Thermophotovoltaics, Solar and Fuel Cells

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Overview of Current Investigations

Thermophotovoltaics (TPV) is a promising energy conversion technology for producing electricity from sources of thermal energy. The efficient recovery of waste heat is a key goal of TPV. The TPV process comprises three conceptual stages, in which an emitter first converts a source of thermal energy into infrared light, which is propagated to a collector stage and is subsequently converted into electrical energy. Effective TPV emitters must produce light that couples efficiently to the PV cell. Since PV cells only respond well to light in a limited frequency range near their bandgap, emitters can minimize losses by radiating light only in that frequency range. The resulting losses are much lower than those from conventional blackbody emitters, which radiate much of their light in the wrong spectral regions for efficient energy conversion by the collectors.

New approaches to TPV emitters use electrospun titania nanofibers modified with rare-earth oxides to produce emitters with spectral outputs tuned to emit near the bandgap of GaSb and other commercially available photovoltaic cells. Nanofiber emitters provide the additional benefit of having a geometry that maximizes the ratio between surface area (providing net emission) and volume (causing re-absorption). Furthermore, nanofiber emitters are essentially isothermal, preventing cooler regions from re-absorbing the light radiated by warmer regions.

Our approach to developing a global model of the TPV system is to develop simple models for each of the three system components: the emitter, which converts thermal energy into infrared light; the radiation transport, which determines the proportion of radiated light arriving at the collector; and the collector, which converts this light into electricity. We piece the three submodels together, forming a comprehensive model that predicts system efficiency and power density.

Our initial efforts address some aspects of these issues through a series of parametric studies, using one-dimensional and two-dimensional homogenized models of a device proposed for automotive applications. A nanofiber-based TPV system could be easily incorporated into a filter structure for the generation of energy from vehicle exhaust streams. The emitter material is wrapped around the outside of the exhaust pipe or placed inside the pipe, which provides the thermal energy source, and emits light radially from the emitter surfaces. We examine the total net irradiance (power density) produced by this device under a number of conditions. An optimal distribution and concentration of rare-earth material is found to exist, and geometric and temperature effects are also observed.

Due to the finite supply of fossil fuels and the harmful emissions that result from their use, there is a global initiative to reduce the world's reliance upon these energy sources. Hydrogen is an alternative fuel that can be used in almost every application where fossil fuels are used today, but without greenhouse consequences.

The basic goal of this project is to develop an efficient proton electrolyte membrane **photoelectrolysis cell (PEMPC)** to serve as a solar-powered hydrogen generator. A 1 cm by 1 cm cell has the potential to produce up to 1 milliliter of hydrogen gas per minute. A practical PEMPC may be realized by: (i) increasing the efficiency of photon–electron transfer at the photoelectrodes for enhanced electrolysis, (ii) increasing the efficiency of the proton transport through the proton electrolyte membrane (PEM) under a variety of temperature and moisture conditions and (iii) fabricating a workaday membrane-electrode assembly (MEA).

To meet these challenges, an investigative team of chemists, electrochemists, physicists, polymer scientists and engineers, and applied mathematicians are conducting an interdisciplinary effort (i) to improve industry standard PEMs that presently do not function under low and high moisture conditions, (ii) to synthesize and fabricate a new class of PEMs that conduct protons independent of water, (iii) to assemble a novel class of nanowire photoelectrode arrays, (iv) to manufacture a practical MEA, (v) to characterize the operational features of the components of the PEMPC, and (vi) to develop mathematical models as a predictive tool for discovering efficient design strategies for hydrogen generation.

A related project is considering a nano-scale, dye-sensitized (or Graetzel) **solar cell**.