I.B. CONTEXT STATEMENT

CLiPS Vision and Goals

The **Vision** of the Center for Layered Polymeric Systems (CLiPS) is to create an integrated program of research and education through the vehicle of a unique microlayering and nanolayering process technology at Case Western Reserve University (CWRU). CLiPS will be a powerful national model for distinguished research and for successful recruitment of American students from diverse backgrounds into the science and engineering workforce. CLIPS partner institutions include the University of Texas at Austin (UT), Fisk University, the University of Southern Mississippi (USM), Northwestern University, the Naval Research Laboratory NRL), Kent State University (KSU) and the Cleveland Metropolitan School District (CMSD). The Center Director is Professor Eric Baer. He is aided in the management of the Center by Associate Directors for Research, Education & Diversity, and External Affairs. The strategic plan for achieving the CLiPS vision is focused with the assistance of a diverse External Advisory Board.

CLiPS Partner Institutions

The Center:

- Integrates activities of research platforms with multi-level educational programs to train a diverse American workforce that can meet the challenges of new nanotechnologies
- Focuses the integrated research and education activities on national priorities in defense, environment, energy, and health
- Disseminates the knowledge developed through the integrated Center research and educational activities to the larger audience beyond the partner institutions
- Serves as a compelling model for expanding relationships between minority-serving colleges and universities, and major research universities

The CLiPS approach strategically integrates polymer science and engineering with research in nanotechnology, optics, laser physics, membranes, energy, device development and other scientific disciplines in a "**polymers-plus**" concept. The multidisciplinary nature of the research program flows naturally into graduate and undergraduate education. Integrated educational programs mirror the polymers-plus idea to introduce modular coursework in emerging cross-disciplinary areas. Students and faculty trained in this area are uniquely positioned to make major contributions to the fields of polymer science and technology, physics, chemical and polymer engineering, and nanotechnology. For example, the CLiPS research and education partnership between CWRU and Fisk University is broadening participation of African-American students in the science and technology programs at both universities. To attract undergraduate students to CLiPS Research Experience for Undergraduates (REU) and graduate programs, the Center has added three historically Black colleges to the Affiliates Program in addition to our regular recruiting efforts. The REU Program and Affiliate schools have been an important source of graduate students for CLiPS partner institutions. In addition, the Polymer Envoys Program engages high school students from the Cleveland Metropolitan School District, the East Cleveland Schools, and the

Cleveland Heights-University Heights School District. Similar programs involve local school districts at the other major CLiPS partner institutions (UT, Fisk, and USM). In the exploration of polymer science and engineering as academic pursuits and eventual careers, this program is serving as a model for the partners to form linkages with local public high schools. CLiPS engages large numbers of pre-high school students in STEM activities both as part of our recruiting effort for the Polymer Envoys Program and to help fulfill CLiPS's educational mission.

Recognizing that personal contacts are an important influence in the career choice of college graduates, CLiPS has established affiliations with non-PhD-granting schools that offer strong undergraduate science and engineering programs to stimulate enrollment of American students in CLiPS graduate programs. CLiPS Affiliates are Ohio Northern University, Rose-Hulman Institute of Technology, Youngstown State University, Bowie State University, Central State University, and Kentucky State University.

Fundamentally new materials are obtained by forced-assembly of polymers into layers no thicker than the radius of gyration of an individual polymer molecule. CLiPS research activities are organized into five platforms to exploit the microlayer and nanolayer structures: (1) Rheology and New Processing focuses on integrating rheology into the multilayering process, and will explore combinations of rheologically dissimilar materials to create new polymer-based structures; (2) advanced Membranes and Transport Phenomena that exploit the layered hierarchy to achieve unique transport properties; (3) novel Optic and Electronic Systems based on the advanced layered materials, (4) new Science and Technology Initiatives that probe a fundamental understanding and explore new opportunities for the layered structures, and (5) Templated Interfaces and Reactions looking at the chemistry inside multilayers and potential surface modifications, particularly those related to biological materials.

The Center endeavors to become a unique global resource for the dissemination of knowledge in the area of layered polymeric systems and a national force for engaging audiences at all levels in polymer science and engineering. The Center fosters linkages between academia and industry in order to accelerate the development of new product initiatives.

Highlights of 2013-14

- The **Management and Operational Structure** continues to function smoothly.
    - The Development Committee has been expanded and its topic area subgroups have been actively pursuing external funding for Center-initiated programs.
    - Interactions with industry continue to be strong with eighteen companies engaged in collaborations with CLiPS researchers.
    - The CLiPS Envoys program is being integrated throughout the CWRU School of Engineering and in STEM departments in the School of Arts and Sciences.
    - Ongoing planning is taking place regarding the CLiPS Envoy-inspired STEM Academy. Current efforts are aimed at developing pilot studies, and in identifying additional collaborators and funding sources for the program.
- **Platform I: Rheology and New Processing** – 2013-14 saw the continued consolidation of Platform I activities.
    - The innovative solventless micro and nano-fibers project was transferred to Platform IV. Two new projects were formally established: one on Nano-confined Polymer Blends and one on Ultra-high Water Barrier Films for Flexible Electronics.
    - In the area of Extensional Rheometry of Polymer Melts a new dual controlled stress/rate extensional rheometer for polymer melts was developed that allows CLiPS to perform the full spectrum of rheological characterization. The project is now devoted to the characterization and modeling of various polymer systems.
    - With New Multilayering Technologies, novel materials were processed with 3:1 viscosity ratio and 10:1 elasticity ratio. These materials have been successfully processed into films with up to 65 layers.

- A 3rd generation die has been designed which will give CLiPS the capability of layering materials that have high viscosity and high elasticity ratios.
- The project on on-line sensors was fully implemented, with the first instrument, an on-line sample collector, has been put into operation.

- **Platform II: Membranes and Transport Phenomena** continued to make progress in fundamental understanding of transport phenomena in micro- and nano-layered systems by performing systematic experimental and modeling studies to identify the dominant controlling structural variables.
  - This understanding of fundamental transport phenomena is being used to design and optimize unique layered systems for food and electronic packaging, drug delivery and diagnostic devices.
  - Examples in this area include the following multi-institutional projects:
    - Development of High Barrier Layered Systems Using Particulates
    - Multilayer Fouling-Resistant Membranes
    - Desalination Membranes from Multilayered Polymers
    - Oxygen Scavengers for Packaging Applications
    - High Barrier Materials from LCPs
  - Several projects have reached maturity and are being sunset (physical aging in confined nanolayers, multilayer fouling-resistant membranes based on dopamine, POSS nanoconfinement, and solvent-free processing of membranes.
  - New areas being investigated include characterization of water vapor transport and multicomponent transport in barrier and membrane materials, fundamentals of water and ion transport in polymers, and multilayer processing of liquid crystalline polymers.
- **Platform III: Optics and Electronic Systems** continues to make excellent progress on its projects, several of which are highlighted below:
  - Optical Data Storage - The main activity and accomplishment in the past year is the development of the read-write apparatus so that the physical mechanism of writing can be studied. Results of the studies so far indicate that a robust writing protocol for short pulses (fast writing times) can be developed. The nonlinear response exhibited will result in minimal writing and reading cross-talk allowing many layers to be written and at least tens of thousands of read cycles.
  - Electro-optic Materials – Several large batches of amphiphilic second-order chromophores were supplied to the groups of Baer and Singer. Tri-layer co-extrusion runs have been carried out with several sets of polymers. It was found that even in the best films produced, the second harmonic signal was weak. Work is now aimed at identifying a chromophore with a large nonlinear optical response.
  - Lasers and Coherent Phenomena – New work with multilayer appliques demonstrating the use of appliques to shift laser diode wavelengths and thresholds were completed along with a detailed study of enhanced surface absorption using appliques. A new study on the use of appliques to enhance surface magneto-optic Kerr rotation was begun in a collaboration between Youngstown State and Rose-Hulman.
- **Platform IV: Science & Technology Innovations** focuses on science and technology innovations in microlayered and nanolayered materials and involves teams from CWRU, UT, Fisk and NRL who explore new opportunities for the enabling technology. Examples of project highlights are listed below:
  - Co-extruded Nanofiber Systems – significant efforts have been mobilized to advance innovations in the production of continuous polymer nanofibers using a melt-based processing technique comprised of multilayer coextrusion, orientation, and separation procedures. Projects include:
    - Fiber Fabrications Optimization
    - Biological Applications

