Monday Morning, October 15, 2007

The Industrial Physics Forum 2007: The Energy Challenge

Room: 602/603 - Session IPF-MoM

Energy Efficiency

Moderator: J. Hobbs, American Institute of Physics

8:00am **IPF-MoM1 Solar Photovoltaics: At the Tipping Point**, ***L. Kazmerski***, National Renewable Energy Laboratory **INVITED**

The prospects of current and coming solar-photovoltaic (PV) technologies are envisioned, arguing this solar-electricity source is at a tipping point in the complex worldwide energy outlook. The co-requirements for policy and technology investments are strongly supported. The emphasis of this presentation is on R&D advances (cell, materials, and module options), with indications of the limitations and strengths of crystalline (Si and GaAs) and thin-film (a-Si:H, Si, $Cu(In,Ga)(Se,S)_2$, CdTe). The contributions and technological pathways for now and near-term technologies (silicon, III-Vs, and thin films) and status and forecasts for next-generation PV (organics, nanotechnologies, non-conventional junction approaches) are evaluated. Recent advances in concentrators, new directions for thin films, and materials/device technology issues are discussed in terms of technology evolution and progress. Insights to technical and other investments needed to tip photovoltaics to its next level of contribution as a significant clean-energy partner in the world energy portfolio. The need for R&D accelerating the now and imminent (evolutionary) technologies balanced with work in mid-term (disruptive) approaches is highlighted. Moreover, technology progress and ownership for next generation solar PV mandates a balanced investment in research on revolutionary (long-term) technologies (quantum dots, multi-multijunctions, intermediate-band concepts, nanotubes, bio-inspired, thermophotonics, . . .) having high-risk, but extremely high performance and cost returns for our next generations of energy consumers. This presentation provides insights (some irreverent, some entertaining) into how this technology has developed---and where we can expect to be by this mid-21st century.

8:40am **IPF-MoM3 The Physics of Terrestrial Concentrator Solar Cells with Over 40% Efficiency**, ***R.R. King***, *D.C. Law, K.M. Edmondson, C.M. Fetzer, G.S. Kinsey, H. Yoon, D.D. Krut, J.H. Ermer, R.A. Sherif, N.H. Karam*, Spectrolab, Inc. **INVITED**

Solar cell efficiency is one of the most enabling device parameters for widespread implementation of solar electricity generation on Earth, since high efficiency dramatically reduces not only the cell area needed to generate a given power, but also the cost of all area-related components in a photovoltaic system. The efficiency of a solar cell with a single energy band gap E_g in unconcentrated sunlight is quite limited by fundamental considerations, such as thermalization of photogenerated electrons and holes, non-absorption of low energy photons, and the limited quasi-Fermi level splitting at one sun. Multijunction concentrator cells are able to overcome these fundamental efficiency limits, and as a result have attracted much attention recently for cost-effective terrestrial photovoltaics. If the subcell bandgaps for the multijunction solar cell are chosen from metamorphic semiconductors that are lattice-mismatched to the growth substrate, theoretical efficiencies can be raised even higher than for lattice-matched designs. Advances in the design of metamorphic subcells to reduce carrier recombination and increase voltage, wide-bandgap tunnel junctions, metamorphic buffers to transition to the lattice constant of the active subcells, concentrator cell anti-reflection coating and grid design, and integration into current-matched 3-junction cells have resulted in new heights in solar cell performance. A metamorphic $Ga_{0.44}In_{0.56}P$/ $Ga_{0.92}In_{0.08}As$/ Ge 3-junction solar cell has reached a record 40.7% efficiency at 240 suns, under the standard reporting spectrum for terrestrial concentrator cells (AM1.5 direct, low-AOD, 24.0 W/cm^2, 25°C). This metamorphic 3-junction device is the first solar cell to reach over 40% in efficiency, and has the highest solar conversion efficiency for any type of photovoltaic cell to date. Experimental lattice-matched 3-junction cells have now also achieved over 40% efficiency, with 40.1% measured at 135 suns. The multijunction structure of these cells and their operation at concentration allow efficiencies substantially above the Shockley-Queisser limit[1] of 30% for a single-band-gap device at one sun, and above the theoretical limit of 37% for single-band-gap cells at 1000 suns,[2] to now be achieved in practice.

[1]W. Shockley and H. J. Queisser, J. Appl. Phys., 32, 510 (1961).

[2]C. H. Henry, J. Appl. Phys., 51, 4494 (1980).

9:20am **IPF-MoM5 Thermoelectrics and Waste Heat Recovery**, ***L.E. Bell***, BSST LLC **INVITED**

Thermoelectric (TE) devices are reversible, solid-state heat engines. When a temperature difference is applied across a TE array, electric power is produced; and when electric power is applied, a portion of the array cools (sinks thermal power) and another portion heats (produces thermal power). Increased needs to lower energy costs and reduce green house gas emissions have renewed interest in the technology. TE applications have been limited most importantly by lower conversion efficiency, but also by the cost of the materials and systems. Recent advances in performance through the development of more efficient thermodynamic cycles, laboratory demonstrations of improved materials, and the availability of more comprehensive design tools, have increased interest in the application of the technology for power generation uses. The recent recognition of the need to reduce CO_2 emissions has renewed interest in TE technology with respect to waste heat harvesting from vehicle exhaust. Since the 1960's, TEs have been employed in critical military and space applications where their demonstrated ruggedness and maintenance-free operation has outweighed energy conversion efficiency limitations. Target applications are small to midsize (up to 40 kW) sources of exhaust waste heat and include: vehicle exhaust residential, commercial, and industrial fuel-fired heating systems; diesel powered electric generators; and other similar applications. TE technology is evolving to the point where systems with conversion efficiencies of 6% to possibly 20% are being investigated. Prospects for successful implementation of TE technology for waste heat recovery to reduce CO_2 and other green house gas emissions are discussed for a range of business sectors for which the technology appears attractive. Examples of current approaches to implementation are given, along with estimates for critical system characteristics including projected size, weight, efficiency, and rough costs. Important current programs funded by various U.S. and foreign government agencies are described and their level of technical and commercial readiness are assessed.

10:20am **IPF-MoM8 Current Status of Solid State Lighting**, ***S. Nakamura***, University of California, Santa Barbara **INVITED**

The light emitting diode (LED) takes electrical energy and converts it to bright bluelight. The light generation is very energy efficient (60%), which is much better than normal incandescent bulb (5%). The light is generated inside of a crystal of gallium nitride (GaN), and it only requires a 3-volt battery. The efficiency of white LEDs that use blue LEDs will become higher, almost close to 100% (currently 150 lm/W). Then, all of the conventional lighting, such as incandescent bulbs (10 lm/W), fluorescent lamps (70 lm/W), and others, would be replaced with the white LEDs in order to save energy and resources. Also, these white LEDs would be operated by a battery powered by a solar cell in the daytime. So, it means that this lighting would be operated with clean energy thanks to its high efficiency and low voltage operation. In the developing countries, there is no electricity and no light at night. However, white LEDs operated with a small battery powered by a solar cell in the daytime could be used as a light source in those developing countries.

11:00am **IPF-MoM10 Emerging Energy Policy on Capitol Hill**, ***M. Kenderdine***, GTI **INVITED**

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