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# Photoelectrochemical Hydrogen Production

In recent years under the sponsorship of DOE, the Thin Films Laboratory [1] at HNEI has been developing high-efficiency, potentially low-cost, photoelectrochemical (PEC) systems to produce hydrogen directly from water using sunlight as the energy source. The main thrust of the research has been the development of integrated multijunction photoelectrode configurations comprising low-cost semiconductor, catalytic, and protective thin-films deposited on stainless-steel foil substrates. HNEI continues to work closely with the DOE?s Working Group on PEC Hydrogen Production, and maintains international ties with the IEA (International Energy Association) annexes focusing on similar research.

Important accomplishments have included: 1) the development of thin film cobalt-molybdenum (CoMo) and iron-nickel oxide (Fe:NiOx) catalysts for alkaline electrolysis which exhibited negligible performance degradation in continuous operation for over 5,000 hours; 2) demonstration of 7.8% solar-to-hydrogen efficiency in a small scale reactor using monolithically-stacked triple junction amorphous silicon/germanium alloy thin film solar cells coated with CoMo hydrogen catalyst, and using a stainless-steel counter electrode coated with Fe:NiOx oxygen catalyst; 3) development of indium-tin oxide (ITO) thin films with low resistivity and good alkaline corrosion resistance for use as buffer layers in integrated thin-film photoelectrodes; 4) development of thermally-evaporated copper-indium-gallium-diselenide (CIGS) films for use in photoelectrode structures which have achieved photovoltaic efficiencies in excess of 12% in devices fabricated on metal foil substrates; and 5) design of a robust 'hybrid' photoelectrode configuration monolithically combining a tandem amorphous silicon device in series with a thick, photoactive over-coating of nano-structured iron oxide for optimal efficiency and stability.

For more complete and detailed information, please refer to the following resources:

***D.O.E. Annual Reports:***

2005 - HNEI: Photoelectrochemical Hydrogen Production [2]
2004 - HNEI: Photoelectrochemical Hydrogen Production [3]
2003 - HNEI: Photoelectrochemical Hydrogen Production [4]
2002 - HNEI: Photoelectrochemical Hydrogen Production [5]
2001 - HNEI: Photoelectrochemical Hydrogen Production [6]
2000 - HNEI: Photoelectrochemical Hydrogen Production [7]
1999 - HNEI: Photoelectrochemical Hydrogen Production [8]
1998 - HNEI: Photoelectrochemical Hydrogen Production [9]

***Conference Presentations:***

ECS_04 (Electrochemical Society Joint Meeting 2004) - HNEI: Optimization of a Hybrid Photoelectrode for Solar Water-Splitting

[10]

ECS_04 (Electrochemical Society Joint Meeting 2004) - HNEI: Nitrogen Doping of Reactively-Sputtered Tungsten Oxide Films for Photoelectrochemical Applications [11]

IMRC_02 (International Materials Research Congress 2002) - HNEI: A Hybrid Multijunction Photoelectrode for Hydrogen Production Fabricated with Amorphous Silicon/Germanium and Iron Oxide Thin Films [12]

ICAM_01 (International Conference on Advanced Materials 2001) - HNEI: Design Considerations for a Hybrid Amorphous Silicon/Photoelectrochemical Multijunction Cell for Hydrogen Production [13]

***Publications:***


Miller E. L., Marsen, B., Paluselli, D., Rocheleau, R.E.,"Optimization of Hybrid Photoelectrodes for Solar Water Splitting", 2005, ***Electrochemical and Solid-State Letters***, **8**, A247-249.

Miller E. L., Marsen, B., Paluselli, D., Rocheleau, "Development of Reactively Sputtered Metal Oxide Films for Hydrogen-Producing Hybrid Multijunction Photoelectrodes", 2005, ***Solar Energy Materials and Solar Cells***, **88**(2), 131-144.

Miller E. L., Paluselli, D., Marsen, B., Rocheleau, R. E., "Low-Temperature Sputtered Iron Oxide for Thin Film Devices", 2004, ***Thin Solid Films***, **466**, 307-313.

Miller, E. L., Rocheleau, R. E., Khan, S., "A Hybrid Multijunction Photoelectrode for Hydrogen Production Fabricated with Amorphous Silicon/Germanium and Iron Oxide Thin Films", ***International Journal of Hydrogen Energy***, 2004, **29**(9), 907-914.

Miller, E. L., Rocheleau, R. E., Deng, X.M., "Design Considerations for a Hybrid Amorphous Silicon / Photoelectrochemical Multijunction Cell for Hydrogen Production", ***International Journal of Hydrogen Energy***, 2003, **28**(6), 615-623.

Rocheleau, R. E., Miller, E. L., Misra, A., "High-efficiency Photoelectrochemical Hydrogen Production using Multijunction Amorphous Silicon Photoelectrodes", ***Energy and Fuels***, 1998, **12**, 3-10.

Miller, E. L., Rocheleau, R. E., "Electrochemical and Electrochromic Behavior of Reactively Sputtered Nickel Oxide", ***Journal of the Electrochemical Society***, 1997, **144**(6), 1995-2003.

Miller, E. L., Rocheleau, R. E., "Electrochemical Behavior of Reactively Sputtered Iron-Doped Nickel Oxide", ***Journal of the Electrochemical Society***, 1997, **144**(9), 3072-3077.

Rocheleau, R. E., Miller, E. L., "Photoelectrochemical Production of Hydrogen: Engineering Loss Analysis", ***International Journal of Hydrogen Energy***, 1997, **22**(8), 771-782.

Mathews, N. R., Miller, E. L. , Sebastian, P. J., Hernandez, M. M., Mathew, X., Gamboa, S. A., "Electrochemical Characterization of a-Sic In Different Electrolytes", ***International Journal of Hydrogen Energy***, 2004, **29**(9), 941-944.

Miller, E. L., Paluselli, D., Marsen, B., Rocheleau, R.E., "Development of Reactively Sputtered Metal Oxide Films for Hydrogen-Producing Hybrid Multijunction Photoelectrodes", 2004, ***International Journal of Hydrogen Energy***, in press.

Rocheleau, R. E., Miller, E. L. and Misra, A., High-efficiency photoelectrochemical hydrogen production

using multijunction amorphous silicon photoelectrodes, ***Energy and Fuels***, 1998, **12**, 3-10.

Miller, E. L. and Rocheleau, R. E., Electrochemical and electrochromic behavior of reactively sputtered nickel oxide, ***Journal of the Electrochemical Society***, 1997, **144**(6), 1995-2003.

Miller, E. L. and Rocheleau, R. E., Electrochemical behavior of reactively sputtered iron-doped nickel oxide, ***Journal of the Electrochemical Society***, 1997, **144**(9), 3072-3077.

Rocheleau, R. E. and Miller, E. L., Photoelectrochemical production of hydrogen: engineering loss analysis, ***International Journal of Hydrogen Energy***, 1997, **22**(8), 771-782.

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Hawaii Natural Energy Institute ? 1680 East West Road, POST 109 ? Honolulu, HI 96822 ? Ph: (808) 956-8890 ? Fax: (808) 956-2336 ? Email:Contact ?

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