Contributed paper

OPTO-ELECTRONICS REVIEW **10**(1), 17–21 (2002)

# Antiferroelectric and V-shape liquid crystal on silicon microdisplays

J.M. OTÓN*[1], R. DĄBROWSKI[2], X. QUINTANA[1], V. URRUCHI[1], and J.L. GAYO[1]

[1]Dpt. Tecnología Fotónica, E.T.S. Ingenieros de Telecomunicación, Universidad Politécnica de Madrid, Ciudad Universitaria, 28040 Madrid, Spain

[2]Institute of Chemistry, Military University of Technology, 2 Kaliskiego Str., 00-908 Warsaw, Poland

*In this work, the use of antiferroelectric and V-shape liquid crystals for video projection using LCOS microdisplays has been explored. Antiferroelectric grey levels arise from a double symmetric hysteresis loop that can be stabilised by a constant holding voltage, thus an active matrix is not strictly required in this case. If used, then the voltage levels and the waveform must be adjusted to fulfil the voltage limitations dictated by the matrix. V-shape materials lack hysteresis; therefore the active matrix is mandatory to stabilise the levels. Voltage limitations, however, are less restrictive in this case, since V-shape smectics require just a few volts for full switching.*

**Keywords:** antiferroelectric, V-shape, LCOS, active matrix, waveform.

## 1. Introduction

A number of smectic liquid crystals showing ferroelectricity, when confined in thin cells, become surface-stabilised. These materials show in-plane switching (IPS), an interesting feature for display applications. Moreover, some of these liquid crystals, e.g. antiferroelectrics and V-shape thresholdless smectics, show an intrinsic analogue grey scale [1], along with reduced switching time, making them attractive for high-resolution video-rate applications.

On the other hand, liquid-crystal on silicon (LCOS) microdisplays have demonstrated to be an interesting alternative to transmissive spatial light modulators based on thin-film transistor (TFT) technology. The active matrix of LCOS displays is fabricated on silicon wafers, using standard microelectronic techniques, an advantage compared to TFT silicon-on-glass manufacturing. However, large area silicon wafers cannot be prepared and light transmission is curtailed by the substrate. Therefore, LCOS technology is employed in miniature reflective displays.

In this work different driving waveforms for both types of smectic liquid crystals: tristate AFLCs and V-shaped are studied. All the waveforms shown below have been tested and optimised using transmissive and reflective test cells, made either on glass or on silicon (dummy silicon backplanes). Once test cells were manufactured and filled with a number of materials, specific waveforms for LCOS driving were designed [2]. Excellent grey scales have been demonstrated in both cases with the frame rates over 200 Hz, allowing the use of sequential colour at video rate.

The paper is divided into two parts, concerning waveform design for tristate antiferroelectric liquid crystals (TSAFLCs) and V-shaped (thresholdless) smectics liquid crystals (TLAFLCs) respectively.

## 2. Experimental

### 2.1. Waveforms for passive matrix displays

Figure 1 shows the electrooptic response of a surface-stabilised TSAFLC when driven by a low frequency triangular wave. This typical double hysteresis loop can be used as a reference to design waveforms. The loop is just a

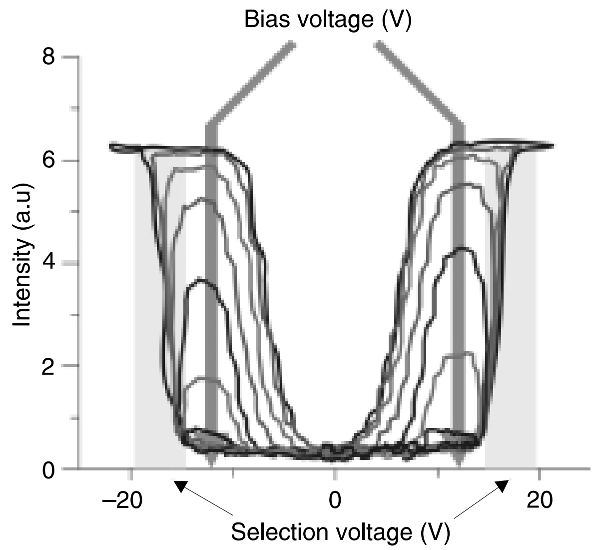


Fig. 1. E-O response of TSAFLCs with low frequency triangular wave.

