Chapter 2

Principle

2.1 Introduction

Due to the technical challenge for the backlight system in conventional transflective LCDs, many methods, such as tunable mirror [7] and dielectric multilayer [8], have been reported to solve this issue. Although these methods can overcome the issue of lower light efficiency, but additional issues are caused. Therefore, micro-optics components, which are easier fabricated and have been widely applied in many fields, are adopted to solve the problem initially. Diffractive components (Fresnel lens [9] [10] [11] and grating [12] [13] [14]) and micro-lens array are proposed and described in the following. Besides, transmissive light efficiency enhancement will be calculated to determine the capability of collecting light, respectively.

2.2 Related Methods

2.2.1 Tunable Mirror

Tunable mirror is composed of a Cholesteric Liquid Crystal (Ch-LC) layer and a phase retardation film, as shown in Fig. 2.1. By switching the arrangement of molecular of Ch-LC, the incident ambient light and backlight can be reflected and transmitted effectively. Hence, the light efficiency in reflective mode and transmissive mode can be improved. However, in order to switch the molecular state of Ch-LC, additional circuits must be used and then result in complicated circuit design. Besides, due to the limitation of Ch-LC, the bandwidth of display also becomes narrow.

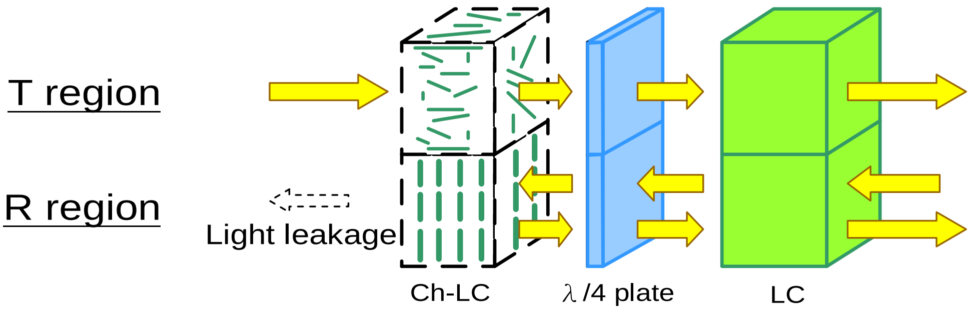


Fig. 2.1. Schematic diagram of tunable mirror

2.2.2 Dielectric Multilayer

Dielectric multilayer is composed of dielectric materials with various refractive indices, as shown in Fig. 2.2. By properly arranging different dielectric materials, the incident ambient light can be multiple reflected at the interfaces of various materials, thus the reflection of ambient light can be increased. However, it will cause parallax image. Besides, this method only can improve the light efficiency in reflective mode. As a result, dielectric multilayer is not the best solution of enhancing light efficiency.

