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Optical vortices by a modal liquid crystal spiral phase plate

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In the last years, many experimental and theoretical research groups worldwide are actively working in the generation of singular optical components such as optical vortices. The main reason is the great number of applications that have been proposed in the last years [1-3]

The aim of this work has been focused on designing and theoretically analyzing novel structures for generation this type of optical element. They are based on nematic liquid crystals (LC) and modal control technique. The operating principle is based on a high resistivity layer that distributes the voltage over the LC surface [4]. This voltage produces a similar phase distribution due to the LC birefringence. A simulation program based on modal theory and Finite Element Method (FEM) is used to estimate the voltage distribution in these structures. Also the minimization of Gibbs free energy (W_G) gives the molecular position as a function of the applied voltage.

These structures have several advantages over spatial light modulators, for example light efficiency, fabrication costs, simple control with low voltages, scalable to micrometric ranges, etc. The proposed devices could be easily fabricated in a clean room with low cost elements.

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Abstract:

An ideal spiral phase plate based on liquid crystals and high resistivity layers is proposed and theoretically analyzed. The proposed structures generates a spiral-like voltage with simple voltage control. The liquid crystal layer produces an optical phase shift that depends on the voltage distribution. These two effects cause light passing through the device to be twisted like a corkscrew around its travel axis. Because of the continuous phase shift, the proposed device is expected to exhibit a conversion efficiency of approximately 100%. In addition, this device is more efficient and simpler than previously reported optical vortex generators. Moreover, the device is completely reconfigurable, i.e., the operating wavelengths and topological charges are tunable. The device can be used, to reduce the fabrication costs of current devices, and to generate different orbital angular momentum (OAM) modes with improved light efficiency, simplicity, and possibility of reconfiguration.

1. Theoretical background

1) Voltage distributon:

The voltage distribution is estimated by Maxwell equations using Finite element method.

2) Gibbs energy:

The molecular position is solved by using Fran-Oseen equation:

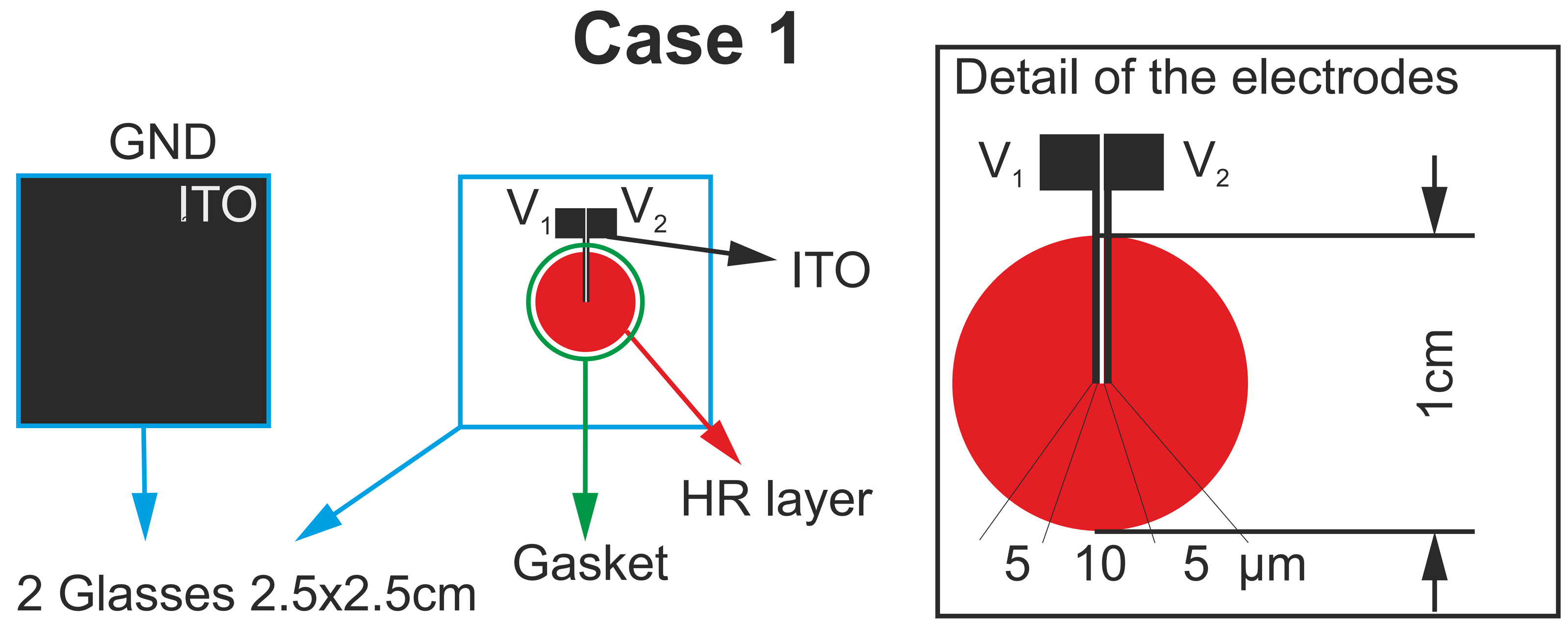
$$F_G = K_{11}\left(\nabla \vec{n}\right)^2 + K_{22}\left(\vec{n}\cdot\nabla\times\vec{n}+\frac{2\pi}{\xi}\right) + K_{33}\left|\vec{n}\times\nabla\times\vec{n}\right|^2 - \frac{1}{2}\vec{D}\bullet\vec{E}$$

