

# References

- [1] J. W. Allen, "Organic electroluminescence and competing technologies," *Journal of Luminescence* **60-61**, pp. 906–911 (1994).
- [2] American College of Radiology/National Electrical Manufacturers Assoc. (ACR/NEMA) technical report, *Digital Imaging and Communications in Medicine (DICOM), Part 3.14, Grayscale Standard Display Function* (January 1998).
- [3] V. I. Arkhipov, E. V. Emelianova, Y. H. Tak, and H. Bässler, "Charge injection into light-emitting diodes: theory and experiment," *Journal of Applied Physics* **84**, pp. 848–856 (1998).
- [4] A. Badano, "Image Quality Degradation by Light Scattering Processes in High Performance Display Devices for Medical Imaging," Ph.D. thesis, University of Michigan (1999).
- [5] A. Badano, "Modeling the bidirectional reflectance of emissive displays," *Applied Optics* **42(19)**, pp. 3847–3852 (2002).
- [6] A. Badano, "Principles of cathode ray tube and liquid crystal display devices," *Advances in Digital Radiography: RSNA Categorical Course in Diagnostic Radiology Physics*, pp. 91–102, Radiological Society of North America, Oak Brook, IL (2003).
- [7] A. Badano, S. Drilling, B. Imhoff, R. J. Jennings, R. M. Gagne, and E. Muka, "Noise in flat-panel displays with sub-pixel structure," *Medical Physics*, in press.
- [8] A. Badano and M. J. Flynn, "A method for measuring veiling glare in high performance display devices," *Applied Optics* **39(13)**, pp. 2059–2066 (2000).
- [9] A. Badano and M. J. Flynn, "Monte Carlo modeling of the luminance spread function in flat panel displays," *International Display Research Conference* **17**, pp. 382–385, Society for Information Display, San Jose, CA (1997).
- [10] A. Badano, M. J. Flynn, and J. Kanicki, "Accurate small-spot luminance measurements," *Displays* **23**, pp. 177–182 (2002).
- [11] A. Badano, M. J. Flynn, and J. Kanicki, "Small spot contrast measurements in high-performance displays," *Proc. of the 1999 SID International Symposium*, pp. 516–519 (1999).
- [12] A. Badano, M. J. Flynn, S. Martin, and J. Kanicki, "Angular dependence of the luminance and contrast in medical imaging monochrome active-matrix liquid crystal displays," *Medical Physics* **30(10)**, pp. 2602–2613 (2003).

- [13] A. Badano, M. J. Flynn, E. Muka, K. Compton, and T. Monsees, "Veiling glare point-spread function of medical imaging monitors," *SPIE Proc.* **3658**, pp. 458–467 (1999).
- [14] A. Badano, S. J. Hipper, and R. J. Jennings, "Luminance effects on display resolution and noise," *SPIE Proc.* **4681**, pp. 305–313 (2002).
- [15] A. Badano and J. Kanicki, "Characterization of crosstalk in high-resolution active-matrix liquid crystal displays for medical imaging," *SPIE Proc.* **4295**, pp. 248–253 (2001).
- [16] A. Badano, S.-J. Lee, J. Kanicki, E.F. Kelley, and R.J. Jennings, "Bidirectional reflectance of organic light-emitting displays," *International Display Research Conference* **21**, pp. 21–24 (2001).
- [17] M. A. Baldo, M. E. Thompson, and S. R. Forrest, "High-efficiency fluorescent organic light-emitting devices using a phosphorescent sensitizer," *Nature* **403**, pp. 750–753 (2000).
- [18] P. G. J. Barten, *Contrast Sensitivity of the Human Eye and its Effect on Image Quality*, **PM 72**, SPIE Press, Bellingham, WA (1999).
- [19] P. G. J. Barten, "Effects of quantization and pixel structure on the image quality of color matrix displays," *Journal of the SID* **1(2)**, pp. 147–153 (1993).
- [20] P. G. J. Barten, "Physical model for the contrast sensitivity of the human eye," *SPIE Proc.* **1666**, pp. 57–72 (1992).
- [21] P. G. J. Barten, "Subjective image quality of HDTV pictures," *International Display Research Conference* **19**, p. 598 (1989).
- [22] B. Baxter, H. Ravindra, and R. A. Normann, "Changes in lesion detectability caused by light adaptation in retinal photoreceptors," *Investigative Radiology* **17**, pp. 394–401 (1982).
- [23] D. A. Baylor and M. G. F. Fuortes, "Electrical responses of single cones in the retina of the turtle," *Journal of Physiology* **207**, pp. 77–92 (1970).
- [24] M. E. Becker, "Evaluation and characterization of display reflectance," *Displays* **19**, pp. 35–54 (1998).
- [25] C. Beckman, O. Nilsson, and L.-E. Paulsson, "Intraocular light scattering in vision, artistic painting, and photography," *Applied Optics* **33(21)**, pp. 4749–4753 (July 1994).
- [26] M. Berggren, A. Dodabalapur, R. E. Slusher, and Z. Bao, "Light amplification in organic thin films using cascade energy transfer," *Nature* **389**, pp. 466–469 (1997).
- [27] M. T. Bernius, M. Inbasekaran, J. O'Brien, and W. Wu, "Progress with light-emitting polymers," *Advanced Materials* **12(23)**, pp.1737–1750 (2000).
- [28] A. Bernsten, Y. Croonen, C. Liedenbaum, H. Schoo, R. J. Visser, J. Vleggaar, et al., "Stability of polymer LEDs," *Optical Materials* **9**, pp. 125–133 (1998).
- [29] A. Bernsten, P. van de Weijer, Y. Croonen, C. Liedenbaum, and J. Vleggaar, "Stability of polymer light-emitting diodes," *Philips Journal of Research* **51**, pp. 511–525 (1998).