  - Multilayer Film Technology Advancements – a second area of focus expands use of multilayer films for actuation and shape memory via incorporation of active elements within select layers and selection of synergistic material systems, and tailors barrier properties and surface behavior via coating of multilayer surfaces. Projects include:
    - Electroactive Nanomaterials
    - Shape Memory Materials
  - Multilayer Dielectrics **-** Fundamental efforts in dielectric materials are also ongoing. One focused are is the need in power electronics and pulsed power applications for dielectric capacitors with high energy density, low losses, and high temperature capabilities. Currently we have achieved understanding of the underlying mechanism of the better performance fo these multilayer dielectric films. We also investigated high temperature performance of polysulfone (PSF)/PVDF multilayer films.
- **Platform V: Templated Interfaces and Reactions** – was established in late 2012. Projects in this platform include:
  - precursor materials and pre- or post-processing chemistry such as precursor polymers with thermal, photo, electrical, and chemical field response that are amenable to patterning and ordering
  - nanomaterials and guest-host systems,
  - biological materials and proteins
  - self-immolative polymers and controlled gradients and degradation.
- **Knowledge Transfer**
  - During this reporting period, CLiPS faculty and staff members have generated **84 publications** in peer-reviewed journals and participated in **128 presentations** at professional meetings.
  - Since the inception of the Center, five patents have been issues, and applications have been made for twenty-four additional patents. Further information about patents and licensing is in the Outputs and Issues section of this report.
  - Three businesses have been spun off from the Center.
    - Founded in 2008, Advanced Hydro in Austin, Texas has eight full time employees, is selling product commercially and was profitable in 2012. This company is focused on commercializing the patent pending technology to reduce fouling of membranes used for water purification and filtration systems.
    - PolymerPlus in Cleveland, Ohio, is focused on creating GRIN lens technology based on polymer multilayer films and on developing commercial technology and applications for additional patents generated by the Center. Founded in 2010, PolymerPlus currently has fourteen full time employees and serves both corporate and government clients.
    - Folio Photonics in Cleveland, Ohio, is focused on commercialization of the optical data storage technology based on innovative multilayer film technology developed in CLiPS.
  - Three centers of research focus growing out of CLiPS technology have also been established
    - CAPP – the Center for Advanced Polymer Processing, established in 2011
    - MORE Center – Materials for Opto/Electronics Research and Education, established in 2011
    - CDES **-** the Center for Dielectric and Energy Storage established in 2012
- **Honors and Awards**

  CLiPS faculty members and students earned the following honors and awards:

  Faculty Members**:**

  Eric Baer (CWRU) – *The Paul J. Flory Research Prize, POLYCHAR22, 2014*
  Eric Baer – *The William Fowler Award for Distinguished Research in Physics, 2014*
  Rigoberto Advincula (CWRU) – *2013 Herman Mark Scholar Award of the Polymer Chemistry Division, ACS*
  Benny Freeman (UT) – *Joe J. King Professional Engineering Award, 2013*
  Benny Freeman – *Clarence (Larry) G. Gerhold Award, AIChE, 2013*

Benny Freeman – *Fellow, Industrial & Eng. Chemistry Research Division of ACS, 2013*
LaShanda Korley (CWRU) – *Young Talent Award, Polymers for Advanced Technologies, 2013*
Tobin Marks (NW) – *Fellow, American Chemical Society, 2013*
Donald Paul (UT) – *Institute Award for Excellence in Industrial Gases Technology, AIChE, 2013*
Jon Pokorski (CWRU) – *ACS PRF Young Investigator Award, 2013*
David Schiraldi (CWRU) – *Fellow, American Chemical Society, 2013*
Jie Shan (CWRU) – Fellow, American Physical Society, 2014

Post-Doctoral Associate:

Michele Galizia (UT) – *Best Reviewer Award, Journal of Membrane Science, 2014*

Graduate Students:

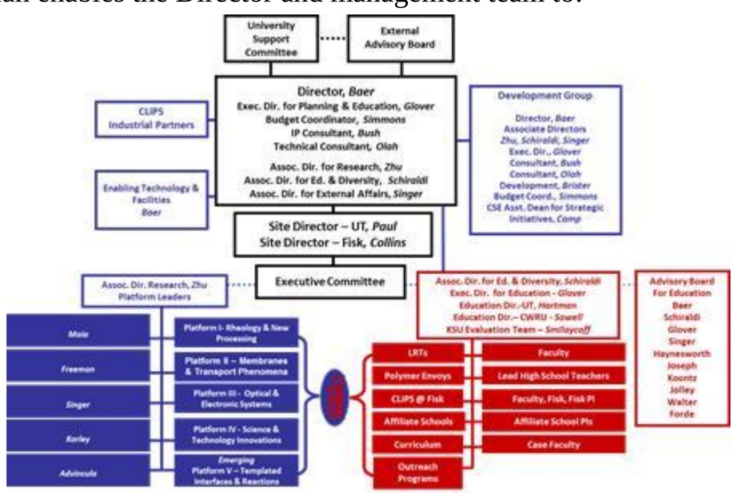
Zhenpeng Li (UT) – *3rd Place Poster Prize, AIChE Annual Meeting, 2014*
Sidney Carson (CWRU) – *1st Place Poster Prize,* ANTEC, 2014
Alex Jordan (CWRU) – *CLiPS Student Recognition Award, 2014*
Matt Herbert (CWRU) – *CLiPS Student Recognition Award, 2014*
Kezhen Yin (CWRU) – *CLiPS Student Recognition Award, 2014*
Guojun Zhang (CWRU) – *CLiPS Student Recognition Award, 2014*

High School Polymer Envoys:

Brandon Williams (CWRU) – *Honorable Mention, Research ShowCASE, 2014*
Advaith Anand (UT) – *Second Place, Engineering Environment Project Olympiad, 2013*

Leadership and Management

The CLiPS organization and operation plan enables the Director and management team to:



- Provide leadership for realization of the Vision through the Strategic Plan
- Ensure integration of multidisciplinary research, education and knowledge transfer activities
- Promote broad participation of the various constituencies that make up CLiPS
- Establish team-based research programs with mechanisms for growth and renewal
- Create a national model for expanding relationships between minority-serving colleges and universities and research universities
- Enable recruitment and education of students with diverse cultural backgrounds into science-oriented careers
- Facilitate education of multi-disciplinary, team-oriented students within traditional university settings
- Maintain effective day-to-day management, fiscal responsibility and reporting functions

The management and operation plan is shown in the **Organizational Plan** (see figure above, also Appendix B).

