Contents

Foreword xiii
Preface to the First Edition xv
Preface to the Second Edition xvii
About the Author xix

1 Introduction 1

2 Liquid Crystal Materials and Liquid Crystal Cells 3
  2.1 Properties of Liquid Crystals 3
    2.1.1 Shape and phases of liquid crystals 3
    2.1.2 Material properties of anisotropic liquid crystals 6
  2.2 The Operation of a Twisted Nematic LCD 11
    2.2.1 The electro-optical effects in transmissive twisted nematic LC cells 11
    2.2.2 The addressing of LCDs by TFTs 18

3 Electro-optic Effects in Untwisted Nematic Liquid Crystals 21
  3.1 The Planar and Harmonic Wave of Light 21
  3.2 Propagation of Polarized Light in Birefringent Untwisted Nematic Liquid Crystal Cells 26
    3.2.1 The propagation of light in a Fréedericksz cell 26
    3.2.2 The transmissive Fréedericksz cell 31
    3.2.3 The reflective Fréedericksz cell 37
    3.2.4 The Fréedericksz cell as a phase-only modulator 39
    3.2.5 The DAP cell or the vertically aligned cell 42
    3.2.6 The HAN cell 44
    3.2.7 The π cell 46
    3.2.8 Switching dynamics of untwisted nematic LCDs 48
    3.2.9 Fast blue phase liquid crystals 54

4 Electro-optic Effects in Twisted Nematic Liquid Crystals 57
  4.1 The Propagation of Polarized Light in Twisted Nematic Liquid Crystal Cells 57
4.2 The Various Types of TN Cells
4.2.1 The regular TN cell
4.2.2 The supertwisted nematic LC cell (STN-LCD)
4.2.3 The mixed mode twisted nematic cell (MTN cell)
4.2.4 Reflective TN cells
4.3 Electronically Controlled Birefringence for the Generation of Colour

5 Descriptions of Polarization
5.1 The Characterizations of Polarization
5.2 A Differential Equation for the Propagation of Polarized Light through Anisotropic Media
5.3 Special Cases for Propagation of Light
5.3.1 Incidence of linearly polarized light
5.3.2 Incident light is circularly polarized

6 Propagation of Light with an Arbitrary Incident Angle through Anisotropic Media
6.1 Basic Equations for the Propagation of Light
6.2 Enhancement of the Performance of LC Cells
6.2.1 The degradation of picture quality
6.2.2 Optical compensation foils for the enhancement of picture quality
6.2.2.1 The enhancement of contrast
6.2.2.2 Compensation foils for LC molecules with different optical axis
6.2.3 Suppression of grey shade inversion and the preservation of grey shade stability
6.2.4 Fabrication of compensation foils
6.3 Electro-optic Effects with Wide Viewing Angle
6.3.1 Multidomain pixels
6.3.2 In-plane switching
6.3.3 Optically compensated bend cells
6.4 Multidomain VA Cells, Especially for TV
6.4.1 The torque generated by an electric field
6.4.2 The requirements for a VA display, especially for TV
6.4.2.1 The speeds of operation
6.4.2.2 Colour shift, change in contrast and image sticking
6.4.3 VA cells for TV applications
6.4.3.1 Multidomain VA cells with protrusions (MVAs)
6.4.3.2 Patterned VA cells (PVAs)
6.4.3.3 PVA cells with two subpixels (CS-S-PVAs)
6.4.3.4 Cell technologies avoiding a delayed optical response
   – Polymer sustained alignment (PSA)
   – Mountain shaped cell surface
6.4.3.5 The continuous pinwheel alignment (CPA)
6.5 Polarizers with Increased Luminous Output
6.5.1 A reflective linear polarizer
6.5.2 A reflective polarizer working with circularly polarized light
6.6 Two Non-birefringent Foils

7 Modified Nematic Liquid Crystal Displays
7.1 Polymer Dispersed LCDs (PDLCDs)
7.1.1 The operation of a PDLCD
7.1.2 Applications of PDLCDs
X CONTENTS

