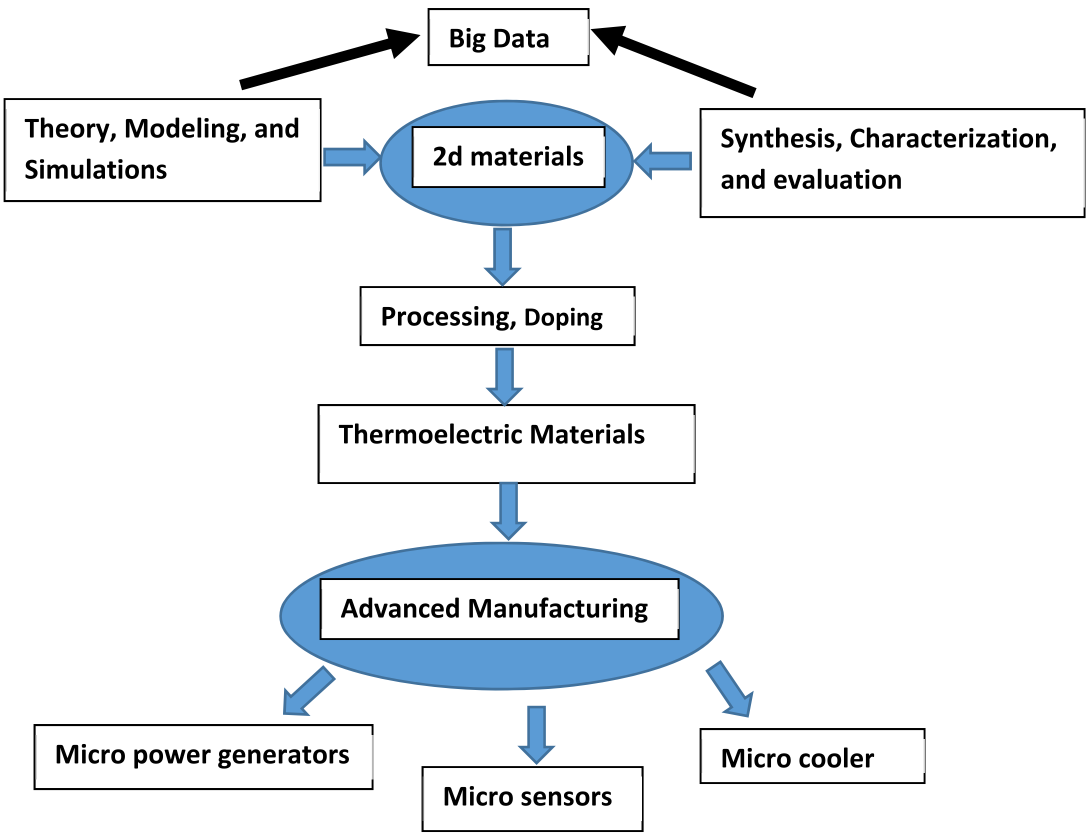
Advanced Manufacturing of Micro-Sized Thermoelectric Devices

Proposal Goals: This proposal seeks to discover novel thermoelectric materials with enhanced thermoelectric figure of merit and intends to design novel micro-sized thermoelectric devices using advanced manufacturing processes for efficient cooling, sensing, and power generation applications that are required in many industries (*e.g.*, automobile industries, microelectronics, *etc*.). To develop the various aspects of this project, we have assembled a team that has extensive expertise in material synthesis and characterization techniques, advanced manufacturing processes, device integration techniques, and materials modeling and simulation.

Project Overview Figure:



Rationale for manufacturing micro-sized power generators, coolers, and sensors: There is pressing need for the advancement of micro-structured low-dimensional thermoelectric materials with improved figure of merit for numerous applications ranging from efficient power generation and cooling to various sensing. The waste recovery has a wide range of applications ranging from small energy harvesters integrated into wireless sensor networks to larger harvesters that can be integrated into automobiles. For example, the electric kinetic energy recovery system in some hybrid cars is in part charged up with energy generated via recovery of heat from the exhaust flow. The automobile companies are interested in developing such a thermoelectric technology. Furthermore, thermoelectric generators are required for powering temperature sensors in many industrial automation condition monitoring.

Autonomous sensor systems for automobile industry offer increased reliability due to the reduction of cable connections, novel sensing applications made possible by wireless data transfer at low cost. These systems consist of a power generator, energy storage and data transceiver. The technological challenge for realizing such system is most of all the construction and fabrication of a mini power generator that matches the dimensions of standard sensor modules. It is shown that low power thermoelectric generators can supply autonomous sensor systems with up to 7 mW utilizing waste energy of the engine.

In Unmanned Aerial Vehicles (UAV) (*e.g.,* drones), thermoelectric systems provide support for a surveillance suite of sensors, which facilitate the vehicle's image recording capability. Sensors equipped with a thermoelectric system provide higher image sensitivity and clarity. Optimized thermoelectric cooling solutions of minimal size, weight and power output is essential for maximum endurance and performance of image sensors in remote environments.

Beyond power generation and cooling applications, thermoelectric materials can also be used as micro gas sensors. Thermoelectric gas sensors are one of the best candidates for effective and inexpensive gas detection. The micro-thermoelectric gas sensor is a micro-transducer converting the temperature change due to the reaction heat between a catalyst and gas species to an electric signal via the Seebeck effect.

All of the thermoelectric devices (power generator, coolers, and sensors) mentioned above require advanced manufacturing processes including microfabrication, packaging, and integration, *etc.*

Rational Design of Thermoelectric Materials: The thermoelectric power generation, cooling and heating applications are based on dimensionless thermoelectric figure of merit, $ZT = S^2\sigma T/\kappa$, where S, σ, T and κ are the Seebeck coefficient, electrical conductivity, absolute temperature and thermal conductivity, respectively. The difficulty of optimization of ZT lies in the fact the above parameters are generally interdependent. Therefore, it is a challenge to develop advanced thermoelectric materials with optimization of these conflicting properties to increase ZT.

We will utilize high-throughput computer framework as a tool for selecting/screening high efficiency thermoelectric materials for the device applications listed in the previous paragraph. A selected subset of thermoelectric materials that we plan to use in our initial investigations are: (i) monolayers of ATeI (A=Sb and Bi), which have been shown theoretically to have impressive ZT values, (ii) nanosheets of tin disulfide (SnS_2) and SnSe, which exhibit negative correlation between σ and κ. In other words, as the thickness of SnS_2 (or Snse) decreases, σ increases whereas κ decreases, (iii) recently discovered Mg_3Sb_2-based and germanium-doped magnesium stannide alloys. In these alloys, by manipulating the carrier scattering mechanism, one can obtain a substantial improvement in carrier mobility, and hence one can improve the power factor.

Broader Scientific Impact: The proposed thermoelectric device when embedded into a wireless technology may find applications in various other industries that require continuous process monitoring that may include hazardous gas leaks, *etc*. The medical industry may find thermoelectric micro coolers to aid in cryosurgical techniques. The computer industry may find applications of thermoelectric devices in solving thermal problems in microelectronics, including the cooling of integrated circuits.

Educational Experience: We propose to expand our graduate curriculum to include industrial internships in order to better prepare our students to enter into the STEM workforce. We also plan to form a partnership with the National Physical Science Consortium that has a program that matches the employer-sponsored industrial sector employees with the universities.