Thick LC Devices Stabilized by Polymer Wall Surface for Millimeter Wave Control

Tomoya Haneda[1], Takahiro Ishinabe[1], Yosei Shibata[1], Hiroyasu Sato[1] Qiang Chen[1], Hideo Fujikake[1]

E-mail: tomoya.haneda.p1@dc.tohoku.ac.jp
[1]Tohoku University, 6-6-05 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
Keywords: nematic liquid crystal, reflect array, polymer wall

ABSTRACT

We propose a wall-type LC device for thick LC devices for millimeter-wave phase shift to speed up the fall response. As a result, we have revealed the alignment state of LC molecules inside the polymer wall by optical evaluation.

1 Introduction

In recent years, Beyond 5G have the advantage of enabling faster data transmission rates and simultaneous connection of many terminals. Therefore, it has attracted much attention [1]. However, Beyond 5G has a problem of narrow coverage area of radio waves. This is because millimeter waves emitted from base stations have weak diffraction signals in buildings such as high-rise buildings. To solve this problem, the use of Reflect Arrays (RA) has attracted attention [2], [3]. Fig. 1 shows the expansion of the coverage area using RA. Fig. 2 shows a conceptual diagram of the RA. As shown in Fig. 2, the RA consists of reflector elements arranged in a periodic array, and by changing the electrical length of each element, the phase of the scattered wave is changed. This allows the beam direction to be controlled arbitrarily [4].

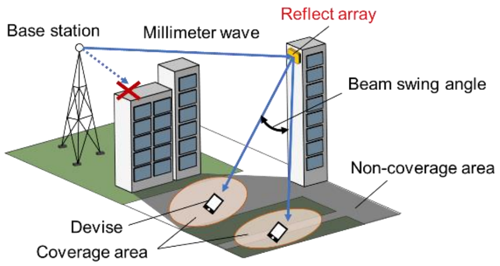


Fig. 1 Expansion of coverage area

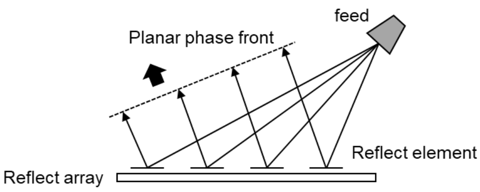


Fig. 2 The reflection of radio wave

As a typical example of phase control, a device that uses the change in electrical length caused by diode switching has been reported [5]. However, in the case of using a diode for the reflect array, its rectification characteristics distort the current, which may cause harmonics. These harmonics may cause interference in other frequency bands.

Therefore, in this report, we focused on phase control using dielectric anisotropy of nematic LC. The unique feature of this method is that the beam is controlled by controlling the alignment of LC molecules with a low-frequency AC voltage [6]. In general, however, thick LC layers (100 µm or more) are required to enhance the effect of LC on dielectric constant change [7]. As a result, the fall-response time of LC molecules becomes very long. To improve the fall-response time, methods using PDLC (polymer dispersed LC) [8] and PSLC (polymer-stabilized LC) [9] have been reported. However, these devices have a high proportion of polymer materials in the LC layer. As a result, there were problems such as high driving voltage and reduced amount of phase shift. To solve this problem, we had proposed a method of dividing a thick LC layer in the thickness direction with LC-polymer films [10]. However, in this method, the voltage is shared between LC-polymer films and LC layers, and the electric field applied to the LC layers is considered to be reduced. Therefore, it is expected to be difficult to achieve lower voltages.

Therefore, we considered a method in which the interior of the thick LC layer is divided by a lattice-like partition structure to enable a fast response, suppress the drive voltage, and secure the amount of phase shift. In this study, we proposed a LC device that introduces the polymer wall and evaluated the basic behavior of the alignment change of the LC in the device we fabricated.

2 Principle of "wall-type LC device"

The realignment of LC devices used in displays is realized by the anchoring force from the surface of the alignment film. It has been reported that the fall-response time required for its operation is proportional to the square of the distance between the top and bottom substrates (thickness of the LC layer) [11].

In this section, we describe the principle of our proposed thick LC device with the polymer wall. The principle of operation is shown in Fig. 3. The LC layer is delimited by the polymer wall, and the alignment of the LC molecules is controlled by the anchoring force from the wall.