- [30] H. Blume and B. M. Hemminger, "Image presentation in digital radiology: perspectives on the emerging DICOM display function standard and its application," *Radiographics* **17**, pp. 769–777 (1997).
- [31] M. Born and E. Wolf, *Principles of Optics, Third Edition*, Pergamon Press, London (1965).
- [32] R. W. Boyd, *Radiometry and the Detection of Optical Radiation*, John Wiley & Sons, New York (1983).
- [33] D. Braun, "Crosstalk in passive matrix polymer LED displays," *Synthetic Metals* **92**, pp. 107–113 (1998).
- [34] R. Brinkley, G. Xu, A. Abileah, R. Brinkley, G. Xu, A. Abileah, et al., "Wide-viewing-angle AMLCD optimized for gray-scale operation," *Proc. of the Society for Information Display* **29**, pp. 471–474 (1998).
- [35] P. L. Burn, A. B. Holmes, and A. Kraft, "Chemical tuning of electroluminescent copolymers to improve emission efficiencies and allow patterning," *Nature* **356**, pp. 47–49 (1992).
- [36] J. H. Burroughes, D. D. C. Bradley, A. R. Brown, R. N. Marks, K. Mackay, R. H. Friend, et al., "Light-emitting diodes based on conjugated polymers," *Nature* **347**, pp. 539–541 (1990).
- [37] P. E. Burrows, V. Bulovic, S. R. Forrest, L. S. Sapochak, D. M. McCarty, and M. E. Thompson, "Reliability and degradation of organic light emitting devices," *Applied Physics Letters* **65(23)**, pp. 2922–2924 (1994).
- [38] P. E. Burrows, G. Gu, V. Bulovic, Z. Shen, S. R. Forrest, and M. E. Thompson, "Achieving full-color organic light-emitting devices for lightweight, flat-panel displays," *IEEE Transactions on Electron Devices* **44(8)**, pp. 1188–1203 (1997).
- [39] P. E. Burrows, Z. Shen, and S. R. Forrest, "Saturated full color stacked organic light emitting devices," *International Display Research Conference* **17**, pp. 318–321 (1997).
- [40] C. Challener, "Fast-growing polymer-OLED market is pursued by major chemical players," *Chemical Market Reporter* **258**, pp. 22–23 (2000).
- [41] C.-Y. Chen and J. Kanicki, "High field-effect mobility a-Si:H TFT based on high deposition-rate PECVD materials," *IEEE Transactions on Electron Devices* **17**, pp. 437–439 (1996).
- [42] J. Chen, P. J. Bos, D. R. Bryant, D. L. Johnson, S. H. Jamal, and J. R. Kelly, "Four-domain TN-LCD fabricated by reverse rubbing or double evaporation," *Proc. of the Society for Information Display* **26**, pp. 865–868 (1995).
- [43] J. Chen, K.-H. Kim, J.-J. Jyu, J. H. Souk, J. R. Kelly, and P. J. Bos, "Optimum film compensation modes for TN and VA LCDs," *Proc. of the Society for Information Design 1998*, pp. 315–318 (1998).
- [44] X. Cheng, Y. Hong, J. Kanicki, and L. J. Guo, "High-resolution organic polymer light-emitting pixels fabricated by imprinting technique," *J. Vac. Sci. Technol. B* **20(6)**, pp. 2877–2880 (2002).
- [45] P. J. Collings, *Liquid Crystals, Nature's Delicate Phase of Matter*, A. Hilger, Bristol, England (1990).

- [46] K. Compton, *Image Performance in CRT Displays*, SPIE Press, Vol. TT54, Bellingham, WA (2003).
- [47] B. K. Crone, P. S. Davids, I. H. Campbell, and D. L. Smith, "Device model investigation of single layer organic light emitting diodes," *Journal of Applied Physics* **84**, pp. 833–842 (1998).
- [48] S. Daly, "The visible differences predictor: an algorithm for the assessment of image fidelity," in *Digital Images and Human Vision*, Andrew B. Watson, Editor, pp. 179–206, MIT Press, Cambridge, MA (1993).
- [49] R. M. A. Dawson, Z. Shen, D. A. Furst, S. Connor, J. Hsu, M. G. Kane, et al., "Design of an improved pixel for polysilicon active matrix organic LED display," *SID Tech. Dig.* **29**, pp. 11–14 (1998).
- [50] R. M. A. Dawson, Z. Shen, D.A. Furst, S. Connor, J. Hsu, M.G. Kane, et al., "The impact of the transient response of organic light emitting diodes on the design of active matrix OLED displays," in *IEDM Tech. Dig.*, pp. 875–878 (1998).
- [51] S. W. Depp and W. E. Howard, "Flat-panel displays," *Scientific American* **3(40)**, pp. 90–97 (March 1993).
- [52] G. C. de Vries, "Contrast-enhancement under low ambient illumination," *Proc. of the Society for Information Display* **26**, pp. 32–35 (1995).
- [53] P. Dyreklev, M. Berggren, O. Inganäs, M. R. Andersson, O. Wennerström, and T. Hjertberg, "Polarised electroluminescence from an oriented substituted polythiophene in a light emitting diode," *Advanced Materials* **7**, pp. 43–45 (1995).
- [54] G. M. Ehemann, R. LaPeruta, and E. R. Garrity, "Method of Determining the Quality of an Aluminized, Luminescent Screen for a CRT," U.S. Patent No. 5,640,019 (1997).
- [55] M. Elias, L. Simonot, and M. Menu, "Bidirectional reflectance of a diffuse background covered by a partly absorbing layer," *Optics Communications* **191**, pp. 1–7 (2001).
- [56] D. Fish, N. Young, M. Childs, W. Steer, D. George, D. McCulloch, et al., "A comparison of pixel circuits for active matrix polymer/organic LED displays," *SID Tech. Dig.* **33**, pp. 968–971 (2002).
- [57] A. E. Flanders, R. H. Wiggins III, and M. E. Gozum, "Handheld computers in radiology," *Radiographics* **23**, pp. 1035–1047 (2003).
- [58] Flat Panel Display Measurements Standard Working Group, Video Electronics Standards Association (VESA), *Flat Panel Display Measurements Standard, Version 2.0* (May 2003).
- [59] M. J. Flynn, DisplayTool software, available upon request to mikef@rad.hfh.edu.
- [60] M. J. Flynn and A. Badano, "Image quality degradation by light scattering in display devices," *Journal of Digital Imaging* **12(2)**, pp. 50–59 (May 1999).
- [61] M. J. Flynn, Jerzy Kanicki, Aldo Badano, and William R. Eyler, "High-fidelity electronic display of digital radiographs," *Radiographics* **19(6)**, pp. 1653–1669 (1999).

