

Laser Beam Shaping with Optically Patterned Liquid Crystals

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Summer High School Research Program 2009

1. Abstract

Current laser beam shapers such as those used in the OMEGA EP laser system for spatial gain precompensation are made of small metal pixels arranged in a pattern to create a beam shaping device. Laser beam shapers can also be made from liquid crystals (LCs). Because of their unique properties, LCs can be oriented so that they transmit, block, or change the phase of incident light when viewed with the aid of polarizers. This orientation is controlled by a polymer alignment layer in close contact with the LC material. If this alignment layer is a linearly photopolymerizable polymer (LPP) and it is irradiated with polarized UV light, the LC molecules will align along the polymer chains. Irradiating the LPP through a mask, followed by rotating the substrate and irradiating again without the mask, allows the orientation of LCs in different regions of the substrate to be controlled. This process can be used to produce pixellated LC devices that function similarly to metal beam shapers, with both a greater variety of optical effects and a substantially higher laser damage threshold. Future applications of these devices could include erasable and rewriteable beam shapers and apodizers.

2. Introduction

In high-energy laser systems, optimal energy extraction below the damage threshold of the optical components is obtained using an incident beam with a uniform intensity distribution, e.g., a high-order super-Gaussian beam. However, the laser beam must pass through an amplifier with spatially varying gain before it becomes final output. When a uniform beam goes through this amplifier, the intensity in various parts of the beam is changed so that it is no longer uniform. A beam shaper is therefore used *before* the beam goes through the amplifier to precompensate for the effect that the amplifier has on the beam. The shaper transmission and the amplifier gain effectively “cancel out” and the final beam is uniform and high intensity, just as desired.

The OMEGA EP laser system currently uses metal laser shaping devices¹. These devices are made with a grid of microscopic pixels. Each pixel either has the metal removed to leave behind fused silica glass or the metal is still there. Even though each pixel is either full transmission or no transmission, these devices can be manipulated so that, on a macroscopic level, a grayscale between full transmission and no transmission may be achieved. For instance, a higher percentage of metal pixels will result in a shaper that locally lets a lower amount of light through, whereas a higher percentage of glass pixels will result in a higher local transmission.

These metal beam shapers have a damage threshold of around 0.2 J/cm^2 (at 1054 nm, 1 ns), which is very low. The photoalignment layer of liquid crystal (LC) devices has a damage threshold of $27\text{-}60 \text{ J/cm}^2$ (at 1054 nm, 1 ns),² which is much higher than that of the metal beam shaper. The only thing limiting the damage threshold of this device is the LC material itself which may range from $9\text{-}18 \text{ J/cm}^2$, depending on the type of LC. This has been proven in OMEGA, where LC waveplates and polarizers are currently used.²

Liquid crystals can be used in the same manner as the metal beam shapers. Liquid crystals can be combined with a polarizer and oriented in two ways so that one way blocks the passage of polarized light and the other way lets the same type of polarized light through (Figure 1). Ideally, they would be oriented in such a way that one of the two orientations would *completely* block that type of polarized light and the other would allow for *full* transmission.

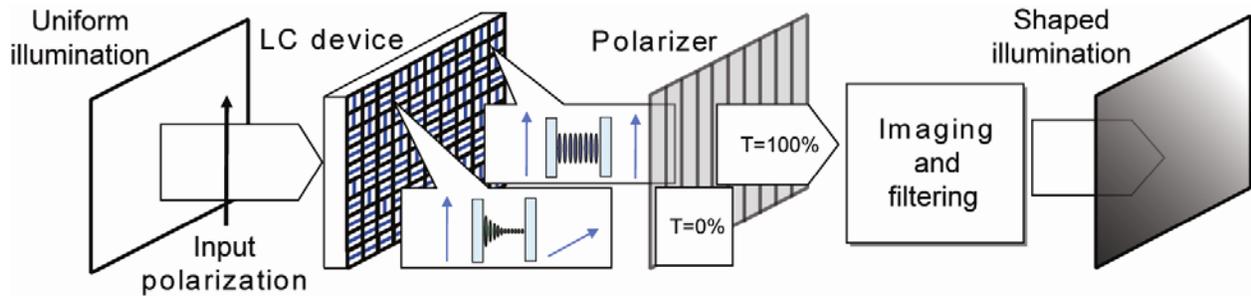


Figure 1: Principle of beam shaping by polarization engineering

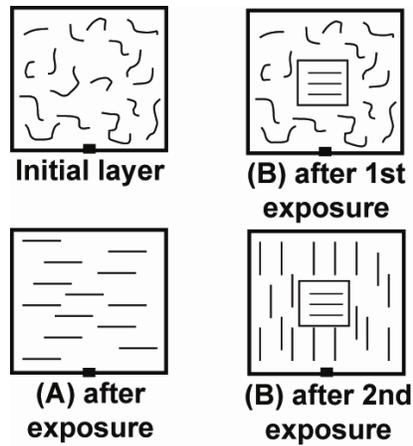


Figure 2: A substrate coated with an LPP before exposure (random orientation); substrate (A) after uniform exposure, substrate (B) after first exposure through a mask with a transparent central square, and substrate (B) after second exposure without mask. The lines on the substrate surfaces indicate orientation of LC molecules.

