Center on Materials and Devices for Information Technology Research

Annual Report

August 1, 2002 – July 31, 2003

STC Annual Report

I. GENERAL INFORMATION

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Executive Summary:

The National Science Foundation (NSF) Science & Technology Center (STC) on Materials & Devices for Information Technology Research (MDITR) hit the ground running upon receipt of funding in late October 2002 (with an August 1, 2002 start date). The immediate objective of the Center Management was (1) to implement the Cooperative Agreement securing an effective and dynamic management structure and (2) to implement the Strategic Plan by moving forward toward the vision of the Center which is "to become a national research and education resource for the photonic and information technology communities by providing innovative solutions to the ever-changing challenges that the information technology industry and the broader society will experience in the next decades." The immediate objective has been accomplished through the implementation of an effective intra-center communication system that initially involved weekly meetings with telephone conference calls with the management team and more recently weekly videoconferencing meetings. The viability of the management structure is evident from the fact that it has responded effectively to challenges associated with participants changing professional affiliations and to the changing economic climate that influences industrial interactions, has promoted collaborative research that has achieved significant scientific and technological advances toward realization of five year goals, has launched key educational activities (including web module development and educational workshops), and has succeeded in satisfying the key components of the Cooperative Agreement.

With respect to the Cooperative Agreement, a full time Manager of Center Administration (Karen Monteiro) has been hired as well as a full time Director of Education, Human Resource Development and Outreach (EHRDO) (Dr. Jasmine Bryant). All hires are extremely qualified individuals who also are from under-represented groups. A full-time webmaster has been hired at the University of Washington (UW) and a comparable appointment has been made at University of Arizona (UA). To support these key administrators, a part time fiscal specialist and administrative assistant have been added. The Administrative Core, consisting of the above individuals, together with the Executive Committee, has implemented the key communication, statistical information gathering and analysis, and reporting functions. This administrative structure has also demonstrated that it can respond effectively to unanticipated challenges including the anticipated move of four Center participants from UA to Georgia Institute of Technology (GaTech) and challenges of formalizing industrial affiliations associated with intellectual property issues in the current economic climate. Each potential problem has been

turned into an opportunity and the capability of the Center to meet its vision has been enhanced as a consequence.

We will shortly review each of the Center goals stated in the strategic plan and indicate progress toward achieving those goals; however, we would first illustrate that this Center is indeed already successful in achieving highly integrated, interdisciplinary, multi-institutional research and education that is having national impact. As an example we note that the **Theory Thrust (TT)** has implemented quantum and statistical mechanical methods that have led to new paradigms for the design of electro-optic chromophores and their incorporation into nanoscopic material lattices of acentric (ferroelectric) order. Researchers in the **Electro-Optic and All-Optical Materials Thrust (EOAOT)** have used this theoretical guidance to prepare new materials exhibiting electro-optic coefficients of greater than 100 pm/V at all telecommunication wavelengths (a critical step toward meeting five year Center goals in this thrust). New microwave synthesis techniques have been developed that not only enhance reaction yields but also permit isolation of key intermediates associated with the implementation of theoretically suggested paradigms. Other researchers in the EOAOT have implemented new device concepts including all organic ring microresonator devices (motivating support by Intel Corporation of $75K/year), organic/silicon microresonator structures, organic/inorganic photonic bandgap device structures, superprism structures, and voltage controlled coupling structures. These major advances in theory, materials synthesis and processing, and device development involved researchers and students (including extended stay travel exchanges between universities) at UW, Caltech, USC, UA, and Norfolk State University from the disciplines of chemistry, physics, electrical engineering, and material science & engineering. This work has motivated several industrial and Federal laboratory research efforts, e.g., the optical gyro program at China Lake/Redstone Arsenal; and has motivated several new Federal initiatives, e.g., a multi-million dollar Boeing-DARPA effort on chipscale wavelength division multiplexing (CS-WDM) for mobile platforms and a new DARPA molecular photonics (MORPH) Focal Point initiative to be funded under the Chip-to-Chip Optical Interconnect BAA (this funding would involve interaction of STC participants with Lockheed Martin, Photonics Systems, Lumera, and Arizona Microsystems). STC members presented invited lectures in public forums including the Distinguished Lecture Series of the NSF, the Seattle Technology Alliance, and various Federal and industrially-sponsored workshops. The dramatic successes achieved through the unique interactions of this Center argue that the ten-year goals related to electro-optic materials and device development will almost certainly be achieved with significant economic consequence. The successes achieved to-date also illustrate the integrative nature of various research, education, knowledge transfer, and technology transfer activities. Indeed, the research on electro-optic materials correlate with other materials initiatives in the Center; for example, the new DARPA MORPH program focuses on both electro-optic and all-optical materials reflecting the advances that have occurred in both categories.

Below we list the Center goals as stated in our original strategic plan. Following the goals in **boldface** we briefly note the progress that has been made toward the realization of those goals.

- Developing, by rational design that exploits recent advances in quantum and statistical mechanics, transformative new electro-optic materials and devices with enhanced properties including bandwidth, drive voltage, optical loss, power consumption, and stability—**Center goals for material performance have been met or exceeded in every category, new device structures have been demonstrated, a seed project (at University of Maryland Baltimore County) on terahertz generation and detection has been very successful, materials and device concepts are being successfully transitioned to (and indeed are stimulating) Federal and industrial initiatives. Public awareness of this success is**

growing and we are attracting the interest of young people, including those from under-represented groups, in this area of research. The research is being featured in an upcoming special issue of the Journal of Polymer Science on photorefractive and EO materials.

- Enabling all-optical information processing by development of new third-order nonlinear optical materials that offer ultra-fast, large nonlinearities and low loss at telecommunication wavelengths—**Important improvements have been made in the magnitude of third order optical nonlinearities and progress toward five year goals is on track. Already materials have been identified and used to demonstrate a variety of applications ranging from pulse diagnostics for telecommunication to image reconstruction. Our advances have been recognized as critical by DARPA and new DARPA funding is being awarded for our researchers at UW and GaTech. The collaboration between researchers at UW/CalTech/GaTech on incorporating luminescent and third-order materials into optical fibers (Ann Mescher) and photonic bandgap devices (Alex Scherer) may represent a breakthrough relevant not only to information processing but to sensing. These achievements are of interest to Boeing and other companies. A start-up company has been launched by seed project collaborator Professor Charles Spangler of Montana State University.**
- Implementing new infrared light sources, amplifiers, and detectors based on organic and hybrid electroluminescent materials that can be readily integrated into opto-chips—**Progress is on schedule but this was viewed as an objective with anticipated impact occurring in the longer term. A strong interaction has been established between Professor Heeger (UCSB) and researchers at UW and UA with material advances being transitioned to DuPont Displays. Dendritic quinacrione derivatives for organic light emitting diodes and lasers have been synthesized and incorporated into displays. Materials are being incorporated into plastic optical fibers for optically pumped lasers by Ann Mescher and into powdered thin-film AC electroluminescent devices by Durel Corporation.**
- Integrating, seamlessly, materials and devices from the nanoscale to the microscale using self assembly, two-photon photolithography, and reactive ion etching for the low cost production of dense 3D optical and electro-optical circuitry—**Exceptional progress (work by William Steier, Joseph Perry, Axel Scherer, and Amnon Yariv) has been made in a variety of projects in this area. Three dimensional micro-ring resonator WDM transmitter/receiver systems have been fabricated. Both single and double ring resonators have been fabricated and exceptional performance parameters (free spectral range, voltage sensitivity product, finesse) have been demonstrated. A start-up company, Focal Point Microsystems, has been launched to exploit two-photon photolithography.**
- Exploiting photonic bandgap lattices and control of coupling to microresonators to enhance both second (electro-optic) and third-order nonlinear optical device performance—**Exceptional progress (work by Axel Scherer, Younan Xia, William Steier, and Amnon Yariv) has been achieved in theoretically and experimentally exploring microresonator, superprism, and photon bandgap structures. Both all polymer and organic/inorganic (silicon) hybrid device structures have been investigated incorporating both second (electro-optic) and third-order all-optical nonlinear optical materials. A DARPA/Boeing funded exploitation of these advances has been launched and collaborations with Northwestern and Cornell Universities have been initiated. Incorporation of third-order and luminescent materials from UW and UA into Caltech fabricated devices suggest the potential for a new generation of sensors. A start-up company, Luxtera, has been launched to exploit this technology.**

- Producing organic electronic materials and devices that will be processed into low cost circuits—**This is a longer-term objective and important progress has been made in the area of charge transport (one of the benchmarks of STC progress in this and related transport dependent material and device development efforts). For example, a room temperature electron mobility of 10^{-3} cm^2/V has been measured by time of flight experiments in self-assembled columnar discotic liquid crystals based on oxadiazoles (*Langmuir*, in press).**
- Creating cross-disciplinary curricula and educational resource materials that are directly tied to the research function and expertise of this Center and evaluating their impact—**Such educational material development is on track. A web based educational module on refraction is nearing completion in terms of the projected preliminary development phase and will be piloted early this summer. Educational materials have been developed and implemented into a variety of courses at the participating universities, e.g., Chem 560 at UW, and Chem 535 at UA. In addition an ethics handbook for the Center is being created to supplement ethics training courses.**
- Recruiting and tracking, proactively, under-represented minorities and women, into the Center, through seminar programs, internships, fellowships, strategic interactions with the Alliance for Nonlinear Optics, Northern Arizona U., Norfolk State University, and Cal State U. Los Angeles—**This effort is on track. Funding from the American Chemical Society for a Workshop on the Chemistry of Information Technology has been secured. The planning of this workshop (scheduled for June 18-25, 2003) has been completed. In addition, a symposium will be held in June as well. The proceedings from this workshop/conference will be published as a special issue of the *Journal of Physical Chemistry*. Seminars have been presented at designated minority institutions such as Norfolk State University and Florida International University and student participation has been secured in Center workshops and other research/education experiences. Extensive outreach to the K-graduate under-represented minority communities has been initiated coordinating with existing community, state, and Federal programs and institutions.**
- Enabling commercialization of new technology developed within the center by licensing to industry, by tracking developed technology, and by fostering the creation of new spin-off companies—**Three new start-up companies (Luxtera, Focal Point Microsystems, and TPA Technologies) have been launched and interaction with a number of established companies have been initiated. Considerable attention has been given to define improved paradigms for enhanced knowledge and technology transfer. Significant progress has been made despite current economic difficulties and the research of this Center is clearly inspiring new initiatives in Federal and State governments and in American industry.**

No significant changes in plans have been made although adjustments have been made due to external events affecting the Center. These include the anticipated movement of four core faculty (Marder, Perry, Brédas, Kippelen) from UA to GaTech. A subaward will be made to GaTech following completion of negotiations. While negotiations are not yet complete, it is clear that the performance of the Center will be enhanced by this modification and that all matching and intellectual property agreements will be maintained. GaTech's historical national leadership role in the training of minority students will ensure that diversity in the Center will be enhanced. The diversity of participating faculty has also been enhanced by the addition of Michal Lipson (Assistant Professor of Electrical Engineering at Cornell). Michal brings important new material and device concepts to the STC, promotes interaction with the Cornell Nanofabrication Facility, and promotes coordination with DARPA funded technology development.

Delayed funding, evolving NSF management requirements, and new opportunities for the Center have necessitated adjustments. The Center has lost one senior participant (Professor Kalonji who has withdrawn from the STC to focus on other activities) and added Galen Stucky (UCSB) to its team. These changes demonstrate that the Center is able to adapt to ever changing situations to optimize implementation of Center goals. Implementation of an industrial affiliates program is a work in progress. Implications for intellectual property had to be carefully considered at some length and in consultation with the Strategic Advisory Board of the Center. The current economic climate is dramatically impacting corporate decision making processes. Nevertheless, important knowledge and technology transfer is being implemented as is ethics training.

A formal meeting of the Strategic (external) Advisory Board, as well as several informal meetings of working groups of that Board, has been held. The Strategic Advisory Board is fulfilling its role in providing input related to all aspects of the Center and is facilitating contact with important components of the broader community (industry, educational organizations, state government, charitable foundations, and community groups). A second meeting of the SAB is planned to coincide with the June workshop.

From the administrative side, all key administrative positions have been filled after national searches where attention was paid to equal opportunity employment. The Center website has been launched for information dissemination and database management. Formal policies and responsibilities have been defined. Critical training activities have been initiated.

II. **RESEARCH**

Performance and Management Indicators

The performance and management indicators are as indicated in the Strategic Plan. Because the Center has been functioning for such a very short period of time, it is unrealistic to attempt to draw sweeping conclusions concerning performance; however, all indicators would suggest that the Research Component is well ahead of schedule and that the research management structure is functioning effectively. Research successes have attracted national attention and have motivated decisions in both industry and the Federal government. Material and device benchmarks appear to be either met or exceeded; however, because of the very early stage of research and knowledge/transfer of research products, it would seem unwise to revise indicators at this time. The performance benchmarks and management indicators outlined in the Strategic Plan were carefully developed in a consultative manner with participation of STC personnel, the Strategic Advisory Board, industrial input, and input from NSF panels and staff. We are confident that only minor adjustments (if any) are required and these are best considered after the site visit review on July 7-8, 2003.

No problems have been encountered that have impeded progress toward the Center's Research Goals. Indeed, as noted above, progress is either as anticipated or exceeding expectations. For the sake of completeness in this report, we note that the following issues are being addressed during this reporting period.

The anticipated move of Professors Marder, Perry, Brédas, and Kippelen to Georgia Institute of Technology is being actively accommodated. The Center Management Team has been actively involved in assuring that this move does not affect in any negative way the research (or other critical functions) of this Center. Proactive management appears to be turning this event into an important opportunity for the Center to expand its impact in research, education, outreach, knowledge transfer and technology transfer.

The device development efforts involving ring microresonators, superprisms, photonic crystal structures, and controlled critical coupling structures are novel and, as such, critical materials processing issues had not been addressed. These were truly "new" efforts and effective teams of material scientists and device engineers had to be assembled and coordinated into a force that could quickly adapt to specific problems such as materials integration on the nanometer scale. In truth, anticipated problems have been quickly addressed and surprisingly successful results are being realized. Effective exchanges of personnel are occurring between universities and between universities, participating industries, and government laboratories.

While we anticipate future problems (both of scientific and management natures), the resources and management structure of an STC appears to provide a very effective paradigm for dealing with problems that would be much more challenging if encountered in a single investigator format.

THRUSTS

Thrust Name	Organic Electro-Optic and All Optical Switching Materials and Devices
PI Name	Thrust Leader: Alex Jen

Goals and Benchmarks:

The vision in this thrust is to develop "disruptive" E-O and AOS materials and devices for light-weight, low drive voltage, and ultrahigh-speed information processing. This will be achieved through "end-to-end" cross-disciplinary collaboration in theory, material synthesis, processing, and device design and fabrication. The E-O activity of materials will be significantly enhanced through improved poling efficiency of dendrimers that are developed through theory-guided structural design to overcome deleterious inter-chromophore interactions. Five-year goals of the thrust are to: (i) develop materials with high E-O activities (r_{33} > 100 pm/V); (ii) develop traveling wave and resonant E-O devices and processes to increase bandwidths (> 100 GHz-cm) and lower drive voltages (<0.7 V); (iii) demonstrate long-term thermal stability at 85°C and photochemical stability (input power of 20 mW) of the operating devices. Ten-year goals are to (i) further enhance E-O activities (r_{33} > 200 pm/V), increase bandwidths (> 200 GHz-cm), and lower drive voltages (<0.3 V); (ii) scale-up the synthesis of high performance E-O materials; (iii) demonstrate AOS device feasibility; (iv) integrate E-O devices with organic electronic circuitry developed in the Center; and (v) develop highly integrated modules that satisfy the standards of the Telecommunications Industry (Telecordia standards).

Connection of Thrust to STC Goals: This thrust provides a linkage between advanced optical materials and innovative processing techniques to develop powerful new photonic devices.

Industrial Participants: Agilent, Boeing, Corning, DuPont, Intel, IPITEK, Lucent, Lockheed-Martin, Lumera, Motorola.

Activities, Highlights, Outcomes, and Future Plans

(1) Development of Improved Electro-Optic Chromophores: A number of new chromophores have been prepared and evaluated. Paradigms for the systematic improvement of molecular first hyperpolarizability have been identified through effective coordination with the **Theoretical Thrust**. These include the following:

(a) Replacement of methyl groups on the cyanofuran acceptor (of FTC and CLD type chromophores) with one or two trifluromethyl groups leads to factors of 1.5-2.0 improvement in molecular hyperpolarizability (β).

(b) Replacement of one or two cyano groups of the cyanofuran acceptor with strong acceptor groups like nitro groups or the sulfonyl trifluromethyl groups leads to factors of two improvements in molecular first hyperpolarizability. These observations suggest the paradigm of mixed ligand acceptors for improving beta.

(c) Development of gradient bridge structures (containing a thiophene moiety on the electron donor half of the bridge and a thiazole moiety on the electron acceptor half of the bridge) leads to improved molecular first hyperpolarizability.

(d) Development of new acceptors (e.g., replacement of the methylene ether moiety of the cyanofuran acceptor with an amide moiety) leads to significant improvement of molecular first hyperpolarizability.

(e) Preliminary success has been realized in developing new donor segments.

Individually the above advances have already led to record electro-optic activity with coefficients greater than 100 pm/V (100-130 pm/V) realized at both 1.3 and 1.55 microns telecommunication wavelengths. These values are 3-4 times greater than those of lithium niobate. When implemented together, these theoretically inspired chromophore modifications may lead to still further improvement in molecular first hyperpolarizability. Long-term stability at 85°C has been demonstrated for these chromophores in a high glass transition polyquinoline (PQ-100) host polymer. Future research will focus on combining the above-mentioned strategies together with synthesizing, in some cases, longer versions of the above chromophores. This activity should lead to further improvements in molecular first hyperpolarizability. Chromophores will be incorporated into a variety of hardened lattice structures (see below) and the resulting materials will be transitioned to device prototyping after synthetic production has been optimized.

(2) Development of New Synthetic Methodology Including Microwave Synthesis Techniques: A number of synthetic reaction scheme improvements have been realized by **Jen** and **Dalton** that increase the yield in the synthesis of electro-optic chromophores; however, the most important general advance in the synthetic area has involved the application of microwave synthesis techniques. Microwave synthesis has permitted dramatic improvements in reaction yields and the shortening of reaction times for a number of coupling, protection/deprotection, etc. reactions central to the preparation of electro-optic chromophores. Moreover, microwave-assisted synthesis techniques have permitted, for the first time, isolation of the key imine intermediate crucial to the synthesis of mixed ligand acceptor chromophores. The outcome has been the production of chromophores exhibiting record hyperpolarizability. Future plans call for increased utilization of microwave synthesis and ultimately translating the capability to scale-up conditions. Commercial suppliers of microwave synthetic equipment have become very interested in our success; support both for research and educational purposes may become available from these suppliers.

(3) Development of New Capabilities for Improved Measurement of Beta: The STC currently houses perhaps the only remaining active HyperRayleigh Scattering (HRS) measurement facility available for the characterization of molecular first hyperpolarizability. This facility has been upgraded and is being modified for wavelength agile measurement capability in the infrared (0.7-2.5 microns) by **Reid** and **Dalton**. Previous facilities typically permitted measurement only at one fixed wavelength such as 1.06 microns. Our new instrumentation has been utilized for hyperpolarizability measurements on the chromophores synthesized by researchers of this STC. Measurements have also identified problems with values determined for traditional reference standards and an attempt is being made to obtain improved values for commonly used reference standards. The basis of the improved capability is the fundamental advance in laser, detector, and parametric amplifier components realized over the past five years. This facility will likely become a national resource for the characterization of molecular first hyperpolarizability. Future work calls for affecting measurement of chromophores synthesized so as to understand factors contributing to both molecular hyperpolarizability and the translation of that hyperpolarizability to macroscopic electro-optic activity. Beta must be known if order parameters are to be defined from macroscopic electro-optic activity coefficients. Future plans call for complementing HRS measurements with other related measurements.

(4) Synthesis of Electro-Optic Dendrimers and Dendronized Polymers: A variety of electro-optic chromophores containing dendrimers and dendronized polymers have been prepared by **Jen** and **Dalton** that lead to significant (e.g., factors of 2 or 3) improvements in electro-optic activity compared to the same chromophores existing in chromophores/polymer composite materials. Values of over 100 pm/V have been achieved even for chromophores available at the start of this STC. Such materials have also been found to lead to improved optical transparency (reduced optical loss) and to improved stability (both thermal and photochemical). Important integrated activities between nanometer scale materials synthesis and processing and the statistical mechanical calculations of the Theory Thrust have resulted in dramatic improvements in ferroelectric chromophore order (acentric order parameters). A great breakthrough in the realization of ferroelectric order for nanostructured materials are being achieved that could ultimately lead to electro-optic materials exhibiting activity of many hundreds of picometers/volt. Future work will focus on (1) exploring new supramolecular material architectures (working with

theorists of the Theory Thrust) with the aim of increasing acentric order parameters and perhaps even achieving perfect ferroelectric order and (2) incorporating new and improved chromophores into currently identified dendrimer and dendronized polymer architectures. The new integrated theory/synthesis team effort would seem a sure-fire approach to the realization of five-year objectives. As particularly successful architectures are identified consideration will be given to optimizing the chemistries leading to those materials and to the scale up of the reactions. Of course, new materials will be transitioned to device efforts and there will clearly be pressure for accelerating this process for new DARPA/NRO/MDA device programs.

(5) Development of Hardened Electro-Optic Materials: A variety of new lattice hardening (crosslinking) schemes have been developed by **Jen** group including protocols based on reaction of trifluorovinyl ether moieties for forming perfluorocyclobutane bridged polymers and based on the reverse Diels-Alder reaction. These protocols have led to hardened materials with thermal stability (assessed by the dynamic assay method) on the order of 200°C and have led to materials characterized by low optical loss. The outcome of this effort is the production of materials that appear to meet Telacordia standards. Future research will involve utilizing these protocols with new and improved chromophores and with new nanostructured material components (dendrimers and dendronized polymers).

(6) Exploration of Photochemical Stability: Singlet oxygen scavengers were shown to significantly enhance the photochemical stability of organic electro-optic materials. The addition of these materials to composite materials produces some plasticization of the polymer lattice. This plasticization facilitates oxygen diffusion and leads to accelerated photochemical decomposition of chromophores once the scavengers are consumed. Simple packaging to reduce oxygen exposure, together with the use of small concentrations of scavengers by **Dalton** and **Steier** groups, leads to dramatic enhancement of photochemical stability. The outcome of various accelerated studies of photochemical instability is the identification of several paradigms for dramatically improving photochemical stability of electro-optic materials and certainly improving materials to the point of adequate stability for commercial application. Future work will involve the combination of various identified methods of improvement (use of singlet oxygen quenchers, lattice hardening, chromophore modification including the use of steric protection of reactive sites) by **Dalton** and **Jen**. Knowledge gained will be applied to the utilization of new and improved chromophore materials.