*e-mail: jmoton@etsit.up.es

reference showing where the AFLC would stabilise at every applied voltage.

Figure 2 shows the simplest waveform that can be used to drive these materials. If a greyscale is desired, driving of TSAFLCs requires a selection pulse ①, by which the outer slope of the loops is reached, and a holding voltage (bias) ②, to maintain the grey level along the frame time. Then, the cycle is repeated ③④ with the opposite loop to DC compensate the whole waveform. Data are included in the selection pulses. The waveform, therefore, can be used to multiplex passive matrix AFLCs. However, this waveform cannot be used as is, since TSAFLC materials show a memory effect by which the grey level achieved in one cycle depends on the previous ones. To avoid this undesirable dependence, the pixel must be erased by bringing it to a known state (always the same) before every cycle. There are three known states in TSAFLC hysteresis loops: the relaxed AFLC state at 0 V and the two symmetric FLC saturated states at the outer ends of the loops.

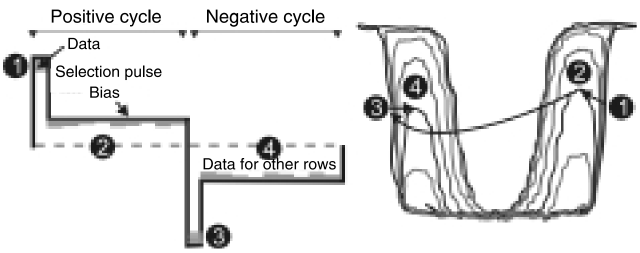


Fig. 2. Basic waveform for TSAFLC driving. Data are included onto the selection pulse.

The waveform should include one of these states in every cycle. Several waveforms have been proposed depending on the adopted erasing strategy – relaxation or saturation. Relaxation seems to produce better greyscales, while saturation is faster, hence best suited for video. The main waveforms are shown in Fig. 3. We propose a waveform based on forced relaxation, in which the reset time is substantially reduced by applying a voltage well after the bias period.

Figure 3(a) simply includes a reset time ③ to allow the pixel to relax. This waveform cannot be used in LCOS since the relaxation time of current materials at room temperature is several ms, i.e., comparable to the whole frame time of sequential colour and video rate. Figure 3(b) is the waveform chosen for LCOS. Selection pulses ①⑤ and bias regions ② are similar to previous ones. Before reset ④, however, a short counter pulse ③ – the well – is applied. It has been experimentally shown by us that a correctly designed well pulse reduces up to two orders of magnitude the relaxation time [3] (e.g., below 100 μs). It must be stressed, however, that this may require two extra voltage levels (total, 7 levels), for either amplitude or time of the well must be freely set.

Figures 3(c) and 3(d) are two waveforms based on saturation. Figure 3(c) has been proposed by Okada [4,5] and Fig. 3(d) is our proposal. Both are fast, however, both show less satisfactory greyscales than the former waveforms.

As mentioned above, these waveforms can be used in passive multiplexed displays. Rows are sequentially scanned with either of these waveforms, while data for each row are written in the columns during their corresponding slot times. In any given row, pixels "see" their own data during the selection time, and data for others rows during bias and reset time. It follows that crosstalking may arise if data voltage levels are significant compared to selection and bias. Optimisation of waveforms and fabrication conditions have led to low dynamic range (<2.5 V) greyscales, allowing high multiplex levels with low crosstalk.

