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## **Photoalignment – an alternative aligning technique for TN LCD**

### **Introduction**

In order to obtain good quality and homogeneity of liquid crystal alignment in liquid crystal devices many different technological routes are used. A typical liquid crystal, LC, cell is clearly depicted in Figure 4. The aligning materials, both the organic and inorganic ones, cover the substrates and ensure an orienting process in the LC material thanks to their anisotropic properties. Anisotropy in layers may be generated in such physicochemical processes as: laser writing [1], silica oxide deposition [2, 3], microrubbing [4], plasma beam irradiation [5], ion-beam irradiation [6], photoalignment, *PA*, Langmuir-Blodgett layer deposition [7], usage of dendrimer-like structures with azo-moieties attached [8], or with a commonly used technique – rubbing. Each of the processes mentioned above has its advantages and disadvantages in preparation of liquid crystal devices, dependent on their further utilisation. For example the rubbing technique gives good and strong anchoring of LC molecules, but it has some limitations for manufacturing certain structures in which different parts of one cell are to be arranged in different directions and, for instance, to prepare ferroelectric LC cells which require very low cell thickness and high purity of aligning medium [9]. As for preparing layers that are suitable to providing diversified optical axes in one LC cell, the photoalignment technique seems to be the appropriate one. Moreover, the *PA* technique opens the route to providing an appropriate molecular tilt and controlled anchoring energy.

### **Photoalignment techniques**

Polyimide materials are widely used in semiconductor technology due to their thermal, chemical and physical durability and high electrical resistivity [10]. The introduction of some photosensitisers to the polyimide precursor mixture [11] or some photorefractive groups to the polyimide structure opened the path to easy chemical etching processes in manufacturing elements for the needs of the optoelectronic industry. These chemical agents, which have incorporated groups like cinnamates [12, 13, 14], coumarins [15, 16] and chalcones [17], may also be used in the process

of liquid crystal device preparation. Thus photoalignment techniques are those in which light is the factor that induces anisotropy of the aligning layer [18].

Not only is the change occurring during (or after) irradiation able to display chemical, irreversible nature, but can also be achieved by some physical changes, such as *cis-trans* isomerisation which is present in azo-compounds. Photosensitive agents can be divided into two main groups: positive-tone and negative-tone materials depending on the type of chemical reaction – decomposition, dimerisation or topochemical photocrosslinking [19].

The present contribution had two main goals. The first one was to obtain homogeneous and very thin layers of photodefinable material. The other one was to induce anisotropy in layers using polarised light and then use those layers to prepare liquid crystal cells and measure electrooptical characteristics of these cells.

## Experimental methods

In the present work photoalignment polyimide agent (manufactured by HD Microsystems) was investigated. This was negative-tone PI named HD-4110 (esterified polyamic acid ester), routinely used as photoresist in semiconductor technology. Another tested compound: material B-12 was synthesized at the Institute of Chemistry of New Materials NAS of Belarus. Material B-12 is a clear 0.5% solution of the prepolymer in a two solvent system: easily volatile ethyl acetate and slower evaporating *n*-butyl acetate. This polymer is composed of macromolecules with side groups of the photosensitive benzaldehyde groups, which was confirmed by magnetic resonance study of proton  $^1\text{H}$  NMR.

The procedure of polyimide layers preparation involves several steps, which are: (1) cleaning and drying the substrates, (2) preparation of adhesion promoter solution (3) preparation of the polyimide solutions, (4) deposition of the adhesion promoter, (5) baking of substrate covered with adhesion promoter, (6) deposition of polyimide, (7) soft bake process – evaporation of diluent, and (8) UV exposure (usually linearly polarised ultraviolet light, LPUV). Layers prepared in such a manner should be ready to use in building LC cells.

## Preparation of polyimide layers, thickness measurements

In our work 0.5% to 5% solution of polyimide precursor HD-4100 in *N*-methylpyrrolidone, NMP, was used. Such solutions show insufficient adhesion to the substrates (glass plate covered with indium-tin oxide, ITO), which means that they do not yield homogenous layers and roll up at the edge of the substrates. The first technological step was then to prepare the solution of adhesion promoter. The adhesion promoter used is named U-13 (made by Unisil), the chemical structure of which is shown in Figure 1.