The Director, Eric Baer, is a Distinguished University Professor, and Herbert Henry Dow Professor of Science and Engineering. He sets the Vision of CLiPS, leads the strategic planning process with involvement of the membership in an ongoing manner, acts as the intellectual leader in setting research priorities in collaboration with the Platform Leaders, verifies communication across participating groups, ensures integration of diversity throughout CLiPS programs, identifies and mentors new faculty into CLiPS, negotiates fiscal and policy issues with the university on behalf of

CLiPS, and makes final decisions on key management positions and resource allocation. With input from the Associate Directors and the Executive Committee, the Director identifies measures for evaluating success in both research and education, and defines indicators of program success. He also leads the industrial outreach and spinoff activities of the Center.

The management team includes the Associate Directors. Lei Zhu, Associate Director for Research, works with the Director to coordinate and develop research activities that extend across the CLiPS research platforms and identifies potential collaborative initiatives that cross platforms and/or institutions. David Schiraldi, Associate Director for Education and Diversity, oversees CLiPS Education and Diversity programs in cooperation with the Director, and provides technical leadership to the Center's educational vision and programming. Kenneth Singer, Associate Director for External Affairs, works with the Director to promote knowledge transfer and commercialization of CLiPS research and technologies, and develops new sources of external funding, enhances Center's outreach and external collaboration.

Pamela Glover serves as Executive Director for Planning and Education. She is a full-time staff member. She leads in the planning, implementation, assessment and innovation of the integrated research and education programs. She also assists the director in day-to-day management of CLiPS, serves as liaison with NSF, e.g. for Site Visits and Annual Reports, maintains the Center records, assists in public relations and marketing activities, and ensures that the Center operates according to NSF policies for STCs and all federal regulations and statutes. She is assisted in managing CLiPS education programs by Tryreno Sowell, Director for Education and Diversity, who is a full-time staff member at CWRU, and new staff member, Risa Hartman, Director for Education and Diversity at the University of Texas where she is committed half-time to CLiPS education and outreach programs. Ms. Glover's staff includes Aaron Brister who is charged with working on proposal applications and other writing activities. In his role, Mr. Brister provides proposal writing support to both CLiPS research and education activities. Ms. Glover is also assisted by Katherine Binder, Assistant for Operations.

Patricia Simmons is the Budget Coordinator for CLiPS. She oversees all of the documentation and the fiscal reporting functions of the Center.

Dr. Charles Bush serves as a Development Consultant to the Center. He coordinates the intellectual property, industrial outreach and business development activities of the center. He comes from a 32-year career in management of industrial R&D and other technical functions at an executive level. He works with Center faculty to develop industrial collaborations and identify research results that are ready for patent protection.

Dr. Andy Olah joined the Center as Technical Consultant early in 2014. He has considerable research and management experience with polymeric materials. His focus in CLiPS is on developing multi-investigator proposals.

The committee structure facilitates effective and efficient operation of the research, education and diversity programs while maintaining close communication and interaction between the faculty and staff. The Executive Committee, chaired by the Director, meets monthly with faculty and staff members at the partner institutions via teleconference. These meetings cover management and organizational aspects of the center and include discussions of the research and education experience of the students and the integration of diversity into the programs.

Technical topics are addressed in regular Platform meetings. The highly interactive research projects require regular meetings for planning and discussion. The platform committees are chaired by the platform leaders and consist of the platform faculty, students and research associates. The flexibility of web-based meetings greatly facilitates inclusion of faculty and students at the partner and affiliate institutions.

The education and diversity programs are coordinated by the Education Program Committee, which meets twice a month to assist the Executive Director for Planning and Education with implementation, translation, and evaluation of the integrated education and outreach programs. The committee membership includes the Director, the Associate Director for Education & Diversity, the Executive Director for Education & Planning, the two Education and Diversity Directors (CWRU & UT), the KSU evaluation team, and the Education Program Coordinators at Fisk University and the University of Southern Mississippi.

The Director is assisted by a diverse External Advisory Board (EAB). Of the 12–member board, two of the members are African-American, two are women, and one has a disability. The EAB meets regularly to review the CLiPS Strategic and Implementation Plan (SIP), to review progress toward research and education goals, to assess the sufficiency of available resources for CLiPS to ensure achievement of the CLiPS integrated research and education mission, and to make a written assessment for the university administration.

Intellectual Merit of the Center

Research Vision and Goals

A broad range of new science and innovation is emerging from CLiPS unique technology. CLiPS is becoming a global resource for microlayered and nanolayered polymeric materials. The CLiPS research activities:

- Define and implement interdisciplinary research programs that exploit the large interfacial area and the unique nanoscale confinement made possible by reducing the dimensions and dimensionality of the layers.
- Use these architectures to create and explore new materials with unique transport behavior, dielectric behavior, and interactions with light.
- Focus the integrated research activities on national priorities of defense, environment, energy, and health.

To achieve these goals, the research programs are organized into five research platforms:

- Rheology and New Processing (at CWRU and UT) enables fabrication of hierarchical microlayered and nanolayered complex polymer-based structures and systems using new feedblocks and multiplier dies, as well as the capability to accurately simulate multi-layered flows inside said equipment.
- Novel Membranes and Transport Phenomena exploit the layered hierarchy to achieve unique transport properties. Researchers from UT, CWRU, USM, and Fisk collaborate in this thrust area under the leadership of UT. Research is focused on solvent-free processing of high-flux, high selectivity layered membranes for gas separation and water purification membranes; high performance barrier materials based on forced assembly of nano- and microlayered liquid crystalline polymers and nanocomposite systems; high barrier systems based on multilayered oxygen scavenging membranes; layered membranes with improved fouling resistance; and fundamentals of nanoconfinement on physical aging in layered systems.
- Innovative Optical and Electronic Systems are based on advanced layered materials. Teams from CWRU, Northwestern, Youngstown State, and Rose-Hulman collaborate in the development and testing of devices. New work on active materials and polymer synthesis will strengthen the laser and optical data storage projects.
- The layer-multiplying process opens new opportunities for Science and Technology Initiatives. Significant efforts have been mobilized to advance innovations in the production of continuous polymer nanofibers using a melt-based processing technique comprised of multilayer coextrusion, orientation, and separation procedures. One focused area is the need in power electronics and pulsed power applications for dielectric capacitors with high energy density, low losses, and high temperature capabilities. We have achieved a breakthrough by combining a high breakdown strength polymer with a high dielectric constant, PVDF, as multilayer films. The layered films exhibited enhanced breakdown strength, low dissipation factor, and low hysteresis. Their superiority was also demonstrated in a couple of prototype capacitors. The research in Platform IV is leading to the discovery and understanding of new structures and new phenomena. These findings can be the basis for more complex hierarchical organizations and new materials systems and explores fundamental questions of confinement-induced phenomena within all Platforms.

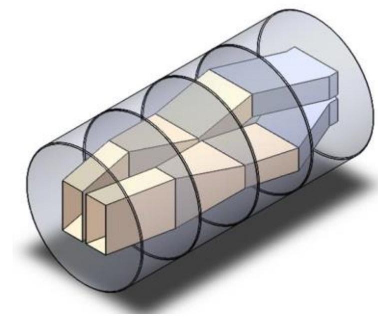
- Templated Interfaces and Reactions is looking at the chemistry inside the multilayers and surface modification. The goals in this platform are to increase chemical and surface functionality: compatibility with processing conditions utilizing patterning and nanofiber fabrication techniques; and to pursue applications in drug delivery, therapeutic agents, optical devices and lenses, tissue engineering, and membrane modification.

Research Accomplishments and Highlights

In addition to the research platforms described below, the multilayering technology that forms the foundation for CLiPS research is part of the Enabling Technology and Facilities Division that facilitates the needs of all of the platforms under the leadership of the Director.