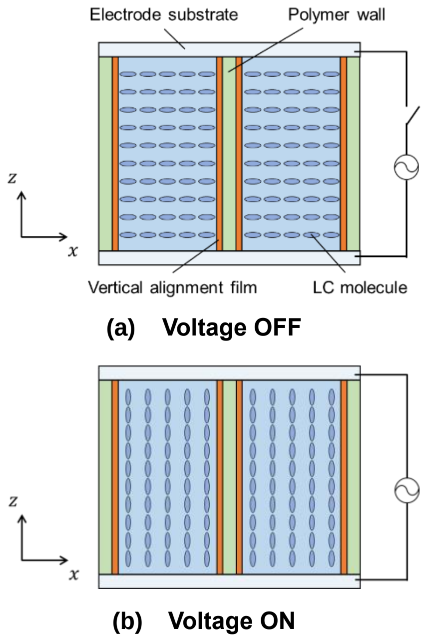


Fig. 3 Cross-section view of the wall-type LC device

As shown in Fig. 3 (a), a vertically alignment film is applied to the sides of the polymer wall. Therefore, when the voltage is off, the long axis of the LC molecules is aligned parallel to the substrate surface. When the voltage is turned ON, the LC molecules are aligned vertically to the substrate, as shown in Fig. 3 (b). By changing the alignment direction of LC molecules in this way, the effective dielectric constant of the entire device is changed, and the direction of radio wave reflection can be changed. Furthermore, when the applied voltage is removed, the LC molecules are aligned parallel to the substrate due to the anchoring force from the vertical alignment film applied on the side of the polymer wall. Therefore, the fall-response time of the proposed device is considered to depend on the length of the "short axis spacing" in Fig. 3. Therefore, it is expected that in the future, any desired fall-response time can be achieved by controlling the "short axis spacing" regardless of the thickness of the LC layer. The characteristic of the wall-type LC device is that the alignment of LC molecules is controlled by the anchoring force from the polymer wall interface, rather than in the thickness direction. In addition, since materials other than LC, such as polymers, are not added, suppression of driving voltage is expected.

3 Fabrication of polymer wall and application of alignment film on polymer wall

3.1 Fabrication of polymer wall

Since the polymer wall functions as a spacer for the LC layer, it is necessary to improve its stability. Therefore, we considered forming a lattice-like polymer wall, as shown in Fig. 4.

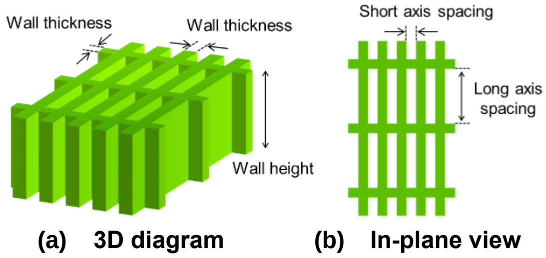


Fig. 4 Polymer wall structure

It is expected that the volume of the area where the dielectric constant changes (i.e., the volume of the LC portion) will decrease with the adoption of the wall structure. However, in the future, by making the "wall thickness" in Fig. 4 (a) thinner, the volume of the wall portion will decrease, and the ratio of the LC portion will increase, thus ensuring a large dielectric constant change.

A simplified diagram of the polymer wall fabrication process is shown in Fig. 5. Polymer walls were fabricated by two-photon polymerization. This is a method in which two lasers with different wavelengths are irradiated at the same spot to form a 3D model (Voxel) by the photo-polymerization reaction [12]. This technique allows the photocurable resin (drop) to be cured with higher resolution than the one-photon polymerization.