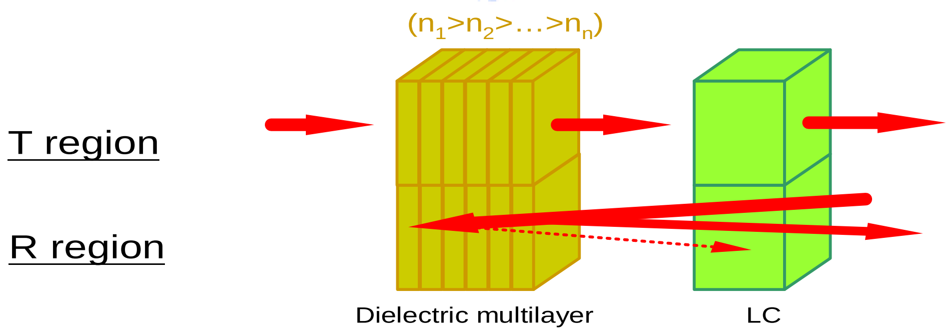


Fig. 2.2. Schematic of dielectric multilayer

2.3 Micro-Optics Components on Transflective LCD

In contrast to tunable mirror and dielectric multilayer, micro-optics components can eliminate the issues of bandwidth limitation and parallax image. Moreover, Micro-optics components are easier fabricated and have been widely applied in many fields. Thus, micro-optics components are considered to solve the problem of lower light efficiency. As schematically shown in Fig. 2.3, micro-optics components are established on the bottom surface of lower glass. The function of micro-optics components is to collect all the incident backlight and focus it on transmissive regions. By designing properly, minimum spot size of collected backlight can be obtained on the top surface of lower glass. Therefore, the area of transmissive and reflective regions can be further reduced and increased, respectively. Consequently, the light efficiency in transmissive and reflective modes can be enhanced substantially. Micro-optics components are classified into refractive and diffractive types. The features of these devices are described in the following.

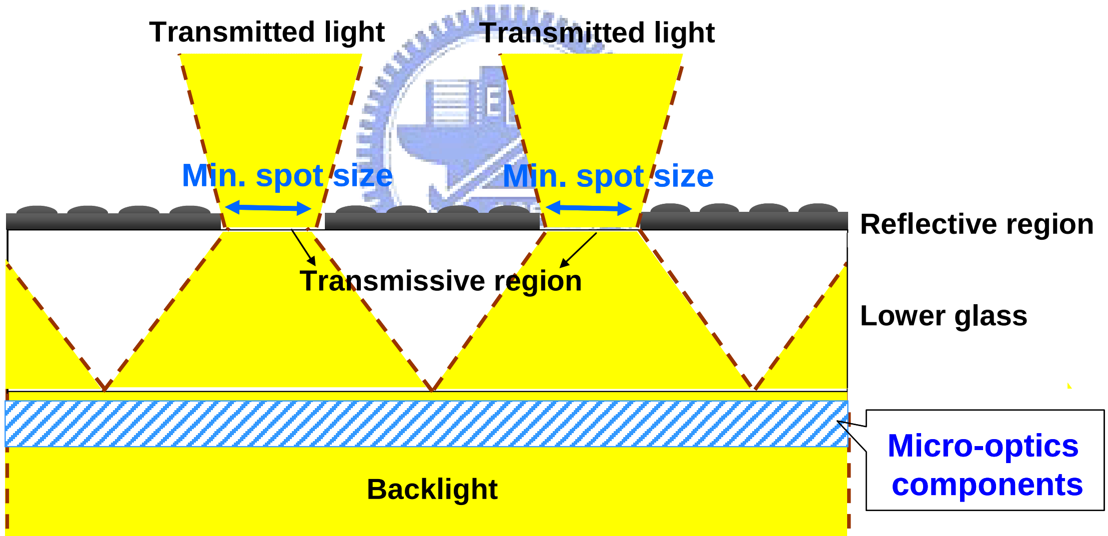


Fig. 2.3. Illustrated figure of micro-optics on transflective LCD

2.3.1 Diffractive Component (Fresnel Lens)

First, a Fresnel lens is considered as a backlight collective component. The configuration of a Fresnel lens is illustrated as Fig. 2.4. According to the diffraction principle of the Fresnel zones, the radius of Fresnel zone can be calculated. Assuming that all of the light entering the Fresnel lens can exit from the aperture, then the light efficiency can be increased to $(3/2.5)^2=144\%$. However, due to the fabrication limitation, the Fresnel lens only can be treated as a binary component. Thus, the first diffractive efficiency is about 35%, that the light efficiency enhancement in transmissive mode is only about 115%, consequently, not adequate for the device applications yet.

