# Novel Design Techniques for Transflective Liquid Crystal Displays

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## Abstract

*Novel design techniques of half switching method, double layer structure, and multidomain structure for transflective liquid crystal display modes are introduced. Design examples of these techniques which perform excellent display characteristics are described.*

## 1. Introduction

Lately, for information and communication portable devices such as mobile phone, PDA (Personal Digital Assistant), and viewfinder of digital camera, low power consumption is required. Reflective-LCDs can reduce power consumption, because it does not need any back light source. Reflective modes are lightweight and have high contrast ratio in the environment as bright as day time.

However, they have the demerit of decreasing luminance in dark place [1, 2]. LCD makers have been making an effort to fabricate transflective panels due to the request to offer good picture quality in both indoor and outdoor environments.

In this paper, novel design techniques for transflective LCDs are introduced, and examples of these transflective modes are also described.

## 2. Standard transflective LCDs

Optical principle of standard transflective LCDs is explained in Fig. 1. In reflective mode, the incident light comes out when the phase retardation is 0 or λ after passing the retardation layer twice. Zero transmission occurs when the phase retardation is λ/2. In transmissive mode, the light also comes out when the phase retardation is 0 or λ after passing wave plate, transflective layer, and retardation layer. Dark state of transmissive mode is achieved when the phase retardation is λ/2 after passing those optical components. It is the key points of design for transflective LCDs that the retardations of each transmissive mode and reflective mode should satisfy these conditions.

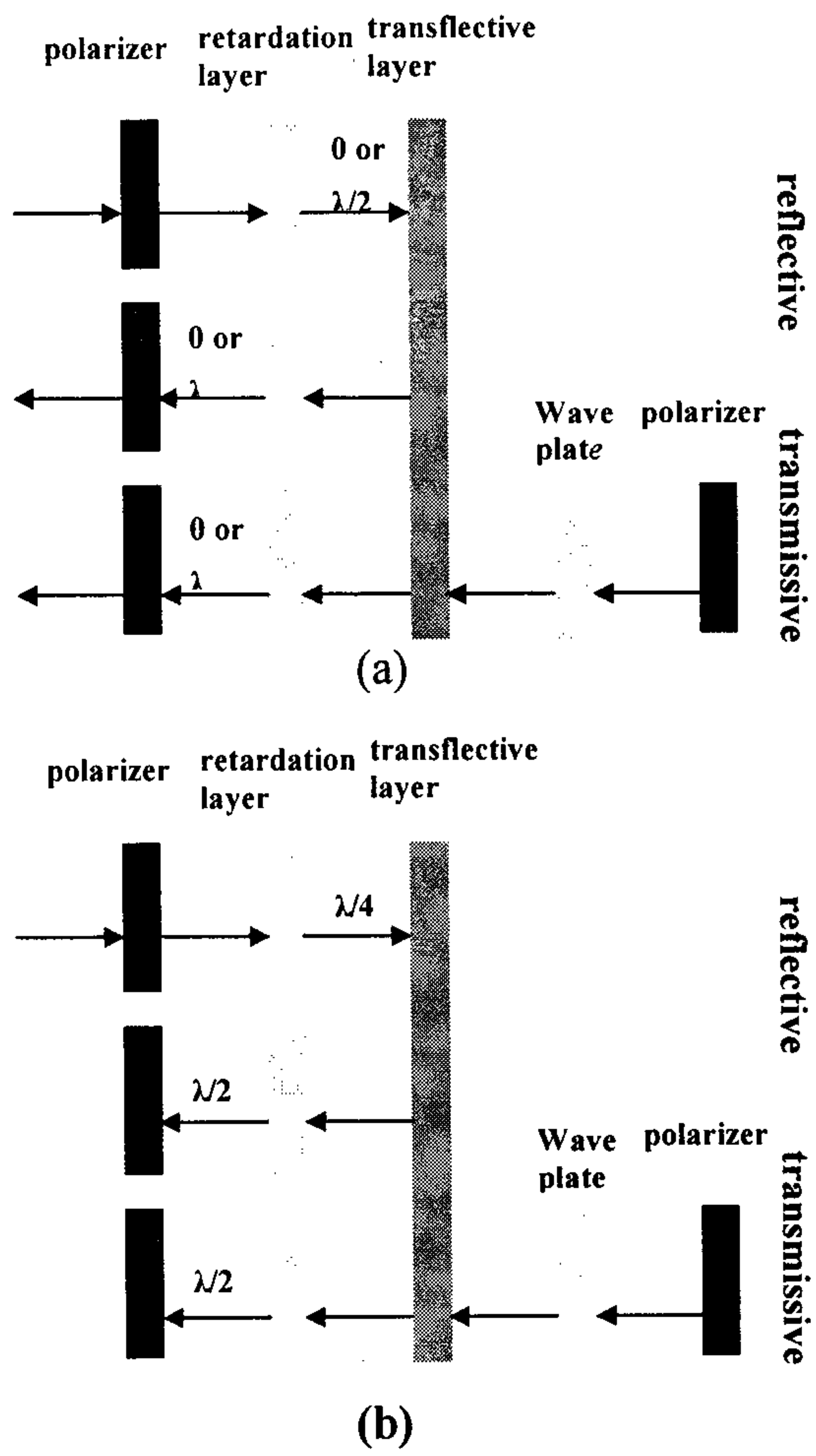


**Figure 1. Optical principle of transflective LCD: (a) Bright state, and (b) dark state.**

In typical transflective LCDs, one pixel is divided into transmissive area and reflective area. The pixel structures of general transflective LCDs can take one of two forms, either multi cell gap structure [3-4] or single cell gap structure with a reflective polarizer [5].