(7) Investigation of Optical Loss: A number of studies of optical loss associated with absorption and scattering mechanisms were carried out by **Jen** and **Dalton** in a variety of collaborative studies both within the STC and external to the STC (e.g., photothermal deflection measurements on electro-optic materials produced within the STC but carried out by **Barto** at Lockheed Martin, Palo Alto). Partial fluorination of chromophore-containing dendrimers was shown to lead to significantly reduced absorption loss at telecommunication wavelengths. The trifluorovinyl ether crosslinking reagent (discussed above with respect to lattice hardening) not only leads to significantly enhanced thermal stability but also to low optical loss (e.g., to values as low as 0.1 dB/cm when coupled with significant fluorination of the electro-optic material). Detailed studies of optical loss were carried out in stripline and ring microresonator structures. Three loss mechanisms were identified for ring microresonators constructed from organic electro-optic materials and organic cladding materials: Material loss, scattering loss (from waveguide surface roughness), and bending loss. The former two loss mechanisms contribute about 1 dB of loss while the last mechanism dominates. Indeed, the last mechanism ultimately defines the size of ring microresonators that can be utilized. The outcome of this investigation of optical loss is a dramatically improved understanding of optical loss mechanisms in a variety of device structures. Moroever, optical loss values for devices fabricated from organic materials

are beginning to approach loss values for the best inorganic materials and dramatically smaller than the best loss values achieved for gallium arsenide (and related) electro-absorptive modulators. Future studies will focus on characterizing loss in new materials and new device structures including superprisms and photonic bandgap structures.

(8) Waveguide Development with Soft Lithography: We have successfully used soft-lithography to pattern channel waveguide structures for device fabrication. Several novel passive waveguide structures such as 1x4 coupler and array waveguide gratings have been fabricated by **Jen/Xia** and **Yariv** groups using a very low optical loss polymer (0.12 dB/cm @ 1.55 micron) developed by STC researchers. The outcome is an alternative to waveguide patterning by reactive ion etching (RIE) and photolithographic methods. Future studies will involve the utilization of newly developed materials and adaptation of the approach to the fabrication of active device structures.

(9) Hybrid Material Waveguides: Both hybrid polymer/sol-gel waveguide modulators and hybrid polymer/glass waveguide modulators have been successfully fabricated through the collaboration between the **Peyghambarian** and **Jen** groups. The hybrid approach overcomes certain limitations associated with an all-polymeric modulator approach, such as efficient and reliable coupling between single-mode fibers and modulators, reduced propagation losses, elimination of waveguiding instability, and better adaptability to general optical polarization conditions. We have demonstrated efficient vertical transition between sol-gel waveguide and electro-optic polymer, with similar results in ion-exchanged glass. We also have our first preliminary results on E-O modulation using hybrid E-O polymer/selectively buried sol-gel. This successful demonstration enabled inexpensive device fabrication, stable waveguiding, and easy fiber connection. Future studies will involve newly developed electro-optic chromophores and supramolecular (dendrimer and dendronized polymers) as the organic component of hybrid materials.

(10) Integration of Photonic and Electronic Components: **Steier** and **Dalton** have developed the methods to integrate the polymer devices with other photonic and electronic components and circuits into a single integrated module. We are studying the applications of polymers in an optical computer back-plane. During the period we have:

- Demonstrated an integrated Mach Zehnder modulator which uses the EO polymer only in the arms of the interferometer and uses low loss polymers elsewhere. This greatly reduces the chip loss and the fiber coupling loss.
- Demonstrated both single and two coupled polymer ring resonators and their application for a widely tunable optical source.
- Initiated a study of devices and waveguides for optical backplanes operating at 850 nm and 980 nm.

Future studies will utilize new materials developed within the STC and will involve increasing interaction with industrial research efforts including those at Intel, IBM, Agilent, Boeing, and Lockheed Martin as well as a number of smaller companies.

(11) Exploration of Ring Microresonator Device Structures: Well-established computational models and analyses have been used by **Steier** and **Dalton** to design polymer based waveguide-microresonator devices. The fabrication methods we have developed to create these devices are, in themselves, novel to EO polymeric optical devices. Initial work on single ring microresonators, which involved utilizing 2000 year vintage CLD/APC electro-optic materials, resulted in devices with free spectral range (FSR) values of 300 GHz to 1 THz and per channel modulation bandwidths of 12-18 GHz (Q values on the order of 1 million lead to wavelength discrimination of 0.01 nanometer at telecommunication wavelengths). Drive

voltages as low as 1 volt were used to effect manipulation of both digital and analog data at both 1.3 and 1.55 micron telecommunication bands. Double ring microresonator devices were fabricated by **Steier** that permitted tuning of an oscillator across the band of the erbium amplifier (1520-1560 nm). A voltage tuning of 0.04 nm/V and thermal tuning of 0.6 nm/mW was demonstrated. Side mode suppression was greater than 30 dB. A distinct advantage of organic microring resonators is that both thermal and athermal designs can be implemented. Microring resonators can be used for active wavelength division multiplexing (single chip rates of 500 Gb/s is a realistic short term goal), active wavelength selective filtering, 3-D optical interconnection, wavelength tuning of optical sources, and pulse storage & manipulation devices. Preliminary results have led to research support from Intel Corporation in the amount of $75,000/year. Future work will focus on utilizing new active and passive materials (for realization of greater index of refraction contrast between active and cladding materials). Future studies will also explore a variety of new device designs including athermal designs. Device packages based on multiple resonators (e.g., WDM transmitter/receiver resonators) integrated on a single chip will be explored.

(12) Exploration of Photonic Bandgap Waveguide Structures: A collaborative study involving STC researchers at UW (**Dalton**), Caltech (**Scherer**), and USC (**Steier**) together with researchers at Boeing, Motorola, and Northwestern are exploring the incorporation of electro-optic and all-optical materials into very high Q photonic bandgap waveguide, ring nanoresonator, and superprism structures. A variety of deposition techniques (spin casting, vapor phase, and sequential self-assembly synthesis) are being explored. Theoretical and experimental studies are being correlated to define the maximum index change that can be achieved with different device structures. Preliminary results have supported a successful application to the DARPA chip scale wavelength division multiplexing (CS-WDM) for mobile platforms BAA. In this program, organic materials are directly incorporated into silicon device structures. Potential applications include analog and digital data management and a new generation of sensor technology. Future work will continue all of the studies that have been commenced, will compare the stability of photonic bandgap devices with standard stripline devices, and will incorporate newly developed materials into such devices.

(13) Exploration of Voltage-Controlled Critical Coupling Device Structures: Preliminary studies of device structures that effect data management by voltage control of critical coupling have been carried out. Work to the present has focused on proof of concept of device designs (which has been successfully demonstrated) and on incorporation of active materials into device structures. Future studies will focus on methods of incorporating active EO materials into device structures and on utilizing new electro-optic materials.

(14) Terahertz Signal Generation and Detection: Professor **Hayden**, University of Maryland Baltimore County (a seed project) has demonstrated successful generation and detection of terahertz signals utilizing organic electro-optic materials. The demonstrated performance exceeds that of any know inorganic materials. Future studies will focus on incorporating new electro-optic materials into device structures. Future studies will also focus on the issue of fabricating the thick film devices necessary for terahertz signal generation and detection.

(15) Fabrication of Low Insertion Loss Coupling Structures: A variety of low insertion loss coupling strategies have been explored with the outcome of achieving per facet coupling of better loss than 1 dB (as low as 0.1 dB) per facet. Professor **Lipson** of the Department of Electrical Engineering, Cornell University has joined this effort exploring tapered transition structures. Future work will involve continuation of the research which has been initiated.

(16) Improvement of All-Optical Materials: Integrated theoretical and experimental efforts have resulted in materials with improved third order optical nonlinearity. The results have contributed to the successful realization of additional support from DARPA for this area. Materials are being provided to Professor **Scherer** of Caltech for incorporation into photonic bandgap device structures. Future studies will continue this integrated research program and seek preliminary incorporation of materials into device structures (both fiber and resonated structures).

In addition to the above results, materials were provided to a number of research efforts external to the STC including the optical gyroscope program at China Lake Naval Weapons Laboratory/Army Redstone Arsenal; the electro-optic device program at the Air Force Research Laboratory (AFRL) at Wright Patterson AFB; the electro-optic device program at AFRL at Rome, NY; the electro-optic device program at Boeing, Seattle; the electro-optic device program at Lockheed Martin, Palo Alto; the electro-optic device program at University of Texas-Austin; the electro-optic device program at Photonics Systems; the electro-optic device program at Lumera Corporation; and to an electro-optic device program sponsored by Intel Corporation.

Thrust Name	Theory
PI Name	Thrust Leader: Bruce Robinson

Goal

The goal of the theoretical thrust is to provide the computational tools for the end-to-end design of materials and devices having unprecedented performance. This requires improved theory at all levels ranging from first-principles molecular quantum mechanics, to statistical mechanics for intermediate length scales, to the simulation of devices at the micrometer scale. In the early stages, the thrust will focus on fundamental quantum mechanical theory of individual molecules and its use to model charge transport in organic media and to develop force fields for use in statistical mechanical modeling. A short-term goal is the validation of models and codes by simulating properties of well-characterized materials. Five year goals are to (i) develop and use codes for simulating the properties of target materials to be used in the fabrication of new devices, and to (ii) develop codes that integrate quantum mechanical and statistical mechanical treatments of materials at the molecular level with electromagnetic wave propagation for simulating the performance of devices. Ten year goals of the thrust are to (i) produce and disseminate codes that are useful tools for the chemical design of materials and the engineering design of devices including codes for calculation of dielectric properties, nonlinear optical properties, charge transport, large structure optimization, molecular dynamics, and device response, and to (ii) evaluate the accuracy of the codes on test data sets and demonstrate use of the codes in systematically improving the performance of materials and devices. The goals of the theory thrust have not changed.

Management Indicators

In the first year, one of our management indicators has been the staffing of the individual groups that comprise the components of the theory thrust. Specifically, one of our major management goals has been the staffing of each group with qualified and well-trained individuals. As mentioned under problems, finding these individuals has been difficult. However, we have made progress in this area. In particular, bringing Bruce Eichinger from Accelrys into the project has been a major accomplishment. He is a polymer theoretician with an international reputation and has experience with DFT calculations and condensed matter theory. He has proven to be an important addition to the team. The Rehr group has added a new graduate student and is still interviewing people for a postdoctoral position in their group. All other groups are fully staffed and ready.

Graduate student recruitment is highly competitive at the present time and while several offers were made, students chose to pursue their studies at other locations. After more extensive searching we have recruited and hired several extremely talented students.

The theory thrust provides fundamental understanding for the design of new EO and AO materials developed by the other thrust areas. The Brédas group works closely with the Marder, Perry, and Kippelen groups at the University of Arizona and more recently with synthesis and processing groups at the University of Washington. The Prezhdo and Robinson groups work closely with the Dalton and Jen groups at the University of Washington and more recently with groups across the STC. In both cases the theory groups calculate the energetics and the optical properties of proposed or recently synthesized structures to determine whether there are any flaws in the structures and whether the structures are likely to lead to new materials with improved properties. These theory groups compare methods and results on different test molecules, as will be discussed below.

Another indicator of success of the theory thrust is the development of a variety of computational techniques that are all compared among each other and with experimental data. As this comparative work continues, it will allow us to determine the best methods to use to interpret and validate the optical properties of the newly developed chromophores for the electro-optical materials. These codes will enable the development of materials with tuned optical properties and enable experimentalists to design devices having predictable optical characteristics.

The developments in the current year have moved on a broad front to tune the properties of individual chromophores, understand the advantages of dendrimer synthesis, optimize optical response conditions and concentrations, begin to cross check among different computational approaches, and finally to treat the problem of light interacting with ordered arrays of chromophores and with ordered patterns of chromophore and non-chromophore arrangements to determine the photonics properties of materials.

<u>Theoretical guidance for the improvement of molecular hyperpolarizability:</u>
Semi-empirical calculations of molecular first hyperpolarizability (β) have explained experimental observations made by researchers of this STC (see **Electro-Optic and All-Optical Materials Thrust**), researchers at Lockheed Martin, and researchers at Corning and have led to novel molecular architectures for development of next generation electro-optic materials.

The Brédas group, using a semi-empirical quantum theory codes -- Modified Intermediate Neglect of Differential Overlap (MINDO), has determined the optimal arrangement of acceptor groups on chromophores, when considering the placement of three acceptors which can be either -CN or -NO_2 moieties. The Robinson group has developed the Accelrys DMOL programs, which use DFT to determine the optical polarization parameters μ, α and β for a series of test molecules as well as novel molecules developed by the Jen and Dalton groups.

(a) The observation (by Dalton/Jen, Lockheed Martin, and Corning) that replacement of the methyl groups of the cyano furan acceptor (of FTC and CLD type chromophores) by trifluoromethyl methyl groups leads to improvement of molecular first hyperpolarizability has been simulated by several different types of quantum mechanical calculations.

(b) Quantum mechanical calculations predicted that replacement of the methylene ether segment of the cyanofuran acceptor with an amide moiety should lead to a factor of two improvement in molecular first hyperpolarizability. This prediction was subsequently verified by both hyper-Rayleigh scattering (HRS) and electro-optic measurements. Indeed, an electro-optic coefficient of 101 pm/V (at 1.55 microns wavelength) was recorded for a moderately short chromophore containing the new acceptor. Identification of this new acceptor represents a significant advance in the development of improved electro-optic materials.
(c) Quantum mechanical calculations and experimental measurements have confirmed that replacement of one or two of the cyano groups of the cyanofuran acceptor group with other strong acceptors such as nitro groups lead to significant improvements in molecular first hyperpolarizability. This new paradigm for developing improved chromophores can be described as exploiting “mixed ligand acceptors”.
(d) Quantum mechanical calculations are being used to investigate new donors and bridge segments as well as acceptor segments. Preliminary results suggest several new paradigms for further improvement of electro-optic materials.

The outcome has been the simulation and development of dramatically improved chromophores. Future studies will consider chromophore structures that involve combinations of the above modifications.

<u>Modified Atomistic Monte Carlo Calculations of Multi-Chromophore Containing Dendrimers</u>:
The statistical mechanical methods developed by Robinson and Dalton have been extended to treat multi-chromophore-containing dendrimers. The approach is to develop modified atomistic Monte Carlo methods. Relatively rigid segments (e.g., electro-optic chromophores) of the supramolecular dendrimers are treated as rigid objects while flexible segments are treated in an atomistic manner. The Monte Carlo techniques include the effects of dipoles and van der Waals type forces. Calculations suggest that the motional restrictions associated with covalent bonds of dendrimer structures can assist the realization of acentric (near-ferroelectric) ordering under electric field poling. The outcome has been the realization of nanostructured materials leading to record electro-optic activity (greater than 100 pm/V at all telecommunication wavelengths and 3-4 times that of lithium niobate). Future studies will involve studies of dendronized polymers as well as further studies of multi-chromophore containing dendrimers.

The Robinson and Prezhdo groups have used these Statistical Mechanical methods to determine the most stable configurations for the 3 and 4 arm junction dendrimer-based chromophores developed by the Jen and Dalton groups. The results show why the 3 arm structure should give improved electro-optic properties (as confirmed by experiment). The Prezhdo group has reinforced these results by taking a different theoretical approach: Self-consistent, mean field theory has also explained the collective structures of chromophores and has shown the different phases that arrays of chromophores can adopt. In particular, they estimate that the 3 arm structure should be twice as effective as a simple chromophore (at comparable concentration) without the dendrimer connections. The Robinson and Prezhdo groups are comparing different methods to determine whether they give comparable explanations.

<u>Standardizing the calculations</u>

Of considerable importance is the use of a common molecular architecture among the various groups. The structure, a model chromophore developed and used by the Brédas group, is being used by the Robinson and Rehr groups as well now. With this structure the three groups are comparing the optical properties determined by the various, different computational techniques. The Rehr group is developing codes to study the optical properties of large-scale arrays of chromophores. In particular, it is difficult to determine how a material with dynamic, light dependent refractive indices will respond to the light field and how it will scatter or bend light. Of considerable importance therefore, is to have a reference chromophore that has been optimized by many different methods.

Finding Super-Ordered States

The Robinson group has been exploring organization of dipoles to find arrangements that give enhanced order over the simple cubic lattice at the same density. They have found that placing the dipoles closer on the axis common with the poling field and further apart on the other axes (still keeping the overall density fixed) can increase the ordering by a factor of two. This increase comes in around 10% loading. The group is now looking for modified dipoles to extend the range of order up to 20% loading. At that point, one is competitive with conventional methods. If the trend continues then there will be a factor of two improvement. This architecture will then be converted into structures that will take advantage of this spatial arrangement of chromophores.

Understanding the ratio of singlet vs. triplet exciton formation in electroluminescent polymers. The Brédas group has examined the cross-sections for intra- and inter-molecular recombination of a pair of positive and negative polarons into singlet and triplet excitons in model phenylenevinylene conjugated chains. The relative efficiency for singlet versus triplet exciton generation is found to be mainly determined by the energy separation, Δ_s, between the initial charge-separated state and the lowest-lying S_1 singlet excited state. The group will test whether these results transfer to larger conjugated polyenes that are of direct interest to experimentalist.

Plans for the next year

Quantum Calculations on new chromophores
The Brédas group will explore other chromophores for better optical properties. The Goddard group will use a set of chromophores, already developed as a test set, to give classical charge distributions, and convert them into united atom potentials. The Prezhdo group will compare mean field and Monte Carlo approaches to understand the basis of both. The Robinson group will calculate electronic and optical properties of newly synthesized multichromophoric molecules, develop united atom Monte Carlo methods to look for super ordered arrays and optimum geometries of chromophores. The Hayden group will study the interaction of chromophores and polymers to understand solvent interactions using all-atom, kinetic Monte Carlo methods. The Rehr group will develop all-optical scattering codes to predict optical properties of arrays of chromophores. The Bertsch and Goddard groups will collaborate to develop time dependent DFT codes to study excited state properties of molecules, needed to understand electron transport in EO and AO materials.

The statistical mechanical modeling
The Robinson and Prezhdo groups are collaborating to describe molecules with different levels of a "United Atom type" approach that currently includes dipolar and van der Waals forces. It is important to use more realistic, classical potentials for the molecules. To this end, the Goddard group is developing a reactive force field description of molecules, ReaxFF, that describes both ground state and transition states for reactions. ReaxFF will be validated by comparing to experimental and quantum mechanical results. The ReaxFF will be used to provide potentials needed by the Robinson group for use in statistical mechanical calculations. Additionally, in

collaboration with Brédas at UA, the Goddard group will integrate semiempirical excited state capabilities into ReaxFF to incorporate exciton behavior into these simulations.

Excited State Codes

The Goddard group will implement TD-DFT approaches for excited states of molecules and solid polymers into existing quantum software [Jaguar (developed in collaboration with Schrödinger Inc) for finite molecules and SeqQuest (developed in collaboration with Sandia National Laboratories)] for periodically infinite polymers and will test this methodology by comparing to experiment and to other *ab initio* methods of describing excited states. The development and application of this TD-DFT functionality will be in collaboration with George Bertsch at UW and Jean-Luc Brédas at UA. These methods will be applied to the various Electric Optic Materials being pursed experimentally in this project, including the chromophore containing dendrimers. In a similar development, to look at electron injection and electron transfer properties, the Prezhdo group is modeling ultra-fast electron transfer (ET) dynamics across chromophore-semiconductor interfaces. They have already developed an initial version of the non-adiabatic molecular dynamics code that will be used to study the ET process across chromophore-semiconductor interfaces in real time and at the molecular level. The code, when tested against a system typical of the chromophore-semiconductor systems in Graetzel-type cells, reproduced the time-resolved experimental data on the electron injection rate. The codes will be improved and used to understand the processes of electron injection needed in the devices being developed by the Scherer group at Caltech and the Steier group at USC.

Determining Optical Properties for NLO chromophores

The Robinson and Prezhdo groups have examined various QM methods to calculate optical properties of pNA and other known molecules and conclude that the correct geometry is best obtained by high level calculations but that the best polarizations and hyperpolarizations are found from minimum basis sets, and DFT works about as well as MP2 for determining the optical properties. When examining larger chromophores, more typical of the types being made, it was found that the best agreement was obtained with large basis sets using DFT. We are up to speed on getting polarizabilities and hyperpolarizabilities using DMOL by Accelrys but only at zero frequency. We need to develop methods to obtain these parameters at other frequencies, particularly the 1.0 to 1.6 micron wavelength range which is the telecom communications range and the light fields often used in optical experiments such as EFISH and hyper-Rayleigh scattering. These groups will use direct time dependent quantum calculations (using the GAMES codes) and TD-DFT to compare more exact calculations with time dependent perturbation techniques currently employed by the Brédas group.

Photonics Properties of Active Materials

The Rehr group is developing codes to calculate the dielectric and optical response of the NLO chromophores. As a first step toward this objective they have extended the real-space multiple scattering codes (based on FEFF8 codes) to the optical regime with the assumption of energy independent transition matrix elements and other approximations. As learned from comparing with the experimental energy loss spectrum for Cu (and other systems) the agreement is in semi-quantitative agreement with experiment from the visible to the x-ray regime. The next step is to successively remove the various approximations used in codes in the initial phase. The improved codes will include the energy dependence in the transition matrix elements and hence provide a more quantitative theory in the optical regime. The Rehr group will also investigate the importance of local field effects, and plans to develop subroutines for the propagator matrix elements and scattering matrix for photons scattered by a dielectric sphere.

Thrust Name	Microfabrication and Nanoengineered Materials
PI Name	Thrust Leader: Joseph Perry

Thrust Description

This thrust will focus on the themes of assembling materials on multiple length scales, integration of EO polymers, $\chi^{(3)}$ polymers, organic gain materials into photonic and electronic devices, and free-form 3D mesoscale patterning. Our mission is to advance the fabrication and nanoengineering of photonic materials and devices, and to provide the tools needed to create a new generation of high-performance, low-cost active photonic and electronic devices for information technologies and telecommunications. Our vision is that this thrust, with theoretical and modeling support and working in an integrated manner with the EO materials and devices thrust and the organic light sources and electronics thrust, will lead to materials and microfabrication processes for the creation of new types of active photonic devices, in 2-D and 3-D photonic crystals with tunable characteristics, and in 3-D photonic circuits.

