Micro-optics Components for Liquid Crystal Displays Applications

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Abstract

Microoptics has become the key technology in liquid crystal display systems due to its capabilities of miniaturization and design flexibility. We successfully demonstrate five different microoptical components for enhancing the image quality, providing better functions, increasing light efficiency, and generating 3D images in LCD applications.

1. Introduction

Microoptics has emerged as a new branch of science during the past 10-20 years and is gradually making its way towards commercialization in a number of fields. Because of its capabilities of miniaturization and design flexibility, microoptics has become the key technology for building compact optoelectronic system.

Liquid crystal displays (LCDs), a kind of optoelectronic system, has the desired features of thin format, compact size, light weight, low power consumption, and high image quality. All these desired properties of LCD can fulfill the requirements of the applications including mobile devices, notebook, digital camera, etc. With the developments of these various applications, LCDs have become the most important information displays technology.

In liquid crystal displays, microoptical components also contribute various novel devices that bring more flexibility in system design to increase the overall performance, thus, offering more appealing LCDs. In this paper, microoptical components used for enhancing the image quality and generating the 3D images will be described and demonstrated, respectively.

2. Micro-optics for LC display systems

Design flexibility is one of the advantages of microoptics. We presented five different microoptical structures for various display applications: 1. Random grating light control film[1],[2] for increasing the brightness of reflective images. 2. Image enhanced reflector[3],[4] for achieving "transflective" cholesteric LCDs. 3. Microtube array[5],[6] for improving the backlight utilization of transflective LCDs. 4. Sub-wavelength grating[7],[8] for doubling the backlight efficiency. 5. Grooved-lightguide with focusing foil[9] for generating 3D images. The detailed design and experimental results are described in the following.

2.1 Random grating light control film

Applications of transflective LCDs(TR-LCDs) are still limited due to the low brightness of reflective images. Therefore, random grating light control film(RG-LCF), as shown in Fig. 1, which can direct light incident from multiple directions collectively for viewing in achieving much enhanced brightness of reflective image was proposed. The grating pitches and orientations were designed properly to improve the brightness and uniformity. Additionally, the size of each grating is $25\times25\mu m^2$ and the arrangement in a single pixel is randomized in order to avoid the moiré patterns and dispersion.