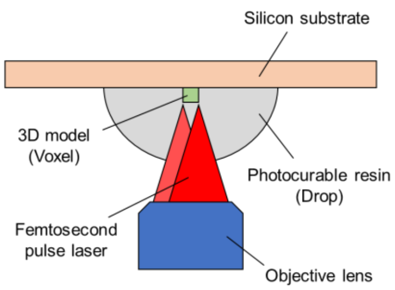
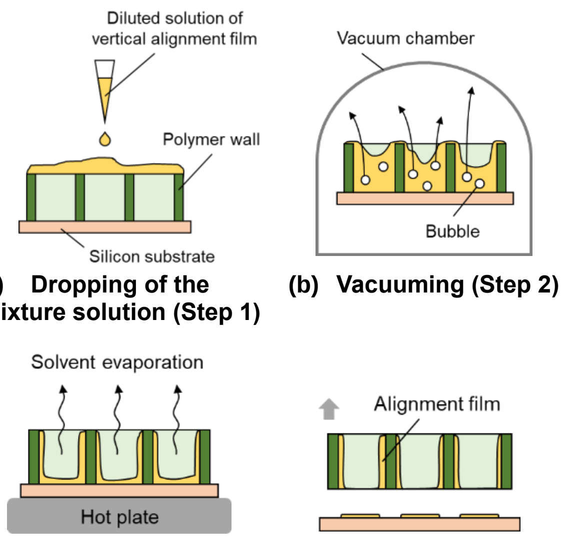


Fig. 5 Polymer wall fabrication method

The polymer wall is formed by focusing a laser beam inside a droplet of photo-curable resin dropped on a silicon substrate. The size of the polymer wall is wall thick: 25 μm, wall height: 100 μm, short axis spacing: 30 μm, and long axis spacing: 200 μm.

3.2 Application of alignment film on polymer wall

The process of applying the vertically alignment film to the polymer wall is shown in Fig. 6. In this process, when only vertically alignment film (SE4811, Nissan Chemical) was applied, the space between polymer walls was filled as shown in Fig. 7 (a). Therefore, we used a mixture solution of vertically alignment film, SE4811: 10 wt%, and solvent, 1-methyl-2-pyrrolidone (TCI): 90 wt%. In addition, vertically aligned LC cells have been fabricated using SE4811 at a concentration of 10 wt% and confirmed to be sufficiently aligned.

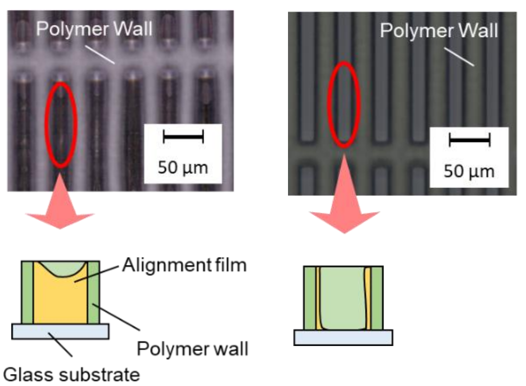


(a) Dropping of the mixture solution (Step 1) **(b) Vacuuming (Step 2)**

(c) Sintering of alignment film (Step 3) **(d) Peel off polymer wall (Step 4)**

Fig. 6 Process of applying alignment film to polymer wall

First, spread this mixture over the top surface of the polymer wall (Step 1). A vacuum is then drawn (1 h) in a desiccator to allow the alignment film to penetrate the spaces between the polymer walls (Step 2). Next, the alignment film is sintered (hot plate [100 °C, 10 min], oven [120 °C, 10 min]) to evaporate the solvent (Step 3). Finally, the polymer wall with the alignment film applied is peeled off from the silicon substrate (Step 4). A microscopic image of the polymer wall after Step 4 is shown in Fig. 7 (b).



(a) SE4811: 100 wt% **(b) SE4811: 10 wt%**

Fig. 7 Thickness control of vertically alignment film

From Fig. 7, it is considered that the alignment film could be applied without filling the space for the LC. The applied alignment film is applied on the four sides of the polymer wall. However, as shown in Fig. 4 (b), the enclosed LC will be subjected to strong anchoring force from the long side of the rectangular space.

4 Evaluation of LC alignment

In this section, we observed the alignment state of LC in the polymer wall. To identify the alignment direction of LC molecules, a mixture of LC (E-7, LCC): 99.9 wt% and dichroic dye (G241, Hayashibara Co., Ltd): 0.1 wt% was injected. The guest-host effect [13], in which dichroic dye molecules are aligned along the alignment of LC molecules, occurs. Therefore, the alignment state of the LC can be revealed by polarized light observation. The injection process is shown in Fig. 8.