3) MDA-98-1602 nematic LC:

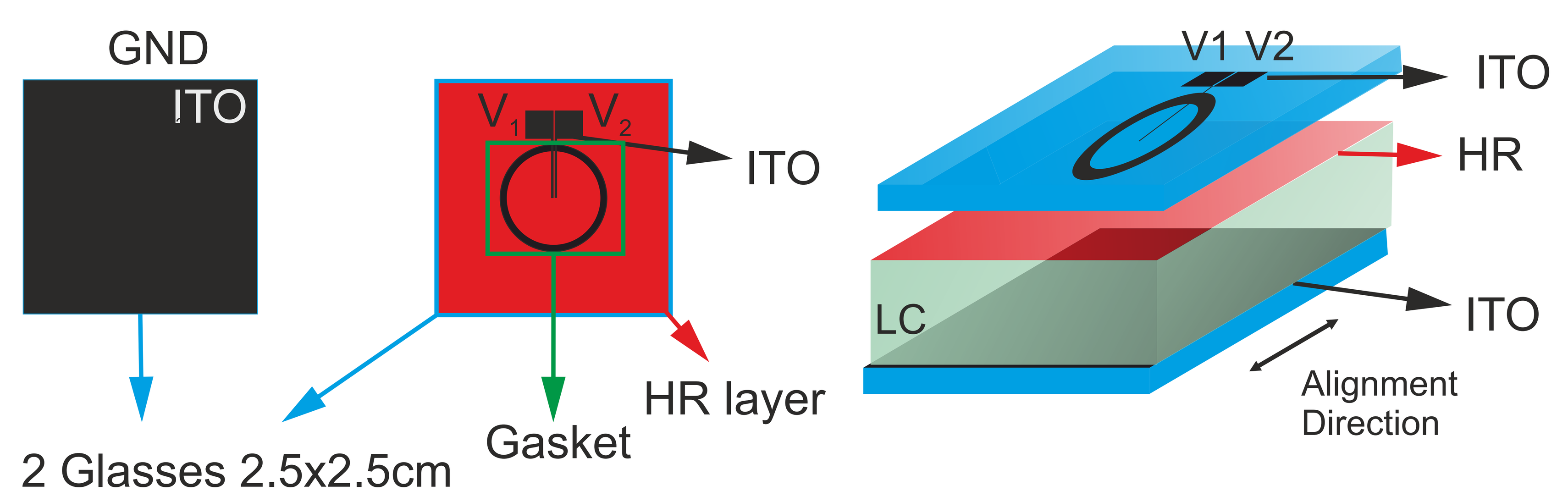
Elastic Constants	Birefringence	Permittivity
K_{11}=15.7 pN	n_e=1.7779	ε_e=16.2
K_{22}=8 pN	n_o=1.5113	ε_o=12
K_{33}=13.6 pN	Δn=0.2666	$\Delta\varepsilon$=4.3