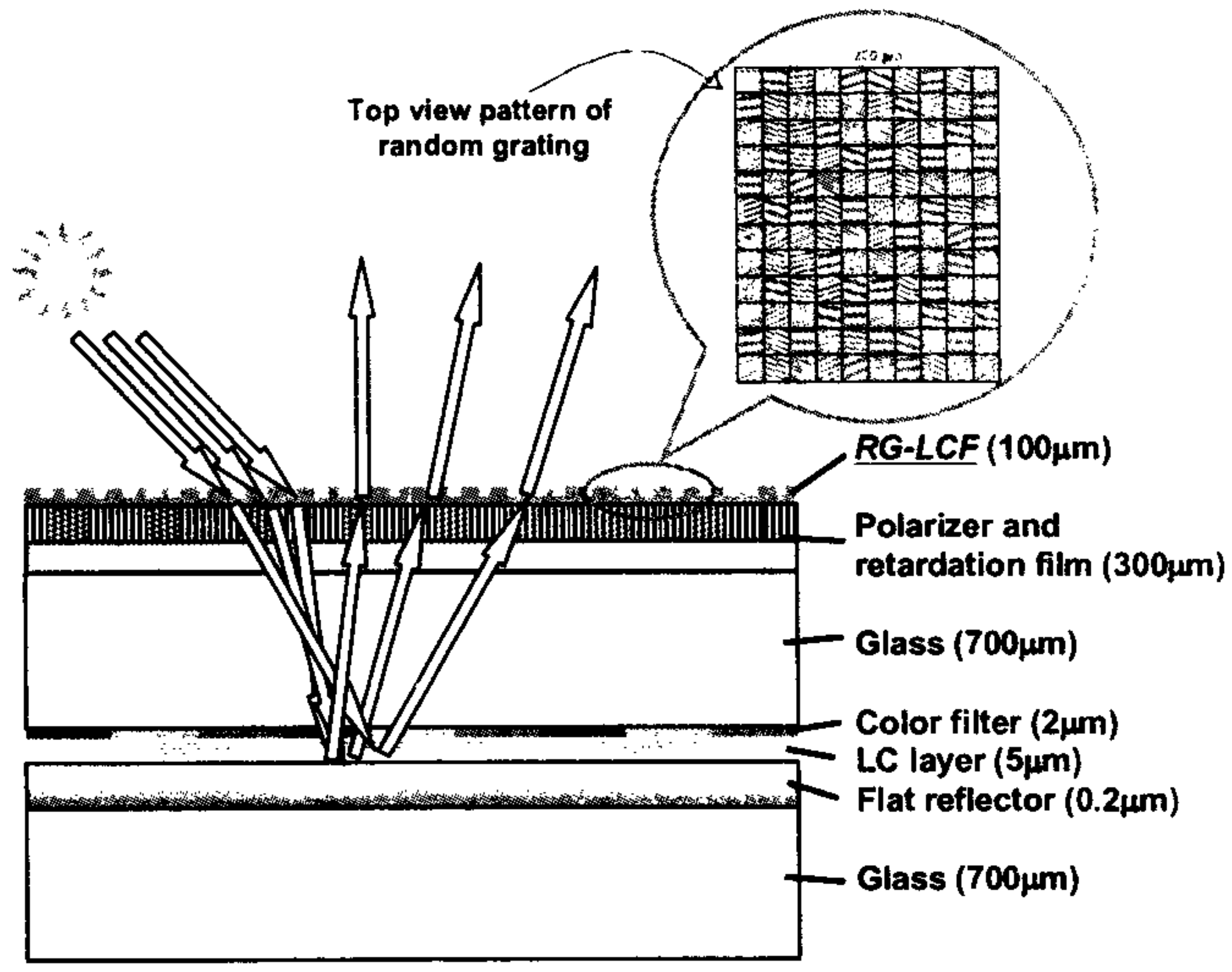
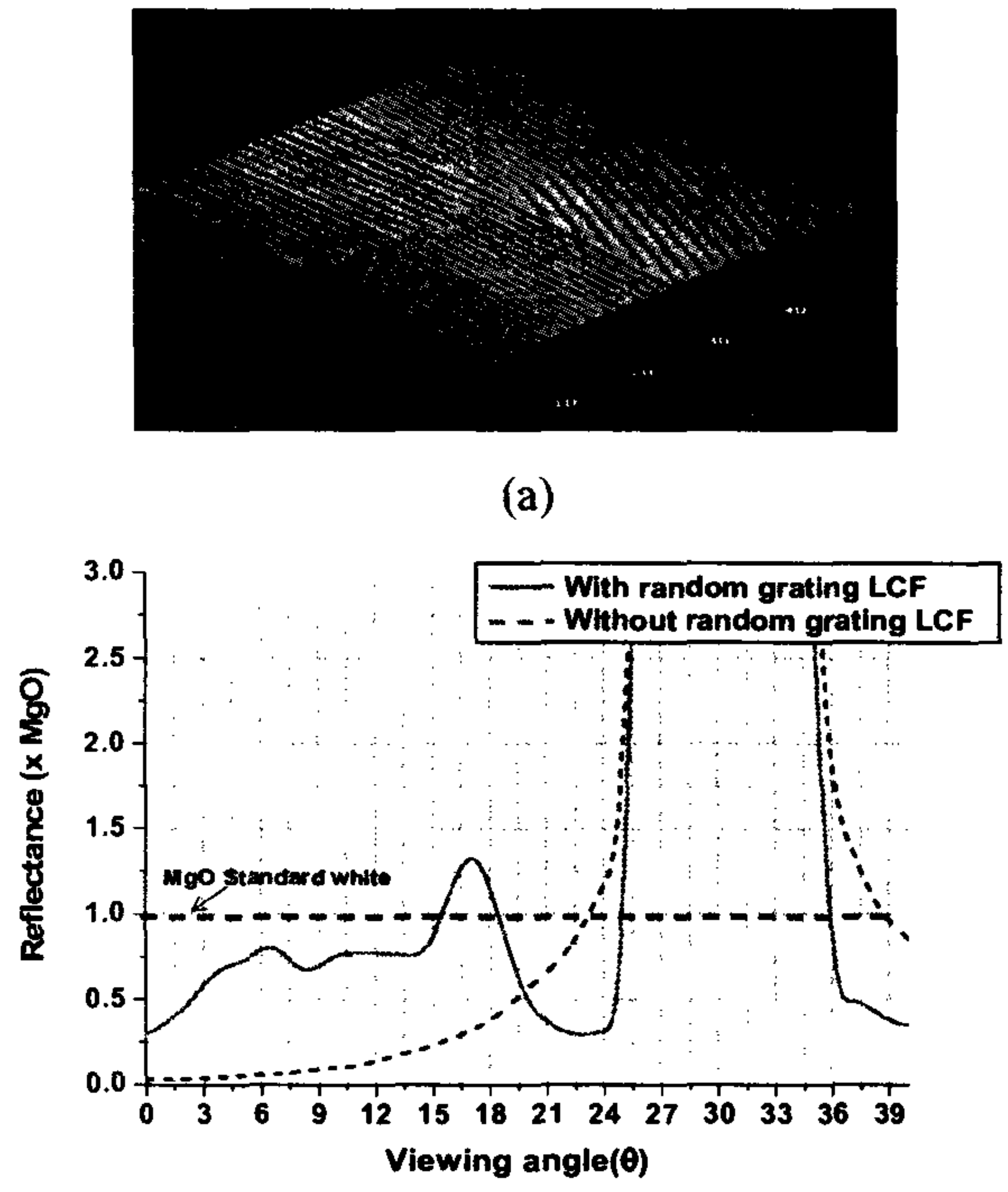


Fig. 1. Configuration of a TR-LCD with the RG-LCF laminated onto the front surface.

A standard VLSI and stamp molding process can be used to fabricate the random grating structure on a 100μm thick plastic thin foil economically. The fabricated grating structure imaged by AFM is shown in Fig. 2(a). The reflected light distribution of a transflective LCD with RG-LCF is shown as the solid line in Fig. 2(b), where the dashed lines show the specular reflection without the RG-LCF. Obviously, the transflective LCDs using LCF provides more uniform reflected light within typical viewing region from 0 to 25°, with higher reflectance and better image quality.