- [62] M. J. Flynn, T. McDonald, E. G. DiBello, J. L. Jorgensen, and W. Worobey, "Flat panel display technology for high performance radiographic imaging," *SPIE Proc.* **2431**, pp. 360–371 (1995).
- [63] S. R. Forrest, P. E. Burrows, Z. Shen, G. Gu, V. Bulovic, and M. E. Thompson, "The stacked OLED (SOLED): a new type of organic device for achieving high-resolution full-color displays," *Synthetic Metals* **91**, pp. 9–13 (1997).
- [64] S. R. Forrest, P. E. Burrows, and M. E. Thompson, "The dawn of organic electronics," *IEEE Spectrum* **37(8)**, pp. 29–34 (2000).
- [65] R. H. Fowler and L. Nordheim, "Electron emission in intense electric fields," *Proc. Roy. Soc. London* **119A**, pp. 173–181 (1928).
- [66] M. Fujihira, L. M. Do, A. Koike, and E. M. Han, "Growth of dark spots by interdiffusion across organic layers in organic electroluminescent devices," *Applied Physics Letters* **68(13)**, pp. 1787–1789 (1996).
- [67] Y. Fukuda, T. Watanabe, T. Wakimoto, S. Miyaguchi, and M. Tsuchida, "An organic LED display exhibiting pure RGB colors," *Synthetic Metals* **111-112**, pp. 1–6 (2000).
- [68] R. E. Gill, P. van de Weijer, C. T. H. Liedenbaum, H. F. M. Schoo, A. Berntsen, J. J. M. Vleggaar, et al., "Stability and characterization of large area polymer light-emitting diodes over extended periods," *Optical Materials* **12(2-3)**, pp. 183–187 (1999).
- [69] N. C. Greenham, S. C. Moratti, D. D. C. Bradley, R. H. Friend, and A. B. Holmes, "Efficient light-emitting diodes based on polymers with high electron affinities," *Nature* **365**, pp. 628–630 (1993).
- [70] G. Gu and S. R. Forrest, "Design of flat-panel displays based on organic light-emitting devices," *IEEE Journal on Selected Topics in Quantum Electronics* **4(1)**, pp. 83–99 (1998).
- [71] R. W. Gymer, "Organic electroluminescent displays," *Endeavour* **20**, pp. 115–120 (1996).
- [72] M. Hack, R. Kwong, M. S. Weaver, M. Lu, and J. J. Brown, "Active-matrix technology for high efficiency OLED displays," in *Proc. of IDMC '02*, pp. 57–60 (2002).
- [73] T. B. Harvey III, Q. Shi, and F. So, "Passivated Organic Device having Alternating Layers of Polymer and Dielectric," U.S. Patent No. 5,757,126 (May 1998).
- [74] F. Hasselbach and H.-R. Krauss, "Backscattered electrons and their influence on contrast in the scanning electron microscope," *Scanning Microscopy* **2(2)**, pp. 1947–1956 (1988).
- [75] Y. He, "Polyfluorene Light-Emitting Devices and a-Si:H TFT Pixel Circuits for Active-Matrix Organic Light Emitting Displays," Ph.D. thesis, University of Michigan (2000).
- [76] Y. He, S. Gong, R. Hattori, and J. Kanicki, "High performance organic polymer light-emitting heterostructure devices," *Applied Physics Letters* **74**, pp. 2265–2267 (1999).