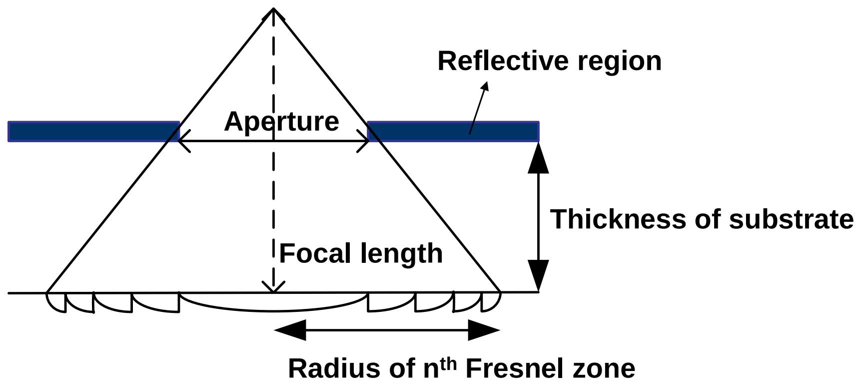


Fig. 2.4. Schematic diagram of Fresnel lens

2.3.2 Diffractive Component (Grating)

Secondly, a grating structure is also considered as a backlight collective component. The structure of a grating is depicted in Fig. 2.5. The diffraction angles θ are calculated for three colors of light, Red, Green, and Blue, respectively. Here, the diffractive efficiencies of Red, Green and Blue rays are also considered on the actual condition, thus the calculated light efficiency enhancements for R, G and B rays are about 123%, 120% and 117%, respectively, which still can not achieve our target as well.

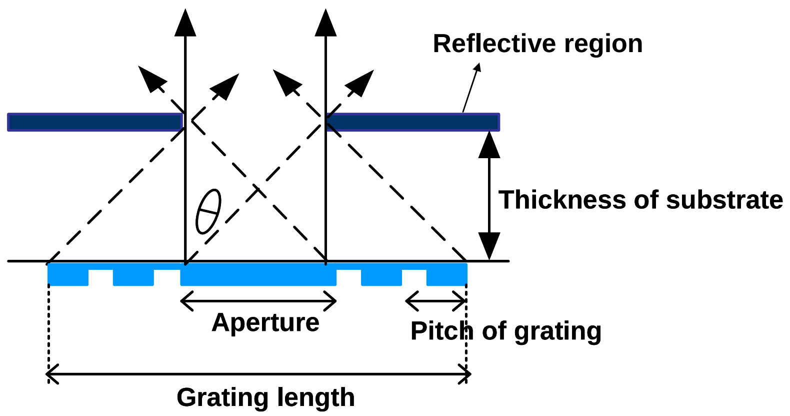


Fig. 2.5. Schematic diagram of grating

2.3.3 Refractive Component (Micro-lens)

Because the light efficiency of diffractive components is limited by diffraction effect, micro-lens is proposed based on less loss caused by diffraction effect and less complicated in fabrication process. The schematic of micro-lens is shown as Fig. 2.6. Based on the principle of collecting light [15], its light efficiency enhancement is approximated to 190%. Thus, micro-lens is adopted as the backlight collective component to enhance the light efficiency of transflective LCD.

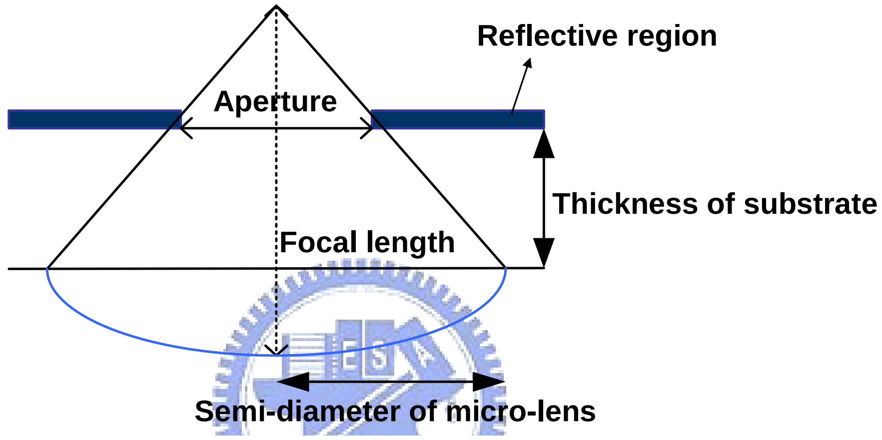


Fig. 2.6. Schematic diagram of micro-lens

2.4 Design of Micro-lens

From the above discussions, we conclude that the micro-lens can provide higher light efficiency enhancement. As a result, the micro-lens is proposed as backlight collective component and its detail features are described in the following.

