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Center for Energy Harvesting Materials and Systems

The CEHMS Chronicle

Charting the Future for Energy Harvesting Technologies

Special points of interest:

- Don't forget to sign up for the 2013 Energy Harvesting Workshop, July 14-18 in Hannover, Germany!
- We will be updating our website shortly to reflect our current equipment capabilities.
- Next **IAB meeting** will take place in Hannover, Germany in July.

Inside this issue:

By Dr. Walter Voit and Dr. Shashank Priya

The Center for Energy Harvesting Materials and Systems (CEHMS) has made significant progress over the past several years in identifying and implementing a variety of materials and systems for energy harvesting across a broad range of platforms. This brief overview outlines the structure of the center and briefly discusses some example technologies based upon the ongoing seed programs. The goal of this short article is to familiarize the reader with the structure and research of CEHMS.

The center is subdivided into five technical thrusts, each of which focuses on key industrially-relevant technical problems in that respective scientific area. The thrust icons which appear throughout CEHMS literature and reporting are shown in **Figure 1**. The "Thermal" thrust which is led by Scott Huxtable at Virginia Tech and Ray Baughman at UT Dallas focuses on thermoelectric materials, concentrated solar power, phase change materials and shape memory materials. Within the "Mechanical" thrust led by Muhammad Hajj at Virginia Tech and Walter Voit at UT Dallas, fundamental studies are undertaken on a variety of materials and devices including piezoelectrics, electromagnetics, electrostatics, electrets, elastomers, wind turbines and water turbines. Related inquiries into aeroelastic instabilities and tensegrity structures are being explored as well. One of the recent focus of this thrust has been on bio-medical technologies exploring both in-vivo and ex-vivo devices. In the "Production" thrust, led by Marc Wurz at Leibniz University, Khai Ngo at Virginia Tech and Duncan MacFarlane at UT Dallas, key areas include systems engineering, scalability and mass manufacturing. Our international site, Leibniz Universität in Hannover, Germany, adds extra core competencies into this critical area. The "Chemical" thrust is led by Dennis Smith at UT Dallas and Mike Ellis at Virginia Tech. This thrust focuses on exploring new methods to store energy including batteries and supercapacitors with projects related to photovoltaics, fuel cells and biomass. The "Power Electronics and Communications" thrust is led by Babak Fahimi at UT Dallas and Dong Ha at Virginia Tech. Its major emphasis is to design the next generation of low power energy harvesting circuits, wireless radios, wireless power transfer and new methods to transfer and harvest radio frequency energy.

With the basics of these thrusts in mind, it is imperative to begin to understand the landscape within certain thrust areas as to develop a picture for our corporate partners about the current state-of-the-art in certain fields and propose a credible research program to move along a technical roadmap that promotes the continued innovation. This article seeks to establish a framework based on the roadmap construction via spider charts for conveying the status of certain devices or materials from different thrusts

Figure 1. The CEHMS is divided into five thrust areas: thermal, mechanical, production, chemical and power electronics and communications. Each thrust represents fundamental to applied research in specific areas that can have applications across application test beds such as the defense sector, the mining industry, the biomedical device industry and the energy sector, including heating and cooling, oil and gas extraction, refining and distribution and alternative energies.

Charting the Future of Energy Harvesting Technologies, Cont.

and attempts to discuss methodologies by which CEHMS can help expand the current capabilities ranging from materials all the way to devices to benefit our sponsor companies. The spider charts can be used to compare specific devices or materials within a single thrust as shown in **Figure 2**, or describe application landscapes that involve fundamental research efforts that are drawn from multiple thrusts. Figure 2 depicts a project currently funded by the CEHMS center and being explored for commercialization. The focus in this project is on developing novel shape changing radio frequency identification (RFID) antennas that can be manufactured using pseudo 2-dimensional manufacturing techniques and subsequently deformed into complex 3-D shapes at later stages of processing. This project is an example of the pre-competitive research on flexible antennas that could be easily manufactured onto flexible substrates and subsequently bent into curvilinear shapes to conform to specified application-driven geometries, such as around chips inside of a smart phone for telecommunications applications, around nerves inside the body for biomedical device applications, on peripheral components of turbines or drills for applications in the energy sector, or around the I-beam of a truss in a structural health monitoring environment on civil structures. In the case of Figure 2, the overview merely serves to indicate the potential for a new technology by defining "better" properties of given parameters as those that are further from the center core of the chart. Thus devices or materials that enclose the largest areas, or ones that enclose areas that others do not, represent compelling opportunities to create future value for member companies who have first glimpse of these kinds of technologies and can begin to build market penetration strategies around emerging technologies. Figures include a Technology Readiness Level (TRL) indicator that indicates the maturity of evolving technologies during development and early operations.

