Alteration of Physical Properties of Nanoparticle Embedded liquid Crystal Causing the Enhancement of the Performance of LCDs

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Abstract

Doping the nanoparticles of Pd, p-$BaTiO_3$, SiO_2 and MgO into LCs alters their physical properties such as K_{ii}, $\Delta\varepsilon$, Δn, S, γ_1, and T_{NI}. Except for K_{33}, all these parameters decreases and thus bring the reduction of operating voltage and/or response times.

1. Introduction

Nowadays, there exists need to realize LCDs featured by low power consumption and fast response speed. To solve these problems, we have adopted an approach of the doping of nanoparticles or polymeric nanostructure such as Pd, p-$BaTiO_3$, SiO_2, MgO, and photo curable acrylate monomers into the host LC media of LCDs. We have determined the physical quantities such as K_{ii}, $\Delta\varepsilon$, Δn, S (order parameter), γ_1, and these physical quantities decrease, except for K_{ii}, by the existence of nanoparticles.

This effect is shown to cause the enhancement of the performance of LCDs such that the reduction of threshold voltage, operating voltage and response times.

2. Experimental

2.1 Synthesis of nanoparticles

Metal nanoparticles were synthesized by alcohol reduction under the coexistence with LC molecules; [1] the nanoparticles of p-$BaTiO_3$ and SiO_2 by sol-gel method; [2] and MgO by a vapor phase reaction. [3] The size of our nanoparticles are from 2nm to 50nm. We have synthesized and used an appropriate ligand molecules covering each nanoparticle to protect their aggregation. We also synthesized and used polymeric nanostructure.

2.2 LCDs cells and measurements

We fabricated LCD cells with the modes of TN. ECB, IPS/FFS, and VA and tested their V-T and T-time characteristics at the temperature from -30 °C to 80 °C, where we used NLC, MO-16, MO-26, and NLC-6 (DIC) with Δn=2.

2.3 Characterization of nanoparticle embedded NLCs

We determined K_{ii}, $\Delta\varepsilon$, Δn, S, γ_1 using EC-1 and Model 6254 (Toyo), LCD-5200 (OHTSUKA), and OPTIPRO (SHINTECH) for understanding how these parameters give an affect to the results obtained in this research.

3. Results and discussion

3.1 Metal nanoparticle embedded NLCs

Through our research, it is shown that there are two cases: one is the case (A) where each nanoparticles is covered with a diffusion cloud that is an aligned phase of NLC and having a different electrical properties from the residual NLC medium; and the other is the case (B) where no diffusion cloud exists. This difference is brought about by the difference of the chemical synthesizing procedures; and the most useful way to judge (A) or (B) is to conduct a dielectric spectroscopy. In the case of (A) the dielectric function is the Debye type and accompanies the dielectric relaxation frequencies extending from 100Hz to 10kHz depending on the concentration and material, and also a finite dielectric strength giving a gain, $G = \{\varepsilon(\infty) - \varepsilon(0)\} / \varepsilon(\infty)$ that reaches about 10. This phenomenon is also called the Maxwell-Wagner effect; further, an LCD with this LC exhibits an FM-EO response below $f<10f_R$. [4,5] Contrary to this, in the case (B) no Debye type dispersion occurs and the dielectric relaxation frequency is about 8 Hz, and no gain, G=1; and further, this LC is used for implementing a direct multiplexed LCD. We have formulated a dielectric function with f_R and G based on an equivalent circuit, the phenomena in the case (A) is theoretically explained as a function of the ratio of capacitor of diffusion cloud that has a negative value and the capacitor of LC host medium with the volume of v=V/N, where V and N being the volume of NLC cell and number of nanoparticles.

Further, the capacitance of a diffusion cloud containing a metal nanoparticle is negative; this gives G>1.

3.2 Inorganic non-ferroelectric nanoparticle embedded NLCs

We synthesized and used non-ferroelectric inorganic nanoparticles such as p-$BaTiO_3$, SiO_2, and MgO.

Table 1 shows an example how physical properties of NLC alter by the doping of SiO_2 nanoparticles.

TABLE 1. Physical properties of nanoparticle embedded NLC-6

Sample	Δε	Δn	K_{11} (pN)	K_{33} (pN)	V_{th}	γ_1 (mPas)
NLC-6 pure	5.3	0.21	13.2	18.1	1.73	280
NLC-6 SiO_2	4.7	0.175	11.3	23.5	1.51	240

As shown in Table 1, except for K_{33}, all the other quantities decreases by doping nanoparticle. These behaviors may be interpreted by the decrease of order parameter. [6] In a previous paper, we reported how the order parameter decreases with the doping of nanoparticles, [4] however, in this paper, we show the decreases of Δn, since it is proportional to, ordre parameter S.