In multi cell gap structure, transmissive area and reflective area have different cell gaps, by which retardation of each transmissive mode and reflective mode satisfy separately the optical principle of transflective LCDs. Figure 2 shows cross-sectional view of a pixel with different cell gaps. Transmissive area has double the cell gap of reflective area.

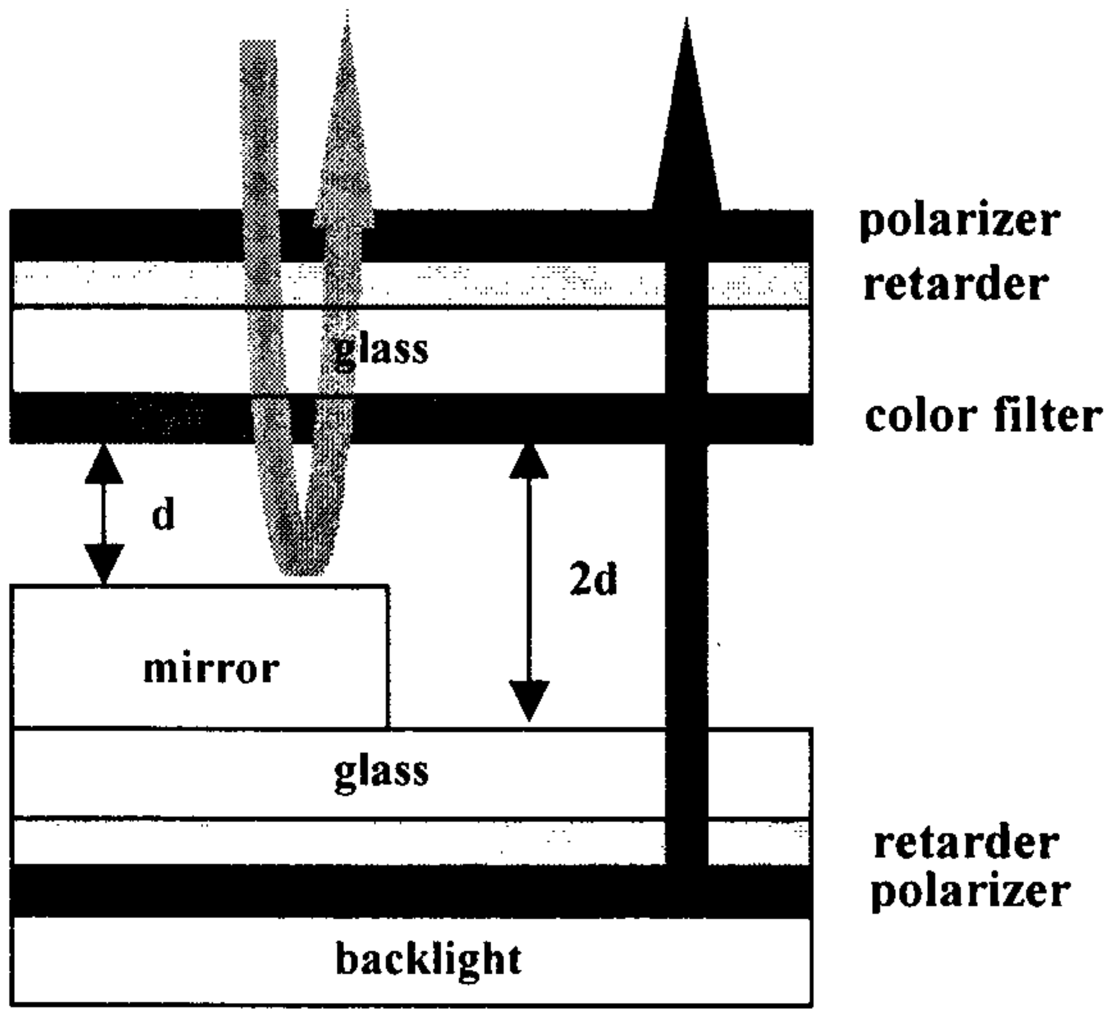


**Figure 2. Cross-sectional view of a pixel with multi cell gap.**

Single cell gap structure with a reflective polarizer was proposed [5] for transflective mode. This mode consists of a gray film for absorbing unnecessary light and two crossed polarizers one of which is a reflective polarizer. This reflective polarizer reflects P and transmits S polarization.

Operational principles are shown in Fig. 3. In the reflective mode, bright state is achieved with a voltage on-state, because P wave from top polarizer is not phase retarded by the LC layer and it reflected by the reflective polarizer. Therefore, P wave comes out thought the top polarizer without phase retardation. In the voltage-off state, P wave from top polarizer is changed to S wave by the LC layer. This S wave transmits through the reflective polarizer and finally, it is absorbed by gray film. Therefore, dark state is realized.