(b)

Fig. 2. (a) The 3D view and (b) the reflectance profile of the RG-LCF laminated on a TR-LCD.

2.2 Image enhanced reflector

Reflective cholesteric liquid crystal display (Ch-LCD) is a strong contender for e-papers, e-books, etc. To enable a display to be useable from dark to bright sunlight conditions, transflective display is a good option. However, the conventional transflective approach does not apply to the cholesteric display. Both reflective and transmissive sub-pixels display bright state, but lack of dark state. We demonstrated a transflective Ch-LCD by placing an image-enhanced reflector (IER) above the transmissive part to reflect the backlight into the reflection pixels, as illustrated in Fig. 3. This IER design functions equally well for both monochrome and full color cholesteric displays. Due to the similar paths of transmissive and reflective light, the same bright state for both reflective and transmissive channels can be obtained. Thus, the Ch-LCD maintains good readability in any ambience.

The half-tone mask technology equipped with excimer laser micromachining was used to fabricate the prototype IER structure on a glass substrate, as shown in Fig. 4(a). Prior to examine the function of IER, we prepared a simple monochrome Ch-LCD test sample with conventional backlight. The images of reflective (left part) and transmissive (right part) mode are shown in Fig. 4(b). The photos successfully demonstrate that this novel transflective Ch-LCD can display same image color in any ambient condition by using image-enhanced reflector.

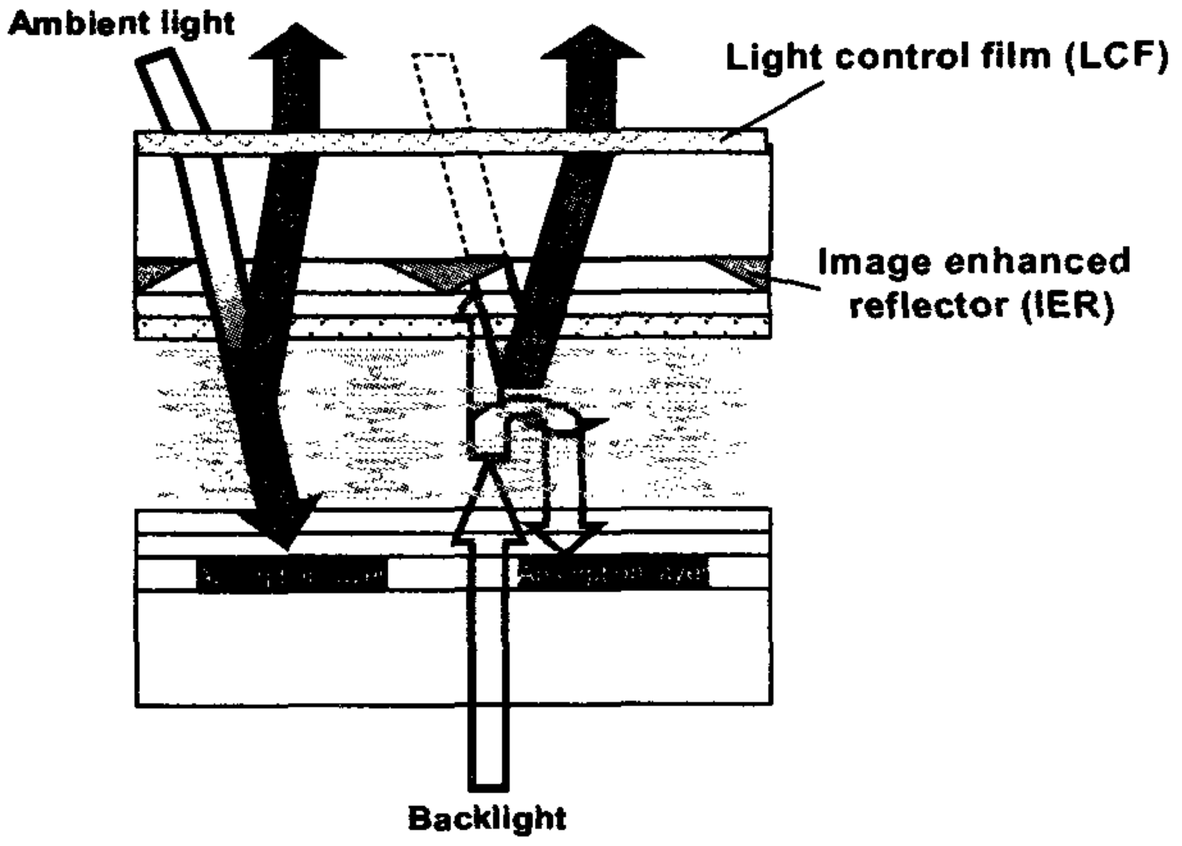
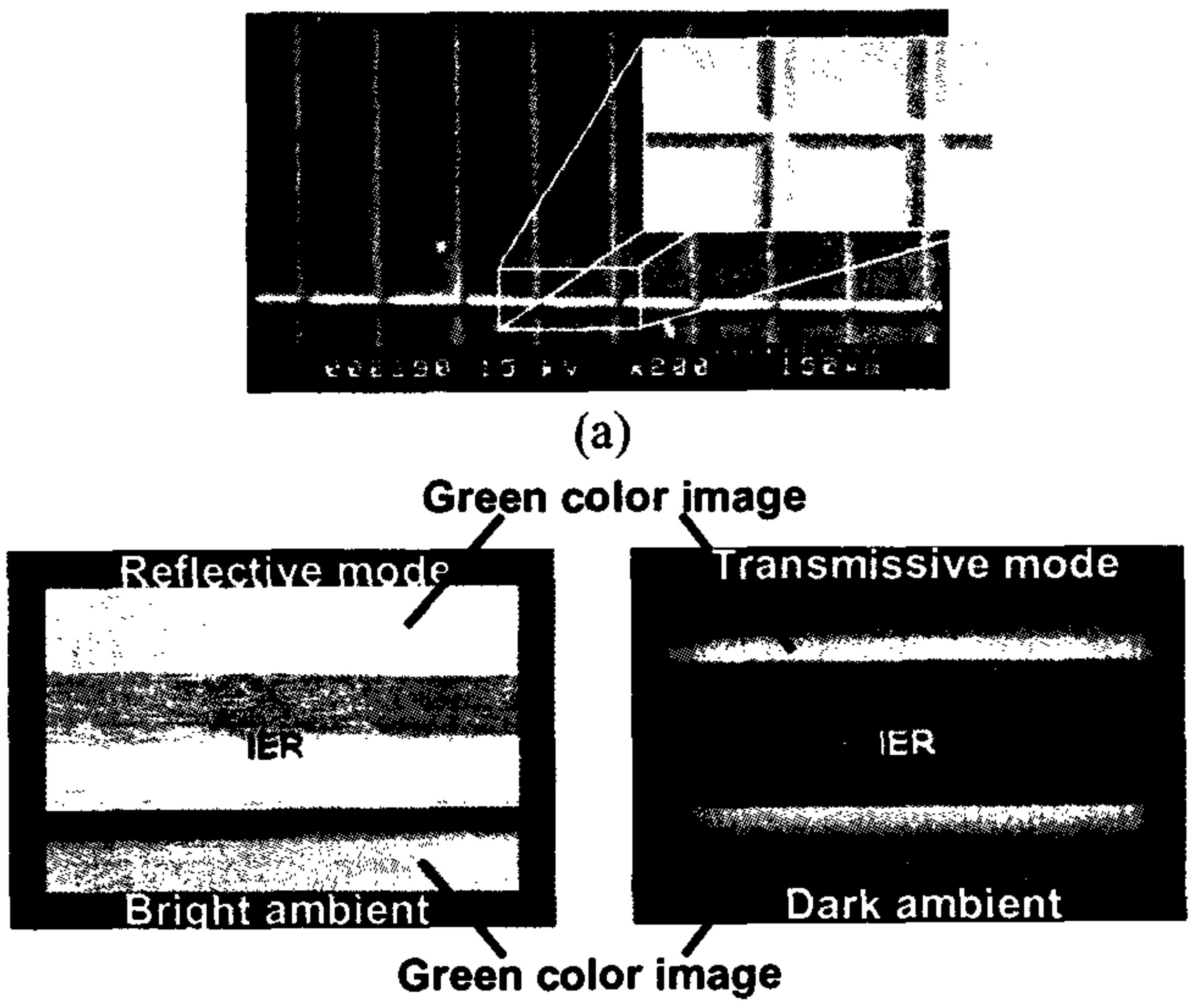


