

CHARLES FELDMAN

FOURTH EUROPEAN COMMUNITIES PHOTOVOLTAIC SOLAR ENERGY CONFERENCE: A TRIP REPORT

The Fourth European Communities Photovoltaic Solar Energy Conference was held May 10-14, 1982, in Stresa, Italy. The conference was sponsored by the Commission of European Communities, the Italian Ministry of Research in Industry, and the U.S. Institute of Electrical and Electronics Engineers. Thirty-four countries were represented, with the largest number of participants coming from West Germany, France, Italy, the United States, and Great Britain, in that order. Although it was chiefly a European Communities conference, there were representatives from Japan, South Africa, Brazil, Algeria, Tunisia, Syria, and Vietnam, as well as the United States, for a total of 538 participants.

The opening session, given by members of the Commission of European Communities and the Italian Ministry, introduced the key word of the entire conference: *cost* — the single item restricting large-scale use of solar photovoltaics for terrestrial use. While experimental cells for space use are approaching 20% efficiency, with cost no object, the terrestrial solar cell community would apparently settle for less than 10% if the price were right. Cost is computed in European Currency Units (1 ECU \approx \$1 U.S.). In spite of the importance of cost, few actual figures were quoted during the conference. A system cost of less than 2 ECU/watt by the year 2000 seems to be the general opinion. System cost is roughly double the cell cost. It appears that small (1 to 5 kW_p*) stand-alone photovoltaic power units are within two to three years of becoming competitive with diesel generators and will be extremely important in underdeveloped countries — a large potential market! (Some people claim that the cost is already competitive with diesels.) There are demonstration installations in nine or ten underdeveloped countries, including India, Mali, New Guinea, and Algeria. The prime use of these low-power units is for hospital refrigeration (e.g., storage of vaccines), irrigation, pumping water, and communication. Photovoltaic units in these countries are being built by private firms with both local government and international financing. The smallest demonstration unit was in

Algeria (0.5 kW_p), while the largest was in Saudi Arabia (350 kW_p).

The great interest in small stand-alone power units is gratifying in view of the APL colloquium in 1977 by Dr. I. H. Usmani from the United Nations. Usmani described the desperate requirements of hundreds of millions of people for just small quantities of electricity. An Italian group from Bologna described, in fact, a 1.4 kW_p photovoltaic unit coupled with a 2.5 kW wind power generator system, complete with battery storage, that resembled the concept outlined by Usmani. The system has been operating for about a year and has met all the needs of a remote farm in northern Italy.

The use of photovoltaic energy in the developed countries, except for limited purposes, is considered simply a luxury. Practical photovoltaic power in countries with extensive existing grid systems will probably not arrive until the year 2000, and then only a small percentage (about 1%) of the total electric power consumption is expected to be so generated. However, demonstration projects are being undertaken or contemplated in almost every developed country, including the United States. Switzerland, for example, has considered installing photovoltaic panels on high mountain peaks that are above the clouds. The solar power would be a natural supplement to its hydroelectric plants. With few exceptions, all demonstration facilities are based on silicon single-crystal wafers mounted on flat panels.

Following the introductory session, the conference subject matter was divided into applications and engineering studies, fundamental studies, and materials and thin film studies. Most of the presentations were in the form of poster sessions.

Materials currently of importance for photovoltaics are crystalline silicon, amorphous silicon/hydrogen alloys, copper sulfide/cadmium sulfide, and gallium arsenide, in approximately that order. Silicon still dominates the photovoltaic industry, and techniques for reducing the costs of producing the raw material, as well as for crystal growth and wafer production, were discussed. Along with the term "metallurgical silicon" and "semiconductor grade silicon" we now have the term "solar grade silicon," a

*W_p indicates watts generated at peak solar intensity.

material whose purity and cost are not quite as high as those of the semiconductor grade. The normal way of producing semiconductor grade material by going through a gas phase is too expensive and is incapable of producing the quantities necessary for the envisioned widespread solar energy use. Therefore, other purification techniques, such as directional freezing, gettering, and leaching, are being evaluated. Gallium arsenide is also a contender for bulk crystalline photovoltaic devices, provided optical concentrating techniques are used.

