Chapter 1

Introduction

1.1 Portable Products

Portable applications are continually growing with rapid progress of computer, internet and multimedia markets. In this trend, technologies capable of displaying mass information in pictures and contents become increasingly demanded. Based on different applications, there are several types of display technologies, such as Plasma Display Panel (PDP), Cathod Ray Tube (CRT), and Liquid Crystal Display (LCD). Among all approaches, LCD can provide many desired features of thin format, compact size, light weight, and high image quality. All these features can fulfill the requirements of portable applications. As a result, LCDs have become the most important information display in portable products.

1.2 Liquid Crystal Display

Due to the significant merits of thinner volume, lighter weight, and lower power consumption, Liquid Crystal Display is widely utilized for portable applications. A transmissive type LCD, which equipped with an illuminator called a backlight placed at the rear surface, is used to exhibit information. The amount of light emitted from backlight which passes through the liquid crystal layer is controlled by the liquid crystal panel to realize images, as shown in Fig. 1.1. Although transmissive type LCD can provide high contrast ratio and better color saturation by using backlight, but the amount of transmitted light is relatively small. The backlight consumes 50% or more of the total power consumption. Besides, the transmittances of polarizer and color filter are 50% and 30%, respectively. Therefore, a typical transmissive type LCD only has a light efficiency of about 7.4%. The problem can be solved by utilizing a brighter backlight, but the power consumption will be further increased. Moreover, transmissive type LCD will washout under brighter environment. As a result, transmissive type LCD is not suitable for portable applications.

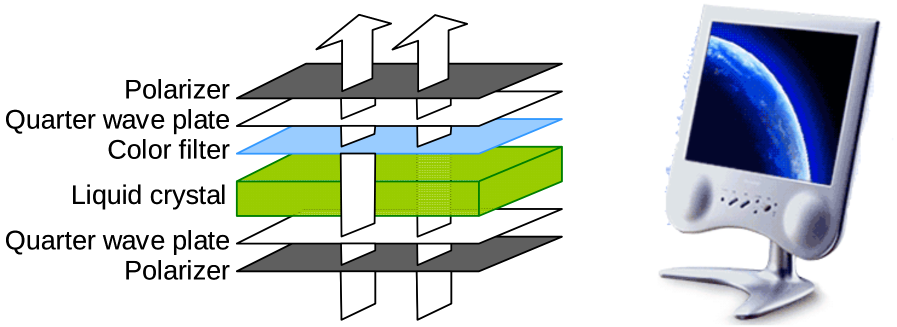

Fig. 1.1. Transmissive type LCD

In order to overcome the issues of transmissive type LCD, a reflective type LCD was proposed, as shown in Fig. 1.2. The reflective type LCD is composed of an inner or outer reflector and a liquid crystal panel. Because the information is realized by using reflector to reflect ambient light, the luminance of reflected light is close to that of environment. Hence, washout effect can be reduced substantially. Besides, power consumption issue can be eliminated due to removing backlight. However, since the reflective type LCD uses the ambient light for performing the images, the luminance of reflected light extremely depends on the surrounding environment, and is always loses its visibility in dark environment. Furthermore, to control the optical properties of ambient light is difficult. As a result, reflective type LCD, which can not provide higher contrast ratio and color saturation under all environments, seems also unsuitable for portable applications.

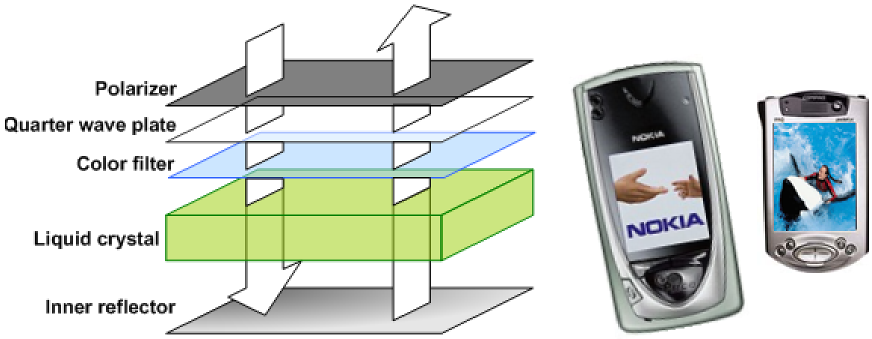

Fig. 1.2. Reflective type LCD

In order to improve the issues of transmissive and reflective LCDs, a configuration which realizes both the transmissive and reflective type display in one liquid crystal device has been developed and named transflective type LCDs, as shown in Fig. 1.3.

