Transflective Liquid Crystal Display with Partial Switching

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Shin-Tson Wu

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A high reflection and transmission transflective liquid crystal display (TLCD) that requires only a single cell gap. Instead of reducing the cell gap of the R sub-pixel region, the invention reduces the birefringence change $\Delta n$ of reflective pixels (R) so that the total retardation change $\Delta n$ of R is equal to that of the transmissive pixels (T). This is realized by a partial switching of the pixels of approximately 45 degrees which occurs in the reflective pixel (R) region of the single cell gap by applying fringing fields, generated by a discontinuous electrode, to the molecules in the reflective pixel (R) region of the cell gap.

5 Claims, 3 Drawing Sheets
Fig. 1a
Single Cell Gap
(PRIOR ART)

Fig. 1b
Double Cell Gap
(PRIOR ART)

Fig. 2a
(PRIOR ART)

Fig. 2b
(PRIOR ART)

R-V and T-V of a single cell gap VA transflective LCD with continuous electrode for both T and R regions. Cell gap = 3.6um, delta n = 0.1
I-R & T of a double cell-gap VA transflective LCD.

Cell gap = 1.8um (R) and 3.6um (T), dm = 0.1
Common electrode
Pixel electrode

W = electrode width, G = electrode gap

W=1um, G=1um. Cell gap = 3.6um, delta n = 0.1
TRANSLECTIVE LIQUID CRYSTAL
DISPLAY WITH PARTIAL SWITCHING

This invention relates to transmission type liquid crystal displays (LCD), and in particular to methods and apparatus for producing transflective liquid crystal displays (TLCD) with partial switching capability.

BACKGROUND AND PRIOR ART

Conventional transmission-type Liquid Crystal Displays (LCDs) exhibit high contrast ratios with good color saturation. However, their power consumption is high due to the need for a backlight. At bright ambient, e.g., outdoor, the display is washed out completely and hence loses its legibility. On the other hand, a reflective LCD uses ambient light for reading out the displayed images and hence retains its legibility under bright ambient. Their power consumption is reduced dramatically due to the lack of a backlight.

However, the readability of a reflective LCD is lost under poor ambient light. In addition, its contrast ratio is also lower than that of the transmission-type LCD.

In order to overcome the above inadequacies, transflective LCDs (TLCD) have been developed to allow good legibility under any ambient light environment. In these displays the pixel is divided into R (reflective) and T (transmissive) sub-pixels. The T sub-pixel doesn’t have a reflector so that the light only passes the LC layer once. In order to achieve high light efficiency for both T and R modes, the double cell gap approach is often used.

The cell gap transflective LCD (TLCD) usually leads to low efficiency for the transmission T. In order to attain high T and R, one often needs to turn to the double cell gap approach. This approach however leads to a much more complicated structure as well as a very demanding fabrication process. The fabrication process needs to have good control over the difference between the two cell gaps, which depends on the control of the extra layer (usually organic). This control can be difficult which results in non-uniformity in the cell gap and hence deterioration of the LCD optical performance. Moreover, this difference in cell gap between R and T regions also leads to different response times between T and R displays modes.

These difficulties are best illustrated using a transflective LCD (TLCD) with a VA (Vertical alignment) LC mode. For example, if the cell gap (d) is the same for both R and T as shown in FIG. 2a, due to the double-path experienced by R, the reflected light from R would have experienced a total retardation change of 2.Δn.d which is twice as large as that of T which is Δn.d. Hence the rate of reflection change is twice as fast as that of T, resulting in unequal light level change as shown in FIG. 2b. Hence R reaches 100% brightness at 2.75V whereas T only reaches 50% at the same voltage. Thus a transflective LCD (TLCD) using this structure would have the on-state voltage, Von, at 2.75V which leads to only 50% light efficiency for T.

On the other hand, in the double cell gap approach as shown in FIG. 3a, the cell gap in the R region is reduced to d/2 so that the total path length for R (double-path) remains equal to d=(2xd/2) which is the same as that of T. This structure results in equal retardation change and brightness change for both R and T as shown in FIG. 3b. Both R and T thus can have high efficiency of 100%.

