NORTH CAROLINA A&T STATE UNIVERSITY
ADVANCED MATERIALS AND NANOTECHNOLOGY CLUSTER
WHITE PAPER

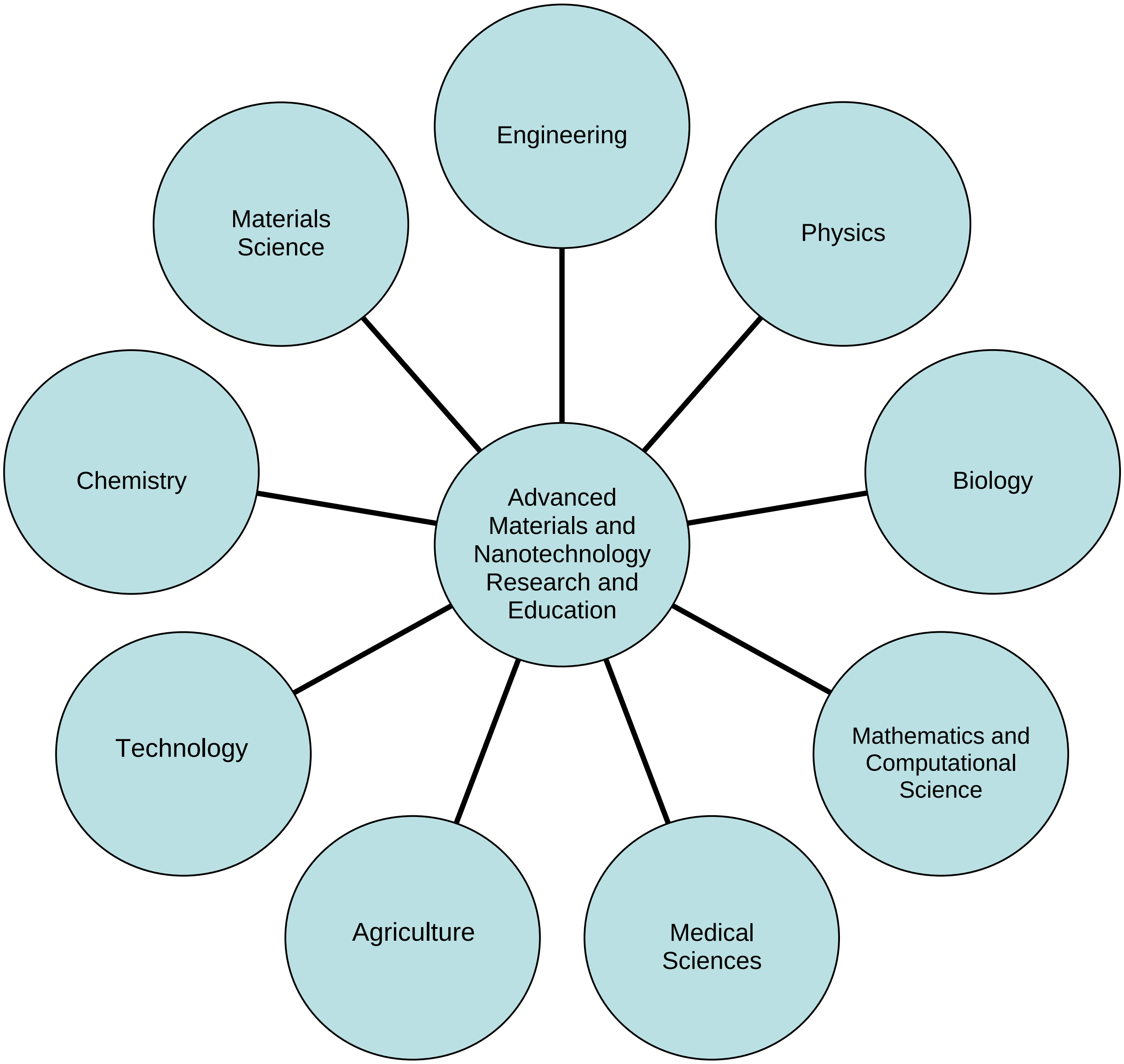
Vision

The Advanced Materials and Nanotechnology research cluster will be an educational and research resource of excellence for the State of North Carolina and the nation in the field of smart, multifunctional and other advanced materials. This will be achieved through the collaboration of academe, government agencies and private industry in developing basic and applied research programs and commercially relevant technological innovations with a focus on student participation and learning.