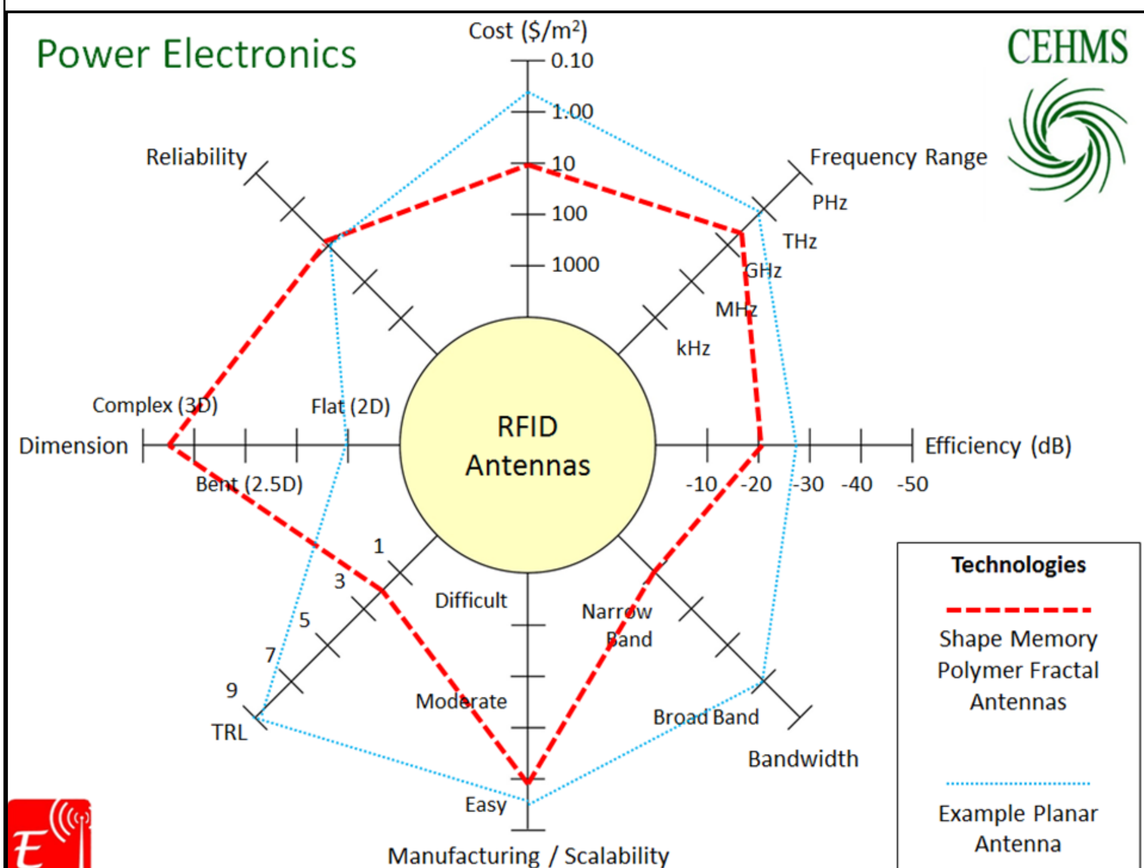

Figure 2 Example Power Electronics and Communications thrust spider chart describes the state of the art in radio frequency ID antennas and compares those to current materials undergoing evaluation in the center this year.

As a more detailed example, **Figure 3** is a projection for another CEHMS funded project with support from materials manufacturers comparing a variety of piezoelectric materials within the Mechanical Thrust. The most important 8 parameters for the research are identified and compared across the different piezoelectric devices. For instance, although the pure polymer-based polyvinylidene difluoride (PVDF) materials are the cheapest to manufacture, their d_{33} (longitudinal piezoelectric constant) value falls much below than that which can be reached

Charting the Future of Energy Harvesting Technologies, Cont.