A search in the United States Patent Office of the subject matter of this invention (hereafter disclosed) developed the following 7 U.S. patents and 2 published U.S. patent applications:

U.S. Pat. No. 4,256,377 to Krueger, et al is concerned with the development of an alignment for producing vertical alignment which has little to do with partial switching for TLCDs;

U.S. Pat. No. 5,113,273 to Mochizuki, et al is concerned with the improvement of the memory of an electro-optic response of ferroelectric liquid crystals;

U.S. Pat. No. 5,128,786 to Yanagisawa is about Black Matrix used for TFT-LCD devices which is of no relevance to the invention claimed herein;

U.S. Pat. No. 5,400,047 to Beesely is about the improvement of the response time of an electroluminescent display with no discussion of partial switching;

U.S. Pat. No. 5,515,189 to Kuratomi, et al is concerned with LC spatial light modulators for a neural network and not for transflective direct-view displays;

U.S. Pat. No. 6,043,605 to Park improves plasma displays by a floating auxiliary electrode which teaching is not relevant to LCDs;

U.S. Pat. No. 6,344,080 B1 to Kim, et al (as is the foregoing citation) is relevant only to plasma displays;

U.S. Pat. No. Publication 2001/0046666 A1 to Park although it teaches an alignment film for LCDs does not disclose any technique for generating TLCDs; and,

U.S. Pat. No. Publication 2001/0043297 A1 to Arai does not involve partial switching and is concerned with Twisted Nematic (TN) and Super Twisted Nematic LCDs.

None of the references developed in the search provided any suggestions for reducing the difficulties faced to attain high light efficiencies using only a single cell gap for its mass production using the present LC technology.

SUMMARY OF THE INVENTION

A primary objective of the invention is to provide high reflection (R) and transmission (T) transflective liquid crystal displays (TLCDs) with a single gap technique without having to use a double cell gap.
A secondary objective of the invention is to provide high
reflection (R) and transmission (T) transflective liquid crys-

tal displays (LCDs) having a high performance for displaying
high quality images when an ambient light is not bright
enough, particularly on color reflective displays.

A third objective of the invention is to provide high
reflection (R) and transmission (T) transflective liquid crys-

tal displays (LCDs) having partial switching of molecules
within the reflective pixels in a single gap LCD.

In accordance with this invention, there is provided a
method of producing high reflection (R) and transmission
(T) transflective liquid crystal displays (LCDs) with a single
gap comprising the step of reducing the birefringence change
\( \Delta n \) of reflective pixels (R) in a single gap liquid
crystal display (LCD) so that total retardation \( \Delta n \) of the
reflective pixels (R) is approximately equal to total retarda-
tion \( \Delta n \) of transmissive pixels in said single gap LCD.

Also in accordance with this invention there is provided
a single gap, transflective liquid crystal display (TLCD)
comprising: a single gap liquid crystal display (LCD) having
transmissive pixels (T) and reflective pixels (R); and, means
for reducing birefringence change \( \Delta n \) of the reflective pixels
(R) in a single gap liquid crystal display (LCD) so that total
retardation \( \Delta n \) of the reflective pixels (R) is approximately
equal to total retardation \( \Delta n \) of transmissive pixels in the
single gap LCD.

Further objects and advantages of this invention will be
apparent from the following detailed description of a pre-
sently preferred embodiment which is illustrated schemati-
cally in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1a shows a transflective liquid crystal (TLCD) of the
prior art using a single cell gap.

FIG. 1b shows a TLCD of the prior art using a double cell
gap.

FIG. 2a shows the structure of a single cell gap vertically
aligned (VA) TLCD pixels showing switching under an
applied electric field.

FIG. 2b shows plots of the reflection vs. voltage and
transmission vs. voltage plots of the device of FIG. 2a.

FIG. 3a shows the structure of a double cell gap VATLCD
pixels showing switching under an applied electric field.