In the transmissive mode, bright state is achieved with the voltage-off state. S wave from bottom polarizer is converted to P wave. This P wave comes out through the top polarizer because polarization direction of the wave is parallel to the transmission axis of top polarizer. Therefore, dark state is realized with voltage-on state. S wave from bottom polarizer is preserved while passing the LC layer. This S wave is blocked by top polarizer.

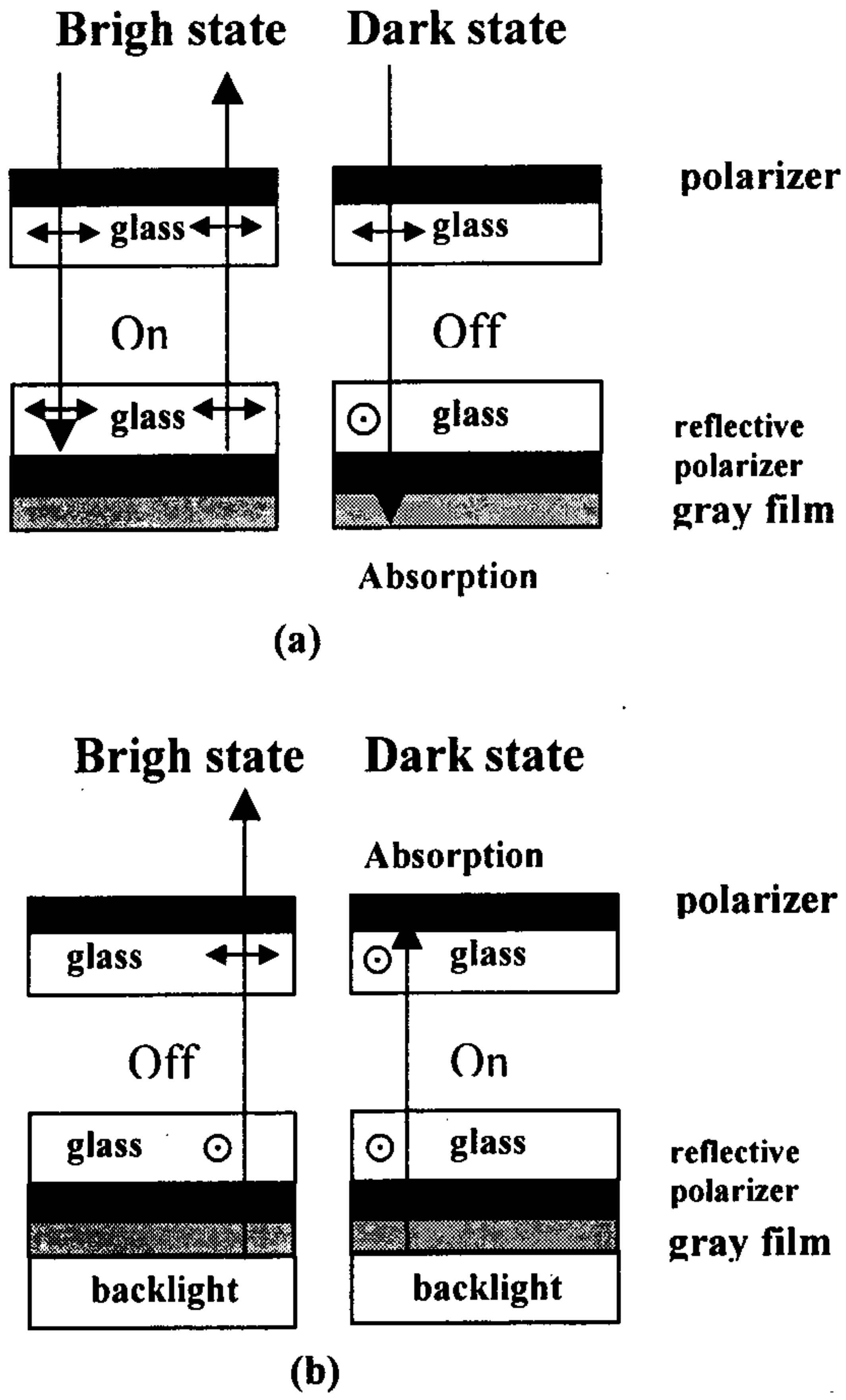


**Figure 3. Cross-sectional view of a pixel with reflective polarizer: (a) Reflective mode and (b) transmissive mode.**

## 3. Transflective LCD mode with half switching driving

In practice, transflective mode with multi cell gap requires complex manufacture process. It is also difficult to obtain good optical performance for both the reflective and transmissive modes only with pixel structures using reflective polarizer, because there is image inversion between transmissive and reflective modes. In order to improve good performance for both modes, it must be driven by half switching driving method with transflective layer [6]. This half switching method means that LC cell is driven by different driving pulses for transmissive and reflective modes. For normally dark mode in transmissive mode, LC cell is fully switched for bright state. However, in reflective mode this cell is switched to intermediate state between initial state below threshold voltage and fully switched state like bright state in transmissive mode to achieve maximum brightness.