Fulfilling this vision will be achieved through interdisciplinary interaction and integration of resources to develop and promote a collaborative culture that stimulates growth of advanced materials and nanotechnology research. Synergistic research will result from collective efforts of scientists and engineers across disciplines including Materials Science and Materials Engineering, Chemical Science and Chemical Engineering, Physical and Computer Sciences, Electrical, Industrial and Bioenvironmental Engineering, Processing and Manufacturing.

Goals of the Advanced Materials and Nanotechnology research cluster are to:

- Develop intellectual capital through interdisciplinary learning, discovery, engagement and operational excellence
- Achieve excellence in basic & applied research
- Enhance undergraduate and graduate curricula by developing common interdisciplinary courses
- Provide hands-on research experiences for students
- Strengthen outreach activities and involvement of K-12 in the nanoscience field
- Generate commercially relevant technological innovations
- Support the career development of faculty and the professional community at large by developing interdisciplinary seminars and workshops and promoting and rewarding interdisciplinary, as well as inter-institutional, collaborations
- Offer research and educational services to industry
- Integrate into Federal diversity-focused programs (NSF, DOD, NASA, DOE, FAA, and others) to address the STEM Continuum
- Serve as a model of collaboration between academe, government and industry at the national and global levels and generate funding from diversified sources



Interdisciplinary Nature of Advanced Materials and Nanotechnology Cluster

Impact

Research on nanoscale and other advanced materials, processes, devices and systems performed by the Advanced Materials and Nanotechnology Cluster will generate both the fundamental scientific understanding of the inorganic, organic and biological properties of materials, and the enabling engineering and technology for breakthrough next-generation applications ranging from structural materials to smart structures, and from microelectronics to medicine. Concurrently, it will prepare the next generation high-tech work force, and ensure the training of significant numbers of African-American and other underrepresented minority scientists and engineers crucial to maintaining our nation's lead in economic and scientific growth.

Definitions

Advanced Materials (*'Materials by Design'*) are materials synthesized through the synergistic use of fundamental science principles, engineering and technology to generate unique or highly enhanced properties compared to traditional materials.

Nanochemistry and *nanophysics* research emphasizes the role of intermolecular forces in chemistry, as the basis for both molecular recognition and molecular assembly.

Nanoscience refers to the interdisciplinary scientific study of the structure and behavior of matter at the intermediate scale between the molecular and the microscopic world, that is, the nanoscale (1-100 nm).

Nanomaterials have grain sizes between 1-100 nm and exhibit interesting physical and mechanical properties, that are different than those of their bulk counterparts. These properties include improved hardness, increased ductility and toughness, and reduced elastic modulus compared to their coarse grained counterparts.

Nanotechnology is the development and use of engineering and technology solutions to overcome significant barriers to adapt these nanomaterials for practical applications in society.

Background

Materials have always played an important role in our society. Many of the advances that affect our day-to-day life and our future depend on the innovations in materials knowledge. An interdisciplinary approach that spans the entire dimensional continuum from atomic and molecular level through nano, micro, meso and macro scale needs to be supported by well-grounded fundamental science studies of related areas including quantum physics, mechanics, processing, characterization and modeling.

Strengths

a. Research Expertise

NCA&T's research has achieved national and international prominence in areas such as novel and innovative composite systems, nanoengineered coatings, semiconductors, nanomagnetic sensors, membrane materials, solid oxide fuel cells (SOFC) and proton exchange membrane (PEM) fuel cells, and structural health monitoring. Research programs have been generated in the science and technology of Monolithic Materials, Composites, Novel Optonic, Electronic and Smart Materials and Devices, Polymeric Materials, Materials for Civil Infrastructure, Sensors and Smart Structures, Nanoengineered and Surface Engineered Materials, and Multifunctional Materials and the closely related fundamental issues of Nanochemistry, Nanophysics especially the quantum Physics of Materials, Processing, Imaging and Computation, and Performance Evaluation and Modeling.

