Materials Aspects for fast switchable NLC/FLC Devices

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Abstract

In this review, several aspects for improving the quality of materials parameters of Nematic Liquid Crystals (NLCs) and Ferroelectric Liquid Crystals (FLCs) will be discussed. In particular the decrease of the response time is a need. It will be demonstrated that the materials parameters of NLCs and FLCs can be improved among other ways due to optimization of chemical structures of the NLCs and /or FLCs mixtures, due to doping them with nanomaterials and by using fast elastic relaxation processes.

1. Introduction

Nowadays, a challenging problem in the Liquid Crystal Display Technology is among others the suppressing of the switching time of the used Liquid Crystals into the microsecond range. For commercial displays mainly NLCs are used but they fulfill this requirement only slightly, because the on and off times are as lowest in the order of 10 milliseconds. From the technological point of view, TFT addressing is therefore needed.

On the other hand, the response time of FLCs is much shorter, namely in the order of 100 microseconds, but for commercial applications a lot of problems exist as are domain structures, zig-zag defects, sensitivity against mechanical shock, high driving voltage etc. For application, one must find out ways to overcome those problems.

Generally, there are several ways to reduce the response time of Liquid Crystals (LCs).

One of them is the reduction of the rotational viscocity of the LC mixture (1). It can be done by optimization of the mixtures, e.g. by using new components with molecules having more favorable geometrical dimensions (e.g. different and new kinds of two rings molecules). Because many excellent chemical structures are in use so far, as a consequence one must search for new classes holding the optimized properties of the known materials but improving the response time.

The second way is the utilization of some materials leading to the increace of the internal electric field inside the LC layers. In this technology, the most perspectives way is doping the LC with some nanomaterials having high electron affinity. The most suitable example of this type of nanoobjects are carbon nanotubes (CNT). Due to the delocalized electrons and the huge area of interaction with surrounding materials, CNTs efficiently trap the ions/charges which are always present in LC mixture resulting in the reduction of the depolarization field. The efficiency of this method was demonstrated in NLCs by Huang et.al. (2).

The third way for improvement of the response time is to employ the electroopical effects, where fast

relaxation processes induced by the elastic forces play a dominant role. This method is already tested for NLCs mixtures (3), but as well as for FLCs (4).

In our talk we will contribute to the improvement of several important materials parameters of NLCs and FLCs.

2. New strategies for improving NLC/FLC mixture parameters

Beside the need for fast response time there are a lot of further requirements as low threshold, low power consumption, good sharpness of the electrooptical curve, low voltage operating monostable and bistable devices, pixel stability etc. but as well as broad nematic and/or ferroelectric liquid crystal range between -30 ^{0}C and 100 ^{0}C.

For FLC devices the zig-zag defects must be excluded and the mechanical stability must be established.

Throughout the talk experimental data of newly developed NLC/FLC materials (5) (W. Haase, V. Bezborodov, V. Lapanik, Europ. Patent Application, 10.06.2007) will be presented in comparison to those of known ones.

For example a chiral nematic liquid crystal mixture mainly prepared out of subst. thiocyanato phenylcyclohexanes and doped with a known chiral dopant showed for a cell gap of 4.1 μm at room temperature response times t_{on} = 4.7 ms and t_{off} = 14.8 ms. In comparison the same basic composition could be improved by a newly developed chiral dopand (6). For the same amount as before for the new dopant and under the same experimental conditions we received a response time (t_{on}+t_{off}) of 0.96 ms, which is a really remarkable improvement. Moreover using our improvement (6) we could show rather good bistability as longer as two weeks.

For FLCs, a mixture was created mainly based on subst. phenylpyrimidins with a known chiral dopant. In comparison, a mixture prepared under the same condition but using our newly developed chiral dopant (6), showed a much broader SmC* range (101.5 K compared to 70 K), moreover a rather good and stable contrast ratio under applying mechanical pressure. The response time of the mixture using the new dopand is much lower as of that in the mixture with the known dopand.

3. Liquid crystal nanocomposites

As it was demonstrated during last two years, the electrooptical properties of the liquid crystal cells can be greatly modified by incorporation of nanoobjects. Among all nanomaterials available up-to-now, the Single Walled Carbon Nanotubes (SWCNTs) look as the most suitable for such applications. SWCNTs have several attractive properties making them useful in liquid crystal technology. The main important of them are the existence of the delocalized π electrons which can trap the impurity ions/charges and the huge area of interaction of SWCNTs and LCs.

