Nanosystems ERC for Translational Applications of Nanoscale Multiferroic Systems (TANMS)

University of California, Los Angeles (lead institution)

Engineering an ESP (efficiency, size, and power) revolution in miniature electronic devices

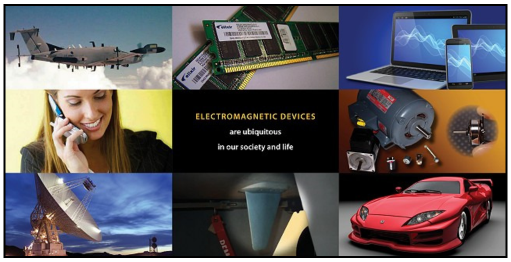
A National Science Foundation Engineering Research Center since 2012

Partner Institutions:

- ***University of California, Berkeley***
- ***Cornell University***
- ***California State University, Northridge***
- ***Northeastern University***

Electromagnetic devices are ubiquitous throughout our society. Among those having the greatest impact on the way we live are memory devices, antennas, and electromagnetic motors. All these devices generate magnetic fields by passing a current through a wire, a concept originally discovered by Oersted in 1820. While this technology works extremely well on the large scale, the magnetic field generated decreases with size, making it impossible to design miniature electromagnetic devices that are efficient and powerful, yet small.

TANMS seeks to overcome this limitation by using recent discoveries regarding nanoscale multiferroic materials to realize and control a large magnetic effect at length scales smaller than are presently possible. TANMS' vision is to demonstrate this discovery on three testbed systems (memory, antennas, and nanoscale motors), leading to a paradigm shift in engineering of electromagnetic devices by direct coupling between electricity and magnetism that increases energy efficiency (E), reduces physical size (S), and increases power (P) output—what we term ESP. This overarching goal guides TANMS' fundamental research program, technology translational activities, and educational/mentoring programs.



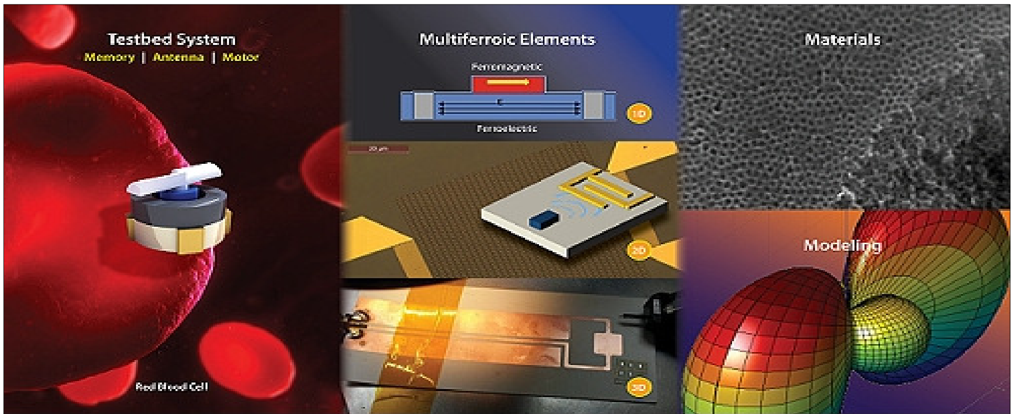
Electromagnetic devices are ubiquitous in our society and our lives.

Research

The unique aspect of multiferroic materials is the intrinsic coupling between polarization and magnetization within a material, so that an external electric field (not current) spontaneously magnetizes the material. This multiferroic approach is analogous to putting a voltage-controlled ON/OFF switch on a permanent magnet, thereby removing the scaling limitations associated with Oersted's current-through-a-wire approach. TANMS' goal is to demonstrate this discovery on three testbed systems, producing a new approach to controlling magnetism (and thus ESP) in miniature electromagnetic devices once believed to be out of the reach of engineering design.

TANMS' research program utilizes a top-down research strategy focusing on three testbed demonstration modules—memory, antennas, and nanoscale motors—applicable to mobile electronics as well as other nano-electronic products. Typical length scales of interest in TANMS testbeds are dimensions less than one micron, or one-fifth the size of a red blood cell. The three testbeds are supported by five cross-disciplinary fundamental research thrusts designed to explore engineering principles through the testbeds as well as provide fundamental discoveries for new electromagnetic devices.