Fig. 3. Cross-sectional plot of the transflective Ch-LCD with image enhanced reflector (IER).



(b)

Fig. 4. (a) The top view of fabricated IER and (b) The demo photos of the same color images for both reflective and transmissive modes.

2.3 Microtube array

In conventional transflective LCDs, the reflective area is regarded as a block that backlight can not pass through. In order to overcome the issue, a novel structure, micro-tube array, was proposed to collect the backlight into the transmissive area to increase light utilization efficiency of backlight in transflective LCDs. The characteristic of this design is to make use of a micro-tube structure which is similar to a funnel in shape and to allow most backlight enter this structure from larger aperture, as shown in Fig. 5. On account of the characteristic of the funnel structure, most of incident light can be collected to smaller aperture so that light efficiency of the backlight can be increased substantially.

A prototype micro-tube array, as shown in Fig. 6(a), was fabricated by a typical TFT-LCD process. The measured transmissive light efficiency enhancement of micro-tube array structure is shown in Fig. 6(b). The measured enhancement in different viewing angle was a factor of 1.65 to 2.3, and the averaged enhancement was a factor of 1.81. As a result, the novel transflective LCDs with micro-tube array can be made with lower power consumption due to the higher backlight efficiency, which will be more competitive in the mobile display market.

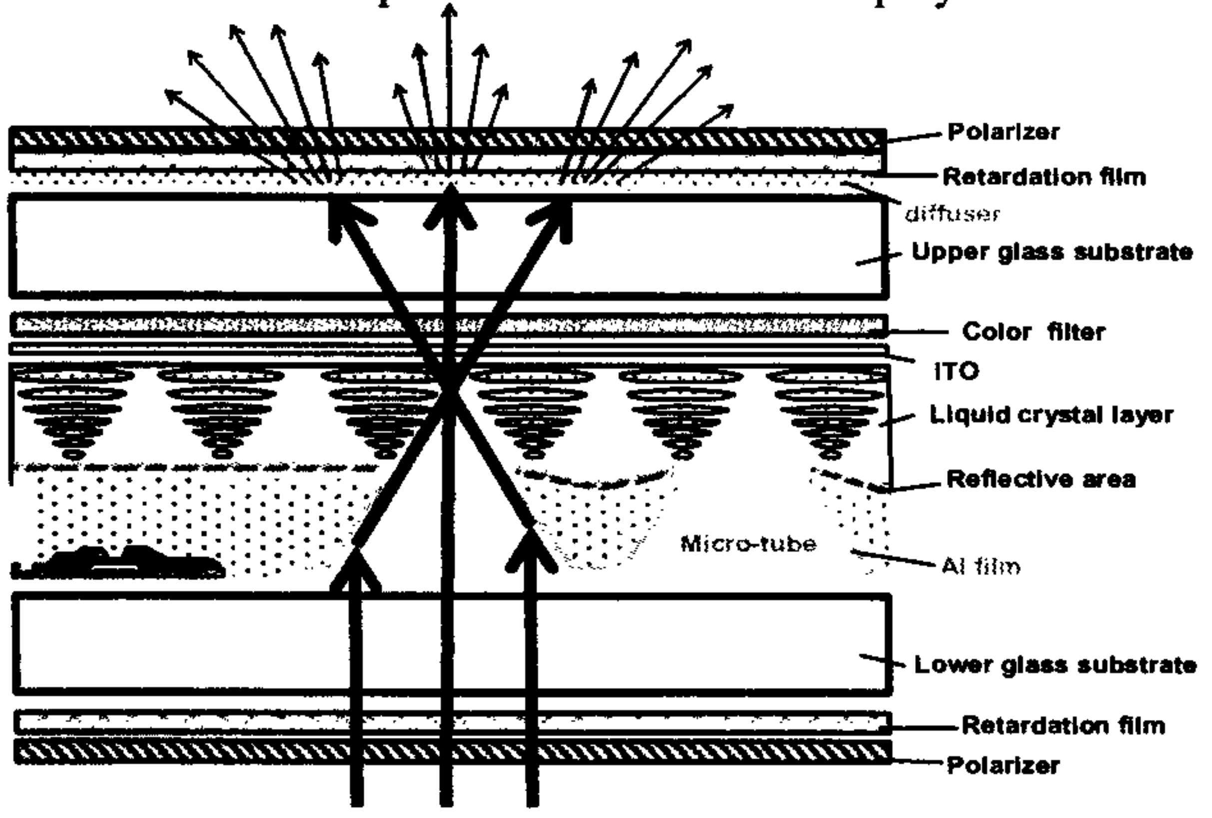
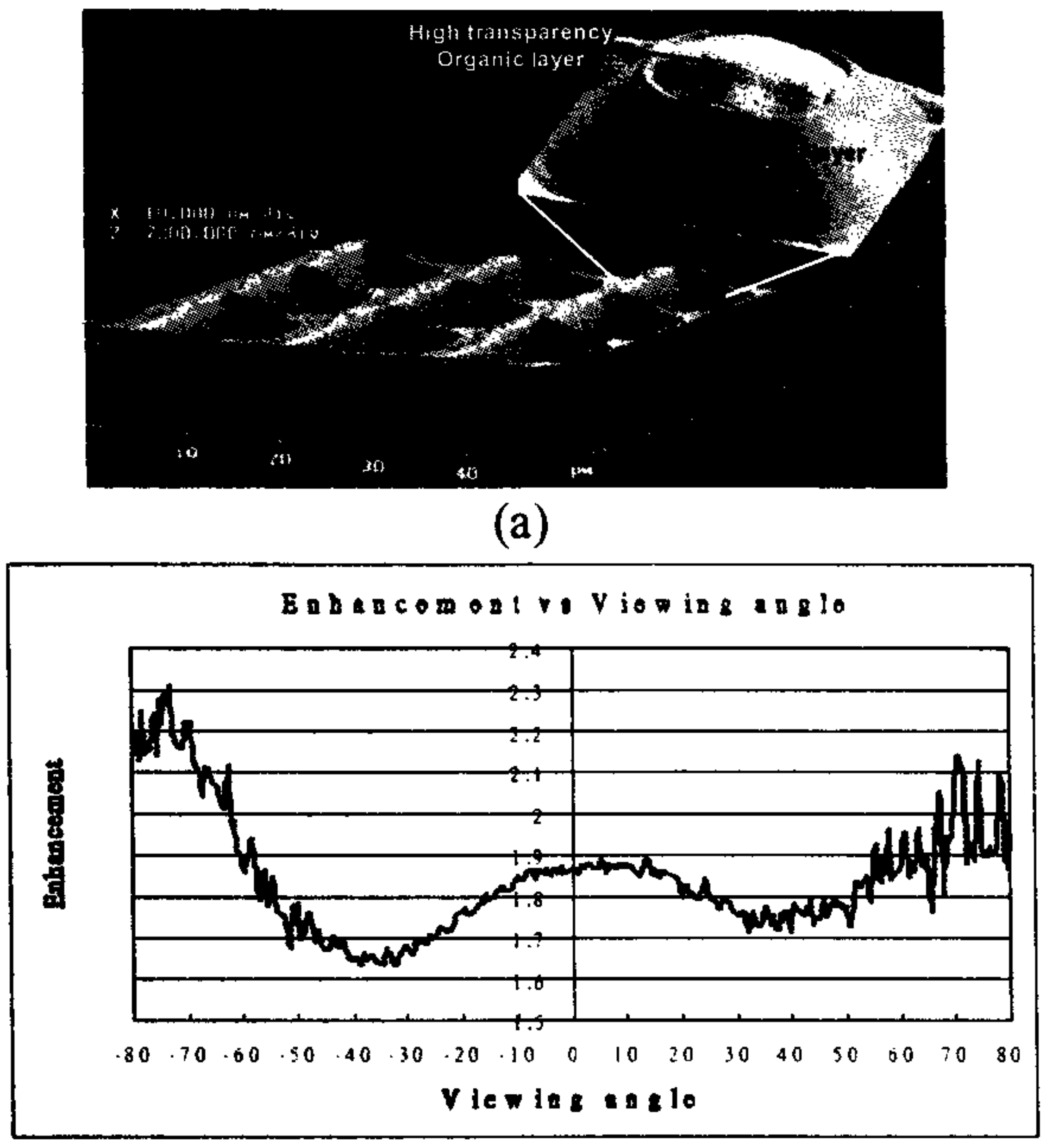