Thrust Projects and Collaborations

- ***2D and 3D Photonic Bandgap Structures:*** **Jen, Perry, Scherer, Stucky, Xia**
- ***Patterned Self-Assembly Chemistry:*** **Jen, Marder, Perry, Stucky, Xia**
- ***Materials Chemistry for Two-Photon Lithography:*** **Jen, Marder, Perry**
- ***Macromolecular Data Storage:*** **Marder, Mansuripur, Perry**
- ***Structural and Optical Characterization:*** **Campbell, Perry, Scherer**

Collaborative team interactions have begun on a few projects within the thrust and good initial progress has been made. These interactions involve the participation by several faculty and direct interaction of students and post-docs undertaking the research work. Some of these activities involve interactions across thrusts and among members who are participating in two or more thrusts. For example, Scherer, Jen, and Dalton have begun a collaboration that aims to incorporate highly active electro-optic polymer materials into 2D silicon photonic bandgap structures with the goal of making the bandgap structures that are electrically tunable. Materials have been transferred and students have been exchanged between laboratories. Stucky, Perry, Marder and Xia are collaborating on the development of 3D photonic crystal structures through the use of two-photon 3D lithography and self-assembly or backfilling chemistry to incorporate high refractive index and optically active materials into polymeric or colloidal particle templates that have a form useful in photonic microdevices. Template structures have been transferred from the Perry group to the Stucky group and initial backfilling experiments have been performed. Students and post-docs are interacting directly, leading to enhanced training and education of students across different areas of expertise. Marder's group has transferred newly developed high-sensitivity, two-photon initiators to the Perry group for development of improved photopolymer systems for 3D lithography. Mansuripur, Perry, Marder, and Peyghambarian have teamed up to investigate macromolecular data storage that holds promise for ultrahigh density information storage. Microfluidic structures fabricated in the Perry and Peyghambariam group have been transferred to the Manusuripur group which has been fabricating nanopore based read/write stations for processing information on individual macromolecular chains. Initial experiments have demonstrated the ability to integrate microfluidic and nanopore structures and to measure distinct electrical transients from different types of polynucleic acid chains. Students are being exposed to highly cross disciplinary concepts and methods. While this is just the beginning, we believe that we are off to a very good start in the formation of integrative activities both within this thrust and among the different thrusts in the STC.

Objectives

Develop materials and microfabrication processes to create new types of active photonic devices, to provide tunability in 2D & 3D photonic crystals, and to take photonic devices into the 3rd dimension.

Milestones

The 5-year milestones for this thrust are 1) Materials and processes for 3D fabrication with 50 nm resolution over square centimeters. 2) Low loss (<1 dB) 3D tapered optical couplers. 3) New materials and methods for writing 3D optical circuits, 5x increase in a real waveguide density. 4) Large-area (1 cm^2) 3D photonic crystal structures with well-defined defects. 5) Adding a "tuning knob" to 2D and 3D photonic devices with EO polymers. 6) Integration of EO, $\chi^{(3)}$, and amplifying polymers into microresonators devices. 7) Assess potential for integrated biological data storage. Looking to the future, we envision the following milestones over a 10-year period: 1) Integrated photonic chips based on integration of polymer and semiconductor optical materials, and electronic materials to produce inexpensive, versatile systems. 2) Solitonic device structures based on $\chi^{(3)}$ polymers for ultrafast self-guided switching. 3) Tailor made integrated photonic systems for ultrasensitive chemical/biological analysis making use of responsive character of polymers. 4) Integrated photonic/electronic microsystems for biological data storage.

Future Plans

Our plans for the next award year call for continuing and expanding the activities initiated during the past reporting period. A collaborative effort will be launched with researchers at Northwestern University (led by Professor Tobin Marks) to add Merrifield-type sequential synthesis (exploiting robotic control) to our repertoire of nanoscopic fabrication methodology. In particular, an effort will be made to integrate such methodology with photonic crystal circuitry and ring microresonators being fabricated within the STC.

Thrust Name	Light Emission and Organic Electronics
PI Name	Thrust Leader: Bernard Kippelen

Research Objectives

The thrust is focusing on the central processes of charge transport and light-emission in organic and hybrid materials with tailored morphology. New materials under development include dendrimers, self-assembled mesophases, and semi-crystalline thin films processed by physical vapor deposition. The objectives are to: (i) develop new light-sources for telecommunications and displays; (ii) develop stable high-mobility organic materials for electronics. These materials will be processed at low temperature and inserted into devices on shatterproof plastic flexible substrates using printing and soft lithography techniques. Each task is vertically integrated and incorporates four core competencies: (i) new material synthesis; (ii) theory and modeling; (iii) characterization of the optical and electrical properties in bulk, thin films, and nanostructured forms of the materials and interfaces with metals; (iv) device fabrication, performance testing, and optimization of processing techniques.

The thrust consists of the following three major research areas:

A. Light Sources for Telecommunications

Objectives: Develop amplifiers and fiber lasers based on rare-earth doped dendrimers. Develop conjugated polymers and molecules with infra-red emission.

Approach: Use dendrimer chemistries and site isolation to control absorption, emission, and energy transfer. Develop materials with high concentrations of rare-earth elements such as Er/Yb with long lifetimes. Demonstrate amplifiers with high gain, short length, high spectral bandwidth, and small footprint. Fabricate tunable fiber lasers pumped by inorganic semiconductor lasers. Design new conjugated polymers and molecules with infra-red emission.

Participants and their role: **Frechet, Harper,** and **McGrath** are synthesizing new lanthanide containing dendrimers. **Kippelen** and **Mathine** will fabricate waveguide structures and measure emission lifetimes and cross-section, optical gain and losses. **Mescher** will incorporate the new materials into optical fibers.

B. Light Sources for Displays

Objectives: Develop organic light emitting diodes with increased stability, performance, and functionality. Develop displays for the near infra-red.

Approach: Develop new materials with higher ionization potential and electron affinity that are less sensitive to oxygen and compatible with stable metal electrodes. Make the material photopatternable and crosslinkable to allow easy fabrication of pixels, multilayer processing from solution, and integration with organic electronic drivers. Lower operating voltage and increase light output by using doping and/or high-mobility materials such as self-assembled mesophases. Use site isolation in dendrimers to optimize color purity of devices. Increase lifetimes by decreasing the operating voltage to reduce Joule heating effects, controlling morphology changes during heating, tailoring interfaces to improve adhesion at organic/metal interface.

Participants and their role: **Marder** is synthesizing oxadiazole and phthalocyanine containing mesophases for electron and hole transport, **Frechet** is synthesizing dendrimers for white-light emission, **Jenekhe** is synthesizing side-chain and main-chain infra-red emitting polymers. **McGrath** is synthesizing light-emitting quinacridone dendrimers. **Kippelen** is fabricating organic light-emitting diodes with these new materials and is testing their optical and electrical properties. **Heeger** is developing light-emitting electrochemical cells and is improving their stability and lifetime by creating frozen junctions using cross-linking approaches. **Armstrong** and **Campbell** are characterizing organic/metal interfaces and frontier orbitals of the newly developed materials using combined adsorption microcalorimetry and photoemission spectroscopy.

C. Organic Electronics

Objectives: Develop an organic material platform to develop low cost, large area electronic circuits on plastic substrates for applications that do not require high speed and high current. Develop thermally stable high-mobility organic materials with mobilities comparable to amorphous silicon (0.5 - 1 cm^2/Vs).

Approach: Synthesize highly ordered organic materials that can be processed from solution or by physical vapor deposition. Explore the intrinsic limitations to high mobility in organic materials through a combined experimental/theory experiment. Fabricate field-effect transistors with high on/off ratios and low drive voltages. Increase functionality of these devices and develop phototransistors and light-emitting transistors. Fabricate electrically injected lasers. Integrate organic FETs with OLEDs. Develop a library of key electronic components and derive their corresponding SPICE parameters.

Participants and their role: **Marder** is synthesizing high-mobility mesophases and small molecules that can be processed into thin films using vapor deposition. **Jenekhe** is synthesizing various azaacene derivatives for transistors. **Kippelen** and **Mathine** are fabricating and testing organic field-effect transistors, and are developing organic capacitors. **Kippelen** is measuring the transport properties of the newly developed materials by time-of-flight experiments. **Armstrong** and **Campbell,** with complementary tools, will study interfacial chemistries of organic/metal interfaces. In particular, they will study band-edge misalignment and interfacial chemistries using various photoemission spectroscopies. In the first year they will start with pentacene and NTCDI as models and later expand their studies to the new materials under development in the Center. **Frank** is developing materials that exhibit spin-correlated conductivity for spintronics applications.

Progress in Three Subthrust Areas

During the first year, we have made significant progress in all three research areas of this thrust:

A. Light Sources for Telecommunications

Activities and Results: New lanthanide-containing dendrimers have been synthesized (**Harper**) and their photophysical characterization has been performed. Site-isolation phenomena as well as antenna effects have been quantified in europium-cored dendrimers. The synthesis of erbium-cored dendrimers (**Harper and McGrath**) is in progress and should be completed by the end of the first year. Fluorinated polymers incorporating lanthanide coordination complexes have been prepared (**Harper**) and work has started to incorporate them into micro-ring resonator structures in collaboration with colleagues from the thrust on electro-optics devices (**Steier**). Efficient green light has been generated, through third-harmonic generation using an infra-red laser emitting at 1500 nm, in organic dyes having strong third-order nonlinear optical properties (**Marder, Kippelen**). Real-time imaging through scattering media using third-harmonic generation in these chromophores has been demonstrated. These molecules have been delivered to the University of Washington (**Mescher**) for incorporation into PMMA optical fibers. Osmium dendrimers have been successfully incorporated into PMMA fibers. The fiber absorbs UV and emits red light. Procedures have been optimized for purifying and drying MMA monomer, incorporating the dendrimer, casting the material into a preform rod shape, polymerizing the preform, and finally drawing the preform into a fiber (PMMA host) of any specified diameter from 100 to 1000 microns. At this time, the optimal diameter tolerance that was achieved is +/- 5 microns.

Plan for the next reporting period: Luminescent properties of the newly synthesized erbium-cored dendrimers will be studied in thin film and waveguide geometries (**Kippelen, Mathine**). Most promising materials will be incorporated into plastic optical fibers (**Mescher**) and stimulated emission in these structures will be measured (**Kippelen, Mathine**). New generations of modified materials will be synthesized based on the feedback received from the photophysical experiments conducted on the first generation of materials. Third-order optical parametric amplification experiments will be conducted in single mode plastic fibers doped with the novel third-order nonlinear dopant molecules. Using feedback control system, preforms will be drawn into fibers with diameter tolerance of +/- 1 micron. Fiber optic lasers incorporating rare-earth dopants will be designed and fabricated.

B. Light Sources for Displays

Activities and Results: Photocrosslinkable hole-transport polymers with various ionization potentials have been synthesized (**Marder**) and incorporated as photodefinable hole-transport layers in organic light-emitting diodes (**Kippelen**). The polymers were obtained by copolymerization of bis(diarylamino)biphenyl-based acrylate monomers with cinnamate-functionalized acrylate moieties. Polymers with a range of redox potentials were obtained by varying the substitution patterns of the bis(diarylamino)biphenyl units. The 2+2 cycloaddition of the cinnamate moieties following UV irradiation allows for patterning of the polymer, and simultaneously enables the fabrication of multilayer structures from solution. Hole mobilities have been measured in these copolymers using the time-of-flight technique. Electroluminescent devices with multiple hole-transport layers having different ionization potentials have been fabricated from solution and the quantum efficiency of these devices could be improved compared with devices based on a single hole-transport layer. Lifetimes of devices fabricated from various hole-transport polymers and small molecules have been measured. Ongoing efforts focus on the control and the understanding of the role of surface energies of these different materials using self-assembling monolayers (**Armstrong, Campbell**).

Several generations of dendritic quinacridone derivatives for organic light-emitting diodes and lasers have been synthesized at the gram quantity level (**McGrath**). Nearly 100% photoluminescence efficiencies could be achieved in these materials. The electrochemical characterization of these materials has been completed. Molecules have been sent to the University of Washington (**Mescher**) to be incorporated into plastic optical fibers for optically pumped lasers emitting in the visible. Materials sent to Durel Corporation for incorporation into powered thin-film AC electroluminescent devices (collaboration UA, UW, Durel Corp.; **McGrath**, **Armstrong**, **Kippelen**, Durel Corp., **Mescher**).

In the area of light-emitting electrochemical cells, an ampholytic co-monomer (AMPS/METMA) has been synthesized (**Heeger**) and combined with emissive conducting polymers such as MEH-PPV. Devices that consist of a thin film of this mixture sandwiched between two electrodes are being fabricated and evaluated. Current efforts focus on the polymerization of the co-monomer to freeze the junction after the desired charge distribution is achieved.

Plan for the next reporting period: We will incorporate quinacridone containing dendrimers synthesized by **McGrath** into organic light-emitting devices processed from solution to increase device efficiency using Forster energy transfer. Dendrimers will provide site isolation and prevent self-quenching, and simultaneously will enable the processing of these materials from solution. These materials will be combined with the crosslinkable hole transport materials that have been fully characterized (**Marder, Kippelen**). White light sources with good color rendition will be fabricated by combining dendrimers emitting at different colors (**Frechet, Kippelen**).

C. Organic Electronics

Activities and Results: discotic liquid crystals based on oxadiazoles with benzene and triazene cores have been synthesized (**Marder**) and their charge mobility has been measured using time-of-flight experiments (**Kippelen**). The materials were found to form a columnar discotic liquid crystalline mesophase between 38°C and ca. 210°C. The time-of-flight electron mobility at room temperature was as 10^{-3} $cm^2V^{-1}s^{-1}$, which is the highest electron mobility measured at room temperature in oxadiazole-based compounds. Solution-based fabrication procedures of electrodes on plastic flexible substrates were developed and micro-size features could be fabricated using micro-contact printing and photolithography (**Kippelen**). New dielectrics that can be patterned as gate oxides have been developed and characterized. Films with good dielectric strength could be fabricated. Pin hole densities could be measured with high sensitivity using electrochemical techniques (**Armstrong, Mathine, Kippelen**). Organic field-effect transistors were fabricated on silicon substrates using pentacene as the organic semiconductor. Very low threshold voltages (< 1 V) could be obtained (**Mathine**) by treating the gate oxide with a coupling agent. Several devices have been designed and modeled including a seven stage ring oscillator, an inverter, NAND and NOR gates. Gold surfaces modified with alkanethiols and partially fluorinated alkanethiols were characterized by UV-photoelectron spectroscopy (**Armstrong**). Changes in the effective work function of these surfaces due to the presence of significant interfacial dipoles are observed as alkyl chain length is increased, and as the fraction of fluorinated methylene groups is increased in a constant length alkyl chain. Comparison of the shifts in gold/SAM vacuum level (changes in effective work function) as a function of the apparent dipole moment of the molecule provides an estimate of the band-edge offsets for these molecules on the gold surface and an estimate of the intrinsic dipole moment for the gold-thiolate bond, both relevant to the functioning and efficiency of electrode/organic interfaces in organic electronic devices.

Plan for the next reporting period**:**

New generations of discotic liquid crystal compounds in which the core is larger and can help impart greater order will be synthesized. In particular, compounds containing phthalocyanine, pyrene and aza aromatic cores will be examined (**Marder**). Charge mobility in these materials will be measured by time-of-flight experiments and in field-effect transistor geometry (**Kippelen**). In addition, the use of metallo-organic compounds such as metal dithiolene compounds will be explored. These materials can also form meso-phases and are readily reduced. Applications of these materials as transport materials in OFETs will be investigated. In the next reporting period we build and test a seven stage ring oscillator, an inverter, and NAND/NOR gates (**Mathine/Kippelen**). We will focus on other modifiers on gold, ITO, silica thin films on Au, etc. and try to extend this work to all of the interfaces of interest in emerging OFET technologies (**Armstrong**). During the second reporting period, we will also develop organic photodetectors (**Marder/Kippelen**).

III. **EDUCATION**

Educational Objectives

The overall educational objectives remain unchanged since initially defined in the Center's strategic plan. The Center's educational objectives are to:

a. Create a better-trained, diverse workforce in the area of materials and devices for information technology, and to improve the diversity of that work force through proactive recruiting and innovative web-based cooperative learning;
b. Create new opportunities for providing interdisciplinary, hands-on education by facilitating exchange of students amongst groups with diverse research capabilities and interests;
c. Design, implement, and assess new educational approaches that provide more flexible and accessible career pathways for students; and,
d. Provide ethics training through lectures given at each university to all incoming members; topics will include scientific integrity, the concept of inventorship, accurate record keeping, and the requirement to share credit.

The Center has made a great deal of progress toward these objectives in the design and implementation of a variety of Center activities. For example, an upcoming *ACS-PRF Workshop on the Chemistry of Information Technology* hosted by the Center will provide an inter-disciplinary, hands-on educational experience for a variety of participants from across the country; the design of web modules for the teaching of concepts central to information technology ultimately will lead to innovative web opportunities and provide new educational approaches for a diverse audience; and the Center's growing partnership with the Alliance for Non-Linear Optics will foster the development of a diverse workforce. In addition, a significant number of Center participants, including many undergraduates, have presented their research findings at professional conferences and workshops in K-12 and business arenas. Combined with ethics training in the form of seminars, courses, and guidelines for accurate record-keeping, these presentations have helped to convey an understanding of inventorship within the Center and its surrounding communities. It is expected that the educational efforts of the Center will be even more robust in the next reporting period. Now that the Center's management infrastructure has been established, including the newly hired Education Director, the Center's management will refine and clarify the existing objectives to better align with existing resources of organizations belonging to the Center, the needs of the communities surrounding the Center, and expertise and resources from within the Center. The refinement of objectives will enable the development of more clearly defined measurable goals, outcomes and related activities. This work will be informed by the expertise of an external advisory committee.

Performance and Management Indicators

This report will address goals identified in the Center's strategic plan which relate directly to those educational objectives mentioned above (see 1a.). The goals are:

(i) To recruit and track, proactively, individuals from under-represented groups into the Center, through seminar programs, internships, fellowships, and strategic interactions with the Alliance for Nonlinear Optics, Northern Arizona University, Norfolk State University, and California State University Los Angeles; and,

(ii) To create cross-disciplinary curricula and educational resource materials that are directly tied to the research function and expertise of this Center, and to evaluate their impact.

In an effort to measure our progress toward these goals, we have laid the groundwork for long-term information gathering. Specifically, we have recently constructed a Center-wide database for tracking the demographics and activities of all Center Participants and Affiliates. This dynamic database will be further expanded to track the graduation and future plans of Center students as well as the involvement of external participants in Center activities. It will be accessible through the internal portion of the Center's website and available to Center participants and staff.

The Center has also initiated a partnership with the University of Washington's Office of Educational Assessment (OEA) by providing the salary of Tamara Walser a program evaluator hired to work with the Center. The OEA will work closely with the Center's management in the refinement of goals and objectives, and correspondingly the Center management will work closely with OEA to develop and implement the evaluation plan.

To describe our progress thus far, each educational activity described below will reference the goals and objectives addressed.

Problems Encountered

The Center has encountered initial challenges toward the establishment of the education management team. The late hiring of the education management team was a direct result of delayed Center funding and staff turnover/reorganization (specifically, Gretchen Kalonji withdrew from the Center to pursue other interests). In the interim, Bruce Robinson and Natia Frank were pressed into service as coordinators of the Center's education efforts. While this slowed the rapid development of widespread Center activities, the newly hired education staff has tremendous potential. The Director of Education, Dr. Jasmine Bryant, has a PhD in inorganic chemistry, and a Master's Degree in Teaching. She is a former fellow in the NSF's GK-12 program and has experience in public and private K-12 education and outreach programs. The Center is also pursuing negotiations for a partnership with the University of Washington's K-12 Institute for Science and Mathematics Education. This Institute, established by the university's central administration, supports the university's mission to partner with and support Washington state's K-12 community. The work of the Institute fosters collaborative, systemic efforts for reform in science and mathematics education. These ties will be especially useful in harnessing the existing educational resources in the Center communities as well as rapidly defining effective plans for future Center efforts.

Initial efforts at UA to recruit teachers to be involved with Center activities has proven difficult. Specifically, the involvement of teachers in the design of web modules will require greater effort, as the web modules are the most advanced activity. It is perceived that depressed budgets of local school systems and lack of release time have contributed to this situation. The hiring of Rachel Morgan (as a post-doctoral fellow in Vicente Talanquer's science education research group) at UA is expected to improve the interface with the K-12 community significantly over the next year.

Internal Educational Activities

A number of activities have taken place that address the educational objectives and goals of the Center. These have taken the form of workshops, conferences, web module development, presentations, lab experiences and coursework. For each of the activities we have provided a narrative description. To the descriptions below, we have added information specifying the goals and objectives addressed by each activity. The impacts of these activities will become visible in the next reporting period as the education management team and all Center participants will work with the Office of Educational Assessment to develop and implement measurement strategies.

Activity Name	ACS-PRF Workshop on The Chemistry of Information Technology
Led by	Natia Frank, Bruce Robinson, Jasmine Bryant
Intended Audience	Undergraduates, graduate students, post-docs, new faculty, community college educators, industry scientists
Approx Number of Attendees (if appl.)	40 participants, 15 speakers, other 20-30 attendees
Objectives/Goals Addressed	Objectives a, b Goals: i, ii

The *ACS-PRF Workshop on the Chemistry of Information Technology* (funded by a grant from the Petroleum Research Fund) will take place on the University of Washington campus from June 18-25, 2003. It consists of a four-day workshop facilitated by Center faculty including laboratory experiences, tutorials, and education and reflective sessions. The workshop is followed by a three-day symposium composed of 36 talks given by leaders in the field of information technology. Workshop sessions will be recorded by UW TV and posted on the web. The symposium presentations will be published in a special, dedicated issue of the Journal of Physical Chemistry. The goals of this workshop are to educate and inform a diverse workforce as well as to integrate research and education. An initial assessment of the workshop will be organized by OEA. This will include a reflective session at the conclusion of the workshop in which participants will be able to provide feedback as well as discuss ways in which they will be able to use this information within the context of their organization – particularly how it relates to their educational practices. This session will provide a basis for designing future workshops. Secondary-level teachers will be included in the workshop (see External Activities, below).

Activity Name	Web modules
Led by	Neal Armstrong
Intended Audience	Undergraduates (initially), K-12 through post-graduate
Approx Number of Attendees (if appl.)	
Objectives/Goals Addressed	Objectives: a, b, c Goals: ii

One of the central activities of the educational efforts of the Center is the development of a web-based curriculum, in optics and optical materials, which ultimately will be vertically (K-12 through postgraduate) and horizontally (cross-disciplinary) integrated. The design of the initial web module is being approached as a pilot research activity around the delivery of web-based content and will provide the basis for the development of further modules. Specifically, the process will address the best way to implement web-based education activities, identification of the audience, how best to access the information, an assessment of user understanding at several levels, and how teachers might use the modules. The first six months of activity have been dedicated to the following tasks: a) hiring the appropriate staff in the Department of

Chemistry (Mike Bruck) at Arizona to work effectively with the UW group, b) beginning the creation of the web-page format for this curriculum, c) purchasing the necessary equipment to support this effort, d) beginning the design of the curriculum modules with staff from Faculty Instructional Services at Arizona (most particularly, Jennifer Franklin), e) initiating the first educational module on Refraction and f) the hiring of Rachel Morgan to assist in the interaction with local schools.