b. Research Centers

Researchers are playing a major role in exploring the fundamental science as well as developing futuristic applications in the arenas of homeland security, transportation and energy through various centers - NSF Center for Research Excellence in Science and Technology (CREST), Center for Advanced Materials and Smart Structures (CAMSS), Center for Composite Materials Research (CCMR), DoD Center for Nanoscience, Nanomaterials and Multifunctional Materials (CNN) for Homeland Security, NSF Nanoscale Science and Engineering Center (NSEC), NSF-Nanoscale Interdisciplinary Research Teams (NIRT). In addition, materials research activities overlap with the research mission of the CoE's NASA-National Institute for Aerospace (NIA) and NASA Center for Aerospace Research (CAR). These contributions have added visibility to the institution and established a powerful asset for cultivating intellectual capital.

c. Strategic Research Partnerships (APPENDIX A)

Scientists working in the above areas and Centers have very active collaborations with various universities, research institutions and industries on a national and global level. Their outreach activities have achieved national norms of excellence, including the organizing of major international conferences each year and serving on the editorial boards of various international journals and on the executive boards of professional societies, resulting in extramural awards and recognition for the University.

d. Outreach (APPENDIX B)

Research and educational outreach has included national and global activities. Faculty researchers have organized and sponsored international conferences, symposia, technical sessions, major government interdisciplinary workshops, journals, etc.

e. Interdisciplinary Experience (APPENDIX C)

Researchers in the Advanced Materials and Nanotechnology cluster have an established track record of distinctive visionary interdisciplinary activities.

Scope of Research

The following research topic areas have been identified for the Advanced Materials and Nanotechnology cluster:

- Surface Engineered Materials
- Composite Processing, Testing and Modeling
- Nanocomposites and Other Innovative Composites
- Electronic and Smart Materials
- Polymer Engineering
- Structural Health Monitoring
- Solid Oxide Fuel Cells
- Computational Imaging
- Catalysis in Energy Production and Consumption
- Nanochemistry and Nanophysics
- Direct Write Technologies and Medical Sciences
- Nanotechnology in Agriculture and Food Industries

Surface Engineered Materials
Surface engineered materials are materials with specialty coatings to improve thermal barrier, corrosion, and tribological properties and biocompatibility. These coatings help reduce the cost of manufacturing and hence increase profitability of businesses. The specialty coatings are also used for biomaterials delivering improved healthcare products. Physical vapor deposition coatings like DLC are used in orthopedic implants and in dental implants. Impregnated coatings can be used for low cost high performance parts for textile machinery and automotive industries.

Composite Processing, Testing and Modeling
Integrated composite technology provides a framework for the processing, performance evaluation and modeling of the novel composite materials and configurations and their relationship to processing conditions, along with subsequent modeling and simulation of structures made of these materials. This includes the failure behavior and analysis. Nanofiber research, Carbon/Carbon and high temperature materials research, Fly ash products research, Fire test and high heat flux investigations and other related futuristic composites activities will play key roles.

Nanocomposites and Other Innovative Composites
Crystal structures, interfaces, and grain boundaries play a dominant role in determining the electrical, optical, dielectric, magnetic, and mechanical properties of a large number of materials. Novel functionality (hardness / strength / ductility / creep) can be designed into advanced nano and innovative composites by employing a suitable nanoscale or other fine scale architecture to control the properties. Presently, considerable research is being performed related to the theoretical, computational and experimental aspects of nanophase-based materials with embedded or surface bonded smart layers with the goal of improving the performance of structures and components.

Electronic and Smart Materials
Sensors based on electronic materials are able to sense and respond appropriately to mitigate or solve undesirable problems associated with structural health monitoring. The properties of these materials can be engineered by manipulating thin film stresses and grain boundary characteristics. Thin film heterostructures have been produced for room temperature sensor applications and smart structures. A new class of compound semiconductors could result in a more robust and cost-effective semiconductor material for optoelectronic devices, such as light emitting diodes and lasers. Sensor materials activities are geared towards tunable magnetic materials to fiber optics based ubiquitous intrusion sensors, and brillouin-fiber phase conjugation mirror for high power laser beam cleanup and power enhancement for missile and aircraft remote sensing activities.