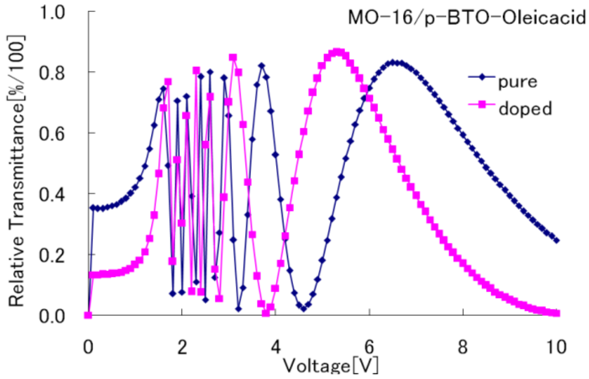

Figure 1 V-T curves of ECB-LCD cells with and without doping nanoparticles

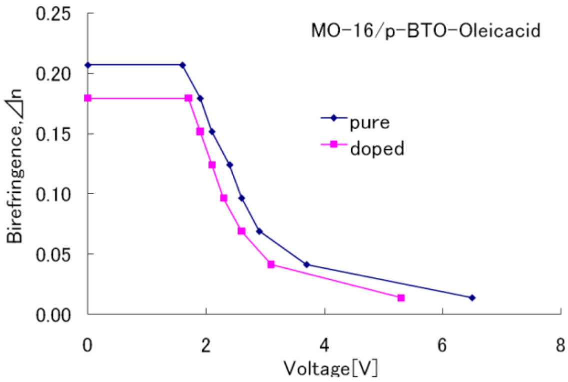

Figure 2 Birefringence of ECB cells with and without doping nanoparticles Calculated using the data in Fig.1.

Figure 1 demonstrates how the operation voltage decreases in an ECB cell with nanoparticles of p-$BaTiO_3$; and we calculated Δn from the data of Fig.1; the results are shown in Fig. 2 that exhibits Δn decreases by 16.7%. We also determined the values of the rotational viscosity that decreases by 14%. At this moment, we are able to discuss these behaviors by referring existing literature as follows: Imura and Okano [7] and Helfric [8] derived a formula for the viscosity such that

$$\gamma_1 = C_2 S^2 , \qquad (1)$$

this may suggest that γ_1 decreases with decreasing the S.

Kimura et al [9] obtained the formulae for K_{ii} such that

$$K_{11} = \frac{1}{2}\left\{\frac{A}{kT} + 3\gamma_e n\left(1 - \frac{\langle P_4 \rangle}{S}\right)\right\} R^2 S^2 nkT \qquad (2)$$

$$K_{22} = \frac{1}{2}\left\{\frac{A}{kT} + \gamma_e n\left(1 - \frac{\langle P_4 \rangle}{S}\right)\right\} R^2 S^2 nkT \quad (3)$$

$$K_{33} = \frac{1}{2}\left\{\frac{A}{kT} + 3\gamma_e n\left(1 + \frac{4\langle P_4 \rangle}{S}\right)\right\} R^2 S^2 nkT \quad (4)$$

According to these equations, K_{11} may decreases with decreasing the S, and K_{33} may increase due to the increase of the second term that expresses the contribution from the Oseen steric interaction.

This may suggest that the existing of nanoparticles may make a LC molecule effectively long.

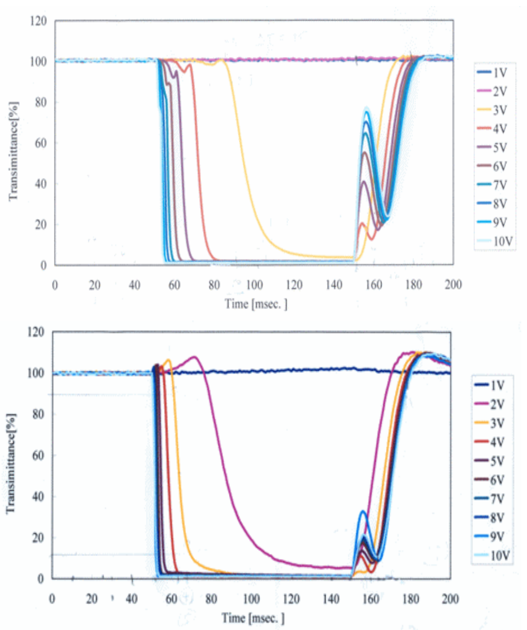

Figure 3 Temporal behavior of TN-LCD cells with and without doping nanoparticles

Figure 3 demonstrate temporal behaviors of TN-LCDs with and without doping the nanoparticles of p-$BaTiO_3$, where tremendon decrease of the delay time, that of back flow, and also response times by 9 times. Abovementioned results obtained in this research using non-ferroelectric p-$BaTiO_3$ synthesized by a sol-gel method are different from those by Reznikov et al obtained by using ferroelectric nanoparticles. [9]

The response time is expressed as

$$t_{off}=\gamma_1 d^2/\pi^2 K_{eff}\,, \quad (5)$$

therefore the t_{off} depends on the ratio, γ_1/K_{eff}.This ratio may depend on the temperature dependence of γ_1 and K_{eff} and also on the operation mode having a relevant K_{eff}.

Along with these researches, we have also studied a field sequential fullcolor LCD using polymer-stabilized V shaped (PSV)-FLCD[[10]; more detailed results will be published else where.

4. Conclusions

1. Metal nanoparticle doped NLCs are divided into two types depending on the synthesizing processes: one is that each nanoparticle covered with a diffusion cloud and exhibit Debye type dispersion with the dielectric relaxation frequency f_R of 100Hz-10kHz, and the a large dielectric strength with the gain of 10; and also exhibits an FM-OE response with a short response time; the other is featured by no diffusion cloud and has no Debye type dispersion and the f_R locates at 8Hz; this NLCs are useful to implement direct multiplexed matrix LCD with a fast speed response at a low temperature, -30 °C .
2. Inorganic and non-ferroelectric nanoparticle doped NLC show the decrease in K_{11}, $\Delta\varepsilon$, Δn, V_{th}, S, γ_1, and T_{NI}; but only K_{33} increases. These behaviors may be interpreted by the decrease of order parameter and due the modification of inter molecular interaction of NLC molecules.

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