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Formation of the anisotropic ITO-based orienting layers for the liquid crystal devices

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Abstract. In this paper, the influence of the CO_2 laser ablation on the indium-tin oxide (ITO) and ITO with carbon nanotubes (CNTs) was considered. The ITO and CNTs were deposited on the Crown K8 substrates via the laser-oriented deposition technique. The anisotropy of the wetting angle for the laser-ablated pure ITO and ITO with the CNTs thin films was considered and compared. The ablation of pure ITO thin films under the CO_2-laser provides the arithmetical mean deviation of the profile in the range of 1.0-1.3 nm (in parallel direction relative to laser ablation) and in the range of 1.6.-1.7 nm (in perpendicular direction). In the case for the ITO with CNTs the mean deviation of the profile corresponds to the ranges of 6.2-9.1 nm and of 10.9-24.3 nm for the parallel and perpendicular directions respectively. The anisotropy of the height distribution leads to the same tendency in the wetting angle. The mean value of the wetting angle anisotropy for pure ITO is 31.6° and for ITO with CNTs it is 48.3°. The possibility to control the anisotropy of the wetting angle via the deposition of the CNTs and the laser ablation allow considering the ITO modifications as the universal electrical contacts and alignment layers for the twisted-nematic liquid crystal devices.

Keywords: indium-tin oxides, wetting angle, laser processing, liquid crystal devices_

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Формирование анизотропных ориентирующих слоев на основе ITO для жидкокристаллических устройств

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Аннотация. В текущей работе рассмотрена возможность изменения анизотропии смачивания тонких пленок на основе оксидов индия и олова (ITO) при помощи лазерной абляции CO_2-лазером. Среднее значение анизотропии угла смачивания для чистых ITO пленок составило 31,6°, а для ITO с лазерно-осажденными углеродными нанотрубками среднее значение этого параметра равно 56,5°. Возможность перестройки анизотропии смачивания при помощи лазерной абляции и осаждения углеродных нанотрубок позволяет рассматривать тонкие пленки на основе ITO в качестве электрических контактов и ориентирующих покрытий при разработке жидкокристаллических устройств с конфигурацией скрученного нематика.

Ключевые слова: оксиды индия и олова, угол смачивания, лазерная обработка, жидкокристаллические устройства

Финансирование: Работа имеет инициативный характер.

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Introduction

Liquid crystal (LC) mesophase is an important material for the electro-optical applications (display elements, modulation and conversion devices, laser techniques, etc.) due to the easy change of the mechanical, electrical and optical properties under the external field. The basic electrically tunable nematic LC device consists of the mesophase, orienting layers, transparent contacts and optical substrates. In case for the application of the external electric field, the nematic LC molecules change the orientation among the field. As the results, the devices based on the LC have much usage in the display technologies, opto-electronic techniques and biomedical systems [1–3]. The properties of the LC devices extremely depend on the distribution of the LC molecules versus the volume and interface [4–5]. The design of the orienting layers is an important problem, because their properties influence on the pre-tilt angles of the LC and on their further distribution. The three basics configurations (twist, splay, and bend) of the LC alignment could be considered in the LC devices. In nowadays the significant numbers of the researches are connected with the development of the alignment layers based on the organic structures [6–8]. However, these organic structures increase the electrical consumption in the devices. Moreover, the additional layers lead to the optical losses, thus, the brightness and related parameters are also limited.

In the recent researches, the ITO thin films were considered as a universal layer in the LC cells, which simultaneously performed functions of the contacts, anti-reflective coatings and orienting layers [9–11]. In the current paper, the formation of the ITO modifications for the twist-nematic configurations of the LC cells was considered.

Materials and Methods

ITO thin films were deposited on the Crown K8 substrates via the laser-oriented deposition (LOD) method. For these issues, the CO_2 laser (operated at the wavelength of λ = 10.6 μm, power of P = 30 W) with the conjugated electro-mechanical modules were used [12]. The thickness of the ITO films was approximately 100 nm. For the modification of the ITO thin films, the SWCNTs (Sigma-Aldrich, No. 704121, CAS: 308068-56-6) with chirality <7,6> (>77% content of the CNTs) were used. Taking into account the chirality indices, these CNTs have semiconductor properties, the average diameter was 0.83 nm. In order, to provide the anisotropy conditions, the ITO modifications were patterned via the CO_2-marker (λ = 10.6 μm; P = 21 W; modulation frequency, f = 1 kHz; beam diameter, d = 150 μm; the velocity of the processing, v = 50 mm/s). The pattern consisted of the parallel stripes with the length of 10 mm and step of 5 mm (Fig. 1,*a*).

