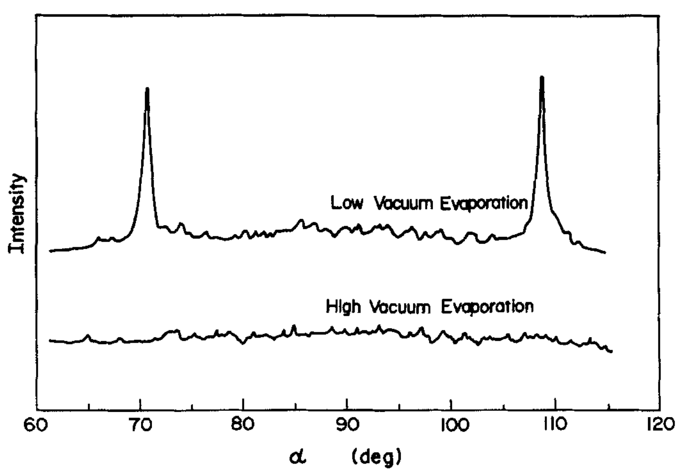


FIGURE 6 X-ray scattering intensity vs. cell rotation angle $\alpha$, (at 25°C).

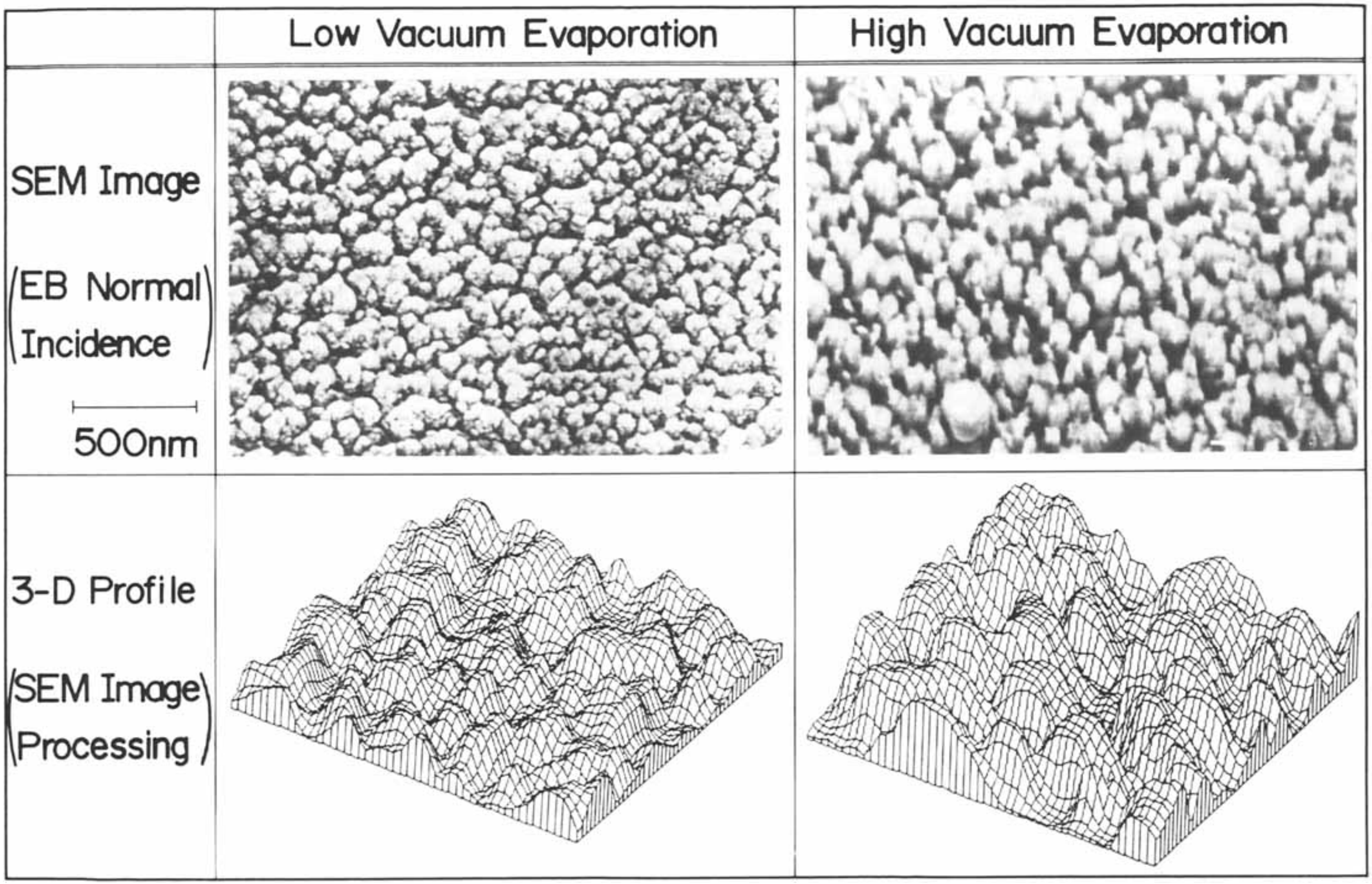


FIGURE 7 SEM images and corresponding 3-D profiles of obliquely evaporated SiO surfaces. See Color Plate V.

the low vacuum evaporation. The columns on the surface of this film are less tilted to the substrate normal than that of the film evaporated in the high vacuum. It is known that $\alpha_A$, the column tilt angle of obliquely evaporated films in high vacuums, is given by

$$\alpha_A = \tan^{-1}\{(\tan\alpha_1)/2\},$$

where $\alpha_1$ is the incidence angle of vapor.[7] This equation means that the more tilted columns are obtained as the incident angle of the vapor increases and that the column tilt angle ($\alpha_A$) is settled by the incident angle ($\alpha_1$). Nevertheless the columns with the low vacuum evaporation are less tilted as if they were formed at a much smaller incident angle than 85°. It is probably because the straightness of the vapor beam decreases by the reduction of mean free path in the low vacuum. Uemura *et al.* reported on the similar aligning method as ours that the layer direction of FLC was parallel to the evaporation direction where the incident angle was below 60° and that the layer direction was normal to the evaporation direction where the incidence angle was above 80°.[8] The layer direction in the alignment obtained with the low vacuum SiO corresponds to the one by the incident angle below 60°. So it can be concluded that the alignment obtained by obliquely evaporated SiO depends greatly on the columnar structure of SiO films.

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