- [77] Y. He, R. Hattori, and J. Kanicki, "Current-source a-Si:H thin-film transistor circuit for active-matrix organic light-emitting displays," *IEEE Electron Device Letters* **21(12)**, pp. 590–592 (2000).
- [78] Y. He, R. Hattori, and J. Kanicki, "Improved a-Si:H TFT pixel electrode circuits for active-matrix organic light emitting displays," *IEEE Transactions on Electron Devices* **48(7)**, pp. 1322–1325 (2001).
- [79] S. Hecht and Y. Hsia, "Dark adaptation following light adaptation to red and white lights," *Journal of the Optical Society of America* **35(4)**, pp. 261–267 (April 1945).
- [80] S. Hecht and Y. Hsia, "Relation between visual acuity and illumination," *Journal of General Physiology* **11**, pp. 255–281 (1928).
- [81] P. K. H. Ho, J.-S. Kim, J. H. Burroughes, H. Becker, S. F. Y. Li, T. M. Brown, et al., "Molecular-scale interface engineering for polymer light-emitting diodes," *Nature* **404**, pp. 481–484 (2000).
- [82] C. D. Hoke, H. Mori, and P. J. Bos, "An ultra-wide-viewing angle STNLC with a negative-birefringence compensation film," *International Display Research Conference* **17**, pp. 21–24 (1997).
- [83] Y. Hong, J. Kanicki, and R. Hattori, "Novel poly-Si TFT pixel electrode circuits and current programmed active-matrix driving methods for AM-OLED," *SID Tech. Dig.* **33**, pp. 618–621 (2002).
- [84] Y. Hong, J.-Y. Nahm, and J. Kanicki, "100 dpi 4-a-Si:H TFTs active-matrix organic polymer light-emitting display," *IEEE Journal of Selected Topics in Quantum Electronics* **10**, pp. 16–25 (2004).
- [85] Y. Hong, J.-Y. Nahm, and J. Kanicki, "Optoelectrical properties of four amorphous silicon thin-film transistors 200 dpi active-matrix organic polymer light-emitting display," *Applied Physics Letters* **83(16)**, pp. 3233–3235 (2003).
- [86] Y. Hong, J.-Y. Nahm, and J. Kanicki, "200 dpi 4-a-Si:H TFTs current-driven AM-PLEDs," *SID '03 Digest*, pp. 22–25 (2003).
- [87] ISO Technical Report 9241-7, *Ergonomic Requirements for Office Work with Visual Display Terminals* (1997).
- [88] G. E. Jabbour, S. E. Shaheen, M. M. Morrell, B. Kippelen, N. R. Armstrong, and N. Peyghambarian, "Aluminum composite cathodes: a new method for the fabrication of efficient and bright organic light-emitting devices," *Optics and Photonics News* **10(4)**, p. 24 (1999).
- [89] Y.-C. Jeong, C.-C. Park, and L.-S. Kim, "A new crosstalk compensation method in line inversion TFT-LCDs," *IEEE Transactions on Systems and Circuits*, **44(6)**, pp. 552–555 (1997).
- [90] G. R. Jones, E. F. Kelley, and T. A. Germer, "Specular and diffuse reflection measurements of electronic displays," *Proc. of the Society for Information Display* **27**, pp. 203–206 (1996).
- [91] G. W. Jones, W. E. Howard, and S. M. Zimmerman, "Sealing structure for organic light emitting devices," U.S. Patent No. 6,198,220 B1 (2001).

- [92] E. Kaneko, *Liquid Crystal TV Display: Principles and Applications of Liquid Crystal Displays*, KTK Scientific Publishers, Tokyo (1987).
- [93] J. Kanicki, Y. He, and R. Hattori, "a-Si:H pixel electrode circuits for AM-OLEDs," *SPIE Proc.* 4295, pp. 147–158 (2001).
- [94] J. Kanicki, J. Lan, A. Catalano, J. Keane, W. Den Boer, and T. Gu, "Patterning of transparent conductive oxide thin films by wet etching for a-Si:H TFT-LCDs," *Journal of Electronic Materials* **25**, pp. 1806–1817 (1996).
- [95] M. Kawasaki, N. Tani, and R. Onishi, "Improvement of contrast and brightness by using crystal pigment phosphor screens," *Proc. of the Society for Information Display* **29**, pp. 266–269 (1998).
- [96] P. A. Keller, *The Cathode-Ray Tube: Technology, History and Applications*, Palisades Press, New York (1992).
- [97] E. F. Kelley, "Display reflectance model based on BRDF," *Displays* **19**, pp. 27–34 (1998).
- [98] J. Kido, K. Masato, and N. Katsutoshi, "Multilayer white light-emitting organic electroluminescent device," *Science* **267**, pp. 1132–1334 (March 1995).
- [99] J. H. Kim, Y. Hong, and J. Kanicki, "Amorphous silicon thin-film transistors-based organic polymer light-emitting displays," *IEEE Electron Device Letters* **24(7)**, pp. 451–453 (2003).
- [100] M. Kimura, I. Yudasaka, S. Kanbe, H. Kobayashi, H. Kiguchi, S. Seki, et al., "Low-temperature polysilicon thin-film transistor driving with integrated driver for high-resolution light emitting polymer display," *IEEE Trans. Electron Devices* **46(12)**, pp. 2282–2288 (1999).
- [101] Kodak, "Kodak, Sanyo unveil 15-inch flat-panel display," <http://www.nl.kodak.com/US/en/corp/display/sanyoFlat.jhtml>, Chiba, Japan, posted October 2, 2002.
- [102] K. Kohm, "Visual CRT sharpness estimation using a fiducial marker set," *SPIE Proc.* **4319**, pp. 286–297 (2001).
- [103] H. Kubota, S. Miyaguchi, S. Ishizuka, T. Wakimoto, J. Funaki, Y. Fukuda, et al., "Organic LED full color passive-matrix display," *Journal of Luminescence* **87-89**, pp. 56–60 (2000).
- [104] J.-H. Lan and J. Kanicki, "Planarized copper-gate hydrogenated amorphous silicon thin-film transistors for active-matrix liquid crystal displays," *IEEE Transactions on Electron Devices* **20(3)**, p. 129 (1999).
- [105] S. Lee, A. Badano, and J. Kanicki, "Monte Carlo modeling of organic polymer light-emitting devices on flexible plastic substrates," *SPIE Proc.* **4800**, pp. 156–163 (2002).
- [106] G. Leising, S. Tasch, F. Meghdadi, L. Athouel, G. Froyer, and U. Scherf, "Blue electroluminescence with ladder-type poly(para-phenylene) and parahexaphenyl," *Synthetic Metals* **81**, pp. 185–189 (1996).
- [107] X. C. Li, F. Cacialli, M. Giles, J. Gruner, R. H. Friend, A. B. Holmes, et al., "Light-emitting-diodes based on Poly(Methacrylate)s with distyrylbenzene and oxadiazole side-chains," *Advanced Materials* **7**, pp. 898–900 (1995).