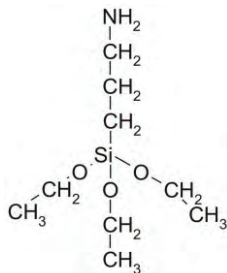


Fig. 1. Chemical structure of adhesion promoter U-13, 3-aminopropyltriethoxysilane [21]

The substrates were dipped in 0.1% water solution of U-13 for 30 minutes and after that time each of them was treated with compressed air followed by 15-minute baking at 115°C. After this procedure the solution of polyimide precursor was deposited on substrates covered with adhesion-promoter layer and soft-baked in a convector for 10 minutes at 80°C. The adhesion of HD-4110 solution was fairly good. Thickness measurement was carried out with the use of SPM 9001 spectrophotometer (Prema). Thickness of obtained layers varied from 80 nm up to 145 nm, which was dependent on the polyimide precursor concentration.

The coating from the material B-12 was applied using the spin-coating technology. The solutions were applied through a teflon syringe filter having an average pore size of 0.22  $\mu\text{m}$  on the pre-cleaned glass substrate with the ITO layer. It was decided to use a concentration in the original solution due to the low concentrations of prepolymer. The centrifuge used for test solution is shown in Figure 2. Notations used in the diagram: A – a step of applying a solution over the entire surface of the substrate B – a step of leveling a layer C – layer of the pre-drying step.

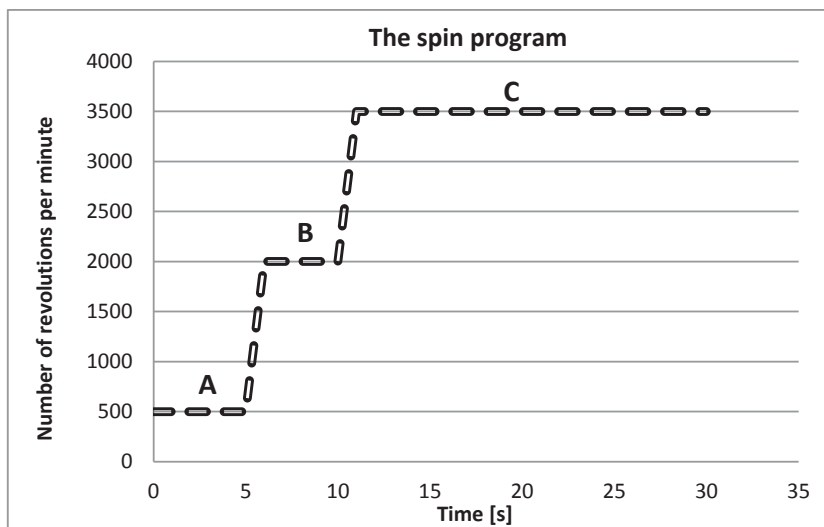


Fig. 2. The spin program of the material used to impose ordering B-12

Thus prepared layers were thin and uniform, as shown in Fig. 3.