Platform I: Rheology and New Processing

2013-14 saw the continued consolidation of Platform I activities, with the project on micro and nano-fibers having reached maturity and being transferred to Platform IV, while two new projects were formally established. This reporting period also saw the consolidation of CAPP-Center for Advanced Polymer Processing and of PolymerPlus, a start-up company spun-off the Platform's activity in 2010.



Optimized design of multiplier die

Extensional Rheometry of Polymer Melts:
This project continues to focus on the development of a new dual controlled stress/rate extensional rheometer for polymer melts that will allow CLiPS to perform the full spectrum of rheological characterization of the materials. This instrument became operational in 2011 and the project is now devoted essentially to the characterization and modeling of various polymer systems and no longer on equipment development.

New Multilayering Technologies:
On the technology side, the project on New Multilayering technologies is advancing well, with materials with 3:1 viscosity ratio and a 10:1 elasticity ratio already successfully layered up to 65 layers. A 3rd generation die is already designed. This is anticipated to be the final die design that will give CLiPS the capability to layer melts of high viscosity and high elasticity ratios. Finally, the project on on-line sensors was fully implemented, with the first instrument, an on-line sample collector, already operational.

New Materials:
Two new projects have been launched, one on nano-confined polymer blends and one on ultra-high water barrier films for flexible electronics.

Platform II - Membranes and Transport Phenomena - Highlights & Summary of Accomplishments

Fundamental understanding of transport phenomena in micro- and nano-layered systems will be developed by performing systematic experimental and modeling studies to identify the dominant controlling structural variables. This understanding of fundamental transport phenomena will be used to design and optimize unique layered systems for food and electronic packaging, drug delivery and diagnostic devices. Layered material systems will be optimized to exhibit transport-property profiles that may be otherwise inaccessible.

Development of High Barrier Layered Systems using Particulates
Work continued on development of high gas barrier multilayered nanocomposites containing high aspect ratio layered silicates and graphene. The mechanism responsible for considerable enhancement of gas barrier upon annealing of these multilayers was revealed, namely it was attributed to formation of skewed

platelet aggregates resulting from filled layers shrinking. In addition to polyethylenes, polyethylene oxides exhibit a strong moving boundary effect and thus can be used for development of a new kind of high gas barrier multilayered nanocomposites containing nanoparticulates.

Multilayer Fouling Resistant Membranes

Membranes are attractive for use in water purification because of their ability to remove nearly all water contaminants, their small environmental and spatial footprint, and their economic advantages over alternative technologies. However, a significant challenge facing widespread implementation of membranes for liquid purification is fouling. Fouling is the deposition of matter in a membrane's pores or on its surface that leads to changes in membrane transport characteristics. Dopamine is a naturally occurring hormone and neurotransmitter. Lee et al. recently reported that under alkaline conditions, a dopamine solution undergoes polymerization to form a polymer that mimics the properties of mussel adhesive plaque. The polydopamine polymer will non-selectively deposit onto virtually any surface. The deposition will be on the order of 1-100 nanometers in thickness on nonporous substrates depending on contact time. During this past year, we have used our new constant-flux apparatus to further study the impact of dopamine deposition conditions and operating parameters on fouling of ultrafiltration and microfiltration membranes. We have developed protocols to identify the threshold flux (i.e., the minimum flux required for stable membrane operation in a fouling feedwater) and are correlating it with membrane surface properties and operating conditions. Our startup company, Advanced Hydro, that emerged from this study, continues to make inroads into the oil and gas as well as wastewater purification industries.

Sulfonated Polysulfone Desalination Membranes by Melt Coextrusion

All desalination membranes currently in use are produced via solution processing of monomers that undergo an interfacial reaction at an oil/water interface to produce aromatic polyamide interfacial composite membranes. Large volumes of volatile, flammable hydrocarbon solvents are used in this process. The goal of this research project is to develop solventless, melt-processible, coextruded membranes for desalination. A multilayer coextrusion process is envisioned to prepare disulfonated poly(arylene ether sulfone) (BPS) thin film composite membranes for desalination. By making membranes via coextrusion, it may be possible to achieve high quality BPS thin film composite membranes at lower cost with more efficient processing. At UT, the rheology of blends of BPS materials with poly(ethylene glycol) plasticizers was characterized, and conditions were identified which would enable co-extrusion of plasticized BPS with polypropylene. The plasticizer can be extracted following melt processing, and transport property measurements are being conducted on these new melt-extruded materials.

Synthesis and Characterization of Novel Chlorine Resistant Polyamide-Polyetheramide Reverse Osmosis Membranes for Desalination of Seawater.

This project, headquartered at Fisk University, is complementary to the project above on multilayer desalination membranes, and researchers at Fisk University are exploring new types of polymers for use as desalination membrane materials. Several new types of polymers were synthesized during the past year, and they will be characterized with respect to their water and ion transport properties at the University of Texas.

Multilayered Materials for Modified Atmosphere Packaging Materials

The preservation of fresh produce as it passes through the supply chain is an important economic and safety issue. Although traditionally achieved through refrigeration, food preservation can also be addressed by controlling the gaseous atmosphere around the produce. This alternative, known as modified atmosphere packaging, or MAP, has recently been shown to be a useful strategy for use with or without refrigeration and has opened up significant opportunities for membrane technology. This project, headquartered both at Case and UT, focused on multilayer membranes with tunable CO_2/O_2 selectivity. Poly(ethylene oxide), or PEO, materials have exceptionally high CO_2/O_2 selectivity; however, these materials are not directly suitable for this application, owing largely to their low gas permeability and high water solubility. Thermoplastic elastomers produced by Arkema Inc., known as PEBAX block copolymers, were used in this study. PEBAX 2533 has been coextruded at Case, and initial membrane production and permeation measurements have been made. Films of PEBAX 2533 (80PTMEO-PA12) with thicknesses as little as 7 μm have been achieved, and composite films with selective layers in the tens of microns have been produced. Additional characterization of the porous layers required for membrane applications was also been undertaken. The initial objectives of this project have been achieved, and this project has been sunsetted.

<u>Oxygen Scavengers for Packaging Applications</u>
Polymers with double bonds, such as poly(butadiene), have been pursued as ultra-high oxygen barrier materials for food packaging and other applications. We are expanding this study to additional melt processable oxygen scavenging polymers, such as MXD-6 and other diene containing materials, and

<u>Properties and Ordering of Confined Main Chain Liquid Crystalline Polymers</u>
In this project, high quality multilayer LCP films with micro- and nano-layers of LCP were produced by developing a rheology modification procedure. This has resulted in a new manuscript and provisional patent filing. The UT student working on this project, Zhenpeng Li, won a 3rd place poster award in the Materials Engineering and Sciences Division Poster Session at the 2013 AIChE Annual Meeting out of ~80-100 posters. He also won the Chevron Best Poster Award at the Graduate and Industry Networking conference at UT-Austin. Both were Clips posters. The initial results from this project have stimulated interactions with Celanese and a major food packaging company to drive towards scale-up of our process and, ultimately, commercialization.

<u>Fundamental Analysis of Ion Transport in Polymeric Membranes</u>
In support of the project related to desalination membranes via melt extrusion, we have undertaken a long-range, fundamental exploration of ion transport in polymer membranes. Such studies underpin all efforts in preparing multilayer membranes for desalination and for other energy-related applications, such as electrodialysis, forward osmosis, etc. We have established fundamental membrane characterization facilities in our laboratories at UT to characterize individual ion sorption in polymers as well as measure multicomponent ion and water transport properties in single and multilayer membranes. We have recently added capabilities to measure electric field driven resistance in membranes of interest. Our focus for the coming year will be to develop fundamental understanding allowing a connection between ion transport under both concentration gradient driven diffusion (important in desalination applications, for example) and electric field driven diffusion (important in electrodialysis, for example). Such fundamental studies will be used to further elucidate systematic structure/property studies in this area, leading to clearer design rules to prepare new membrane materials for such applications.