- [108] F. R. Libsch and A. Lien, "A compensation driving method for reducing crosstalk in XGA and higher-resolution TFT-LCDs," *Proc. of the Society for Information Display* **26**, pp. 253–256 (1995).
- [109] F. R. Libsch and A. Lien, "Understanding crosstalk in high-resolution color thin-film-transistor liquid crystal displays," *IBM Journal of Research and Development* **42(3/4)**, pp. 467–479 (May 1998).
- [110] J.-J. Lih, C-F Sung, M. S. Weaver, M. Hack, and J. J. Brown, "A phosphorescent active-matrix OLED display driven by amorphous silicon backplane," *SID Tech. Dig.* **34**, pp. 14–17 (2003).
- [111] S. F. Lim, K. Ke, W. Wang, and S. J. Chua, "Correlation between dark spot growth and pinhole size in organic light-emitting diodes," *Applied Physics Letters* **78**, pp. 2116–2118 (2001).
- [112] M. Lindfors, "Accuracy and repeatability of the ISO 9241-7 test method," *Displays* **19**, pp. 3–16 (1998).
- [113] C. J. Lloyd, M. Mizukami, and P. R. Boyce, "A preliminary model of lightning display interaction," *Journal of the Illuminating Engineering Society* **25(2)**, pp. 59–69 (1996).
- [114] J. R. Mansell and A. W. Woodhead, "Contrast loss in image devices due to electrons back-scattered from the fluorescent screen," *Journal of Physics D: Applied Physics* **16**, pp. 2269–2278 (1983).
- [115] S. Martin, A. Badano, and J. Kanicki, "Characterization of a high quality monochrome AM-LCD monitor for digital radiology," *SPIE Proc.* **4681**, pp. 293–304 (2002).
- [116] Y. Masutani, S. Tahata, M. Hayashi, T. Onawa, K. Kobayashi, K. Nagata, et al., "Novel TFT-array structure for LCD monitors with in-plane switching mode," *Proc. of the Society for Information Display* **28**, pp. 15–18 (1997).
- [117] J. McElvain, H. Antoniadis, M. R. Hueschen, J. N. Miller, D. M. Roitman, J. R. Sheats, et al., "Formation and growth of black spots in organic light-emitting diodes," *Journal of Applied Physics* **80**, pp. 6002–6007 (1996).
- [118] Z. Meng and M. Wong, "Active-matrix organic light-emitting diode displays realized using metal-induced unilaterally crystallized polycrystalline silicon thin-film transistors," *IEEE Trans. Electron Devices* **49(6)**, pp. 991–996 (2002).
- [119] D. Mentley, *Flat Panel Display Market Overview*, iSuppli/Stanford Resources (2002).
- [120] D. E. Mentley, "State of flat-panel display technology and future trends," *Proc. of the IEEE* **90(4)**, pp. 453–459 (2002).
- [121] A. A. Michelson, *Studies in Optics*, The University of Chicago Press, Chicago (1962).
- [122] I. S. Millard, "High-efficiency polyfluorene polymers suitable for RGB applications," *Synthetic Metals* **111-112**, pp. 119–123 (2000).
- [123] H. Mori and P. J. Bos, "Application of a negative birefringence film to various LCD modes," *International Display Research Conference* **17**, pp. M88–M97 (1997).