FIG. 3b shows plots of the reflection vs. voltage and
transmission vs. voltage plots of the device of FIG. 3a.

FIG. 4 shows the partial switching scheme of the single
gap LCD of the invention.

FIG. 5 shows the generation of strong fringing fields using
the discontinuous electrode in the single gap LCD of the
invention.

FIG. 6 shows reflective voltage (R-V) and transmission
voltage (T-V) plots of a single cell gap VA TLCD with
partial switching in the R sub-pixel region.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Before explaining the disclosed embodiment of the pres-
cent invention in detail, it is to be understood that the
invention is not limited in its application to the details of the
particular arrangement shown since the invention is capable
of other embodiments. Also, the terminology used herein is
for the purpose of description and not of limitation.

In accordance with invention disclosed hereafter, it has
been found that instead of reducing the cell gap from \( d \) to
\( d/2 \), one can reduce the birefringence change from \( \Delta n \) to
\( \Delta n/2 \) in the R region by the use of partial switching. The
molecules are switched by approximately 45° instead of the
normal 90°. In this case the resultant retardation change for
the double-path R remains at \( (\Delta n/2) \times (2d) = \Delta n \), which is
the same as that of T. This leads to high light efficiency for both
T and R using the simple single cell gap structure.

What follows is a demonstration of a suitable scheme for
generating such kind of partial switching. This is achieved
by generating a strong fringing field in the R region by using
a discontinuous pixel electrode (or common electrode). The
scheme and purpose of this fringing field are quite different
from the FFS (Fringe-Field-Switching) which is a reported
wide-viewing-angle technology for LCDs. The differences
are as follows:

a. the FFS scheme requires the common electrode to be on
the same side of the substrate as the pixel electrode in
order to generate strong in-plane-switching. However,
in this invention the common electrode is on the other
substrate which has a similar structure as the standard
TFT-LCD using normal electric field; and,
b. the purpose is not to generate in-plane-switching but
instead to deviate the electric field from its normal
direction to the oblique direction to generate partial
switching.

Thus the fringing field scheme of the invention has both
different structure and purpose compared with the existing
FFS TFT-LCDs.

The invention describes a technique for achieving high
light efficiency for both R (reflective) and T (transmissive)
pixels without using the double cell gap approach. It is based
on the fact that the output light level change of a LCD, which
is equal to light efficiency in this case, is proportional to the
total retardation change experienced by the incident light
traveling in the LC layer of the device. The total retardation
change \( \Delta n \) is a product of 1) birefringence change, \( \Delta n \),
‘seen’ by the incident light as a result of the reorientation
of the liquid crystal molecules upon an applied voltage and 2)
total path length traveled by the incident light in the LC layer
which \( d \) is equal to the cell gap, \( d \), for a single-path light.

Instead of reducing the cell gap of the R sub-pixel region,
one reduces the birefringence change \( \Delta n \) of R so that the
total retardation change \( \Delta n \) of R is equal to that of T. In this
case one can use a single cell gap to achieve both high R and
T.

Reference should now be made to FIG. 4 to best under-
stand the invention. Instead of reducing the cell gap \( d \)
in the R region to half, the invention reduces the birefringence
change \( \Delta n \) in the reflective region to half so that the
total retardation remains the same. This can be achieved by
partially switching the LC molecules 44. Instead of switch-
ing the LC molecules 46 to 90° as would be done by the
normal electric field, one partially switches the LC mol-
ocules 44 in the R region to approximately 45° as shown in
FIG. 4, resulting in a birefringence change of \( \Delta n/2 \) instead of
\( \Delta n \). The total retardation change for R thus remains at
\( \Delta n \times (2d) = \Delta n \) since the total path for R in the LC layer
is \( 2d \). Both T and R are expected to give almost equal and
high efficiency under this condition.