Exploring luminescent sensors derived from perturbations of metal-metal interactions
Compounds containing early- and late-transition metals in the same system have a unique feature in that they contain d-electron deficient and reach, early- and late-transition metals, respectively, in the same molecule. Bimetallic complexes containing group 11 metals (copper, silver, and gold) on one end and group 4, 5, or 6 metals (such as titanium, zirconium etc.) on the other are especially targeted in this project. These binuclear complexes exhibit unusual properties since

both metals participate simultaneously to give a new substrate activity. The metal-metal interaction in the complexes is a source of intense luminescence, where the fluorescent light changes its color based on the atoms surrounding the metal center. Hence, different atoms can reveal their presence by the different colors of the fluorescent light emitted by the compounds. The systems are capable of becoming sensors to detect the presence of small concentrations of components. The synthetic strategy involves bridging the two metal atoms using mixed organic ligands containing hard and soft coordination sites. The hard component will be used to coordinate the early transition metal, while the soft site will be capable of coordinating the late transition metal in its close proximity.

Polymer Engineering

Engineered polymer materials and coatings can exhibit wide variety of viscoelastic, wear, corrosive and fire protective and advanced sensing properties. Current polymer research activities include study of new polymer materials formulation and effect of nanofillers on enhancement of corrosion protective wear, and fire resistant properties of polymer coatings, new sensor development based on nanofiller embedded polymers, development of smart-structured multilayered impact-responsive drag and noise reduction polymer coatings for reducing fuel usage, impact of turbulence, electrochemical corrosion and sonar detection on naval vehicles, and study of biodegradation of polymer materials.

Structural Health Monitoring

Health management of infrastructure such as air and space vehicles, nuclear facilities, oil pipelines, chemical plants, buildings, and bridges is a national priority. Timely detection of critical damage is essential for averting catastrophic failures in structures and an improved artificial neural system is being developed for incorporation into a composite panel for real time health monitoring. We have developed and patented a technology for an efficient and cost effective way of monitoring growth of cracks and other forms of damage in air and space vehicles and other structures.

Solid Oxide Fuel Cells

The solid oxide fuel cell technology offers a clean, pollution-free technology for electricity. It continues to show great promise for the generation of electricity for an increasing range of applications related to homeland security and armored personnel, as well as large stationary electricity generation, and development of small, distributed power sources.

Computational Imaging

Among the variety of available methods to probe the damaged state of a structure, direct imaging is the most important for understanding and modeling the process because it provides the most comprehensive data, and is the basic correlative for other detection methods. To assess the development and damage state of a structure, the stages from pre- to post-damage must be established, probable damage inception sites and conditions identified, and simulations and virtual testing on likely failure modes performed. Computational imaging, which combines advanced microstructural image analysis with computational materials science, provides a comprehensive approach toward that end.

Catalysis in Energy Production and Consumption
Research is being carried out for conversion of farm gases to electrical energy. Advanced materials such as nanocomposites are being developed for use as catalysts for this application. In addition, nanoengineered catalysts are of great value in removal of carbon monoxide from the exhaust at significantly lower temperatures than conventional catalytic converters.

Nanochemistry and Nanophysics
Nanoclusters represent a phase of matter intermediate between a gas and a solid where chemical reactions can be probed in a nanostructurally-controlled environment. Gas phase nanoclusters have shown promise as tools for elucidating the molecular-scale interactions between ions and solvent that influence electronic structure and reactivity in bulk solutions. They offer significant improvement in control over the local environment surrounding an ion, which is unattainable in the condensed phase. Ionic nanoclusters constitute prototypes for studying elementary interactions between ions and atoms or molecules and can model a variety of physical and chemical processes such as electronic energy transfer, metal-ligand interactions, solvation effects and metal-insulator transitions. The research topics under this sub group include, but are not limited to: *Photochemistry within nanoclusters, Nanoalloys, Solvation of aqueous M + (Alkali Metal) in the gas-phase And Computations.*

