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Final Report on the Charmey Workshop (Part III):

Outcome of Group Discussions

This part contains the results of the most important event of the workshop, namely the discussions in freely chosen groups. The format of the reports has been defined by the groups also, following only very general guidelines. Thus, sometimes the authors mentioned are the members of a group, in other instances a rapporteur had been designated by the group as the author. Some groups chose to attribute specific ideas to the individual that forwarded them first by indicating its name at the beginning of the corresponding paragraph. - During review of the draft report, participants had the opportunity to express their support of ideas developed in other groups. These declarations of support are added at the end of each report.

Long-Range Photovoltaic R&D Concepts

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1. Background of Conventional Solar Cells

Solar-cell technology has moved strongly into commercial development and thus most solar-cell research and development does not fall under the category of long-term R&D. However, it is useful to point out some of the current topics of interest as they relate to solar-cell R&D.

Long-range R&D goals of «conventional» photovoltaic technology can be pursued via theoretical work and computer modelling. New materials should be postulated and synthesized, ideally tailored by bandgap and crystal structure, to act as the constituents of multijunction solar cells. It is important to stimulate new theoretical studies (such as microstructure techniques) to provide a screening method to select promising candidates for new semiconductor materials. These materials should be capable of low-cost large-area deposition to give amorphous or polycrystalline thin films. New low-cost polymeric

moisture-resistant encapsulating materials need to be developed. The goal should be low-cost (< 5 cents per kWh), high-efficiency (> 30%), long-life (> 30 years) photovoltaic modules manufactured to be easily incorporated into new houses or easily retrofitted to older houses.

For all photovoltaic systems, there is a need for all-solid-state, efficient, and reliable power conditioners (inverters) which incorporate power tracking for optimum output at a wide range of input DC power levels. Also, for stand-alone systems, low-cost totally reversible battery systems must be developed.

2. Biocompatible Ultra-Thin Solar Cells

There is another type of solar cell which deserves greater attention for long-range R&D. These cells would involve ultra-thin (< 100 nm) films, be of very low cost and would consist of biocompatible materials. These cells may degrade faster than conventional solar cells so they might need to be replaced after a few years. Due to their biocompatibility they could be produced in large quantities without adverse effects on the environment. These cells would be

compatible, not only with the conversion of sunlight to electricity, but would also couple effectively into chemical energy storage and other interesting photochemical processes (e.g., information storage or biochemical reactions). With the rapid progress in the development of electrically conducting polymers, it is envisioned that polymer-based thin-film systems could be manufactured in large-area, consumer-friendly intergrated arrays for easy installation.

Characteristics of the Device

As a thin-film system, the device would have three basic layers: a cheap (probably plastic) substrate coated with a conducting layer (perhaps a wide-bandgap semiconductor film), an active layer containing the chromophores, and a protective transparent layer containing a conducting grid.

The active layer could be a mono- or multilayer system with organic or inorganic semiconductors.

Organic or Inorganic Semiconductor

This would have to be composed of materials with a very high absorption coefficient (> 90% absorption in < 100 nm), reasonable stability, low internal resistance, a high current quantum yield, and an absorption edge in the range 700-900 nm. No materials are now known which fulfill all of these criteria, but there is a reasonable possibility that such materials can be developed. Certain organic dyes (e.g. porphyrins, phthalocyanines) and certain inorganic materials (like FeS₂) do have the required absorption coefficients, but currently have far too high an internal resistance.



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layer configuration which could approach the very high efficiencies predicted for multijunction cells. The sensitized monolayer system simultaneously meets the requirements of high absorptivity, low internal resistance, and high degree of organization. Yield is governed by the photoelectrochemical properties of the monolayer.

An alternative approach to high optical absorptivity makes use of multilayer charge-transfer systems. Then it is necessary to design the assembly in such a way, that the internal resistance to electron flow is sufficiently low. Research should concentrate on defining the requirements to obtain such low resistance, specifically with respect to mutual orientation, distance, and degree of organization.

