Introduction: Mobile Displays

Why Transflective LCDs?

Imprinting Technique for Patterned Retarders

- Imprinting Process
- LCP Patterned Retarders

Transflective LCDs with In-cell Retarders

- TN transflective LCD (Planar Alignment)
- Inverse TN transflective LCD (Vertical Alignment)

Conclusion
Ubiquitous Era
- Increasing demand for portable electronics & display components
- Good performances in both indoor & outdoor environments

Requirements for Mobile Displays
- Low power consumption
- Good readability in any environment
- Thin in volume
- Light in weight

Outdoor Requirements
- High level of reflectance
  - White paper ~ 80%
  - Newspaper ~ 50%
  - Visible reflectance ~ 40%
- High contrast
  - White paper ~ 20 : 1
  - Newspaper ~ 7 : 1
- Full-color capability
  - No saturation/blur in color

Need a New Type of LCD: Transflective !!
- Good readability: transmissive type with backlight
- Low power consumption: reflective type under ambient light
Transflective Configurations

A Basic Transflective LCD Structure

- polarizer glass
- LC layer
- reflector glass

V_{off} V_{on} reflectors region
V_{off} V_{on} transmissive region

Two Main Configurations of Transflective LCDs

- Dual cell gap configuration
  - Good performances in transmissive and reflective areas
  - Difficulty in pixel fabrication
- Single cell gap configuration
  - Simple fabrication process of pixel elements
  - Optical compensation by a patterned retarder

Existing Patterning Process

Photo-alignment of LCP

- Resolution of \( \geq 2 \ \mu m \)
- Weak anchoring energy (\( \approx 10^{-6} \ \text{J/m}^2 \)): not reliable at high T's
- Complex patterning process: Two LPUV, one UV exposed

Need a new patterning technology!!
New Patterning Technologies

- **Soft Lithography Technologies**
  - Non-photolithographic techniques
    - *Imprinting* method
    - Replica molding (REM)
    - Micro-molding in capillaries (MIMIC)
    - Solvent-assisted micro-molding (SAMIM)

- **Advantages of Soft Litho Technologies**
  - Easy & simple process, applicable for flexible substrates
  - 2D/3D microstructures by a single step process
  - Easy patterning of planar/curved surfaces
  - Low temperature process
  - Cost-effective

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**Imprinting Process of LCP**

- **Imprinting** Process of a LCP patterned retarder
  - Master : UV curable polymer (NOA65, Norland Ltd.) on PET
  - Polymer mold : PDMS on Master
  - LCP material : RMS 03-001 (E. Merck)

  - Resolution of $\geq 50$ nm (typically 200 nm)
  - Strong anchoring energy ($\approx 10^{-4}$ J/m²): No extra alignment layer
    (Berreman’s elastic description)
- **SEM images of imprinted LCP layers**
  - Polymer mold having different patterns
    - Period from 3um to 8um
  - Period: 3um 3um 8um
  - Ratio: 1:2 1:1 1:1
  - Successful transfer of the patterns onto the LCP layer

- **Microscopic Textures of Imprinted LCP layers**
  - Imprinted LCP layers with different patterns
  - Period(ratio): 3um (1:2) 3um (1:1) 8um (1:1)
  - Well-aligned LCP molecules during imprinting (periods ≤ 5µm)
    - $2\pi d\Delta n/\lambda \approx 1.57 : \text{QWP}$
LCP Patterned Retarders

- **Imprinting of LCP patterned retarder**
  - LCP material: RMS 03-001C (E. Merck)
  - Spin-coating of LCP @ 2500 RPM for 30sec
  - Pre-baking @ 65°C for 10min
  - Imprinting of the LCP layer
  - PDMS mold with different patterns
  - UV exposure @ 40mW for 300sec in N₂

→ **LCP patterned retarder**

- **Domain width of imprinted LCP layer**
  - SEM image
  - Microscopic images: domain widths

  - Well-defined periodic domains in imprinted, patterned LCP retarder
Optical Retardation

- $2\pi d \Delta n/\lambda = 1.57$ (QWP)
- Same retardation in both domains

Microscopic Textures

- $45^\circ$ domains: QWP for R-areas
- $0^\circ$ domains: dummy for T-areas

Transreflective LCDs with Retarders

- TN Transreflective LCD with in-cell patterned retarder
  - Single cell gap & multi LC modes ($45^\circ$-TN, $90^\circ$-TN)
  - Multi-functional imprinted LCP layer
    - Self-homogeneous alignment (no alignment layer)
    - In-cell patterned retarder
Electro-optic transmission

- Measured T/R data agree with simulation results
- In-cell patterned retarder by *imprinting*
  - No optical parallax and compactness
  - No extra alignment layer

ITN Transreflective LCD with **in-cell patterned retarder**

- Single cell gap & single inverse TN(ITN) LC mode
- Multi-functional *imprinted* LCP layer
  - Self-homeotropic alignment (*silane treatment*)
    - trichloro (1H,1H,2H,2H-perfluoroctyl) silane
  - In-cell patterned retarder

Dark state ($V_{on}$) Bright state ($V_{off}$)
Microscopic Textures of \([LC+\text{silane treated LCP retarder}]\)

- Voltage ‘OFF’
  - Net retardation (\("0\"+LCP)
    - QWP for 45° for R
    - Dummy for 0° for T

- Voltage ‘ON’
  - Net retardation (LC+LCP)
    - HWP for 45° for R
    - Dummy for 0° for T

Optical Retardation of \([LC+LCP]\)

- Voltage ‘OFF’
  - LCP layer (QWP)
  - LC layer (no retardation)
  \[2\pi d \Delta n/\lambda = 1.57 \text{ (QWP)}\]

- Voltage ‘ON’
  - LCP layer (QWP)
  - LC layer (QWP)
  \[2\pi d \Delta n/\lambda = 3.14 \text{ (HWP)}\]
EO transmission of ITN transflective LCD

- High transmittance and high reflectance simultaneously
- Measured T/R data agree well with simulation results
- In-cell patterned retarder by imprinting
  - No optical parallax and compactness

Conclusion

- Imprinted optical films based on LCP material
  - Resolution of ≥ 50 nm
  - Strong anchoring energy (∼ 10^{-4} J/m²)
  - Advantages
    - Only one-step process
    - Easy patterning of LCP retarders
    - No extra alignment layer (Berreman’s elastic description)
- Transflective LCDs with in-cell patterned LCP retarders
  - In-cell patterned retarder by imprinting
    - No optical parallax and compactness
  - Multi-functional LCP: retarder & alignment for TRF-TN
  - High transmittance and high reflectance for TRF-ITN