14.6 The Entire Addressing System 266
14.7 Layouts of Pixels with TFT Switches 269
14.8 Fabrication Processes of a-Si TFTs 272
14.9 Addressing of VA Displays 277
14.9.1 Overshoot and undershoot driving of LCDs 277
14.9.2 The dynamic capacitance compensation (DCC) 281
14.9.3 Fringe field accelerated decay of luminance 288
14.9.4 The addressing of two subpixels 292
14.9.5 Biased vertical alignment (BVA) 295
14.10 Motion Blur 298
14.10.1 Causes, characterization and remedies of blur 298
14.10.2 Systems with decreased blur 310
14.10.2.1 Edge enhancement for reduced blur 310
14.10.2.2 Black insertion techniques 312
14.10.2.3 Scanning backlights 313
14.10.2.4 Higher frame rates for reducing blur 315
14.10.3 Modelling of blur 320
14.11 The Optical Response of a VA Cell 329
14.12 Reduction of the Optical Response Time by a Special Addressing Waveform 334

15 Addressing of LCDs with Poly-Si TFTs 339
15.1 Fabrication Steps for Top- and Bottom-Gate Poly-Si TFTs 340
15.2 Laser Crystallization by Scanning or Large Area Anneal 344
15.3 Lightly Doped Drains for Poly-Si TFTs 345
15.4 The Kink Effect and its Suppression 347
15.5 Circuits with Poly-Si TFTs 349

16 Liquid Crystal on Silicon Displays 353
16.1 Fabrication of LCOS with DRAM-Type Analog Addressing 353
16.2 SRAM-Type Digital Addressing of LCOS 355
16.3 Microdisplays Using LCOS Technology 360

17 Addressing of Liquid Crystal Displays with Metal-Insulator-Metal Pixel Switches 363

18 Addressing of LCDs with Two-Terminal Devices and Optical, Plasma, Laser and e-beam Techniques 373

19 Components of LCD Cells 381
19.1 Additive Colours Generated by Absorptive Photosensitive Pigmented Colour Filters 381
19.2 Additive and Subtractive Colours Generated by Reflective Dichroic Colour Filters 383
19.3 Colour Generation by Three Stacked Displays 385
19.4 LED Backlights 386
19.4.1 The advantages of LEDs as backlights 386
19.4.2 LED technology 386
19.4.3 Optics for LED backlights 395
19.4.4 Special applications for LED backlights 405
  19.4.4.1 Saving power and realizing scanning with LED backlights 405
  19.4.4.2 Field sequential displays with LED backlights 407
  19.4.4.3 Active matrix addressed LED backlights 409
19.4.5 The electronic addressing of LEDs 409
19.5 Cell Assembly 411

20 Projectors with Liquid Crystal Light Valves 415
20.1 Single Transmissive Light Valve Systems 415
  20.1.1 The basic single light valve system 415
  20.1.2 The field sequential colour projector 416
  20.1.3 A single panel scrolling projector 417
  20.1.4 Single light valve projector with angular colour separation 418
  20.1.5 Single light valve projectors with a colour grating 418
20.2 Systems with Three Light Valves 420
  20.2.1 Projectors with three transmissive light valves 420
  20.2.2 Projectors with three reflective light valves 421
  20.2.3 Projectors with three LCOS light valves 422
20.3 Projectors with Two LC Light Valves 422
20.4 A Rear Projector with One or Three Light Valves 422
20.5 A Projector with Three Optically Addressed Light Valves 423

21 Liquid Crystal Displays with Plastic Substrates 427
21.1 Advantages of Plastic Substrates 427
21.2 Plastic Substrates and their Properties 428
21.3 Barrier Layers for Plastic Substrates 429
21.4 Thermo-Mechanical Problems with Plastic 430
21.5 Fabrication of TFTs and MIMs at Low Process Temperatures 435
  21.5.1 Fabrication of a-Si:H TFTs at low temperature 435
  21.5.2 Fabrication of low temperature poly-Si TFTs 435
  21.5.3 Fabrication of MIMs at low temperature 437
  21.5.4 Conductors and transparent electrodes for plastic substrates 438
21.6 Transfer of High Temperature Fabricated AMLCDs to a Flexible Substrate 438

22 Printing of Layers for LC Cells 443
22.1 Printing Technologies 443
  22.1.1 Flexographic printing 443
  22.1.2 Knife coating 444
  22.1.3 Ink-jet printing 444
  22.1.4 Silk screen printing 448
22.2 Surface Properties for Printing 449
22.3 Printing of Components for Displays 455
  22.3.1 Ink-jet printed colour filters, alignment layers and phosphors for LED Backlights 455
  22.3.2 Flexographic printing of alignment layers and of nematic liquid crystals 456
  22.3.3 Printing of OTFTs 457
22.4 Cell Building by Lamination 461