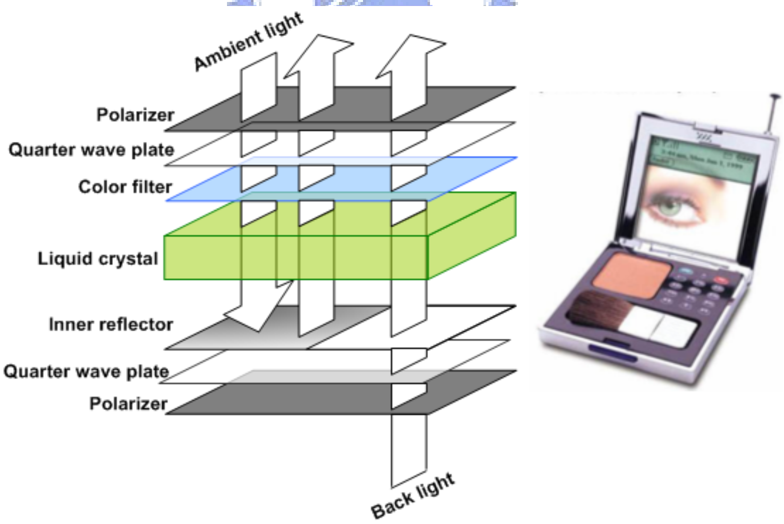

Fig. 1.3. Transflective type LCD

1.3 Transflective LCDs

The liquid crystal displays using both the transmitted light and reflected light are generally referred to transflective LCDs, which can provide better image quality under any circumstance. There are several kinds of transflective LCDs: transflective

LCD with transflector [1], single cell gap structure [2] [3] and double cell gap structure [4] [5] [6], etc. Following the approach and characteristic of each transflective LCD will be introduced.

1.3.1 Transflective LCDs with Transflector Device

A transflective LCD which comprises a transflector between liquid crystal cell and glass substrate is shown in Fig. 1.4. The transflector equips the function of partially transmission and reflection. In the transmissive mode, backlight passes through transflector to display information. On the other hand, ambient light is reflected by transflector to realize images in the reflective mode.

