Conf-9205195--1

ANL/CP--76114

DE92 015259

Materials Science in Solar Cell Development*

Jong-Hee Park
Materials and Components Technology Division
Argonne National Laboratory
Argonne, Illinois 60439, USA

April 1992

Invited paper to be presented at the '92 Spring Workshop in Energy Resources Session, Seoul, Korea, May 25-31, 1992.

* Work supported by the U.S. Department of Energy, under Contract W-31-109-Eng-38.

DISCLAIMER

Materials Science in Solar Cell Developments

Jong-Hee PARK
Materials and Components Technology Division
Argonne National Laboratory, Argonne, Illinois 60439 USA

INTRODUCTION

Solar cells were developed during the 1950s, primarily at the Bell Telephone and RCA Laboratories.[1-3] In the long term, development of renewable energy sources using solar voltaic convertors can supplement the limited availability of fossil and nuclear fuel, and the environmental impacts of such power sources.

The USA and Japan initiated the framework for solar power plants approximately 15 to 20 years ago. Initial solar cell development, and solar power work in the US focused on space power systems. However, Japan has focused on hydrogen generation using solar heat (~3000°C) or solar cells for separation of oxygen and hydrogen by electrolysis of water. Hydrogen and oxygen could be used in mobile energy systems (e.g., automobiles). England, has explored methods to produce solar cell panels using transparent glass substrates, etc.

The nature of solar cell development is merged with that of the silicon semiconductor industries, and thus is mainly related to the technology of fabrication of single crystals. The efficiency of solar cell power plants must be improved considerably for them to become practical. Renewable energy sources such as the solar voltaic convertor are based on well-developed industrial technology. Stable solar voltaic convertors would eliminate pollution problems, stimulate high-technology industries such as communications and aerospace and increase the demand for solar energy systems.

PROGRESS

At the present time, Siemens Solar Industries is the world leader in the development and manufacture of high-efficiency photovoltaic (solar electric) products. The history of Siemens Solar Industries is the history of much of the world's solar cell development. Photovoltaic technology was first developed for space programs. Early space-program cells—which were brittle and easily broken—were less than 1 in.^{2} in area and cost \$2000 per peak watt. (A peak watt is the rate of production of electricity from a solar cell at noon on a sunny day.) However, in less than a year, the small company had produced a terrestrial solar cell with ten times the area of the space cell for one-tenth the cost. These were fabricated into strong, portable, reliable modules that became the industry standard.

In 1975, the company set a goal to reduce the cost of photovoltaics so that solar electricity would be economical for an ever-increasing range of uses. In 1977, this goal become a reality, and R&D efforts immediately began to achieve important milestones in the photovoltaic industry. By 1980, the company had built the world's first automated solar cell factory, becoming the first photovoltaic manufacturer to produce one-million-watt (MW) solar cells in less than a year. In 1982, they set up a 1-MW photovoltaic power plant in Histerperia, California. The next year (1983), Siemens completed a 6.5–MW power station in central California. This gave utility companies the opportunity to see photovoltaics as a viable alternative to nonrenewable energy sources. Now, solar electricity is in use everywhere—powering microwave and radio transmitters and receivers; providing residential electrification for light, television, radio and computers; and producing electricity to pump water. In 1990, an additional manufacturing facility was brought on line to keep pace with the rapidly growing photovoltaic market. So far, single-crystal silicon-solar cells are being marketed. However, to improve the efficiency of this established technology, new, more advanced photovoltaic materials are being developed.

STATUS

The first problem is the development budget. Solar cell power plants can be categorized in two groups, namely long–term and short–term projects, depending on the planning—i.e., what kind of power will be generated. Most previous developments were reported at the laboratory scale, while very recently, many universities and high schools have built solar cell vehicles for demonstration.[4] Normally, these use silicon–based solar cells provided by vendors or developed for R & D purposes, for testing and obtaining statistical data from these activities. Many solar energy generation projects were discontinued after 1984 because of their very high costs. The present situation could be considered as a political issue because other possible renewable energy sources for the near future are also strong candidates along with solar power plants.

The present solar cell technologies are largely based on high–quality silicon, the principal solar cell component, fabricated into various shapes using various compositions, e.g., single-silicon crystal, polycrystal, or thick and thin films, n- or p-types, etc.[5] However, in order to create a practical system, far more engineering elements must be considered, including the achievement of higher efficiencies with respect to the optical absorption coefficient as a function of wavelength (thereby determining the optimal film thickness for the highest efficiency). Because silicon is an indirect semiconductor, the momentum changes during electronic transition. Amorphous silicon will have problems with localization of heterogeneous behavior due to localized crystallization, while in the case of polycrystalline silicon and epitaxial films, the localized behavior in grain boundaries or in film/substrate interfaces must be considered. In addition, the fabrication of interfaces requires mechanical stability, especially in high-temperature processes where consideration must be given to thermal expansion of both materials (to avoid thermal cracking, microcracking, or wide-open grain boundaries) and to chemical composition (especially carrier concentration, which is related to thermodynamic equilibrium).

Another major engineering concern is materials degradation due to environmental exposure. Information must be obtained on local–area airborne particles, weather conditions, precipitation, acidity, temperature, etc. Materials degradation in a terrestrial solar–cell power plant is an extremely important issue for long–duration reliability. Such degradation includes fatigue cracking due to diurnal temperature variation, and stress-corrosion cracking because of severe weather conditions.

CONCLUSIONS

The present–day development of solar cells is merged with the silicon semi–conductor industries. However, much effort is still required in order to fabricate cells with the highest possible efficiencies and greatly reduced costs. This is closely related to coating technology.

FUTURE WORK

Important issues in solar cell developments are (1) well-planned R&D and documentation.and (2) need for collaborative efforts in engineering design.

ACKNOWLEDGMENT

Work supported by the U.S. Department of Energy, under Contract W-31-109-Eng-38.

REFERENCES

1. D. M. Chapin, C. S. Fuller, and G. L. Pearson, A New Silicon p-n Junction Photocell for Converting Solar Radiation Into Electric Power," J. Appl. Phys. 25, 676-677 (1954)
2. D. M. Price, "Silicon Solar Energy Conversion," J. Appl. Phys. 26, 535-540 (1955).
3. J. J. Loferski, "Theoretical Considerations Governing the Choice of the Optimum Semi–conductor for Photovoltaic Solar Energy Conversion," J. Appl. Phys. 27, 777-784 (1956).
4. M. Stimson, Siemens Solar Industries, personal communication (1992).
5. C. E. Morosanu, Thin Film by Chemical Vapor Deposition, Elsevier, Amsterdam (1990).