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The durability of a liquid crystal modulator for use with a high power laser

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Abstract
The durability of a liquid crystal (LC) modulator for use with a high power laser is measured at a wavelength of 808 nm. It is shown that the LC modulator can withstand a laser power density of 133 W cm^{-2}. For a laser power density greater than 133 W cm^{-2} the phase transition is caused by the absorption of the material. In order to improve the durability, the absorption of glass, polyimide (PI), indium tin oxide and LC were measured. Results indicated that the phase transition of the nematic LC is mainly caused by the absorption of glass and PI. These results can be used for a LC modulator with nematic LC material, and it is important to use an LC modulator in optical systems with high power lasers.

Keywords: liquid-crystal devices, laser damage, spatial light modulator

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Liquid crystal (LC) modulators have been used for optical testing [1], wavefront correction [2, 3], computer generated holography [4, 5] and beam steering [6]. They are particularly useful for wavefront correction in adaptive optics systems [7]. The temporal bandwidth problem has been solved by using a dual frequency LC [8]. Sometimes an LC modulator is used to correct a distorted laser beam with high luminous power, for example in laser weapons, and in such cases the LC modulator may possibly be damaged. Consequently, we should consider the durability of LC modulators under illumination by high power lasers.

Many studies have been made of the temperature characteristics of LC material [9–11]. But these just measured the temperature characteristic of the LC by using the heating method and did not investigate the effect of the high power laser. Recently, a study of a heat-resistant LC spatial light modulator for high-power lasers was made by Gu [12].

In this paper the durability of LC modulators is discussed and a method for improving their durability is given. As LC modulators are very expensive and can be damaged by a high power laser, a LC modulator with a single pixel was fabricated and used in all of our experiments. We used a continuous laser with wavelength of 808 nm is our experiments.

2. Measuring the durability of the LC modulator

2.1. The transmission method

The nematic LC (NLC) material RDP-92975 (DIC) was selected for investigation of its ability to withstand laser irradiation because NLC material is used in most LC modulators. One twisted nematic (TN) cell was fabricated as the LC modulator with a twisted angle of 90°. First, the ability to withstand the laser power was investigated by measuring the variation in light transmission of the LC modulator with the optical setup shown in figure 1. One 5 mW He–Ne laser was chosen as the illuminating source and an optical power meter was used to detect the change in the intensity while the light traverses the polarizer, LC cell and the analyser. A tunable high power GaAs laser with a fibre output was selected to test

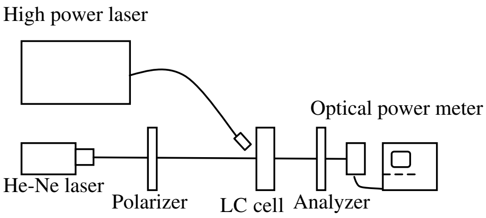

Figure 1. Optical layout for measuring the durability.

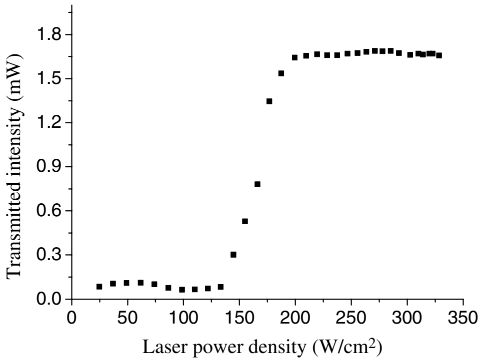

Figure 2. The transmitted intensity as a function of the laser power density.

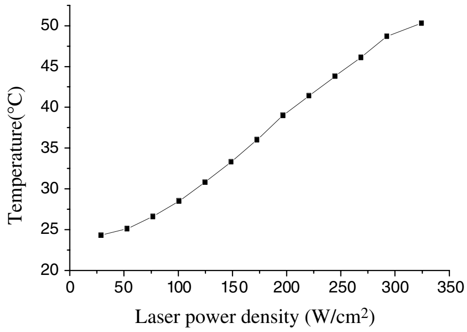

Figure 3. The temperature as a function of laser power density.

