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# Micro-optical phase modulators based on liquid crystal technology

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**Keywords:** Liquid crystals, optical phase modulator, micro-optical elements.

## Abstract

Liquid crystals (LCs) have been the subject of numerous developments during the past 50 years. In some areas have competed with other materials, but in other cases, their anisotropic properties easily modifiable through the application of external fields (mechanical, electric or magnetic) are unique. Therefore, now and in the future LCs will be the protagonists of a multitude of applications, mostly non-related with displays (LCDs). Today, there are wide variety of research lines open. For example, optical communications, microwave and terahertz, nanotechnology, medicine, biology and biochemistry, security, sensors and optical phase modulators.

An optical phase modulator is an optical element used to control the phase of light. They have multiple applications, for example ophthalmological applications, tunable zooms, beam steering, correction of aberrations, astronomy, 3D vision applications, etc. The displays and photonics application group (GDAF) of Carlos III university of Madrid (UC3M) in collaboration with CEMDATIC of Polytechnic University of Madrid (UPM) have extended the knowledge in this field by the proposal of several advanced micro-optical phase modulators. These, obtain with simply topologies either common optical elements, e.g. microlenses for autostereoscopic devices [1], aberration controllers for rectangular micro-optical elements [2] and microlenses with reduced aberrations and tunable rotation [3], or singular optical elements, e.g. micro-axicon arrays [4], tunable prisms [5] and tunable optical vortices [6].

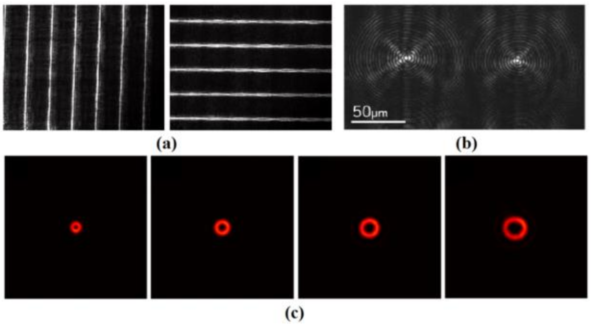

Fig. 1. Focusing capabilities of the proposed devices, (a) rotary lens, (b) Bessel beams of the microaxicon array and (c) tunable optical vortex.

The proposed devices have several advantages over classic optical elements. For example, they are tunable, easy to fabricate and low cost. Moreover, owing to the continuous optical phase shift of these devices, the light efficiency is improved with respect to other technologies based on spatial light modulators (SLM). These devices can be very useful in novel applications (e.g. OAM fiber optics communications, atom manipulation, generation of Bessel beam arrays, etc.).

**Acknowledgements.** TEC2013-47342-C2-2-R and SINFOTON S2013/MIT-2790.

## References

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[3] J. F. Algorri, V. Urruchi, N. Bennis, and J. M. Sánchez-Pena, "Cylindrical liquid crystal microlens array with rotary axis and tunable capability," IEEE Electron Device Lett., vol. 36, no. 6, pp. 582-584 (2015).
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[5] J. F. Algorri, G.D. Love, V. Urruchi, "Modal liquid crystal array of optical elements," Opt. Express, vol. 21, no. 21, pp. 24809–24818 (2013).
[6] J. F. Algorri, V. Urruchi, B. Garcia-Camara, and J. M. Sanchez-Pena, "Generation of Optical Vortices by an Ideal Liquid Crystal Spiral Phase Plate," IEEE Electron Device Lett., vol. 35, no. 8, pp. 856–858 (2014).

Ver póster

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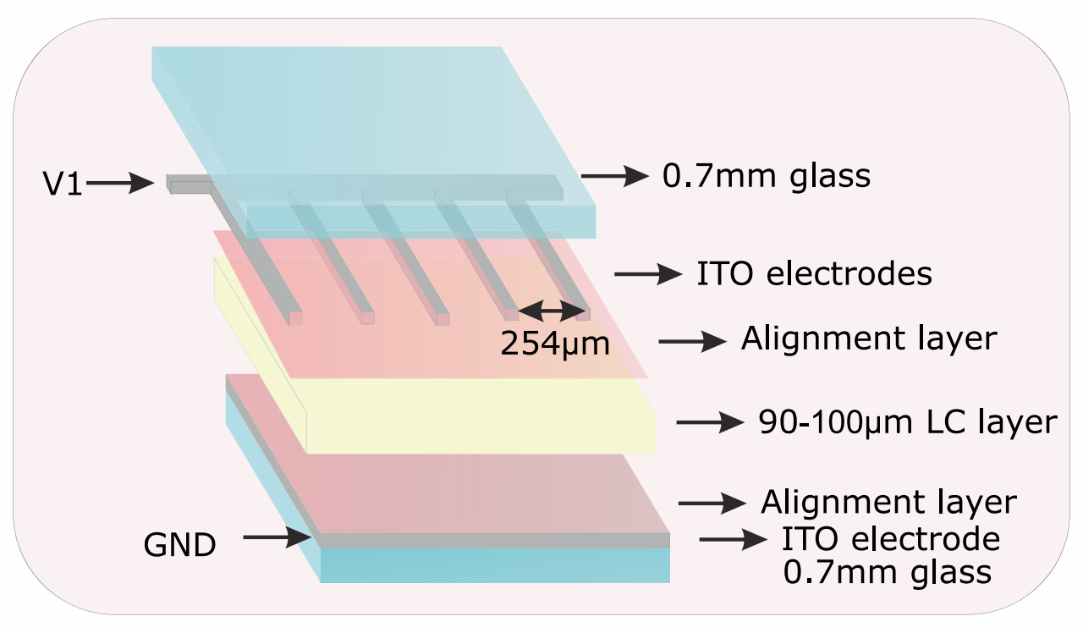
## Abstract:

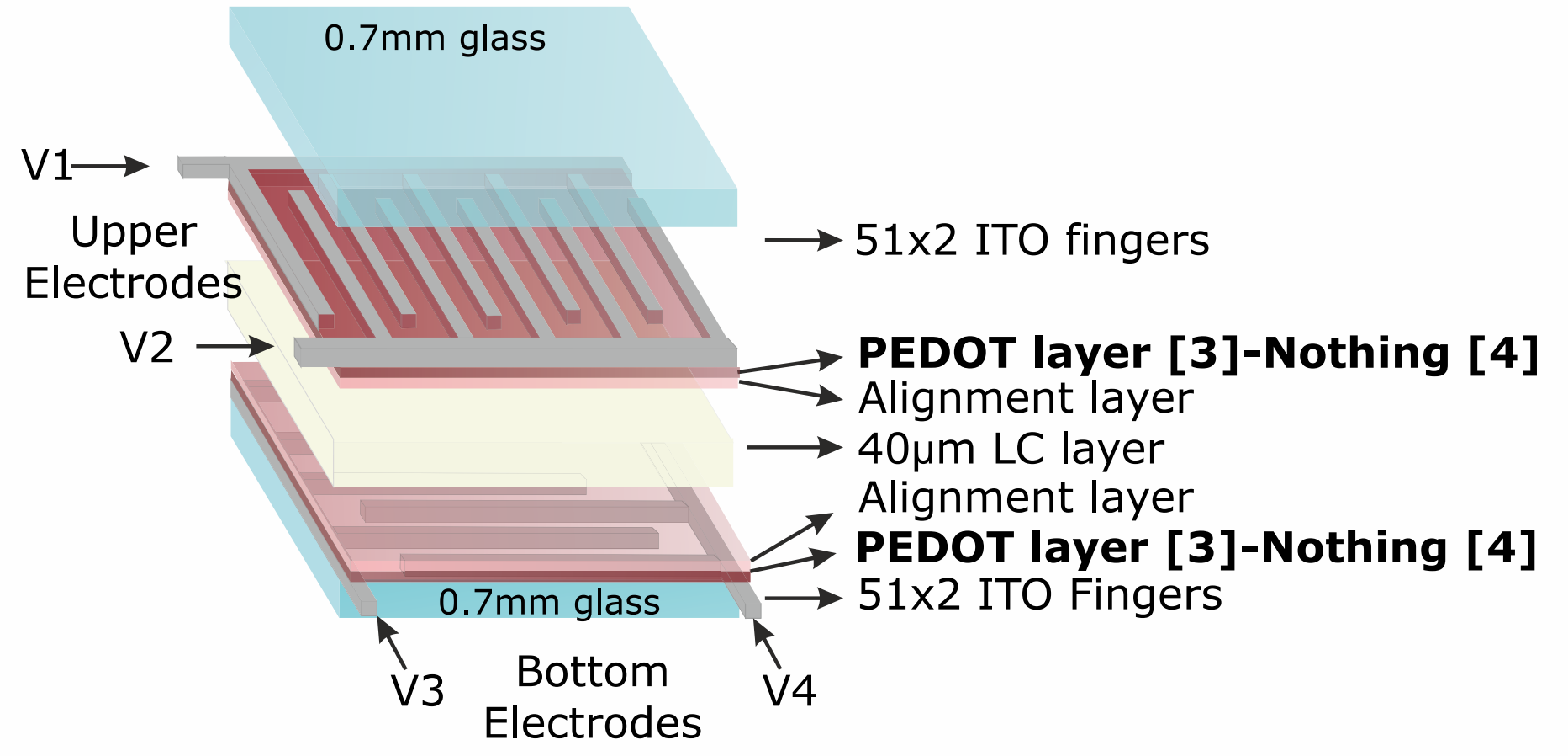
An optical phase modulator is an optical element used to control the phase of light. They have multiple applications, for example ophthalmological applications, tunable zooms, beam steering, correction of aberrations, astronomy, 3D vision applications, etc. The displays and photonics application group (GDAF) of Carlos III university of Madrid (UC3M) in collaboration with CEMDATIC of Polytechnic University of Madrid (UPM) have extended the knowledge in this field by the proposal of several advanced micro-optical phase modulators. These, obtain with simply topologies either common optical elements, e.g. microlenses for autostereoscopic devices [1], aberration controllers for rectangular micro-optical elements [2] and microlenses with reduced aberrations and tunable rotation [4], or singular optical elements, e.g. micro-axicon arrays [3] and tunable optical vortices [5].

## Devices

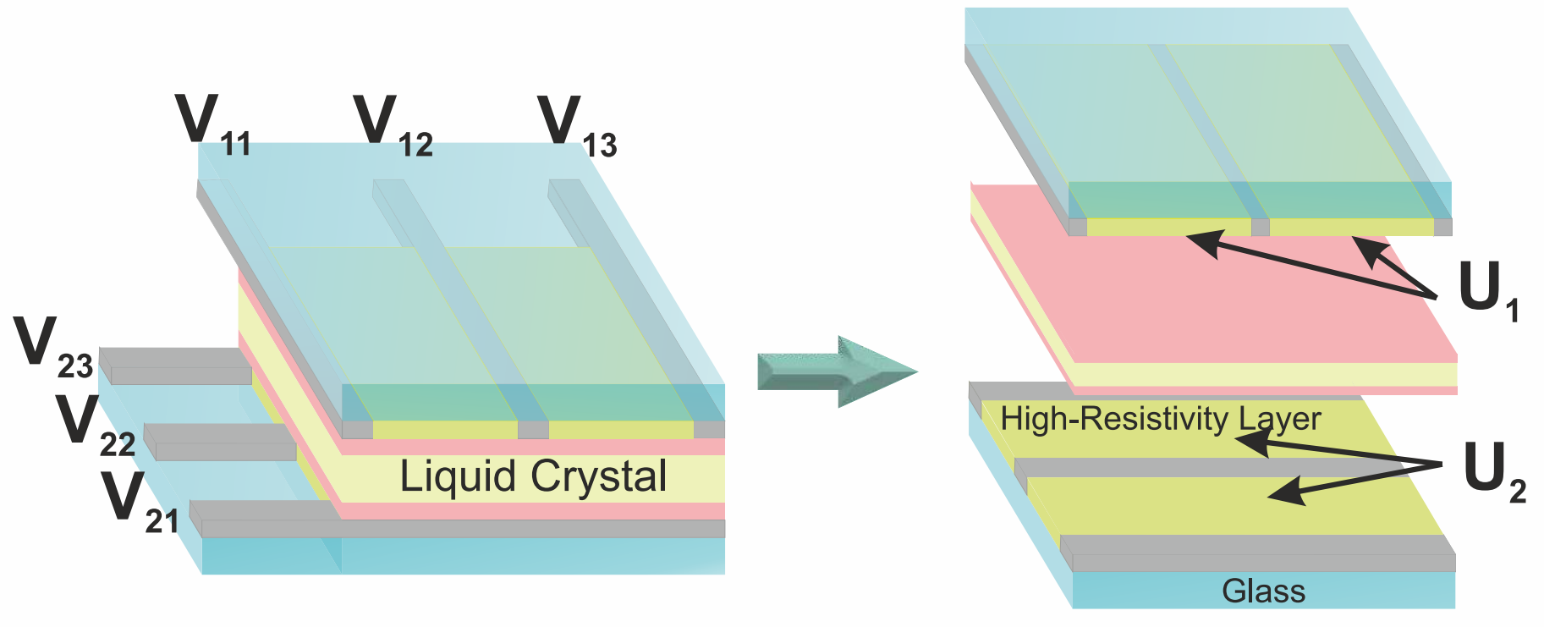
### Device 1 [1] [2]