Nanochemistry and nanophysics research projects can involve bulk synthetic techniques, advanced microscopy techniques, computational molecular modeling and/or organic synthesis of new molecules designed to control nanoparticle formation, or spontaneously assemble into complex architectures. Controlling the size of the nanoclusters determines the ability of the catalyst to decompose pollutants. Quantum effects that come into play at ultra small sizes greatly increase their effectiveness. Also, these same catalysts have the potential to produce fuels – like hydrogen—by the decomposition of water and hydrogen sulfide, using sunlight. There is an available option to expand this to areas that include bionanotechnology and involve life scientists.

Direct Write Technologies and Medical Sciences
Direct Write Technologies employ customized inkjet systems for deposition of picoliter volumes of a variety of fluid types onto substrates. This research thrust holds immense promise for a wide sector of applications ranging from micro-electronics fabrication to drug delivery and bio-chemical sensors. A&T recently established a strong, cutting edge facility for the above research. Specifically, the research is focused on developing various innovative technologies for manufacturing miniaturized System-on-Chip solutions. These include engineering the bio-compatible polymer chips that can sense toxic elements within the environment. Complex bio-chemical reactions such as DNA analysis can be performed using precisely controlled fluid delivery techniques. Another dimension to this research thrust is the modeling of transport phenomena for complex bio-fluids laden with different nanoparticulate morphologies for various bioengineering applications.

Nanotechnology in Agriculture and Food Industry

Nanotechnology is emerging as an enabling technology for customization of agricultural production and food products. Nanoscience and technology are increasingly providing answers to specific needs such as gene characterization and metabolic pathways in plant and animal production as well as a better understanding of the interaction of human body with foods. In agricultural production, nanotechnology is being used in the form of nanosensors for detection of pest, pest nanocides, genetic selection of plants and animals for optimal production, and targeted therapies. Nanotechnology applications in the food industry include (1) Packaging such as active packaging that responds to environmental conditions and/or provide superior barrier properties thereby protecting food quality, (2) Food Safety for which nano and nano-based sensors enable detection of food contaminants (e.g. pathogenic bacteria, and toxic substances), nanoscale systems (e.g. FRID) are used to track and monitor agricultural and food products to prevent tampering and ensure safety, and (3) Food quality and health where nanoparticle compounds are used to improve food quality (preventing oxidiation or environmental degradation of health promoting compounds such as antioxidants and micronutrients).

Research and Educational Challenges

Advanced Materials and Nanotechnology will revolutionize next-generation applications ranging from materials to electronics to medicine. To position US industry strategically in a leadership role, we need to equip students with the multidisciplinary skills needed for nano and other innovative STEM fields. The challenge is to create a cross-disciplinary infrastructure that transcends departmental barriers and lends itself to the integration of research and education in this vital field of advanced engineered materials and nanosciences. The cluster needs to take on the charge to: (1) promote advanced materials and nanotechnology as a unifying research and education discipline; (2) develop multidisciplinary curricula for training the new generation of graduate students; and (3) recruit talented undergraduate and graduate students including underrepresented groups into this field of immense technological importance.

Under the umbrella of this cluster, we need to develop new courses and curricula. These courses should be structured to be taught through traditional and web-based methods. Further, it is necessary to establish a clearinghouse as part of the cluster for effective dissemination of research materials, courses and applied research findings, etc.

Assets

The Advanced Materials and Nanotechnology cluster will leverage the existing human and hardware resources of the University to achieve stated goals. This cluster's resources include state-of-the-art equipment housed at facilities and laboratories located on campus (See APPENDIX D), in addition to faculty experts and experienced research associates, extensive experience with a variety of research programs and projects, and strategic partnerships and collaborations discussed previously.