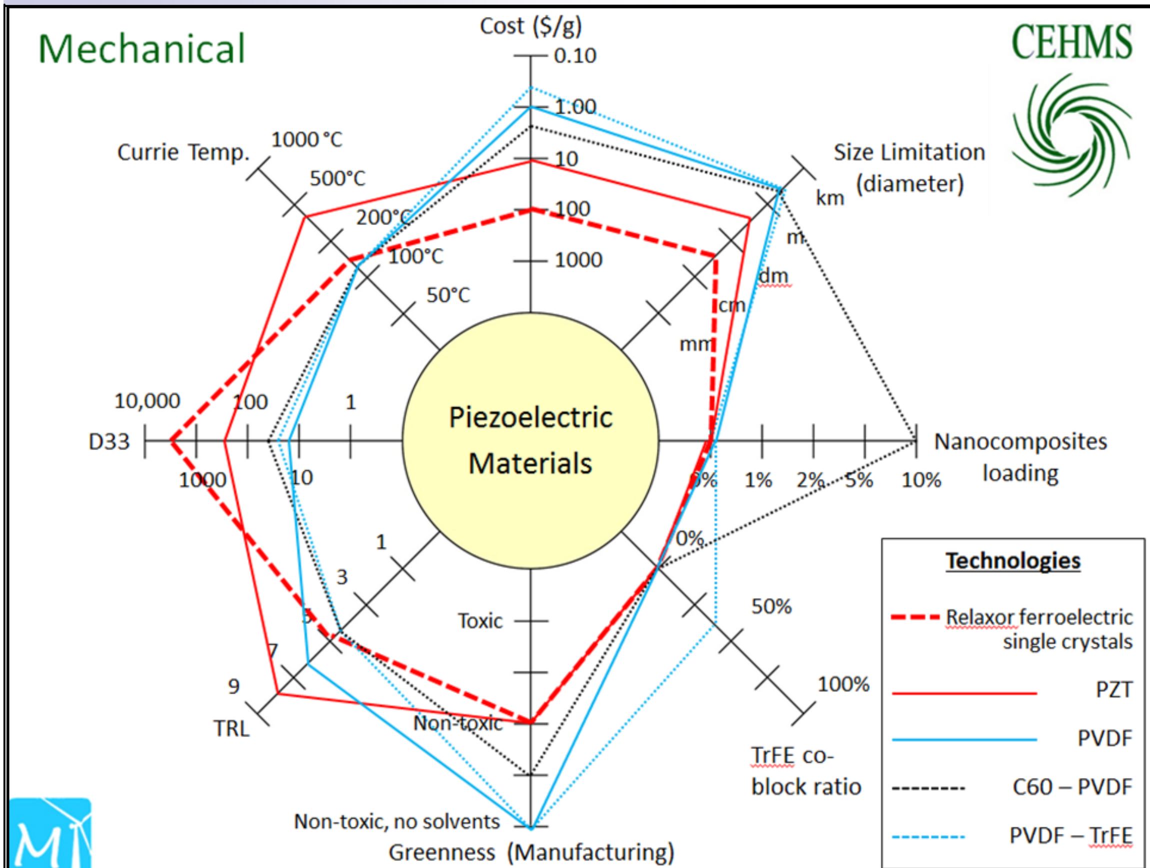

Figure 3 Example Mechanical Thrust Spider Chart describes the manufacturing, cost and properties tradeoffs associated with various forms of piezoelectric materials. Corporate partners that are seeking to use piezoelectric materials to solve specific problems can use information such as this to help decide which material may be best for them to explore.

with relaxor ferroelectric single crystals. However, these softer ceramic crystals can be grown to limited diameters, requiring platinum crucibles, and have low transition temperatures, which limits the size and number of devices. In order to overcome these challenges, CEHMS has made great strides in the field of both textured ceramics and polymer nanocomposites. For example – recently CEHMS researchers have demonstrated one of the highest energy density piezoelectric ceramic materials based upon the solid solution of lead zirconate titanate – lead magnesium niobate. CEHMS researchers are also exploring techniques to enhance the d_{33} value of polymeric piezoelectric nanocomposites that contain buckeyballs or are copolymerized with tetrafluoroethylene (TrFE). These processes are also non-toxic and solvent free making them especially suitable for green processing.