At the systems level (see left pane of figure on following page) design, fabrication, and testing of the three testbed systems is the primary focus. Systems-level requirements from these testbeds provide research problems for three of TANMS' five research thrusts (see figure, middle). These three research thrusts focus on understanding the complex electro-magnetic-mechanical response of engineering elements such as optimizing the magnetoelectric material coupling (1D), understanding the complex dynamic magnetoelectric interactions (2D), or implementing electro-magneto-mechanical control (3D). These tasks are



In TANMS' research program, the testbed system (left) drives the development of multiferroic elements (middle), supported by basic research in materials synthesis and modeling (right).

differentiated by their level of complexity and represent a synergistic approach to overcoming barriers defined by complexity and dimensionality. The three thrusts define modeling and material property problems for the remaining two fundamental research thrusts (see figure, right). These two latter thrusts focus on theoretical modeling and material synthesis. These efforts seek to predict the complex multiferroic systems response and to begin developing new materials and processes required for fabrication and testing of components in the engineering elements. The five research thrusts work together synergistically in support of the three TANMS testbeds' systems goals.

The goals of TANMS' three testbed systems are:

- **Memory:** increasing the write *efficiency* so as to essentially keep energy requirements from negatively impacting the battery's footprint
- **Antenna:** reducing antenna *size* by slowing the wave speed and providing the community with the much sought-after electronically small antenna
- **Nanoscale motor:** increasing the *power* density by controlling magnetization states with power densities larger than those available in macroscale motors.

These three system-level advancements in efficiency, size, and power represent the driving system metrics guiding TANMS' fundamental studies in engineering and basic science. The accomplishments expected from TANMS represent a revolutionary change in the way in which our society designs and constructs future electromagnetic devices on the small scale.

Education

TANMS' education program is focused on preparing the next generation of engineers and scientists with a superior education coupled with entrepreneurial skills essential for the U.S. to maintain leadership in the global academic and industrial workforce. The TANMS stance is that a diverse and inclusive program forms a technically competent and innovative talent pool leading to powerful new discoveries. In responding to industry's need for engineers to be leaders, independent thinkers, innovators, and business-savvy entrepreneurs, TANMS interweaves entrepreneurial training and deep peer mentoring into the TANMS culture. This approach has led to a TANMS comprehensive education program formulated around two unique "global" programs, i.e., the *Cradle to Career* strategy and our *entrepreneurial training* program.

The peer group mentoring program is at the core of the "Cradle-to-Career" concept—an approach in which students are mentored as cohorts and in diverse groupings focused on complex topics important to the U.S.' future economic development, with an emphasis on multiferroics.

Six undergraduate students team in the URP with Director for Diversity and K-20 Outreach Rick Ainsworth (far left) and graduate mentor Diana Chien (far right).

Specifically, postdoctoral researchers mentor and collaborate with graduate students who, in turn, mentor undergraduate groups who mentor high school groups, all under the supervision of TANMS investigators. This deep peer mentoring strategy is supported by TANMS' Academic Curriculum, helping students become proficient and world experts in the area of multiferroics.

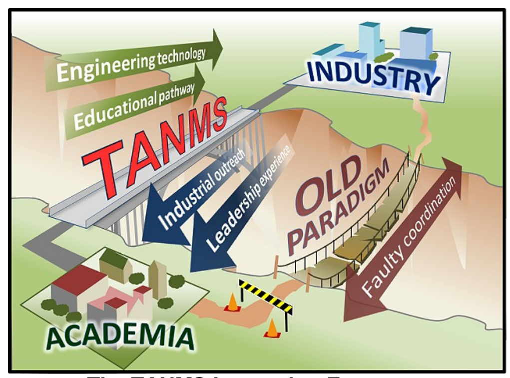
The mentoring system is enhanced by TANMS "deep dive" modules emphasizing entrepreneurial engineering case studies and skillset development. The TANMS theory of educational change posits that providing K-20 students with a comprehensive entrepreneurial experience coupled with a Cradle-to-Career mentoring strategy produces a more heterogeneous, well-rounded engineering graduate who is substantially more creative, innovative, and adaptive to the global engineering and business environment than those generally available today. This program includes developing long-term relationships with K-12 students and high school teachers to participate in research while becoming familiar with electromagnetics and multiferroics. Some of the important TANMS education programs and the students they target are shown in the accompanying table.