- [124] E. Muka, T. Mertelmeier, and R. M. Slone, "Impact of phosphor luminance noise on the specification of high-resolution CRT displays for medical imaging," *SPIE Proc.* **3031**, pp. 210–221 (1997).
- [125] S. Musa, "Active-matrix liquid-crystal displays," *Scientific American* **277**, pp. 87–92 (1997).
- [126] M. S. Nam, J. W. Wu, Y. J. Choi, K. H. Yoon, J. H. Jung, J. Y. Kim, et al., "Wide-viewing-angle TFT-LCD with photoaligned four-domain TN mode," *Proc. of the Society for Information Display* **28**, pp. 933–936 (1997).
- [127] J. A. Nichols, T. N. Jackson, M. H. Lu, and M. Hack, "a-Si:H TFT active-matrix phosphorescent OLED pixel," *SID Tech. Dig.* **33**, pp. 1368–1371 (2002).
- [128] R. A. Norman, B. S. Baxter, and H. Ravindra, "Photoreceptor contributions to contrast sensitivity: Applications in radiological diagnosis," *IEEE Transactions on Systems, Man, and Cybernetics* **SMC-13(5)**, pp. 944–953 (1983).
- [129] R. A. Norman and I. Perlman, "The effects of background illumination on the photoresponses of red and green cones," *Journal of General Physiology* **286**, pp. 491–507 (1979).
- [130] R. A. Norman and F. S. Werblin, "Control of retinal sensitivity: light and dark adaptation of vertebrate rods and cones," *Journal of General Physiology* **63**, pp. 37–61 (1974).
- [131] K. Ohmuro, S. Kataoka, T. Sasaki, and Y. Koike, "Development of super-high-image-quality vertical-alignment-mode LCD," *Proc. of the Society for Information Display* **28**, pp. 845–848 (1997).
- [132] M. Ohta, H. Tsutsu, H. Takahara, I. Kobayashi, T. Uemura, and Y. Takubo, "A novel current programmed pixel for active matrix OLED displays," *SID Tech. Dig.* **34**, pp. 108–111 (2003).
- [133] Y. Ono, Y. Ohtani, K. Hiratsuka, and T. Morimoto, "A new antireflective and antistatic double-layered coating for CRTs," *Proc. of the Society for Information Display* **23**, pp. 511–514 (1992).
- [134] L. Ozawa, *Cathodoluminescence: Theory and Applications*, Kodansha, Tokyo (1990).
- [135] E. Peli, J. Yang, R. Goldstein, and A. Reeves, "Effect of luminance on suprathreshold contrast perception," *Journal of the Optical Society of America A* **8**, pp. 1352–1359 (August 1991).
- [136] M. Pope, H. Kallmann, and P. Magnante, "Electroluminescence in organic crystals," *Journal of Chem. Phys.* **38**, pp. 2042–2048 (1963).
- [137] D. A. Reimann, M. J. Flynn, and J. J. Ciarelli, "System to maintain perceptually linear networked display devices," *SPIE Proc.* **2431**, pp. 316–326 (1995).
- [138] O. W. Richardson, "On the negative radiation from hot platinum," *Proc. Camb. Phil. Soc.* **11**, p. 286 (1902).
- [139] G. G. Roberts, M. McGinnity, W. A. Barlow, and P. S. Vincett, "Electroluminescence, photoluminescence and electroabsorption of a lightly substituted anthracene langmuir film," *Solid State Communications* **32**, pp. 683–686 (1979).

- [140] J. W. Roberts and E. F. Kelley, "Measurements of static noise in display images," *SPIE Proc.* **4295**, pp. 211–218 (2001).
- [141] S. P. Rogers, "Organic Electroluminescent Device Hermetic Encapsulation Package and Method of Fabrication," U.S. Patent No. 5,874,804 (1999).
- [142] B. E. A. Saleh and K. Lu, "The Fourier scope: An optical instrument for measuring LCD viewing-angle characteristics," *Journal of the SID* **4(1)**, pp. 33–40 (1996).
- [143] E. Samei, A. Badano, D. Chakraborty, K. Compton, C. Cornelius, K. Corrigan, et al., *Assessment of Display Performance for Medical Imaging Systems*, draft report of the American Association of Physicists in Medicine Task Group 18, Version 9.1 (2003).
- [144] E. Samei and M. J. Flynn, "A method for in-field evaluation of the modulation transfer function of electronic display devices," *SPIE Proc.* **4319**, pp. 599–607 (2001).
- [145] Samsung SDI Co., "SDI develops ultra fine high-speed LCD for handset," <http://www.samsungsdi.co.kr> (in Japanese and English), posted July 30, 2003.
- [146] J. L. Sanford and F. R. Libsch, "TFT AMOLED pixel circuits and driving methods," *SID Tech. Dig.* **34**, pp. 10–13 (2003).
- [147] T. Sasaoka, M. Sekiya, A. Yumoto, J. Yamada, T. Hirano, Y. Iwase, et al., "A 13.0-inch AM-OLED display with top emitting structure and adaptive current mode programmed pixel circuit (TAC)," *SID Tech. Dig.* **32**, pp.384–387 (2001).
- [148] W. Schottky and J. Issendorff, "Quasineutrale elektrische diffusion im ruhen und strömenden gas," *Zeitschrift für Physik* **31**, pp. 163–201 (1925).
- [149] M. I. Sezan, K. L. Yip, and S. J. Daly, "Uniform perceptual quantization: applications to digital radiology," *IEEE Transactions on Systems, Man, and Cybernetics* **SMC-17(4)**, pp. 622–634 (1987).
- [150] T. Shimoda, M. Kimura, S. Seki, H. Kobayashi, S. Kanbe, S. Miyashita, et al., "Technology for active matrix light emitting polymer displays," in *Proc. IEDM '99*, pp. 107–110 (1999).
- [151] T. Shimoda, H. Ohshima, S. Miyashita, M. Kimura, T. Ozawa, I. Yudasaka, et al., "High resolution light emitting polymer display driven by low temperature polysilicon thin film transistor with integrated driver," *Proc. Asia Display '98*, pp. 217–220 (1998).
- [152] G. Spencer, P. Shirley, K. Zimmerman, and D. P. Greenberg, "Physically based glare effects for digital images," in *Computer Graphics Proceedings, Annual Conference Series SIGGRAPH 95*, pp. 325–334 (1995).
- [153] W. S. Stiles, "The effect of glare on the brightness difference threshold," *Proc. Royal Soc. London* **B104**, pp. 322–351 (1929).
- [154] W. S. Stiles and B. H. Crawford, "The luminous efficiency of rays entering the eye pupil at different points," *Proc. Royal Soc. London* **122**, pp. 428–450 (1937).
- [155] C. W. Tang and S. A. Van Slyke, "Organic electroluminescent diodes," *Applied Physics Letters* **51(12)**, pp. 913–915 (September 1987).