The final figure in this short overview, **Figure 4**, is a detailed analysis of a material designed with support from a member company to ultimately build implantable neural interfaces on smart polymers that can be wirelessly powered for chronic neural microstimulation and that can transmit signals back outside the body. The development of stable chronic peripheral interfaces has the potential to revolutionize neuroprosthetic applications and help mitigate the functional losses associated with peripheral nerve function and spinal cord injury among other things. Several major limitations with current technologies exist. CEHMS researchers hope to ultimately be able to deliver 10s of microWatts of power at narrow energy bands near 2.6 GHz to power chronically implanted devices. We also seek to understand the immune response to these devices at various time points after implantation and discover ways to reduce the scarring response and enable long term neural recording and/or stimulation. The applications possible with the furthering of pre-competitive intellectual property such as delivering predictable amounts of power to specific locations often deep within the body, also has auxiliary uses in related fields. For instance, the ability to communicate at specific frequencies with wireless sensor networks that can be made on flexible substrates, very inexpensively could work in large factory or office settings to convey status information on a large scale. Low swelling polymer substrates, coupled with enhancements in device lifetime promise to enable a host of applications for member companies in their respective industries.

Charting the Future of Energy Harvesting Technologies, Cont.

In summary, the CEHMS research teams have gone to considerable efforts to provide an outline for specific technological areas related to energy harvesting materials and systems and continue to help member companies find ways to translate new innovations from the research labs into the marketplace. These broad examples give some indication of the kinds of information presented to member companies during regular meetings in the center. Over the next half-decade, CEHMS member companies will lead the way across the world in pushing new energy harvesting technologies into the market place based on first access to university generated intellectual property. CEHMS teams have already started the transition of the lab based prototypes into commercial products and we expect this trend to grow rapidly in the coming years. Annual events that rotate location at sponsor university sites include an Energy Summit, held during the last week of January each year and an Energy Harvesting Workshop, held during late July each year.