A method for partial switching is to use an oblique electric
field. Through computer simulations, a method for generat-
ing a suitable oblique electric field to achieve the required
partial switching is by generating the fringing field between
a discontinuous pixel electrode 50 and common electrode 52
as shown in FIG. 5. The discontinuous electrode 50 needs to
have narrow width W (Typically<approximately 10 μm) and
narrow gap G (typically<approximately 3 μm), so that the
fringing field dominates. This causes the LC molecules in
and near the gap region to switch partially and hence reduce the resultant single-path retardation change. The discontinuous electrode can be fabricated on top of the reflector with a thin layer of insulating layer (e.g. SiO_2) between them. Alternatively, the discontinuous electrode can also be fabricated using the common electrode on the color filter substrate instead of the pixel electrode on the reflector substrate. In this case, no additional insulating layer or modification is required on the reflector.

As an example, FIG. 6 shows the light efficiency of R and T as a function of voltage for a VA transmissive device with a discontinuous electrode of approximately 1 µm width and approximately 1 µm gap in the R region. The electrode in the T region remains continuous. As can be seen, the light efficiency for R reaches 100% at approximately 3.75 V. If one biases the device at this voltage the on-state (V_on), efficiency for T is approximately 90% which is much higher than that of a single cell gap device without discontinuous electrode. The efficiency of T is not 100% since the partial switching in R in this case is not ideal, i.e. the molecules are not all switched to 45° at the voltage as the molecules in T switched to 90°. However, by proper design, the efficiencies can be optimized. Although the electrode width W and electrode gap G are best kept below or equal to approximately 10 µm and approximately 3 µm, respectively, to ensure a strong fringing field, the actual limits depend on the cell gap of the device. The higher the cell gap, the wider the electrode width and gap are permitted since the fringe field can extend to a wider region. Therefore the amount of partial switching can remain more or less the same despite of the larger electrode width and gap.

Table 1 shows examples of the results obtained using different combinations of electrode width and electrode gap. The results illustrate that the principle of partial switching can indeed be a very novel and simple approach to attaining high R and T efficiencies for a single cell gap TLCD without using the complicated double cell gap approach.

<table>
<thead>
<tr>
<th>Width (W)/µm</th>
<th>Gap (G)/µm</th>
<th>Von/V</th>
<th>R/%</th>
<th>T/%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>3.6</td>
<td>100</td>
<td>87</td>
</tr>
<tr>
<td>1</td>
<td>3.5</td>
<td>4</td>
<td>94</td>
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<tr>
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<td>3.75</td>
<td>82</td>
<td>90</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>2.85</td>
<td>50</td>
<td>86</td>
</tr>
</tbody>
</table>

Most of the results in Table 1 are based on a cell gap of approximately 3.6 µm as an example.

This invention discloses a very novel and simple technique of achieving high Reflection and Transmission TLCDs without using the double cell gap approach. The invention is based on the surprising fact that, instead of reducing the cell gap from d to d/2, it is possible to reduce the birefringence change from Δn to Δn/2 in the R region by the use of partial switching. The molecules are switched by approximately 45° instead of the normal 90°. In this case the resultant retardation change for the double-path R remains at (Δn/2)·(2d)=Δn, which is the same as that of T. This leads to high light efficiency for both T and R using the simple single cell gap structure.

There has been demonstrated a suitable scheme for generating such kind of partial switching. This is achieved by generating a strong fringing field in the R region by using discontinuous pixel electrode (or common electrode). The scheme and purpose of this fringing field are quite different from the FFS (Fringe-Field-Switching) which is a reported wide-viewing-angle technology for LCDs. The differences are as follows:

(a) the FFS scheme requires the common electrode to be on the same side of the substrate as the pixel electrode in order to generate strong in-plane-switching. However, in this invention, the common electrode is on the other substrate which has a similar structure as the standard TFT-LCD using normal electric field; and,

(b) the purpose of the invention is not to generate in-plane-switching but instead deviate the electric field from the normal direction to the oblique direction to generate partial switching with an fringing field scheme of different structure and purpose compared with the existing FFS TFT-LCDs.