3. Structures

Case 1

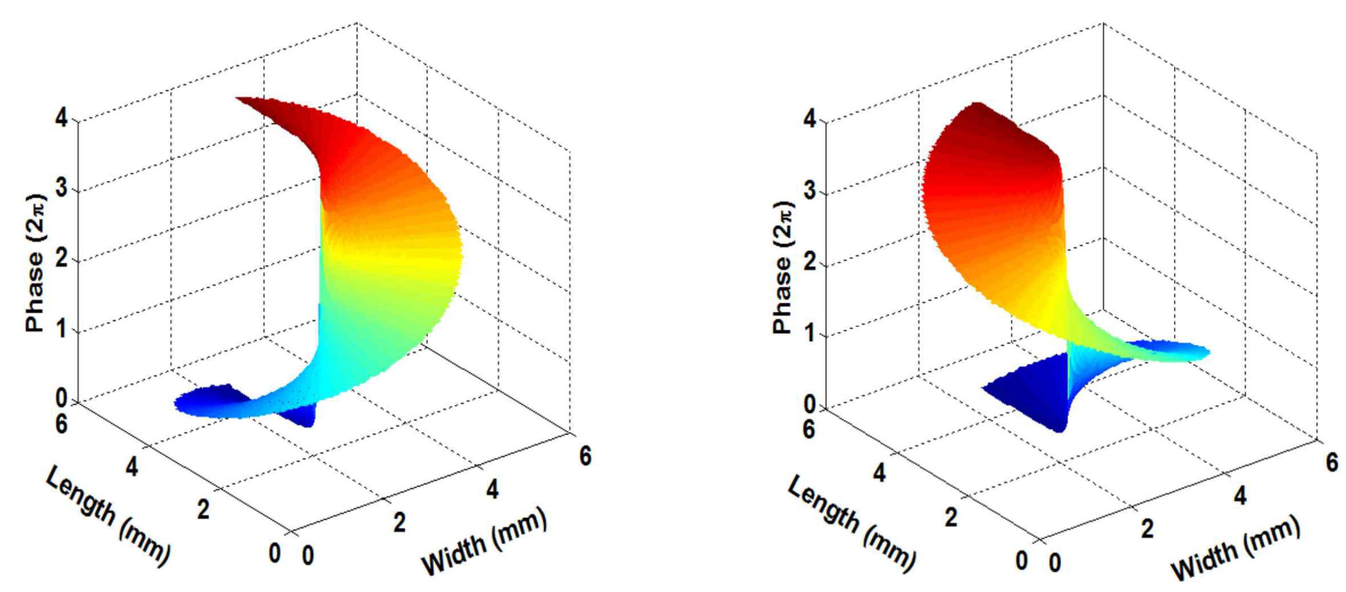


Case 2



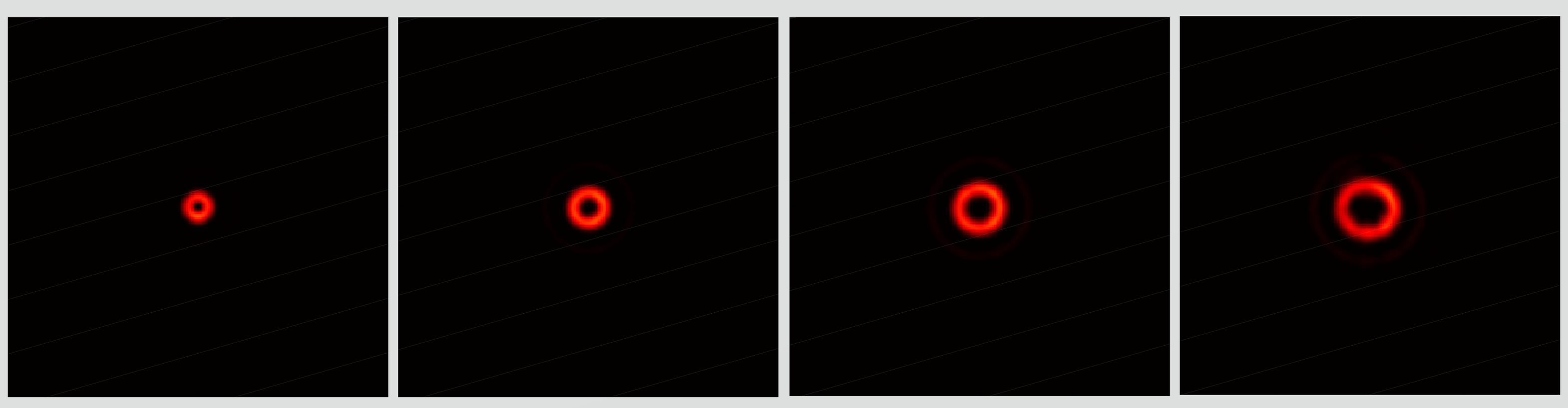
- **Case 1**: Is the optimal case. The HR (High Resistivity) layer has a circular shape to distribute the voltage. The main problem is the difficulty to obtain HR layers with this specific shape.
- **Case 2:** By using a circular electrode the HR layer can be evenly deposited over the electrodes. In this case the electrodes have to be more conductive, e.g. silver, copper, gold, etc.