There are currently two methods used to align LCs on a surface. The first and standard method is mechanical buffing. In this process, LCs are aligned by rubbing the coated substrate with a velvet cloth. However, this is a very dirty process, so a new method for aligning LCs has emerged.³ This “photobuffing” process is a non-contact process, making it cleaner than mechanical buffing which involves a buffing mechanism actually making contact with the substrate, which in turn may impart foreign particles upon the surface.^{4,5} In the process of photobuffing a linearly photopolymerizable polymer (LPP) is deposited on a glass substrate. When the LPP is first laid down on the substrate,

the polymer molecules are in a random order (Figure 2). When exposed to polarized UV light, the long polymer chains line up perpendicular to the direction of the polarization. LCs will align themselves along these polymer chains. This process makes it possible to pattern LC cells. This can be done by irradiating the LPP with a mask and then rotating the substrate and irradiating a second time without a mask (Figure 2). With buffing, patterning is very difficult and rarely produces good results.^{6,7}

3. Experiment

Substrates were cut from glass microscope slides with a glasscutter. Pre-cut fused silica glass substrates were also used. These substrates were wetted with water and scrubbed with 0.05 μm deagglomerated alumina micropolish, rinsed with DI water, and then cleaned in an ultrasonic bath at 69°C for 60 minutes. The substrates were then dried with an air gun and put on a hotplate to dry at 110°C for 10 minutes.

The cleaned substrates were placed on a spin-coater and flooded with pure cyclohexanone. The spin-coater was covered with a glass dish for 2 minutes to prevent evaporation and allow cyclohexanone to equilibrate with the glass substrate and produce a saturated vapor atmosphere. Excess cyclohexanone was spun off at 3000 rpm for 30 seconds to remove it from the surface of the substrate so that the LPP could then be applied. Approximately 0.3 mL of 25% diluted ROLIC ROP-103/2CP (LPP) was then deposited on the substrate through a 0.2 μm PTFE 25 mm hydrophobic syringe filter. After waiting 30 seconds, the substrate was spun at 3000 rpm for 60 seconds. The coated substrates were allowed to air-dry for 10 minutes before being irradiated with UV light.

Photoalignment was accomplished by placing the substrates on a rotatable stage beneath a 500-watt UV lamp at 325 nm. They were placed beneath a “pile of plates” polarizer made of



Figure 3: apparatus used to hold Brewster's angle polarizer

fused silica microscope slides arranged at Brewster's angle of 56.1° (Figure 3). Photopatterning of the alignment layer was accomplished by irradiating one substrate at 0° rotation, with no mask. The second substrate was irradiated first with a patterned mask. Then, the mask was removed, the substrate was rotated 90° , and it was irradiated without any mask. Irradiation times between 1 and 5 minutes were used.

After being irradiated, substrates were baked on a hot plate at 130°C for 10 minutes. A “spacer epoxy” was created by dispersing glass microspheres into EPO-TEK[®] OG154 UV epoxy. To create a cell, a small amount of this “spacer epoxy” was placed on each of the four corners of the first substrate. The second substrate was placed on the first one in such a way that the initial direction of 0° of rotation in each substrate was 180° from that of the other (anti-parallel assembly). The epoxy was cured under a UV lamp for 3 minutes. The assembled cells were filled with nematic E7 on a hotplate at 82°C , sealed with epoxy around the edges, and allowed to cure for 15 to 20 minutes. The completed devices were then cleaned using acetone to remove any excess LC and epoxy from the optical surfaces.

4. Discussion

A contrast ratio (ratio of maximum transmission to minimum transmission) of up to 167:1 has been measured using an infrared laser. A contrast ratio of at least 1000:1 would be

necessary for use in a laser system. A higher contrast ratio could be achieved with improvements in the photolithography technique.