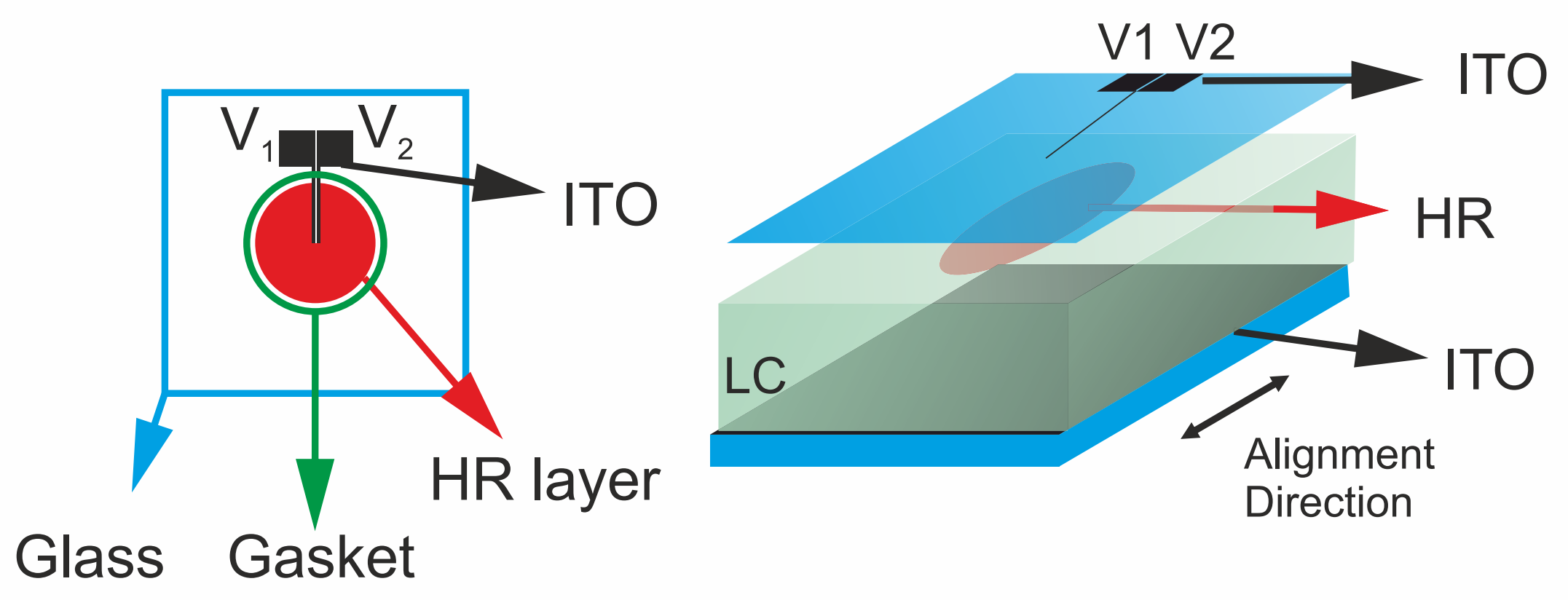
### Device 2 [3] [4]