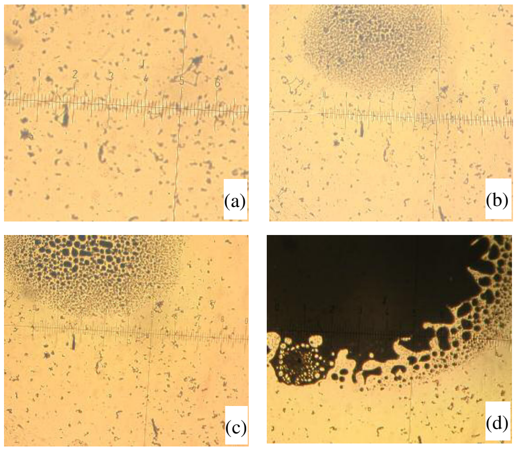

Figure 4. Observed results with the digital camera: (a) for a laser power density less than 133 W cm^{-2}; (b) and (c) for a laser power density larger than 133 W cm^{-2}; (d) for a laser power density of 153 W cm^{-2}.

the durability of the LC modulator. The GaAs laser has 23 W maximum power, 808 nm wavelength and a Gaussian beam. The aperture diameter of the fibre is 400 μm. The diameter of the light disc is approximately 3 mm when it reaches the surface of the LC modulator. The polarizer and the analyser are parallel aligned, so the TN cell with this analyser and polarizer is a normally black mode. The He–Ne laser and GaAs laser illuminate the same area on the LC modulator in order to accurately measure the change in intensity. The power of the GaAs laser was tuned and the optical power meter used to measure the power change of the He–Ne laser. Figure 2 shows the change in the transmitted intensity with increasing GaAs laser power density. It indicates that the transmitted intensity increases dramatically while the laser power density is larger than 133 W cm^{-2}, but remains almost constant when the laser power density is more than 187 W cm^{-2}.

The temperature change of the LC modulator was measured with a thermocouple, as shown in figure 3. It was found that the temperature increases as the laser power is increased, and the maximum temperature is 50.3 °C. As the clear point of RDP-92975 is 100 °C, phase transition of the LC material does not take place. However, the thermocouple is placed near the area of the light and cannot measure the temperature of the area of the light directly; this may cause a large error in the temperature. Consequently, we think that the change in the transmission may be caused by:

(1) Rotation of the LC molecule; if the light passes the TN cell and its electric field vector has an angle with the long axis of the LC molecule, its electric field will interact with the inducible dipole of the LC molecule. Then, it is possible for the LC molecule to be rotated along the direction of the electric field vector. For low laser power, the molecule cannot be rotated and the transmitted intensity is almost unchanged. As the laser power continues to increase, the LC molecule is rotated and the transmitted intensity increases accordingly. The molecule cannot be rotated while the alignment of the LC molecule is parallel to the electric field vector. Consequently, the transmitted intensity remains unchanged.

(2) Phase transition; the high power may lead to an increase in temperature of the LC modulator as the LC modulator absorbs the laser power. If the temperature is higher than the clear point, phase transition of the LC material will take place and the transmitted intensity will increase drastically. The transmitted intensity will not change while the LC transforms to completely isotropic material.

2.2. *Observation with a polarized light microscope*

In order to verify our considerations, a polarized light microscope and a digital camera were used to observe the change in the LC material. The polarizer and analyser of the polarized microscope are vertically aligned. We also control the diameter of the light disc to be approximately 3 mm when it reaches the surface of the LC modulator. Figure 4 shows the observed results while the laser power density

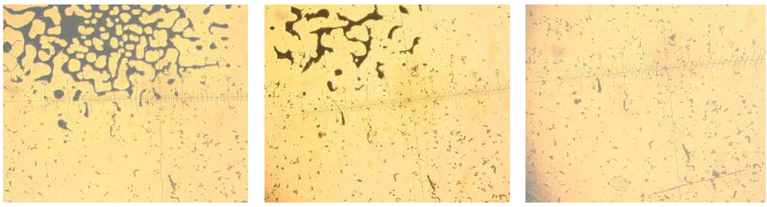

Figure 5. The observed results for decrease in the laser power density from 141 W cm^{-2} to 133 W cm^{-2}.

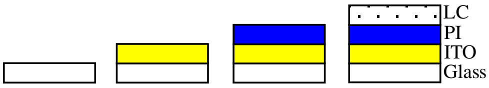

Figure 6. The structure of the four samples.

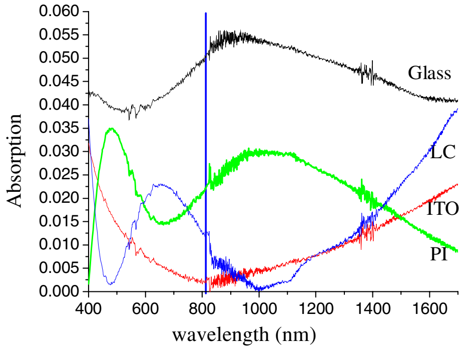

Figure 7. The absorption curves for glass, LC, ITO and PI.

changes from 0 to 153 W cm^{-2}. On the condition that the laser power density is lower than 133 W cm^{-2}, the LC does not have a phase transition as the observed area remains in the homogeneous bright state (figure 4(a)). However, phase transition takes place when the laser power density is larger than 133 W cm^{-2} (figures 4(b) and (c)). The area of the phase transition increases as the laser power density becomes larger and larger (figure 4(d)). If the changed area is caused by molecule rotation, the whole of the changed area should be homogeneous. But the changed area is composed of the small black and bright areas. Consequently, we can say that the drastic increase in transmitted intensity at 133 W cm^{-2} is caused by phase transition of the LC and not the rotation of the LC molecule. Then, we increase the power density to the maximum value of 325 W cm^{-2} and hold it for some minutes. After the laser is turned off, the observed area returns to the bright state.