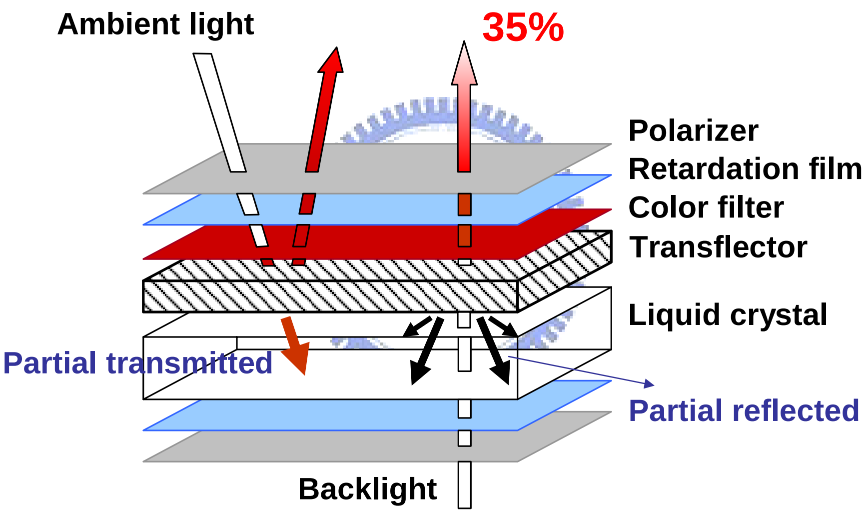

Fig. 1.4. Transflective type LCD with transflector

However, in practical applications, the reflection of the transflector is approximately 65% of the incident light. Consequentially, 35% of ambient light will be wasted in the reflective mode. Moreover, as the display is used in transmissive mode, 65% of backlight will be reflected, thus decreasing backlight efficiency. An increase of the transmission in the transmissive mode worsens the brightness and contrast in the reflective mode. As a result, a transflective LCD with a transflector is not good enough yet due to lower backlight utilization.

1.3.2 Singe-cell Gap Structure

A transflective LCD with divided sub-pixels was developed by Sharp corporation, as shown in Fig. 1.5. The divided sub-pixel is composed of transmissive (T) and reflective (R) regions. In general, the ratio of R and T area is 4:1 or 7:3. In bright environment, the incident light on T regions is absorbed by lower polarizer and then the device operates as a reflective type LCD. On the other hand, in dark environment, the backlight transmits T regions and then works as a transmissive type LCD. As implied in the name of single cell gap, the cell gap of T and R regions are equal. In addition, according to the construction of single-cell gap, the optical path lengths of transmitted backlight and reflected ambient light are different. Therefore, the optimized condition for R regions is not suitable for T regions, thus decreasing 50% of light efficiency of transmitted backlight. Besides, for R regions, the ambient light travels color filter twice. In contrast, the backlight transmits color filter only once for T regions. As a result, the color balance between the R and T regions is also a challenge for such a transflective display. Hence, single-cell gap structure is also not a good solution of transflective LCD due to different color saturation and lower backlight efficiency.

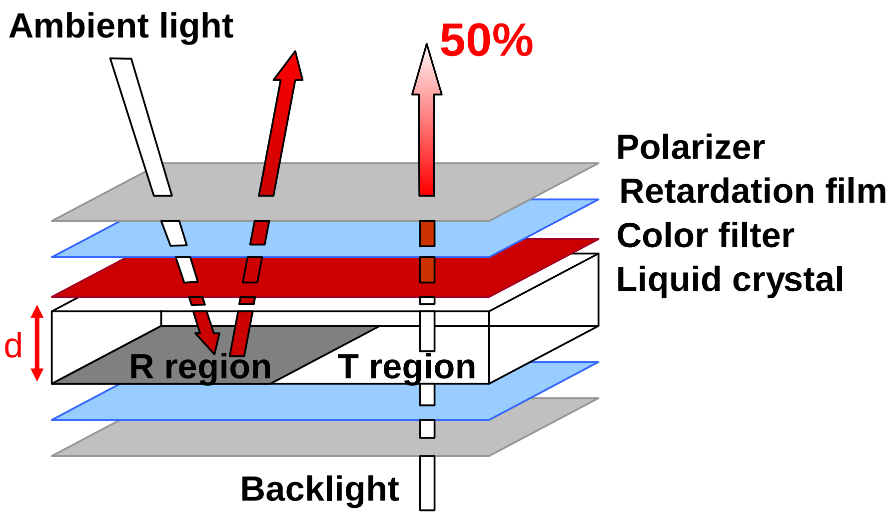

Fig. 1.5. Single-cell gap transflective LCD

1.3.3 Double-Cell Gap Structure

In order to overcome the lower backlight efficiency of single-cell gap transflective LCDs, another structure named double-cell gap structure was proposed by Sharp corporation, as shown in Fig. 1.6. As implied in the name of double-cell gap, the cell gap in T regions is twice as much as that in R regions. When the liquid crystal in R regions is designed to provide a $\lambda/4$ retardation, the liquid crystal in T regions would provide a $\lambda/2$ retardation due to double thickness. Thus, the optical path difference in T and R regions are the same. As a result, both R and T regions can provide high light efficiency. Although backlight efficiency of double-cell gap is higher than that of single-cell gap, but the different liquid crystal thickness will cause different response time, thus decreasing image quality. Moreover, employing double-cell gap on substrate is more complex and results in higher cost. Hence, double-cell gap structure seems also not the best solution of transflective LCD.