### Device 3 [5]

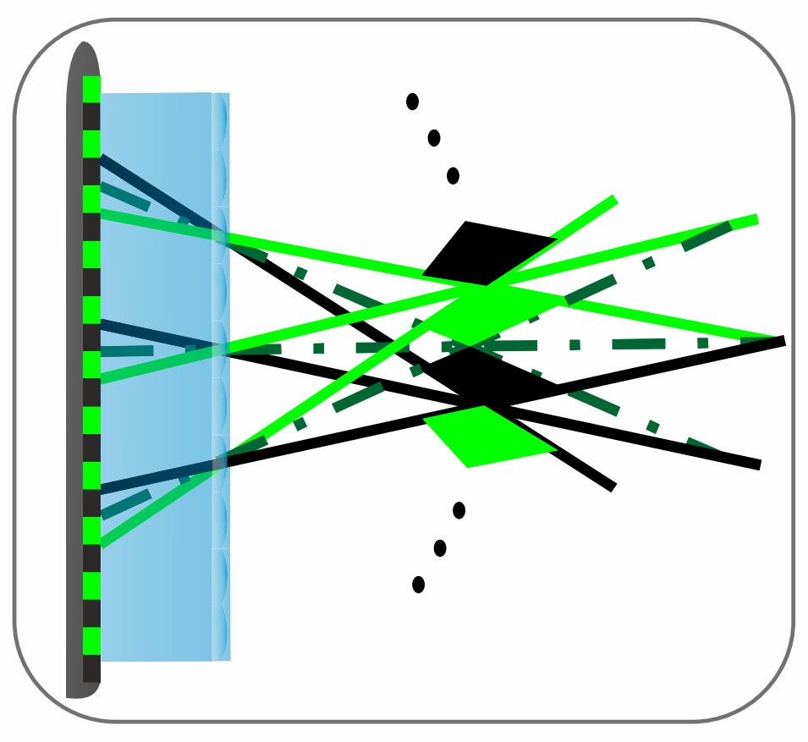


### Device 4 [6]

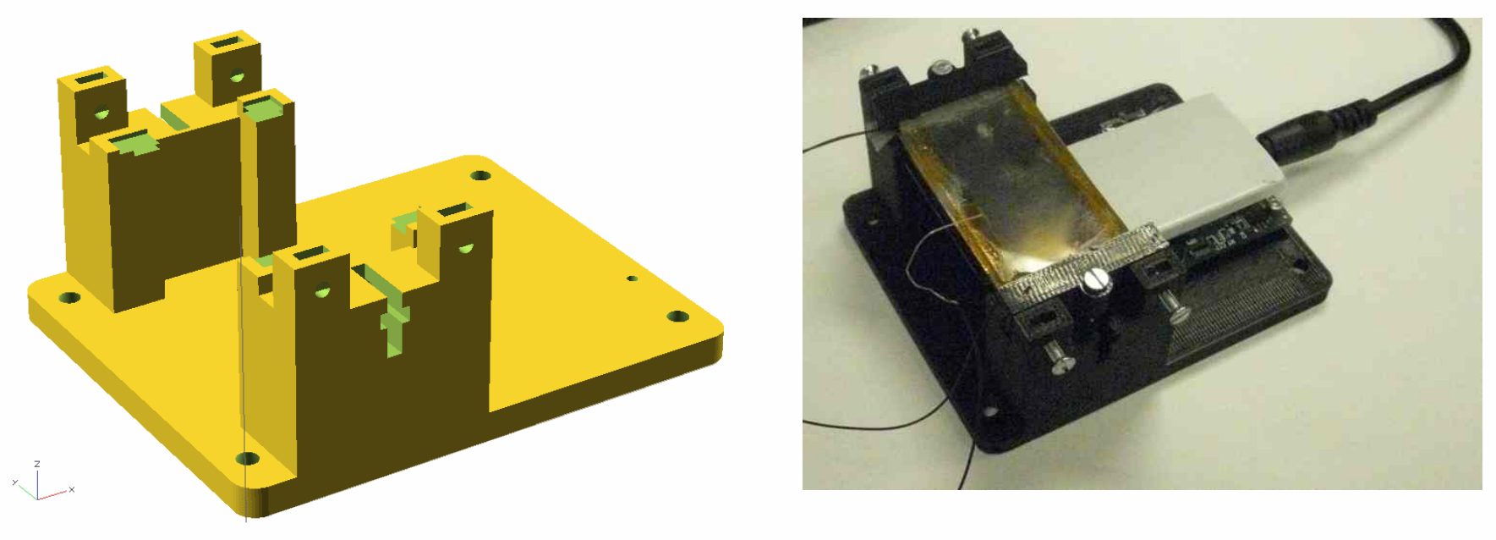


## Applications

### Device 1 Autostereoscopic Device [1]

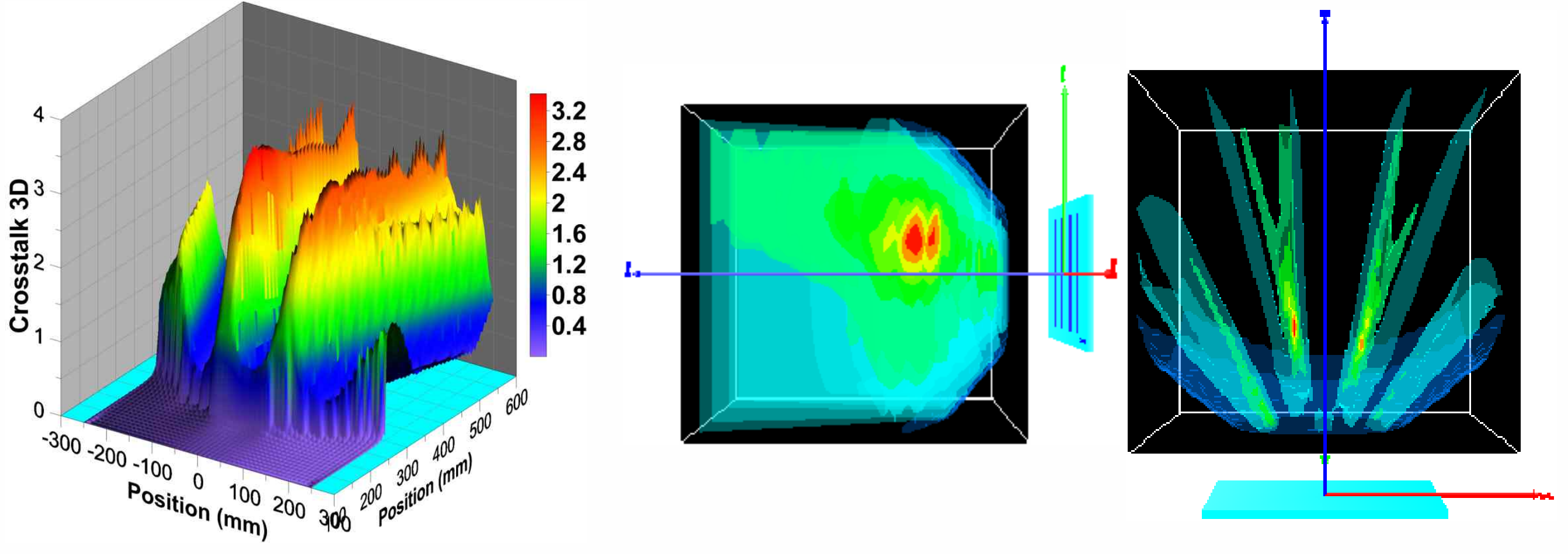


Working Principle