Platform III - Optic and Electronic Systems – Highlights and Accomplishments
The goal for Platform III is to explore the science and application of micro- and nano-layered polymeric materials for photonics, optoelectronics, and energy technology.

<u>Optical Data Storage</u>
The main activity and accomplishment in the past year is the development of the read/write apparatus so that the physical mechanism of writing can be studied. In particular, a high power CW 405 nm wavelength laser that can be modulated with pulsing down to 30 ns was purchased and installed into the read/write apparatus. With this laser, a detailed study of the intensity and pulse duration (fluence) dependence of the fluorescence contrast reduction was carried out. It was found that the writing process becomes nonlinear at pulse durations below about 1 microsecond. Further, the writing mechanism was studied in detail and found to be nonlinear due to mostly thermal effects with some contribution from reverse saturable absorption. Pulses as short as 100 ns could cause bleaching within the power range of the laser. The thermal mechanism was modeled and found that the temperature at the focused writing spot could be as

high as 1000C. These results indicate that a robust writing protocol for short pulses (fast writing times) can be developed. The nonlinear response will result in minimal writing and reading cross-talk allow many layers to be written and at least tens of thousands of read cycles. These results were published in the Journal of the Optical Society of America B. A standard sample configuration based on laminating a single writing layer between two buffer layers has been developed in order to test new chromophores in a well-controlled manner.

Electro-optic materials

Several large batches of amphiphilic second-order chromophores have been supplied to the groups of Baer and Singer. Tri-layer co-extrusion runs have been carried out with several sets of polymers. It was found that SAN25/Chromophore/EVOH/PVDF multilayer film produce the best films. It was found that the second harmonic signal was weak from these films. Additional experiments were carried out on single layer films and laminated films, including electric field poling. The experiments that indicate that the chromophore has a small nonlinear optical response in the form it takes in the films. Work is now aimed at identifying a chromophore with a large nonlinear optical response.

Coherence effects in photovoltaic devices

Initial and impressive resonance coupling between photons and semiconductor optical absorption was demonstrated with several organic bulk-heterojunction photovoltaic donor polymers. It was discovered that these effects were due to the formation of cavity polaritons, a remarkable fact given that the photovoltaic device structure includes a transparent conducting electrode with low reflectivity. These results were communicated in a high-impact journal. Work was next initiated in a more general direction to demonstrate and understand the formation of cavity polaritons in multilayer optical structures with a view toward extending this work to tandem photovoltaic cells. A program to investigate new materials and fabrication approaches for use in these studies was initiated. A publication in Optics Expressed appeared and second is in press to appear in Advanced Energy Materials.

Lasers and coherent phenomena

Experiments on and modeling of distributed Bragg and distributed feedback laser temperature tuning and temperature stabilization were completed and published. The flexibility to choose designs for multilayer devices with either enhanced temperature tunability or improved thermal stability, depending upon system needs, should prove technologically advantageous for a wide range of multilayer devices. A detailed review of surface emitting all-polymer distributed feedback lasers was also published, as well as a theoretical treatment of cascaded optical nonlinearities of guest-host systems in thin-film geometries.

With respect to the multilayer appliqués, demonstrations of the use of appliqués to shift laser diode wavelengths and thresholds were completed along with a detailed study of enhanced surface absorption using appliqués. A new study on the use of appliqués to enhance surface magneto-optic Kerr rotation was begun in acollaboration between Youngstown State and Rose-Hulman. Related coherent optical phenomena projects, including an experimental study of surface patterning of microlenses on multilayers and a theory of coherent perfect optical polarization rotation in multilayers has been completed.

Colloidal antireflection coatings

Maarij Syed and Adam Nolte employed one junior undergraduate student during summer of 2013 to investigate the environmental response of colloidal antireflection coatings. Ross Chongson worked on the fabrication of AR films during the first three weeks and then spent the rest of the time in characterizing the humidity and temperature response of these films using spectroscopic ellipsometry. He also worked on using a silane treatment to mitigate the effects of environmental factors like humidity. The mitigating effects of silane treatment were verified by ellipsometric testing. Staring in winter and spring terms (November 2103 thru now) of 2013/2014 Ross and another student Theo Famprikis continued to work on improving the silane treatment. They are also quantifying the environmental response by using a quartz crystal monitor (QCM) to substantiate the findings from ellipsometry. These results are being compiled for publications.

During the period ranging from November 2013 thru March 2014, optical engineering undergraduate Caleb Gannon worked on developing an optical model for a lens system that will be used in read / write applications.

Platform IV - Science & Technology Innovations – Highlights and Accomplishments
Platform IV on science and technology innovations in microlayered and nanolayered materials involves a team from CWRU who explore new opportunities for the enabling technology and its derivatives (e.g. fiber fabrication) under the continued leadership of Professor LaShanda Korley. The research in Platform IV is leading to the discovery and understanding of new structures and new phenomena. These findings can be the basis for more complex hierarchical organizations and new materials systems and explores fundamental questions of confinement-induced phenomena within all Platforms.

<u>Co-extruded Nanofiber Systems</u>
Significant efforts have been mobilized to advance innovations in the production of continuous polymer nanofibers using a melt-based processing technique comprised of multilayer coextrusion, orientation, and separation procedures. A few projects are highlighted below:

<u>Fiber Fabrication Optimization</u> (*Baer, Korley, Wnek*)
Using co-extrusion and multiplication techniques, it has been demonstrated that rectangular, high surface nanofibers can be produced from any melt-processable polymer via this cost-effective and environmental-friendly approach. The ability to produce nanofibers from two or more types of polymers simultaneously has been achieved; dissolution and mechanical separation techniques can separate the polymer nanofibers from PCL/PEO, PA6/PET, and PP/PE systems. Post-processing orientation has been systematically investigated as a method to strengthen and align the nanofiber systems. For example, polyolefin nanofibers (polypropylene/low density polyethylene) (PP/LDPE) nanofibers were oriented at a 21.7x draw ratio, which increased the Herman's orientation factor for PP from 0.016 to 0.95, indicating PP molecular chains are highly oriented along the fiber direction due to orientation. Young's modulus and tensile strength were improved by 21.0 times and a 28.5 times, respectively. After delamination, PP and LDPE fiber lateral sizes measured 0.44 ± 0.008 µm by 0.99 ± 0.12 µm. In another study of poly(ethylene oxide) (PEO, matrix)/poly(caprolactone) (PCL, fiber), PEO removal/PCL fiber delamination was optimized by using a 24 hour water wash, 24 hour methanol wash, and 30 minute water washing at 750 psi; PEO was almost completely removed (final composition: 99.2 wt% PCL, 0.8 wt% PEO) while simultaneously producing well-defined rectangular PCL fibers with dimensions 1.6 ± 0.4 m (thickness) × 2.6 ± 0.6 m (width). These optimization achievements in separation and orientation will directly impact efforts in filtration and biological applications.

<u>Biological Applications</u> (*Pokorski, Wnek*)
In one investigation, PCL nanofibers containing 5-30% of an antifugal drug (clotrimazole) were fabricated by the coextrusion and multiplication process. Release of clotrimazole from the imbibed, as-extruded PCL fiber was shown to be higher when compared to electrospun PCL fibers loaded with clotrimazole; ongoing studies are focused on efficacy of the released clotrimazole and applications to topical delivery. Another area of focus is the surface functionalization of extruded PCL fibers to promote cell proliferation and differentiation. Specifically, modification of PCL with a photoreactive moiety was achieved to present an alkyne group suitable for copper-catalyzed azide-alkyne cylcloadditon reaction with an azido- fibronectin-derived peptide (RGD). The PCL-RGD fibers promoted adhesion, growth, and proliferation of NIH 3T3 fibroblasts, and were able to provide enhanced adhesion and spreading along the fibers than neat extruded PCL fibers. Applications in spinal cord injury are targeted for future work.