Multilayer charge-transfer systems may consist of stacks of one or more types of compound. A single layer should have internal, low-lying charge-transfer states. Mixed assemblies should consist of alternating layers of electron donors and acceptors at a distance and orientation favoring

electron transport. By modifying the redox properties of subsequent layers, the assembly may act as an organic semiconductor, exhibiting photo-induced charge separation.

To obtain high current quantum yield, the ratio of the rate constants for charge separation and recombination should be as high as possible. Multilayer systems exhibiting multistep electron transport are expected to result in high current yield.

Technology should be further developed for the preparation of well-defined, highly organized thin-film assemblies by chemical synthesis, linking the photoactive compounds to electrically-conducting surfaces by modified vacuum deposition and deposition from solution.

The concepts presented above may also be applied to organized microheterogeneous systems (e.g., colloids and microemulsions) which are designed to couple the primary photochemical electron-transfer reactions to (bio)chemical processes. These could involve generation of energy-

Mono- and Multilayer Active Assemblies

These assemblies of inorganic or organic compounds, suitable for photo-induced charge separation, should meet the requirements as above, i.e., high absorptivity out to 700-900 nm, low internal resistance, and a high current quantum yield; in addition they should have a high degree of spacial organization. Sufficient optical absorption cannot be obtained by monolayers of either organic or inorganic compounds. Therefore the optical absorption cross-section has to be increased by either an optical antenna system or a multilayer system.

Fig. III1 gives an example of the use of an antenna system containing a series of sensitizers acting as excitation energy transfer agents, coupled to a charge-separating monolayer. This concept is based on the mechanism by which photosynthesis converts sunlight into chemical energy. Sunlight would be absorbed by a series of sensitizers covering the near-UV and visible solar spectrum. These sensitizers would be embedded in an electrically conducting layer (e.g., a conducting polymer) and would act as a light-gathering antenna in the sense that excitation energy would be transferred from one sensitizer to another until the excitation reaches a monolayer of a red-sensitive chromophore. Here the excited state of this chromophore would inject an electron (with high quantum yield) into the conduction band of a wide-bandgap, heavily-doped semiconductor, e.g., In-doped SnO₂ (this step has already been demonstrated). Electrons would flow from the monolayer chromophore to the base semiconductor, through an external load and finally back through a surface grid and the conducting sensitizer layer.

Indeed it may be possible to utilize this type of a monolayer-based cell in a multi-

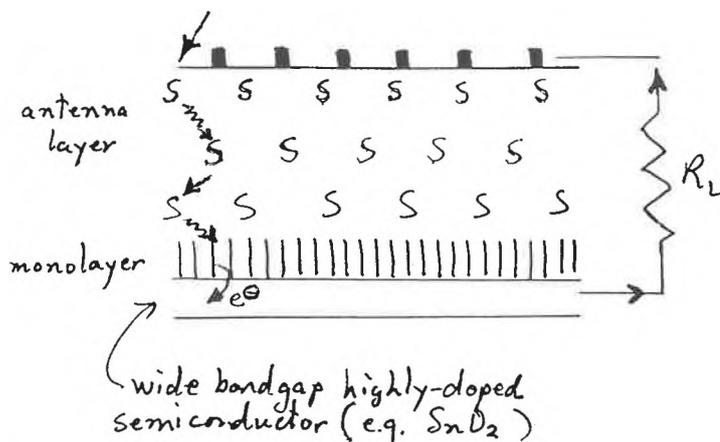
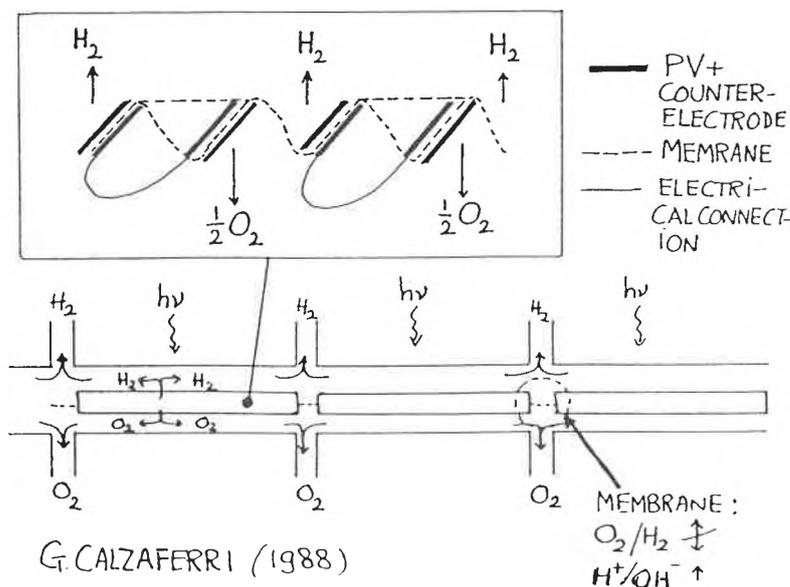