Masud Mansuripur has outlined content for the initial module. The topic of refraction has been chosen for this pilot module because it is closely aligned with the Center and is the area most advanced in Center research. The development of the interface for the module navigation is being led by Jennifer Franklin. Mike Bruck is leading the development of the module navigation system which includes a Concept Map interface and User History/Tracking system. Examples of the activities to be used in the first/pilot module can be found at:

http://www.ece.arizona.edu/~chandanp/work/Physics1/
http://www.ece.arizona.edu/~chandanp/work/Physics2/

Activity Name	ANLO Partnerships
Led by	Natia Frank, Seth Marder
Intended Audience	Undergraduates and faculty of partnership schools
Approx Number of Attendees (if appl.)	
Objectives/Goals Addressed	Objectives a, b Goals: i, ii

As part of our effort to reach more diverse populations, we have pursued a strong outreach program to traditionally Hispanic, Black and western-USA Native American colleges. Specifically, we have initiated collaborations with the Alliance for Nonlinear Optics (ANLO, Dr. Tatiana Timofeeva of New Mexico Highlands University, Director). Most ANLO investigators are from minority and historically black colleges and universities (U. Texas, El Paso; New Mexico Highlands U.; Spelman College; U. Puerto Rico at Mayaguez; Grambling State U.; U. Alabama at Huntsville; and Alabama A&M U.). ANLO concentrates on collaborative research projects in optical materials while reducing isolation between minority and historically black colleges and university-funded projects -- it cuts across racial, ethnic, regional, and educational boundaries. To these ends, several personal contacts have been established between STC and minority institutions: a) Perry (UA) has provided assistance in reviewing a project and provided a letter of support to Sarkisov (AA&MU). b) Brédas (UA) will be admitting an undergraduate from Cardelino's group (Spelman) for undergraduate research. c) Robinson and Eichinger (UW) have provided assistance to Timofeeva (NMHU) in the acquisition and operation of a molecular modeling program (Cerius2) and plans for a collaborative computational project are under way. In addition, an undergraduate from the Timofeeva group will be joining the Robinson group for summer undergraduate research. d) Marder (UA) and Timofeeva (NMHU) have collaborated in the preparation of a short structural/synthetic manuscript. e) Dalton (UW) has provided assistance to NMHU by reviewing a NASA grant proposal and providing a letter of support.

Furthermore, we intend to pursue relationships with additional colleges and universities. For example, Larry Dalton is a member of the advisory board and helped to secure funding for the Center for Research and Education on Advanced Materials at Norfolk State University (NSU), an historically black college. Furthermore, four students and one faculty member from NSU will be participating in our *ACS-PRF Workshop on the Chemistry of Information Technology*.

Activity Name	Undergraduate Opportunities
Led by	Individual Faculty/Jasmine Bryant
Intended Audience	Graduate Students, undergraduates, and faculty
Approx Number of Attendees (if appl.)	
Objectives/Goals Addressed	Objectives a, b Goals: i, ii

We have provided a number of undergraduate students with opportunities to perform research in Center laboratories. Across Center sites, there are currently 37 undergraduates taking on responsibilities for individual and joint research projects. These undergraduates attend group meetings, including joint, inter-disciplinary meetings of Center researchers. These research experiences generally last from three months to several years – providing students with authentic, hands-on experiences in the field of information technology. The research findings of these students have been presented at a variety of local and national conferences, including campus undergraduate research conferences, the Northwest section meeting of the American Chemical Society (ACS), and the ACS national meeting. Furthermore, plans are in place for undergraduates from ANLO partner schools to partake in summer research with Center faculty.

Activity Name	Faculty/graduate student presentations
Led by	Individual Faculty/Jasmine Bryant
Intended Audience	Undergraduates, graduate students, faculty
Approx Number of Attendees (if appl.)	
Objectives/Goals Addressed	Objectives a, b Goals: i

Over 80 talks have been given by Center participants at scientific conferences, workshops, and community engagements (see Section VIII. Center-Wide Outputs and Issues). These presentations assist the Center in its efforts to transfer the research of the Center to an educational format. For example, Masud Mansuripur's lecture "How do CD- and DVD- Players Work?" has been made available as a streaming video at:

(http://www.vala.arizona.edu/vss-bin/vss_SR/torpey/search)

Also, Larry Dalton has given two talks for the University of Washington Science Forum. The response was enthusiastic and UW TV recorded the presentation and will make this available as part of continuing education and outreach.

Activity Name	High-Tech Entrepreneurship Speaker Series
Led by	The Center for Technology Entrepreneurship
Intended Audience	Students from Science, Engineering, and Business; Faculty; and individuals from Industry and the Business Community
Approx Number of Attendees (if appl.)	150
Objectives/Goals Addressed	Objectives a, b Goals: i

The Center-related goal of participating in this program was the introduction of students, non-STC faculty, and the business community to key technologies being pursued in the Center. The anticipated output was an increased interest on the part of students, faculty, and the community in Center research. In the short term, an enthusiastic response occurred with a half dozen students expressing interest in opportunities such as the certificate program involving combined business and science/engineering education. There was an enthusiastic response from the Business sector. Coupled with the very favorable responses received from the Technology Alliance, Washington Community Development Roundtable, Science Forum, and other community related lectures (see section 2b below), a group of business leaders (including those of the Technology Alliance) met with members of the Washington State Legislature to campaign for State funding of a Center for Strategic Advantage to be coupled with the Center. Several Seattle-based companies have approached the Office of Intellectual Property and Technology Transfer at the University of Washington to pursue licensing of technology produced within the Center. We will continue to develop these relationships, but it is still too soon to assess the longer-term impact of such a speaker series.

Activity Name	Frontiers in Nanotechology, BIOENG 599
Led by	The Center for Nanotechnology
Intended Audience	Graduate Students from Science and Engineering
Approx Number of Attendees (if appl.)	> 20
Objectives/Goals Addressed	Objectives a, b Goals: ii

Center faculty teach significant components of this course including those related to nanophotonics, nanoelectronics, sensors, MEMS, etc. This course is an important component of the Nanotechnology PhD program. The anticipated outcome of participation in the teaching of this course was improved interdisciplinary education of graduate students and advanced undergraduate students as well as the opportunity to build bridges to related technology programs. This course has been very successful in training students within the Center in topics related to nanoscience and nanotechnology. A significant fraction, if not a majority, of students taking this course are now pursuing research within the Center.

<u>External Educational Activities</u>

Activity Name	ACS-PRF Workshop on the Chemistry of Information Technology
Led by	Natia Frank, Bruce Robinson, Jasmine Bryant, Neal Armstrong
Intended Audience	Pre-college science teachers
Approx Number of Attendees (if appl.)	5
Objectives/Goals Addressed	Objectives: a, b, c Goals: ii

As part of the *ACS-PRF Workshop on The Chemistry of Information Technology* (described above), we have invited pre-college science teachers with strong backgrounds in chemistry to increase their knowledge in the field of Information Technology. Afternoon sessions will allow teachers to explore ways in which to incorporate workshop information into their classroom. We will also provide supplemental information and additional activities for K-12 teachers, including the opportunity for teachers to review and pilot web module activities.

Activity Name	Faculty/graduate student presentations
Led by	Individual Faculty/Jasmine Bryant

Intended Audience	K-12 students and teachers, general public
Approx Number of Attendees (if appl.)	
Objectives/Goals Addressed	Objectives: a, b, c Goals: ii

Many Center participants have realized the importance of communicating their research to the K-12 community. As a result, Center participants have been involved in a variety of activities. These include science fair judging and assistance, presentations at teacher workshops, lectures given in the business community, the mentoring of high school students, and classroom science demonstrations. For example, Greg Phelan, a Center graduate student and a NSF GK-12 Fellow, has given presentations at teacher workshops at The Villa Academy, Emerson Schools, and the African American Academy. Center graduate students Leo Fifield and Rhys Lawson have given presentations about Nanotechnology to 4^{th}, 5^{th} and 6^{th} graders at Cathcart Elementary School. Larry Dalton, the Center Director, is currently mentoring 3 high school students: helping Adrian Lee of Beaver Lake Middle School on a science project; assisting Rafi Kuttner of Mercer Island High School with a project on information technology carried out in laboratories at UW; and advising Emma Mullen of Newport High School on her science project (conducted in UW laboratories) for the Intel Science Fair Competition.

Activity Name	Technology Alliance Lecture Series
Led by	Seattle Technology Alliance
Intended Audience	High Technology Business Community
Approx Number of Attendees (if appl.)	> 300
Objectives/Goals Addressed	Objectives: a, b, c Goals: i

The goal of participation in this activity was to strengthen Center interactions with the Seattle high technology business community. The lectures have been enthusiastically received and the Technology Alliance has become a lobby group for the Center with the Washington State Legislature and with other community business groups. The Technology Alliance supports an Education and Outreach program that in many ways dovetails with that of the Center. In this regard, the Technology Alliance has become an active promoter of our education efforts. Dr. Lynn Nixon of Agilent has played an invaluable role in coordinating the interaction of Center efforts with local, State, and industrial K-12 efforts and with the WASL testing program. While meaningful assessment can be accomplished only after more time has transpired, the initial prognosis is very positive. The Technology Alliance has elected Center Director Larry Dalton to membership, which further facilitates coordination of Center and Technology Alliance activities.

Activity Name	Washington Community Roundtable Luncheon Lecture Series
Led by	Seattle Chamber of Commerce
Intended Audience	Community Leaders
Approx Number of Attendees (if appl.)	> 100
Objectives/Goals Addressed	Objectives: a, b Goals: i

Participation in this lecture series was aimed at the facilitation of knowledge transfer to the business community as well as the building of a working relationship that would advance education, outreach, and knowledge transfer efforts. An enthusiastic response has been received. Meetings with Seattle Mayor Nickels, members of the Gates Foundation, and Paul Allen have resulted. The law firm Preston Gates has provided release time for partner Marty Smith to work with the Center to coordinate education efforts with those of the Gates Foundation.

Professional Development Activities

Center participants have taken part in a variety of professional development activities including: conferences and workshops, an ethics course and/or presentation, coursework and lecture series, and joint, inter-disciplinary group meetings.   The above mentioned *ACS-PRF Workshop on the Chemistry of Information Technology* provides a forum for the exchange of knowledge amongst a diverse group of participants. Undergraduates, graduate students, post-docs and faculty participated in both attending and presenting at a variety of conferences – over 80 presentations by Center faculty alone (see Section VIII. Center-Wide Outputs and Issues). Furthermore, in an effort to provide ethics training to Center participants, we have scheduled an ethics and intellectual property seminar to be attended by UW Center staff. We have further encouraged Center students at the UW to participate in an ethics course involving weekly discussions of: authorship of papers and responsibility for their contents, intellectual property and copyright, protection of oneself and one's colleagues from the publishing of bad work, the process of checking that other people have not done the work earlier, how a research group should be run and what the responsibilities of its leader and other members are, how and why good records are kept, and the balance between secretiveness and openness. All Center participants have received information regarding proper notebook maintenance and record-keeping. These efforts speak specifically to educational objective d. above. Many Center students also participate in weekly inter-disciplinary group meetings in order to exchange information and knowledge within the Center.

Integration of Research and Education

The Center strives to create a program and a culture that fosters the integration of teaching and research. Concepts central to each of the research thrusts will be reflected in the content of the web-based curricular resources, undergraduate research experiences, inter-disciplinary lectures, talks that are presented by our Center graduate students and faculty, weekly inter-disciplinary group meetings, our PRF summer workshop as well as our partnership with the Center for Technology Entrepreneurship (at UW).   The summer workshop offers opportunities for Center faculty to provide exposure to high level research, as well as the fundamental underlying concepts central to Center research activities, to a broad audience – the K-12 teaching community, undergraduate and graduate, as well as the professional community (industry, post-doc, faculty) in the form of tutorials and laboratory experiences. It also provides instructors (K-Gray) the opportunity to hear inter-disciplinary lectures and to reflect on ways to incorporate this information into their educational practices. The creation of web modules takes advantage of content experts already on board at UA to provide design leadership.

The Center for Technology Entrepreneurship promotes the integration of research and education in a number of ways while serving as a contact point for science, engineering, business, and law. Most specifically, research, education, knowledge transfer, and technology transfer are facilitated through (1) the New Venture Creation Laboratory where students from science and engineering work together with students from the School of Business (and Law) to evaluate the commercial potential of research being pursued in the Center, (2) the High-Tech Entrepreneurship Speaker Series of the CTE whereby scientists (from the Center) and successful entrepreneurs from the community share their experiences and research advances,

(3) through a new certificate program designed to provide graduate students in science and engineering with an introduction to entrepreneurial thinking from a business perspective, and (4) a business plan competition which provides students experience in writing business plans. A Workshop with participation of Center scientists and engineers together with faculty from the UW School of Business will focus on providing students with a concentrated experience in topics ranging from ethics to entrepreneurship. This Workshop will ultimately be coordinated with the Annual Meeting of the Center and will involve a day focused on review of potential for technology transfer of specific STC research activities.

Future Plans

Despite the delay in establishing the education segment of the Center's management team, progress in the field of education has been made. Our plans for the upcoming year primarily center on a concerted effort to refine and clarify our educational objectives and goals, roles and responsibilities, and to refine and expand the scale and effectiveness of current activities. To this end, we have an active process in place. A working team of education-focused participants (Neal Armstrong, Vicente Talanquer, Jenny Franklin, Michael Bruck (all at UA), Jasmine Bryant, Natia Frank, Bruce Robinson, (UW Center Personnel), Laura Collins and Tamara Walser (UW Office of Educational Assessment) meets bi-weekly via videoconferencing for activity planning. We will more clearly define Center and faculty interactions as well as increase our active solicitation of funds to promote and expand educational activities.

APPENDIX IIIa

"*Half Hockey Puck*" Refraction Experiment

Storyboard for Video Recording
3/27/2002 – mab/jf

Video 1. Single Red laser - Refraction

Set up instructions:

1. accurately align and orient polarization of beam
2. accurately align center sample on rotating stage

Recording instructions:

3. **long-view** – record while rotating 360º
4. **zoom** – record while zooming to close-up
5. **close-up** – record while rotating 360º

Post-production instructions

6. combine 3-4-5 into single QTVR with center click on long-view and close-up activating a zoom to the other
7. create roll-over labels for all components of experiment
8. create caption to point out and identify Total Internal Reflectance for appropriate frames of rotating long-view and close-up

Video 2. Single Red laser – Brewster's Angle

Set up (#1) instructions:

1. accurately align and orient polarization of beam
2. accurately align center sample on rotating stage
3. determine method to simultaneously visualize refracted beam passing through sample and intensity and position of reflected beam on outer graduated ring
    a. single camera setup at appropriate angle to view sample and ring
    b. dual cameras setup to view sample and ring separately, synchronize videos in post-production with PIP (picture-in-picture) simultaneous views

Recording instructions:

4. rotate sample through Brewster's angle and record sample and reflected beam position and intensity (illustrate total loss of intensity)

Set up (#2) instructions:

5. re-align polarization of beam by 90º

Recording instructions:

6. rotate sample through Brewster's angle and record sample and reflected beam position and intensity (illustrate no loss of intensity)

Video 3. Dual Lasers, Red and (Green or Blue) – Refraction with Dispersion

Set up instructions:

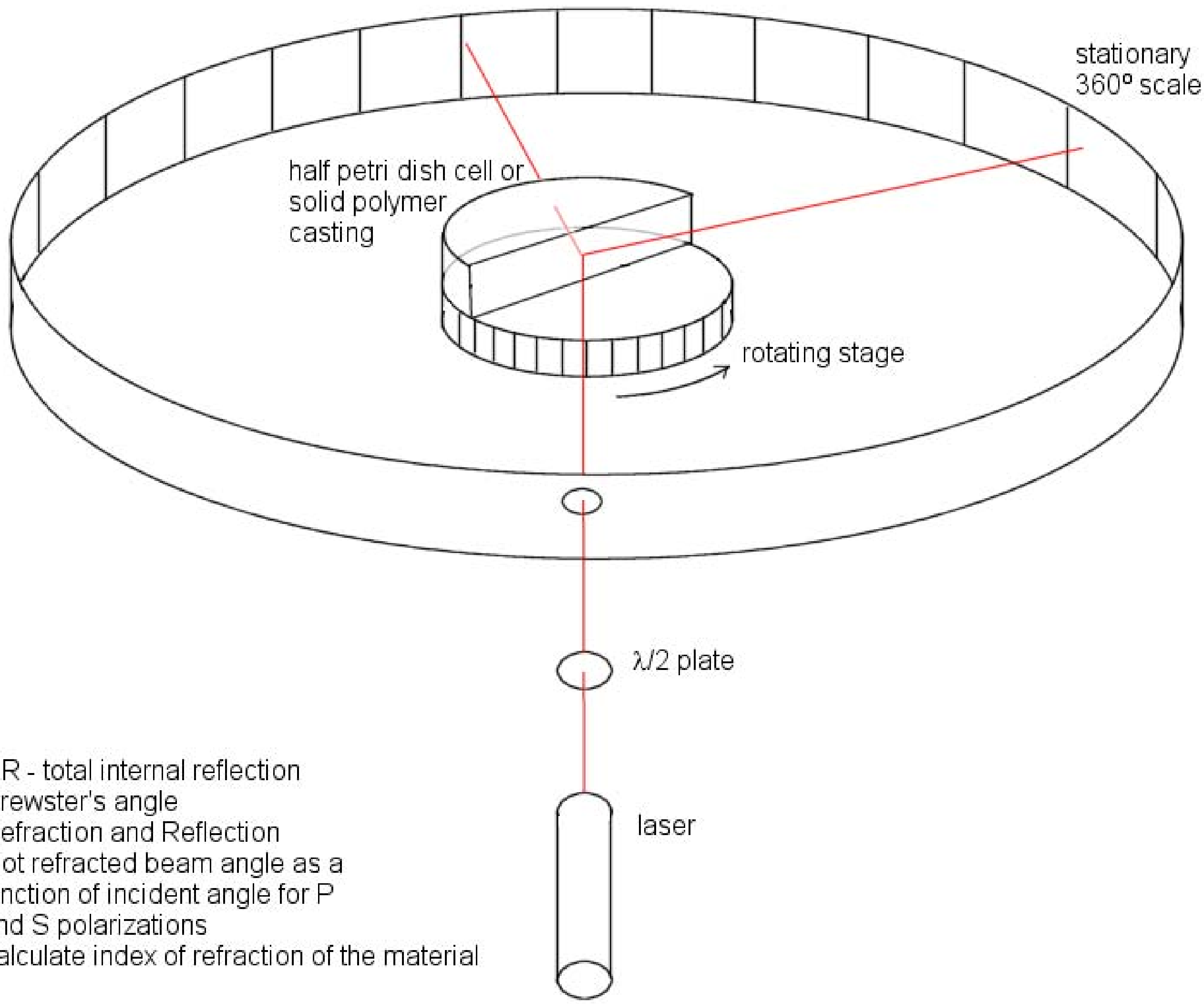
1. accurately align and orient polarization of beam
2. accurately align center sample on rotating stage

Recording instructions:

3. **long-view** – record while rotating 360º
4. **zoom** – record while zooming to close-up
5. **close-up** – record while rotating 360º

Post-production instructions

6. combine 3-4-5 into single QTVR with center click on long-view and close-up activating a zoom to the other
7. create roll-over labels for all components of experiment
8. create pop-up label to identify Total Internal Reflectance for appropriate frames of rotating long-view and close-up



1. TIR - total internal reflection
2. Brewster's angle
3. Refraction and Reflection
4. plot refracted beam angle as a function of incident angle for P and S polarizations
5. calculate index of refraction of the material

IV. KNOWLEDGE TRANSFER

Knowledge Transfer Objectives

The Center's overall knowledge transfer objective is the communication of technical knowledge related to the materials and devices of information technology at multiple levels and in a compelling manner that increases interest in the discipline. Vehicles of knowledge transfer that we will exploit include use of printed matter (texts, encyclopedia chapters, and journal articles), our Center web site, workshops, conferences, special courses, community lectures, science museums, and interactions with industries and Federal research centers.

While overall knowledge transfer objectives have not changed, this period focused on implementing activities that would become continuing knowledge transfer activities. With respect to our proposed annual workshop and conference, we applied for an American Chemical Society Petroleum Research Fund Type H Grant to help leverage funding for our NSF STC efforts. Our application for a Workshop on the Chemistry of Information Technology was one of four proposals selected for funding and we were awarded $125,000 for this Workshop to be held June 18-35, 2003 at the University of Washington. This workshop focuses on knowledge transfer to selected undergraduates, graduate students, postdoctoral fellows, young faculty, and industrial researchers. The proceedings of the workshop/conference will be published in a special issue of the *Journal of Physical Chemistry*. Participants from under-represented groups will be selected assuring an opportunity to increase diversity in the workforce of the discipline. This workshop/conference is also viewed as an opportunity to preview modules developed for our web based educational resource. Moreover, lecture material developed for the workshop is expected to be relevant to the development of future topical modules.

With Marcel Dekker, Inc and John Wiley-VCH publishers, researchers in the Center will develop two texts on the subject of *Polymers for Lightwave and Integrated Optics* and *Polymer-based Waveguides for Integrated Optics*. These topical texts, together with future texts including those that are developed by collaborators at historically black colleges and universities and with special journal issues dedicated to the subject matter of our STC, should prove to be an important reference resource. Again, the writing of these texts should help to develop materials for topically-related web resource modules. Two invited topical reviews of electro-optic research (one of the four thrust areas) have been recently published in Advanced Materials (***Adv. Mater., 2002***, *14(19)*, 1339) and Advances of Polymer Science (***Adv. Poly. Sci., 2003***, *161*, 1). In addition, another invited review in this area was prepared and will be published shortly in the *Journal of Physics: Condensed Matter* (the article is currently available on-line).

A number of corporate seminars have been presented to provide introduction to the STC including at IBM, Agilent, Corning and the Seattle Technology Alliance. Research collaborations that involve frequent knowledge transfer (meetings and reviews) have been launched with Boeing, Lumera, Lockheed Martin, Durel, Focal Point Technologies, Lucent, DuPont, Nitto Denko Corporation, Nippon Sheet Glass, MicroCoatings Technologies, Industrial Technology Research Institute, Air Force Research Laboratories, Pacific Northwest National Laboratory, Redstone Arsenal, China Lake Naval Weapons Laboratory, and Luxtera. Several presentations at international conferences, including the 2003 IUPAC Conference, have been made providing knowledge transfer to the scientific community. Lectures such as the University of Washington Science Forum and Washington Community Development Roundtable have provided knowledge transfer to the general public. Unsolicited invited presentations have also been given to governmental groups (Congressmen McDermott and Dicks; Seattle Mayor Nickels, Select Committee on Science & Technology of the British House of Lords, etc.)

Invited presentations by numerous STC members have also been given at a number of workshops organized by Federal funding agencies including DARPA, NSF, DoE, and MDA. These presentations have proven to the forerunner of awards from DARPA in the areas of Chip Scale Wavelength Division Multiplexing for Mobile Platforms and Chip to Chip Optical Interconnects. These awards not only represent the formalization of knowledge and technology transfer for groups of collaborating center investigators but they also formalize Center/Corporate/Federal Agency technology transfer interactions. An argument can be made that research in the STC inspired to a considerable extent these new initiatives. Three new start-up companies are derivative from the activities of the members of the STC.

Performance and Management Indicators

The initial performance and management indicators will focus on the number of various types of activities. Success will not be judged simply by the criteria of a constantly increasing number of activities but by the maintenance of an acceptable number of activities that contribute to desired knowledge transfer. Evaluation of performance will attempt to take into account factors external to the Center, such as national economy, that nevertheless affect the way that transferred knowledge is received and utilized. The impact of knowledge transfer on those participating in Center workshops will be tracked by surveys that document subsequent choices and performance of participants.