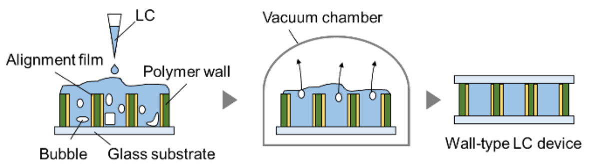
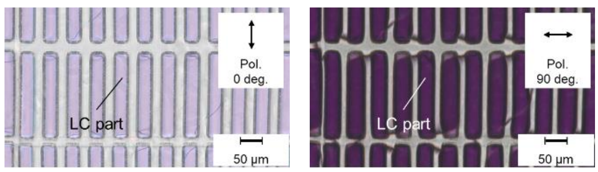


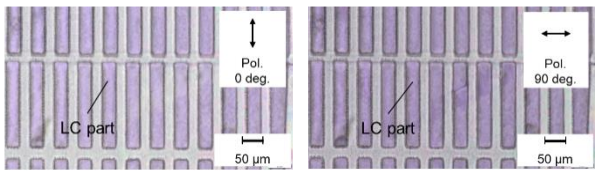
Fig. 8 LC injection process

After the polymer wall is peeled off from the silicon substrate, it is placed on a glass substrate with electrodes. The mixture is dropped into it and vacuumed (1 h) in a desiccator. Finally, the upper glass substrate with electrodes is overlaid. Microscopic images of the wall-type LC device fabricated in this way are shown in Fig. 9 when linearly polarized light is incident on the device. For comparison, a device in which the mixture was injected into the polymer wall without the alignment film was also fabricated. Microscopic images taken under similar conditions are shown in Fig. 10.



(a) Pol.: 0 deg. **(b) Pol.: 90 deg.**

Fig. 9 Microscopic images of the wall-type LC device (With alignment film)



(a) Pol.: 0 deg. **(b) Pol.: 90 deg.**

Fig. 10 Microscopic images of the wall-type LC device (Without alignment film)

Fig. 9 (b) shows a clear absorption of light compared to Fig. 9 (a). The dichroic dye used in this study has a property of strong absorption of light when the direction of its long axis is parallel to the direction of linear polarization. The guest dichroic dyes are aligned in the long axis direction of the host LC. This suggests that the long axis of LC molecules is aligned parallel to the substrate (in the x direction in Fig. 3). Comparison of Fig. 10 (a) and (b) shows that no significant light absorption is observed. Therefore, without the alignment film coating process, the long axis of LC molecules is considered to be aligned vertically to the substrate (in the z direction in Fig. 3). These results suggest that the application of the vertically alignment film on the polymer wall could achieve the alignment of the LC as shown in Fig. 3 (b).

Fig. 11 shows the results of applying voltages to the fabricated wall-type LC devices. The applied voltages were 10, 20, and 30 V.

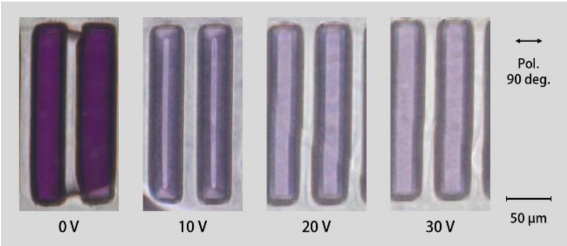


Fig. 11 Alignment states for various voltages

Fig. 11 shows that the light absorption is weakened by applying voltage. This suggests that the LC molecules were aligned vertically to the substrate by applying the voltage. It is also observed that the higher the voltage, the less the unevenness of light absorption near the polymer wall. This suggests that the LC near the polymer wall can also be driven by applying a high voltage. Furthermore, by applying parallel alignment films to the top and bottom two substrates, it is expected that the alignment of the LC will be further stabilized and alignment defects will be eliminated.

In the future, we plan to evaluate the response time of the LC in the proposed structure, as well as the thickness and anchoring strength of the applied alignment film.

5 Conclusions

In this report, we proposed a wall-type LC device for thick LC devices for millimeter-wave phase shift. The proposed structure is expected to speed up the fall response and lower the voltage in thick LC. In addition, we evaluated the LC alignment in the polymer wall, and realized LC alignment control by applying the vertically alignment film on the polymer wall.

Acknowledgements

The fabrication of polymer wall was supported by Dai Nippon Printing Co., Ltd.

This research was supported by the Ministry of Internal Affairs and Communications, Japan (JPJ000254).

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