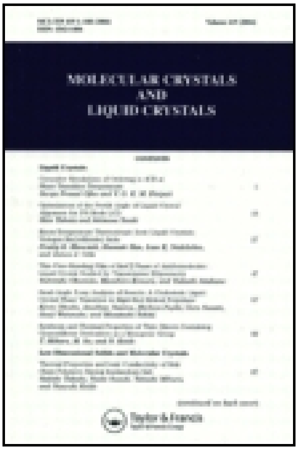

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Laser-Damage Resistance of the Liquid Crystal Modulators

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Laser-damage resistance of the Liquid Crystal Modulators

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Experimental results have been given on laser-damage resistance of the liquid crystal modulator with longitudinal operating electrical field. It was shown that laser-damage resistance of the modulator is limited by the ITO transparent electrodes and equals 2.5 - 2.9 J/cm^2 at 1.06 nm, τ = 15 ns. To improve this parameter we proposed an liquid crystal structure controlled by a transverse electric field in which the ITO electrodes are removed out of the zone intense laser radiation. The main characteristics of this mode liquid crystal modulator are discussed.

Keywords: liquid crystal modulator, laser-damage resistance

Laser damage resistance of Liquid Crystal Modulators with longitudinal operating electrical field

Liquid Crystal Modulators (LCM) are well known and used in a wide range of optical systems. Usually the LCM consists of a number of thin film layers sandwiched between two glass substrates. Transparent electrodes are deposited on the inner surfaces of the glass plates. Initial orientation of the liquid crystal (LC) molecules is determined by alignment layers deposited on transparent electrodes. The thickness of the LC layer is defined by a dielectric spacer. Electro-optical properties of LC layer are controlled by a longitudinal electric field. Light to be modulated passes through all layers of the LCM. Main characteristics of the LCM are:

- maximum modulation frequency;
- speed of response;
- contrast ratio;
- transmission in dark state;
- transmission in light state;
- laser damage resistance.

The last parameter is extremely important in applications of the LCM involving high power laser systems.

We tested laser damage resistance of twisted nematic LCM and its elements: glass substrates, ITO transparent electrodes, alignment and LC layers. We conducted laser interaction experiments using focused output beam a single-mode single frequency Q-switched YAG:Nd laser. Output energy was varied from 15 to 40 mJ, pulse duration was 15 ns, repetition rate - 3 Hz. Special feature of our testing method was use of a probe beam of auxiliary He-Ne laser to visualize damages (Fig. 1). Shlieren picture of tested spot was observed on a screen. The criterion of laser damage was either optical distortions of the probe beam or laser-induced breakdown. The reference sample of polished glass (K-8) substrate was used for the calibration of laser energy density.

The results of laser-damage tests are given in Table 1.

Glass plates and LC materials based on cyanobiphenyls do not limit laser-damage resistance of the LCMs. Laser-damage threshold of alignment layers was slightly less then 6.9 J/cm^2. These layers were prepared by resistive vacuum evaporation of GeO. It was found that this value depends on the conditions of the vacuum process and the thickness of the layer. Transparent ITO electrodes were prepared by standard technological process of cathode sputtering in glow discharge in atmosphere of Ar and O_2. The ITO layers have minimal laser-damage resistance of : 2.9 J/cm^2. It seems that the reason for the damage was thermal heating owing to absorption of the laser radiation by small metal particles or admixtures. The laser-damage resistance of LC cells tested was about the same. Damage in the LCM was displayed by the formation of gas bubbles. Near the damage threshold we observed dissolution of these gas bubbles. We believe that this reversible process was caused by local heating of the LC material near the ITO layers by absorbed laser radiation. Further increasing laser energy density results in the appearance of indissoluble gas bubbles, degradation of the LC materials and the formation of carbonaceous residues. Laser damage threshold of LC cells tested was 2.5 -

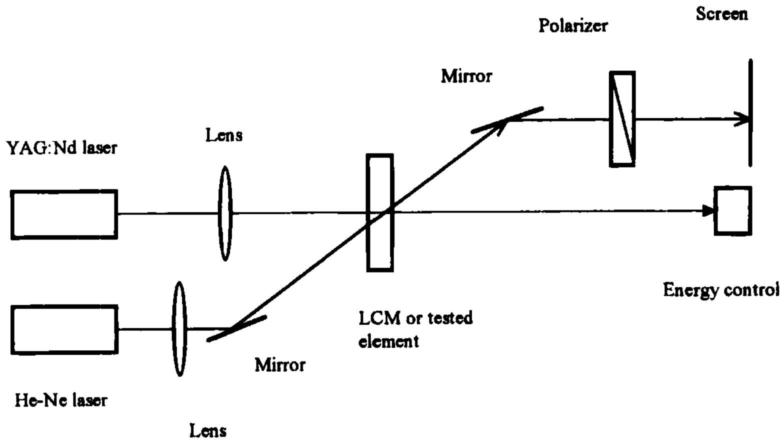

FIGURE 1. Experimental setup for measurement of laser-damage resistance.