## 2.2. Design of driving schemes for AFLCs on LCOS

Previously chosen waveform [Fig. 3(b)] is suitable for driving AFLCs on LCOS. In such active devices, data can be made independent of selection (i.e., no sequential row

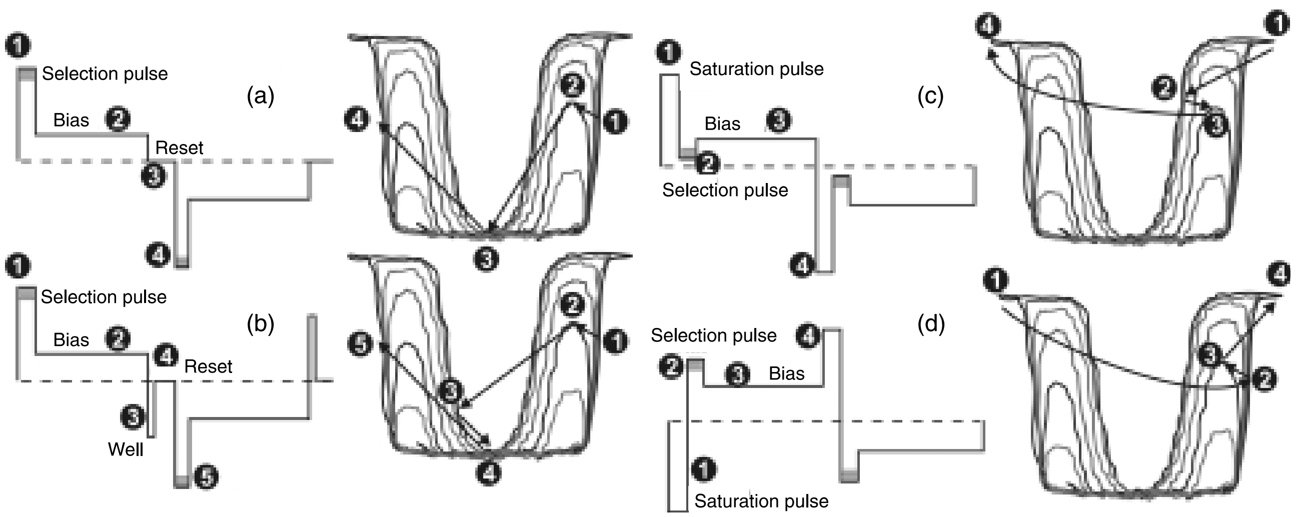


Fig. 3. Several waveform including erasing pulses by relaxation and saturation.

scanning is required). On the other hand, data writing takes a substantial fraction (~25%) of the frame time. The remaining time should be mostly assigned to viewing (lighting); otherwise the display would be dark.

To achieve this time distribution, we have tested the possibility of sharing the LC reset time and the data writing time (Fig. 4). This can be done as the AFLC material threshold is much higher than the highest data levels. In such scheme, all data are written in advance, and a single selection – bias–well – reset pulse is applied to the counter electrode afterwards. The cell then switches as a whole.

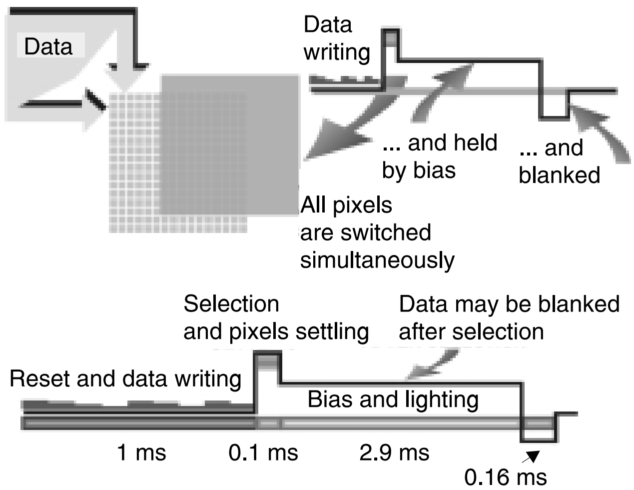


Fig. 4. Waveform proposed for a silicon backplane filled with TSAFLC material.

The scheme has a decisive advantage: All pixels have the same chance to switch. Relaxation, bias and selection are simultaneous for all pixels. No crosstalk can be produced. Moreover, transmission need not be stabilised within the frametime. Indeed, the material does not reach a stable transmission but the integral transmission (during lighting time) for any given grey level is the same for any pixel. Therefore, a simple gamma correction should produce the correct greyscale.