- [156] S. Terada, G. Izumi, Y. Sato, M. Takahashi, M. Tada, K. Kawase, et al., "A 24-inch AM-OLED display with XGA resolution by novel seamless tiling technology," *SID Tech. Dig.* **34**, pp. 1463–1465 (2003).
- [157] H. S. Tong and G. Prando, "Hygroscopic ion-induced antiglare/antistatic coating for CRT applications," *Proc. of the Society for Information Display* **23**, pp. 514–517 (1992).
- [158] Toshiba Matsushita Display Technology Co., Ltd., "Toshiba Matsushita Display Technology introduces world's largest polymer organic light-emitting diode display," [http://www.tmdisplay.com/tm\\_dsp/press/2002/04-16a.htm](http://www.tmdisplay.com/tm_dsp/press/2002/04-16a.htm), posted April 16, 2002.
- [159] T. Tsujimura, Y. Kobayashi, K. Murayama, A. Tanaka, M. Morooka, E. Fukumoto, et al., "A 20-inch OLED display driven by super-amorphous-silicon technology," *SID Tech. Dig.* **34**, pp. 6–9 (2003).
- [160] N. Umezu, Y. Nakano, T. Sakai, R. Yoshitake, W. Herlitschke, and S. Kubota, "Specular and diffuse reflection measurement feasibility study of ISO 9241, part 7: method," *Displays* **19**, pp. 17–25 (1998).
- [161] J. J. van Oekel, "Improving the contrast of CRTs under low ambient illumination with a graphite coating," *Proc. of the Society for Information Display* **26**, pp. 427–430 (1995).
- [162] J. J. van Oekel, M. J. Severens, G. M. H. Timmermans, and A. A. M. Mouws, "Improving contrast and color saturation of CRTs by  $\text{Al}_2\text{O}_3$  shadow mask coating," *Proc. of the Society for Information Display* **28**, pp. 436–439 (1997).
- [163] P. S. Vincett, W. A. Barlow, R. A. Hann, and G. G. Roberts, "Electrical conduction and low voltage blue electroluminescence in vacuum-deposited organic films," *Thin Solid Films* **94**, pp. 171–183 (1982).
- [164] H. Wakemoto, S. Asada, N. Kato, Y. Yamamoto, M. Tsukane, T. Tsurugi, et al., "An advanced in-plane switching mode TFT-LCD," *Proc. of the Society for Information Display* **26**, pp. 929–932 (1997).
- [165] M. Weibrecht, G. Spekowius, P. Quadflieg, et al., "Image quality assessment of monochrome monitors for medical soft copy displays," *SPIE Proc.* **3031**, pp. 232–244 (1997).
- [166] S. L. Wright, S. Millman, and M. Kodate, "Measurement and digital compensation of crosstalk and photoleakage in high-resolution TFTLCDs," *SPIE Proc.* **3636**, pp. 200–211 (1999).
- [167] N. Yamada, S. Kohzaki, F. Funada, and K. Awane, "A full-color video-rate anti-ferroelectric LCD with wide viewing angle," *Proc. of the Society for Information Display* **17**, pp. 789–792 (1995).
- [168] Y. Yang and S. C. Chang, "Pyramid-shaped pixels for full-color organic emissive displays," *Applied Physics Letters* **77**(7), pp. 936–938 (2000).
- [169] G. Yu, H. Nishino, A. J. Heeger, T. A. Chen, and R. D. Rieke, "Enhanced electroluminescence from semiconducting polymer blends," *Synthetic Metals* **72**, pp. 249–252 (1995).

- 
- [170] C. Zhang, H. Von Seggern, B. Kraabel, H. W. Schmidt, and A. J. Heeger, "Blue emission from polymer light-emitting diodes using non-conjugated polymer blends with air-stable electrodes," *Synthetic Metals* **72**, pp. 185–188 (1995).
- [171] K. Ziemelis, "Display technology: glowing developments," *Nature* **399**, pp. 408–411 (2000).
- [172] S. M. Zimmerman, G. W. Jones, and H. E. Webster, "Sealing Structure for Organic Light Emitting Devices," U.S. Patent No. 6,198,220 (May 2001).

# Index

## A

AAPM, 137  
active drive, 43  
active matrix (AM)  
  addressing, 82, 84  
  defined, 44  
adaptation, 9  
addressing schemes, 81  
ambient illumination, 18, 100, 105–107  
aperture grille, 17, 32  
aperture ratio, 45, 99

## B

backlight, 43  
backscattering, 17  
bandwidth, 31  
barrier, 79  
bidirectional reflection distribution function,  
  131  
birefringent films, 51

## C

carrier  
  injection, 57–58  
  mobility, 59  
cathodo-luminescent display, 25, 29  
CCD camera, 124, 126  
charge-transport layer, 57  
color bleeding, 69  
color filters, 42  
cones, 10  
conic probe, 116  
contrast  
  physical, 5  
  ratio, 100, 114  
  threshold, 6  
copolymers, 64  
cosine distribution, 48  
cost, 1, 52  
crosstalk  
  classification, 116  
  electronic, 48  
  optical, 48

CRT emissions  
  Lambertian, 109  
  quasi-Lambertian, 109  
current-driven pixel electrode circuits, 93

## D

dark spots, 64, 77  
deflection, 31  
Dexter transfer, 61  
diffuse reflectance, 129  
diffuse reflection coefficient, 21, 133  
DIN, 137  
direct addressing, 82  
director, 40  
dispenser cathodes, 26  
display  
  calibration, 106  
  controller, 36  
  metrology, 105  
  requirements, 22  
down conversion, 69  
driving circuits, 81  
dust particles, 77  
dynamic focus, 33