TABLE 1. Laser-damage resistance of the LC modulators and its elements.

LC modulator elements	Laser-damage resistance at wavelength 1.06 mcrm and impulse duration 15 ns, J/cm^2
Glass substrate, K-8	> 16.0
Liquid crystal layer $\Delta n = 0.22$; $\Delta\varepsilon = +12.0$; $\Delta t = 0 - 59\ ^{\circ}C$	> 16.0
Alignment layer, GeO, d = 300 °A Oblique vacuum deposition	6.9
ITO transparent electrode, cathode sputtering, 90% In_2O_3 + 10 % SnO_2, Conductivity - 200 Ω/□	2.5 - 2.9
LC modulator with longitudinal electric field	2.5 - 2.9
LC modulator with transverse electric field	6.7 - 6.9

2.9 J/cm^2. This energy density corresponds to the appearance of dissoluble gas bubbles.

It is obvious that this laser-damage resistance does not meet the requirements of some laser systems and optical devices.

Electro-Optical Characteristics and Laser Damage Resistance of the Liquid Crystal Modulator with Transverse Operating Electric Field

To improve the laser-damage resistance we propose a new LCM structure in which the ITO electrodes are removed out of the zone of intensive laser radiation. In this structure the optical properties of the LC layer are controlled by a transverse electric field.

The LCM configuration is shown in Fig.2. The electrodes are made as thin strip from ITO. The transparent strip electrodes are deposited on one glass substrate only. The other side of the LC layer is limited by a glass substrate without electrodes. Both inner surfaces of the glass plates are coated with alignment layers. As alignment layers we used oblique evaporated GeO with thickness 200 - 300 °A. The control voltage is applied to two neighboring electrodes. The laser beam to be modulated passes through the gap between them. We studied the electro-optical properties of the LCMs with two

initial alignment of LC molecules (Fig.3):

- homogeneous orientation of LC molecules along the electrodes direction (S-structure);
- twisted structure (T-structure).

The effect of applied voltage on LC and its optical properties are shown in Fig 3. The electrode width was 1 mm, the gap between electrodes (l) was changed from 10 to 300 μm and LC layer thickness d from 3 to 10 μm. LC materials was used with following parameters : $\Delta n = 0.22$; $\Delta\varepsilon = +12.0$; $\Delta t = 0$ - 59°C. The LCM was driven by a triggered pulse generator giving electrical pulses of variable duration and amplitude. Electro-optical response was measured at 633 nm.

Typical electro-optical characteristic for twisted structure is shown in Fig. 4. Transmission of the T-structure in parallel polarization is minimum in the off-state (U = 0). Increasing the applied voltage results in untwisting of the initial T-structure and leading to increasing transmission in the gap between the electrodes. The dependence of contrast ratio as a function of applied voltage is monotonic. The contrast ratio for this structure was not less then 400:1. The threshold voltage U_{th} of this electro-optical effect has approximately linear dependence on the gap width l between two neighbouring

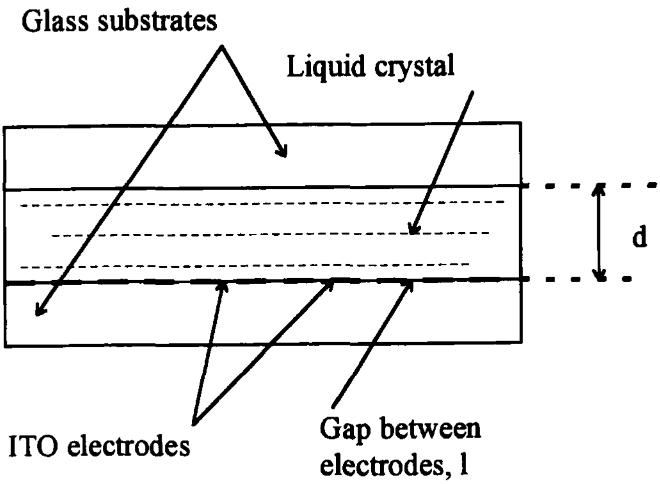

FIGURE 2. The LCM configuration with transverse operating electric field.

