

ALCOM Update

NSF Science and Technology Center for Advanced Liquid Crystalline Optical Materials

Consortium of Kent, Case Western Reserve, and Akron

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DECEMBER 1997

Diverse ALCOM education program reaches all ages

The Education Outreach program efforts continue to be wide ranging, reaching a variety of diverse groups, from girl scouts to business professional and retirees. The efforts focus on two key areas: university post-graduate education in the field of liquid crystals and science and mathematics education at the K-12 level.

K-12 Education

The Education Project participates in direct outreach support for teachers and K-12 educational institutions in the form of visits to schools and museums and workshops for students and teachers. A total of 1,315 students and teachers participated in these programs over the past year. As part of the Creative Connections Summer Program at KSU, a week-long course on the science of liquid crystals was offered (see *ALCOM Update*, Sept. 1997).

The ALCOM K-12 Educational Program has been working in conjunction with the Great Lakes Science Center of Cleveland to bring liquid crystal science to the general public. With the help of Max Godfrey, the Education Program Coordina-



Dr. Max Godfrey involves students in demonstrating the physics of liquid crystals during a school visit.

tor, the Science Center redesigned its PDLC window display. The museum and the Educational Program are incorporating PDLC construction into the "Material's Bar" hands-on program at the museum, and are exploring the possibility of creating an educational display demonstrating the science of liquid crystals.

Chemical Physics Graduate Program

The Chemical Physics Interdisciplinary Program at Kent State University is in its fourth year and has grown to include 22 doctoral students. Students conduct their own seminars and present their research projects and results to other students.

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Joint JLCS/ALCOM symposium held

Tokyo was the site of the first Japanese Liquid Crystal Society/ALCOM Joint Symposium held November 17. Approximately fifty university and industrial researchers were in attendance for the half-day meeting that featured six presentations and a roundtable discussion. ALCOM was represented by professors Lavrentovich and Kelly (KSU).

As the keynote speaker, Prof. S. Kobayashi described a photopolymer stabilized FLC display and presented recent results on photoalignment. Other speakers

were Prof. Y. B. Kim from the Kon Kuk University (Surface Morphology of Rubbed Polyimide), Prof. Y. Iimura from Tokyo University (Dichroic STN Displays), Dr. H. Takatsu from Dainippon Ink (UV-Curable Liquid Crystals), Prof. Lavrentovich (Light Induced Instabilities in Liquid Crystals), and Prof. Kelly (Dynamics of TNs).

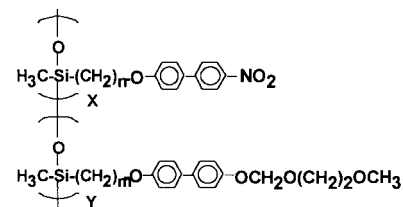
The consensus was that the forum for exchange between ALCOM and the JLCS was very useful and should be continued but a more centrally located site such as Hawaii might bolster participation.

RESEARCH NOTES

Polar Ultra-thin Film for Nonlinear Optical Applications

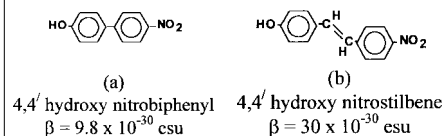
T. Srikkhirin, O. Ostroverkhova, D.E. Schuele, K.D. Singer, J.A. Mann, Jr., and J.B. Lando, Case Western Reserve University

We report dynamical studies of the ultra thin Langmuir Blodgett films of a side chain polysiloxane copolymer.