The invention avoids the need of using the double cell gap approach to achieve high light efficiency for both R and T. As described before, the double cell gap approach leads to a much more complicated structure as well as demanding fabrication process. The fabrication process needs to have very good control over the difference between the two cell gaps, which depends on the control of the extra layer (usually organic). This good control can be difficult which results in non-uniformity in the cell gap and hence deterioration of the LCD optical performance.

Unlike the double cell gap approach, this single cell gap leads to no difference in response time between T and R displays modes.

The invention can also save costs since this scheme doesn’t require a major extra component to form the discontinuous electrode instead of the normal continuous electrode in the R region. In the case of double cell gap, it requires an extra thick organic layer to form the double cell gap structure.

The invention has applications for handheld and mobile communications such as but not limited to mobile telephones, personal digital assistants (PDA), e-books, and the like.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.
We claim:

1. A method of producing high reflection (R) and transmission (T) transflective liquid crystal displays (LCDs) with a single gap, comprising the step of:
   - providing a single gap liquid crystal display (LCD) having a liquid crystal layer between a discontinuous pixel electrode and a common electrode, the liquid crystal layer having a cell gap thickness $d$ that is approximately identical throughout the single cell gap liquid crystal display;
   - reducing the birefringence change $\Delta n$ of reflective pixels (R) in the single gap liquid crystal display (LCD) by approximately $\frac{1}{2}$ by partially switching molecules in the reflective pixels (R) approximately 45 degrees so that total retardation $\Delta n d$ of the reflective pixels (R) is approximately equal to total retardation $\Delta n d$ of transmissive pixels in the single gap LCD; and
   - applying an electric field between the discontinuous pixel electrode and the common electrode to generate a fringing field in the reflective pixels (R) to partially switch the liquid crystal molecules to approximately 45 degrees in the reflective region to reduce the birefringence change $\Delta n$ of reflective pixels (R) in a single gap liquid crystal display (LCD) to approximately $\Delta n / 2$ without reducing the cell gap $d$ so that total retardation $\Delta n d$ of the reflective pixels (R) is approximately equal to the total retardation $\Delta n d$ of the transmissive pixels in the single gap LCD, wherein said total retardation $\Delta n d$ is achieved without the use of compensators, polarizers and alignment films for obtaining the approximately 45 degree reorientation of the liquid crystal molecules.

2. The method of claim 1, wherein the discontinuous pixel electrode includes:
   - a narrow width of less than approximately 10 $\mu$m; and
   - a narrow gap of less than approximately 3 $\mu$m.

3. The method of claim 1, further comprising the step of:
   - increasing width and gap spacing limits in the discontinuous electrode as the cell gap size increases.

4. A high reflection (R) and transmission (T) transflective liquid crystal display (TLCD), comprising:
   - a single gap liquid crystal display (LCD) having transmissive pixels (T) and reflective pixels (R) in a transmissive region and a reflective region that has a mirror-reflector with a thickness, the single gap liquid crystal display having a liquid crystal layer thickness between a discontinuous reflective pixel electrode and a common electrode that remains identical in both the transmissive region and the reflective region when taking into account the thickness of the mirror-reflector in the reflective region; and,
   - means for applying an electric field between the discontinuous pixel electrode and the common electrode to generate a fringing field in the reflective pixels (R) to partially switch the liquid crystal molecules to approximately 45 degrees in the reflective region to reduce the birefringence change $\Delta n$ of reflective pixels (R) in a single gap liquid crystal display (LCD) to approximately $\Delta n / 2$ without reducing the cell gap $d$ so that total retardation $\Delta n d$ of the reflective pixels (R) is approximately equal to the total retardation $\Delta n d$ of the transmissive pixels in the single gap LCD, wherein said total retardation $\Delta n d$ is achieved without the use of compensators, polarizers and alignment films for obtaining the approximately 45 degree reorientation of the liquid crystal molecules.

5. The LCD of claim 4, wherein the discontinuous pixel electrode includes:
   - a narrow width of less than approximately 10 $\mu$m; and
   - a narrow gap of less than approximately 3 $\mu$m.