**A lenticular positioner has been designed with OpenSCAD and realized with a 3D printer.**

### Autostereoscopic Effect, 3D Contrast

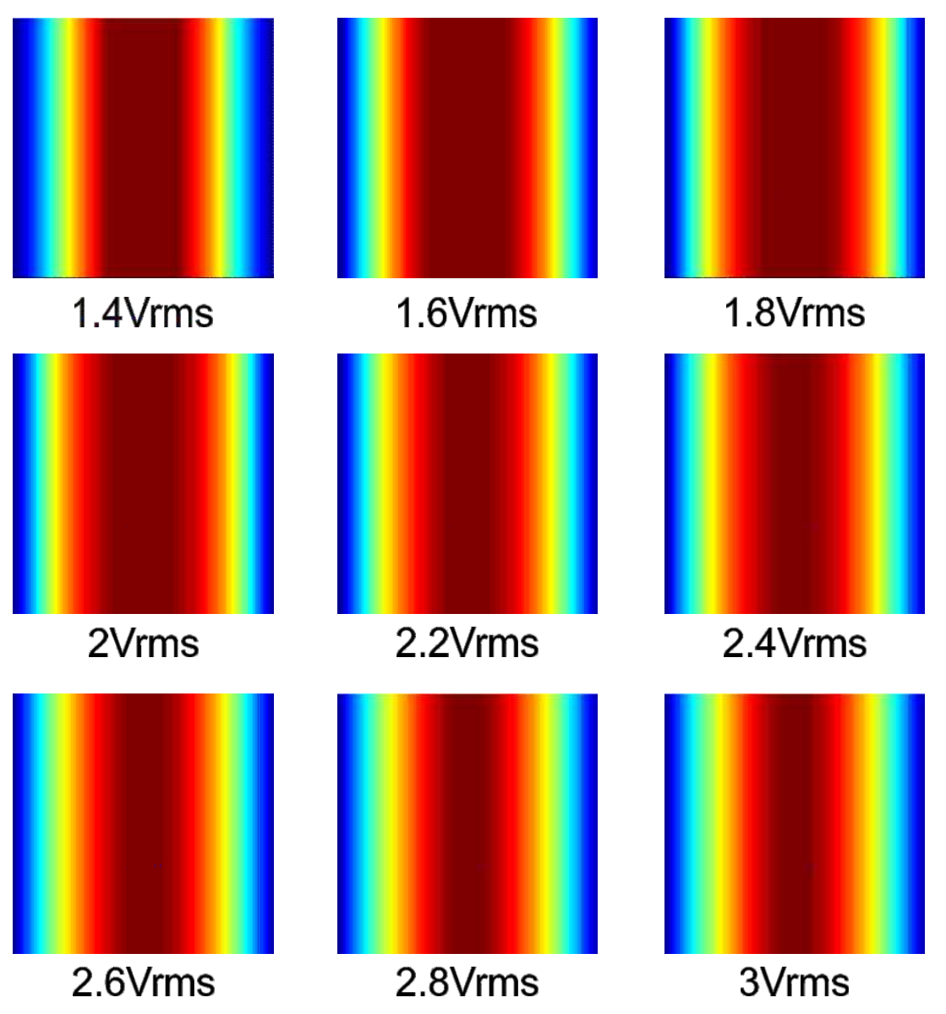


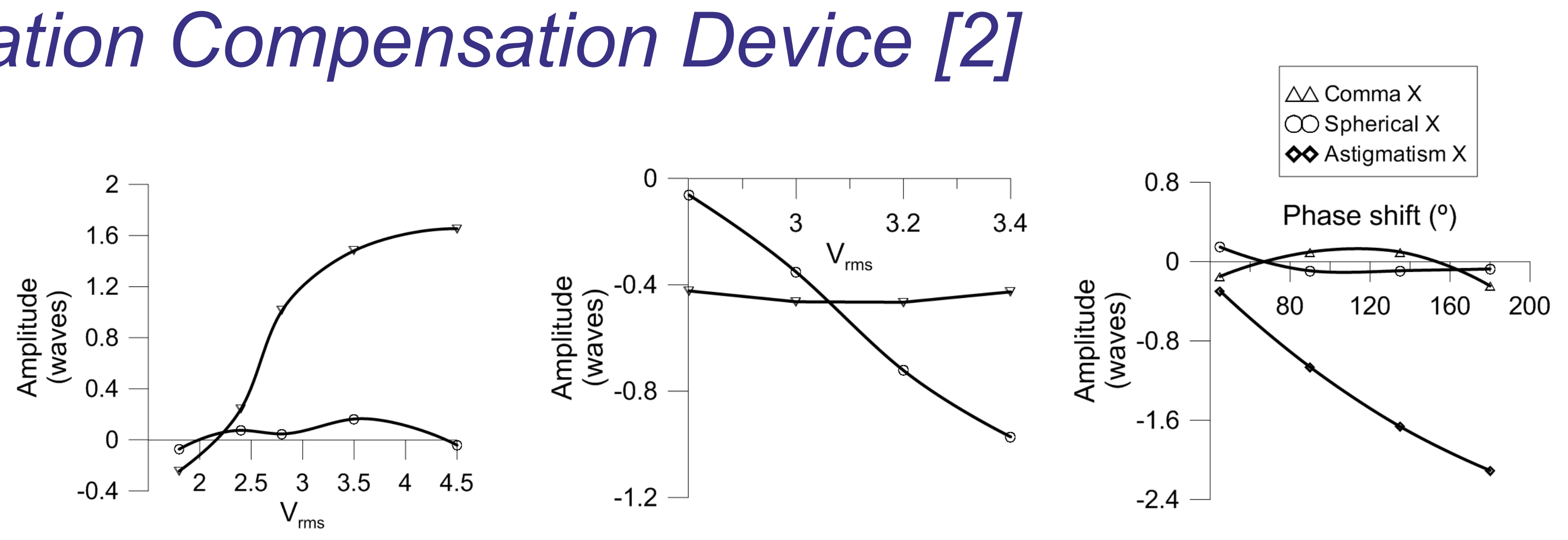
### Flip Effect, two views at different angles