Where $m=n=11, 10, 5,$ and 4

Preparation of a low loss polar ultra thin film of the above copolymer having an order parameter close to 1 was successfully prepared by the Langmuir Blodgett technique. Chromophores used in sidechains are



The dynamics of polar ultra-thin Langmuir Blodgett films of the above materials are revealed through our dielectric study. The effect of the spacer length, copolymer composition and chromophore type were investigated. We found that copolymers with long spacer lengths (10 and 11) exhibited two relaxation processes. The first process is at about room temperature and is only observed in the initial temperature cycle. The second process occurs at a temperature close to the K-LC transition in the bulk. The second process shows an activation energy of about 180-200kJ/mol. The shorter spacer length, Cop5, does not exhibit the initial peak. It shows only the

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FROM THE DIRECTOR

A successful year for ALCOM

by John L. West

1997 has been a successful year for ALCOM. Following a two-day site visit in June, the NSF has committed full funding for ALCOM through 2001. The Ohio Board of Regents and the Ohio Department of Development continue their strong support of the Center, pledging \$3M for equipment and \$365K/year for ALCOM outreach programs, respectively.

The LCI dedicated its new building in June and construction of the new clean room was completed in October. ALCOM published over ninety papers, was granted three patents and filed five patent applications. ALCOM joined with the Japanese Liquid Crystal Society to hold our first joint symposium in November followed by the symposium on *Reflective Displays* in December.

In 1997, AlphaMicron, Corning, Lumex, and S-VISION joined the ALCOM Industrial Partnership Program, bringing the total num-

ber of active members to 31. We are particularly proud of the new companies, AlphaMicron and S-VISION, established in Northeast Ohio because of ALCOM. The education outreach programs have been cited as models by the NSF Board and the on-line *Polymers and Liquid Crystals* tutorial has received national acclaim.

In 1998 ALCOM will build on its success and look to the future. With the annual retreat in January, we will begin to plan beyond 2001 and identify ways of continuing ALCOM. We plan to build on our strengths in liquid crystals, polymers and displays, and the strong collaboration between Kent, Case and Akron. We will rely on the advice, guidance, and support of the industrial partners to set a course that will maintain our leadership in liquid crystals, keep us at the forefront of basic and applied research, and continue to provide unique educational opportunities. I look forward to working together to continue our success.

ALCOM symposium on Reflective Displays held

A two-day symposium on *Reflective Displays* was held December 11-12 in Cuyahoga Falls, Ohio, attracting over 150 participants.

Invited speakers were S.T. Wu (Hughes Research) who spoke on *Reflective TFT TN Displays*; K.H. Yang (IBM), *Nematic LC Modes and LC Phase Gratings for Reflective Projection Displays*; Y. Iimura (Tokyo University), *Dichroic Dye Liquid Crystal Reflective Displays*; D.L. Wortman (3M Company), *A Recent Advance in Reflective Po-*

larizer Technology; T. Sonehara (Seiko Epson), *Internal Reflective Inverted Scattering (IRIS) Color LCDs*; H. Yuan (dpiX, A Xerox Co.), *Holographic PDLC Reflective Displays*; N.K. Sheridan (Xerox PARC), *The Gyricon Rotating Ball Display*; D. Davis (Kent Displays), *Multicolor High-Resolution Reflective Cholesteric Displays*; and R.B. Akins (Motorola), *Consumer Requirements for Reflective Displays*.

Speakers reviewed most of the liquid

SYMPOSIUM, continued on page 8

crystals, and liquid crystal displays.

The site is being accessed for self-study by students and for preparation of research projects and laboratory work. Middle and high school teachers are requesting copies of the CD ROM for classroom presentations.

The site is receiving 20,000-30,000 hits per month. Comments from viewers include requests for more detailed information. As a result, more references will be added.

"We are being complimented as an excellent example of the kind of web site these viewers had hoped would grow on the web," said CWRU Professor Bill Gordon.

"Judging by the comments from people in academic settings, the tutorial seems

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ALCOM

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Consortium of Kent, Case Western Reserve and Akron

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Associate Director - J.L. Koenig

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J.L. Koenig, J.B. Lando, J.A. Mann,
R.G. Petschek, C. Rosenblatt, D.E. Schuele,
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Summer Undergraduate Research

ALCOM sponsored 26 undergraduate students during the summer to conduct research with principal investigators from all three universities. This program is also used as a means of attracting students to pursue graduate careers in science.

