Research Areas

- Electrochemical Materials & Devices
- Electronic, Magnetic & Photonic Materials
- Energy
- Materials Processing
- Nanomaterials & Nanotechnology

Research Interests

Our research focuses on renewable energy and, in particular, photovoltaics. The goal in each project is to design and develop efficient, low cost and reliable solar cells to harness solar energy. Towards this end, we conduct fundamental research on synthesis and characterization of relevant materials and devices. Currently, my students and I are working on various kinds of solar cells including:

1. quantum-dot solar cells,
2. dye-sensitized solar cells,
3. copper indium gallium diselenide (CIGS) solar cells, and
4. copper zinc tin sulfide (selenide) (CZTS) solar cells.

**Quantum-dot solar cells** - Quantum confinement of electrons and holes in nanometer size crystals (quantum dots or QDs), endows them with properties that may be advantageous in solar cells. The principle advantages of using QDs in solar cells include (i) the tunability of their band gap and energy levels by changing the QD size, (ii) potential for generating multiple electron-hole pairs per photon, and (iii) potential for harnessing hot electrons or holes. Moreover, QDs can be prepared in large quantities as stable colloidal solutions under mild conditions and deposited on surfaces of various planar or nanostructured substrates as thin films through inexpensive high-throughput coating processes to form photovoltaic devices. For these reasons, solar cells based on QDs may have the potential to achieve high power conversion efficiencies at low cost and are promising candidates for third
generation photovoltaic devices. Specifically, we explore new types of solar cells that are based on heterojunctions between QDs and wide band gap semiconductors such as ZnO and TiO$_2$. We study methods for QD and ZnO and TiO$_2$ nanowire synthesis as well as methods for assembling solar cells from QDs and nanowires. We design and conduct experiments to elucidate the fundamentals of how QD-solar cells work.

**Dye-sensitized solar cells** - The dye-sensitized solar cell (DSSC) is one of the most promising alternatives to inorganic p-n junction based solar cells. A typical DSSC is made by depositing, on a transparent conducting oxide (TCO) substrate, a porous titanium dioxide thin film that consists of crystalline nanoparticles abutted against each other and photosensitizing this film with a dye adsorbed on the surface of the nanoparticles. The pores are filled with a liquid electrolyte containing a redox couple to form a semiconductor-dye-electrolyte junction with high interfacial area. A second transparent photocathode coated with a thin platinum layer is placed across from the photosensitized semiconductor photoanode to complete the cell. During solar cell operation, the dye absorbs the photons and electrons are excited from the highest occupied molecular orbitals (HOMO) to the lowest unoccupied molecular orbitals (LUMO) of the dye. The excited electron is rapidly injected into the titanium dioxide, diffuses through the nanoporous semiconductor network and is collected at the TCO electrode. We explore improving dye-sensitized solar cell efficiency using nanowires instead of nanocrystalline particles. Nanowires provide direct collection pathways for electrons from the point of injection to the TCO electrode and have the potential to improve the charge collection efficiency of DSSCs because electron percolation through the particle network is replaced by direct electron transport to the anode.

**CIGS solar cells** - Copper indium gallium diselenide (CIGS) solar cells are emerging as one of the low-cost alternatives to crystalline silicon solar cells. While efficiencies exceeding 20% have been achieved on small scale in the laboratory, making large area CIGS solar cells that are resistant to environmental factors such as humidity remains a challenge. My students and I work on understanding charge transport and recombination in CIG solar cells as well as modifications of the high efficiency solar cell design and new materials to improve its reliability. We collaborate with Professor Steve Campbell in the Electrical and Computer Engineering Department.

**CZTS solar cells** - Thin film solar cells based on CdTe and CIGS are amongst the most promising second generation solar cell technologies. However, availability of tellurium and indium in the earth's crust may limit the terrawatt-scale production of thin film solar cells based on CdTe and CIGS. My students and I work on a new promising absorber material, Cu$_2$ZnSnS$_4$Se$_{4-x}$ (CZTS), that is like CIGS in many respects but consists of abundant and nontoxic elements. We use three different synthesis methods for depositing thin CZTS films. These include vacuum coevaporation, sulfurization of sputtered stacks of copper, zinc and tin, and deposition from colloidal dispersions of CZTS nanoparticles. We study the structural, electrical and optical properties of the CZTS films and CZTS solar cells using a suite of characterization methods.

**Plasma Research** - Plasma etching and deposition enables the fabrication of a wide variety of devices including microprocessors, memory devices, sensors, nozzles for inkjet printing and solar cells. We study the homogeneous and heterogeneous reactions and transport phenomena occurring in chemically reactive gas plasmas. The objective is to understand how process conditions dictate plasma properties which in turn affect the etch rate, selectivity with respect to the mask, uniformity and anisotropy. We use multiple surface and plasma characterization methods to investigate the key factors that determine the species concentrations and energy distributions in the plasma. Where necessary, we complement the experiments with modeling of the plasma and plasma-surface interactions. Recent specific projects include plasma enhanced chemical vapor deposition of carbon nanotubes and the effect of nanoparticles on the plasma properties.

**Awards**

2009 Plasma Prize of the Plasma Science and Technology Division of the AVS
2005 Fellow of the AVS
2005 University of Houston Distinguished Young Engineering Alumnus
1999 Peter Mark Memorial Award of the American Vacuum Society
1997 Camille Dreyfus Teacher-Scholar Award
1994 National Science Foundation National Young Investigator Award
1993 Norman Hackerman Young Author Award of The Electrochemical Society
Selected Publications


B. S. Tosun, R. K. Feist, A. Gunawan, K. A. Mkhoyan, S. A. Campbell and E. S. Aydil, “Sputter Deposition of


S. Ramalingam, E. S. Aydil, and D. Maroudas, “Molecular Dynamics Study of the Interactions of Small Thermal and