Figure 4 shows the transflective LCDs with half switching method for twisted vertically aligned (TVA) mode [7]. TVA cell has a cell gap of 2.94 um, a twist angle of 68°. In order to have high contrast ratio for reflective mode, transmissive axis of polarizer and optic axis of wide band λ/4 film are located at 0° and 45°, respectively. Under the transflective layer, transmissive axis of polarizer and optic axis of wide band are located at 90° and -45° for dark state of transmissive mode. Scattering film (haze film) and C plate can be used to improve the viewing angle characteristics.

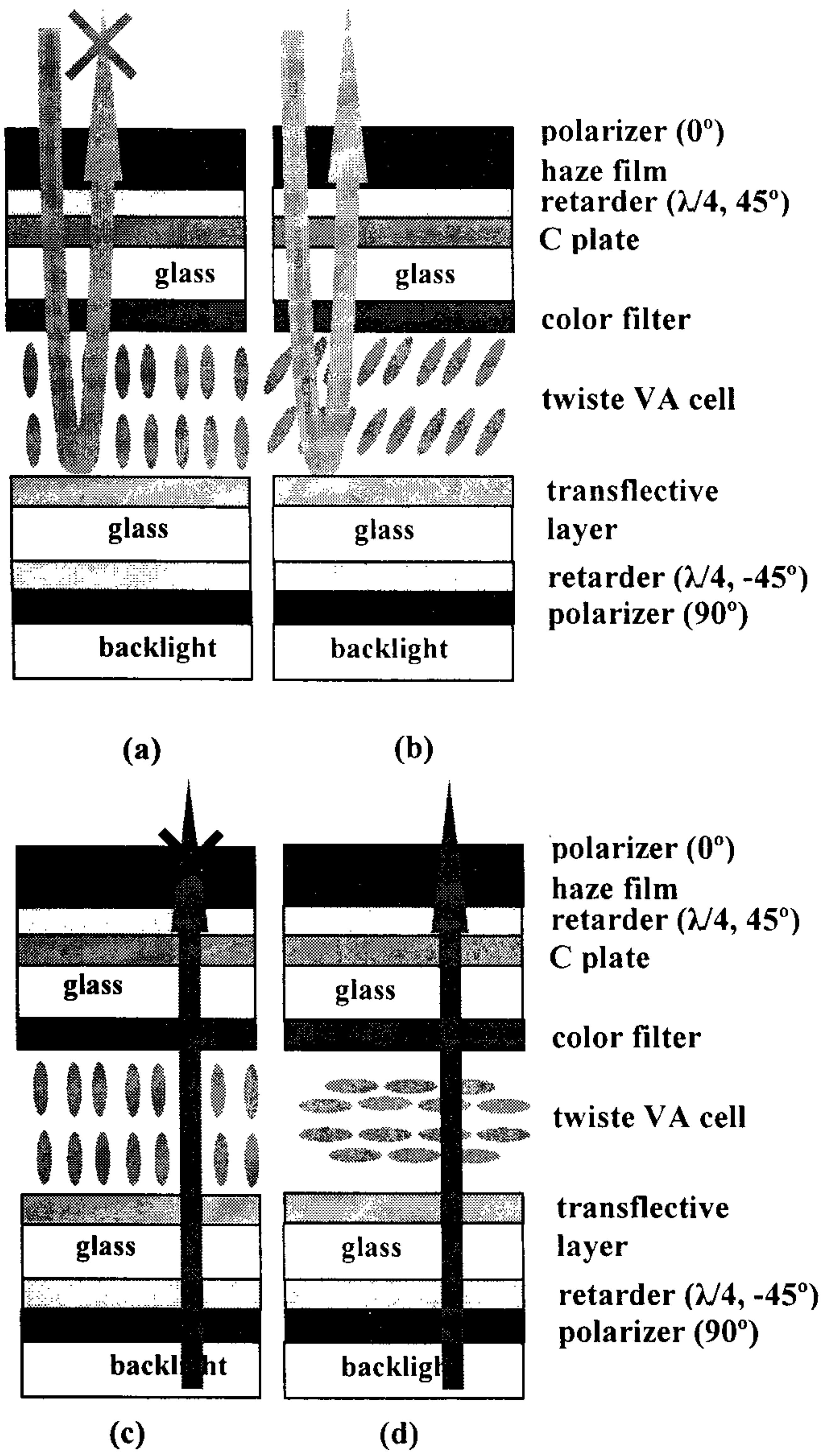


**Figure 4. Transflective LCDs with half switching method in TVA mode for (a) dark and (b) bright states in reflective mode and (c) dark and (d) bright states in transmissive mode.**

## 4. Transflective LCD mode with double layer structure.

The structure of the transflective AFLCD with double layer structure is shown in Fig. 5. It is composed of two polarizers, a dual AFLC cell, a transflective layer, two wide-band quarter-wave films, and a backlight unit [8]. In the configuration of the dual AFLC cell, the rubbing directions of two AFLC cells are crossed. The tilt angle and dΔn of both AFLC cells are 22.5° and 275nm, respectively. Optic axis of AFLC cell 1 in AF-state is coincident with the transmission axis of the polarizer adjacent to the AFLC cell 1, and that of AFLC cell 2 is crossed with that of the polarizer.