On-Line Tutorial (<http://plc.cwru.edu>)

The on-line Polymers and Liquid Crystals (PLC) tutorial developed at CWRU is continuing to attract praise and attention. The tutorial was developed as a web based multimedia textbook providing a basic introduction at the college freshman level to the fields of polymers, liquid crystals, polymer liquid

PRINCIPAL INVESTIGATORS



DAVID W. ALLENDER (KSU)

Allender received his Ph.D. (1975) in Physics from the University of Illinois. He joined the Kent Physics faculty and the Liquid Crystal Institute research staff in 1975. His contributions to the ALCOM theoretical component concern modulation and instabilities, surfaces and linear/nonlinear optical properties. He is a member of the Operations Committee.

LAURA M. BARTOLO (KSU)

Bartolo received her Master of Information and Library Science (1979) from the State University of New York at Buffalo. She joined the Kent Library and Media Services faculty in 1992. Her work in ALCOM focuses on information management and technology.



PHILIP J. BOS (KSU)

Bos received his Ph.D. (1978) in Physics from Kent State University. He is a member of the Chemical Physics graduate faculty. At the Liquid Crystal Institute he specializes in applications of liquid crystals. He serves ALCOM as director of the Industrial Partnership Program.

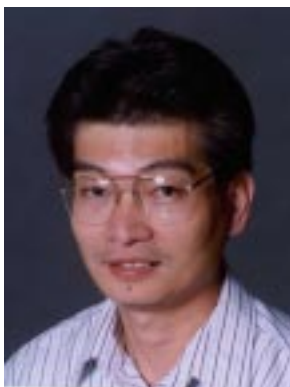
STEPHEN Z.D. CHENG (UA)

Cheng received his Ph.D. (1985) in Polymer Science from Rensselaer Polytechnic Institute. He is a professor in the Department of Polymer Science at the University of Akron. His contribution to ALCOM is physical characterization of liquid crystalline polymer structures.



LIANG-CHY CHIEN (KSU)

Chien received his Ph.D. (1988) in Polymer Chemistry from the University of Southern Mississippi. He is a member of the Chemical Physics graduate faculty within the Liquid Crystal Institute. His contributions to ALCOM include preparation and characterization of liquid crystal materials and polymer stabilized liquid crystals and devices.



PUBLICATIONS

"Monte Carlo Simulations of Stable Point Defects in Hybrid Nematic Films," C. Chiccoli, O.D. Lavrentovich, P. Pasini, C. Zannoni, *Phys. Rev. Letters* **79**, 4401-4404 (1997).

"Cholesteric Gratings with Field-Controlled Period," D. Subacius, S.V. Shiyankovskii, P. Bos, O.D. Lavrentovich, *App. Phys. Lett.* **71**, 3323-3325 (1997).

"X-Ray Scattering Study of a Smectic-A Liquid Crystal Partially Confined Between Free Surface and Microgrooved Substrates," Y. Shi, L.J. Martinez-Miranda, S. Kumar, *Mol. Cryst. Liq. Cryst.* **301**, 73-78 (1997).

"Surface Anchoring Solitary Waves in Antiferroelectric Liquid Crystals," Y.-K. Yu, X.Y. Wang, P.L. Taylor, *Mol. Cryst. Liq. Cryst.* **301**, 177-182 (1997).

"The Effect of Polymer Networks on the Electro-Distortional Characteristics of Nematic Liquid Crystals," J. Li, J.E. Anderson, C.D. Hoke, T. Nose, J.P. Bos, *Mol. Cryst. Liq. Cryst.* **301**, 261-266 (1997).

"Monitoring of Photopolymerization through Dielectric Spectroscopy," D. Schuele, R. Renner, D. Coleman, *Mol. Cryst. Liq. Cryst.* **299**, 343-352 (1997).

PUBLICATIONS. continued on page 5

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appropriate to the instructional level we are aiming at," commented Gordon.

ALCOM Education Website

A Silicon Graphics workstation was added as a server for the website. The workstation provides the foundation for the project's developments on the Internet.

The web project also provides an innovative use of web technology as an educational resource. Based on the Online Experiment pilot project (<http://olbers.kent.edu/alcomed/Experiment/eo.html>), the project incorporates different online experiments with new hierarchically-based hypertext resources and existing mail-out demonstration kits to create a distance education laboratory tutorial on liquid crystals.