Several crucial points in this scheme have been tested:

- data writing during LC reset does not affect the material relaxation to AFLC state,
- grey levels are maintained by bias. Data are needed only during selection. Once the pixel is switched, the grey level is hold by bias voltage. This means that data may be blanked in the backplane during bias. In this way, all pixels “see” the same applied voltage,
- selection pulse may affect stored data. Even so, the greyscale is maintained,
- if data storage is not affected by selection, and no blanking after selection is applied, pixels would “see” different voltage levels, depending on their grey levels. We have checked that this scheme also gives an excellent greyscale, although its dynamic range is obviously different,
- if data range is below 2.5 V, no significant differences are found between pixels whose data are written at the beginning and the end of the writing time,
- greyscale depends on temperature. Fortunately increasing temperature shifts the entire greyscale parallel to itself. Thus, temperature correction, if required, should be a simple DC offset voltage on each cycle.

As in the passive case, grey levels obtained in the positive and negative cycles are not the same. If RGB frames were alternated between positive and negative cycles, a component with 1/2 frame rate frequency would appear giving substantial flickering. A possible solution (Fig. 5) is to use sequences RGBG or RBGB, so that every colour is always represented with either positive or negative frames.

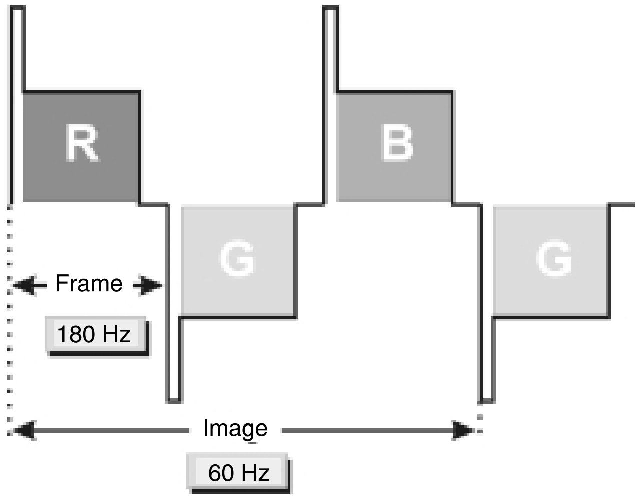


Fig. 5. Four colours RGBG. Green colour is duplicated to increase brightness.

The above items do not take into account that data are not bipolar, but unipolar. As a result, the whole waveform is shifted towards positive values. This must be taken into account when adjusting the voltage levels of the positive and negative cycles.

## 2.3. Design of driving schemes for V-shape onto LCOS

V-shaped FLCs, formerly known as thresholdless antiferroelectric LCs (TLAFLCs) [6] have been used as a very attractive alternative to ferroelectric LCs. The main advantage in this case is low switching voltage, compatible with silicon backplane levels, and the presence of an analogue grey scale.

At present, the name V-shaped FLCs is preferred to thresholdless AFLCs. Paradoxically, the electrooptical response of these materials is often W-shaped rather than V-shaped (Fig. 6).

Design constraints of waveforms for V-shaped in silicon backplane, rely on sequential lighting of the display. The frame time is about 5 ms. Under these conditions, the materials do not reach stable grey levels. This goes unno-

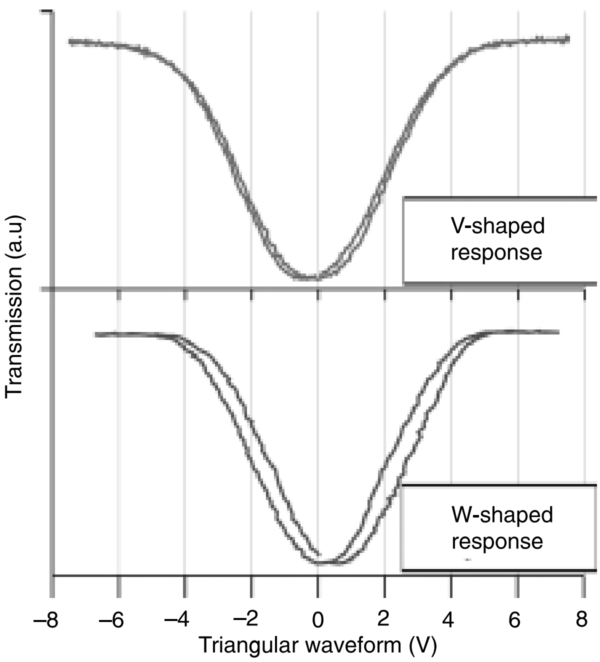


Fig. 6. Different electrooptical responses obtained in V-shaped materials. W-shape appears more often than V-shape.