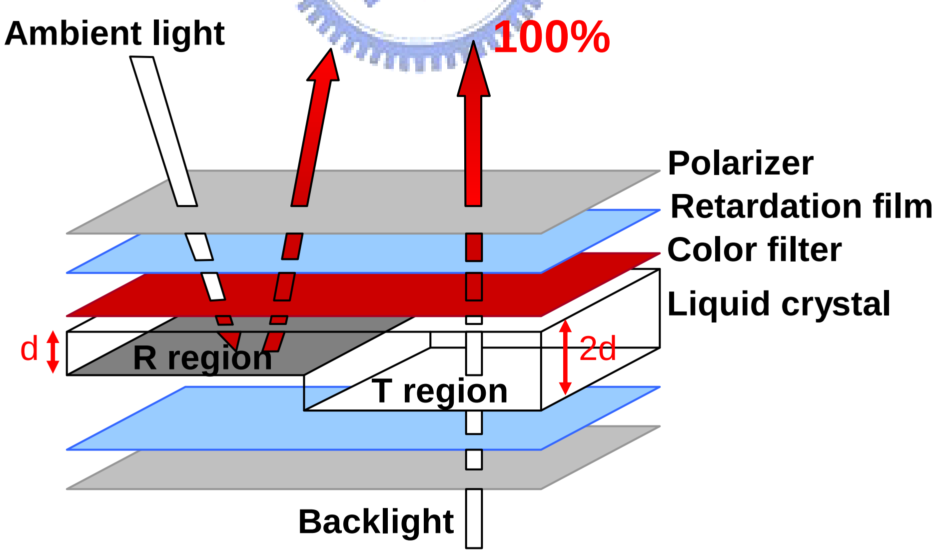

Fig. 1.6. Double-cell gap transflective LCDs

1.4 Motivation and Objective of This Thesis

As illustrated above, in single-cell gap and double-cell gap transflective LCDs, each sub-pixel is divided to reflective and transmissive regions. In brightness state, the incident ambient light is reflected by the reflective region and then illuminates images. In dark state, the incident backlight is transmitted through the transmissive region and display information. However, when making use of backlight as light source, some light is obstructed by the reflective region and results in lower backlight utilization. Therefore, a novel optical structure, micro-lens array, was proposed to enhance the backlight efficiency. The characteristic of this design is to make use of a micro-lens array structure to collect all the incident backlight and focus it on transmissive regions. Based on the capability of micro-lens array for collecting light, the minimum spot size of collected backlight will locate on transmissive regions. As a result, transmissive regions can be reduced while increasing reflective regions. Consequently, light efficiency in transmissive and reflective modes can be enhanced simultaneously.

Although micro-lens array can provide higher collective capability and then increases light efficiency of transflective LCDs, the integration of micro-lens array into transflective LCDs is a critical issue. The misalignment between micro-lens array and transmissive regions will cause light leakage and results in lower contrast ratio. Therefore, a novel fabrication process including self-aligned exposure was proposed to eliminate the alignment error and fabricate micro-lens array simultaneously in the following experiments.

1.5 Arrangement of This Thesis

The thesis is arranged as following: the principles and the characteristic of the micro-lens array will be described in **Chapter 2.** In **Chapter 3,** the proposed novel fabrication process is described. Besides, the measurement equipments used to characterize the geometrical shape of micro-lens array and evaluate the optical performance of micro-lens array are illustrated. In **Chapter 4,** the simulated results including light efficiency, light efficiency enhancement, and various radius of micro-lens structure and aperture size of reflective regions, which used to verify and optimize our design, will be discussed**.** In **Chapter 5,** according to the experimental results, several parameters in fabrication process are discussed, and then the designed structure will be realized and modified. The conclusion of the dissertation and the future work are given in **Chapter 6.**