Ask-a-Scientist

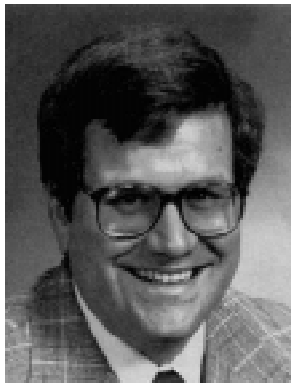
The Ask-A-Scientist program was converted from an email-based answer service to a web-based discussion board, allowing the viewer easier and wider access to the question and answer dialogue between participants and scientists.

INVESTIGATORS, continued on page 4



PAUL FARRELL (KSU)

Farrell received his Ph.D. (1983) in Numerical Computation and Analysis from Trinity College, Dublin. He joined the Mathematics and Computer Science faculty in 1985. His contributions to ALCOM include scientific visualization and parallel and distributed computational methods for the simulation of liquid crystal materials.



MICHAEL FISCH (JCU)

Fisch received his Ph.D. (1981) in Applied Physics from Harvard University. He joined the Department of Physics at John Carroll University in 1985. His ALCOM research focuses on the optics of liquid crystals and complex fluids.



JULIA E. FULGHUM (KSU)

Fulghum received her Ph.D. (1987) in Chemistry from the University of North Carolina. She joined the Kent Chemistry faculty in 1989. Her work in ALCOM focuses on surfaces and alignment layers using X-ray photoelectron spectroscopy.



WILLIAM L. GORDON (CWRU)

Gordon received his Ph.D. (1954) from The Ohio State University. He joined the Case Western Reserve University Physics faculty in 1955. He is involved in the ALCOM Educational Outreach Program through work on the World Wide Web based multimedia textbook "Polymers and Liquid Crystals."



FRANK W. HARRIS (UA)

Harris received his Ph.D. in Organic Chemistry (1968) from the University of Iowa. He joined the University of Akron faculty in 1983 as a professor of Polymer Science. Dr. Harris contributes his expertise in polymerization and structure/property relationships in liquid crystal polymers to ALCOM and serves as Akron's representative on the Operations Committee. He is co-director of the New Materials and Effects project.

DANIELE FINOTELLO (KSU)

Finotello received his Ph.D. (1985) in Physics from the State University of New York at Buffalo. He joined the Kent Physics faculty in 1988. A member of the Liquid Crystal Institute, his research under the ALCOM program concerns liquid crystal phase transitions in restricted geometries using high resolution AC calorimetry, and studies of liquid crystal orientational order using deuterium NMR.



EUGENE C. GARTLAND, JR. (KSU)

Gartland received his Ph.D. (1980) in Applied Mathematics from Purdue University. He joined the Kent Mathematics/Computer Science faculty in 1987. His contribution to the ALCOM theoretical program is the application of numerical computational methods in the simulation of liquid crystal materials under confinement.



STEVEN HUDSON (CWRU)

Hudson received his Ph.D. (1990) in Polymer Science and Engineering from the University of Massachusetts, Amherst. He joined the Macromolecular Science faculty at CWRU in 1993. His research involves the morphology of polymer/liquid crystal composites by optical and electron microscopies and he has developed a simple model that predicts their structure. He is co-director of the Heterogeneous Structures project.



ALEXANDER JAMIESON (CWRU)

Jamieson received his Ph.D. (1969) in Physical Chemistry from Oxford University. He is Professor and Chair of the Case Western Reserve University Macromolecular Science Department. His studies in the ALCOM center are on light-scattering and viscoelastic properties.



JACK R. KELLY (KSU)

Kelly received his Ph.D. (1979) in Physics from Clarkson University. He joined the Liquid Crystal Institute staff in 1988. He is an associate professor in the Chemical Physics graduate program within the LCI. His contributions to ALCOM include display devices and physical properties of liquid crystals. He serves on the Operations Committee and as co-director of the project on Device Modeling and Applications.