For the relief characterization in the micro-scale the atomic force microscope Solver Next NT-MDT (contact mode, scan area of 30 μm × 30 μm, scan rate of 1 Hz) with the data processing software (Image Analysis P9) were used. The characterization of the orienting properties was estimated via the measurement of the wetting angle in the *xz*- and *yz*-projections. The *y*-axis is parallel and *x*-axis is perpendicular to the direction of the ablation (Fig. 1,*a*). For these issues, the OCA-15 EC (Dataphysics) measurement system with the sessile drop method were used.

The parameters of the drop were the following: volume of 0.5–0.7 μL, the material was distilled water, surface free tension was 72.8 mN/m (total), 48.1 mN/m (polar component), 24.7 mN/m (dispersive component).

Results and Discussion

Thin films based on the ITO with the CNTs have higher laser strength in comparison with the pure ITO, due to the increased surface of the heat dissipation [9]. Due to this reason, under the same conditions of the laser ablation, the traces in the ITO with CNTs are more ordered (Fig. 1, *a*, *b*).

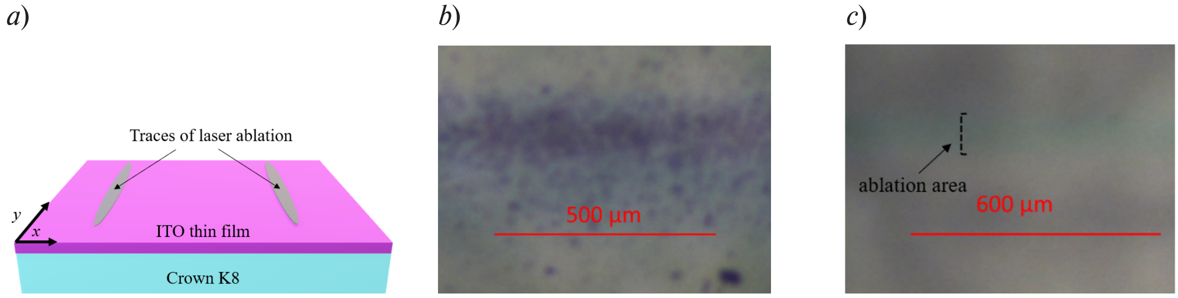

Fig. 1. Laser ablation of the ITO modifications: schematic image of the samples (*a*); microscopy image of the laser ablated (λ = 10.6 μm, P = 10 W, d = 0.15 mm, v = 50 mm/s) pure ITO (*b*) and ITO with the CNTs (*c*) thin films

The orientation of the liquid crystals in the volume depends on the pre-tilt angle and the roughness of the alignment relief respectively. The laser ablation performs the anisotropic conditions of the relief. According to the AFM data from Table 1, the arithmetical mean deviation of the profile (R_a) of pure ITO in the ablated areas rises from 1.0–1.3 nm (for *yz*-projections) to 1.6–1.8 nm (for *xz*-projections). The mean height of the CNTs clusters is approximately 40–60 nm (depends), due to this fact, the maximum profile peak height (R_p) and valley depth (R_v) for the ITO with the CNTs in 1 order higher in comparison with the pure ITO. As a result, the anisotropy $\Delta R_a = R_a(x)$-$R_a(y)$ for the ITO with the CNTs under the laser the higher as well.

The anisotropy of the alignment properties in the ITO modifications could be visualized via the wetting angle measurements. Fig. 2,*a* demonstrates the initial distribution of the wetting angle for pure ITO without the laser ablation. In this case the relief is isotropic, thus the wetting angle in the *xz*-projection (perpendicular, $\theta_\perp$) and *yz*-projection (parallel, $\theta_\parallel$) are equal to each other for the same drops. The laser ablation leads to the decrease of the wetting angle to $\theta_\parallel$ = 39.1–59.6° (Fig. 2,*b*) and $\theta_\perp$ = 75.8–85.6° (Fig. 2,*c*).

In order to increase the anisotropy of the wetting, the relief based on the ITO with the CNTs could be used. Due to the rise of the surface area under the deposition of the CNTs [11], the wetting angle becomes bigger as well (Fig. 3,*a*). The rise of initial wetting angle and the higher values of the relief's anisotropy (Table 1) lead to greater anisotropy of the wetting angle: $\theta_\parallel$ = 46.7–65.4° (Fig. 3,*b*) and $\theta_\perp$ = 75.8–85.6° (Fig. 3,*c*).

