



Chemochromic Hydrogen Leak Detectors

Robust, simple, and easy-to-detect, color-changing hydrogen sensors warn against explosion hazard.

John F. Kennedy Space Center, Florida

At NASA, hydrogen safety is a key concern for space shuttle processing. Leaks of any level must be quickly recognized and addressed due to hydrogen's lower explosion limit. Chemochromic devices have been developed to detect hydrogen gas in several embodiments. Because hydrogen is odorless and colorless and poses an explosion hazard, there is an emerging need for sensors to quickly and accurately detect low levels of leaking hydrogen in fuel cells and other advanced energy-generating systems in which hydrogen is used as fuel.

The device incorporates a chemochromic pigment into a base polymer. The article can reversibly or irreversibly change color upon exposure to hydrogen. The irreversible pigment changes color from a light beige to a dark gray. The sensitivity of the pigment can be tailored to its application by altering its exposure to gas through

the incorporation of one or more additives or polymer matrix. Furthermore, through the incorporation of insulating additives, the chemochromic sensor can operate at cryogenic temperatures as low as 78 K.

A chemochromic detector of this type can be manufactured into any feasible polymer part including injection molded plastic parts, fiber-spun textiles, or extruded tapes. The detectors are simple, inexpensive, portable, and do not require an external power source. The chemochromic detectors were installed and removed easily at the KSC launch pad without need for special expertise. These detectors may require an external monitor such as the human eye, camera, or electronic detector; however, they could be left in place, unmonitored, and examined later for color change to determine whether there had been exposure to hydrogen.

In one type of envisioned application, chemochromic detectors would be fabricated as outer layers (e.g., casings or coatings) on high-pressure hydrogen storage tanks and other components of hydrogen-handling systems to provide visible indications of hydrogen leaks caused by fatigue failures or other failures in those systems. In another type of envisioned application, chemochromic detectors of this type could be optoelectronically instrumented for monitoring to provide measured digital indications of color changes indicative of the presence of hydrogen.

This work was done by Luke Roberson, Janine Captain, Martha Williams, Trent Smith, and LaNetra Tate of Kennedy Space Center; and Ali Raissi, Nahid Mohajeri, Nazim Muradov, and Gary Bokerman of Florida Solar Energy Center. For additional information, contact the Kennedy Space Center Innovative Partnerships Program Office at (321) 861-7158. KSC-13088

Compatibility of Segments of Thermoelectric Generators

A compatibility factor that depends only on material and temperature has been defined.

NASA's Jet Propulsion Laboratory, Pasadena, California

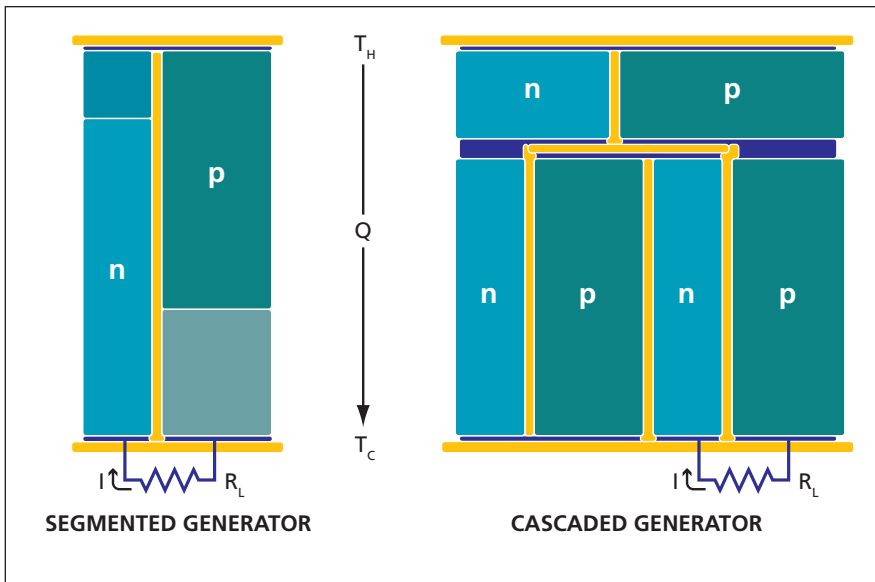
A method of calculating (usually for the purpose of maximizing) the power-conversion efficiency of a segmented thermoelectric generator is based on equations derived from the fundamental equations of thermoelectricity. Because it is directly traceable to first principles, the method provides physical explanations in addition to predictions of phenomena involved in segmentation. In comparison with the finite-element method used heretofore to predict (without being able to explain) the behavior of a segmented thermoelectric generator, this method is much simpler to implement in practice: in particular, the efficiency of a segmented thermoelectric generator can be estimated by evaluating equations using only hand-held calculator with this method. In addition, the method provides for determi-

nation of cascading ratios. The concept of cascading is illustrated in the figure and the definition of the "cascading ratio" is defined in the figure caption.