JACK L. KOENIG (CWRU)

Koenig received his Ph.D. (1959) in Physical Chemistry from the University of Nebraska. He joined the CWRU faculty in 1963. He is the J. Donnell Institute professor in the Macromolecular Science Department and director of the NMR laboratory. His ALCOM contributions include NMR and FTIR analysis of polymer/liquid crystal blends. He has been active in the development of the educational polymer tutorial web site. He serves as associate director of ALCOM and is a member of the Operations Committee.



SATYENDRA KUMAR (KSU)

Kumar received his Ph.D. (1981) in Solid-State Physics from the University of Illinois. He joined the Kent Physics faculty in 1987. He is a member of the Liquid Crystal Institute and also holds a joint appointment as Professor in the Chemical Physics Interdisciplinary Program. His basic research in the ALCOM program centers on structure and phase transition studies using microcalorimetry, atomic force microscopy, X-ray diffraction, and small angle neutron scattering. His group's applied research focuses on applications of ferroelectric liquid crystals and liquid crystal alignment layers.



THIEN KYU (UA)

Kyu received his Ph.D. (1980) in Polymer Chemistry from Kyoto University, Japan. He joined the Polymer Engineering faculty at the University of Akron in 1983. His specialities in the ALCOM program are thermodynamics and kinetics of electro-optical polymer blends and dispersions.



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K-LC transition with a higher activation energy of about 900kJ/mol.

Increasing nitrobiphenyl composition in the copolymer, spacer 11, does not effect the observed activation energy of the K-LC transition; however, the relaxation for a given frequency is observed at a lower temperature.

The copolymer with the nitrostilbene chromophore shows a greater change in ϵ' and ϵ'' in going through the K-LC transition than in the nitrobiphenyl. This is probably related to the larger polarizability of the nitrostilbene which could result in a higher permanent dipole. The measurement of the second order nonlinear optical response is currently under investigation.

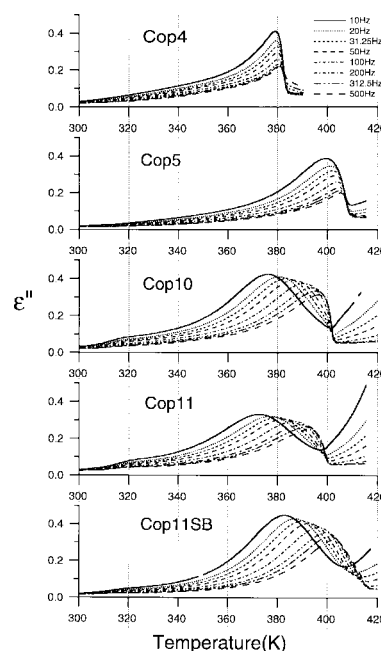


Figure 1 ϵ'' of Cop 4,5,10,11 and 11SB from 10Hz-500Hz.

PUBLICATIONS, from page 3

"A Comparative Structural Study of Three Prospective Longitudinal Ferroelectric Smectic Liquid Crystals," Y. Shi, J.T. Mang, S. Kumar, E.T. Samulski, *Mol. Cryst. Liq. Cryst.* **302**, 47-55 (1997).

"Stable Configurations in Hybrid Nematic Cells in Relation to Thickness and Surface Order," H.G. Galabova, N. Kothekar, D.W. Allender, *Liq. Cryst.* **23**, 803-811 (1997).

"The Effect of Chirality on the Phase Transitions of Chiral/8CB Mixtures," G.S. Iannacchione, S. Qian, M. Wittebrood, D. Finotello, *Mol. Cryst. Liq. Cryst.* **302**, 1-11 (1997).

PRINCIPAL INVESTIGATORS



JEROME B. LANDO (CWRU)

Lando received his Ph.D. (1963) in Physical Chemistry from the Polytechnic Institute of Brooklyn. He joined the Case Western Reserve University Macromolecular Science faculty in 1965. His expertise in the ALCOM program is Langmuir-Blodgett films.