The most difficult problem encountered relates to formalizing the interaction of the STC with industries. This was envisioned as occurring through an Industrial Affiliates group. Requirements of NSF, the State of Washington, and intellectual property issues have made this a complicated and time consuming process to implement and one that must be done with care to ensure its long-term success. Also, the poor economy has influenced the ability of some companies to pay the annual dues despite a clear desire to participate. For example:

- Lucent is interested in collaborating on research (and indeed, such collaboration is occurring informally) but is unable to pay the dues required for membership in the Industrial Affiliates.
- Brewer Sciences' Tony Flaim states "Late 2002 and early 2003 have been difficult for Brewer Science as for many US firms. We've suffered some layoffs and sales are soft at best, meaning we cannot pledge membership at this time. … The 2004 funding, a good portion of which is aimed at developing materials for optoelectronics and MEMS, will enable us to participate more actively in collaborative research. Accordingly, I plan to recommend affiliate membership in MDITR as one of the best investments that Brewer Science can make for its future."

These like many of the problems faced in the past several months largely reflect that the Center has only had a short period of time (from late October to the present--April) to address a range of issues working with constraints. In practice, the rate of development of a working industrial affiliates group has not negatively impacted knowledge transfer and the complexities of the problems associated with its formation are being addressed, in a consultative manner with the Center management, the Strategic Advisory Board, and interested industries.

Knowledge Transfer Activities

Knowledge Transfer Activity	Semiconductor Research Corporation-IFC Topical Workshop on Optical Interconnects, Seattle, WA	
Led by	Semiconductor Research Corporation (SRC) and Defense Advanced Projects Research Agency (DARPA)	
Participants		
	Organization Name	State
1	NSF-STC-MDITR	Washington
2	SRC	California
3	DARPA	Virginia
4	Numerous Industries	Various States

Outcome: Invited presentations by STC participants Dalton (UW) and Scherer (Caltech) presented key segments of this workshop. Subsequently, DARPA released the BAA on Chip to Chip Optical Interconnects. Support for STC research activities in the electro-optic and all-optical materials thrust is being made available through this DARPA initiative. The implementation of this support may be somewhat delayed through the tragic, untimely death of DARPA program manager Dr. William Schneider but this initiative will not only leverage NSF funding but will facilitate enhanced interaction, knowledge transfer, and technology transfer with industry.

Knowledge Transfer Activity	Various DARPA meetings and site visits	
Led by	DARPA	
Participants		
	Organization Name	State
1	NSF-STC-MDITR	Washington
2	DARPA	Virginia
3	Boeing	Washington

Outcome: Award of a DARPA contract for Chip Scale Wavelength Division Multiplexing for Mobile Platforms to Boeing with subcontracts to STC investigators at the University of Washington and the California Institute of Technology. The start-up company would be involved in commercialization (with Boeing) of technology developed. This research is relevant to information management for next generation AWACS and JSTAR platforms as well as satellite platforms.

Knowledge Transfer Activity	NSF/ACS Workshop on the Chemistry of Information Technology--Conference on the Electrical, Optical, and Magnetic Properties of Organic and Hybrid Materials	
Led by	NSF-STC-MDITR	
Participants		
	Organization Name	State
1	NSF-STC-MDITR	Washington
2	Various Universities across the United States	Various States
3	Various Industries	Various States

Outcome: The meeting has not yet been held but is scheduled for June 18-25, 2003. The logistics and program has been finalized. Proceeding will be published in the *Journal of Physical Chemistry*. To leverage NSF funding, a proposal was submitted to the American

Chemical Society Petroleum Research Fund Type H grant program for $125,000 to support this workshop/conference. Our proposal was one of four chosen nationally.

Knowledge Transfer Activity	Los Alamos, Arizona Days Workshop	
Led by	University of Arizona	
Participants		
	Organization Name	State
1	University of Arizona	Arizona
2	Los Alamos National Laboratory	New Mexico

Outcome: Invited presentations by STC participants, Rumi and Marder, presented key segment of this workshop. Aspects of the Center's work on 3D nano and microfabrication chemistry was presented to Los Alamos National Laboratory members. Los Alamos is performing theoretical studies on NSF-STC-MDITR materials, and the MEMs groups at Los Alamos interested in collaborating with STC members on two-photon 3D microfabrication.

Knowledge Transfer Activity	Photonics Initiative Workshop	
Led by	University of Arizona	
Participants		
	Organization Name	State
1	University of Arizona	Arizona
2	University of Washington	Washington
3	NP Photonics Inc	Arizona
4	Numerous Industries	Various States

Outcome: Invited presentations by STC participants Mansuripur: (tutorial on how CDs and DVDs work), Marder, Mazumdar and Kippelen (UA), and Jen (UW) presented key segments of this workshop. Provided industry and academic participants an introduction to research of the NSF-STC-MDITR at a tutorial level. Mansuripur lecture converted laymans presentation of how CD/DVD work which will be available searchably as a streaming video on the UA Virage video system. http://www.vala.arizona.edu/vss-bin/vss_SR/torpey/search

Other Outcomes

Knowledge transfer at various scientific meetings and Federally-sponsored workshops has resulted in interest in utilizing materials developed in this Center in Federal and industrial research laboratories. Materials have been transferred to the Naval Weapons Laboratory at China Lake and to the Army Redstone Arsenal Laboratory for use in the Navy/Army optical gyroscope development program. Materials have been transferred to the Air Force Research Laboratory at Wright Patterson Air Force Based for use in the Air Force electro-optics device program. Intel has commenced funding STC participants (through a contract issued to the University of Southern California) at the rate of $75,000/year for research on electro-optic ring microresonator devices. Durel has initiated collaborative research with STC participants at the University of Arizona on OLED materials. Nitto Denko Corporation has initiated collaborative research with STC participants at the University of Arizona on photorefractive materials. Nippon Sheet Glass Corporation has initiated research with University of Arizona STC participants on all-optical switching materials. STC participants at UCSB and UW are working with DuPont on PLED display materials. STC researchers at UW and USC are working with MicroCoatings Technologies (through a DoD SBIR) on developing new polymer deposition technologies.

Plans for Next Reporting Period

The same type of knowledge transfer activities will be pursued during the next reporting period. At least one and possibly two invited cover feature articles will be prepared for the *Journal of Physical Chemistry*. Center work (Jen) is a basis of a highlight (Marder) in Advanced Functional Materials. An overview article of Center research will be prepared for *Materials Today*. Benefiting from lessons learned in the prototype web module (on refraction) development, efforts will be intensified in the development of web resource modules. Presentations at international conferences will be selectively given more attention. In particular, lectures and tutorials that facilitate collaboration with the European telecommunications community and the Information Society Technology (IST) Program will be pursued including at the 29th European Conference on Optical Communications-14th International Conference on Integrated Optics and Optical Fibre Communication (Rimini, Italy) and the Enrico Fermi and Galieo Galilei Celebrations, International School of Quantum Electronics (Erice, Sicily), ICONO7/ICOPE (Korea), Polymers for Advanced Technologies (FL), 2004 Fragrant Hill Symposium on Molecular and Plastic Electronics and Photonics (China). Members of the STC will submit a proposal to NSF for the creation of an International Materials Institute to foster international collaboration and wide-scale dissemination of information.

V. PARTNERSHIPS

Partnership Objectives

The Center will develop partnerships to enhance the efficacy of research efforts, to enhance education and knowledge transfer, to increase diversity in the workforce, and to promote technology transfer.

Performance and Management Indicators

The Center will establish a database to track partnerships and the outcomes of partnerships. Performance and management indicators will include those already listed for research, education, knowledge transfer, and diversity. These include numbers of joint publications and patents, cooperative workshops and conferences, numbers of members of the workforce involved and most particularly numbers from under-represented groups.

Problems Encountered

The greatest problems encountered have their roots in issues (the economy, funding decisions external to the STC and partnership interactions, etc.) beyond control of the STC. None of these have been showstoppers at this point in time.

Partnership Activities

Partnership Activity		ANLO and Other Designated Minority Institutions	
Led by		NSF-STC-MDITR	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC research facilities & personnel	Collaborative research and education.
2	ANLO Institutions	STC research facilities & personnel	Collaborative research and education.
3	Other Minority Institutions	STC research facilities & personnel	Collaborative research and education.

Goals: To advance the research and educational activities at STC and partner institutions by sharing of resources and by intellectual exchange and to increase diversity at STC institutions and ultimately in the technology workforce by promoting human resource development from under-represented groups.
Output: Collaborative interactions are being initiated. STC personnel are providing support for center activities at designated minority institutions, e.g., Dr. Dalton serves on the advisory board of CREAM at Norfolk State University. Students from partner institutions are being recruited to participate in research and education activities.
Outcome and Impact: It is too soon to assess in a meaningful way the outcome and impact. Collaborative research and publications will definitely occur. STC personnel have assisted designated minority institutions in obtaining some new grants, however, a meaningful assessment can be made only after several years of partnership.

Partnership Activity	Air Force Research Laboratory-Wright Patterson
Led by	AFRL-WP

Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	Materials developed in STC & AFRL-WP cladding materials and device testing facilities	Collaborative research.
2	AFRL-WP	Materials developed in STC & AFRL-WP cladding materials and device testing facilities	Collaborative research.

Goals: To advance the performance of organic electro-optic devices
Output: Collaborative interactions have been initiated and are producing scientific publications.
Outcome and Impact: Collaboration is accelerating the improvement of organic electro-optic devices and advancing technology transfer.

Partnership Activity		DARPA/Boeing/STC Institutions	
Led by		Boeing	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC materials, Boeing engineering expertise nanofabrication capability DARPA funding	Collaborative research.
2	Boeing	STC materials, Boeing engineering expertise nanofabrication capability DARPA funding	Collaborative R&D
3	Luxtera	STC materials, Boeing engineering expertise nanofabrication capability DARPA funding	Collaborative R&D
4	DARPA	STC materials, Boeing engineering expertise nanofabrication capability DARPA funding	Research Product

Goals: To develop high throughput data management platforms based on chip scale wavelength division multiplexing (CS-WDM) for mobile platforms such as next generation AWACS, JSTARS, F-18, JSF-22, and satellite systems.
Output New electro-optic materials are being integrated with silicon circuitry and evaluated in a variety of advanced device structures based on ring resonators, superprisms, and photonic bandgap structures.
Outcome and Impact: If successful, this effort will lead to dramatic reduction in weight and space requirements on mobile platforms and will result in dramatically enhanced data handling capabilities.

Partnership Activity	Naval Weapons Laboratory/Redstone Arsenal/STC
Led by	Naval Weapons Laboratory, China Lake

Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC developed EO materials and device test information	Collaborative research.
2	Redstone Arsenal	STC developed EO materials and device test information	Collaborative research
3	Naval Weapons Laboratory, China Lake	STC developed EO materials and device test information	Collaborative research

Goals: To advance implementation of the Precision Navigation (Optical Gyroscope) Program
Output: Organic electro-optic materials are provided to China Lake and Redstone Arsenal Laboratories and are incorporated into prototype optical gyroscopes. The results of testing are communicated to STC researchers so that improved materials can be developed for this application.
Outcome and Impact: Improved performance of optical gyroscopes has already been achieved using STC materials. If continued improvement can be achieved and important technological advance in navigational guidance will be realized.

Partnership Activity	Intel Corporation Research on Microresonators		
Led by	STC		
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC Microresonator Research	Research Support
2	Intel Corporation	Funding for research ($75k/y)	Technical Information

Goals: To evaluate new signal routing and management technology
Output: The performance of prototype electro-optic microresonators is setting records for data (signal) management by simultaneously exploiting improvements in wavelength and time division multiplexing. Color (wavelength) encoding of information is being achieved with a resolution of 0.01 nanometer over the 1.3 and 1.55 microns telecommunication bands and time division multiplexing is being achieved at a rate of 2-10 Gb/s per wavelength channel. Single chip data rates of 500 Gb/s appear feasible.
Outcome and Impact: The research success could define next generation optical interconnection in computing, not only processor to Internet interconnection, but also module-to-module, chip-to-chip, and on-chip interconnection (signal distribution). Latency and data management bottleneck problems could be greatly reduced with the result of a new era of enhanced computation capability.

Partnership Activity	Lockheed Martin Corporation		
Led by	STC		
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC developed EO materials	Collaborative Research

2	Lockheed Martin	PDS measurements & funding	Collaborative Research

Goals: Improvement of electro-optic materials by research collaboration and sharing of instrumentation facilities
Output: This interaction with Lockheed Martin has greatly enhanced the performance of electro-optic materials by permitting sophisticated materials characterization to be rapidly affected. In particular, measurements such as photothermal deflection spectroscopic measurement of optical loss (not available within the STC) were carried out by Lockheed Martin researchers on materials produced in the STC. Results were shared and published in jointly authored communications.
Outcome and Impact: The efforts and funding support provided by Lockheed Martin contributes important research data into the STC materials development and characterization efforts. Moreover, Lockheed Martin provides independent evaluation of critical materials and device performance parameters (electro-optic activity, stability, drive voltage requirements for different device structures, etc.)

Partnership Activity		New Mexico Highlands University (NMHU)	
Led by		NMHU	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC developed EO materials	Collaborative research
2	NMHU	Characterization	Collaborative research

Goals: Studies of the structure of crystalline NLO materials
Output: This interaction with NHMU has lead to an understanding of the packing in organic chromophores for NLO applications.
Outcome and Impact: The first joint paper in the ANO is in preparation.

Partnership Activity		Durel Corporation	
Led by		STC	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC developed transport materials	Collaborative research
2	Durel	Materials & funding ($120K)	Collaborative research

Goals: Improvement of charge generation and transport in organic and hybrid materials
Output: This interaction with Durel builds upon materials development ongoing in the STC with respect to charge transport materials.
Outcome and Impact: Materials for display applications has been developed. Durel has provided ongoing support to Kippelen and Marder and is considering membership in affiliates program.

Partnership Activity	Nitto Denko Technical Corporation (NDT)
Led by	STC

Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC developed EO materials	Collaborative research
2	NDT	Materials & funding ($200K)	Collaborative research

Goals: Improvement of photorefractive materials by research collaboration and sharing instrumentation facilities
Output: This interaction with NTD builds upon materials development ongoing in the STC with respect to charge transport materials and photosensitizers.
Outcome and Impact: Materials with extremely high photorefractive sensitivities, fast response and excellent phase stability have been demonstrated.

Partnership Activity		Cornell University	
Led by		STC	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC fabrication capabilities	Collaborative research
2	Cornell	Materials	Collaborative research

Goals: Development of positive tone resist for two-photon microfabrication
Output: This interaction with Cornell builds upon materials development and two-photon microfabrication capabilities ongoing in the STC.
Outcome and Impact: Materials with exceptional two-photon sensitivity that can be fabricated in buried channel structures have been demonstrated and a paper has been published in Advanced Materials.

Partnership Activity		Pacific Northwest National Laboratory	
Led by		PNNL	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	Materials & Processing	Collaborative research
2	PNNL	PNNL Funding	Collaborative research

Goals: To accelerate the development of new photonic and electronic technologies and to promote knowledge and technology transfer
Output: Collaborate projects have been launched, PNNL has provided graduate student fellowship support, and collaborative publication are in preparation.
Outcome and Impact: It is too early to characterize long-term outcome and impact, however, Battelle has joined the STC Industrial Affiliates and has a serious interest in participating in technology transfer.

Partnership Activity	Northwestern University
Led by	STC
Participants	

	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	STC developed EO materials	Collaborative research
2	Northwestern University	Merrifield Processing	Collaborative research

Goals: To achieve an alternative approach to incorporating electro-optic materials into photonic crystal structures
Output: Photonic crystal structures and organic electro-optic materials developed in the STC are being sent to Professor Tobin Marks and collaborators at Northwestern University for use with their robotic sequential synthesis exploiting covalent coupling (Merrifield synthesis) method of preparing thin films of electro-optic materials.
Outcome and Impact: It is too soon to ascertain the outcome and impact of this partnership.

Partnership Activity		Center for Technology Entrepreneurship	
Led by		The UW School of Business	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	Faculty and Staff	Education in the Area of Technology Transfer
2	CTE	Faculty and Staff	Education in the Area of Technology Transfer

Goals: The goals are multi-fold and include facilitated interaction of students and faculty in the areas of science, engineering, business, and law in assessing the commercial potential of STC research, in ethics training, in better understanding the process of entrepreneurship, and promoting knowledge and technology transfer.
Output: Output includes (1) the New Venture Creation Laboratory where students from science and engineering work together with students from the School of Business (and Law) to evaluate the commercial potential of research being pursued in the STC, (2) the High-Tech Entrepreneurship Speaker Series of the CTE whereby scientists (from the STC) and successful entrepreneurs from the community share their experiences and research advances, (3) a new certificate program designed to provide graduate students in science and engineering with an introduction to entrepreneurial thinking from a business perspective. A Workshop is being planned to focus on ethics training and technology entrepreneurship.
Problems Encountered: Most faculty and staff changes have had little impact on STC activities and in the area of this partnership the STC has had to deal with a leadership change (the departure of Professor Michael Song from the position of Director of the CTE). Several STC professors, including Larry Dalton and Alex Jen, participated in the proposal (as co-principal investigators) that secured UIF funding for the CTE and the STC has had a major role in CTE activities from the start. However, the CTE program is administratively located in the UW School of Business; thus, the Director of the CTE is appointed by the Dean of the School of Business. With the departure of Professor Song, it was decided to launch a national search for a new Director of the CTE with Professor Suresh Kotha serving as the Interim Director. The decision to pursue a national research focus was reinforced by a $2 million donation from Battelle for an endowed professorship in the School of Business associated with this position. The major impact on STC/CTE activities was that a decision was make to suspend UIF expenditures until the new director was in place. This restriction has forced the delay of implementation of some planned workshops but has otherwise not significantly impacted

activities. In does not affect the award of fellowships to graduate students; these are derivative from private donations (Washington Research Fund, Gates Foundation). The activities noted in Output (above) have proceeded without perturbation.

Outcome and Impact It is too soon to realistically assess the outcome and impact of CTE activities. Certainly, programs such as the High-Tech Entrepreneurship Speakers Series are promoting better contact with the local Seattle Business community. Ethics training is being carried out and increasing involvement of faculty from Science, Engineering, Business, and Law Schools is occurring. An increasingly quantitative assessment can likely be achieved as activities become for formalized.

Partnership Activity		MicroCoating Technology, Inc.	
Led by		NSF-STC-MDITR	
Participants			
	Name of Organization	List Shared Resources (if any)	Use of Resources
1	NSF-STC-MDITR	Materials and Methods	Collaborative Research
2	MicroCoatings Technology	Materials and Methods	Collaborative Research

Goals: To develop more versatile methods of incorporating polymer and dendrimer materials into photonic and electronic device structures.

Output: Several methods of aerosol and vapor phase deposition of macromolecular materials onto and into inorganic and hybrid substrates have been developed. MicroCoatings Technology is providing financial support to the STC in support of this effort. This support level is expected to grow in time. The new deposition technologies are expected to dovetail with the nanoscopic device architectures being developed by STC faculty member Axel Scherer and with the mesoscale device architectures being developed by Bill Steier.

Outcome and Impact: It is too soon to assess long-term outcome and impact but this could be an important manufacturing technology complementing techniques such as spin coating and Merrifield-type sequential (robotic) synthesis.

Other Outcomes

Other outcomes have been recruitment of new graduate students and improvement of diversity of the STC. The most obvious example of this has been the interaction with the ANLO and other designated minority institutions but it has also occurred with industrial interactions. For example, Susan Soggs, an electrical engineer working with Motorola, has decided to pursue a Ph.D. in electrical engineering at UW working with Professor Dalton. She will pursue collaborative research with Professor Ray Chen of the University of Texas at Austin. Takashi Kondo of Lintec Corporation has decided to work with Professor Marder at Georgia Tech on a collaborative program with Professor Kippelen on transport materials. A female undergraduate from New Mexico Highlands University has chosen to pursue her PhD in chemistry working with Professor Perry at Georgia Tech. Neil Tucker, an undergraduate student working with Professor Marder at University of Arizona, has chosen to pursue his PhD at UW as part of the STC. The interactions of the STC have permitted unique training to occur that simply would not have been possible without the existence of the STC.

Plans for Next Reporting Period

Partnership interactions are expected to grow in the next period particularly as members of the STC will be able to coordinate with foreign scientists (e.g., EC) at international meetings in the

Fall of 2003. The Industrial Affiliates program should come into play during the next reporting period providing a logical platform for launching and publicizing partnerships efforts.

VI. DIVERSITY

Diversity Objectives

Increasing diversity in the personnel (students, postdoctoral fellows, faculty, advisory board members, and staff) of this Center is a high priority. This action is expected to ultimately translate into an enhanced diversity in the information technology research and development workforce. Increased diversity in the Center will be achieved by the following specific actions: (i) Diversity in the faculty participants of the Center will be increased by new faculty additions, including those hires explicitly committed to this Center. The Center will provide these new additions a supportive environment with reasonable Center financial support for their research and educational efforts, and mentoring supportive for the realization of their career objectives. These new faculty additions represent important role models for students from under-represented groups. (ii) In like manner, the Center will commit funding for the recruitment of graduate and undergraduate students from under-represented groups into center activities. These students must be nurtured in a supportive environment that recognizes and enhances individual professional aspirations. These students are the key to early stage enhancement of diversity in the workforce. (iii) Recognizing that long-term and truly significant improvement in diversity requires attention to K-12 education, this Center will actively focus on K-12 populations with the greatest percentages of individuals from under-represented groups. K-12 student-mentoring activities will be initiated in collaboration with university minority outreach offices and with the public school systems. Appointments to the Strategic Advisory Board from the public sector (city and state officials responsible for relevant public education programs) and from under-represented groups will aid oversight of these activities. (iv) Public presentations by faculty and students of the Center and public access to the Flandrau Science Center (at the University of Arizona) can play a role in influencing the public perception of those pursuing careers in science and engineering. This public perception can, in turn, play a role in the decisions of individuals from under-represented groups to enter careers in science and engineering. The personnel of this Center will make public outreach presentations and provide resource materials that will positively impact the career decisions of individuals from under-represented groups. The participation of such individuals will be longitudinally tracked at all levels.

Performance and Management Indicators

In the initial stage of this STC, performance and management indicators must simply be numbers of individuals from under-represented groups recruited into the Center. Retention and human resource development will be indicators that can be evaluated in later years. Although we have launched vigorous proactive efforts aimed at addressing increased diversity at all levels and in all activities of the Center, it is too early to realistically assess (except in an anecdotal way) diversity gains in the K-12, undergraduate, graduate, and postdoctoral communities. However, all three hires to the core (full time) day-to-day operational management structure (Director, Administrator, and Director of EHRDO) have been from under-represented groups (URGs) raising the percentage from URGs to 80%. Of faculty members on the Executive Committee (the key management body of the Center), 4 of the 10 members (40%) are from under-represented groups including African American, American Indian, Hispanic, and Female. Of the two new faculty additions to the research component of the Center (Professor Michal Lipson from the Department of Electrical Engineering at Cornell University and Professor Galen Stucky from the Department of Chemistry at University of California, Santa Barbara), one is from an under-represented group. The Center has been very successful in attracting both female students and members of underrepresented minorities at the undergraduate, graduate and postdoctoral levels. The statistics for undergraduates, graduate students, and postdoctoral fellows are available in Section VIII. of this report.

