Electrically Tunable Fresnel lens Based on Azo Dye Doped Nematic Liquid Crystal

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Abstract

Fresnel lens is a kind of lenses, which include dark and bright rings. By adding electrically variable focal length feature to Fresnel lens, a new kind of lens has been introduced. The methyl red dye was doped to nematic liquid crystal with 1% w/w. By illumination of cell with 532 nm laser using a Fresnel lens shaped mask and according to guest host effect, the IR spectroscopy results show that the dye molecules near the cell surface make a hydrogen bond with PVA layer on cell, which make them remains in contact with surface on illuminated parts. Therefore, according to guest-host effect, this kind of dye can make new specifications on liquid crystal cell so, pattern can be print on the surface of cell. This new configuration lead to change the reorientation of LC molecules in the ring shape illuminated parts of cell and the According to experiments, the focal length of developed lens can change from 29 cm to 44 cm.

Keywords: Liquid Crystal, Diffraction, Lens, Fresnel, Azo Dye

Introduction

Fresnel lenses are the collapsed version of ordinary lenses and their working basis on the focusing light by diffraction instead of refraction[1]. The binary phase of the Fresnel lenses leads to the focus the light when the difference between two adjacent zones is equal to an odd multiple of [2]. The problems of regular Fresnel lenses, are their large size and their focal length is constant [4]. With adding variable focal length feature to these kinds of lenses, it can be a significant contribution to elimination of mechanical elements and thus, reduce the volume of optical systems. For this purpose, using Liquid Crystals are the best choice. The electro-optical feature of these materials can be controlled by applying external electric fields[3].

Doping LCs with azo dyes will cause an interesting induction process in these materials. Azo compounds are type of materials with consisting R-N=N-R ‘groups, which R and R’ are alkyl groups[4]. Due to decomposition of the azo linkage (N=N), the molecular form of the azo dyes may change[5]. Thus, this combination can appear in two forms which names are Trans and Sis[6]. With a beam irradiation in the absorption wavelength of the dyes, the probability of trans-cis-trans photoisomerization occurs[7]. In each period, the location and direction of the molecules are randomly bonded. After several cycles, the molecules move away from the polarization direction of the irradiance beam (perpendicularly) and show less risk of beam absorption and cycle participation[8]. Systematically, the number of molecules increases and the molecular directions oriented perpendicularly to the polarization direction of irradiance beam. By doping LC with azo dye, the dyes in the effect of the reorientation of LC molecules are organized[9]. Due to the light field, with a high induction effect, azo dyes are reoriented. This reorientation will apply a torque on the LC molecules, which cause a reorientation on the LC molecules[10].

In this work, by adding 1% azo methyl red dye to nematic liquid crystal structure and print Fresnel Zone pattern on the cell, tunable Fresnel Lens have been made.

Theory

A Fresnel lens, which called Kinoform lens[11], contains number of symmetric radial rings which names are Fresnel zones. This zones are separated to the dark and bright areas and they are such designed to light can through in bright areas and then, we can have constructive interference to making focal point[12]. To study Fresnel lens properties, a simple plane wave that irradiates toward the lens was chosen. Considering a source point with distance equal to r from centre of Fresnel zone plane. The distance between source point and focal point which is calling light travelled length, is showing with r:

$l = \sqrt{r^2 + f^2}$

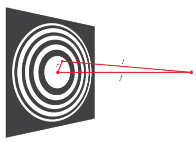


Figure 1: This is a caption

Path of light travelled length between a source point and centre of Fresnel zone ($r = 0$) is equal to focal length:

$l_0 = f$

The goal is finding the source points that are in the focal point will make constructive interactions. When this phenomena occurs if the difference between light travelled length from l_0 is not more than $\frac{\lambda}{2}$:

$l - l_0 < \frac{\lambda}{2}$

The source points, which satisfies this condition, are the first zone. Fig.2 is showing this zone:

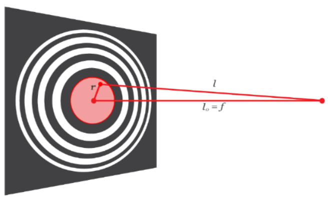


Figure 2: This is a caption

When the source points are far from Fresnel zone, amount of $l - l_0$ is getting more than $\frac{\lambda}{2}$. These points with light travelled length must satisfy this condition:

$\frac{\lambda}{2} < l - l_0 < \lambda$

This condition defines the second zone and will make distraction interaction with first zone. The second zone is showing with blue colour in Fig.3:

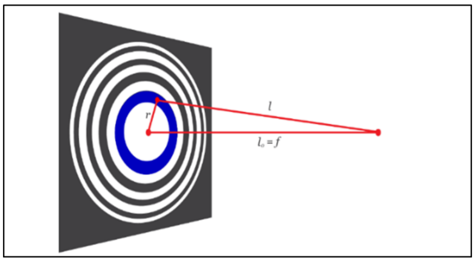


Figure 3: This is a caption

Continuing this process, the definition of nth zone; totally can define as set of source points with light travelled lengths, which satisfies this condition:

$\frac{(n-1)\lambda}{2} < l - l_0 < \frac{n\lambda}{2}$

n is a positive integer from one to N. N is showing number of zones in Fresnel zone.

To calculate the radius of nth zone, one can have[13]:

$R_n^2 = nR_1^2$

The focal length of the manufactured Fresnel lens is related to the first area which can calculate[14]:

$f = \frac{R_1^2}{\lambda}$

The difference between the odd and even areas of the Fresnel lens is π. The first-order diffraction efficiency for an individual phase binary Fresnel zone plate achieved as:

$\eta = \left[\frac{\sin(\frac{m\pi}{2})}{(\frac{m\pi}{2})}\right]^2$

Looking at equation 8, we find that the diffraction efficiency of the primary focus is theoretically 40.5%. In addition, the experimental diffraction efficiency can calculate[11]:

$\eta = \frac{(P - P_0)}{P_t}$

Experimental

Materials

For making Fresnel lens structure which is based on dye-doped LC (DDLC), a 43 micrometre HG cell with indicated ITO layer and also, 1294-1b LC (both are from AWAT-PPT Company – Warsaw, Poland) was used. The properties of this LC is showing in Table 1[15]:

Properties of 1294-1b nematic Liquid Crystal

Liquid Crystal	Molecular Shape	Transition Temperature (TNI)	Ordinary Refractive Index	Extraordinary Refractive Index	Birefringence ( )	D A (
	Isotiosianat Mixture					

In addition, for recording Fresnel pattern, a mask according to the active zone of our cell (5x5 mm2) have made. Characteristics of this mask is in Table2:

Table 2 Properties of designed mas

Number of zones	n=25
Radius of first zone	r1=0.0005 m
Radius of 24th zone	r24=0.002449 m
Radius of 25th zone	r25=0.002500 m
Thickness of 25th zone	d25=51 μm

According to equation (7), the calculated focal length for this mask is 39.5 cm.

Setups

A 100 mW stable green diode laser($\lambda = 532\ nm$)with S (electric field parallel to the groove of the cell) polarization with beam diameter equal to 1 mm was used. The relevant setup for printing pattern on cell's surface is showing of Fig.4:

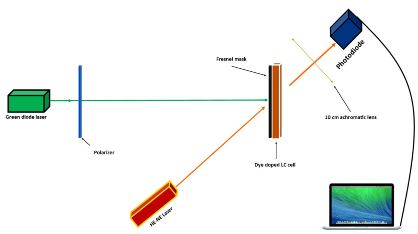


Figure 4: This is a caption

In this setup, a beam, which is coming out from laser, is crossing through a polarizer with S polarization. The mask, which made according to above information, was clinging on the cell with tape adhesive. In addition, a 1 mW stable HE-NE laser was used for probe writing process. A 10 cm achromatic lens (which have less aberration feature) used for focalizing probe beam to photodiode. To evaluate changes in focal length and diffraction efficiency of the lens, we use a 1mW He-Ne laser with P polarization. The relevant setup is showing on Fig.5:

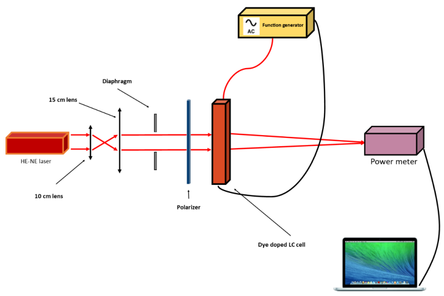


Figure 5: This is a caption

As Fig.5, beam after laser will see two different lenses which was used for parallelism of the beam. After that, a diaphragm used for choosing particular size of the beam. A function generator with square frequency about 1.5 KHz was applied electrical field to cell and a power meter used for locating maximum intensity of light, which was showing focal point.

Results and discussion

Printing Pattern

After filling cell with dye doped liquid crystal and using Fig.4 as printing setup, a tunable Fresnel lens base on dye doped liquid crystal have made. Room temperature was set on 25 C. As first results, we examine printed pattern and mask which have used in printing process under polarized microscope (with 30-micrometre resolution) and comparing them. Fig (6.a) and Fig (6.b) are showing mask and printed pattern on the surface of cell respectively.

During 19 hrs process of printing pattern, a He-Ne laser for studying printing process was used. Diagram is showing oscillation of printing process:

According to the diagram, we can see with passing the time, power of passed beam from the cell is getting weak. This is the result of creation of Fresnel pattern and so, diffraction from pattern.

With recording the Fresnel zone pattern on the cell and making a Fresnel lens, odd and even areas will form on surface of the cell. Indeed, in the areas, which exposed to light, the molecules will reorient perpendicularly to the initial order of the cells and because of the high birefringence of the LC molecules; this will create a refractive index difference between odd zones. Moreover, in the bright zones, with providing sufficient energy of light, impurities inherent to the ionization will add. By applying an external electric field, the created ions will separate and due to the direction of the applied field, will re-orient. Indeed, the separation of loads, between them and the zones without load, an electric field which name is field of spatial load will form. If this field is in the opposite direction to the external electric field, this will cause a reorientation in the molecular director and the modulation of the refractive index. Thus it will cause a modification of the diffraction efficiency. Fig.8 shows reorientation of LC molecules after recording a Fresnel zone pattern on a cell:

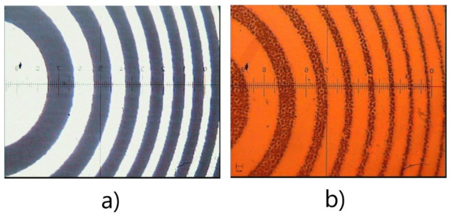


Figure 6: This is a caption

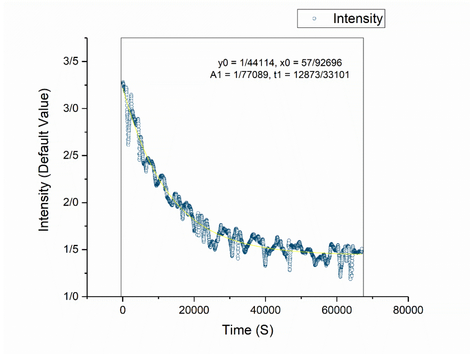


Figure 7: This is a caption

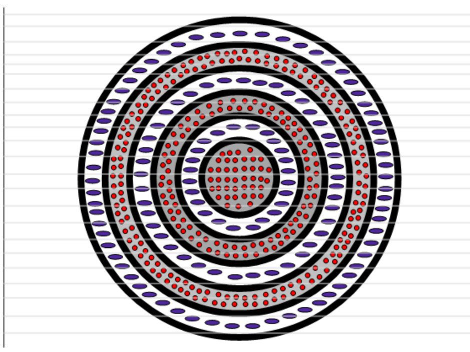
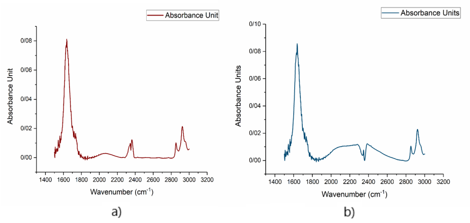


Figure 8: This is a caption

Also, according to IR absorption spectroscopy which is relevant to the way of long tile of azo methyl red linking with surface PVA, understand that hydrogen tile of azo methyl red will link perpendicularly to the surface of cell.



