Summary

In 1968, George H. Heilmeier, Louis A. Zanoni and Luke A. Barton from the RCA (Radio Corporation of America) Laboratories invented the first liquid crystal display (LCD) based on the dynamic scattering mode (DSM). From then on, more and more research interest was dedicated to the inventions of novel LCD modes, and the LCD industry started to grow rapidly. Since the beginning of the 21_{st} century, thin film transistor (TFT) LCDs have dominated the whole display field very successfully. Today, a 5 inch diagonal sized TFT-LCD module with a resolution of 1920×1080 seems to be a basic hardware configuration for smart mobile phones.

Obviously, LCs used for the display applications have gained tremendous commercial success. Beside their applications as displays, lots of research activities by making use of the LC unique electro-optical properties have never stopped in those areas, like LC light intensity attenuators, LC phase shifters, LC beam shaping devices and so forth. In this study, smart electro-optical components for the direction of solid state light are intended to be built for the applications, such as tunable lighting systems, high-efficiency and non-mechanical moving sunlight collectors, 2D/3D switchable autostereoscopic displays and auto-focusing smart contact lenses etcetera.

To deflect a bundle of light, the light wave-front should become tilted after it passes through a specific medium, i.e. its lateral optical path distribution (OPD) is changed. There are basically two ways of changing the OPD: either varying the medium thickness in the light propagating direction or varying the medium refractive index in the lateral direction. The thickness variation reminds us to consider beam deflection based on the interface of LC-polymer grating. While the refractive index variation makes us to think of beam deflection based on the gradient refractive index (GRIN) effect. Therefore, two different approaches for the realization of LC beam steering components are adopted in this research: LC-Grating beam shaping device and LC-GRIN beam steering device.

The optical micro structures play important roles in defining the optical performance of the LC-Grating beam steering devices. The fabrication of optical micro structures is the first step for building this kind of LC components. Different fabricating technologies have been developed by different partners in the

study: diamond tooling (by B-Phot), hot embossing (by B-Phot), laser ablation (by Cmst) and soft lithography (by Cmst). B-phot utilized diamond milling and diamond turning to fabricate various kinds of optical micro structures, such as linear micro prisms with different pitches and blazed angles, circular micro gratings and Fresnel micro lenses with various f-numbers. In Cmst, laser ablation with a shadow mask with a triangular or trapezoidal aperture is implemented to create the linear gratings on different polymer layers. The drawback of the two technologies is their low processing efficiency. Therefore, the micro patterns made by the two techniques are used as master molds for replicating more samples by hot embossing and soft lithography. The micro optical structures fabricated by the four different technologies are fully characterized and discussed.

For a better understanding of the principle of beam deflection, the light beam propagation through the LC-Grating device and the LC-GRIN device is respectively derived by using Huygens-Fresnel's law. The results show that the diffraction pattern is determined by the diffraction equation for both the two LC devices. The beam steering angle of LC-Grating device is dependent on the profile of the LC-Grating interface, its magnitude can be obtained by using Snell's law to this interface. The steering angle of LC-GRIN device is dependent on the optical phase profile, it can be derived by extracting the gradient of the optical phase distribution of each grating unit.

With the fabricated optical micro structures, the assembly of LC-Grating devices is initiated. Different LC alignment technologies are tested by using mechanical rubbing, oblique SiO_2 evaporation and photo-alignment. The experimental results show that both mechanical rubbing and oblique SiO_2 evaporation apply good LC alignment on the polymer micro structures. While the LC alignment induced by photo-alignment does not show good results due to the material issue in Cmst, but similar experiments using a different alignment material are successfully implemented by LCP. Different micro structure substrates are assembled with their flat ITO counterparts, various kinds of beam shaping components are obtained after LC filling, such as linear beam deflectors, circular beam condensers and beam expanders. Optical characterizations with both a laser beam and a white light are fully conducted and analyzed for those devices.

Unlike conventional LC-GRIN beam steering devices using multiple addressing electrodes, the proposed LC-GRIN beam deflector in the study deploys only two addressing electrodes for each grating unit, to reduce the complexity of driving circuits. In order to modulate the LC orientation accurately and smoothly, a highly resistive and patterned PEDOT:PSS thin layer is formed in-between the two electrodes. To find out the optimum PEDOT resistivity, numerical simulations are conducted, showing that an available PEDOT layer with 11 GΩ/sq in sheet resistance gives the best beam steering uniformity over a 2×2 inch device. LC-GRIN beam deflectors with different designs are fabricated, their optical properties are also characterized and compared. The optical measurements are compatible with the theoretical derivations.

Since polarization independent LC beam steering components make the best use of the light intensity, polarizer-free LC components are thereby developed in the study. One solution is to stack two single LC beam deflectors with their LC alignment orthogonal to each other. Each single LC device steers one of the two orthogonal light beam components whose polarization is parallel to the LC alignment. To overcome the high cost of the stacking LC component, another mode-dual frequency cholesteric LC-Grating beam deflector is investigated. Polarization independent beam steering components are realized whose transmission vs. the polarizing angle only varies 4.4% and 3% for the planar state and the homeotropic state, respectively. The response time is measured to be 451 ms, which is fast compared to other nematic LC beam steerers with similar LC thickness. Ultra-fast switching of nematic LC beam steering devices is achieved to be 24.3 ms by using dual frequency driving scheme.

These fruitful results gained from this research work, do pave the way for the large-scale applications of the LC based beam shaping devices and components. One can even envision that more novel LC beam steering systems will come into our life and work in the near future!