Fig. 5. Schematic diagram of a single cell-gap transflective LCD with micro-tube array.



(b)

Fig. 6. (a) The 3D view and (b) the measured backlight efficiency enhancement plot.

2.4 Sub-wavelength grating

Bright and uniform backlight modules are essential for LCDs. The optical efficiency of conventional backlight modules is low due to the lack of p-polarized to s-polarized light conversion. In addition, the complex assembling of optical films usually hinders compact packaging.

An integrated lightguide for novel backlight modules was designed to achieve polarization conversion and compactness for LCD illumination, as shown in Fig. 7. When unpolarized light was coupled to the lightguide, slot structures on the bottom surface guided light out coupling. Light was then reflected by the reflective sheet. Upon the impingement on the sub-wavelength grating on the top surface, only p-polarized light was transmitted while s-polarized light was reflected. S-polarized light was then converted into p-polarized light by passing through the quarter wave plate twice. Therefore, out coupling light was uni-polarized, which was required for LCD illumination.

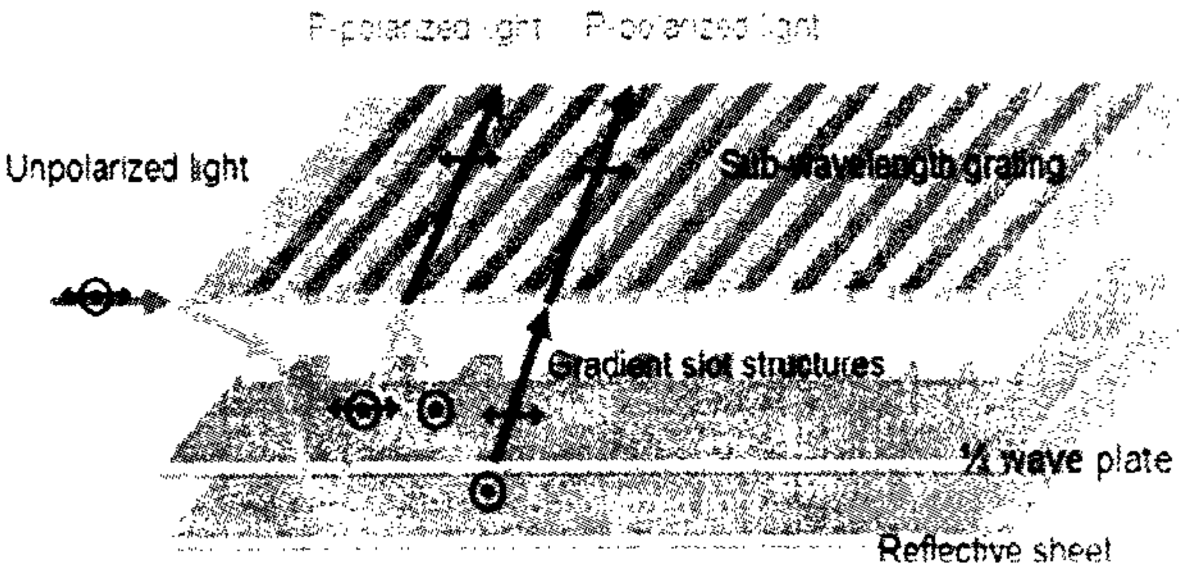
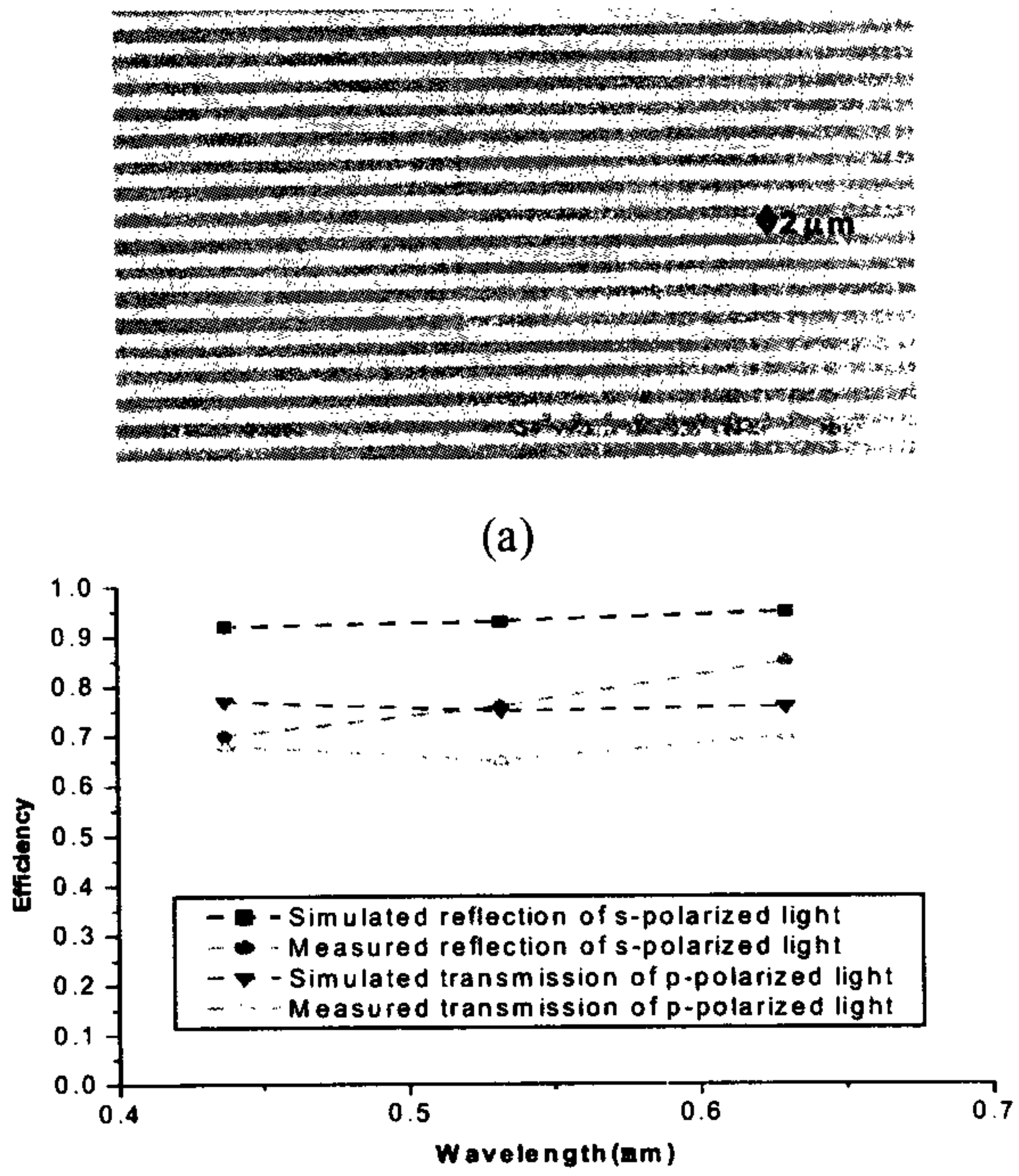


Fig. 7. Schematic layout of an integrated lightguide.



(b)

Fig. 8. (a) SEM photograph and (b) measured results of the sub-wavelength grating.