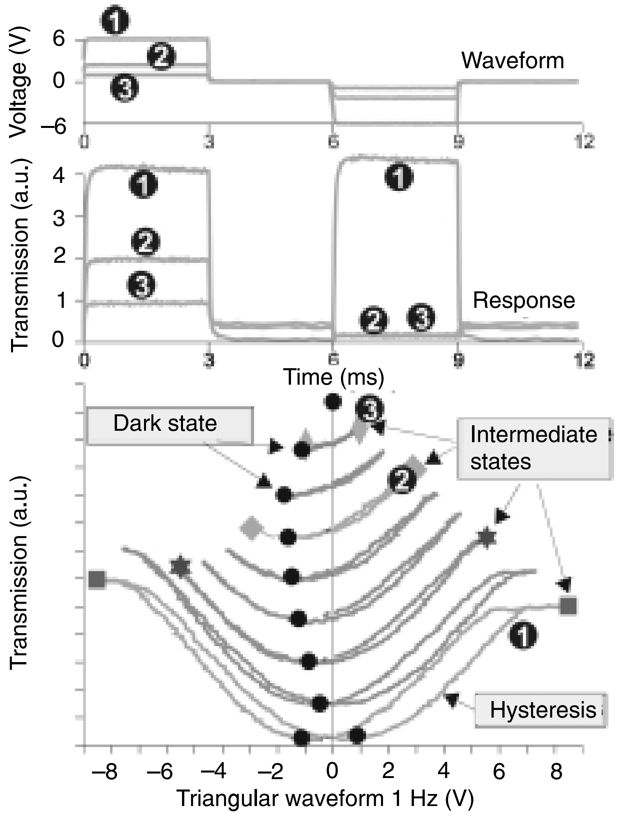


Fig. 7. Specific feature shown by W-shaped TLAFLCs. Saturating pulses are required to switch from either branch to the other. If saturation is not reached, the material may show highly asymmetric behaviour.

ticed for the eye, since the integration time of human vision is larger. However, it is important that every pixel is switched in the same way. Specifically, the time elapsed between the switching pulse and the lighting period must be the same for all pixels. Otherwise pixels would be lighter or darker upon illumination, depending on their position in the display. Note that this is a direct consequence of sequential lighting (and short frametime); it does not affect a backlighted direct-view V-shaped display.

The idea is to switch all pixels at the same time, after the data writing period. This could be easily accomplished in tristate AFLCs for the existence of a (high) voltage threshold avoided premature switching during data writing time. However, thresholdless switching cannot be avoided. The solution proposed is to saturate every pixel during writing time by applying a voltage to the counter electrode.

There is another reason for doing that; W-shaped response is often found in TLAFLCs. Although these materials can be used, extra care must be used in waveform design. The reason is shown in Fig. 7. Several hysteresis cycles for different voltage amplitudes are shown in the bottom graph. (Curves are vertically shifted; actually all of them overlap). The middle graph shows the transmission obtained when applying the voltage signal indicated in the top graph.

The curve labelled hysteresis ①, in the bottom graph, is saturating the cell. W-shaped response is seen in the bottom graph. Two symmetric minima (dark states) are found. Transmission of positive and negative cycles (middle graph) are identical.

This is not the case of a non-saturating signal such the third curve from top ② in the hysteresis plot. In this case, the transmission of the positive cycle is higher, since the same inner branch of the hysteresis curve is used for both, positive and negative pulses. The negative level is close to the minimum transmission (dark state), its transmission being even lower than the zero volt transmission. The moral of this, again, is that pixels must be saturated between positive and negative cycles.