Multilayer Film Technology Advancements

The second area of focus expands our utilization of multilayer films for actuation and shape memory via incorporation of active elements within select layers and selection of synergistic material systems, and tailors barrier properties and surface behavior via coating of multilayer surfaces. Fundamental efforts in dielectric materials are also ongoing. A few projects are highlighted below:

Electroactive Nanomaterials (*Advincula*)- The main objective of this study is to fabricate roll-to-roll co-extruded multilayer films with electroactive shape memory properties. Electrically conductive carbon-based nanofillers such as carbon nanotubes and graphene will be incorporated in the matrix, which can then enable the applied voltages to trigger the shape memory behavior via Joule heating. These electrically triggered shape memory materials have the advantage of having temporal and spatial control of the shape memory process.[2] As dispersion is critical to the realization of the desired properties, research progress has focused on methods of dispersion of unmodified carbon-based nanomaterials within coextrudable polymer systems and the generation of homogeneous monolith polymer composite films for initial characterization.

Shape Memory Materials (*Baer*)

A glass transition-based multilayer shape memory system was fabricated using a thermoplastic polyurethane (TPU, Carbothane 3595A) and poly(vinyl acetate) (PVAc) and exhibited superior performance - ~100% shape fixity and recovery – and high transparency. Expanding upon this recent accomplishment in shape memory, the current focus of this research area is microptics via surface patterning embossing technique with an emphasis on understanding the surface pattern-memory mechanism in these materials.

Multilayer Dielectrics (*Baer, Zhu*)

One focused area is the need in power electronics and pulsed power applications for dielectric capacitors with high energy density, low losses, and high temperature capabilities. We have achieved a breakthrough by combining a high breakdown strength polymer with a high dielectric constant, PVDF, as multilayer films. The layered films exhibited enhanced breakdown strength, low dissipation factor, and low hysteresis. Their superiority was also demonstrated in a couple of prototype capacitors.

Currently, we have achieved understanding of the underlying mechanism of the better performance for these multilayer dielectric films. First, dipole switching is effectively prohibited due to nonuniform distribution of electric fields in different layers. The high dielectric constant PVDF layer experiences a lower nominal electric field and the low dielectric constant polymer layer has a high nominal electric field. The low nominal field in PVDF will not be able to switch the dipoles in PVDF crystals, which is a major source of energy loss. Second, impurity ions in the high dielectric constant PVDF layer play an important role in the hysteresis loss in multilayer films. By confining the ions in nanolayers, the hysteresis loss can be significantly decreased. Third, interfacial polarization is observed for PVDF multilayer films, especially at high electric fields. These highly charged interfaces serve as effective traps in enhancing the breakdown strength of multilayer films.

We also investigated high temperature performance of polysulfone (PSF)/PVDF multilayer films. In addition to the effects of different polarizations, electronic conduction due to enhanced charge carrier mobility at elevated temperatures also plays an important role. Therefore, a highly insulating blocking electrode polymer is necessary for high temperature, high energy density, and low loss capacitor applications. Possible candidates are cyclic olefin copolymers and PTFE-based copolymers.

Platform V –Templated Interfaces and Interactions

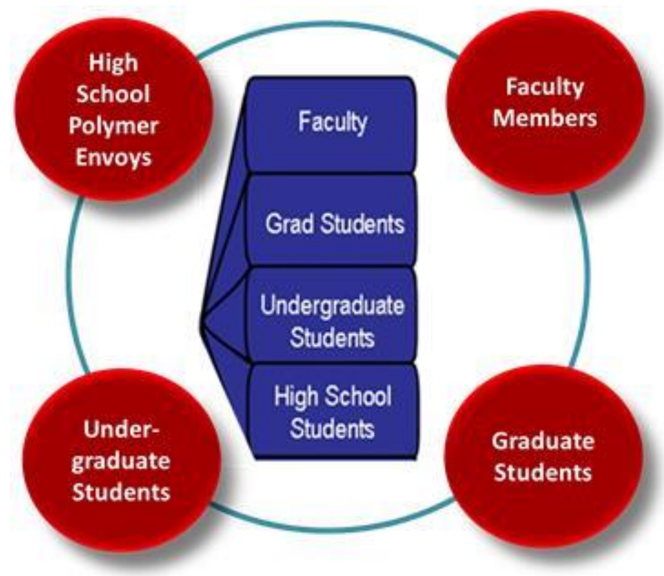
In this new platform, researchers from Macromolecular Science and Engineering, Physics and Biomedical Engineering are looking at, 1) precursor materials and pre- or post-processing chemistry such as precursor polymers with thermal, photo, electrical, and chemical field response that are amenable to patterning and ordering, 2) nanomaterials and guest-host systems, 3) biological materials and proteins, and 4) self-immolative polymers and controlled gradients and degradation.

Additional projects include surfaces, templates and patterning, such as, 1) lithographic and non-lithographic patterning, 2) surface initiated polymerization and polymer brushes, 3) colloidal particle modification and nanocomposites, and 4) nanofiber modification for tissue engineering.

Integration of Research and Education

Vision and Goals

CLiPS's vision is to be the global leader for integration of research and education in polymer science and engineering. To accomplish this, CLiPS integrates its research with multi-level educational programs to stimulate and prepare American students to pursue professional careers with advanced degrees in polymer science and engineering. The multidisciplinary resources of the Center will be employed to develop focused programs that connect and educate a diverse range of American students from elementary school through the PhD level.



CLiPS Education Program Organized as Layered Research Teams

The organizing principle for CLiPS education programs is the Layered Research Team. The team description underscores the multi-disciplinary, interactive nature of the programs and echoes the multilayering process upon which CLiPS research is based.

- The role of faculty members within the layered research team is to: 1) provide guidance and instruction for CLiPS participants, 2) develop project ideas, 3) ensure efficient operation of the layered research teams.
- Postdoctoral Associates work under the direction of a specific senior faculty advisor within the LRT. Mentoring is tailored to the career interests of each postdoctoral researcher and includes grantsmanship, interactions with industry and funding agencies, and collaborations with researchers across CLiPS.
- Our goal for graduate students is for them to become accomplished professionals who can function successfully in industry, academia, or government positions. Through their participation in CLiPS, they: 1) learn research ethics, safety and skills 2) develop professional communication skills, 3) interact with research partners and industrial representatives, 4) serve as mentors for undergraduate, high school and pre-high school students.
- CLiPS undergraduate program goals are to: 1) attract qualified students to CLiPS PhD programs; 2) further our goals for diversity. Our strategies for accomplishing these goals are to: 1) attract exemplary undergraduates to participate in CLiPS research during the academic year, 2) attract undergraduates from across the country to participate in the summer REU program, 3) work with CLiPS affiliates schools – schools that do not offer PhDs in CLiPS fields, but are known for excellent teaching.
- CLiPS program for high school students is the Polymer Envoys program. CLiPS goals for the Polymer Envoys are to raise their awareness of the breadth of STEM careers, reinforce their knowledge in science and math, engage them in engineering research, and encourage their matriculation to college. Pre-High School Student programs in CLiPS provide opportunities at the university and in the community, for younger students to become excited about science and engineering, and to learn about STEM-related opportunities, such as the Polymer Envoys program.