GDAF VIDEO

**With an interlaced image and a digital camera situated at different angles, two different images can be observed.**

### Device 1 Aberration Compensation Device [2]

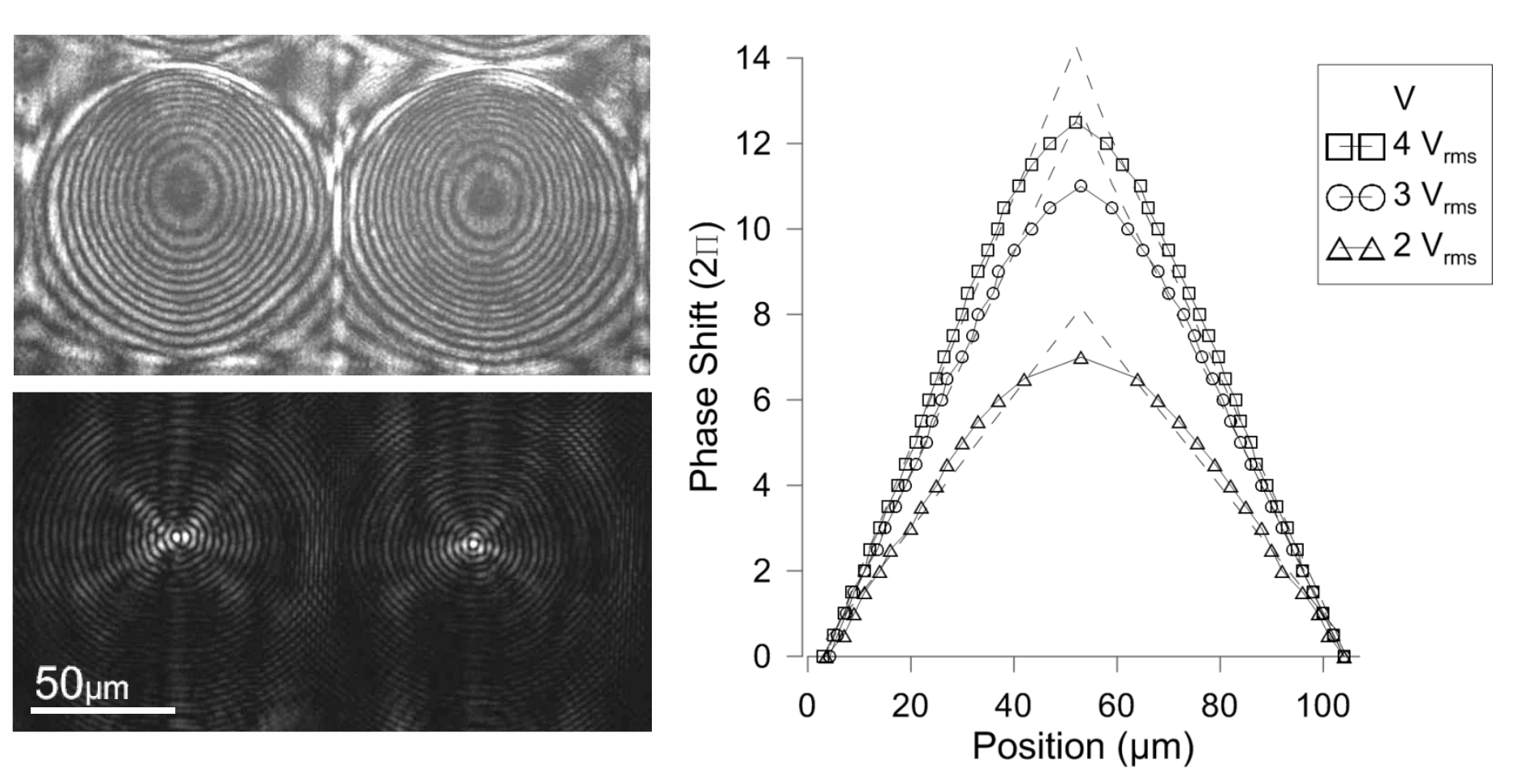




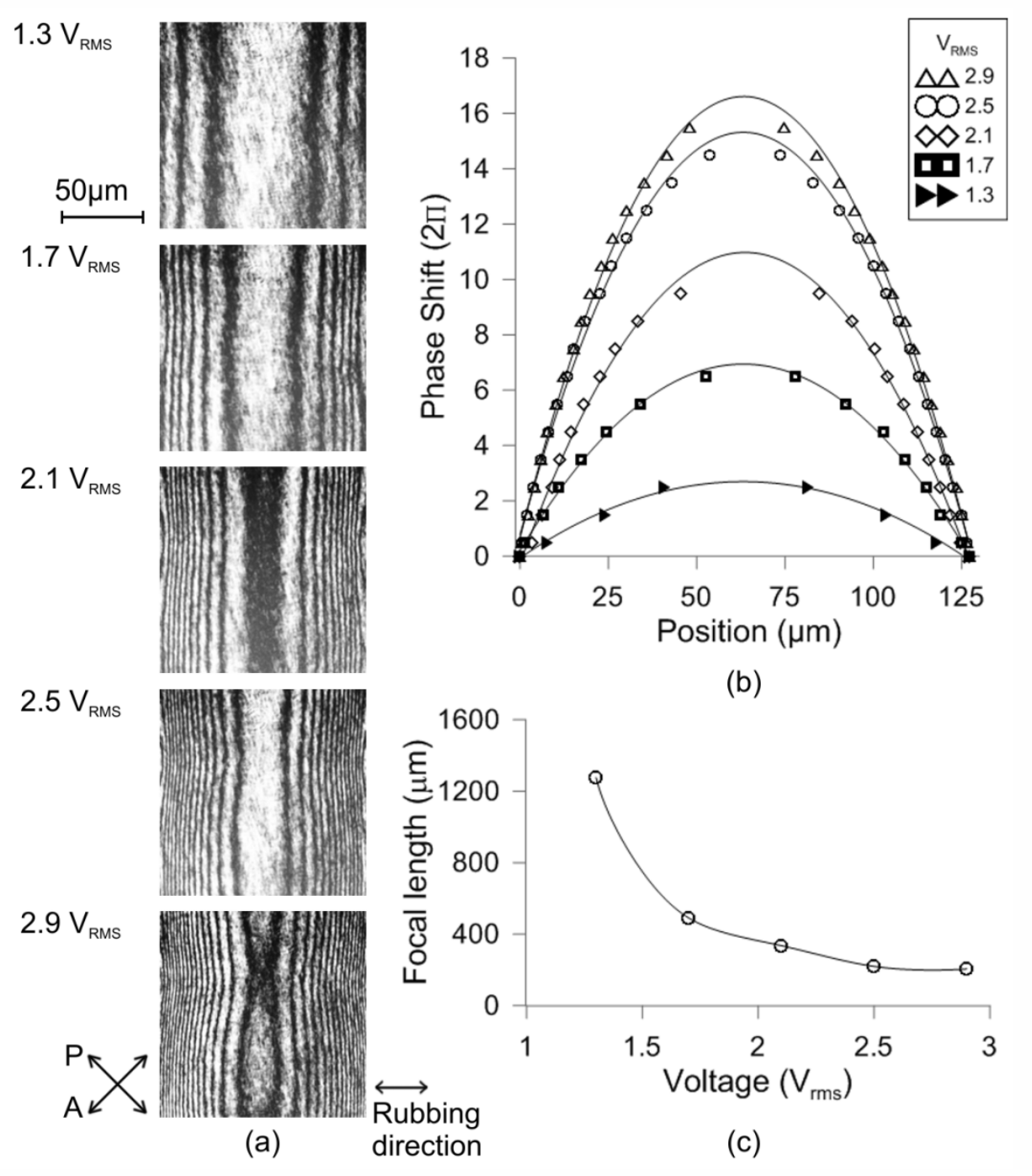
**In this device, some aberration coefficients can be independently tuned by using different strategies in the applied voltage. It can be considered as an aberration compensation device for rectangular micro-apertures.**

### Device 2 Microaxicon array [3] and rotary lens [4]

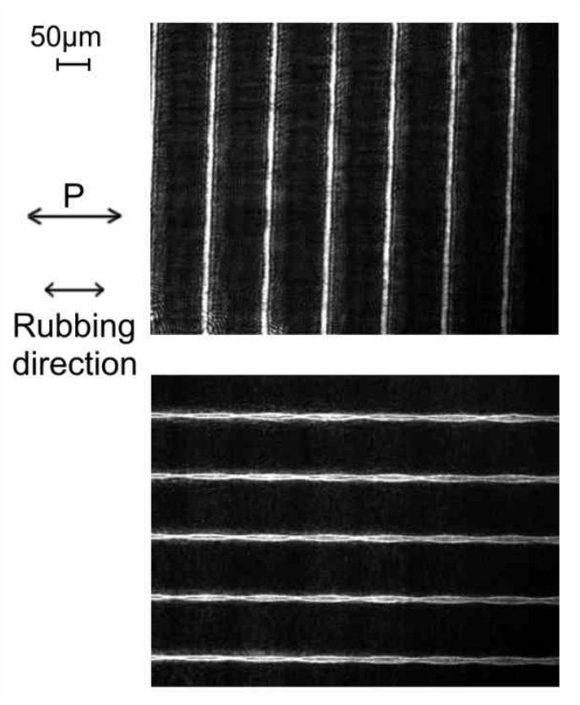
Whit HR layer



**The left images correspond to the interference fringes (upper) and the bessel beams (bottom). In the right image are the axicon phase profiles.**