As for the application in FLCs, the enhancement of the electrooptical response follows from the trapping of ions by SWCNTs and the forming of the electrical double layers on the interface between FLC and alignment layers (see Fig.1). In this case, the depolarization field (E_{dl}), generated by ions on this interface, act opposite to the electrical field applied to the whole cell (E_{ext}). Hence, the real electrical field E applied to the FLC layer is equal to $E=E_{ext} - E_{dl}$ and with this lower as E_{ext}. As a result, the response time (τ_{rise}), which is inversely proportional to the electrical field ($\tau_{rise} = \frac{\gamma_\varphi}{P_s E}$), strongly depend on the electrical field applied to the LC layer. Because of ions trapping in FLC/SWCNT nanodispersion, the depolarization electrical field is lower compared to those of the nondoped FLC mixture. As a result, the response time should be faster in case of nanodispersions.

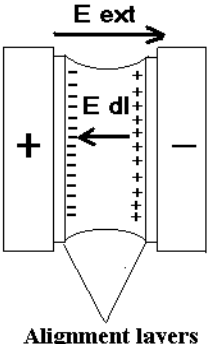

Fig. 1. FLC cell structure, E_{ext} is the external electric field applied to the whole cell, E_{dl} is the depolarization field

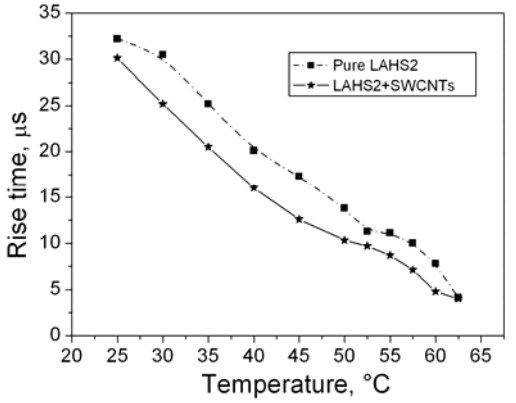

Fig.2 Dependence of the response time of the cells with nanodispersions (stars) and pure FLC (filled squares) on temperature.

For the experimental verification of this idea, the FLC/SWCNT nanodispersion was prepared. The chiral SWCNTs were dispersed in acetone solvent and sonificated during around 8 hours. To receive equivalent conditions, the same amount of pure acetone was added to the undoped LAHS2 mixture. To remove CNT bundles and the rest of chemicals from the synthetic process, the solution was filtered with filter having average pore diameter 500 nm. Due to the low solubility of the nanotubes, the estimated maximum amount of SWCNTs in the liquid crystal is 0.01 wt %, which is below percolation threshold. For our investigations, several cells were manufactured using 1.1 mm thick ITO coated substrates obtained from Merck. The thickness of the cells were predetermined by polystyrene microbeads with an average diameter of 1.5 µm dissolved in photocurable glue. Special care was devoted to prepare the two cells with identical thickness of the active area. One of these cells was filled with FLC/SWCNT nanodispersions and the other one with the pure FLC mixture. The results of the response time measurement are demonstrated on Fig.2. It is clearly seen from this plot that the response time of the FLC/SWCNT is faster then that of the pure FLC sample, which is in full accordance with the prediction. The response time of this nanocomposite can be further improved by increasing the SWCNT concentration (which is a non rivial process) as well as optimization of SWCNTs itself.

3. High frequency DHF effect

The third here described possibility to reduce the response time of FLCs is to use the properties of spatially inhomogeneity of the molecules orientation distribution in Deformed Helix Ferroelectric Liquid Crystals (DHF). The background for this electrooptical mode is the following: Due to the spatial distribution of the FLC molecules and the distortion of the helix, the effective optical anisotropy Δn_{eff} is different from the case of homogeneously aligned sample (SSFLC cells) (because of spatial averaging of the phase retardation of the light passed through the cell). Moreover, Δn_{eff} depends on the applied electric field.

If the applied electric field E is less then the unwinding field E_c, the response time can be inversely proportional to its frequency and has slight dependence on the temperature of the cell.

It was demonstrated that using this approach the response time can be reduced up to 800 ns ($E=5x10^6$ V/m, frequency of the applied voltage -10 kHz). This response time is remarkably stable over the temperature range 15°C-80°C.

4. Summary

Within this report, we presented an view over several techniques for improving the materials parameters of NLCs/FLCs under special consideration of the response time. Three different strategies out of several known ones can be employed, that is, a) optimization of the chemical structure of the NLC/FLC mixtures, b) modification of the internal electric field by doping the FLC with Single Walled Carbon Nanotubes, c) using the microscopically spatial inhomogeneous FLC structure properties and accosciated electrooptical effects.

Depending on the desired applications, these techniques can be successfully employed for optimization of the response and other parameters of the LC mixtures.

5. References

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