Mentoring

CLiPS educational programming includes a comprehensive, multi-level mentoring plan that includes Postdoctoral Researchers. This plan is further discussed in the Education section of this report and is found in its entirety in Appendix F.

Postdoctoral Associates

The success of the postdoctoral associates plan is assessed by monitoring the progress of each associate toward his or her career goals after completing the postdoctoral program. Throughout the course of the Center postdoctoral fellows have gone on to pursue full-time positions in industry and academia.

Graduate Programs

A key indicator of the Center's success is the production of students who enter STEM careers. During the years 2013 -2014, CLiPS graduated sixteen PhDs. Twelve of the 2013-2014 graduates are working in STEM industries; three are in post-doctoral positions and one is undecided.

Masters candidates at Fisk University fulfill the same teaching-learning role in the LRT as the PhD students. This initiative – CLiPS@Fisk - is addressed in the section on Diversity both here and in the body of the report.

Undergraduate Programs

The CLiPS programs for undergraduate students are the *Affiliates Program*, the summer *REU Program* and research in CLiPS labs as members of layered research teams. These activities expose undergraduate students to polymer research and to opportunities in CLiPS.

CLiPS Affiliates are primarily undergraduate institutions which have a strong undergraduate teaching focus and that do not offer PhD programs in CLiPS fields. CLiPS Affiliate institutions are Bowie State University, Central State University, Kentucky State University, Ohio Northern University, Rose Hulman Institute of Technology, Youngstown State University. Activities with CLiPS affiliate schools help further our goal of increasing diversity (three affiliates are HBCUs). The University of Texas has associations with the UT border schools, UT-Pan American and UT-Brownsville.

The REU program introduces CLiPS technologies, polymer science and STEM research to a diverse group of American students. It is also an important pipeline for American students into CLiPS graduate programs. Over the course of the Center, the REU program enrollment has included approximately 50% women with 25% of the total enrollment comprising under-represented groups.

Students work as members of CLiPS Layered Research Teams for ten weeks under the mentorship of a graduate student. In addition to daily research activities, REU students participate in weekly program meetings during which they hone their presentation skills, attend lectures in various areas of polymer science and engineering, and discuss professional ethics. The summer program culminates in the Northeast Ohio Undergraduate Polymer Symposium, an event showcasing the summer research work of undergraduates from CWRU, the University of Akron, Kent State University, and NASA.

High School Program

CLiPS's program for high school students is the Polymer Envoys. This program matches one high school student with one graduate student in a longitudinal relationship that lasts three years. Because of this continuity structure, the program provides significant hands-on research experience and mentoring to a small number of high school students. It has a tremendous impact on the individual student participants, and allows CLiPS to more closely track students to determine short- and long-term impacts.

The program was initiated with the beginning of CLiPS in the fall of 2006. At that time, six students from the Cleveland Metropolitan School District (CMSD) were recruited to become the first class of Polymer Envoys. The University of Texas followed suit, enrolling four students from the Austin Independent School District in the spring of 2007. This year there are twenty-four students in the program across the Center. All of the school districts represented in the Envoys program have a high percentage of students who come from under-represented minority groups. The program in Texas also includes students from Texas School for the Deaf in Austin.

Over the course of the program there have been seventy-one Polymer Envoys enrolled in the program. There are thirty-seven program graduates and all of them are enrolled in college – thirty-two in STEM fields. Ten students left the program before graduating for a variety of reasons. Based on the program's success, legacy efforts in regard to the Polymer Envoys at CWRU involve, 1) expanding and institutionalizing the Envoys program across the School of Engineering and the University, 2) developing a STEM Academy, in cooperation with the CMSD, that will expand and support the Envoys, and work to bolster the Envoys' education in Science, Math and English.

In addition to academic preparation, financial considerations are also important to students applying to a school such as CWRU. In 2012, the university agreed to waive tuition for Polymer Envoy students who apply and are accepted to CWRU. This important development is encouraging. To date there are four Polymer Envoy alumni enrolled at CWRU, one in an engineering PhD program, one a 2013 BS graduate in Sociology, one is a rising junior, and one is a rising sophomore. Both of the undergraduates are Engineering majors.

In 2008, CLiPS partnered with the Kent State University Research and Evaluation Bureau to study the Polymer Envoys Program. The analysis of the yearly study results contained highlights that will help in planning. A significant finding was the influence of the graduate student mentors on the Envoys. The Envoys reported feeling supported by their graduate student mentor and motivated by the graduate student's academic achievement. They look upon the graduate students as role models both socially and academically. The Envoys reported that they have a long-standing interest in science, but that their high schools do not offer the coursework they need to prepare them for college studies in a STEM field. Tutoring in math and science has been integrated into the Envoys program to help the students in their work in the lab.

Pre-High School Programs

CLiPS is currently engaging youngsters across the Center in activities such as:

- Science Sundays at the Austin Children's Museum reaching greater than 1000 visitors annually
- The Middle School Science Club at Fisk University engaging 30-40 student per year
- Introduce a Girl to Engineering at CWRU, reaching 75 middle school young women
- The Martin Luther King Day activity at the Cleveland Museum of Natural History reaching ~150 children and families
- Summer Science Camp at UT – enrolling 25-30 middle school age students for 2 weeks during the summer
- National Youth Sports Program at CWRU – reaching 80-100 students middle-school age youngsters with interactive science activity sessions held each summer

Integration of Diversity into CLiPS Programs, Projects and Activities

Diversity Vision and Overall Goal

CLiPS aims to become a national resource for broadening participation of women, under-represented minorities, and persons with disabilities, in polymer science and engineering, and related fields. In order to accomplish this, CLiPS has developed and will continue to develop initiatives that attract, train, and graduate diverse American students into polymer science and engineering, and related fields. The three goals for diversity are:

- To encourage a diverse range of students to pursue STEM careers through pre-college outreach programs and through collaborations between research universities and minority-serving institutions
- To engage Fisk University graduate students in CLiPS research projects through CLiPS @ Fisk activities

- To impact the diversity of faculty, staff, and students at all CLiPS Institutions in a positive way

Engagement of Diverse Students

The Polymer Envoys Program is a key program through which CLiPS engages pre-college students. Working with the Cleveland Metropolitan School District and the Austin Independent School District gives the program ample access to our target populations. Although this program was described elsewhere, it should be noted that all but five of the seventy-one participants to date have been from under-represented minority groups and half of them have been women.

Guided by experience with the Case-Fisk Alliance, CLiPS is exploring opportunities to engage with other minority-serving institutions. At the University of Texas, CLiPS has developed similar relationships with UT-Pan American and UT-Brownsville, two primarily Hispanic-serving institutions. The University of Texas also has an association with Texas School for the Deaf and has engaged students there in the Polymer Envoys program and other outreach activities.

CLiPS @ Fisk

Building on the earlier Case-Fisk Alliance, the CLiPS program at Fisk has been broadened and renamed CLiPS @ Fisk. The key components of the program are (1) student involvement focused on MS candidates, and (2) student research involvement with CLiPS projects.

Because Fisk does not have a PhD program in polymer science, faculty members often rely on post-doctoral associates for their research. The change of focus to Master's Degree candidates, identified as CLiPS-Fisk Scholars, has broadened the scope of CLiPS activity at Fisk. In the Layered Research Teams at Fisk this year, there are three students who are candidates for a Master's degree, two undergraduate students and three Polymer Envoys. Programs at Fisk include outreach to pre-college and pre-high school students through Saturday Science Academy and middle school Science Club. Finally, coordination of the 3-2 dual degree program between Fisk and CWRU is an important component of the relationship.