Problems Encountered

A major concern with increasing diversity is to not lose sight of the individual from the under-represented groups. Professional development and retention through mentoring at the individual level is critical. Also, substance and content in outreach effort are important. Thus, a heroic and sympathetic participation by all center personnel is critical to the success of efforts to increase diversity. It is important to keep in mind that this battle is largely one of small number statistics, and individual success stories, as well as statistical trends, are important.

Other problems include the short time period between funding of this Center and the current reporting period which does not allow for other than a preliminary implementation of meaningful outreach programs. More funding for efforts to increase diversity could always be used. In particular, at Georgia Tech, several new potential faculty members for the STC who are minorities or female have been identified, but our ability to recruit them into the STC will be in large part dictated by the available level of resources.

Contributions to the Development of Human Resources

With the funding of this Center, an effort was immediately launched to increase the diversity of participation in research activities at the undergraduate, graduate, K-12, postdoctoral, and faculty levels. Efforts were made to improve coordination with the ANLO and colleges/universities with significant populations from under-represented groups. For example, Professor Dalton gave seminars at Norfolk State University and Florida International University. He participated on the scientific advisory broad of the CREAM Center at NSU and assisted several universities in the preparation of proposals to funding agencies (as did other members of the STC). Increased research collaboration with these colleges and universities was organized and plans for summer 2003 research activities were developed. In like manner, meetings were held with faculty and students from K-12 institutions with large populations from under-represented groups and with community leaders (including the Mayor of Seattle and members of the Washington State Legislature). Public lectures were given in community forums (the UW Science Forum, the Seattle Community Development Roundtable, the Seattle Technology Alliance). Efforts were made to coordinate with other education and outreach efforts including the Gates Foundation (through coordination with SAB member Martin Smith), various university, city, and state efforts, and industrial efforts (Boeing, etc.). Jasmine Bryant (who has a Ph.D. in chemistry and experience teaching at the K-12 level) was recruited as Director of EHRDO. At the University of Arizona, Rachel Morgan has been extended an offer of a postdoctoral position working under the mentorship of Vicente Tanaquer to take a leadership role in the development of K-12 modules and outreach to secondary schools in the Tucson school district. Professor Natia Frank, who has demonstrated exceptional capability in managing the graduate recruitment program for the Department of Chemistry at the University of Washington, was given responsibility for the integration of EHRDO and research activities. Additionally, in February a team from Optical Sciences Center at UA did a two day visit to Dine College in Tsaile, AZ, Navajo Reservation, the goal was to bring information to students who have very little exposure to the opportunities awaiting them at the University. This is Arizona's northernmost reservation and borders New Mexico.

During this first reporting period, much attention was focused on developing a workshop on information technology research that would serve both to provide training and as a recruitment vehicle. To leverage NSF STC funding, a proposal was prepared and submitted to the Petroleum Research Fund Type H Grant Program of the American Chemical Society for a Workshop on the Chemistry of Information Technology, special efforts have been made to communicate the opportunity to attend this workshop to minority institutions. This workshop was coupled with a scientific conference on photonic and electronic materials with the intention that these would serve as important recruitment forums (particularly by targeted marketing to those from under-represented groups).

Plans for the Next Reporting Period

Programs involving undergraduate research experiences will be continued into the next reporting period. Following evaluation of current activities at the end of summer 2003 (incorporating analysis from the July 2003 site visit and from the STC Directors' Meeting), we will launch planning of programs for 2003-2004. Workshops focused on undergraduate and graduate students and on K-12 will almost certainly be planned. Efforts will be made to strengthen ties to the ANLO and designated minority institutions. Student and faculty exchanges will be encouraged. Research proposals will be solicited and STC faculty will be encourage to personally assist the research, education, and proposal writing efforts of ANLO faculty and faculty from other designated minority institutions.

Efforts to increase diversity will continue to be an issue in anticipated searches for new faculty positions at the participating STC institutions. The same can be said for staff hires.

The anticipated move of four faculty to Georgia Tech provides a unique opportunity to enhance diversity in the Center.

- Already, a new female student has chosen to attend Georgia Tech specifically because of the opportunity to participate in the STC and will be attending the ACS sponsored workshop this summer.
- Two faculty members at Georgia Tech have been identified and asked to join the STC with seed programs this coming year, both are members of underrepresented minorities.
- ANLO and other minority schools in Atlanta Area: Clark Atlanta, Moorehouse, Spelman College can interact closely with faculty at Georgia Tech throughout the school year.
- Georgia Tech is historically a leading institution for the training of under-represented minority students and is:
    1. No. 1 producer of African-American engineers at the bachelor's, master's, and doctoral levels
    2. No. 2 in engineering bachelor's degrees awarded to all categories of minority students
    3. No. 4 in engineering master's degrees awarded to all categories of minority students
    4. No. 3 in engineering doctoral degrees awarded to all categories of minority students
    5. No. 4 in engineering doctoral degrees awarded to Hispanic students

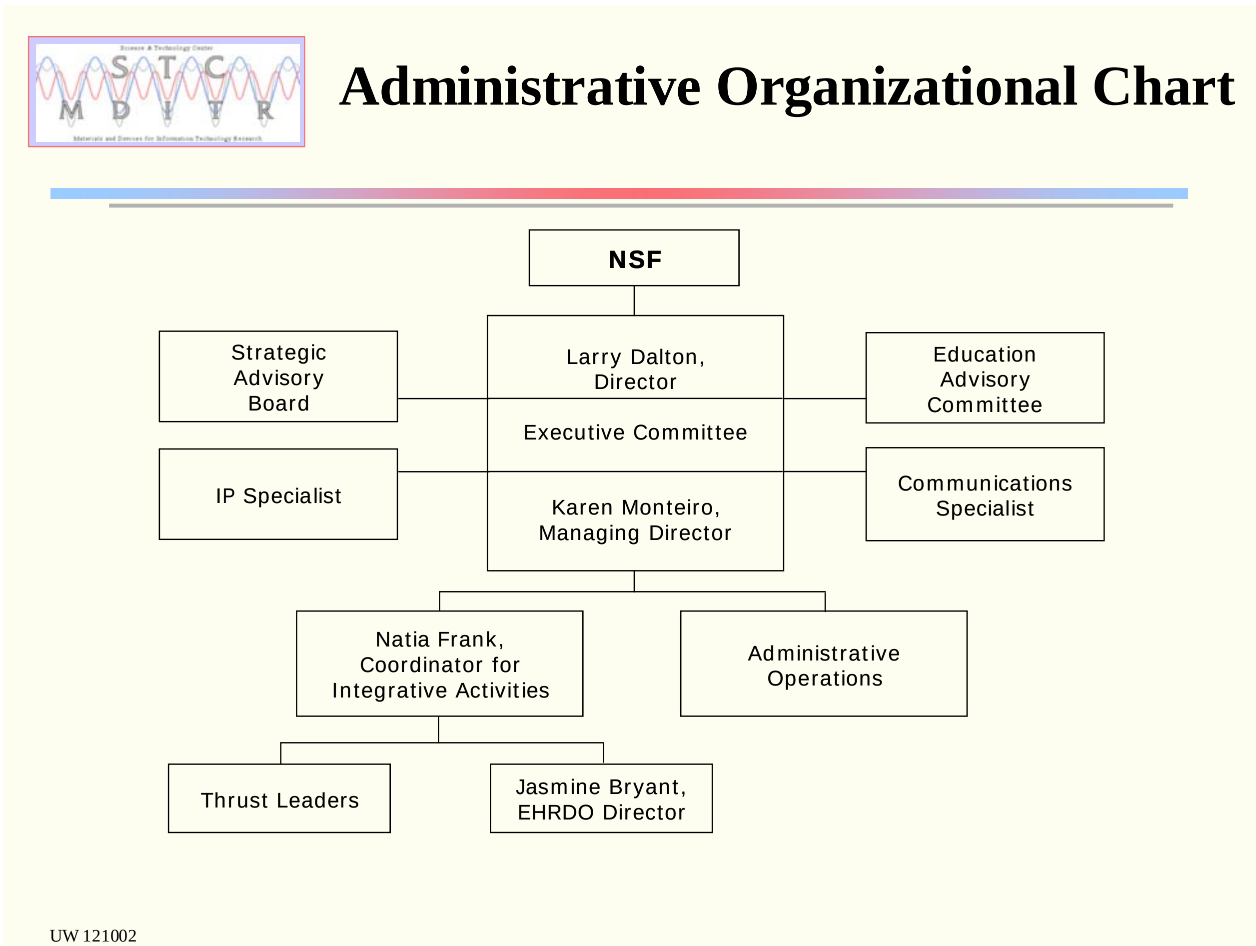
Impact of Activities on Enhancing Diversity of the Center

The activities that have been undertaken and those described in the planned activities represent a clear and substantial commitment to the enhancement of diversity at *all levels within the center.* The impact at the K-12 level can be evaluated meaningfully only over a longer period of time. Faculty and staff hires continue to be a area of emphasis and discussions candidates have been initiated but it is premature to elaborate further until offers have been officially extended and accepted.

VII. MANAGEMENT

Organizational Matters

There have been no major changes in the Center's organizational strategy although there have been some refinements to the original organization chart submitted with the proposal. These refinements are, in part, a response to the NSF requirement for specific administrative positions such as a full-time managing director and a full-time education and outreach director, and in part from practical considerations that have emerged as the Center has been launched. Below is the current organizational chart.



The Management Team meets on a weekly basis by videoconference (unless the agenda does not justify the time of the entire group in which case only the local UW group meets). The Executive Committee consists of the following personnel:

EXECUTIVE COMMITTEE

Administrators
Larry R. Dalton, Director

Alvin L. Kwiram, Executive Director (Chair)
Karen M. Monteiro, Managing Director

Associate Directors
Bruce H. Robinson
Seth Marder
Aaron W. Harper
Neal Armstrong
Natia Frank
Alex Jen

Thrust Leaders
Joseph Perry
Bernard Kippelen
Bruce H. Robinson
Alex Jen

ANLO
Tatiana (Tanya) Timofeeva

SAB
Edel Wasserman (Ex Officio)

The Strategic Advisory Board and the Education Advisory Committee provide advice to the Management Team. In addition, the Knowledge Transfer functions and a Communications function also are linked to the Management Team.

We are pleased that we can now fill in some additional names on our organizational chart. In particular, Karen Monteiro has been appointed as full-time Managing Director of the Center. Karen comes to us from the School of Medicine where she was Administrative Director of the General Clinical Research Center at the University of Washington. She was our first choice out of some forty candidates identified through a national search. She will begin her duties on May 6, at 60% time, and then ramp up to full-time within a month or so as she makes the transition from her present position. From the time that NSF notified us of the award until the time of the offer to Karen took six months.

Likewise, we are pleased to announce the appointment of a full-time Director for the EHRDO program, Jasmine Bryant. Jasmine was our top (full-time) candidate for the position out of some forty candidates that responded to our nationally advertised opening. She began her official duties as of April 18 although she had already worked on a temporary basis since mid-March. Jasmine has a PhD in chemistry from the University of Washington and a Masters in Teaching from Seattle University. She has worked at the Pacific Science Center and taught for two years in middle school and high school.

A few individuals have also decided not to continue in the roles originally envisioned. In our original proposal, Gretchen Kalonji was designated as the Executive Director for EHRDO, and she was involved in the refinement of our education and outreach program for the site visit. However, the subsequent requirement by NSF that there be a full-time Director for EHRDO created complications. Professor Kalonji obviously was not able to become a full-time director, and with a full-time director it was less obvious what the role of the Executive Director would be and how the authority and responsibilities would be divided. After considerable discussion and reflection, Professor Kalonji decided that her expertise could be more effectively used in other programs and she decided to resign from her proposed role in the Center. It remains to be seen whether we will revisit that position or whether we have the necessary human resources in place to mount a strong program in this area.

Likewise, Carl Dirk, former Director of the ANLO program, stepped down from that position and has been replaced by Tatiana Timofeeva. She has participated actively in the Management Team deliberations.

A half-time fiscal specialist, Cyril Margate, has been hired to manage the financial affairs of the Center. A full-time webmaster, Joe Marquez, has been hired to develop the Center website and to manage our telecommunications infrastructure. In addition, a half-time intellectual property officer will soon be appointed who will serve both the Center's programs at the University of Washington as well as the broader photonics programs on campus and will also serve as the Center's liaison on intellectual property matters with the other participating institutions.

Finally, Natia Frank, Assistant Professor of Chemistry, has been appointed as Associate Director for Integrative Activities. Her responsibilities will be, in part, to ensure that there is meaningful coordination between the research activities of the Center and the Education and Outreach activities. She serves as an active member of the Executive Committee and, together with Co-Director, Bruce Robinson, has led our EHRDO efforts during this start-up phase.

Performance and Management Indicators

The original expectation was that the leadership of the Center in consultation with the SAB would develop a set of performance indicators for the Center. Since then, NSF has retained Abt Associates who have developed a comprehensive array of performance measures essentially superseding the role that might have been anticipated for the SAB. We are in the process of developing the databases mandated by NSF via Abt Associates, and a wide array of information is included in this report. We will evaluate this information at the time of the SAB meeting in June to determine whether there are some keystone measures that we should focus on to help us evaluate whether we are making the desired progress with respect to the goals stipulated by NSF. Obviously, the broad objectives are reasonably clear:

- we seek to advance the scientific frontiers in significant and easily recognizable stages as outlined in our Strategic Plan;
- we seek to have a significant impact on the K-12 community, on undergraduate programs both instructional and research, on graduate education, and on the broader continuing education community who wish to learn about the field represented by the Center;
- we seek to expand the opportunities in science of the underrepresented minority community and women by an aggressive outreach program including mentoring activities to ensure greater diversity of the workforce in this field;
- we seek to bring the knowledge developed through the work of the participants in the Center to the public both in terms of published research results, but also in terms of commercial applications where possible and practical;
- we seek to enlist the interest of industry to ensure that the needs of the marketplace are understood by the Center participants and that the private sector understands the implications of the research carried out in the Center; and finally
- we seek to give visibility to the accomplishments of the Center so that the public can understand both the return on their investment and the exciting opportunities these scientific advances create for them and for society at large.

We will continue to refine the management structure to achieve these macroscopic goals, and will continuously examine the variety of measures to develop a sense of the collective activities that contribute to our goals. While we must pay due attention to metrics, our policies and procedures must ensure that we do not lose sight of the critical role of the Center: to provide an environment that nurtures creativity; to support those who are willing to take intellectual risk; and to devote the time to be mentors for our colleagues.

Finally, we are providing substantial support to the Office of Educational Assessment at the UW. The OEA staff will work with the Center not only to refine the various performance measures, particularly in the education and outreach arena, but in addition will actually gather the data from the communities with whom we will be engaged to determine the impact and efficacy of our efforts. These efforts are just getting underway and we are not yet in a position to provide specific outcomes for their work.

Problems Encountered

We have encountered no major problems in our start-up phase that would not be expected for an organization just getting launched. There are obvious growing pains and adjustments that have to be made as we proceed to create the Center. We believe we have made excellent progress on all fronts including the recruiting of personnel as described above, as well as the acquisition, distribution, installation and implementation of telecommunications equipment for videoconferencing. Minor issues would include the difficulty in enlisting the attention of some of our participants to the myriad of administrative overhead that is associated with a Center grant.

A more substantive challenge that we will face in the next reporting period is the anticipated move of four of the key faculty from the University of Arizona to the Georgia Institute of Technology. We are not able to report on this matter at this time (although we expect to have much more information at the time of the Site Visit) because the negotiations of those individuals are still ongoing with their respective institutions. However, we are in touch with the two institutions to ensure that the interests of the Center are being considered in the discussions, that matching requirements are recognized and met, and that the intellectual property agreement is agreed to and signed by Georgia Tech if and when an agreement is consummated.

One of the novel goals of the Center was to enlist the help of the Center for Technology Entrepreneurship in the School of Business (CTE) together with the Office of Intellectual Property and Technology Management (OIPTT) to create a more dynamic program in technology transfer than might be the case traditionally. This effort has not yet taken hold in part because there has been a leadership change in the CTE and in part because we have not had someone who could dedicate sufficient time to the intellectual property issues of the Center. We anticipate that both of these problems will be resolved in the coming months (as indicated above, an offer has been made for the intellectual property management position), and this part of the Center program will have much more to report next time.

Another minor problem was encountered in connection with our industry consortium plans. After considerable discussion both within the Center and with the SAB we arrived at a draft agreement for an industry consortium. However, after further exploration of the implications, especially in connection with intellectual property matters, it was decided to go in the direction of an Industry Affiliates program instead of a formal consortium. The major difference in the Affiliates model is that the membership fee is tendered essentially as a gift that obviates the need for the agreement with the complex intellectual property terms. After further consultation with our industry contacts this seemed like the best alternative. Upon implementation, however, we discovered that a number of companies find it difficult to negotiate the internal corporate approval process for a gift. This has necessitated further discussions and negotiations within the institution and with prospective sponsors. We are making progress and have already received some funds for the Affiliates program. We hope to expand that in the coming months although the current difficult business climate has dramatically dampened the enthusiasm of companies for such sponsorships.

Integration

Integration is clearly a high priority for the NSF Centers and is an essential element to justify the existence of a Center rather than funding individual projects. As indicated above, we have explicitly addressed this problem not only by constantly emphasizing this goal in our Management Team meetings, but also by appointing an Associate Director, Natia Frank, as described in 1a above, with the specific task of seeking greater integration of the research and education efforts. We believe there is a strong philosophical commitment to this goal on the part of the major participants and the progress toward this goal in the few months we have had has been excellent.

However, it is not an easy matter to engage all the participants at a comparable level. In other words, when a faculty member is receiving much less support from the Center than she receives from her own single investigator grants she tends to be less than enthusiastic about the extensive reporting requirements of the Center. As a consequence, it is at times difficult to get responses to requests for the wide range of statistical information that some do not believe is always justified or productive. To address this problem we will simplify as much as possible the reporting requirements, will ask the faculty to designate a graduate student or staff person who would be the point person for such information requests, and will work with NSF to ensure that all the information being requested is truly essential.

A second means for improving integration is to have frequent communications with the participants, to continuously emphasize the key goals of the Center, and to test how well we are addressing them. The weekly Management Team meetings help to facilitate this communication. In the last month, we have begun regular videoconferencing sessions. In time, videoconferencing among subsets of the participants in the Center will probably become routine. We feel this improves the exchange of information. For example, in our recruiting efforts for the administrative directors, representatives from the University of Arizona were members of the respective Search Committees. The final interviews were held by videoconference so that the UA member of the Committee could participate and see the responses and body language of the candidates. This was very effective, and we believe it led to better outcomes.

STRATEGIC ADVISORY BOARD

	Name	Affiliation
1	Ray Baughman	University of Texas at Dallas
2	Neal Dempsey	Bay Partners
3	Christos Dimitrakopoulos	IBM
4	James Dye	Michigan State University
5	Susan Ermer	Lockheed Martin Advanced Technology Center
6	Stephen Forrest	Princeton Mat. Inst., Optoelect. Components
7	Petra Franklin	Vault Capital

8	Peter Gunther	ETH, Zurich
9	Waguih Ishak	Agilent Labs
10	Rick Lytel	Sun Microsystems, Inc.
11	Admiral William Owens	Teledesic, LLC
12	Rick Rashid	Microsoft
13	Elsa Reichmanis	Bell Laboratories, Lucent Technologies
14	James Rottsolk	Cray Inc.
15	Martin Smith	Preston Gates
16	Jonathan St. Clair	Boeing
17	Edel Wasserman	DuPont

VIII. CENTER-WIDE OUTPUTS AND ISSUES

CENTER PUBLICATIONS (Peer Reviewed Publications denoted in bold)

1. P. Rabiei, W. H. Steier, C. Zhang, and L. R. Dalton, "Integrated WDM Polymer Modulator," in Optical Society of America Trends in Optics and Photonics, Vol. 70, Optical Fiber Communication Conference, Technical Digest (Optical Society of America, Washington DC, 2002), pp. 31-33.

2. L. R. Dalton, "New Center for IT Research," *Materials Today*, 5 (September), 38-41 (2002).

3. **P. Raibiei, W. H. Steier, C. Zhang, and L. R. Dalton, "Micro-Photonic Polymer Device," *International Optical Communications*, 14-6 (Autumn, 2002).**

4. **L. R. Dalton, B. H. Robinson, A. K. Y. Jen, W. H. Steier, and R. Neilsen "Systematic Development of High Bandwidth, Low Drive Voltage Organic Electro-Optic Devices and Their Applications," *Opt. Mater.,* 21, 19-28 (2003).**

5. **P. Rabiei, W. H. Steier, C. Zhang, and L. R. Dalton, "Polymer Micro-Ring Filters and Modulators," *J. Lightwave Technology*, 20, 1968-75 (2002).**

6. **S. Liu, M. A. Haller, H. Ma, L. R. Dalton, S. H. Jang, and A. K. Y. Jen, "Focused Microwave-Assisted Synthesis of 2,5-Dihydrofuran Derivatives as Electron Acceptors for Highly Efficient Nonlinear Optical Chromophores," *Adv. Materials*., 15, 603-7 (2003).**

7. **S-W Ahn, W. H. Steier, Y-H Kuo, M-C Oh, H-J Lee, C. Zhang, H. R. Fetterman, "Integration of electro-optic polymer modulators with low-loss fluorinated polymer waveguides" *Optics Letters*, 27, 2109 December (2002)**

8. **Y. Enami, G. Meredith, N. Peyghambarian, M. Kawazu, and A. K.-Y. Jen, "Hybrid electro-optic polymer and selectively buried sol-gel waveguides," *Appl. Phys. Lett.* 82(4), 490-2 (2003)**

9. **Yasufumi Enami, "Electro-Optic Polymers and Waveguide Modulators", PhD Dissertation, December 2002**

10. **W. Stier and O. V. Prezhdo "Non-adiabatic molecular dynamics simulation of light-induced electron transfer from an anchored molecular electron donor to a semiconductor acceptor," *J. Phys. Chem. B*, 106 8047 (2002)**

11. **W. Stier and O. V. Prezhdo "The effect of thermal fluctuations on the light-induced electron transfer from an anchored molecular electron donor to a semiconductor acceptor", *Isr. J. Chem*. 42 213-224 (2003)**

12. **Yu. V. Pereverzev, O. V. Prezhdo, L. R. Dalton "A model of phase transitions in the system of electro-optical dipolar chromophores subject to an electric field", *J. Chem. Phys*., 117 3354 (2002)**

13. **O. V. Prezhdo "Assessment of theoretical approaches to the evaluation of dipole moments of chromophores for non-linear optics," *Adv. Materials*, 14 597 (2002)**

14. **Kernag, C.A.; McGrath, D.V., "Non-aggregating octasubstituted dendritic phthalocyanines," *Chem. Commum.* 1048-1049, (2003)**

15. **B. Domercq, R. D. Hreha, Y.-D. Zhang, N. Larribeau, J. N. Haddock, C. Schultz, S. R. Marder, B. Kippelen, "Photo-patternable hole transport polymers for organic light-emitting diodes," *Chemistry of Materials*, 15, 994-999 (2003).**

16. **H. Ma, S. Liu, J. Luo, S. Suresh, L. Liu, S. H. Kang, M. Haller, Takafumi Sassa, L. R. Dalton, and Alex K.-Y. Jen, "Highly Efficient and Thermally Stable Electro-Optic Dendrimers for Photonics", *Adv. Func. Mater.*, 2002, 12, 565.**

17. **F. Kajzar, K. S. Lee and A. K-Y. Jen, "Polymeric Materials and Their Orientation Techniques for Second-Order Nonlinear Optics", Special Issue for Polymers for Photonic Applications, Invited Review, *Adv. Poly. Sci.*, 2003, 161, 1.**

18. **J. Luo, H. Ma, M. Haller, A. K.-Y. Jen and R. R. Barto, "A Fluorinated Dendritic Nonlinear Optical Chromophore with Improved Comprehensive Properties for Electro-Optics," *Chem. Commun.*, 2002, 8, 888.**

19. **J. Luo, S. Liu, M. Haller, L. Liu, H. Ma, Alex K-Y. Jen, "Design, Synthesis, and Properties of Highly Efficient Side-chain Dendronized Nonlinear Optical Polymers for Electro-optics", *Adv. Materials.*, 2002, 14(23), 1763.**

20. **H. Ma, A. K-Y. Jen, and L. R. Dalton, "Polymer-Based Optical Waveguides: Materials, Process, and Devices", *Adv. Materials*., 2002, 14(19), 1339.**

21. L. R. Dalton, A. K. Y. Jen, B. H. Robinson, and W. H. Steier, "The Rational Design and Production of Organic Electro-Optic Materials and Devices," *Proc. GOMAC*, 2002, 152.