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Diffraction Efficiency

As said previously, for studying diffraction efficiency, we used Fig.5 and equation 9. The power before the cell was 418 mW, after cell 245 mW, and the ambient noise was 0.02 mW. A He-Ne laser used to study the diffraction efficiency. Due to the presence of optical elements in the path of light, decrease in laser power seems to be. Power meter shifts on the x-axis (parallel to output beam) and increase the voltage applied to the cell, the epicentre, according to the diagram below, the intensity can be a slight increase was due to the establishment of the tunability ability of Fresnel lens on the base it is on the cloud:

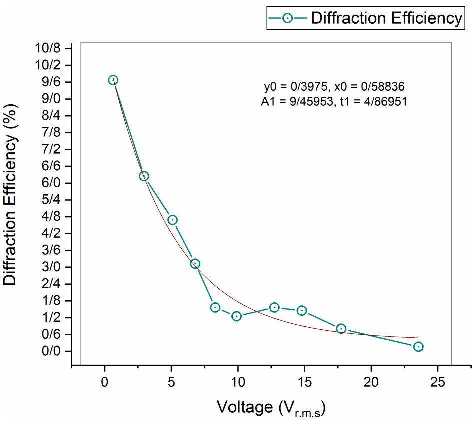

Figure 10: This is a caption

According to the diagram, it seen that the maximum diffraction efficiency (9.37%) is related to the voltage less mode. Because in this case, the molecular guide vector is completely perpendicular to the polarization (P). Thus, the downlink beam will undergo an abnormal refractive index and the rate of passage and diffraction of the edges will decrease and increase accordingly. By applying the voltage, the propagation vector of the molecule is parallel to the inclined polarization and the amount of light passing through the dark areas increases. By applying the final tension, we observe that the lens virtually disappears and passes through the light through a minimal diffraction. In the following forms taken at a fixed distance from the lens, we clearly see the changes in light passing through the lens:

As the voltage increases, the dark areas light gradually.

Similar work has been done by different people. One of these works is based on polymer stabilized Blue Phase liquid crystal Fresnel lens cured by patterned light using a spatial light modulator [16]. According the kind of structure and also, kind of liquid crystals, the lens which made by us, It is quite capable of competing with one another.

Focal length variation

According to the equation 7, mask's focal length theoretically equals to 39.5 cm. With recording mask's pattern on the cell, the experimental focal length in zero condition was reach to 29 cm.

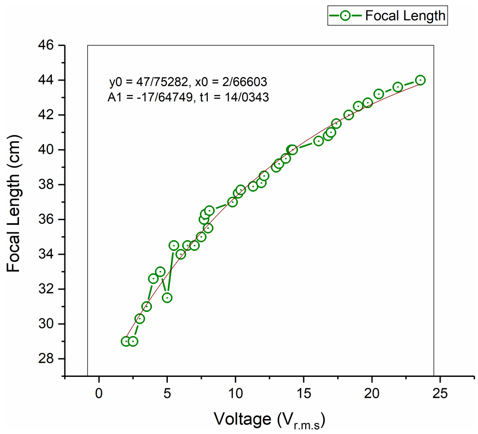

Figure 11: This is a caption

The reason is related to two fundamental things: first, in the theories given for the Fresnel lenses, it is supposed that no light passes through the dark areas and that the front of the light waves in the second region is due than in bright regions, while in the Fresnel lens sample on dark cloudless areas, are not as dark as 100% and pass through a percentage of light. Secondly, in the Fresnel lens, the boundaries of dark and shiny areas act as a sharp boundary and act as an edge, but in the crystal-based Fresnel lens the refractive index of the dark and shiny region does not change suddenly and due to the collective behaviour of the crystalline cloud, on this narrow boundary, the gradient of refractive index appears. It seen that as the applied voltage increases, the observed intensity changes with the photodiode change, which means changing the maximum intensity point or the focal point. (44 cm on 24 Vr.m.s).

Conclusion

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