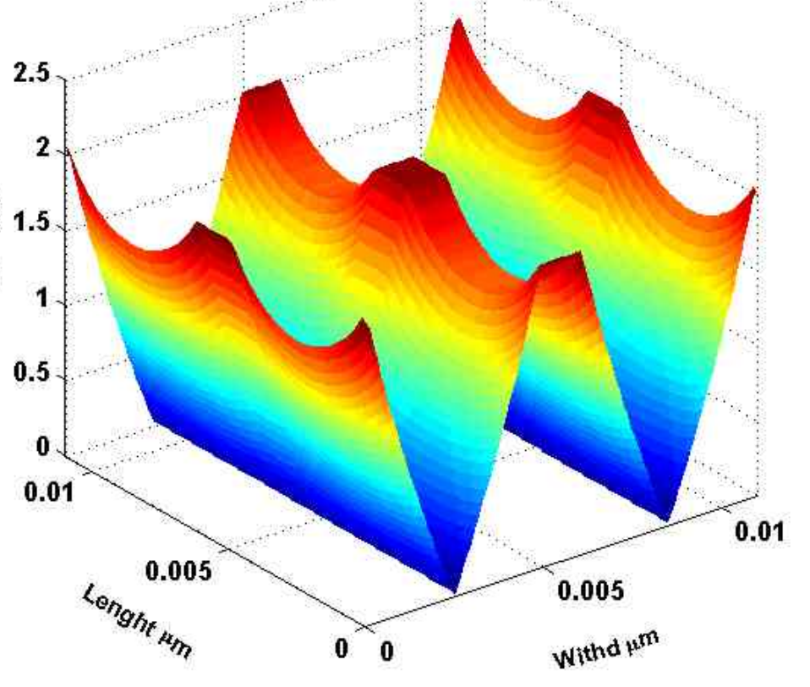
Whitout HR layer

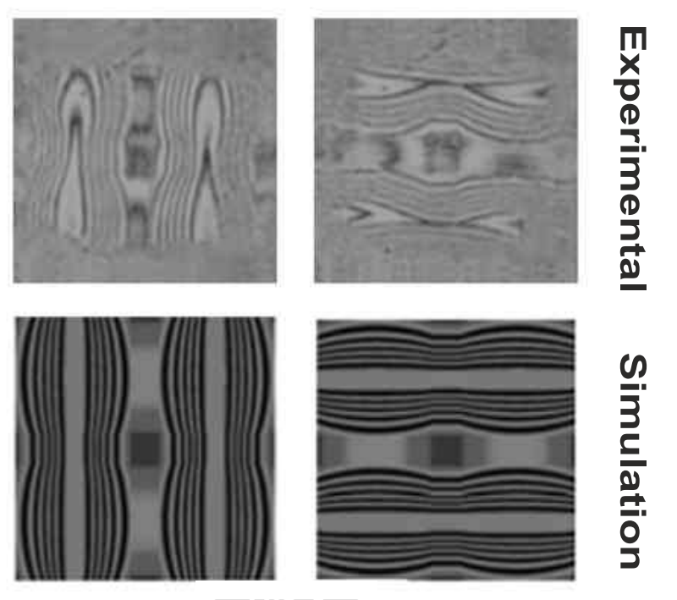


**On the left it is shown a tunability and high optical power. The right images show how the focusing capability can be rotated by changing the applied voltage.**

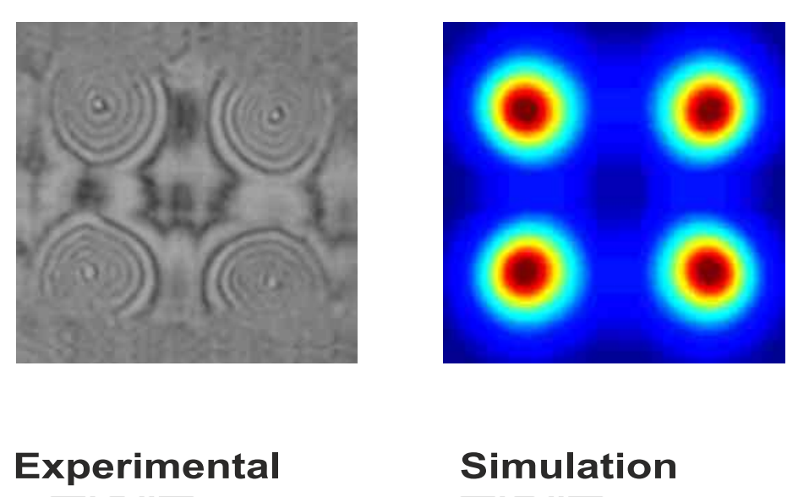
### Device 3 Multi-Optical Device [5]