A correlation was found between exposure time and photoalignment resolution. Substrates that were irradiated with UV light for 5 minutes were found to be overexposed. Smaller features became blurred. Pixels that were supposed to be 10 μm

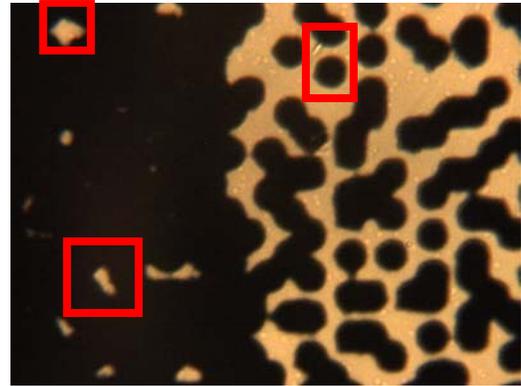
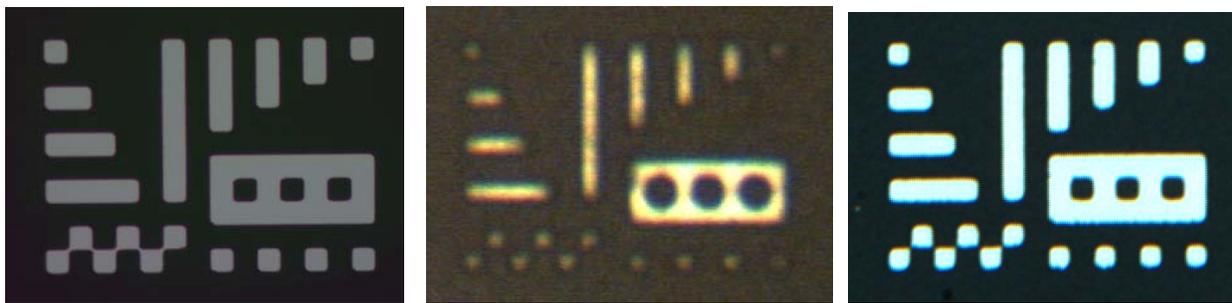


Figure 4: LC devices viewed through crossed polarizers created with a 10 μm pixel mask; all pixels should be the same size squares

became round blobs instead of squares (Figure 4). These pixels overtook regions of the other pixels, making them smaller than 10 μm . The overall transmission was changed. Less light was allowed through because the darker pixels had grown and overtaken the lighter ones. When compared side by side, the mask looked much more uniform and had square pixels. However, when a shorter exposure time of 1 minute was tried, photoalignment resolution greatly increased (Figure 5).



100 μm

Figure 5: metal mask (right), LC devices viewed through crossed polarizers: 5 min exposure time (middle), 1 min exposure time (left)

Regions of reverse twist were found in some cells. Reverse twist is a phenomenon that occurs in twisted nematic cells. If the LC molecules have no preferential twist direction, there is

a 50% chance as to which direction they will twist in. In these cells, domains are formed of the two different twist directions, and lines can be seen on the boundaries of these domains (Figure 6).

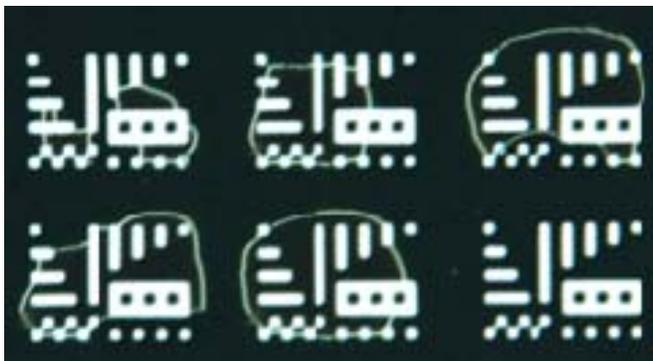


Figure 6: domains of reverse twist

This can be corrected by adding an anti-

reverse twist agent (a small amount of a cholesteric LC) to the E7. This would give the LC molecules a preferred direction in which to rotate.

5. Conclusions

The purpose of this study was to determine whether photopatterning could be applied to pixels as small as 10 μm . It has been determined that this is indeed possible. With more careful and precise photolithography techniques, a sharper image with better contrast could be produced. This study was able to produce pixels much smaller than ever before using photoalignment.

There are many useful applications of the successful photoalignment of these small-sized pixels. These devices could be used in advanced laser systems such as OMEGA EP, eventually replacing the currently used metal beam shapers. Also, the photoalignment process has proven to be more reliable and hopefully will become more widely used in the near future.

Future experiments should be done to determine the optimal exposure time and exposure intensity. Photopatterning could be attempted on pixels smaller than 10 μm to see what sizes of features can be successfully photopatterned. Also, the possibility of making erasable and rewriteable devices with the use of glassy LCs and azobenzene “command layers” should be explored as a long term goal.

6. Acknowledgements

I thank Dr. R. Stephen Craxton for running the LLE high school program and giving high school students a research opportunity. I also thank my advisors, Christophe Dorrer and Kenneth L. Marshall for giving me instruction and supervision. Additionally, I thank all of the Materials Lab staff and students, especially Cathy Fromen and Zeyu Zhao and Mr. Allen Bolognesi from Precision Optical Imaging for his guidance and helpful comments on photolithography techniques.

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