OLEG D. LAVRENTOVICH (KSU)

Lavrentovich received his Ph.D. (1984) in Physics and Mathematics from the Ukrainian Academy of Sciences. He joined the Liquid Crystal Institute research staff in 1992 and the Chemical Physics graduate faculty in 1994. His ALCOM research includes the study of field effects, defects and pattern formation. He is co-director of the Alignment and Surface Induced Phenomena project.

J. ADIN MANN (CWRU)

Mann received his Ph.D. (1962) in Physical Chemistry from Iowa State University. He joined the CWRU Chemical Engineering faculty in 1974. His work in the ALCOM program concerns planar liquid crystal/substrate interfaces.



MARY E. NEUBERT (KSU)

Neubert received her Ph.D. (1968) in Chemistry from the University of Rochester. A senior research fellow in the Liquid Crystal Institute, she is director of the Organic Synthesis Group. Her contributions to ALCOM include synthesis of low-molecular-weight liquid crystals, study of structure/property relationships, and microscopic texture identification.



PETER PALFFY-MUHORAY (KSU)

Palffy-Muhoray received his Ph.D. (1977) in Physics from the University of British Columbia. He joined the LCI staff in 1987. He is Professor of Chemical Physics and LCI Associate Director for basic research. He is the ALCOM Education Program Director and Operations Committee member. His areas of expertise include nonlinear optics, pattern formation, and nonequilibrium phenomena in liquid crystals. He is co-director of the Heterogeneous Structures and Optical Switching and Storage projects.



ROLFE PETSCHKE (CWRU)

Petschek received his Ph.D. (1981) in Physics from Harvard University. He joined the Case Western Reserve University Physics faculty in 1983. His specialities in ALCOM are the relationship between chemical structures and material properties, linear and non-linear optics, and phase sequences and structures. He serves as co-director of the New Materials and Effects project.

CHARLES ROSENBLATT (CWRU)

Rosenblatt received his Ph.D. (1978) from Harvard University. He joined the CWRU Physics faculty in 1987. His ALCOM contributions include studies of phase transitions, magnetic and electric field effects, and surface phenomena. He is a member of the ALCOM Operations Committee and co-director of the Alignment and Surface Induced Phenomena project.



ARDEN RUTTAN (KSU)

Ruttan received his Ph. D. (1977) in Numerical Analysis from Kent State University. He joined the Department of Mathematics and Computer Science in 1983 where he is an professor of computer science. His work in ALCOM focuses on developing distributed computer environments for liquid crystal computations.



PRINCIPAL INVESTIGATORS



DOANLD E. SCHUELE (CWRU)

Schuele received his Ph.D. (1962) in Physics from Case Institute of Technology (now CWRU). He joined the Physics faculty where he holds the Albert A. Michelson Chair. His contributions to ALCOM include dielectric studies of polymer liquid crystals, polymer dispersed liquid crystal systems, photo-polymerization, electro-optic films and Langmuir-Blodgett films.



KENNETH D. SINGER (CWRU)

Singer received his Ph.D. (1981) from the University of Pennsylvania. He joined the CWRU Physics faculty in 1990. His specialty area is in nonlinear optical measurements, materials, and devices. He is co-director of the Optical Switching and Storage project.

SAMUEL SPRUNT (KSU)

Sprunt received his Ph.D. (1989) in Physics from the Massachusetts Institute of Technology. He joined the Kent State Physics faculty in 1995. His ALCOM research focuses on optical studies of structure and dynamics in chiral liquid crystals and liquid crystal/polymer composites.



PHILIP L. TAYLOR (CWRU)

Taylor received his Ph.D. (1962) in Physics from Cambridge University. He joined the Case Western Reserve University Physics faculty in 1964. His theoretical work in the ALCOM program addresses structure and finite-size effects.



ROBERT TWIEG (KSU)

Twieg received his Ph.D. (1975) in Chemistry from the University of California at Berkeley. He joined the Chemistry Department and LCI at Kent in 1997. His work currently involves the design and synthesis of molecules and polymers with novel electronic and optical properties, including liquid crystals and nonlinear optical and photorefractive chromophores.