While various materials were discussed for thin film cells (e.g., copper sulfide/cadmium sulfide, cadmium sulfide/cadmium telluride, and indium phosphide), amorphous silicon-hydrogen alloys are currently receiving the most attention. Cells from amorphous material are relatively easy to fabricate on inexpensive substrates and yield efficiencies of 7 to 8%. However, the cells lose efficiency when exposed to the sun for long periods, and their long-term use is thus questionable.

One approach to low-cost cells is to use impure, non-single-crystal silicon wafers as substrates and to grow epitaxially a pure silicon layer (20 to 50 micrometers) on top. The growth was carried out by chemical vapor deposition at selected temperatures, and the effects of impurity diffusion from the substrate and grain boundaries were described.

The APL paper on antimony doping was the only report at the conference concerned with physical-vapor-deposited silicon thin films. The paper described a method for doping silicon polycrystalline thin films and single crystals (Fig. 1). The method is compatible with the concept of forming photovoltaic cells completely in a vacuum system. Layers of antimony trioxide and silicon were deposited, either simultaneously or sequentially, through masks onto the surface of *p*-type silicon. Heating (e.g., 1100°C, 1 hour) in either an inert atmosphere or oxygen brought about the formation of a silicon oxide-antimony ($\text{SiO}_x\text{-Sb}$) glassy layer and caused antimony to diffuse into the base silicon surface. The oxide complex was then etched off, leaving *n*-type regions

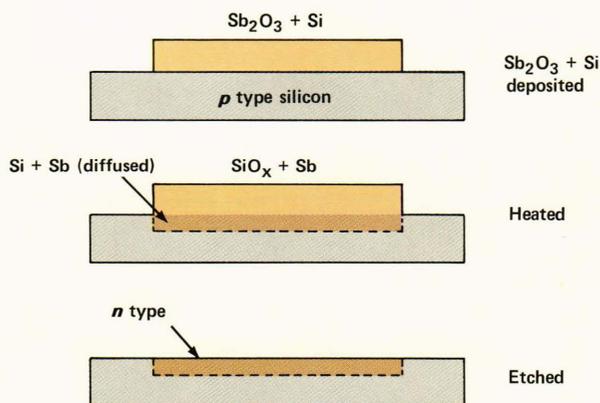


Figure 1 — The APL method of forming an *n/p* junction by thin film deposition.

in the *p*-type material. The *n/p* junctions yielded photovoltages at an insolation level of 0.1 watt/centimeter of about 0.5 volt for single crystals and 0.29 volt for polycrystalline films.

A novel method for producing continuous thin silicon sheets was presented by both a French group from Marcoussis and a German group (Siemens). The groups are apparently working independently. A ribbon of carbon in the form of a mesh or web is pulled through a silicon melt (Fig. 2). The silicon forms a thin layer (about 100 micrometers thick) on both sides of the carbon mesh. The French pull the ribbon at approximately 8 centimeters/minute. After forming the ribbon, the French group heats the ribbon in oxygen at 1000°C to burn off the graphite, leaving two separate layers of silicon, each approximately 100 micrometers thick. They are then able to process this material in a more-or-less standard fashion into 9 to 12% efficient solar cells. The German group has achieved high pulling rates of 2 meters/minute but apparently has not processed its material into solar cells.

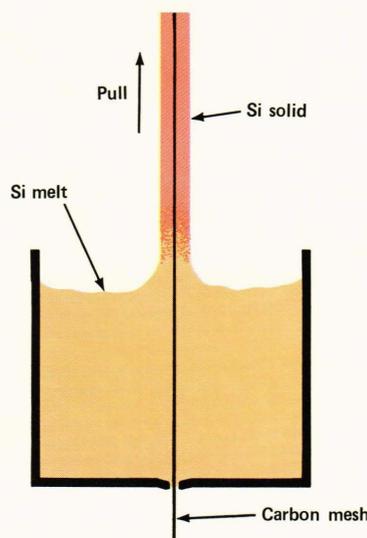


Figure 2 — The carbon web-supported silicon growth technique.