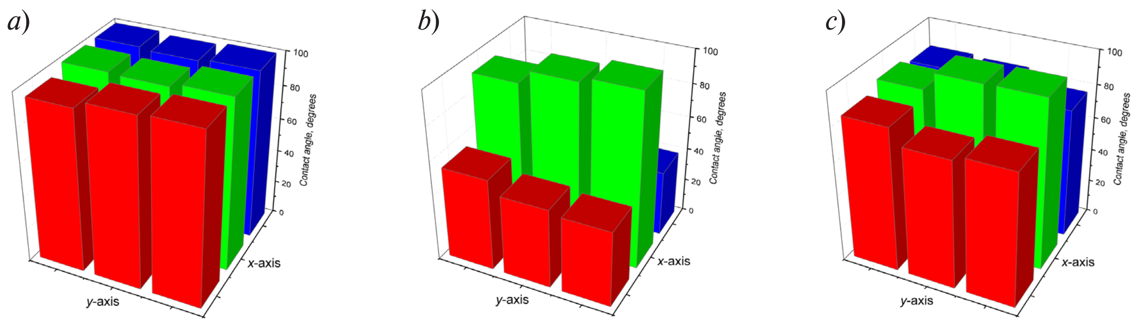

Fig. 2. Contact angle distribution of pure ITO: before the laser ablation (*a*); after the laser ablation: parallel (*b*) and perpendicular (*c*) components

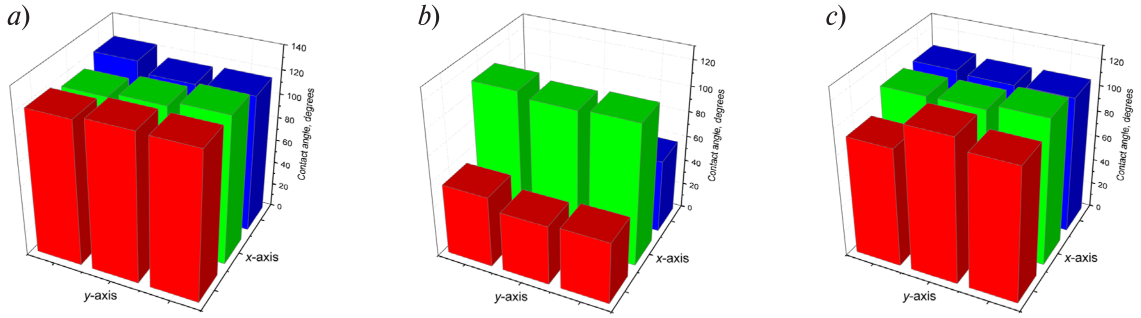

Fig. 3. Contact angle distribution of the ITO with the CNTs: before laser ablation (*a*); after the laser ablation: parallel (*b*) and perpendicular (*c*) components

It should be noticed, that the green markers in Figs. 2–3 correspond to the non-ablated region (the space between). The discussed information regarding to the wetting angle of the ITO modification is demonstrated below.

Table 1

Relief parameters of the ablated areas in the ITO thin films

Structure	No.	*x*-coordinate			*y*-coordinate		
		R_q, nm	R_p, nm	R_v, nm	R_q, nm	R_p, nm	R_v, nm
Pure ITO	1	1.7	5.1	3.8	1.0	2.3	1.8
	2	1.8	4.9	3.7	1.0	2.5	2.2
	3	1.8	4.8	3.8	1.0	2.1	2.9
	4	1.6	5.2	3.6	1.2	3.0	1.9
	5	1.6	5.2	3.6	1.3	3.3	2.0
ITO with CNTs	1	24.3	68.4	73.9	9.1	21.3	16.4
	2	15.7	45.7	48.7	9.1	19.7	17.8
	3	21.9	62.3	52.1	8.5	15.3	18.0
	4	22.0	71.9	49.5	7.1	12.5	17.3
	5	10.9	46.4	32.5	6.2	14.4	13.6

Table 2

Contact angles of the ITO modifications

Structure	Value	Contact angle (min/mean/max), degrees		
		Initial ($\theta_{\parallel} \approx \theta_{\perp}$)	After laser processing	
			$\theta_{\parallel}$	$\theta_{\perp}$
Pure ITO	Min.	95.7	39.1	75.8
	Mean	99.5	49.5	81.1
	Max.	101.2	59.6	85.6
ITO with CNTs	Min.	115.8	46.7	92.2
	Mean	120.2	56.5	104.8
	Max.	124.4	65.4	112.0

Conclusion

The ablation of pure ITO thin films under the CO_2-laser provides the mean anisotropy of the wetting angle $\Delta\theta$ = 31.6°, where $\theta_{\parallel}$ = 39.1–59.6° (mean value of 49.5°) and $\theta_{\perp}$ =75.8–85.6° (mean value of 81.1°). In case for the ITO with the LOD-deposited CNTs, the mean anisotropy $\Delta\theta$ = 48.3, where the parallel and perpendicular component correspond to the ranges 46.7–65.4° (mean of 56.5°) and 92.2–112.0° (mean of 104.8°) respectively. These results can be reasoned via the rise of the relief's anisotropy, what depends on the CNTs clusters impact under the laser ablation. The anisotropy of the wetting angle demonstrates the possibility to change the conditions of the alignment of the LC molecules in order to realize the twisted-nematic configurations in the LC devices.

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