The fabricated pattern of sub-wavelength grating is presented in Fig. 8(a). The transmission and reflection of fabricated sub-wavelength grating were measured by a white light source accompanied with R (630 nm), G (532 nm), B (437 nm) three primary wavelength color filters. The measured and simulated reflection efficiencies versus wavelength are shown in Fig. 8(b). In such an arrangement, the measured reflection efficiencies at λ=437, 532, and 630nm are 70%, 76% and 85% for s-polarized light; transmission efficiencies for p-polarized light are 68%, 65% and 70%, respectively. 1.7 gain factor of polarization efficiency was obtained to increase utilization light for LC illumination.

2.5 Grooved-lightguide with focusing foil

Autostereoscopic 3D display can be generally classified into "spatial-multiplexed type" and "time-multiplexed type". However, spatial-multiplexed approach, such as using parallax barrier, results in resolution of one half or less and brightness degradation compared with time-multiplexed approach. Furthermore, alignment between parallax barrier and LCD pixels hinders its fabrication.

A time-multiplexed 3D display approach was therefore proposed by using switching, directional backlight in combination with fast switching LCD. Two restricted viewing cones were sequentially emitted from switching backlights. Two sets of light sources were switched on sequentially to emit light to the left and the right eyes, respectively. A directional backlight, shown in Fig. 9, is composed of a micro-grooved lightguide in combination with a focusing foil. When light source 1 is switched on, a large inclined angle of viewing cone is emitted from a micro-grooved lightguide. A focusing foil is then utilized to focus the light to the right eye. Similarly, the light is focused to the left eye when light source 2 is switched on.