4. Results



V_1 = 1.2V; V_2 = 2.5V m=+4 | V_1 = 2.5V; V_2 = 1.2V m=-4

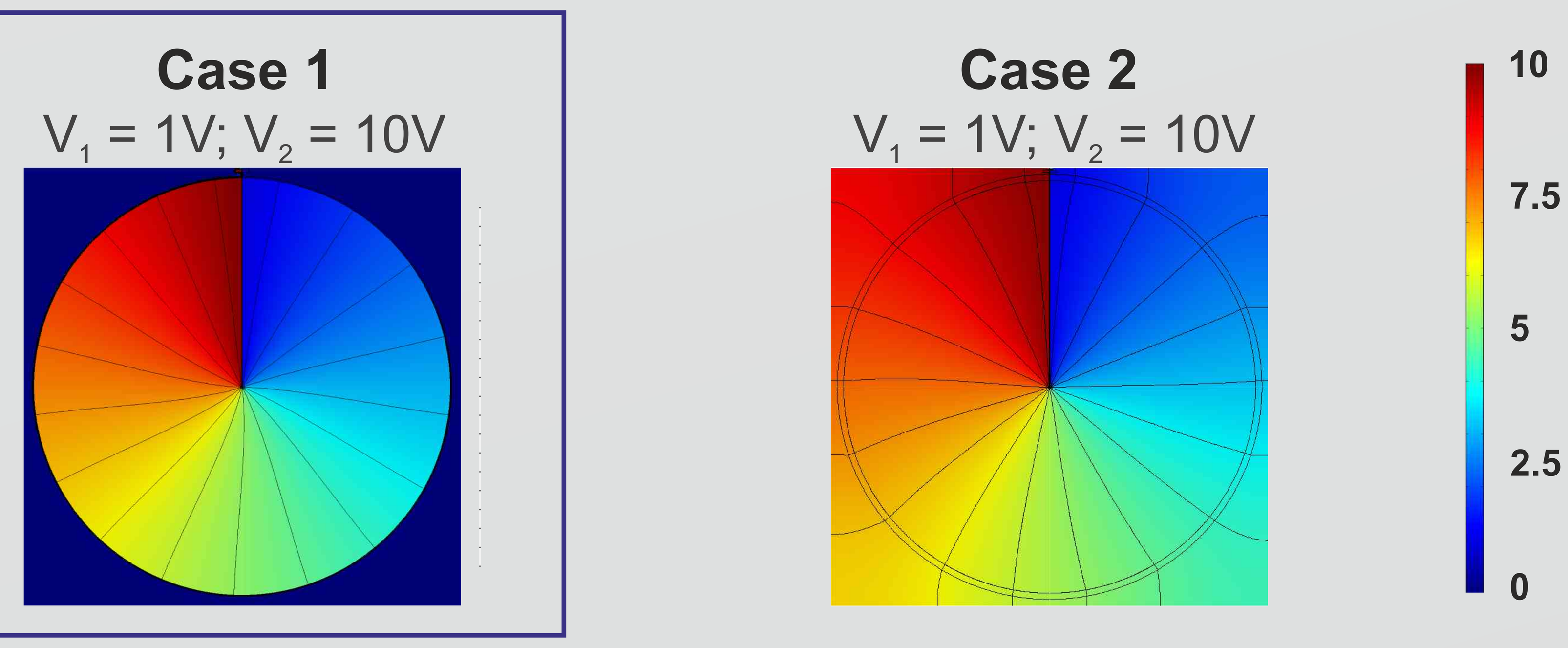
- As can be seen by the voltage isolines, a continuous spiral voltage profile is obtained. Working in the quasi-linear range of the birefringence curve, the phase shift would be like a corkscrew.



m=+1 | m=+2 | m=+3 | m=+4

- The point spread function is obtained by using the Fourier transform of the phase shift
- A tunable topological charge is obtained when different voltages are applied to the electrodes (e.g. m+1: V_1 = 1.2V; V_2 = 1.5V, m+2: V_1 = 1.2V; V_2 = 1.8V , etc.).

Case 1 V_1 = 1V; V_2 = 10V | **Case 2** V_1 = 1V; V_2 = 10V



- **Case 1**: ITO = 2Ω/sq; HR layer = 10MΩ/sq. Several materials could be used, e.g. PEDOT, TiO_2, Thin films of ITO, etc.
- **Case 2:** Silver electrodes = Thickness of 750nm (ρ = 6.29·10^7Ωm). HR layer = 10MΩ/sq.

Conclusions:

- **In summary, a novel optical vortex generator was proposed and theoretically analyzed.**
- **Simulations reveal that small changes in the applied voltage produce large changes in the phase shift.**
- **Owing to the continuous optical phase shift, this device is the best approximation to an ideal SPP proposed to date.**
- **Moreover, the device is completely reconfigurable (operating wavelengths and topological charges are tunable).**
- **Two devices are proposed, in case 2 the fabrication is easier (no need for a circular HR layer).**
- **The device can be used in new applications (e.g. fiber optics communications or atom manipulation), to reduce the fabrication costs of existing devices, and to generate different OAM modes with improved light efficiency, simplicity, and possibility of reconfiguration.**

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