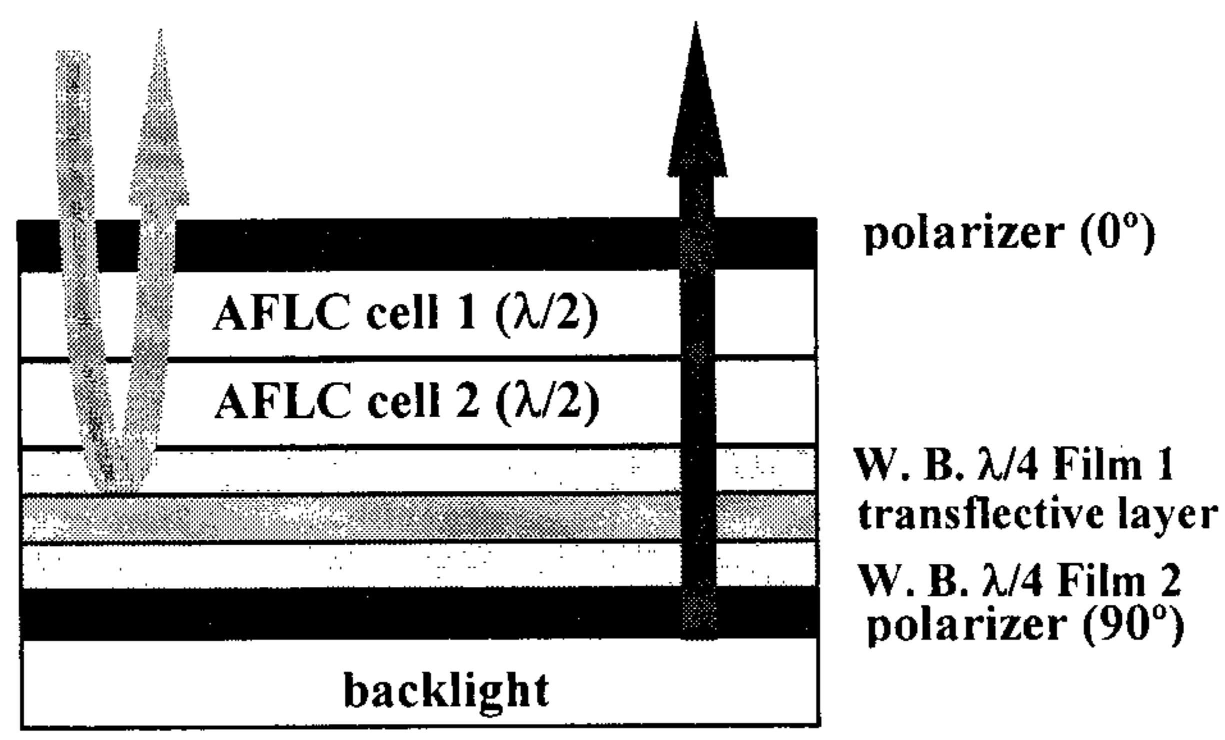


**Figure 5. Transflective mode with double layer structure using AFLC cells.**

The slow axis of the wide-band quarter-wave film 1 is oriented at -45° to the transmission axis of the polarizer and that of the wide-band quarter-wave film 2 is located at 45° to that of the polarizer.

## 5. Transflective LCD mode with multidomain

Recently, the optical configuration is designed by focusing on either the reflective mode or transmissive mode. We also propose a new transflective LCD mode with multidomain structures in which patterned vertically aligned (PVA) mode is used. In this multidomain transflective LCDs, transmissive mode and reflective mode are determined by domains of LC layer [9].

Figure 6 shows cross-sectional view of a pixel with multidomain structure using PVA mode. The upper electrode is not patterned. The insulated reflectors are laid between the patterned bottom electrodes. These parts on the transparent electrodes are designed for transmissive mode, and the other parts which are on the insulated mirrors are designed for reflective mode. The ratio between insulated mirror and transparent electrode is 1/4. The width of insulated mirror and transparent electrod are 6 um and 24 um, respectively.

Multidomain transflective LCDs have the advantages that the manufacturing process is simple, and only one kind of driving circuit can be used.