An important aspect of the method is its approach to the issue of compatibility among segments, in combination with introduction of the concept of compatibility within a segment. Prior approaches involved the use of only averaged material properties. Two materials in direct contact could be examined for compatibility with each other, but there was no general framework for analysis of compatibility. The present method establishes such a framework.

The mathematical derivation of the method begins with the definition of reduced efficiency of a thermoelectric generator as the ratio between (1) its thermal-to-electric power-con-

version efficiency and (2) its Carnot efficiency (the maximum efficiency theoretically attainable, given its hot- and cold-side temperatures). The derivation involves calculation of the reduced efficiency of a model thermoelectric generator for which the hot-side temperature is only infinitesimally greater than the cold-side temperature. The derivation includes consideration of the ratio (u) between the electric current and heat-conduction power and leads to the concept of compatibility factor (s) for a given thermoelectric material, defined as the value of u that maximizes the reduced efficiency of the aforementioned model thermoelectric generator. It turns out that s depends only on the absolute temperature (T) and on intrinsic properties of the ma-



This **Schematic Diagram** compares segmented with cascaded thermoelectric generator. The cascading ratio is defined as the ratio between the numbers of unicouples in the two stages.

material that may vary with the temperature. The equation for s is

$$s \equiv \frac{\sqrt{1 + ZT} - 1}{\alpha T}$$

where Z is the traditional thermoelectric figure of merit, defined as $Z = \alpha^2 / \rho\kappa$; α is the Seebeck coefficient; ρ is the electrical resistivity; and κ is the thermal conductivity.

For maximum efficiency, u should be equal to s , both within a single material, and throughout a segmented thermoelectric-generator leg as a whole. It is in this sense that s serves as a basis for assessing both compatibility among segments and compatibility within a segment (self-compatibility). Given that u remains relatively constant throughout the thermoelectric element, the degree

to which s varies with temperature along a given segment or differs among adjacent segments thus serves as a measure of incompatibility that one strives to minimize.

The compatibility factor can further be used as a quantitative guide for deciding whether a thermoelectric material is better suited for segmentation or cascading. Cascading enables the use of a material that may be suitable for a given temperature stage but is incompatible for segmentation with one or more other materials in the same temperature stage. The simplest option that may be available in a given case is to choose the numbers of unicouples in both temperature stages such that each stage is operating at its optimal u value. Such a choice is embodied in the following expression for the cascading ratio:

$$\frac{g'}{g} = \frac{u'}{u}$$

where g is the number of unicouples per stage and the prime mark distinguishes one stage from the other.

This work was done by G. Jeffrey Snyder and Tristan Ursell of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-30798

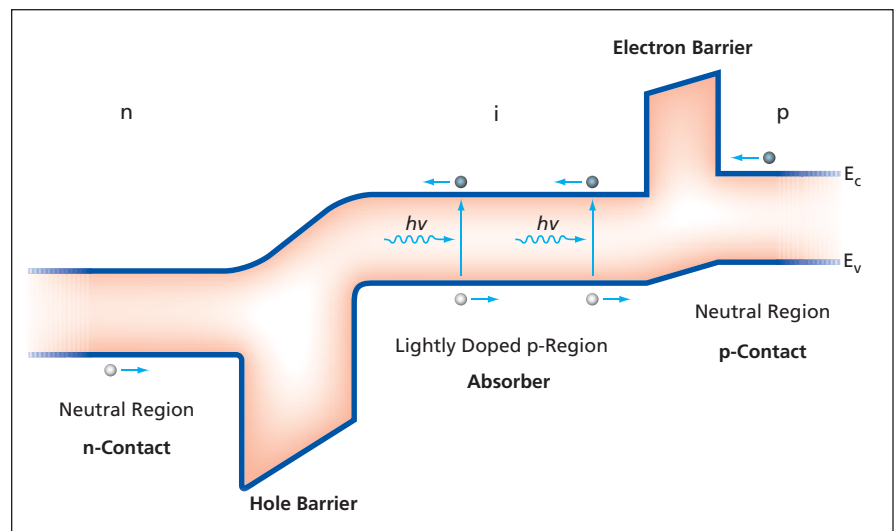
Complementary Barrier Infrared Detector

These detectors can be used in infrared imaging cameras in manufacturing process monitoring, environmental monitoring, and medical imaging.

NASA's Jet Propulsion Laboratory, Pasadena, California

The complementary barrier infrared detector (CBIRD) is designed to eliminate the major dark current sources in the superlattice infrared detector. The concept can also be applied to bulk semiconductor-based infrared detectors. CBIRD uses two different types of specially designed barriers: an electron barrier that blocks electrons but not holes, and a hole barrier that blocks holes but not electrons. The CBIRD structure consists of an n-contact, a hole barrier, an absorber, an electron barrier, and a p-contact.

The barriers are placed at the contact-absorber junctions where, in a conventional p-i-n detector structure, there normally are depletion regions that produce generation-recombination (G-R) dark currents due to Shockley-Read-Hall (SRH) processes. The wider-



This schematic energy band diagram illustrates the **Complementary Barrier Infrared Detector (CBIRD)** concept.