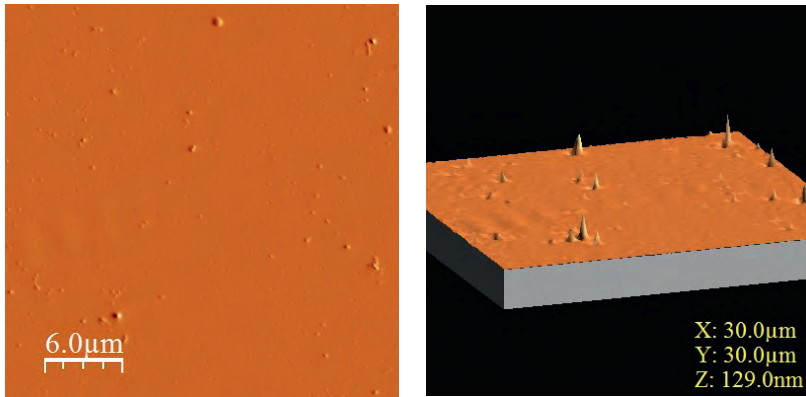


Fig. 3. Results of microscope research (AFM) of B-12 layer

### Anisotropy generation in PI layers, LC cell assembling

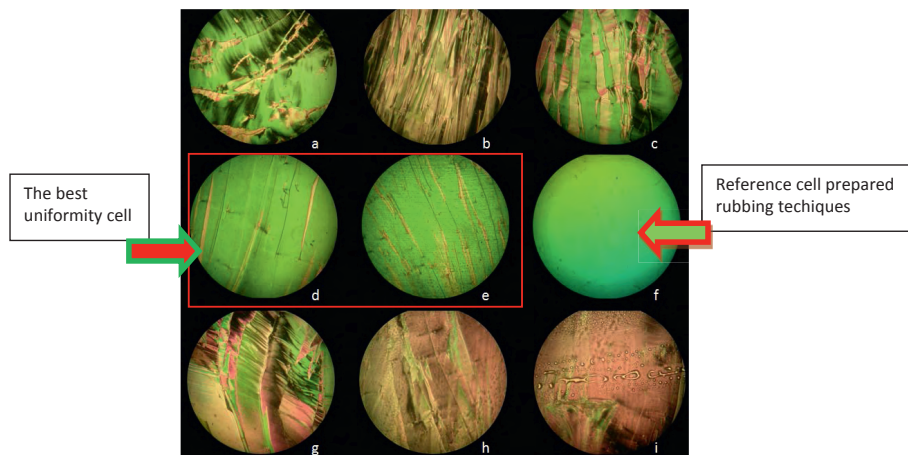
When HD-4110 layers are irradiated with UV radiation, the chemical reactions (topochemical photocrosslinking) take place. It forces the emergence of anisotropy in the structure, especially when linearly polarised ultraviolet irradiation is used. As a source of UV-light, a matrix of nine diodes (APG2C1 UV-LED, 365 nm, Roithner Lasertechnik) was used. To polarise the UV radiation, Glan-Taylor polariser PGT6320 (Dayoptics) was employed. Three types of layers were prepared, which means three different doses of LPUV were used. The layers were irradiated with  $67.5 \text{ mJ/cm}^2$ ,  $135 \text{ mJ/cm}^2$  and  $202.5 \text{ mJ/cm}^2$  so as to examine the influence of the UV dose on layer anisotropy generation.

Figure 4 shows microscopic photographs of TN LC cells obtained using crossed polarisers. The diagonal of the visible field is 2.5 mm.

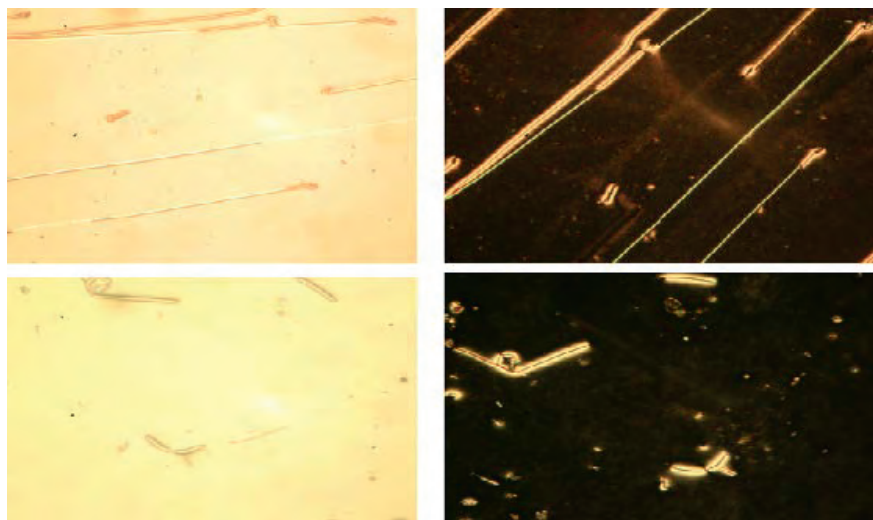
As it can be clearly seen, the best uniformity of liquid crystal layer was obtained using the layers which were irradiated with  $135 \text{ mJ/cm}^2$  (Figure 4: d and e). The dose of  $67.5 \text{ mJ/cm}^2$  is insufficient to cause proper degree of anisotropy in the layer (Figure 4: a, b and c). The dose of  $202.5 \text{ mJ/cm}^2$  probably caused competitive photochemical reactions due to the other (residual, perpendicular) polarisation direction of the LPUV which is unfortunately present in polarised UV light. These reactions may efficiently exacerbate the anisotropy of the orienting layer (Figure 4: g, h and i).

In the case of B-12 layers as a source of UV-light: a high-pressure mercury lamp-xenon (Oriel) or source of UV-light matrix of three LEDs UVTOP250-HL-TO39, 20 mA UV-LED, 250 nm (Roithner Lasertechnik) was used. To polarise the UV radiation, Glan-Taylor polariser PGT6320 (Dayoptics) was employed. Three types of layers were prepared, which means three different doses of LPUV were used. The layers were irradiated with  $240 \text{ mJ/cm}^2$ ,  $480 \text{ mJ/cm}^2$  and  $960 \text{ mJ/cm}^2$ .