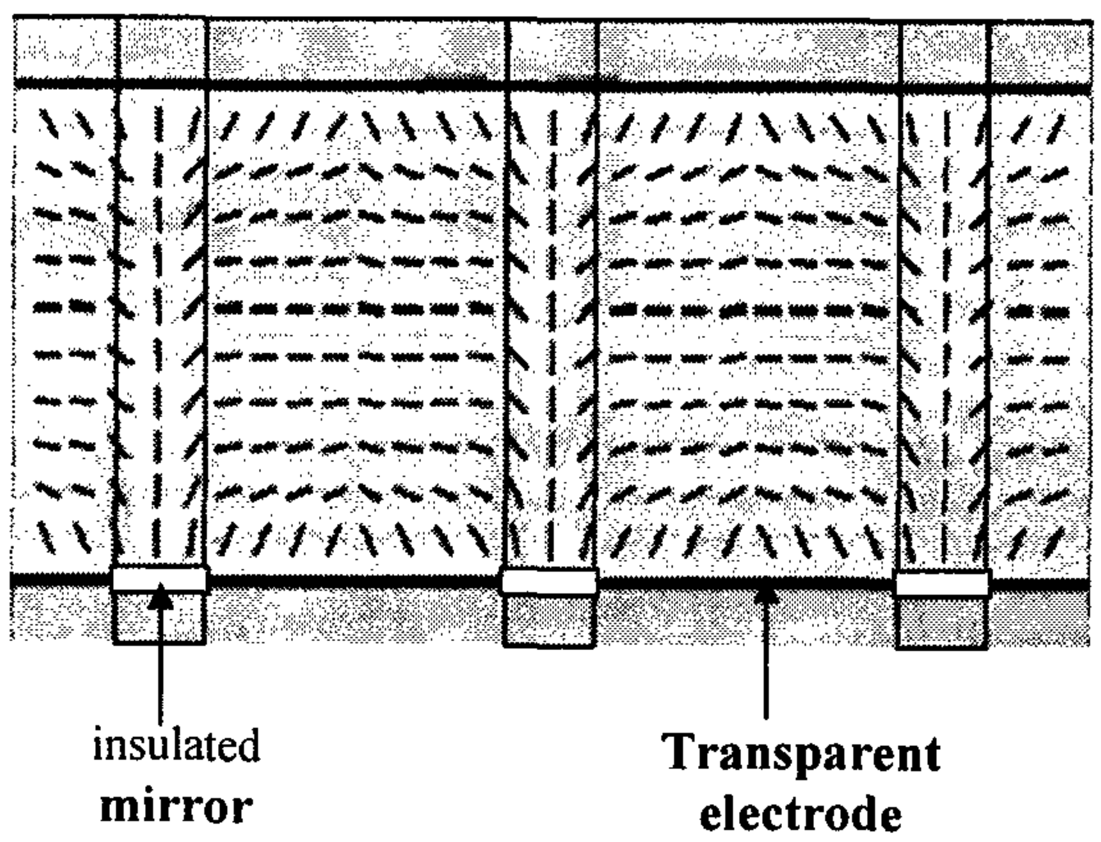


**Fig. 6. Cross-sectional view of a pixel with multidomain structure using PVA mode.**

## 6. Results and discussion

Figure 7 shows the calculated spectral characteristics of both reflective and transmissive modes in transflective LCD with half switching method, where twisted VA mode with a negative dielectric anisotropy of –4.2, a refractive anisotropy of 0.083 and a cell gap of 2.44 um is used. High brightness in both reflective and transmissive modes can be obtained with this half switching driving method. The V-T curves of both reflective and transmissive modes were obtained by experiments as shown in Fig. 8. In order to realize bright state in both modes, applied voltage should be about 4 V in reflective mode and about 7 V in transmissive mode. Therefore, this transflective cell should be driven by two kinds of driving circuits for both modes.

In most LCD mode, this technique can be applied. Design of optical configuration is simple and this transflective LCD can be producted by conventional fabrication processing.

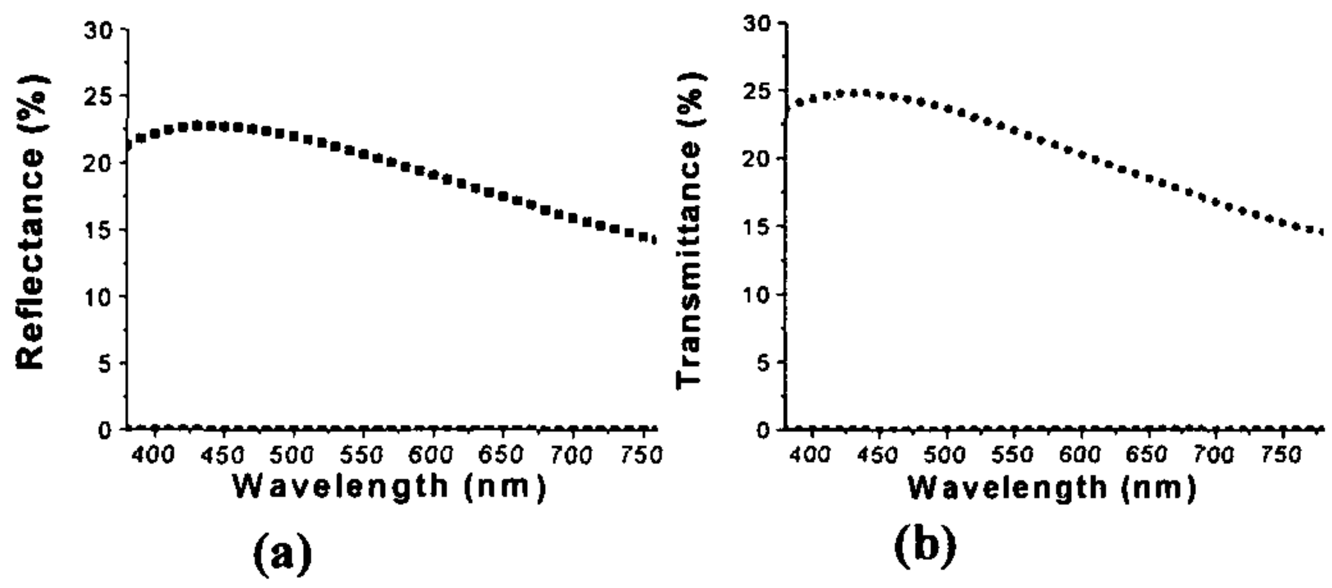


**Figure. 7. Calculated spectral characteristics in off and on states for (a)reflective mode and (b) transmissive mode at transflective TVA LCD with half switching method**