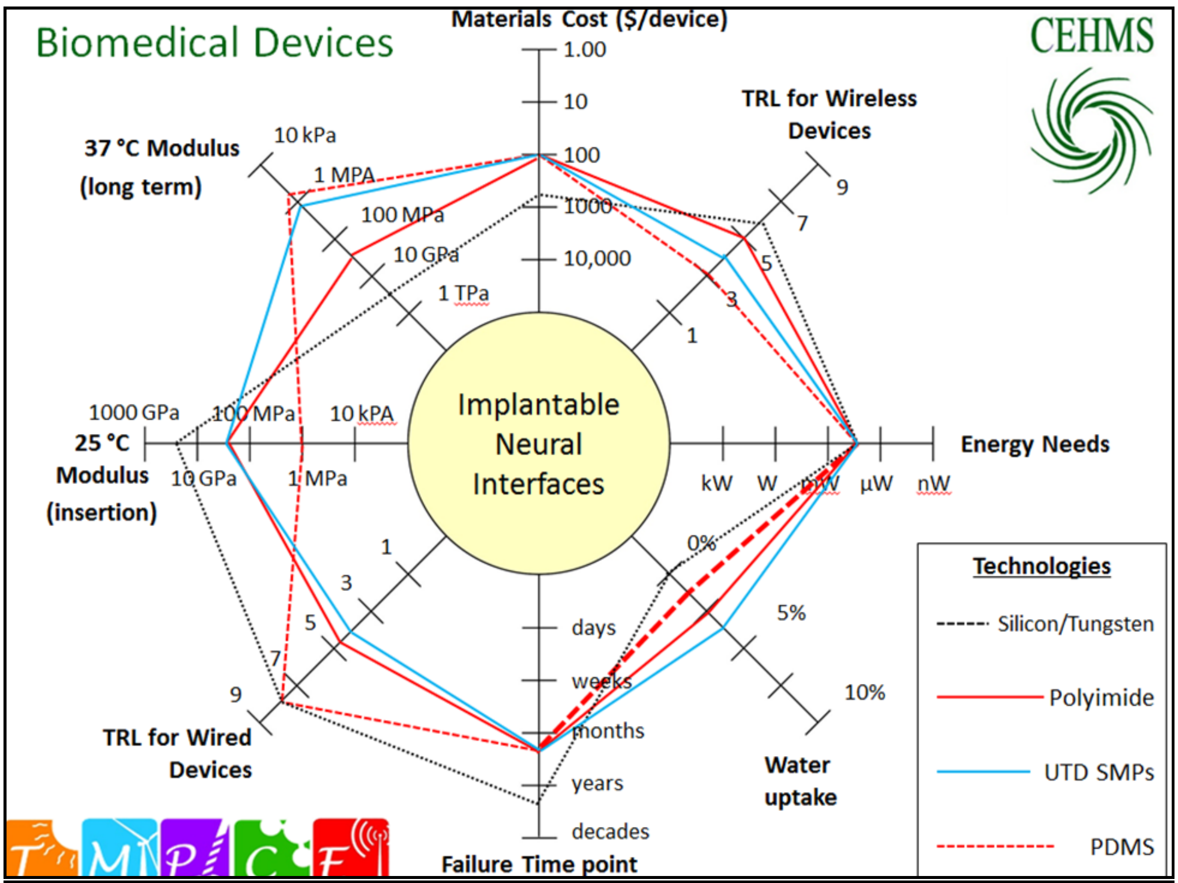

Figure 4. Example spider chart for the biomedical devices test bed takes advantage of a number of key advances from both the CEHMS center and related research at UT Dallas. Based on softening shape memory polymer (SMP) flexible electronics, the UTD SMPs in the legend, these devices offer key advantages over competing materials (silicon, tungsten, polyimides) that are chronically too stiff or others (e.g. polydimethylsiloxane - PDMS) that are too soft upon insertion.

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Researchers Reap Benefits of Energy Harvesting

By Renata Friendorf and Beth Keithly

CEHMS researchers are investigating ways to harvest energy from such diverse sources as mechanical vibrations, wasted heat, radio waves, light, and even movements of the human body.

The goal is to develop ways to convert this unused energy into a form that can self-power the next generation of electronics, eliminating or reducing the need for bulky, limited-life batteries. Beyond the more familiar wind and solar power, energy harvesting has a wide range of potential applications. These include: powering wireless sensor networks placed in "intelligent" buildings, or in hard-to-reach or dangerous areas; monitoring the structural health of aircraft; and biomedical implants that might transmit health data to your doctor or treat a chronic condition.

At a recent scientific conference held at UT Dallas, experts from academia, industry and government labs gathered to share their latest research on energy harvesting. Energy Summit 2013 focused on research initiatives at UT Dallas, Virginia Tech and Leibniz University in Germany, which form a consortium called the Center for Energy Harvesting Materials and Systems (CEHMS). Founded in 2010, CEHMS is an Industry/University Cooperative Research Center funded in part by the National Science Foundation. It includes not only academic institutions, but also corporate members who collaborate on research projects and also provide funding for the center. "The CEHMS consortium is a diverse group with expertise at all levels, from fundamental chemistry and materials science, to developing new models and fabrication techniques, to working on product-centered areas," said Dr. Dennis Smith, co-director of CEHMS and the Robert A. Welch Distinguished Chair in Chemistry at UT Dallas.

"Developing energy-harvesting technology is a necessary step towards a more widespread use of wireless sensor networks, and will enable new types of self-powered applications. Being a member of this consortium provides great benefit and opportunities to researchers and students, as well as local companies."

The two-day Energy Summit covered a wide range of topics, including projects from laboratories in UT Dallas's School of Natural Sciences and Mathematics and the Erik Jonsson School of Engineering and Computer Science.

For example, Dr. Mario Rotea, the Erik Jonsson Chair and head of the Department of Mechanical Engineering at UT Dallas, discussed some of his work aimed at advancing the development of wind energy systems. He represents UT Dallas in a proposed new consortium of universities and companies called WindSTAR that would collaborate with CEHMS on wind energy science and technology issues.