SHI-QING WANG (CWRU)

Wang received his Ph.D. (1987) in Physics from the University of Chicago. He joined the faculties of Macromolecular Science and Physics at Case Western Reserve University in 1989. His research interests are polymer dynamics and rheology in single and multiphase systems. ALCOM work includes dynamics of polymer-liquid crystal phase separation using IR spectroscopy.

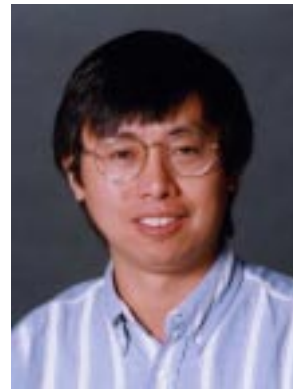
JOHN L. WEST (KSU)

West received his Ph.D. (1980) in Physical Chemistry from Carnegie Mellon University. He joined the LCI staff in 1984. He serves as director of the Liquid Crystal Institute and ALCOM. His research in the ALCOM Center concentrates on PDLC materials and electro-optical devices.



DENG-KE YANG (KSU)

Yang received his Ph.D. (1989) in Physics from University of Hawaii. He is a member of the Chemical Physics graduate faculty within the Liquid Crystal Institute. His specialities in ALCOM are cholesteric liquid crystals, liquid crystal/polymer composites and electro-optic devices. He is co-director of the project on Device Modeling and Applications.



crystal reflective displays and presented their current research results.

"The talks were very interesting and stimulating. Overall the symposium was very successful," reported D.K. Yang (KSU) who co-chaired the symposium with Steve Hudson (CWRU).

A poster session was held with 35 posters presented on reflective displays and other liquid crystal topics. J.W. Doane (Kent Displays) spoke at the banquet on *Cholesteric Reflective Displays: Present and Future*.

A forum comprised of invited speakers capped the program and provided an opportunity for the audience to ask questions of the panel.

DEGREES AND APPOINTMENTS

Timothy Doerr, Ph.D. 1997, Case Western Reserve University. Thesis: "The Mechanics of Complex Molecules." Doerr is the first person ever to perform molecular modeling calculations at an atomic level to study the anchoring of liquid crystals at a polymer surface.

Yoshimasa Ono, former postdoc of Philip Taylor (CWRU), has been appointed Senior Research Scientist at Hitachi Advanced Research Labs where he is engaged in research on liquid-crystal and electroluminescent displays. He is the author of the recently published book, *Electroluminescent Displays*, which forms Volume 1 of the World Scientific Series on Information Displays.

CALENDAR

ALCOM Retreat, Jan. 7-9, 1998
Glenmoor Country Club, Canton, Ohio

NATO Advanced Study Institute on Advances in the Computer Simulation of Liquid Crystals, June 11-21, 1998, Erice, Italy. Held at the Center for Scientific Culture, "Ettore Maiorana," in Erice, a small town in Sicily in the south of Italy. <http://boh03.bo.infn.it/sicl/erice98/index.html>

17th International LC Conference
July 19-24, 1998, Strasbourg, France

4th Liquid Matter Conference
July 3-7, 1999, Univ. of Granada, Spain
<http://www.ugr.es/~liquid99>

Web Sites

ALCOM Home Page

<http://alcom.kent.edu/ALCOM/ALCOM.html>

Liquid Crystal Institute, KSU

<http://www.lci.kent.edu>

Dept. Macromolecular Science, CWRU

<http://k2.scl.cwr.edu/cse/emacs/>

Department of Physics, CWRU

<http://cwsing.phys.cwr.edu/phys/physdept.html>

Polymer Science, University of Akron

<http://www.polymer.uakron.edu/>

On-Line Polymer Liquid Crystal Tutorial

<http://plc.cwr.edu>

Experiment at a Distance

<http://olbers.kent.edu/alcomed/Experiment/eo.html>

Optics of Cholesteric Liquid Crystals

<http://alcom.kent.edu/~tik/choles.html>

ALCOM Education Home Page

<http://olbers.kent.edu/alcomed/k12.html>



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