The waveforms proposed are roughly the same in both cases. Figure 8 shows the W-shaped case. Given a data level ① (Fig. 8, left), it is brought to saturation ② during writing. After writing the counter electrode voltage is brought to dark level ③ where data are superimposed Figs. 3(a) and 3(b). The right waveform is identical, except for a voltage well ③ added to speed up the access to grey levels ④. The well is calculated so, that the time elapsed to reach any level is the same.

Another important point that must be checked is the relationship between stored data voltage and remaining data voltage after the saturation pulse is removed. It shall be taken into account that data are written with voltage on the counter electrode. The charge is shared between the existent capacitors in a non-straightforward manner. Anyhow we have experimentally and theoretically concluded that the greyscale shall not be affected, providing the storage capacity is at least ten times than the pixel capacity. Otherwise corrections must be added to the data voltage to compensate for the deviations.

 

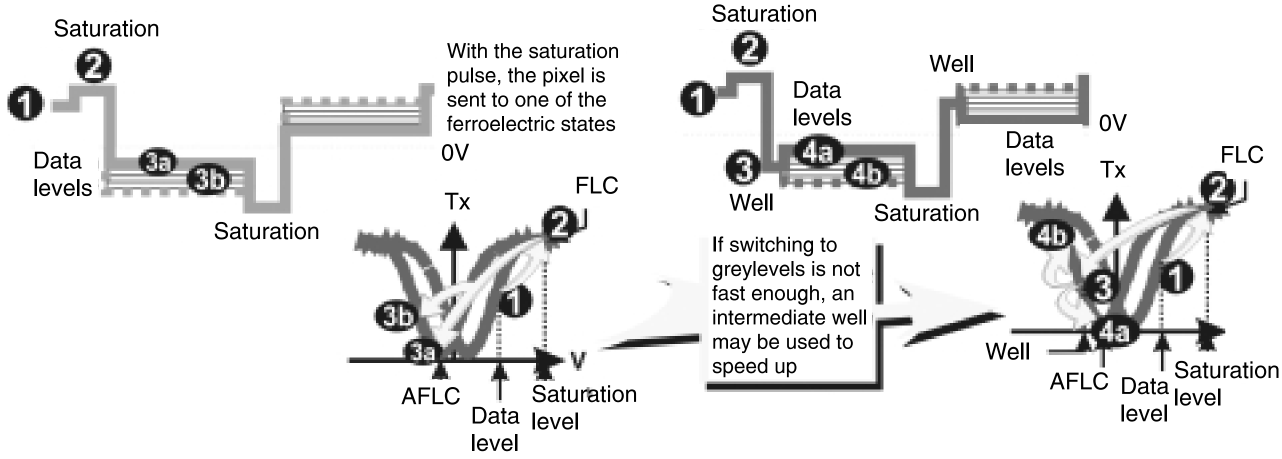


Fig. 8. Waveforms proposed for W-shaped TLAFLCs. The saturation pulse lasts 1.5 ms (the data writing time). Once all data are written, the counter electrode is brought to the dark state level, and data are superimposed. A voltage well (right) may be included to speed up the process.

## 3. Conclusions

LCOS displays can be advantageously associated to either tristate antiferroelectrics or V-shape smectics to produce full--colour, video rate displays. The device may use colour dithering. Specific waveforms running at four times the standard video frequency have been demonstrated in both cases. The system seems to be an alternative to TFT SLM projectors.

## References

1. S.S. Seomun, V.P. Panov, J.K. Vij, A. Fukuda, and J.M. Otón, "Dependence of the molecular orientational states on the surface conditions for the V-shape switching in ferroelectric-like samples", *Phys. Rev.* **E64**, 6404(4) Part1, 0307–0309 (2001).
2. X. Quintana, J.L. Gayo, C. Rodrigo, V. Urruchi, and J.M. Otón, "Addressing waveforms for tristable AFLCs in active matrix displays", *Ferroelectrics* **246**, 211–218 (2000).
3. J.M. Otón, C. Toscano, V. Urruchi, J.L. Gayo, X. Quintana, and L. Sirleto, "Reflective SLMs based on antiferroelectric and V-shape liquid crystals" *9th Int. Topical Meeting on Optics of Liquid Crystals OLC'01*, Sorrento, Italy, 2001.
4. H. Okada, M. Watanabe, H. Onnagawa, and K. Miyashita, "New gray level control technique and its characterization for antiferroelectric liquid crystal cells", *Jpn. J. Appl. Phys.* **34**, L375–L378 (1995).
5. M. Watanabe, Y. Shimano, H. Okada, and H. Onnagawa, "Optimisation method of memory characteristics in antiferroelectric liquid crystals", *Jpn. J. Appl. Phys.* **36**, 767–772 (1997).
6. R. Hasegawa, H. Fujiwara, H. Nagata, Y. Hara, T. Saishu, R. Fukushima, M. Akiyama, H. Okumura, and K. Takatoh, "A 15-in XGA thresholdless antiferroelectric LCD addressed by TFTs and using the quasi-DC driving method", *J. Soc. Inform. Display* **9**, 107–113 (2001).