22. **Y. Enami, N. Peyghambarian, M. Kawazu, and A. K-Y. Jen, "Hybrid Electro-optic Polymer/Selective Buried Sol-gel Waveguides for the Integration of Phase-Modulator at 1.55 mm," *Appl. Phys. Lett.*, 2003, 82(4), 490.**

23. **S-W Ahn, W. H. Steier, Y-H Kuo, M-C Oh, H-J Lee, C. Zhang, H. R. Fetterman, "Integration of electro-optic polymer modulators with low-loss fluorinated polymer waveguides," *Optics Letters*, 2002, 27, 2109.**

24. R. Chen, T. E. Hogen-Esch, "Synthesis And Characterization Of Macrocyclic Poly(4-N,N-Dimethylaminostyrene)" *ACS Div. Polym. Sci, Polym. Prepr.* 2002, 43(2),1142.

25. R. Chen, T. E. Hogen-Esch, "Synthesis And Spectroscopic Studies Of Macrocyclic Poly (9,9-Dimethyl-2 Vinyl fluorene)" *ACS Div. Polym. Sci, Polym. Prepr.* 2003, 44(1) 972.

26. **J. M. Johnson, X. Chen, A. C. Germaine, X. Zang, K. Alberty; T. E. Hogen-Esch, S. E. Bradforth, "Spectroscopy Of Macrocyclic Poly(9,9-Dimethyl-2-Vinyl-Fluorene) As An Artificial Light Harvester", in Ultrafast Phenomena XIII, ed. Miller, Springer-Verlag (2003)**

27. **T. Yu, C. K. Ober, S. M. Kuebler, W. Zhou, S. R. Marder, and J. W. Perry, "Chemically-Amplified Positive Resist System for Two-Photon Three-Dimensional Lithography," *Adv. Materials.*, 15, 517- 521 (2003).**

28. M. Cha, G. Ramos-Ortiz, H.T. Kim, H. Choi, S. Thayumanavan, J. Mendez, S. R. Marder, B. Kippelen, "Broadband efficient third-harmonic generation in an organic film," to be presented at CLEO, Baltimore.

29. **Li YY; Goddard WA; Murthy NS, "Crystal structure and properties of N6/AMCC copolymer from theory and fiber XRD," *Macromolecules,* 2003, Vol 36, Iss 3, pp 900-907.**

30. Casanova J; Kent DR; Goddard WA; Roberts JD, "Quantum-mechanical calculations of the stabilities of fluxional isomers of C4H7+ in solution," *Proceedings Of The National Academy Of Sciences Of The United States Of America 2003*, Vol 100, Iss 1, pp 15-19.

31. **Jang YH; Goddard WA; Noyes KT; Sowers LC; Hwang S; Chung DS, "pK(a) values of guanine in water: Density functional theory calculations combined with Poisson-Boltzmann continuum-solvation model," *J. Phys. Chem. B* 2003, Vol 107, Iss 1, pp 344-357.**

32. **Li YY; Goddard WA, "Nylon 6 crystal structures, folds, and lamellae from theory," *Macromolecules* 2002, Vol 35, Iss 22, pp 8440-8455.**

33. **Jang YH; Chang XY; Blanco M; Hwang SG; Tang YC; Shuler P; Goddard WA, "The MSXX force field for the barium sulfate-water interface," *J. Phys. Chem. B,* 2002, Vol 106, Iss 38, pp 9951-9966.**

34. **Luo SN; Cagin T; Strachan A; Goddard WA; Ahrens TJ, "Molecular dynamics modeling of stishovite," *Earth And Planetary Science Letters 2002*, Vol 202, Iss 1, pp 147-157.**

35. **T. Yu, C.K. Ober, S.M. Kuebler, W. Zhou, S.R. Marder, and J.W. Perry, "Chemically Amplified Positive Resists for Two-Photon Three-Dimensional Microfabrication," *Adv. Materials*, 15, 517-521 (2003).**

36. **Zheng J, Balasundaram R, Gehrke SH, HEffelfinger GS, Goddard WA, Jiang SY, "Cell multipole method for molecular simulations in bulk and confined systems," J. Chem. Phys., Vol 118, Iss 12, 5347-5355 (2003).**

MANUSCRIPTS SUBMITTED (Peer Reviewed Publications denoted in bold)

37. **L. R. Dalton, "Rational Design of Organic Electro-Optic Materials," *J. Phys. Condensed Matter*, (in press).**

38. **L. R. Dalton and D. H. Bale, "Nonlinear Optical Materials," Kirk-Othmer Encyclopedia of Chemical Technology, Fifth Addition, (submitted).**

39. G. Khalil, C. Costin, J. Crafton, S. Grenoble, M. Gouterman, J. Callis, and L. R. Dalton, "Dual Luminophor Pressure Sensitive Paint. I: Ratio of Reference to Sensor Giving a Small Temperature Dependency," *Sensor and Actuator*, (submitted).

40. B. Zelelow, G. E. Khalil, G. Phelan, B. Carlson, M. Gouterman, J. B. Callis, and L. R. Dalton, "Dual Luminophor Pressure Sensitive Paint. II: Lifetime Based Measurement of Pressure and Temperature," *Sensor and Actuator*, (submitted).

41. S. H. Kang, J. Luo, H. Ma, R. R. Barto, C. W. Frank, L. R. Dalton, and A. K. Y. Jen, "A Hyperbranched Aromatic Fluoropolyester for Photonic Applications," *Macromolecules*, (submitted).

42. L. Edman, M. Pauchard, B.Liu, G. Bazan, D. Moses, A.J. Heeger, "Novel Single-Component Light-Emitting Electrochemical Cell with Improved Stability," *Appl. Phys. Lett*., (submitted).

43. L. Sun, J. Kim, C.-H. Jang, A. Dechang, X. Liu, Q. Zhou, , J. M. Taboada, R. T. Chen, J. J. Maki, S. Tang, H. Zhang, W. H. Steier, C. H. Zhang, and L. R. Dalton, "Polymeric Waveguide Prism-Based Electro-Optic Beam Deflector," *Opt. Eng.,* 41, in press.

44. G. M. Spinks, G. G. Wallace, L. S. Fifield, L. R. Dalton, A. Mazzoldi, D. DeRossi, I. I. Khayrullin, and R. H. Baughman, "Pneumatic Carbon Nanotube Actuators," *Adv. Materials.*, (submitted).

45. A. K. Y. Jen, J. Luo, S. Liu, M. Haller, H. Ma, L. Liu, and L. R. Dalton, "Nanoscale Tailoring of Dendrimers and Polymers for Electro-Optic Devices," *Proc. SPIE*, 4991, (submitted).

46. L. R. Dalton, B. H. Robinson, R. Neilsen, A. K. Y. Jen, P. Rabiei, and W. H. Steier, "Rational Design and Preparation of Organic Electro-Optic Materials and Devices," *Proc. SPIE*, 4991, (submitted).

47. Almeida, V.R., R. Panepucci, and M. Lipson, "Nano-taper for Compact Mode Conversion," *Optics Letters*, (submitted).

48. S. Grenoble, M. Gouterman, G. Khalil, J. Callis, and L. Dalton, "Pressure Sensitive Paint (PSP): Concentration Quenching of Platinum and Magnesium Porphyrin Dyes in Polymeric Films," *J. Luminescence*, (submitted).

49. D. Beljonne, A. Ye, Z. Shuai, and J.L. Brédas, "Chain-Length Dependence of Singlet and Triplet Formation Rates in Organic Light-Emitting Diodes", *Nature Materials*, (submitted).

50. M. Halik, W. Wenseleers, C. Grasso, F. Stellacci, E. Zojer, S. Barlow, J.L. Brédas, J.W. Perry, and S. Marder , "Bis(dioxaborine) Compounds with Large Two-Photon Cross Sections, and their Use in the Photodeposition of Silver", *Chem. Comm*., (in press).

51. S. Keinan, E. Zojer, J. L. Brédas, M.A. Ratner, and T. Marks, "Twisted π-System Electro-Optic Chromophores. A CIS vs. MRD-CI", *THEOCHEM*, (in press).

52. W. Stier and O. V. Prezhdo "Non-adiabatic molecular dynamics simulation of solar cell electron transfer", *J. Mol. Struct.*, (in press).

53. **W. Stier and O. V. Prezhdo "Non-adiabatic molecular dynamics: II. Simulation of solar cell electron transfer", *Phys. Chem.-Chem. Phys.*, (in review).**

54. **O. V. Prezhdo, L. R. Dalton "Structural origin of the enhanced electro-optic response of dendrimeric materials", *Chem. Phys. Lett.,* (in press).**

55. **Ya-Dong Zhang, Kim G. Jespersen, Michael Kempe, Julia A. Kornfield, Stephen Barlow, Bernard Kippelen, and Seth R. Marder, "Columnar discotic liquid-crystalline oxadiazoles as electron-transport materials," *Langmuir* accepted for publication (2003).**

56. **D. Alloway, M. Hofmann, D.L. Smith, N.E. Gruhn, A.L. Graham, R. Colorado, Jr., V.H. Wysocki, T. R. Lee, P.A. Lee, N.R. Armstrong, "Interface Dipoles Arising from Self-Assembled Monolayers on Gold: UV Photoemission Studies of Alkanethiols and Partially Fluorinated Alkanethiols," *J. Phys. Chem. B*. (submitted).**

57. **C.L. Donley, W. Xia, B. Minch, R.A.P. Zangmeister, A.S. Drager, K.W. Nebesny, D.F. O'Brien, N.R. Armstrong, "Thin Films of Polymerized Rod-Like Phthalocyanine Aggregates," *Langmuir,* (submitted).**

58. **Steve Bowles and Natia L. Frank, "Spin Density Distribution in a New Class of Delocalized Stable Radicals," full paper manuscript in preparation for *J. Am. Chem. Soc. 2003***

59. **Steve Bowles and Natia L. Frank, "Magnetism and Structural Analysis of Novel Radical p stacks," full paper manuscript in preparation for *Chem Mater.* 2003.**

60. **Benoit Domercq, Richard D. Hreha, Ya-Dong Zhang, Andreas Haldi, Stephen Barlow, Seth R. Marder, and Bernard Kippelen, (Invited paper) "Organic light-emitting diodes with multiple photocrosslinkabke hole transport layers," *J. Poly. Science*, (submitted 2003).**

61. **S. Kang, J. Luo, H. Ma, L. R. Dalton, and A. K-Y. Jen, "Hyperbranched Fluorinated Aromatic Polyester from Mild One-Pot Polymerization of AB2 Hydroxy Acid Monomer," *Macromolecules*, (in press).**

62. **J. Luo, M. Haller, H. Li, L. R. Dalton and A. K-Y. Jen, "Highly Efficient and Thermally Stable Electro-optic Polymer from a Smartly Controlled Poling and Crosslinking Process", *Adv. Materials*, (submitted).**

63. **Y. Enami, N. Peyghambarian, and A. K-Y. Jen, "Wavelength-division multiplexing fiber filter using intracavity polymer/fiber half coupler", *Appl. Phys. Lett.*, (submitted).**

64. **C. Fuentes-Hernandez, D.J. Suh, S. Barlow, G.A. Walker, S.R. Marder, and B. Kippelen, "Efficient and fast hybrid photorefractive polymers sensitized with CdSe nanoparticles,", *Appl. Phys. Lett*., (submitted).**

65. **A.C.T. van Duin and J.S. Sinninghe Damaste, "Computational chemical investigation into isorenieratene cyclisation," *Organic Geochemistry*, (in press).**

66. A.C.T. van Duin, Alejandro Strachan, Shannon Stewman, Qingsong Zhang, Xin Xu, and William A. Goddard, "REaxFFSiO reactive force field for silicon and silicon oxide systems," *J. Phys. Chem. A*, (in press).

CONFERENCE PRESENTATIONS

***Conference*—August 18-22, 2002**—J.L. Brédas, Invited talk, 224th American Chemical Society Meeting, Boston, Massachusetts. "Characterization of the Energy and Charge Transfer Processes in π-Conjugated Semiconducting Oligomers and Polymers."

***Conference*—August 26-30, 2002**—J.L. Brédas, Invited talk, European Physical Society 12th Annual Conference, "Trends in Physics", Budapest, Hungary, "Characterization of the Charge Transport and Energy Transfer Processes in Organic Semiconductors."

***Conference*—September 26, 2002**—J.L. Brédas, Invited talk, Societe Royale de Chimie, "La himie: Une Science d'Actualite", Bruxelles, Belgium, "Les Materiaux Organiques Semi-onducteurs, un Element Clef de l'Electronique et de l'Optique du Futur."

***Conference*—October 10-13, 2002**—L.R. Dalton, 10th Annual Foresight Conference on Molecular Nanotechnology Two invited presentations (one Scientific Tutorial and one Invited Conference Presentation) Bethesda, Maryland. Title of invited lecture: "Breaking the Bandwidth Bottleneck in Telecommunications & Information Processing: New Electro-Optic Materials."

***Conference*—October 21-23, 2002**—Galen Stucky, DFG Workshop on Guest/Host Systems Based on Nanoporous Crystals, Berlin, Germany, "Ordered Porous Solids for the Organization of Matter."

***Conference*—November 18-21, 2002**—Galen Stucky, Symposium on Nanostructured Photonic Materials and Devices, 51st IWCS/Focus Meeting, Orlando, Florida, "The Organization of Hierarchically Structured Functional Units and Domains in 3-D Composite Fibers and Films."

***Conference*—December, 2002**—B.H. Robinson, DARPA Workshop, Washington D.C., "Materials Possible: Improvements in EO Response of Organic Chromophores."

***Conference*—December 1-5, 2002**—J.L. Brédas, Invited talk, Materials Research Society Fall Meeting, Symposium B, Boston, Massachusetts, "Characterization of the Interface Dipole at Organic-Metal Interfaces."

***Conference*—December 1-5, 2002**—J.L. Brédas, Invited talk, Materials Research Society Fall Meeting, Symposium V, Boston, Massachusetts, "Characterization of the Energy and Charge-Transfer Processes in π-Conjugated Semiconducting Oligomers and Polymers."

***Conference*—December 2-6, 2002**—M. Lipson, MRS Fall Meeting, Boston, Massachusetts, "Nano-taper for Compact Mode Conversion."

***Conference*—December 11-13, 2002**—L.R. Dalton, NSF Nanoscale Science and Engineering, NSF Grantees Conference, Arlington, VA, Invited Presentation: "Nanostructured

Optoelectronic Materials: New Concepts in Theoretical Design, Synthesis, and Processing."

***Conference*—December*,* 2002--**P. Rabiei, W. H. Steier, C. Zhang, and L. R. Dalton, "Integrated WDM Polymer Modulator," in Optical Society of America Trends in Optics and Photonics, Vol. 70, Optical Fiber Communication Conference, Technical Digest (Optical Society of America, Washington DC, 2002), pp. 31-33.

***Conference*—January, 2003**—S.R. Marder, Member of the Program Committee; T. Kaino, Chair, Photonics West '03, San Jose, California "Organic Photonic Materials and Devices V Conference."

***Conference*—January 16-17, 2003**—L.R. Dalton, NSF Workshop on Technological Challenges for Flexible, Light-weight, Low-cost and Scalable Organic Electronics and Photonics. Arlington Hilton Hotel & Towers, Arlington, VA--Invited Presentation: Organic Electro-Optic Materials: Present and Future.

***Conference*—January 22, 2003**—J.W. Perry, Topical Meeting on Optical Photonic Bandgap Research, SPAWAR Systems Center, San Diego, CA, "Fabrication of PBG Structures using Two-Photon 3D Lithography."

***Conference*—January 30, 2003**—L.R. Dalton, Photonics West Symposium on Organic Photonic Materials and Devices VI, San Jose, CA. Invited Lecture: "Organic Electro Optics: Exploiting the Best of Electronics and Photonics".

***Conference*—February 9-14, 2003**—J.L. Brédas, Invited talk, "Fifth International Topical Conference on Optical Probes of Conjugated Polymers and Organic & Inorganic Nanostructures", Venice, Italy, "Charge Transport and Energy Transfer Processes in Semiconducting π-Conjugated Oligomers and Polymers."

***Conference*—February 19, 2003**—B. Kippelen, Durel Corp. Technology Conference, Chandler, Arizona, "Organic electroluminescent materials and devices for display."

***Conference*—March 22-25, 2003**—S. Barlow, American Chemical Society National Meeting, New Orleans, "Two-Photon Absorption and Mixed Valence Properties of Dioxaborin Derivatives."

***Conference*—March 22-25, 2003**—J. Wang, American Chemical Society National Meeting, New Orleans, "Synthesis and Characterization of Efficient Two-Photon Acid Generators for 3D Microfabrication."

***Conference*—March 22-25, 2003**—Yang, D, American Chemical Society National Meeting, New Orleans, "Synthesis and Polymerization of Reactive Monoacylglycerols to Stabilized Bicontinuous Cubic Nanoparticles."

***Conference*—March 22-25, 2003**—S.R. Marder, Award Symposium on Organic Electro-Optic and Optoelectronic Materials Honoring the Chemistry of Materials Award Recipient Larry Dalton: "Optimization of Chromophores for Nonlinear Optical Applications."

***Conference*—March 25, 2003**—L.R. Dalton, American Chemical Society National Meeting, New Orleans, Award Symposium on Organic Electro-Optic and Optoelectronic

Materials Honoring the Chemistry of Materials Award Recipient Larry Dalton, Invited Lecture: “Organic Electro-Optic Materials: Past, Present, and Future”.

***Conference*--March 25, 2003—**B.H. Robinson, American Chemical Society National Meeting, New Orleans, Invited Lecture: “Novel Theory for determining the Structures of Dendronized Chromophores; Solving the Loading Problem”.

***Conference*—March 30, 2003**—J.W. Perry, Center for Fundamental Materials Research Symposium, Michigan State University, East Lansing, Michigan, “Multiphoton Absorbing Materials for Patterning of Polymers and Nanocomposites,”

***Conference*--April, 2003**—P. Rabiei, W. H. Steier, "Tunable double micro-ring (DMR) filters for widely tunable lasers" ECIO'03 Conference, Prague.

***Conference*—April 21-25, 2003**—J.L. Brédas, "Charge Transport and Energy Transfer Processes in Semiconducting π-Conjugated Oligomers and Polymers," Materials Research Society Spring Meeting, San Francisco, California.

***Conference*—April 21-25, 2003**—J.L. Brédas, "Intra- and Inter-chain Energy Transfer Processes in an End-capped Conjugated Polymer," Materials Research Society Spring Meeting, San Francisco, California.

***Conference*—April 21-25, 2003**—B. Kippelen, "Organic light-emitting diodes based on multilayer photo-crosslinkable hole transport copolymers," Materials Research Society Spring Meeting, San Francisco, California.

***Conference*—April 21-25, 2003**—B. Kippelen, "Organic photovoltaic cells fabricated from liquid crystalline phthalocyanines," Materials Research Society Spring Meeting, San Francisco, California.

***Conference*—May 12-14, 2003**—M. Mansuripur, P.K. Khulbe, S.M. Kuebler, J.W. Perry, M.S. Giridhar, and N. Peyghambarian, “Information Storage and Retrieval using Macromolecules as Storage Media,” Optical Data Storage Conference (ODS), Vancouver, Canada.

***Conference*--June, 2003**—B. R. Kaafarani, Y. Zhang, K. G. Jespersen, S. Barlow, B. Kippelen, S. R. Marder, "Columnar discotic liquid-crystalline oxadiazole as electron-transport materials,” submitted to National Organic Symposium (NOS), Indiana.

***Conference*--June, 2003**—M. Cha, G. Ramos-Ortiz, S. Thayumanavan, J. Mendez, S. R. Marder, and B. Kippelen, “Efficient third harmonic generation in organic thin films and its applications," to be presented at ICONO'7, Korea.

***Conference*--June, 2003**—M. Cha, G. Ramos-Ortiz, H.T. Kim, H. Choi, S. Thayumanavan, J. Mendez, S. R. Marder, B. Kippelen, "Broadband efficient third-harmonic generation in an organic film," to be presented at CLEO, Baltimore.

***Conference*--June, 2003**—G. Ramos-Ortiz, M. Cha, S. Thayumanavan, J. Mendez, S. R. Marder, and B. Kippelen, "Highly sensitive third-order optical autocorrelator for operation at the telecommunication wavelengths," to be presented at CLEO, Baltimore.

***Conference*—April, 2003**—B. Domercq, R. D. Hreha, C. Carter, J. L. Maldonado, J. N. Haddock, C. Schultz, Y. Zhang, S. R. Marder, B. Kippelen, "Organic light-emitting diodes based on multilayer photo-crosslinkable hole transport copolymers," to be presented at MRS Spring Meeting, San Francisco.

***Conference*-—April, 2003**—S. Yoo, B. Domercq, C. L. Donley, C. Carter, W. Xia, B. A. Minch, D. F. O'Brien, N. R. Armstrong, B. Kippelen, "Organic photovoltaic cells fabricated from liquid crystalline phthalocyanines," to be presented at MRS Spring Meeting, San Francisco, April (2003).

***Conference*—May, 2003**—S.R. Marder, Member of the Scientific Advisory Committee, N.Kim, Chair, International Conference on Organic Photonics and Electronics, Sorak National Park, Korea, “Seventh International Conference on Organic Nonlinear Optics.”

***Conference*—May 12, 2003**— B. A. Minch, C. L. Donley, W. Xia, W. Flora, S. Yoo, B. Domercq, D. F. O'Brien, B. Kippelen, N. R. Armstrong, New discotic materials for PV and OFET applications: liquid crystalline phthalocyanines," to be presented at the 3rd World Conference on Photovoltaic Energy Conversation, Osaka, May 12, (2003).