Cluster Co-Leads:

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APPENDIX A

Strategic partnerships include:

- Joint research and educational activities with various universities, federal facilities and industries and International educational and research units.
- Partnership - NC A&T State University and NCSU: 69 joint publications; co-edited Composites B Engineering Journal, Vol. 30 B, 1999; joint proposals, new courses and student advising.
- Partnership – ORNL: Direct leveraging research funding, joint faculty, joint proposals, joint journal editing, undergraduate and graduate students summer internship at ORNL, joint publications with ORNL scientists.
- MOU - NC A&T State University and University of New Orleans (2000): co-sponsored and co-organized international conferences ICCE/5, ICCE/6, ICCE/7, ICCE/8, ICCE/9, ICCE/10 ICCE/11; co-edited Composites B Engineering Journal, Vol. 30 B, 1999;Vol. 35 B No 2, 2004, joint proposals and joint new journal editions.
- MOU - Naval Undersea Warfare Center, NUWC and NC A&T State University (2001): research funding and employer of 2 PhD minority students.
- Educational Partnership Agreement between Nkrumah University of Science and Technology (Ghana) and NC A&T State University (1999): 3 faculty performing PhD research at CAMSS.
- Educational Partnership Agreement between Dnyaneshwar Vidyapeeth College of Hi-Tech Engineering (India) and NC A&T State University (1999): 1 faculty performing PhD research at CAMSS.
- Collaborative activities with Kumamoto University (Japan): 1 faculty spent 1 year sabbatical at CAMSS
- Strengthen ongoing joint research activities with Frantzevich Institute (Kiev) and Institute for Single Crystals (Kharkov) – Ukraine (Joint conference with NATO at Kiev, June 2003, 2004)
- MOU between NC A&T State University and Inha University, S. Korea (2004): I faculty and student working on joint elctrostatic paper actuator
- MOU between NC A&T State University and Northwestern Polytechnical University, Xian, People's Republic of China (2000)
- MOU under preparation: Southwest Research Institute, TX; (to be signed in 2004)
- Organized Session at 1999 ASEE Conference on Industry Education Collaboration
- Co-sponsored International Composites Meeting - Composites in the Transportation Industry – Sydney, Australia, ACUN-2, Feb 14 - 18, 2000
- Organized Materials Research Society (MRS) Symposium "Laser-Solid Interactions for Materials Processing", San Francisco, CA, 2000.
- Co-sponsored 19th All India Manufacturing Technology, Design and Research Conference, Indian Institute of Technology, Madras, India, December 2000
- Co-sponsored International Composites Meeting – Technology Convergence in Composites Applications – Sydney, Australia, ACUN-3, Feb 6 - 9, 2001
- ASMM2D "Advances in Superconductivity and Magnetism: Materials, Mechanisms and Devices" September 25-28, 2001, Mangalore, India. Organized by Tata Institute of Fundamental Research, India.

- 2001 ASME International Mechanical Engineering Congress and Exposition, “Processing and Understanding of Structural and Electronic Ceramic Materials” Symposium, Nov 11-15, 2001.
- 2002 ASME International Mechanical Engineering Congress and Exposition, “Processing, Characterization and Modeling of Novel Nanoengineered and Surface Engineered Materials” Symposium with full peer-reviewed publication, New Orleans, Nov 17-22, 2002.
- 2003 ASME International Mechanical Engineering Congress and Exposition, “Processing, Characterization and Modeling of Multifunctional Materials” Symposium with full peer-reviewed publication, Washington DC, Nov 16-21, 2003.

APPENDIX B

Globalization includes:

Globalization activities include research and educational outreach activities. The group has been active in organizing and sponsoring international conferences, symposia, technical sessions, major government interdisciplinary workshops, journals, etc. A few selected ones are:

- 1997 Joint ASME/ASCE/SES Summer Meeting, Chicago, "Processing, Characterization and Modeling of High Temperature Monolithic and Composite Materials" Symposium.
- ICCE/5 Fifth International Conference on Composites Engineering, Las Vegas, July 5 – 11, 1998
- ICCE/6 Sixth International Conference on Composites Engineering, Orlando, June 27 – July 3, 1999
- ICCC/7 Seventh International Conference on Composites Engineering, Denver, July 2 – 8, 2000.
- ICCE/8 Eighth International Conference on Composites Engineering, Tenerife, Spain, August 4-11, 2001
- ICCE/9 Ninth International Conference on Composites Engineering, San Diego, CA, July 1-6, 2002
- ICCE/10 Tenth International Conference on Composites Engineering, New Orleans, LA, July 20-26, 2003
- ICCE/11 Eleventh International Conference on Composites Engineering, Hilton Head, SC, Aug 8-14, 2004
- Advanced Research Workshop "Mixed Ionic Electronic Conducting (MIEC) Perovskites for Advanced Energy Systems" Kyiv, Ukraine June 1-5, 2003 (sponsored by CAMSS and NATO) . Also organized a special workshop during this conference on International consortium for global materials research and education
- Organized Materials Research Society (MRS) Symposium "Integration of Advanced Micro and Nanoelectronic Devices – Critical Issues and Solutions," San Francisco, CA, 2004.
- NATO Advanced Research Workshop "Fuel Cell Technologies: State and Perspectives " Kyiv, Ukraine June 6-10, 2004 (co-sponsored by CAMSS)
- International Conference on Advances in Structural Integrity, 14-17 July 2004, Indian Institute of Science, Bangalore, India.
- NSF supported international collaboration in chemical physics with Addis Ababa University, Ethiopia
- NSF supported international collaboration in quantum chemistry with University of Marseille, France.
- Initiated and supported journals and special journal editions (Journal of Structural Health Monitoring (Sage Publishers), Composites Part B Engineering (Elsevier Publishers)

APPENDIX C

Activities include:

- The cluster team annually publish over 40 peer-reviewed publications and 50 other full and extended papers and make an average of over 50 technical presentations annually
- Development of experimental facilities – over 20 research labs at A&T, shared experimental facilities with NCSU, ORNL and other collaborative facilities (at US and international research universities/facilities and federal labs)
- Interdisciplinary work with the recently-established National Institute of Aerospace involving NASA-LaRC and six major universities
- Interdisciplinary student activities including SAE Mini Baja, Formula SAE, and Intercollegiate Auto Racing Association (ICAR-A) Legends car racing (top ten in the country)
- Industrial involvement in curriculum/research development (SwRI, Alcoa, Caterpillar, Siecor, Kopin Corporation, Adiabatics, GE, Cummins, Bodycote, Ford Motor Company, Boeing, Hamilton Sundstrand, Tensar Corporation, Volvo, Michelin, EPRI and Thomas-Built Buses and the list is growing)
- Continuous development of innovative and team-taught courses and curricula for undergraduate and graduate students: (Advanced Materials and Smart Structures I, Principles of Car Race Engineering, Photonic Materials, Quantitative Microstructural Image Analysis, Thin Films, Tribology, Advanced Polymers, Structural Health Monitoring and e-Course initiatives, Spectroscopic techniques, Quantum theory of nanoparticles etc.).
- Research Experience for Undergraduates Programs and routine sponsorship of outreach activities to local area schools
- About 50 visitors on average from academe, industry and government and 25 seminars and presentations annually.

APPENDIX D

MAJOR EQUIPMENT and FACILITIES

Except where otherwise stated, the facilities are located on A&T campus. The following facilities include state-of-the-art equipment worth over $6 M.

- Pulsed Laser Deposition Facility
- Fuel Cell Processing Laboratory
- Coatings Synthesis Laboratory
- Polymer Laboratory
- Composite Fabrication Facility
- Semiconductor Laboratory
- Microscopy and Sample Preparation Laboratory
- Surface Analysis Facility
- Electron Microscopy / EDS Laboratory
- Computation and Image Analysis Lab
- Electronic Materials Characterization Laboratory
- Nondestructive Testing Facility
- Nanoindentation Facility
- Mechanical Testing Laboratory
- High-Temperature Materials Laboratory
- Structural Health Monitoring Research Laboratory
- Instrumentation and Controls Laboratory
- Diesel Combustion Laboratory
- Manufacturing Laboratory
- Magnetron Deposition Facility (under development)
- Nano-fludics Analysis Facility
- X-ray Diffraction Facility
- Physics Laser and associated Characterization Facility
- Super computer facility
- NCSU/ORNL/Other Shared Facilities for Materials Characterization