TANMS Education Programs	Targeted Students
URP: Undergraduate Research Program	TANMS students
REU: Research Experience for Undergraduates	non-TANMS students
YSP: Young Scholar Program	High school students
RET: Research Experience for Teachers	High school math and science teachers

Innovation Ecosystem

TANMS' Innovation Ecosystem rests on an industrial membership structure and concentrates on developing a new translational model for teaming with industries small and large. The essential features of this model are facilitating a culture of entrepreneurial spirit and appreciation within the TANMS research community and engaging industrial partners as mentors and champions for TANMS technology, to accelerate insertion into commercial applications. Developing this culture is important to begin translating TANMS discoveries into products available throughout our society.

The Center's entrepreneurial culture is supported by seminars and other educational activities promoting intellectual property (IP) capture and technology transfer. Through various campus organizations and events, TANMS students are provided with opportunities for learning and participating in business start-ups and technology commercialization. They will become the next generation of leaders championing the development of multiferroic devices in the commercial sector.



The TANMS Innovation Ecosystem

The industrial collaboration developed within TANMS also supports testbed system-level definition and further aids IP transfer. Key components of this collaboration that define a new ecosystem within a university culture are the TANMS' Director of Industrial Relations, the Institute for Technology Advancement (ITA) at UCLA, and TANMS' industrial partners.

The Director of Industrial Relations recruits new companies and interacts with existing member firms to keep members apprised of Center developments, joint proposal/ funding opportunities, and other development possibilities within the Center framework. ITA's mission and expertise is to support business development and commercialization activities for technologies developed.

Working together with industrial partners, TANMS is developing a new entrepreneurial spirit and overcoming the typical obstacles associated with the translation of intellectual property from academia to industry. The Innovation Ecosystem extends throughout all four U.S. partner institutions.

Facilities

TANMS' headquarters is located on the UCLA campus in a 1600 square foot space. The space provides a conference facility, a telepresence room, and offices for the leadership team. Presently the conference facility includes a recording studio that allows recording and broadcasting of seminars, classes, and presentations. The recording studio provides a unique capability to record lectures, workshops, and teacher presentations for wide dissemination beyond the TANMS campuses, including to other universities and K-12 schools. The four TANMS partner universities have extensive facilities and equipment supporting the Center's research program, ranging from computational hardware to nanoscale clean room fabrication equipment, to material characterization apparatuses including new facilities in Engineering VI, coming online in 2014–2015 for quantum metrology with vibration isolation and electromagnetic interference shielding at UCLA.

Center Configuration, Leadership, Team Structure

TANMS is a Gen-3 Nanosystems Engineering Research Center (NERC) funded by NSF. The lead institution is the University of California, Los Angeles (UCLA), partnering with Cornell University, UC Berkeley, and California State University Northridge (CSUN). All four US institutions function as a formal integrated center with shared research and education goals (three testbeds and the Cradle-to-Career mentoring and entrepreneurial training), shared elements of curricula, and a shared program of industrial collaboration including intellectual property. UCLA houses the TANMS headquarters.

The leadership team consists of a Center Director, Deputy Director, Director of Industrial Relations, Administrative Director, Education Director, and Director for Diversity and K-20 Outreach. The Center has established a University Policy Board, a Scientific Advisory Board, and an Industrial Advisory Board to guide the Center's direction. The Center also has a Student Leadership Council to ensure full participation of students in the life of the Center and that interaction occurs among all of its constituents. The Center is founded on the bedrock of engineering research and development efforts led by faculty overseeing the five research thrust areas. These thrust areas encompass a multidisciplinary team distributed across physics, chemistry, chemical engineering, materials science, mechanical engineering, and electrical engineering.

Center Headquarters

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