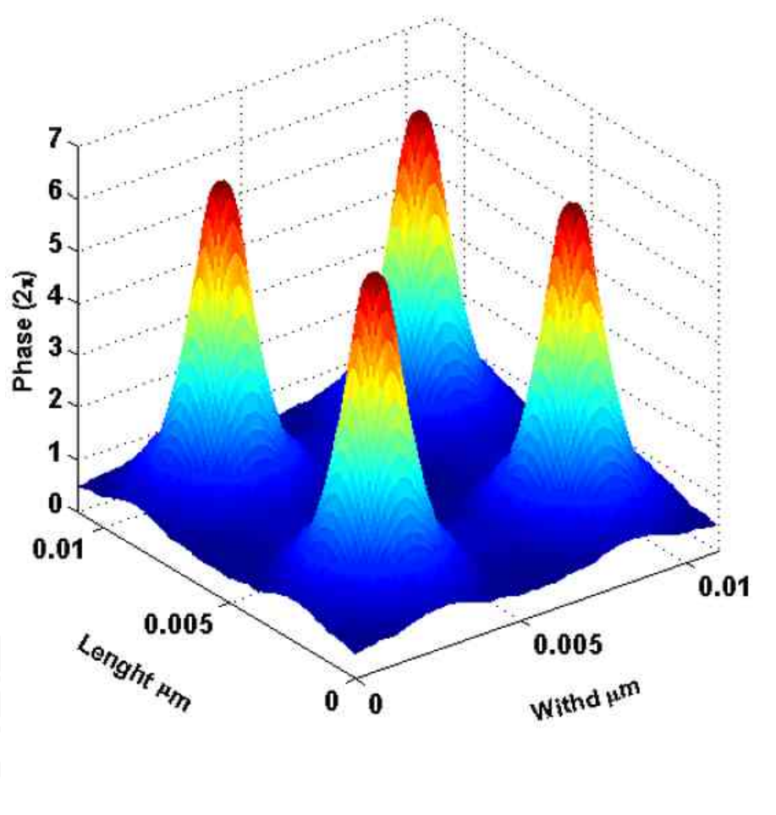
### Tunable Prisms



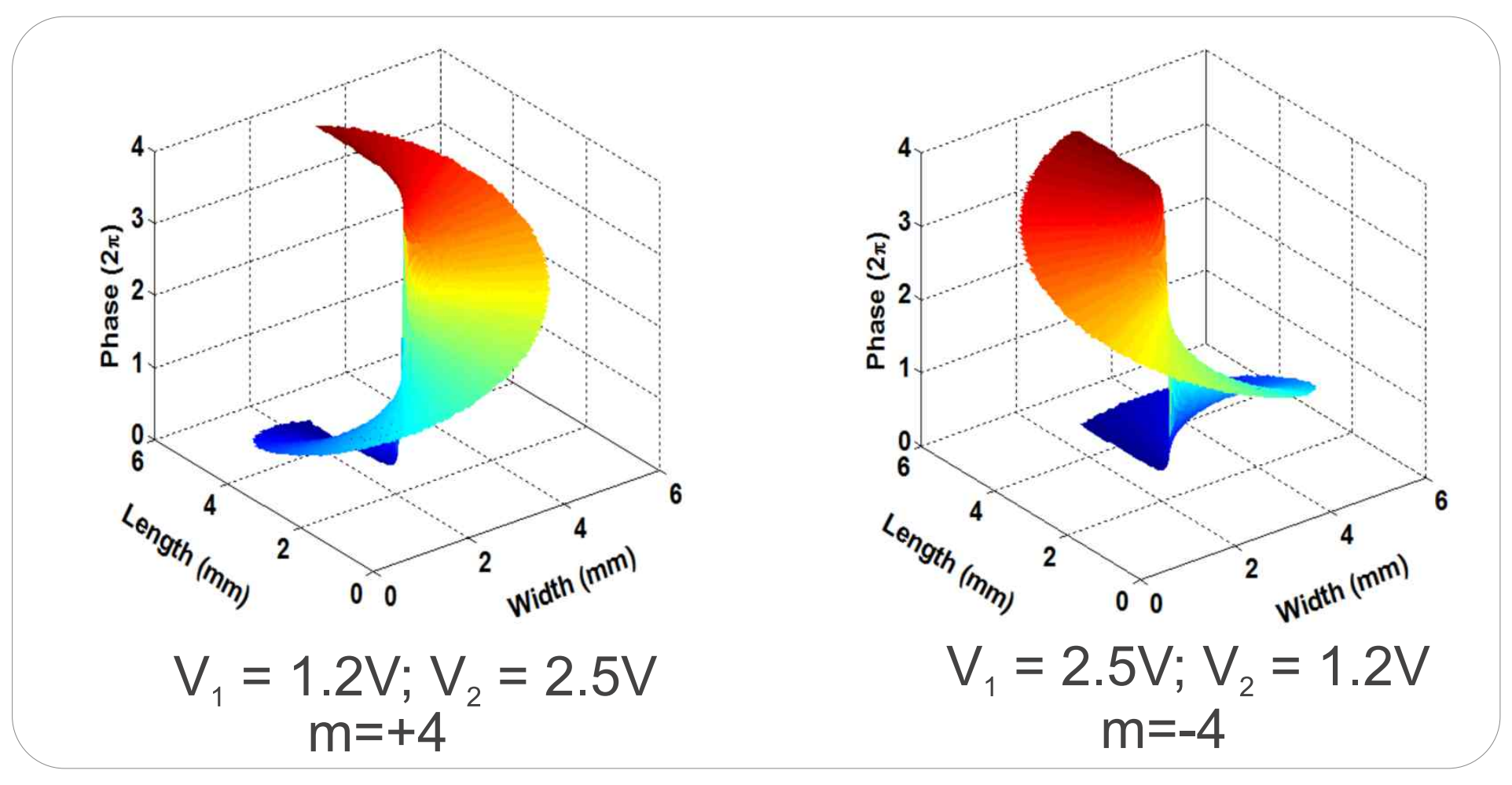


### Tunable Axicons

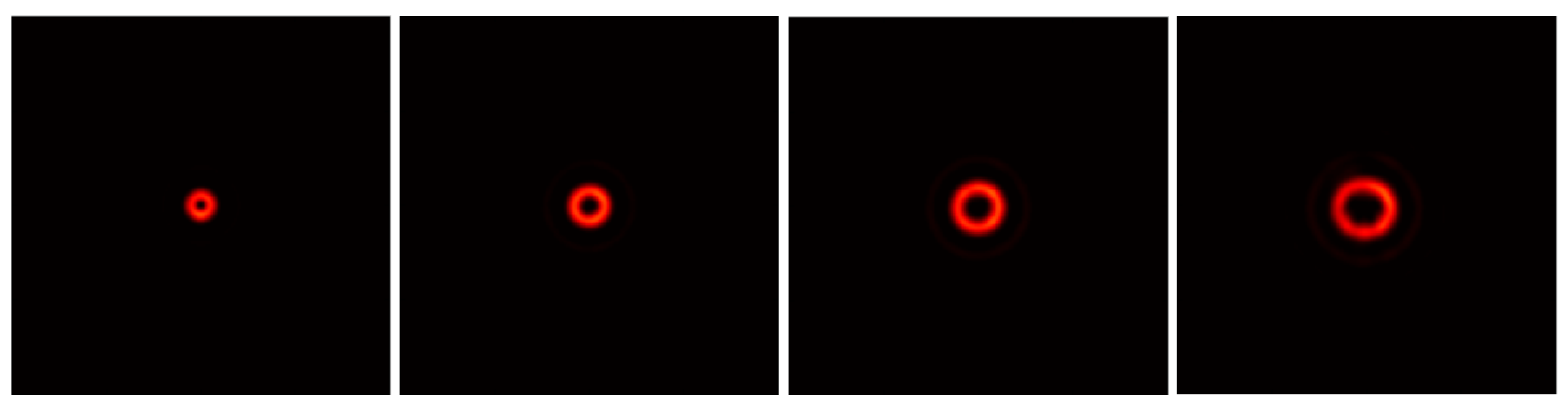




### Device 4 Optical Vortices [6]



- **The structure produces a spiral like phase profile. The light is twisted around its axis of travel.**
- **The result is a tunability of the topological charge (bottom figure).**



## Conclusions:

- **An autostereoscopic prototype based on OLED display, LC microlenses and a lenticular positioner has been designed and manufactured.**
- **Optical aberrations have been modelled and measured in an LC cylindrical microlens for the first time. LC cylindrical lenses are suggested as aberration compensation devices. The aberrations can be independently controlled by different techniques.**
- **A novel microaxion array and a tunable microlens with high optical power a rotary axis have been presented.**
- **We have described a novel configurable and tunable modal LC array of optical elements and presented experimental and simulation results of its electro-optic behaviour.**
- **A continuous spiral phase plate based on LC has been proposed. This structure is capable of generate tunable optical vortices for OAM fiber optic communications.**

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[1] J. F. Algorri, V. Urruchi, J. M. Sánchez-Pena, J. M Otón, "An Autostereoscopic Device for Mobile Applications Based on a Liquid Crystal Microlens Array and an OLED Display," J. Disp. Technol., vol. 46, no. 4, pp. 327-336 (2014).

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