<u>Research Vision</u>

My research interest is in exploring structural and materials concepts such as advanced composites for energy generation, conversion and storage. In my Lab we synthesize a variety of *nanoscale structures* (carbon nanotubes, graphene, metal and silicon nanorods, nano-beams, nano-springs etc.) using techniques such as chemical vapor deposition and oblique angle deposition. *My research is focused on the study of these novel nanostructures for energy and sustainability.* The nexus between energy, sustainability and nanotechnology is an area that shows potential for great scientific and technological advances. More specifically I have focused my work in six areas:

- **Nanostructures for Energy Storage**: Transitioning from gasoline-fueled vehicles to all-electric vehicles is one of the grand challenges of our times. This requires development of rechargeable batteries that can sustain massive current demands (i.e. ultrafast charge/discharge rate capacity) while simultaneously providing high energy density. Presently, Lithium-ion battery technology is unable to meet these stringent requirements. To address this we are developing novel Silicon based ‘nano-scoop’ structures for Lithium-ion battery anodes. We have shown that these electrode materials can be driven at ultrahigh charge-discharge rates of up to 25C (i.e. current density of ~105 A/g). Such high-rate electrode materials show tremendous promise for development of high-power batteries for hybrid and all-electric automotives. We are presently investigating the mechanism(s) responsible for stress alleviation in our nano-scoop structure so as to further optimize its performance while also exploring other novel electrode structures such as Silicon-Graphene composites.

- **Lightweight Nanocomposite Materials**: The ability to reduce structural weight will significantly lower fuel consumption and translate into significant energy savings for aerospace vehicles, automobiles, marine vehicles and also in wind turbine construction. We are investigating the use of graphene and carbon nanotube additives to enhance the stiffness, strength, damping, fracture toughness and fatigue resistance of polymer composites. We have shown orders of magnitude enhancement in properties such as damping ratio, loss modulus and fatigue life at ultra-low nanotube and graphene loading fractions. These results have been published in top journals such as <u>*Nature Materials*</u>*, Nano Letters, Advanced Materials, ACS Nano, Small and APL. I*n the future I am interested in studying *ceramic* and *metal-matrix nanocomposites* and also for the design of novel composites for flame retardency, ballistic and impact damage protection.

- **Energy transfer via Boiling and Condensation on Nanotextured Surfaces**: We have shown that the wetting of water on nanostructured surfaces can be controlled from the super-hydrophobic to the super-hydrophilic range. Moreover use of bio-mimetic two-scale roughness features enables design of robust (stable) super-hydrophobic surfaces with entrapped air/vapor pockets. Such surfaces significantly promote nucleate boiling heat transfer enabling efficient water-to-vapor conversion. This has important implications for systems that utilize pool boiling for energy exchange such as in chip cooling. This work has been published in *Small* and was featured by *Nature News*. We are presently studying the mechanism(s) responsible for the enhanced boiling as well as extending this work to condensers where we are investigating the condensation of vapor on nanostructured surfaces with controllable wetting properties.

- **Nanomaterials based Membrane and Energy Harvesting Technologies:** We are very interested in transport of water and other fluids as well as gases in confined spaces such as interiors of carbon nanotubes, and few-layered graphene platelets. Carbon nanotube membranes are super-hydrophobic and hence mechanical pressure is not an elegant way to inject water into such systems. To control water flow through such membranes we have developed a novel electro-chemical technique to control the wettability of these membanes using electrical bias. Using this method we can also establish large wetting gradients on the membrane surface which can be utilized for water harvesting and controlling droplet motion. This work was published in *Nano Letters*. We are presently extending this work to study gas transport through nanochannels. We also find that water/steam transport through nanotube channels generates a significant voltage in the membranes which can be very attractive for energy harvesting from moving water. We are trying to understand the mechanism(s) behind this effect as well as to extend this work to graphene membranes.

- **Ultra-Low Power Field Emission and Field Ionization:** We have shown that electric field amplification in the vicinity of sharp nanotube tips can be exploited to ionize and detect a range of gas species at ultra-low power. This work was published in *Nature*. We are presently developing novel “nano-cones” by controlled plasma etching of aligned multiwalled carbon nanotube arrays. We have measured field enhancement factors of ~100,000 for such nanocones. We are engaged in understanding the mechanism(s) responsible for this giant field enhancement and developing various applications of this technology.

- **Nanomaterials for Enhanced Combustion**: We are exploring the utilization of a variety of nanomaterials (such as carbon nanotubes and graphene) which entrap heat to enhance combustion processes. We have observed that such nanomaterial enhanced combustion results in significant increase in the energy release rates. Moreover, nanomaterials distributed into combustible mixtures can dramatically alter the rate of chemical reaction, and allow for on-demand spatial and temporal control over the reaction zone. Such transformative approaches to traditional combustion processes are needed for development of the next-generation of high performance aero-propulsion systems.