In order to obtain higher light efficiency in transmissive and reflective modes, the spot size of collected light must be as small as possible. Based on the geometrical optics, the capability of micro-lens for collecting light can be derived. Although a micro-lens illuminated by parallel light source can make the smallest spot, in practice, the parallel light source is difficulty to get. Thus, as illustrated in Fig. 2.7, the divergent angle of incident light source becomes an important parameter to determine the minimum spot size. Besides, as depicted in Fig. 2.8, the radius of micro-lens is also the dominant factor. For light source with a fixed divergent angle, improper radius of micro-lens results in the focusing spot either forward or behind the focusing plane. In contrast, only a properly designed radius of micro-lens can provide the smallest spot size at the focusing plane.

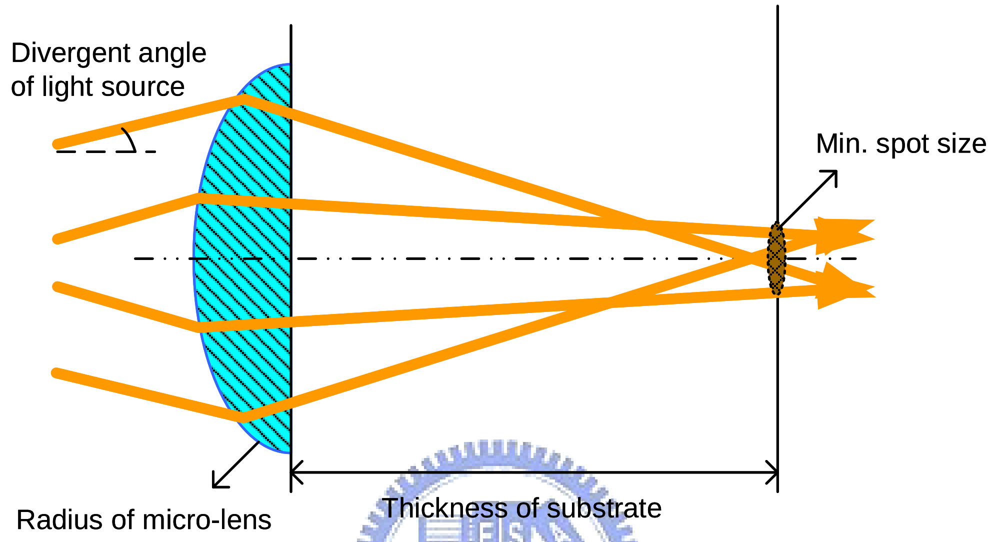
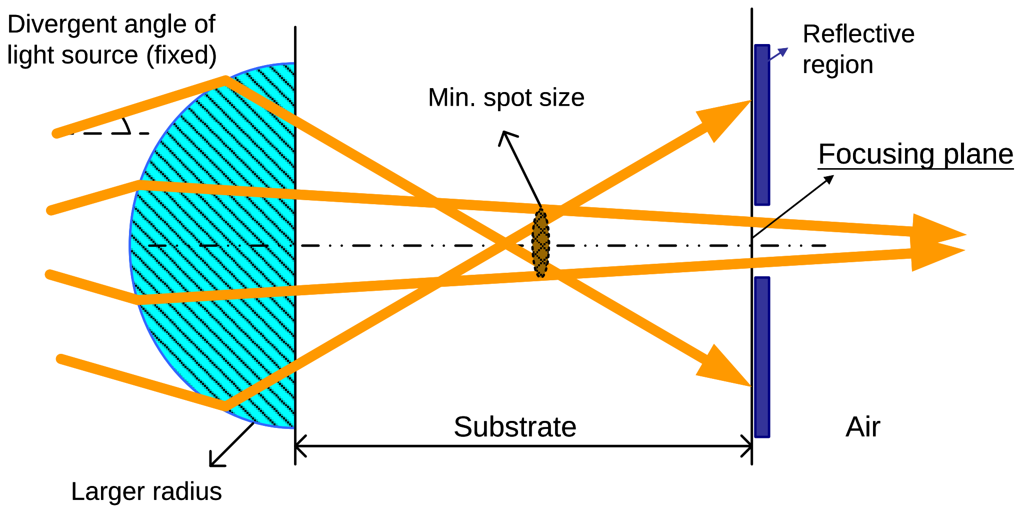
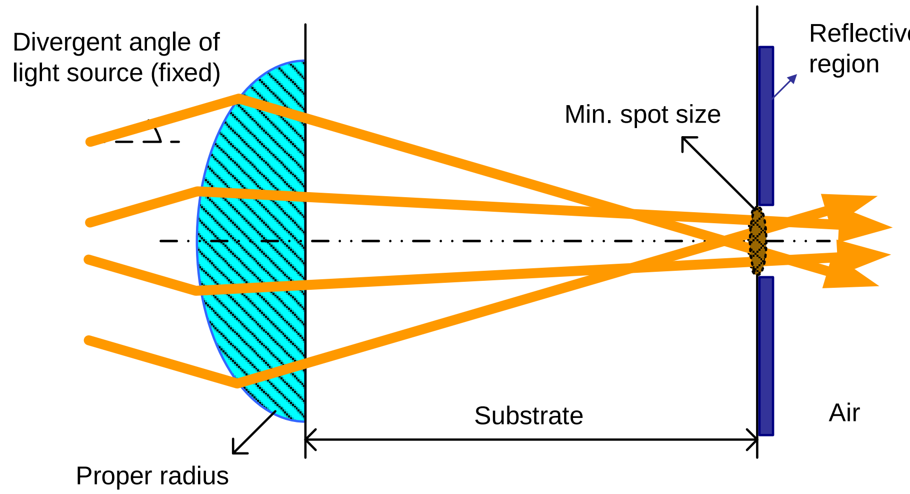