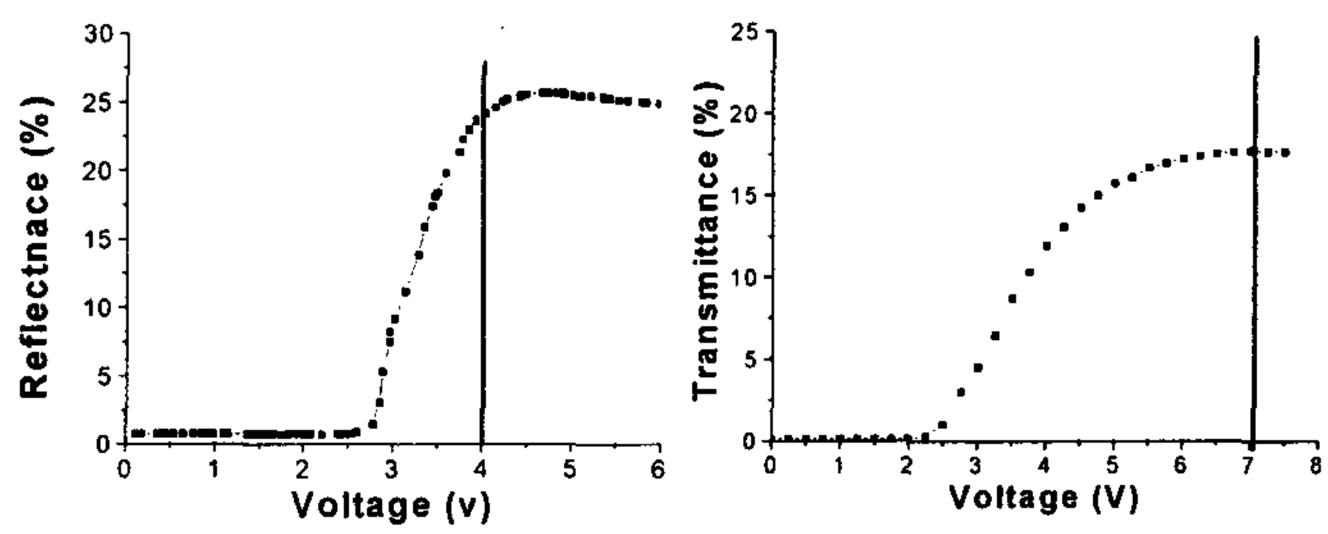


**Figure 8. (a) Reflectance and (b) transmittance with respect to applied voltage in twisted VA transflective mode with half switching method**

In transflective mode with double layer structure using AFLC cell, bright state of transmissive mode is achieved either with both a ferro (+) state of the AFLC cell 1 and a ferro (-) state of the AFLC cell 2 or with both a ferro (-) state of the AFLC cell 1 and a ferro (+) state of the AFLC cell 2. Bright stat of reflective mode is realized with either ferro (-) state or ferro (+) state of the AFLC cell 2 when the AFLC cell 1 is in the antiferro state.

Calculated spectral characteristics of double layer transflective LCD mode are shown in Fig. 9. The transmittance and reflectance of about 25 % can be obtained with double layer structure using AFLC cells. These are the maximum values we can achieve because there is absorption in the polarizer and the aparture ratio of transflective layer is 50 %. Hence the transmittance and reflectance are highest with this configuration.