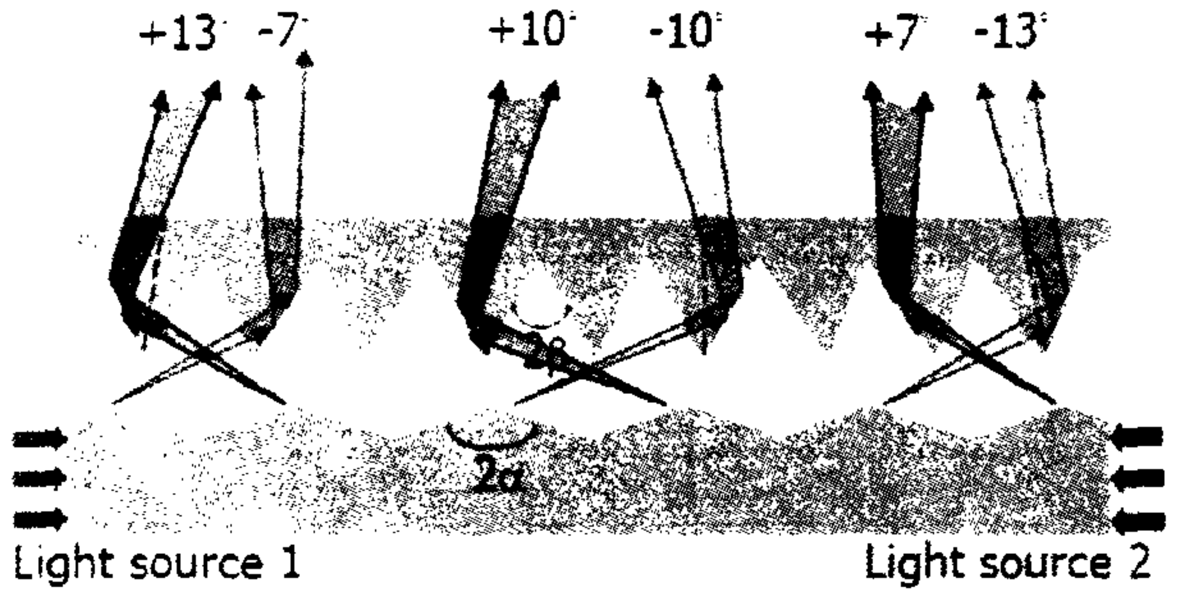


Fig. 9. Micro-grooved lightguide in combination with a focusing foil to redirect light to left and right eyes.

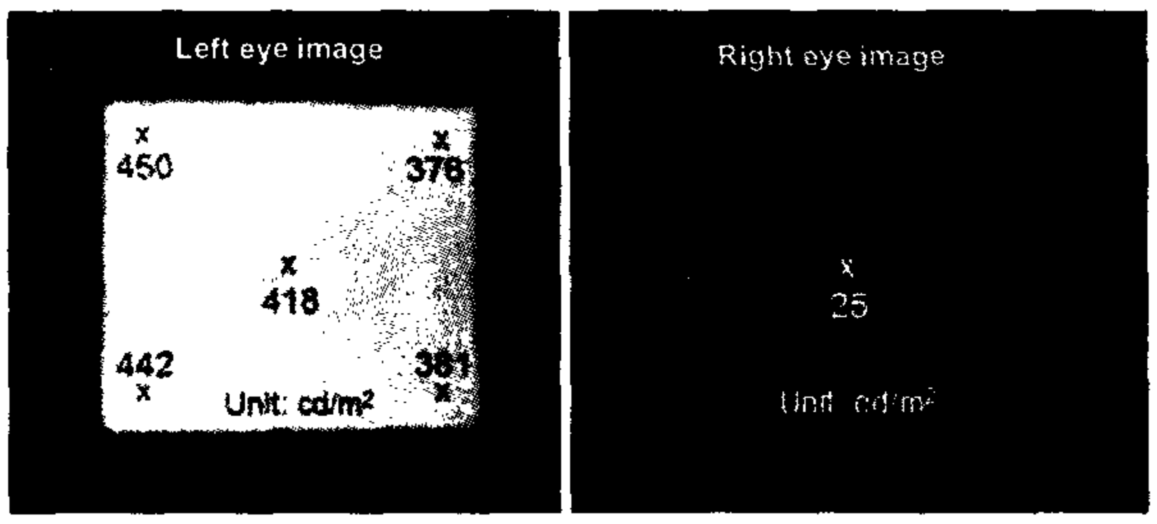


Fig. 10. Photos of source 1 illuminated lightguide at the viewing direction of left eye and right eyes.

The photos to demonstrate source 1 illuminated lightguide at the viewing direction of -10° and 10°, as shown in Fig. 10, where depicts the positions of left and right eyes, respectively. Image of high brightness and uniformity of higher than 80% was observed by our left eye while image of low crosstalk observed by our right eye. The backlight unit provides 2D/3D compatibility without degrading display resolution and brightness in switching mode.

3. Conclusion

Microoptics can meet the needs of miniaturization, cost reduction, and improved performance in LCDs. Random grating light control film enhances the reflectance of reflective image to 0.8x MgO standard white with excellent uniformity. Image enhanced reflector provides transflective function for Ch-LCDs, which become readable in any ambience. Micro-tube array increases the backlight utilization to a factor of 1.8 in transflective LCDs. Sub-wavelength gating almost doubles the backlight efficiency. Furthermore, grooved-lightguide with focusing foil using switchable backlight generates the 2D images into 3D images. Accordingly, the micro-optical technology can greatly enhance the image quality of display systems, and allows the display to be more and more appealing and attractive in various applications.

4. References

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