On the chemistry front, Smith's synthetic chemistry lab is working with advanced materials called piezoelectrics. If a piezoe-

Cary Baur (UTD)

"Developing energy-harvesting technology is a necessary step towards a more widespread use of wireless sensor networks, and will enable new types of self-powered applications."
- Dr. Dennis W. Smith

Drs. Voit (UTD), Smith (UTD), Nessen (Exelis), Priya (VT) and Twiefel (LUH)

Researchers Reap Benefits of Energy Harvesting, Cont.

Presentation from Craig Eppling, *GM*

"Researchers in energy harvesting, flexible electronics and biomedical devices can really learn a lot from one another and build off one another."
- Dr. Walter Voit

Keynote speech from Brian Bradshaw, *BP Capitol*

lectric material is deformed by a mechanical stress – such as stepping on it or subjecting it to vibrations – it produces an electric current. Smith's lab is investigating whether the addition of nanoparticles to certain piezoelectric materials can boost this so-called piezoelectric effect.

CEHMS co-director Dr. Shashank Priya, professor of Mechanical Engineering and the James and Elizabeth Turner Fellow of Engineering at Virginia Tech, collaborates with Smith on piezoelectric research. Among many projects, researchers at Virginia Tech are incorporating piezoelectrics into "smart" tiles that produce electricity when stepped upon, as well as into materials that might be applied like wallpaper to gather light and vibrational energy from walls.

Other university and industry projects include:

- **investigating how to redesign systems to require less power;**
- **an intelligent tire system that harvests energy from the vibrations in a rotating tire, powering embedded sensors that gather and report data on tire pressure, tire conditions and road conditions;**
- **a new class of magnetoelectric materials that can simultaneously convert magnetic fields and vibrations into energy;**
- **a textile-type material that converts wasted thermal energy into electricity, which could be wrapped around hot pipes or auto exhaust pipes to generate power; and**
- **flexible solar cells that could be integrated into textiles, and worn by hikers or soldiers to power portable electronic devices far away from an electric socket.**

Dr. Walter Voit, assistant professor of materials science and engineering at UT Dallas, is investigating biomedical applications for energy harvested from sources such as radio waves or blood flow. He has developed a novel material called a shape memory polymer that shows promise for remaining in the body for long periods of time without producing scar tissue or promoting infection – but to exploit those properties in new devices, he needs power.

"Researchers in energy harvesting, flexible electronics and biomedical devices can really learn a lot from one another, and build off one another," Voit said. "The key to the next generation of these devices is solving the power issue. Here in Dallas with the electronics industry and UT Southwestern Medical Center down the street, we have a real opportunity to build off the materials work we're doing here, as well as the design and modeling work that's going on at Virginia Tech, to really solve some of these power problems and translate that into devices that will help patients."

Energy Summit 2013 also held a research poster competition, which highlighted two dozen projects from CEHMS institutions. Judges awarded first place and $200 to a poster from a UT Dallas group led by Erika Fuentes-Fernandez, a graduate student in materials science and engineering. The project involved the synthesis and characterization of piezoelectric materials for use in thin-film cantilevers that might be used in energy harvesting.

SIDEBAR : **The keynote**

Researchers Reap Benefits of Energy Harvesting, Cont.

speaker for Energy Summit 2013 was Brian Bradshaw. He is a portfolio manager and investment committee member of BP Capital, an investment firm run by T. Boone Pickens. BP Capital trades and invests in energy commodities and energy-related businesses.

During his presentation, Bradshaw discussed some of BP Capital's general strategies and priorities in energy investment, and then took questions from the audience of scientists, engineers and students. The Q&A covered topics such as the economics of natural gas powered vehicles and alternative energy sources. Bradshaw had some advice for students, faculty and entrepreneurs who are thinking about getting into the energy business.

"There are going to be huge opportunities in the coming years," he said. "The intensity of people and assets being put into extracting oil from shale, domestically and ultimately around the world, is not going away. I think there's room for business, technical and innovative-type thinking along each step of the supply chain."

Industrial affiliates, speakers and faculty gather with Brian Bradshaw (BP Capitol) after his keynote speech.