Fig. III1. An example of the use of an antenna system containing a series of sensitizers acting as excitation energy transfer agents, coupled to a charge-separating monolayer.



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Fig. III2. A possible configuration with two electrodes.

rich chemicals (fuels) and the use of fuel cells to extract the stored chemical energy as electrical energy. One such system could consist of plastic foils covered with organized microelectrodes for photoelectrolysis of water. In a «conventional» system photoelectrolysis of water can be achieved by applying three or four photovoltaic cells in series. In a similar manner, water photoelectrolysis can be achieved using organized microelectrodes. Fig. III2 illustrates a possible configuration with two electrodes.

The advantage of the organized microelectrode system over macroscopic electrodes in series is the absence of wiring. A disadvantage is that hydrogen has to be collected over a large area.

These thin-film concepts can be further applied to other photochemical processes such as the production of high-value chemicals (e.g. vitamin D).

Another possible application is the construction of devices integrating thin-films, which could include biological components (e.g., isolated reaction-center proteins from photosynthetic bacteria),

into high-density optical information storage (it is estimated that as much as 50 gigabytes of information could be stored per cm^2) or ultrafast optical switches.

3. Static Concentrators for Photovoltaic Systems

Adolf Goetzberger

A static (non-tracking) concentrator with a concentration ratio of 8–12 has been suggested. It consists of inexpensive refractive material, coupled to high-efficiency state-of-the-art solar cells. This concept promises to yield less-expensive, high-efficiency photovoltaic modules. The technologies needed are presently used in non-solar industry and would have to be adapted. It involves automatic handling of large numbers of small solar cells. These cells can be produced using standard integrated-circuit technology.

An R&D program should be developed including the following goals:

- Optimize optical modelling of concentrators.
- Identify or develop inexpensive, stable plastic materials with a high refractive index.
- Develop the most economical assembly technology.
- Develop suitable bifacial solar cells for two-sided concentrated illumination yielding an additional factor of two in concentration.

This same principle could be useful for photochemical processes in liquids.

Some problems may be expected to arise, such as combination of microelectronics manufacturing techniques with photovoltaic module production. A detailed description of this concept can be obtained [A. Goetzberger, *Proc. IEEE PV-Specialists Conf., Las Vegas, Sept. 1988*, in press].

Long-Range Impact on National or International Global Energy Systems

These ultra-thin solar cells would primarily have an application in domestic household electricity generation. This would favor the evolution of a more decentralized power generation system integrated with central power stations. Probably, as with conventional photovoltaic systems, many of the early applications would be in the Third World. The development of these types of solar cells would have little or no contribution to the greenhouse effect; however, the nature of the materials would have to be designed carefully so as not to cause a disposal problem.

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