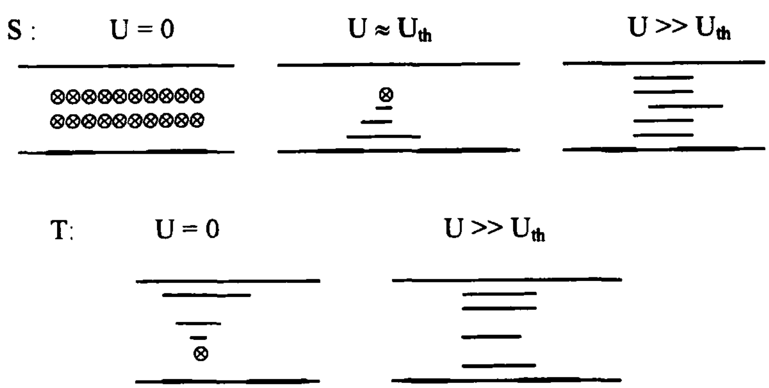

FIGURE 3. Electro-optical effects in S- and T-structures

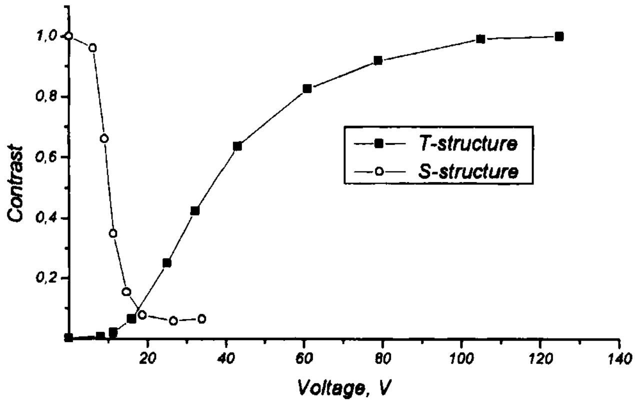

FIGURE 4. Contrast ratio as a function of applied voltage for T-structure (d = 3μm, l = 100 μm, parallel polarizes) and for S-structure (d = 3 μm, l = 20 μm, crossed polarizes)

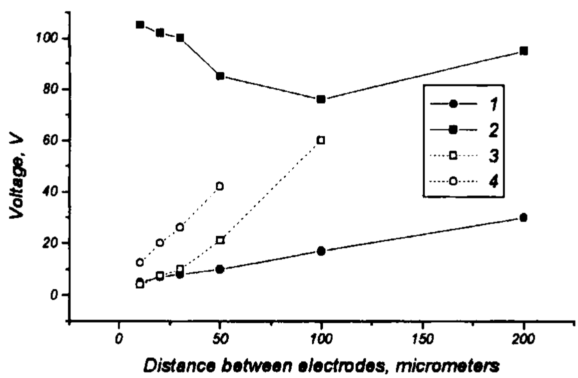

FIGURE 5. Threshold voltage and saturation voltage as a function of distance between electrodes: 1 - threshold voltage for T-structure, 2 - saturation voltage for T-structure, 3 - threshold voltage for S-structure, 4 - saturation voltage for S-structure (d = 3 μm)

electrodes (Fig. 5). This dependence corresponds to the well known expression describing threshold voltage as a function of LC parameters:

$$U_{th} = \frac{\pi l}{d}\sqrt{\frac{4\pi K_{ii}}{\Delta\varepsilon}} \qquad (1),$$

where d - thickness of LC layer, l - distance between electrodes, K_{ii} - corresponding elastic constant, $\Delta\varepsilon$ - dielectric anisotropy. Dependence of saturation voltage U_s on gap width is not monotonic.

In the case of the S-structure (the LC molecules are parallel to the electrodes) the electro-optical characteristics of the effect are also monotonic (Fig. 4). However, the LC molecules are reoriented in a more complicated way (Fig. 3). Voltages that exceed the threshold value result in a spiral twisting; further increasing of voltage leads to untwisting in the opposite direction. The contrast ratio for this case is equal to 20:1. The S-structure also shows an approximately linear dependence of the threshold and saturation voltage vs. gap width Fig. 5, according to equation (1).