Texas Instruments discussed its unique and admittedly high-risk solar energy system (Fig. 3). Concentric *p/n* and *n/p* junctions are formed by diffusion in doped silicon spheres approximately 200 micrometers in diameter. The junction formation leaves the sphere with an outer oxide coating that is selectively etched so that metal contacts can be made to the outer *p* or *n* region and interconnected via an electrolyte. The inner sphere contact uses a flat plate arrangement for interconnection. In a 40 square centimeter module there are 25,000 spheres arranged in a regular array. The *n/p* and *p/n* spheres are separated, forming half cells. The electrical output of the cell is used to electrolyze hydrogen bromide. The hydrogen and bromine are stored separately and are recombined in a fuel cell to produce electricity when

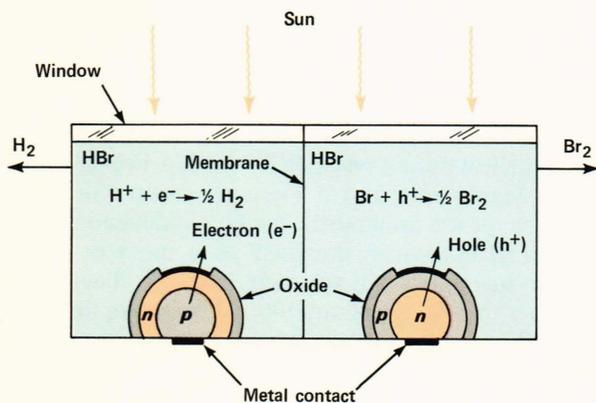


Figure 3 — Texas Instruments photochemical cell.

needed. The system is a closed loop hydrogen bromide system. The aim is to have a completely independent electrical unit — including storage — that can be used in residential homes.

In the area of *p/n* junction formation, several groups (Denmark and France) are exploring the possibility of using boron trifluoride as a source material for direct ion implantation rather than going through the usual mass separation procedure to obtain boron ions only. Various species of ions containing fluorine are implanted into the silicon, and research is being carried out to determine the effect of the fluorine ions on the cell properties. The cells must be annealed following ion implantation to remove the surface damage. The advantage of this technique is that one can use a large ion source and dope (implant) the entire wafer simultaneously, without using scanning techniques.

Another interesting doping technique was described by a group from Arco Solar (U.S.). In this method, a silicon wafer is immersed in a doping gas such as phosphine (PH₃) and then irradiated with a

pulsed laser. The laser melts the surface of the silicon and the gas dissolves in it as it recrystallizes epitaxially. This produces a thin doped region with sharply defined boundaries on the crystal surface. The technique is termed Gas Immersion Laser Diffusion. The authors claim efficiencies of 8.6% without antireflection coating. They also claim that when this technique is used with polycrystalline silicon, the effect of grain boundaries seems to be ameliorated. This has not been confirmed, however, in working cells. (The technique may be pertinent to the APL program.)

Mention must be made of the Japanese work in forming junctions between amorphous silicon hydrogen alloys and amorphous silicon carbide hydrogen alloys. This hetero-junction produces an efficiency of approximately 8%. In spite of the general concern for the lifetime of amorphous hydrogenated cells, the Japanese are proceeding to construct a large manufacturing plant based on this process.

Several talks were given on optical concentration systems. Fresnel lenses, parabolic mirrors, and luminescent (dye) concentrators were described. All focusing systems must follow the sun, and all require some type of cooling arrangement. The efficiency of solar cells increases with concentration, up to about 200 suns in silicon and 1000 suns in gallium arsenide. The luminescent concentrator uses a flat plate, and the emission is internally reflected to the edges, where the cells are mounted. It does not require focusing or sun tracking. The cost effectiveness of concentration systems compared to flat-plate systems is not clear.

The consensus throughout the conference was that photovoltaic solar energy is still an open race. It is not yet obvious which, if any, of the present techniques will meet the long-range requirements of high efficiency and 20-year lifetime, as well as low cost. The conference proceedings will give a good overview of the world status of photovoltaic energy for terrestrial use.