***Conference*—May 12, 2003**— S. Yoo, B. Domercq, C. L. Donley, C. Carter, W. Xia, B. A. Minch, D. F. O'Brien, N. R. Armstrong, B. Kippelen, "Organic photovoltaic cells containing liquid crystalline phthalocyanine," to be presented at the 3rd World Conference on Photovoltaic Energy Conversation, Osaka, May 12, (2003).

***Conference*—June, 2003**—V. Almeida, CLEO 2003, Baltimore Maryland, “Nano-taper Mode-size Converter”

***Conference*—June 18-25, 2003**—L.R. Dalton, NSF/ACS Workshop Conference on the Chemistry of Information Technology/Electrical, Magnetic, and Optical Properties of Organic and Hybrid Materials, multiple presentations.

***Conference*—June, 2003**— B. Kippelen, to be presented at the 7th International Conference on Frontiers of Polymers and Advanced Materials, Bucharest, "Recent advances in organic semiconductors for displays and imaging.”

***Conference*—August, 2003**— Bernard Kippelen, Seunghyup Yoo, Benoit Domercq, Carrie Donley, Chet Carter, Wei Xia, Britt Minch, and Neal Armstrong, to be presented at SPIE annual meeting, San Diego "Semiconducting liquid crystals and their application in organic solar cells."

***Conference*—August, 2003**—Seunghyup Yoo, Benoit Domercq, and Bernard Kippelen, Carrie Donley, Chet Carter, Wei Xia, Britt Minch, David F. O'Brien and Neal Armstrong**,** to be presented at SPIE annual meeting, San Diego, "Organic photovoltaic cells containing discotic liquid crystalline phthalocyanines.”

<u>OTHER ACTIVITIES</u>

August 12-13, 2002—L.R. Dalton, PNNL Nanoscience and Technology Advisory Committee Meeting, Richland, WA.

August 14-16, 2002—L.R. Dalton, Defense Advanced Research Projects Agency (DARPA) Microsystems Technology Office (MTO) CS-WDM Program Kickoff, Whitefish, MT.

August 19-29, 2002—L.R. Dalton, STC Director's Meeting, Atlanta, GA. Overview of UW STC.

August 26, 2002—L.R. Dalton, Invited presentation to U.S. Congressman (D-7th, Washington State) James McDermott, Seattle. The STC and electro-optic materials research.

September 13, 2002—L.R. Dalton, Technology Alliance Presentation, Seattle, WA. Invited Lecture: "Information Technology in the 21st Century: Exploiting the Best of Electronics and Photonics".

September 17, 2002—L.R. Dalton, Washington Roundtable Invited Presentation, Washington Athletic Club. "The New Information Technology Age: Exploiting the Best of Photonics and Electronics".

September 18, 2002—J.L. Brédas, Organizer and chair of the Optics Valley Lecture Series, Tucson, Arizona, Cherry Murray, Bell Labs/Lucent Technologies, "Science & Technology for Future Communications Networks."

September 21-24, 2002—B. Kippelen, PAT 2003, Polymers Advanced Technologies, Ft. Lauderdale, Florida, "Recent advances in photorefractive and third-over nonlinear polymers."

September 30, 2002—L.R. Dalton, National Science Foundation Distinguished Lecturer, Inaugural Lecture 2002-2003 NSF Distinguished Lecture Series, NSF Headquarters, Arlington, VA, "The New Information Age: Exploiting the Best of Electronics and Photonics."

October, 2002— Natia Frank International Conference on Molecular Magnetism, Valencia, Spain.

October 3, 2002—L.R. Dalton, Invited Seminar, California Institute of Technology. "Organic Electro-Optics".

October 9, 2002—L.R. Dalton, Seminar, Norfolk State University, Norfolk Virginia. "Implementing the New Information Technology Age: Exploiting the Best of Photonics and Electronics".

October 11, 2002—J.L. Brédas, Invited seminar, Department of Chemistry, Idaho State University, Pocatello, Idaho, "Plastics are Fantastic: The New Generation of Semiconductors and Metals."

October 15, 2002—J.L. Brédas, Invited seminar, CREOL, University of Central Florida, Orlando, Florida, "Two-Photon Absorption in Organic Chromophores: Structure-Properties Relationships."

October 17, 2002—S.R. Marder, Invited seminar, Bowling Green State University, Bowling Green, Ohio, "Two-Photon Chemistry."

October 23, 2002—L.R. Dalton, Presentation before National Reconnaissance Office Site Visit to the University of Washington. "Organic Electro-Optic Materials: Past, Present, and Future".

October 29, 2002—J.L. Brédas, Invited seminar, Department of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, Georgia, "Charge Transport and Energy Transfer Processes in Organic Semiconductors."

November, 2002—B.H. Robinson, Invited talk, Why Nanostructured Electro-Optic Materials?", Mission Impossible Materials, DARPA Workshop, Washington DC.

November, 2002—B.H. Robinson, Invited talk, North Carolina State University, Raleigh, N.C., "Three Biological Systems: DNA, RNA, Membrane-binding Proteins: Using EPR as a probe of the Structure-function relation - Dynamics-function relation."

November, 2002—B.H. Robinson, Invited talk, DURINT Workshop presentation, SUNY Buffalo, Buffalo, NY "New Developments in Ordering NLO Chromophores."

November 1, 2002—J.L. Brédas, Invited talk, The Moscowitz Memorial Lectureship in Chemistry, Department of Chemistry, University of Minnesota, Minneapolis, Minnesota, "Organic Semiconductors: A Theoretical Characterization of the Basic Parameters Governing Charge Transport."

November 11-13, 2002—L.R. Dalton, DoD DDR&E Nanophotonics & Nanoelectronics Review, University of Buffalo, Buffalo, NY. Invited Presentation: "Nanophotonic Electro-Optic and Opto-Electronic Materials".

November 13, 2002—J.L. Brédas, Organizer and chair of the Optics Valley Lecture Series, Tucson, Arizona, Axel Scherer, California Institute of Technology, "Design, Fabrication and Characterization of Optical Nanocavities."

November 13, 2002— Dominic McGrath, New Mexico Tech "Fighting Terrorism and Disease with Organic Chemistry."

November 21, 2002— Galen Stucky, 50th Cover Lecture, Iowa State University, "Molecular Assembly of Organized Composites."

November 22, 2002—Bernard Kippelen Physics Colloquium, Department of Physics, University of Arizona, "Organic Semiconductors and Their Applications."

November 26, 2002—L.R. Dalton, Seminar, Department of Electrical Engineering, University of Washington. "Preparation and Utilization of Organic Electro-Optic Materials."

November 29, 2002—J.L. Brédas, Invited lecture, College of Sciences Lecture, Université Libre de Bruxelles, Bruxelles, Belgium, "Les Composés Organiques Semi-Conducteurs: Matériaux du Futur."

December, 2002 –B.H. Robinson, Invited talk, High Field Magnet Workshop, High Field Magnet Laboratory, Florida State University, Tallahassee, FL **"**Simulation of EPR Spectra and Modeling Dynamics Effects**."**

December 5, 2002—L.R. Dalton, Seminar, Applied Physics Laboratory, University of Washington. "Materials for Next Generation Telecommunications".

December 5-7, 2002—J.L. Brédas, Invited talk, "New Mountains to Climb: New Phenomena, Materials and Technologies for the 21st Century: Festschriften Honoring Alan G. MacDiarmid's Achievements For His 75th Year" University of Texas at Dallas, Dallas, Texas, "Characterization of the Interface Dipole at Organic-Metal Interfaces."

December 6, 2002—L.R. Dalton, UW Science Forum Lecture, University of Washington. "Implementing the New Information Technology Age: Exploiting the Best of Photonics & Electronics".

December, 2002—B.H. Robinson, High Field Magnet Workshop, High Field Magnet Laboratory, Florida State University, Tallahassee, FL, "Simulation of EPR Spectra and Modeling Dynamics Effects."

January 14-16, 2003—S.R. Marder, National Science Foundation Workshop, "Technological Challenges for Flexible, Light-weight, Low-cost and Scalable Organic Electronics and Photonics", Washington, DC., "New Capabilities for Fabricating Micro and Nanoscale 3D Structures in the 21st Century."

January 15, 2003—J.L. Brédas, Organizer and chair of the Optics Valley Lecture Series, Tucson, Arizona, Richard Friend, University of Cambridge, "Polymer Electronics and Optoelectronics."

January 22, 2003—M. Mansuripur, Invited speaker, 2003 Photonics Initiative Workshop, Tucson Arizona, "How Do CD and DVD Players Work?"

January 22, 2003—A. K-Y. Jen, Invited speaker, 2003 Photonics Initiative Workshop, Tucson Arizona, "Nanoscale Architectural Control."

January 23, 2003—S.R. Marder, 2003 Photonics Initiative Workshop, Tucson, AZ, "Chemistry in Three Dimensions Using Two-Photon Absorption."

January 23, 2003—B. Kippelen, 2003 Photonics Initiative Workshop, Tucson, AZ, "Organic Semiconductors and Their Applications."

January 23, 2003—S. Mazumdar, 2003 Photonics Initiative Workshop, Tucson, AZ, "Many-Body Effects on Charge Recombination and Generation in Organic Devices."

January 22-23, 2003—N. Peyghamabarian, Director of 2003 Photonics Initiative Workshop, Tucson, AZ.

January 24, 2003—L.R. Dalton, DOD DDR&E Review of Polymeric Smart Skin Materials, Seattle, WA. Presentation: "An Overview of Polymeric Smart Skins Materials Research".

January 30-31, 2003—J.L. Brédas, Invited talk, Los Alamos National Laboratory, Los Alamos, New Mexico, "Theoretical Characterization of Charge Transport and Energy Transfer Processes in Organic Semiconductors."

February 10, 2003— Dominic McGrath , Emory University, "Dendrimers in Many Guises, From Passive to Active Roles."

February 11, 2003— Dominic McGrath, Georgia Tech, "Dendrimers in Many Guises, From Passive to Active Roles."

February 13, 2003—L.R. Dalton, Florida International University, Miami, FL. Invited Seminar: "Technology for the 21st Century: Exploiting the Best of Photonics and Electronics".

February 14, 2003—L.R. Dalton, University of Miami, Miami, FL. Invited Seminar: "Technology for the 21st Century: Exploiting the Best of Photonics and Electronics".

February 14-15, 2003—S.R. Marder, Invited speaker, Arizona/Los Alamos Days, Tucson, Arizona, "New Capabilities for Fabricating Micro and Nanoscale 3D Structures in the 21st Century."

February 27, 2003—M. Mansuripur, Invited Seminar, University of Arizona, Aero-Mechanical Engineering Department, Tucson Arizona, "How Do CD and DVD Players Work?"

March, 2003–B.H. Robinson, Invited talk, DARPA Meeting, University of Washington, Seattle, WA, "Developing Better EO Materials: Theoretical Needs."

March, 2003–B.H. Robinson, Invited talk, DARPA Meeting, University of Washington, Seattle, WA, "Developing Better EO Materials: Theoretical Needs."

March 17, 2002—S.R. Marder, Invited seminar, Tulane University, New Orleans, Louisiana "Two-Photon Chemistry."

March 20, 2003–M. Mansuripur, NSF-sponsored ERC for Environmentally Benign Semiconductor Manufacturing, University of Arizona, Tucson, Arizona, "Information Storage and Retrieval using Macromolecules as Storage Media."

March 21, 2003–N. Armstrong, Invited speaker, Galileo Forum, Phoenix Country Club, Phoenix, Arizona, "Nanoscience, Nanotechnology, Optical Materials."

March 31, 2003—L.R. Dalton, Government Microcircuit Applications & Critical Technology (GOMAC)-03 Conference, Tampa, FL. Invited Lecture: "New Organic Electro- Optic Materials for Time and Wavelength Division Multiplexing Applications".

April 8, 2003—L.R. Dalton, Science Forum Lecture, University of Washington. "Lighting the Way in the New Information Technology Age."

April 14, 2003—M. Mansuripur, Invited Seminar, University of Arizona, Department of Engineering, Tucson Arizona, "How Do CD and DVD Players Work?"

April 23, 2003—L.R. Dalton, DARPA/MTO: CS-WDM "Nanophotonics for Mobile Platforms" Review, Boeing, Seattle. Invited Presentation: "Electro-Optic Polymers: Roadmap".

April 24, 2003—L.R. Dalton, Frontiers in Nanotechnology Lecture, BIOE599/CHEM650, University of Washington, Seattle. "Nanotechnology and Information Technology."

May 5-7, 2003—L.R. Dalton, PNNL Nanoscience and Technology Advisory Committee Meeting, Richland, WA

May 17-18, 2003—L.R. Dalton, NSF “Chemical Bonding Centers” Workshop, NSF Headquarters, Arlington, VA

July 7-8, 2003—L.R. Dalton, NSF STC MDITR Site Visit, University of Washington, Seattle

AWARDS AND HONORS

	Recipient	Reason for Award	Award Name and Contributor	Date
1	William Steier	Distinguished Alumnus Award	Electrical and Computer Engineering Department, University of Illinois, Urbana, Ill.	9/2002
2	Jean-Luc Brédas	Member, European Research Advisory Board for Science, Technology, and Innovation (EURAB; equivalent to US National Science Board)	Commissioner for Research of the European Union	2001-present
3	Jean-Luc Brédas	Scientific achievement and contribution as one of the top researchers in the field of conducting polymers, based on the number of citations	ISI Top 100 Most-Cited Researchers for Chemistry http://www.isinet.com/isi/	1992-2002
4	Alan Heeger		Elected to the National Academy of Engineering	2002
5	Alan Heeger	Doctor of Science	(honoris causa) Bar Ilan University, Tel Aviv (Israel)	5/2002
6	David Moilanen	Excellence in Undergraduate Grades, to support tuition cost while pursuing research	Mary Gates Undergraduate Research Award, University of Washington	10/2002
7	David Moilanen	To pay for costs and salary to attend Cambridge University (England) in Graduate School	Cambridge Oversees Trust Fellowship	Starts 9/2003
8	Larry Dalton	Development of organic optoelectronic materials	American Chemical Society Award in the Chemistry of Materials (American Chemical Society/DuPont Corporation)	3/2003
9	Larry Dalton	Development of organic electro-optic materials	Wright Centennial Research Award (AFRL-Wright Patterson)	3/2003
10	Jean-Luc Brédas	Scientific achievement and contribution as top researcher	Regents Professor of the University of Arizona; approved by the Regents Professor Advisory Committee and selected by the President for appointment in fiscal year 2004 (not appointed because of possible move	2003

			to Georgia Institute of Technology).	
11	Neal Armstrong	Contributions to the characterization of interface science related to organic light emitting devices and chemical	Alexander von Humboldt Forschungspreis, contributed by: Alexander von Humboldt Stiftung	2003-2004
12	Sen Liu		MRS 2003 Graduate Student Award Gold Medal Winner	4/2003
13	Axel Scherer	Collaborative Research in Nanotechnology	Humboldt Research Award	2003
14	Bjorn Millard	Excellence in Undergraduate Grades, to support tuition cost while pursuing research	Mary Gates Endowment for Students Research Training Grant, University of Washington	2003
15	Sumitendra Mazumdar		Fellow of the American Physical Society	
16	Rhys Lawson	IGERT Nanontechnology Fellowship	UW Dept. of Nanotechnology, University of Washington	2002-2003
17	Rhys Lawson	WRF/Gates Fellow	UW Business School CTE	6/2003-8/2003
18	Michelle Liu		Kaiser Aluminum Fellowship	2002-2003
19	Michelle Liu	PNNL/UW JIN Fellowship	PNNL/UW Joint Institute of Technology	2002-2003

GRADUATES

	Student Name	Degree(s)	Years to Degree	Placement
1	Yasufumi Enami	Ph.D.	5.5 Years	Post Doc at UA

OUTPUTS OF KNOWLEDGE TRANSFER

	Name of Start-Up Company	Year	Main Product	
1	Luxtera Inc.	2002-2003	Photonic Crystal Circuitry	
2	Focal Point Microsystems	2002-2003	3-D Circuitry fabricated by TPA	
3	TPA Technologies	2002-2003	Technologies Based on TPA	

SUMMARY TABLE

1	the number of participating institutions (all academic institutions that participate in activities at the Center)	21 Academic Institutions
2	the number of institutional partners (total number of non-academic participants, including industry, states, and other federal agencies, at the Center)	9 Institutional Partners
3	the total leveraged support (sum of funding for the Center from all sources *other* than NSF)	$5,755,147
4	the number of participants (total number of people who utilize center facilities; not just persons directly supported by NSF) . Please EXCLUDE affiliates (click for definition)	131 Participants

MEDIA PUBLICITY

Heidi Dietrich, “Retaining the researchers UW experts wooed by schools with bigger checkbooks,” Puget Sound Business Journal, February 13, 2003.

Editor Nancy Joseph, “Major NSF Award for Information Technology Research,” A&S Perspectives, Summer 2002.

Seattle Post-Intelligencer Editorial Board, “The future begins at UW, WSU,” Seattle Post Intelligencer, January 7, 2003.

IX. OTHER IMPACTS

Multiuser Spectroscopic Facility Development

Development in the multiuser spectroscopic facility has focused on two areas: hyper-Rayleigh scattering and optical microscopy. Progress in each area is discussed below:

Hyper-Rayleigh Scattering. Hyper-Rayleigh Scattering (HRS) provides a direct measure of molecular first hyperpolarizabilty (β). This technique is complimentary to the more common technique of Electric Field Induced Second Harmonic Generation (EFISH).[33] In EFISH, an applied electric field induces asymmetry in the system such that second-harmonic generation of an incident laser field occurs. The magnitude of the second-harmonic field is dependent on both molecular dipole moment (μ) and β. To extract β from an EFISH measurement, both μ and β must be known. In a HRS experiment, monochromatic light with frequency ω is incident on a sample and the scattering at 2ω is observed, referred to as the hyper-Rayleigh. The intensity of scattering at 2ω is diagnostic of the magnitude of β. As such, HRS provides a more direct methodology for measuring molecular hyperpolarizabilities.

Although, HRS is a promising method for quantifying molecular non-linear properties, the primary issue limiting the applicability of this technique was that of wavelength tunability. Much of the previous HRS work was performed using 1.9 μm light from a high-powered hydrogen-shifted Nd:YAG laser. Although these experiments were groundbreaking, they were limited to 1064 nm and 1906 nm. The limitations of Nd-YAG excitation sources can in theory be avoided by the use of higher-repetition rate sources, in particular Ti:Sapphire oscillators. However, these systems are tunable over a limited wavelength range (700 nm to ~1000 nm) such that the measurement at wavelengths relevant to telecommunications applications (1.3 μm and 1.5 μm) can not be performed. Only recently have such wavelengths been available through the use of tunable IR optical parametric oscillators.

To address the limitations of excitation tunability outlined above, we have constructed a HRS apparatus based on a Ti:sapphire pumped optical parametric oscillator (Figure 1). First, the output of a Ti:Sapphire oscillator (Spectra Physics Tsunami) can be used for excitation from 740 to 1000 nm. Further tunability is achieved by using the oscillator to pump an optical parametric oscillator (Spectra Physics Opal) which provides output ranging from 1.1 μm to 2.5 μm. This system is now operative, and has been used to provide estimates of β for approximately 16 chromophores recently developed by researchers involved in the STC.

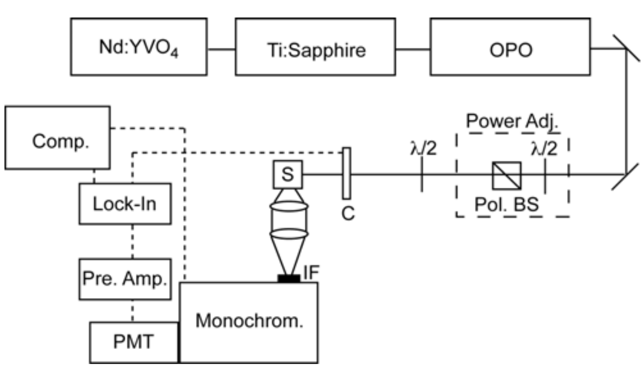


Figure 1. Schematic representation of the HRS apparatus. Excitation is performed using either the Ti:Sapphire oscillator or optical-parametric oscillator (OPO) output. Power is adjusted using a half-wave plate (l/2) and polarizing beamsplitter (Pol. BS.). The excitation beam is modulated using a mechanical chopper (C) synchronized to a lock-in for phase-sensitive detection. The HRS scattering is collected from the sample (S) and delivered to a monochromator. Signal from the PMT is delivered to a pre-amplifier before being imput to the lock-in.

Optical Microscopy. To characterize large assemblies of non-linear optical chromophores doped into polymeric systems, we are developing both linear and non-linear optical microscopy facilities. This facility is used by researchers in the STC to characterize materials, and by students participating in the educational and training mission of the STC. A schematic of the two-photon optical microscope we have constructed and that is currently operational is presented in Figure 2. Excitation is accomplished using a tunable femtosecond Ti-sapphire oscillator (home built) pumped by a Nd:YVO_4 laser (Millennia, Spectra Physics). The oscillator is tunable from 750 nm to 850 nm with a temporal pulse width of 30 fs (full width at half maximum). Before entering the microscope, the excitation beam diameter is increased to fill the microscope objective aperture, with adjustment of the incident power performed using a zero-order half-waveplate in combination with a thin-film polarizer. A second waveplate is used to adjust the polarization of the incident light. An 800-nm dichroic beamsplitter directs the excitation beam through a 1.3-NA oil-immersion objective (Nikon) to a diffraction-limited spot of ~400-nm in diameter. Positioning of the objective relative to the sample is controlled using a piezo-electric actuator (ThorLabs). The sample is scanned via an XY piezo-electric stage (Queensgate) having a spatial range of 100 μm and resolution of 10 nm. Emission is collected by the objective, returns through the dichroic beamsplitter, and is focused using a 200-mm achromatic lens. Rejection of residual fundament is accomplished using a 720-nm short-pass filter. The emission can be directed to a CCD camera for alignment, or imaged onto a pair of single-photon counting photomultipier tubes (Hamamatsu HC135-01) that are not responsive at the excitation wavelengths employed. An avalanche photodiode/photon counting module (Perkin Elmer) is also available for use. As the figure illustrates, polarization optics are available to measure the linear dichroism of the fluorescence in order to determine molecular alignment (see below). We will be taking delivery of a confocal microscope in the upcoming month, and will be installing this system in early summer.

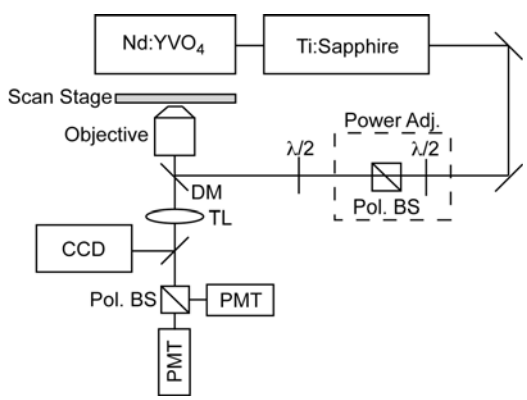


Figure 2. *Schematic of the two-photon optical microscope. λ/2 = half-wave plate, DM = dichroic mirror, TL =tube lens, Pol. BS = polarizing beamsplitter, PMT. Other details are provided in the text.*