Times on for T- and S-structures approximate to a l/U relationship, where l is the gap width and U is the applied voltage. Times on for both S- and T-structures are presented in Fig. 6 and Fig. 7. Minimum time on 0.07 ms was obtained for the T-structure with d = 3 mcrm, l = 10 mcrm, and the applied voltage 90 V. Time off for the LCM with the T-structure was 20 ms. Time off does not depend on the gap width but only on the LC layer thickness. It should be noted that LCMs, controlled by a transverse electric field, exhibit better time characteristics in comparison to the analogous devices with a longitudinal electric field. In the latter rise times are usually 0.5...1 ms. The reason for this is that it is possible to use thin LC layers in LCMs with transverse operating electric field without danger of electrical breakdown. Such breakdown is the main factor limiting times on in LCMs with longitudinal electric field. The breakdown voltage is not because of a liquid crystal characteristic but is the result of technological defects (admixtures to LC, inhomogeneous profile of conducting layers, etc.). These reasons lead inevitably to variations of electric field in LC layer. For transverse geometry, these technological shortcomings are much less important, and one can realize a bigger electric field in LC layer with a smaller thickness, and thus improving the response time of the device.

Laser damage resistance of the LCMs with a transverse electric field was studied in the same setup that was used for testing of the LCM with a longitudinal operating electric field. It was shown that laser damage resistance of the LCM with transverse operating electric field was 6.7 - 6.9 J/cm^2 at 1.06 nm, τ = 15 ns. The improvement of laser-damage resistance was achieved by

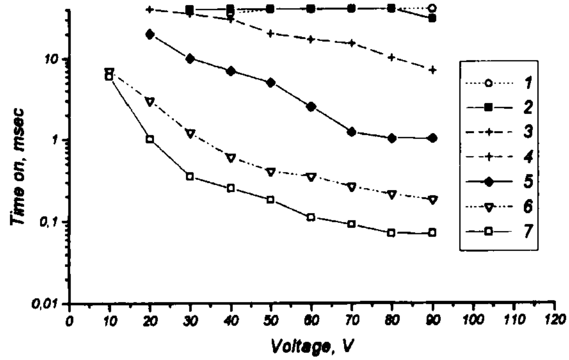

FIGURE 6. Time on (T-structure, d = 3 μm) as a function of applied voltage at different distances between electrodes: 1- 300; 2 - 200; 3 - 100; 4 - 50; 5 - 30; 6 - 20; 7 - 10 μm

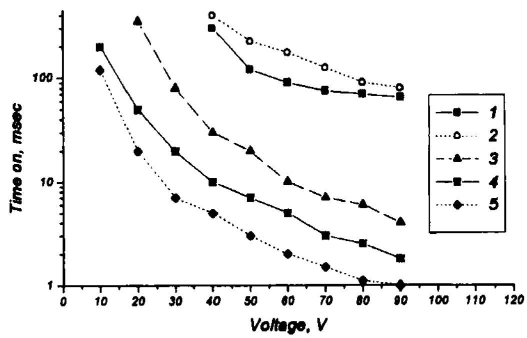

FIGURE 7. Time on (S-structure, d = 10 μm) as a function of applied voltage at different distances between electrodes: 1 - 200; 2 - 300; 3 - 100; 4 - 50; 5 - 20 μm

removing of the ITO transparent electrodes out of the zone of intense laser radiation.

Conclusion

Experimental results have been given on laser-damage resistance of LCMs with longitudinal operating electrical field. It was shown that laser-damage resistance of the LCM is limited by the ITO transparent electrodes and equals 2.5 - 2.9 J/cm^2 at 1.06 nm, τ = 15 ns. To improve this parameter of the LCM we proposed an LCM structure controlled by a transverse electric field in which the ITO electrodes are removed out of the zone intense laser radiation. The main characteristics of the LCM are the following: time on - 0.07 ms, time off - 20 ms, contrast ratio - 400:1 (LC layer thickness - 3 mcrm, distance between electrodes - 10 mcrm, operating voltage - 90 V). The laser-damage resistance of 6.7 - 6.9 J/cm^2 is a promising feature for the LCM with transverse electric field for high power laser applications.

Obtained results allow us to conclude about possibility of use of the LCM with transverse operating electric field as dynamic diaphragm for intracavity laser beam spatial control. The laser systems with internal LCMs can provide swift laser beam scanning, precise addressing of laser radiation and generating of laser beams with complicated spatial structure[3].

References

[1.] F.L.Vladimirov, N.I.Pletneva, V.P.Pokrovskiy, L.N.Soms "Transverse-electric-field induced electro-optical effects in nematic liquid crystals", European Conference on Liquid Crystals, Science and Technology, Zakopane - Poland, March 3 - 8, 1997, Abstracts, D-8

[2.] F.L.Vladimirov, E.A.Morozova ,Sov.J. of Opt. Technol.,**10**, 61,(1989)

[3.] A.F.Kornev, V.P.Pokrovskiy, L.N.Soms, V.K.Stupnikov, J.Opt. Technol. **61**, 1, (1994)