## E

electroluminescence, 56  
electron gun, 28  
encapsulation, 74, 79  
energy transfer, 61  
etching process, 67  
exciton, 60

## F

field effect mobility, 85  
fluorescence, 60  
Förster transfer, 61  
Fourier  
  analysis, 124, 126  
  optics, 113  
Fowler-Nordheim model, 58  
full-color display, 104

**G**

glare  
in the human eye, 13  
sources of, 14  
veiling, 13

**H**

halation, 121  
hole-transporting layer, 57

**I**

illuminance, 4  
indium tin oxide (ITO), 47  
inorganic semiconductors, 103  
in-plane switching, 53  
internal quantum efficiency, 60  
International Electrotechnical Commission (IEC), 138

**J**

just noticeable difference (JND), 7

**L**

Lambertian  
emissions, 65, 109  
reflector, 130  
leakage current, 45, 116  
lifetime, 65, 74  
light  
leakage, 15  
polarization, 40  
transmission, 36  
luminance  
defined, 4  
range, 109  
ratio, 114  
response, 107, 109  
luminous efficiency, 89

**M**

manufacturing, 104  
market, 1, 44, 55, 62, 104  
matrix addressing, 82  
microcavity effects, 74  
modulation transfer function (MTF), 123–124  
moisture, 74, 81  
multiple domains, 52

**N**

Nobel prize, 55  
noise  
spatial, 125

temporal, 125  
noise power spectrum (NPS), 125–127

**O**

OLED  
current-driven, 90, 93  
market, 102  
pixel, 65  
polymers, 62  
small molecules, 62  
stacked, 71  
transparent, 72  
voltage-driven, 90–91  
optical crosstalk, 69  
organic semiconductor, 58  
orientation, 125  
oxygen, 74, 81

**P**

P104, 34  
P45, 34  
passive matrix (PM), 82  
phosphorescence, 60  
photolithographic processes, 67  
photometry, 3  
photopic probe, 110  
photopic sensitivity, 3  
photoreceptor, 6  
pixel  
electrode, 98  
size, 12, 123  
poly (phenylene vinylene) (PPV), 57, 62  
polymer, 57, 62

**Q**

quasi-Lambertian emissions, 109

**R**

radiative recombination, 59  
radiographic film, 133  
radiometry, 3  
resolution, 123  
resolution-to-addressability ratio, 123  
response function, 119  
retina, 10  
Richardson-Schottky model, 58  
rods, 10

**S**

shadow mask, 17, 32  
sharpness, 123  
small-spot contrast ratio, 114  
spacers, 41

spatial frequency, 6  
spatial noise, 126  
specular reflection, 20, 129  
spin coating, 66  
spot size, 33  
static drive, 43  
storage capacitor, 85  
subpixel structures, 65, 75, 127

**T**

temporal noise, 126  
thin-film transistor (TFT)  
  a-Si:H, 86  
  defined, 44  
  organic, 86  
  poly-Si, 87  
  uses, 84-85  
thermal evaporation, 66

**V**

vertical-aligned liquid crystals, 54  
VESA, 138  
voltage-driven pixel electrode  
  circuit, 91

**W**

white box, 132



Aldo Badano received his Ph.D. degree in Nuclear Engineering from the University of Michigan in 1999. He is currently a research scientist with the Division of Imaging and Applied Mathematics, Office of Science and Engineering Laboratories, Center for Devices and Radiological Health, at the U.S. Food and Drug Administration, where he leads a research program on the evaluation of medical displays. Dr. Badano's research focuses on the objective assessment of image quality in medical imaging sensors and image display devices using advanced experimental and computational methods. He is a referee for several scientific journals and a reviewer of technical grants for the U.S. Department of Defense and the National Institutes of Health. He has authored or coauthored more than 60 publications. He is a member of SID, AAPM, and SPIE.



Michael Flynn obtained his Ph.D. in Nuclear Science from the University of Michigan in 1975. He is presently a Senior Scientist at Henry Ford Health System in Detroit, Michigan, where he conducts sponsored research on medical display, digital radiography, and computed tomography. Currently an Adjunct Professor of Nuclear Engineering and Radiological Science at the University of Michigan, Dr. Flynn has taught a graduate course on radiation imaging for over 20 years. His scientific work emphasizes the importance of high-fidelity display to complete the medical imaging process.



Jerzy Kanicki received his Ph.D. degree in Sciences (D.Sc.) from the Universite Libre de Bruxelles (Belgium) in 1982. He subsequently became a Research Staff Member at the IBM Thomas J. Watson Research Center in Yorktown Heights, New York, working on hydrogenated amorphous silicon devices for photo-voltaic and flat-panel display applications. In 1994 he moved to the University of Michigan as a Professor in the Department of Electrical Engineering and Computer Science, where he did leading work on various flat-panel display technologies until 2000. Since 2000 he has worked on a variety of fundamental problems related to organic and molecular electronics. In 2002–2003 he spent a sabbatical year at the Center for Polymers and Organic Solids, University of California-Santa Barbara, conducting research in the area of conducting polymer devices. Dr. Kanicki is the author or coauthor of over 250 publications in journals and conference proceedings, and he has edited two books and three conference proceedings. He has presented numerous invited talks at national and international meetings in the area of organic and inorganic semiconductor devices. More information about his research group activities can be found at [www.eecs.umich.edu/omelab/](http://www.eecs.umich.edu/omelab/).