International Relations: ITT Kanpur

The Indian Institute of Technology (IIT) Kanpur was established in the year 1960 when the Parliament of India passed the 'Institutes of Technology Act 1961' declaring all the IITs as "Institutions of National Importance". Over years, IIT Kanpur has grown into a prestigious institute of higher learning producing meritorious students with excellent career growth and universal recognition. The students get the best of opportunities in the form of highly advanced courses, eminent faculty members, well-equipped laboratories, library, hostels and immense facilities to excel in research and development. The research and education at the institute is mainly directed towards science and engineering education and consists of around 6000 undergraduate and postgraduate students, admitted via stringent selection processes. The institute is consistently ranked among the best Indian engineering education institutions illustrating the efforts of both faculty and students. The major programmes at the institute are in various areas of engineering such as Aerospace, Bioengineering, Civil, Computer Science, Chemical, Electrical, Mechanical, and Materials Science and Engineering and basic sciences i.e. Physics, Chemistry and Mathematics. Besides making contributions to the basic sciences, Institute has been major contributor to several projects of national importance such Solar Energy Initiative, Railway Technologies, Space and Atomic Energy Missions, Healthcare, Nanomaterials and Nanosciences, Electronic Devices and Cyber Security, to name a few. Institute boasts of several linkages and exchange programmes with various prestigious universities and institutions across the world.

Web: http://www.iitk.ac.in/

"The institute is consistently ranked among the best Indian engineering educational institutions…"

ITT Kanpur Logo

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Student Profile: Anthony Marin

Receiving his Bachelor's degree in Mechanical Engineering from Virginia Tech in 2009, Anthony Marin decided to remain a Hokie for his pursuit of a postdoctoral degree. Working under Dr. Shashank Priya, Anthony focused on vibration energy harvesting utilizing electromagnetic induction and smart materials, finding his time as a gradate student and CEHMS member both "challenging and rewarding… CEHMS projects focus on transitioning laboratory science to real world applications [and] the experience gained working on these types of projects will allow me to adapt quickly to the rapid pace of research and product development in industry." Anthony is currently applying to R&D positions within companies in various industries.

Anthony Marin

Laboratory Highlight: LPCAM

The **L**aboratory for **S**ynthetic **P**olymer **C**hemistry & **A**pplied **M**aterials **S**cience (http://www.utdallas.edu/~rmf102020/) at UT Dallas is a state of the art polymer research facility directed by UT Dallas CEHMS site director, Professor Dennis W. Smith, Jr., who's research interests include synthesis, mechanism, structure/property relationships, and applications of polymeric materials and composites. Specific research areas include: fluoropolymers, polyarylene networks, renewable feedstock polymers, re-ground car tire rubber composites, novel carbon fiber precursors, and thermally reversible crosslinkable resins. These polmers and materials have found applications in optics, electro-optics, microelectronics, space durable materials, smart coatings, carbon fiber, wound healing, surgical meshes, processable graphene, hydrogen storage, energy harvesting, and more.

The PCAMS laboratory is comprised of two synthetic labs and a joint thermal analysis / extrusion center in collaboration with Dr. Walter Voit (Associate CEHMS site director at UT Dallas). The synthetic labs are equipped with state of the art small molecule and polymer synthesis capabilities (including air free environments for sensitive reactions) and analytical instrumentation: 500 MHz NMR, ATR-FTIR, UV-Vis, MALDI-TOF-MS, GPC, and GC-MS. The thermal analysis lab utilizes state of the art equipment including DSC, TGA, DMA, MALDI, and certain hybrid instruments including a TGA-MS-FTIR for extensive thermal decomposition analyses. Additionally, the extrusion center is equipped to gather full rheological data and extrude fibers on a preindustrial scale. With these advanced capabilities, the LSPCAMS is able to design, synthesize and test nearly any polymeric material.

Virginia Tech

Erin Singleton
310 Durham Hall
Virginia Tech
Blacksburg, VA 24061
Phone: (540) 231-8355
Email: els027@vt.edu

UT DALLAS The University of Texas at Dallas

Renata Freindorf
University of Texas at Dallas
Richardson, TX
Phone: (972) 883-2915
Email: renata.freindorf@utdallas.edu

Leibniz Universität Hannover

Dr. Jens Twiefel
Leibniz Universität Hannover
Hannover, Germany
Phone: +49 (511) 765-4167
Email: twiefel@ids.uni-hannover.de