The results can be seen on Figure 5:



**Fig. 4.** Photographs of liquid crystal cells: a, b and c are cells prepared using the layers irradiated with  $67.5 \text{ mJ/cm}^2$ , d and e are cells prepared using the layers irradiated with  $135 \text{ mJ/cm}^2$ , f represents the reference cell prepared using rubbed layer of SE-130, g, h and i are cells prepared using the layers irradiated with  $202.5 \text{ mJ/cm}^2$



**Fig. 5.** Examples of microscopic pictures (in polarized light) of liquid crystal cell in the course of the experiment performed with the selection of the optimal power UV radiation. The length of the lower edge of each of the photographs is equal to 0.56 mm

Liquid crystal cells were assembled in such a manner that two layers irradiated with the same UV dose were pulled together to form a twisted structure using NOA-91(Norland Optical Adhesive) photosensitive glue and 10 micrometer spacers. The term 'twist' means that on both substrates the irradiation with LPUV was carried out in the perpendicular direction of polarisation. The reference 10 micrometer

cells were assembled in twisted nematic, *TN* mode using identical substrates covered by rubbed SE-130 (Nissan) aligning agent. All the cells were filled with nematic liquid crystal 1223A (Military University of Technology) in the isotropic phase.

Table 1 summarizes the switching voltage and switching times of different types of liquid crystal cells obtained with B-12 layer.

**Tab. 1.** The switching voltage and switching times for different types of liquid crystal cells

substrate 1 \ substrate 2	SE130									
	$U_{90}$ [V]			$U_{10}$ [V]			$U = 10$ V		$U = 15$ V	
	100 Hz	500 Hz	1 kHz	100 Hz	500 Hz	1 kHz	$t_{ON}$ [ms]	$t_{OFF}$ [ms]	$t_{ON}$ [ms]	$t_{OFF}$ [ms]
B12, 120 mJ/cm <sup>2</sup>	1.75	2.5	8.5	10	24	35	0,7	8,5	1,33	8,8
B12, 240 mJ/cm <sup>2</sup>	1.5	2.75	7	5.5	10	26	1,52	4,4	1,43	4,4
B12, 480 mJ/cm <sup>2</sup>	2	3.25	7.75	8.0	17	23.5	2,14	4,9	1,56	4,9
SE130, (reference)	0.5			5			0.2	2.2	0.15	1.9

It can be seen that there is lengthening of the switching time  $t_{ON}$  with increasing doses of ultraviolet radiation, which the fotoalignment material received. This effect occurs both in the addressing pulse voltage of 10 V and 15 V, wherein the percentage change of 15 V is smaller. What is evident is that the time of the disappearance  $t_{OFF}$  also shortens. The observed effect is smaller at the control voltage with a value of 15 V due to the fact that the influence of the electric field strength is proportionately greater.

## Conclusion

It was shown that polyimide layers which were adequately irradiated using linearly polarized ultraviolet light and were not mechanically treated, show the aligning properties for liquid crystal layers. Such an observation is very important since it fulfilled the main aim of this work – investigation of the non-contact method.

Obtained results show that the quality of the orienting polyimide layer depends on many technological factors. In this work it was shown that the critical factors mentioned above are:

- the polyimide precursor deposition method and its conditions: the polyimide solution concentration and its purity, the diluent type, the rotational speed during the coating process,
- the temperature and the time of the soft bake,

- the polarizer selection, especially the transmittance spectra of the polarizers and their polarization ratios and
- the adequate dose of the LPUV.

The proposed new technology is fairly good to obtain 5–10 cm<sup>2</sup> layers. The alignment quality is not perfect, but the works are still in progress.

The deposition process can be modified to allow the control of quality of the aligning layers and their interaction with liquid crystal.

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**Abstract**

The main aim of this work is to present our investigation in the field of photoalignment as an alternative technique for the rubbing method for composition of liquid crystal display. Liquid crystal displays are widely used in many industrial and commercial applications. The multimedia, CAD and graphics, medical-imaging systems require very high quality images. Such an image can be obtained on the condition of the good liquid crystal alignment. Rubbing is the method conventionally used for these purposes. Unfortunately, this technique has some disadvantages – especially visible in new generation displays.

In this work we introduce the useful photoalignment techniques and in details the results of photocrosslinking and photodegradation in photosensitive polymer materials. We describe the procedure investigated in our laboratory for materials: HD-4100, HD-4110 (DuPont Microsystems) and B-12, as well as the characteristics obtained for the thin polyimide layers: optical homogeneity, thicknesses, surface tension and static electrooptical characteristics.

**Key words:** liquid crystal alignment, photoalignment, liquid crystal displays, photo-crosslinking, photodegradation

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