# Recent publications of OSA

**Handbook of Optics**, *Second Edition*
CD-ROM
**Michael Bass**, *Editor-in-Chief*
**Eric W. Van Stryland, David R. Williams, William L. Wolfe**, *Associate Editors*

This CD-ROM contains material from the most comprehensive optics reference ever published – the 3,500-page, two-volume set of the print-published Handbook of Optics, Second Edition. Prepared by over 100 specialists in the field, this CD-ROM presents basic concepts of optics as well as necessary practical material on components, devices, and materials needed to deal with almost any problem or process in optics. Packed with vivid illustrations and a wealth of data, this handbook provides not only exhaustive reference materials, but also tutorial guidance in every topic area. Users can search, view, and print information as well as import sections into any Windows-compatible word-processor. For PC use only. Nonmembers must order directly from McGraw-Hill..

Price: List – $149.00 Member – $110.00

**Optical Networking**
**Collected Papers of the International Conferences on Optical Fiber Sensors (OFS), 1983–1997**
CD-ROM

Contains the complete contents of the OFS conference series, including post-deadline papers, totaling approximately 5,500 pages of technical content. Papers are searchable by author and keywords in title. Full-text searching can also be done using the Adobe Search interface. Users can browse the full table of contents for each OFS volume, which provides hyperlinks from the paper title to the PDF file containing the complete text.

*Co-published by SPIE, OSA, and lEEE/LEOS.*

1998, ISBN: 0-8194-3044-7

Price: List-$115.00 Member – $85.00

**Handbook of Applied Photometry**
**Casimer DeCusatis**, *Editor*

Photometry is the branch of science that deals with the measurement of light. It is usually viewed as a subset of the broader field of radiometry, which also includes the measurement of radiation outside the visible spectrum. Much of our information about the world comes to us through light, and the observation or detection of light is perhaps one of the most fundamental processes in nature. Fundamental questions, whose answers require photometric measurements cut across many different disciplines, are discussed in this handbook.

1997, ISBN: 1-56396-416-3

Price: List – $90.00 Member – $65.00

**Introduction to Surface Roughness and Scattering, Second Edition**
**Jean M. Bennett and Lars Mattsson**, *Authors*

This acclaimed tutorial is a total reference guide for everyone who works with optics. The type of scattering is classical scattering, not inelastic such as Raman scattering. New sections include: using scanning probe microscopes, correlation methods for rougher surfaces, surface profile measurements, and scattering theories for rougher surfaces. Also, the section on area topography measurements has been completely rewritten and the instruments described are now current.

1999, ISBN: 1-55752-609-5

Price: List – $55.00 Member – $35.00

**ISO 9211 Optics and Optical Instruments – Optical Coatings: A User's Guide**
**Rudolf Hartmann**

The International Standards Organization's 9211 Optical Coating Standard took into account a variety of existing national, military, and commercial standards and practices of defining and specifying coatings. The ISO standard has become general for the international optical community. It provides an appreciation of the details necessary to specify optical coatings. The chapters of this guide are written to correspond with each part of the Standard. ISO 921's definitions, categories and standards in the areas of coatings, imperfections, optical properties, environmental durability and specific test methods, and compared with ANSI, MIL-STD, German and British specifications.

1996, ISBN: 1-55752-462-9

Price: List – $39.00 Member – $28.00

 