Impact on CLiPS Institutions

The Polymer Envoys program is an outstanding example of CLiPS's impact on the institutions involved and is adding to the diversity of the student body at CWRU and UT. In support of Fisk students interested in attending CWRU, two Provost Special Scholarships have been secured to provide financial aid to binary students from Fisk. In addition, CLiPS has actively championed the hiring of women and under-represented minority faculty members (Korley at CWRU; Arnett at Fisk) and will continue to follow that course of action when considering new faculty hires. With CLiPS faculty involvement, the Case School of Engineering has established a program addressing engineering education and outreach, as well as diversity and inclusion components. CLiPS is committed to support such efforts as much as possible.

Partnerships and Knowledge Transfer

The CLiPS goal for Knowledge Transfer is to be a unique global resource for the dissemination of knowledge and technology in the area of layered polymeric systems and the educational programs developed to promote STEM learning and involvement by diverse populations. This requires a complex network of interactions, organized from the standpoints of the: (1) CLiPS participants, (2) Center-related external audiences of government, academic and industrial contacts, (3) and the broader scientific and education communities and the public.

Knowledge Transfer between CLiPS Participants

Meetings

Regularly scheduled administrative and research platform meetings continue to be utilized to meet the Center's goals for knowledge transfer. Web meetings are used to enable effective communication across the different locations of the Center. These regularly scheduled meetings include:

- Weekly or bi-weekly meetings of the platforms
- Monthly meetings of the Executive Committee
- Weekly staff meetings
- Monthly meetings of the Polymer Envoys, liaison teachers and graduate students
- Monthly meetings of the Development Committee with meeting of specific topic-focused subgroups meeting as needed

Larger meetings, which also contribute to accomplishing our knowledge transfer goal, include:

- The Annual Meeting of the Center involving CLiPS participants (faculty members, staff members and students) from all sites; held March 13, 2014
- The External Advisory Board (EAB) meeting on March 13, 2014, coinciding with the CLiPS Annual Meeting

Workshops and Seminars

CLiPS Faculty and Staff members presented three workshops during the 2013-14 reporting period:

- On January 29-30, 2014, a workshop on Polymeric Biosystems was held. This workshop was organized by Rigoberto Advincula and attracted attendees from medicine, bio-medical, and polymer engineering.
- On February 13, 2014, Education and Diversity Directors from 12 of the 14 active STCs met in Cleveland to discuss Best Practices, Opportunities for Collaboration, and STC Legacy Issues.
- On February 28, 2014, CLiPS Faculty and Staff members presented a symposium titled, Frontiers in Polymer Science, to a large audience of faculty members and students at CLiPS Affiliate, Bowie State University.

Educational Assessment

The CLiPS educational partnership with Kent State University's Research and Evaluation Bureau, established to study the Polymer Envoys Program, continued during the current year. This work is investigating the characteristics in the targeted high school students' environments that influence their choice of a STEM career and the impact of CLiPS educational programs on these decisions. The Bureau's annual reports are being used in our plans to improve and expand the Envoys program within CLiPS and beyond.

Broader Scientific Community and the Public

Creation of Intellectual Property and Spin-Off Businesses: Since the inception of the Center, five patents have been issues, and applications have been made for twenty-four additional patents. Patents and licensing are further discussed in the Outputs and Issues section of this report.

Highlights over the past year include:

1. CLiPS faculty members, students and staff generated 84peer-reviewed publications over the past year. In addition, during the same period, there have been 128 research presentations by CLiPS participants**.**
2. Web-conferencing remains an effective tool for communicating in groups across sites. In addition to the executive committee meetings, the research platform meetings and education platform meetings continue to take advantage of this method of communication.

Intellectual Property

CLiPS goal for intellectual property is to create commercial value, businesses, and jobs from the CLiPS research through patents, licensing and spin-off companies.

To date:

- Five patents have been awarded and twenty-four patent applications have been made

- Three businesses have been created based on work done within the Center. The first, Advanced Hydro in Austin, Texas, is focused on commercializing the patent pending technology to reduce fouling of membranes used for water purification and filtration systems. The second, PolymerPlus in Cleveland, Ohio, is focused on creating GRIN lens technology based on polymer multilayer films and on developing commercial technology and applications for additional patents generated by the Center. PolymerPlus holds a license from CWRU for the Aspherical GRIN lens patent application and for the GRIN lens patent generated by research on multilayer films at CWRU prior to the inception of the Center. Folio Photonics was established in Cleveland in 2012 to commercialize the optical data storage technology generated by the Center.
- Three research centers have been established, 1) CAPP the Center for Applied Polymer Processing - this is a consortium between CWRU, CLiPS and various companies and is a state-of-the-art center for advanced polymer blending and compounding and reactive extrusion able to perform basic non-competitive research and development in the area of materials development and manufacturing by intent in support of the polymer, pharmaceutical and food industries, 2) MORE Center – Materials for Opto/electronics Research and Education – established to enhance science and innovation with facilities enabling the fabrication and characterization of materials and devices for solar energy and emerging electronic and optoelectronic technologies and 3) CDES – the Center for Dielectrics and Energy Storage – a consortium of academic and industrial institutions that aims to discover, develop, and translate novel dielectric technologies for energy storage and capacitor applications.

Data Management Plan

CLiPS is a complex Center with many sources of data. To manage the data, CLiPS has developed a data management plan that encompasses, among other strategies, the regular channels of peer-reviewed publications and presentations at professional meetings, control of student laboratory notebooks, and the CLiPS website that chronicles publication activity and provides an overview of CLiPS's research and educational programs. The Center's data management plan is discussed further in the Knowledge Transfer section of this report and may be found in Appendix G.

Value-Added of CLiPS

The field of interdisciplinary macromolecular science and engineering has rapidly emerged over the past ten years at the crossroads of polymer science, materials science, engineering disciplines, chemistry, physics and biology. This field of "polymers plus" enjoins inspiration from nature, innovative processing of microlayer and nanolayer polymeric assemblies (forced assembly), and revolutionary new synthetic polymers with greater control of macromolecular and supermolecular architecture (self-assembly). A critical need exists for innovative microprocessing and nanoprocessing technologies to achieve the envisioned materials systems.

The potential application and economic impact of hierarchically organized polymer and hybrid polymer/inorganic layered systems with length scales ranging from a few nanometers to many microns are extremely broad and encompass diverse areas such as healthcare, energy, defense and environment. The work being accomplished in Platform I on understanding and control of polymer rheology is leading to the combinations of materials previously not possible and leading to structures that can meet performance properties not previously achievable with extrusion technology. This will accommodate the diverse needs of Platforms II, III, and IV and enable them to expand their scope in areas such as membranes and optical/electronic systems and others that are not currently addressed in Platforms II, III and IV.

The broad scope of these research activities requires participation of outstanding researchers and educators in many disciplines, including polymers, optics, electronics, material science, transport, and engineering. CLiPS is uniquely positioned to meet this challenge and has assembled a multidisciplinary, multi-institutional team of investigators. The work of these groups of scientists and engineers is disseminated through the CLiPS Knowledge Transfer program, which provides a vehicle for intellectual exchange with the public and the links to industry will allow for significant technology impact, fostering science and technology in service to society.

Research and education aspects are integrated to create a special environment for discovery, learning and innovation by students at a wide range of levels from elementary grades through graduate level, faculty and associated researchers. Emphasis is placed on teamwork, communication and engagement of students in the research and education activities to make CLiPS a unique place for training a well-qualified academic and industrial workforce. Enhanced diversity and engagement of underrepresented groups is considered a critical component of well-balanced programs and workplaces. CLiPS aim is to exploit the features of modern U.S. society with an emphasis on teamwork, communication, and workforce diversity, in addition to excellence in research and education.