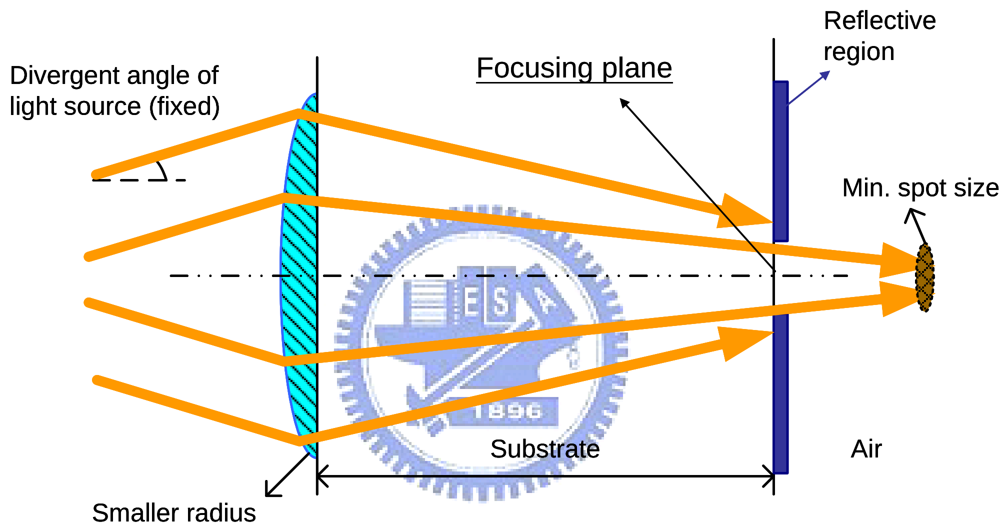
Fig. 2.7. Illustrated figure of definitions of dominant parameters for lens design



(a)



(b)



(c)

Fig. 2.8. Illustration of the minimum spot size as function of radius of micro-lens: (a) larger (b) proper and (c) smaller radius

The whole structure of a transflective LCD consists of a micro-lens array, inner polarizer, internal retarder, glass substrate, ITO electrode and color filter is shown in Fig. 2.9. The micro-lens array is located on the bottom surface of lower glass substrate. Here, in-cell polarizers [16] and patterned retarders [17] are utilized to provide polarization light for LC layer. Using patterned retarders, the optical properties can be patterned on sub-pixel level which improves the LCD on brightness.