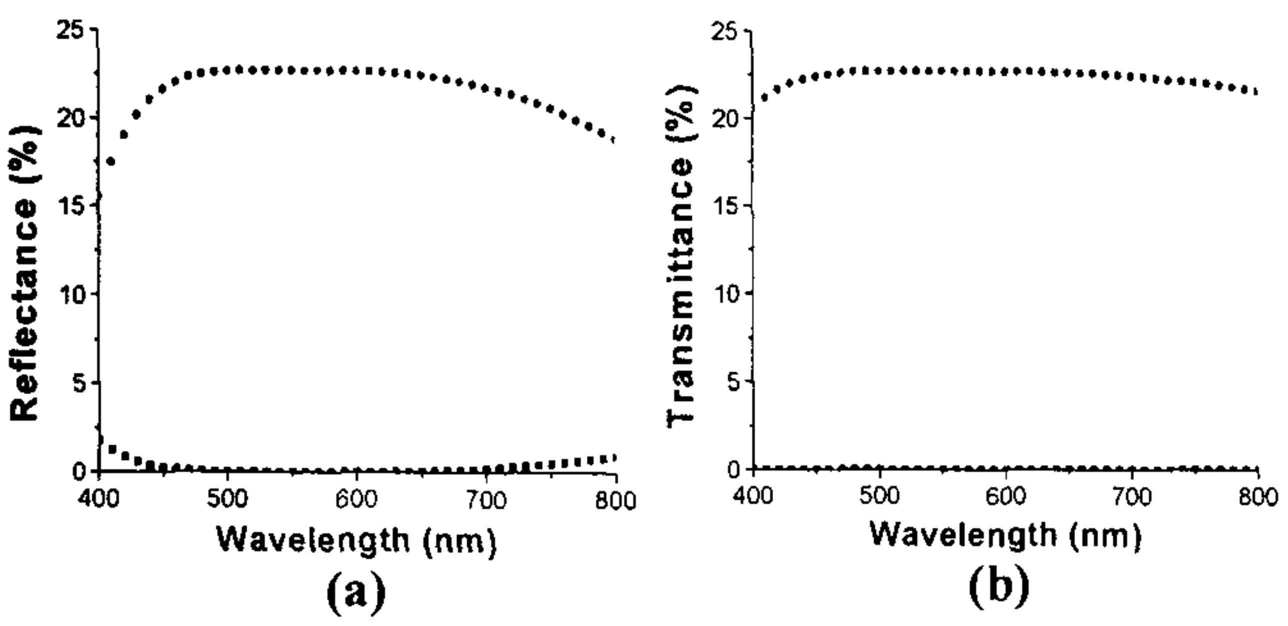


**Figure 9. Spectral characteristics of double layer transflective mode using AFLC cells: dark state and brigh state of (a) reflective mode and (b) transmissive mode**

For Transflective LCD mode with multidomain PVA cell, the calculated transmittance and reflectance with respect to applied voltages are shown in Fig. 10, where a negative dielectric anisotropy of –5.0, a refractive anisotropy of 0.1204 and a cell gap of 4.2 um. This structure can be driven by only one driving circuit, because the saturation voltage in transmissive mode and that in reflective mode are about 4V. The PVA cell can realize the transflective LCD which has merits such as one driving circuit and simplicity of both pixel structure and manufacturing process.

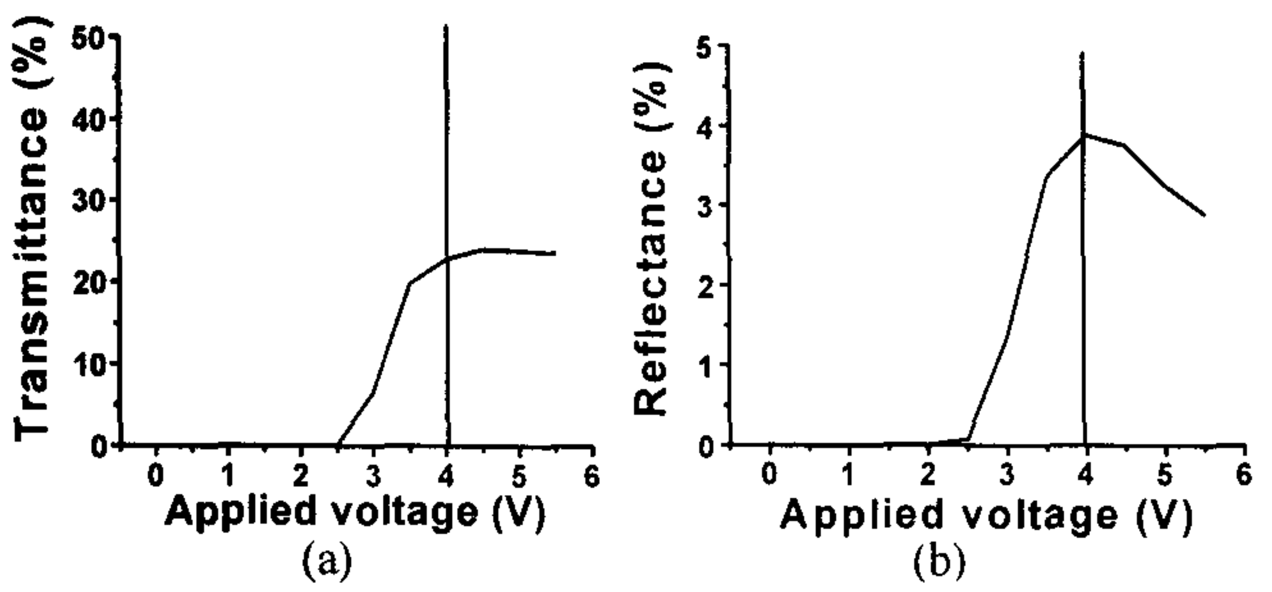


**Figure 10. (a) transmittance and (b) Reflectance according to applied voltages in multidomain PVA cell**

## 7. Conclusion

Novel design techniques with half switching method, double layer structure, and multidomain structure for transflective liquid crystal display modes are introduced and design examples with these techniques are demonstrated.

Though half switching transflective mode require two kinds of driving circuit for each reflective mode and transmissive mode, merits of this method are that in most LCD mode, this technique can be applied, design of optical configuration is simple, and this transflective LCD can be producted by conventional fabrication process. In transflective mode with double layer structure using AFLC cell. Highest transmittance and reflectance without color dispersion can be obtained with this structure. Multidomain with PVA cell can also be used for transflective LCD mode. Multidomain thransflective LCD mode can be driven by one driving circuit and both pixel structure and manufacturing process are simple.

## 8. Acknowledgements

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