To investigate the long time durability of the LC modulator, the laser power density is increased to 141 W cm^{-2} and the LC phase transition takes place. Then, the laser power density is decreased to 133 W cm^{-2}; the observed results are shown in figure 5. This indicates that the material returns to the liquid crystal state while the laser power density is 133 W cm^{-2}. Consequently, the LC modulator keeps a heat balance at a power density of 133 W cm^{-2}.

3. Absorption analysis

The measured results show that the LC modulator has an absorption for the 808 nm laser and we should investigate the absorption of each component of the LC modulator to optimize and decrease the absorption. The LC modulator consists of glass, polyimide (PI), indium tin oxide (ITO) and LC. In order to analyse the absorption of these materials, a block of bare glass with a thickness of 0.7 mm was cut into four pieces. The structure of the four samples is shown in figure 6.

The absorption was measured with an ultraviolet spectrograph (UV3101-PC, Shimadzu) and the results are shown in figure 7. The spectrograph has two light beams. One is a reference beam and the other is used to measure the absorption of the material. First, the reference material is air and the absorption of the glass is measured. Then the glass is moved into the reference beam and the sample with glass and ITO is put into the measurement beam. Thus, the absorption of ITO can be measured. Accordingly, we can also measure the absorption of PI and LC with this method. Results indicate that the absorption is different at different wavelength for these materials. For a wavelength of 808 nm, as shown in figure 7, the relation of the absorption ability is glass > PI > LC > ITO. This indicates that the increase in the temperature of the LC cell is mainly caused by the absorption of glass and PI. Consequently, it is feasible for the LC modulator withstand a higher laser power density by optimizing the material of glass and PI. In addition, if it is used at other wavelengths, we can also select the corresponding material according to the absorption curve.

4. Discussions and conclusions

Optical systems with high power laser, such as laser weapons, are being investigated by many people. Similar to an astronomical telescope, such systems encounter air turbulence, heat distortion and other system aberrations. These distortions can be solved with adaptive optics. An LC modulator is very suitable for be used in such adaptive optics system with a high power laser. Consequently, the durability of the LC modulator to the laser power should be considered and improved.

Measured results show that phase transition in the LC modulator will take place with higher laser powers, caused by the increased temperature. An LC modulator can withstand a laser power density of 133 W cm^{-2} at a wavelength of 808 nm. As the absorption of the material results in an increase in its temperature, the absorption characteristics should be considered. Measured results indicate that the relation of the absorption ability is Glass > PI > LC > ITO. The phase transition of the NLC is mainly caused by the absorption of glass and PI and the LC modulator can withstand a higher laser power density by optimizing the glass and PI material.

Although only an LC modulator with RDP-92975 was investigated, LC modulators with other NLCs will have similar characteristics. Consequently, these results may be used for LC modulators with NLC material.

Acknowledgments

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References

[1] Cao Z L, Xuan L, Hu L F, Liu Y J, Mu Q Q and Li D Y 2005 *Opt. Express* **13** 1059
[2] Love G 1997 *Appl. Opt.* **3** 1517–24
[3] Hu L F, Xuan L, Liu Y J, Cao Z L, Li D Y and Mu Q Q 2004 *Opt. Express* **12** 6403
[4] Tanone A, Zhang Z, Uang C-M, Yu F T S and Gregory D A 1993 *Opt. Eng.* **32** 517
[5] Hu L F 2005 *Chin. J. Liq. Cryst. Displays* **20** 93 (in Chinese)
[6] Wang X, Wang B, Pouch J, Miranda F, Anderson J E and Bos P J 2004 *Opt. Eng.* **43** 2769
[7] Dayton D, Gonglewski J, Restaino S and Browne S 2004 *SPIE* **5490** 1514
[8] Dayton D, Browne S and Gonglewski J 2005 *SPIE* **5894** 58940M-1
[9] Li J, Sebastian G and Wu S T 2004 *J. Appl. Phys.* **96** 19
[10] Anna M L and Uzi E 1987 *Appl. Opt.* **26** 3441
[11] Wu S T 1986 *Phys. Rev.* A **33** 1270
[12] Gu D, Wen B, Mahajan M, Taber D, Winker B, Guthals D, Campbell B and Sox D 2006 *SPIE* **6306** 630602-1