Moreover, the support or carrier sheets and adhesive layers are no longer needed. Furthermore, in-cell polarizers and patterned retarder can be integrated directly into the LCD, thus, improving robustness of the display.

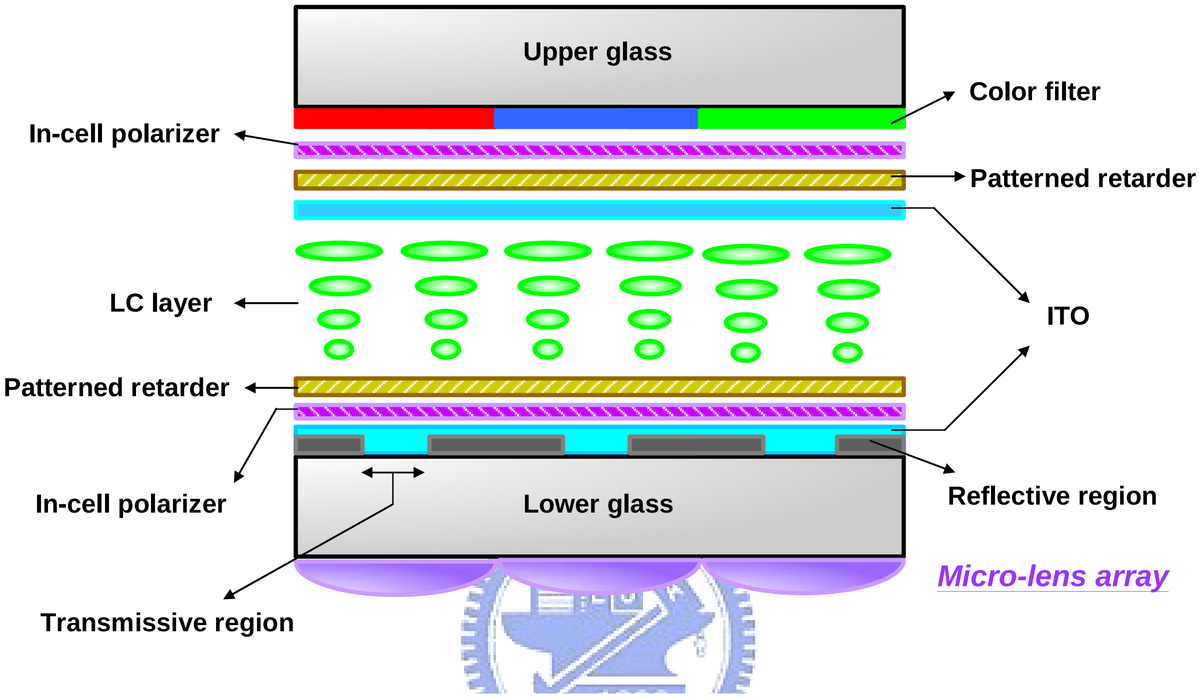


Fig. 2.9. Whole structure of transflective LCD with a micro-lens array

2.5 Summary

Compared with diffractive devices, Fresnel lens and grating, micro-lens array can provide higher light efficiency. By properly design the geometric features of micro-lens array, the minimum the spot size of collected incident light can be obtained and then transmissive regions can be reduced. Thus, the light efficiency in transmissive mode can be increased. Moreover, due to minimizing the spot size, reflective regions also can be increased and result in enhancing the light efficiency in reflective mode. In the following chapter, simulation software will be utilized to further design and optimize micro-lens array structure so that the highest light efficiency enhancement can be obtained.