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STATUS OF RESEARCH AND DEVELOPMENT ACTIVITIES IN MEXICO
RELATED TO PHOTOVOLTAIC APPLICATIONS*

Prepared by

R. Asomoza**

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** Head, Centro de Investigación y de Estudios Avanzados del IPN, Mexico DF, Mexico.

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I. Introduction

Mexico has a great potential for the use of photovoltaic (PV) systems, mainly for two reasons:

- 1) The country has one of the highest average insolation rates in the World and,
- 2) there are about 85,000 rural communities,

having from 50 to 5,000 inhabitants, that are not electrified and will not be connected to the utilities in the near future. This represents about 13% of the total population of the country (about 11 million people). In fact, the electrification of these villages, by conventional means, is very expensive due to the fact that most of them are far from the distribution lines and in many cases they are located in the mountains.

From the market point of view, this represents an enormous amount of PV systems to be installed, even if only a small lighting service is offered to each family. This situation has been recognized long time ago, however, few actions have been undertaken to supply electrical services to those communities.

In the past two years a rural electrification programme, sponsored by the Federal Government, has been set up, which will provide PV lighting systems to many of them. This programme is running with commercially available systems.

A local industry, working with locally developed technology could contribute in a significant way to this electrification programme, having the advantages of: to use locally developed skills; to find technical support in the research and development Centers; to intensify the research and development activities related to new materials for PV applications, and to promote the use of these new materials. The research Centers associated with this industry would find a natural work market for the people trained in this area.

In the following we will describe the activities performed at the CINVESTAV and the results obtained in developing PV technology, as an example of our efforts to establish a national PV industry.

The activities in this area began as early as 1966 and some of them have been sponsored by UNDP-UNESCO.

II. The CINVESTAV Programme

Taking into account that in Mexico the local industry pays little attention to research and development activities, on one side, and that there is not a local PV technology that could be the basis of a Mexican industry, began at the Electrical Engineering Department of a research center, the CINVESTAV.

The CINVESTAV considers that photovoltaic conversion of solar energy is an alternative energy source in the Mexican rural area. The advances in materials research will certainly make this option more competitive by making the cells cheaper and more efficient.

The objectives of the programme initiated at the CINVESTAV were:

- 1) To develop and promote the PV conversion and the applications of solar energy.
- 2) To perform R & D in new semiconductor materials and their device applications.

In accordance to this, the CINVESTAV has participated actively and it has promoted the integral development of the PV conversion, based on its experience in the semiconductor materials and the design of engineering systems.

In this sense, this programme is the only technological development which has been accomplished in Mexico in the semiconductor field in an integral way. It includes the following aspects:

- Materials research
- Technological developments
- Fabrication of solar cells and solar modules in small scale
- Design, calculation and installation in the field of PV systems
- Design and fabrication of electronic charge controllers
- Local radiation field studies
- Consulting to federal and private companies
- Training of people at different levels from technicians to PhD

II.1) Production of solar cells

In order to reach the first objective and to create a culture in the PV conversion, a pilot line for the production of solar modules was designed and installed. This plant would implement and test the technology developed at our laboratories by our Research and Development Group. Once the processes were tested, the technology would be scaled to an industrial level and transferred to private companies. The CINVESTAV would then act as a consulting and technological support group, as well as a training center for engineers and technicians.

The plant was installed from 1979 to 1980 and produced 25 kW-peak/year using three inches single crystalline silicon wafers in an eight hours per day basis. The result was: economically competitive systems.

The specifications of our modules were the following:

MODULE	MS	1722
Power	17.2	watts
Voltage	16.0	volts
Current	1.1	amps
V _{oc}	20.8	volts
I _{cc}	1.2	amps

II.1.1) Projects developed

The main application projects developed by our PV Systems Group were the following:

a) Educational TV

The first TV set working with our modules was installed in 1977 in a small rural community located in the high mountains of Puebla. The system worked six hours per day in a high school.

Its technical data were:

- 30 watts-peak obtained with two modules connected in series.
- a commercial TV set adapted to work at 24 volts DC with 24 watts consumption.
- standard lead-acid batteries with 90 amp-hours at 24 DC volts.
- the system was designed for a five peak hours per day average insolation.

b) Radio communication

In the same year, in 1977, some radio communication systems were designed and installed in the field, also in the mountains of Puebla. The systems consisted of:

- two modules of 15 watts each wired in parallel
- a Motorola transceiver with a power consumption of 61 watts during transmission and 2.4 watts in standby at 13.6 volts
- an electronic charge controller
- standard telephonic batteries with 120 amp-hours at 12-14 volts
- the systems were designed for a five hour per day insolation

c) Water pumping

There have been several projects in this line, the first one consisted in developing a 3/4 HP water pump for 15-25 meters deep wells, working five hours per day. The system worked at 90 volts DC and consisted of a PV array of 735 watts-peak. The total volume pumped was 54 m³/day. It was built in 1979-1980 in our campus in Mexico City.

The technical data for this system were:

- 48 solar modules wired in the following way: six strings in series connected with eight strings in parallel
- 720 watts-peak installed
- seven lead-acid batteries in series
- the electronic charge controller allowed either direct coupling or battery operation

A second system is under test and it consists of a 7.5 HP DC motor working at 120 volts and 46.6 amps. It can pump water from 90 meters deep wells with a flow rate of 3.5 liters/sec.

d) Lighting

In collaboration with the National Indian Institute (NII) and the Minister of Education, the CINVESTAV provided PV lighting systems for the rural schools of the NII. CINVESTAV had the responsibility of the calculation, design, fabrication, test and installation of the systems mentioned above.

The systems consisted of: four modules wired in parallel; standard lead-acid batteries and they were designed for a five peak hours per day insolation. In order to control the charge and to protect the batteries, an automatic charging circuit was developed and fabricated in large scale.

Up to date, the systems designed and developed at the CINVESTAV amount to more than 240 lighting systems, 4 educational TV systems, 18 radio communication systems and 3 water pumping systems.

II.1.2) The national market

As mentioned before, in Mexico there are about eleven million people without conventional electricity distributed in around 85,000 rural communities.

This potential market is limited by two aspects:

- 1) the economical resources of the people in the rural area are rather low
- 2) the transfer of new technologies, in our case PV systems, is difficult to accomplish because the users lack of appropriate knowledge of these technologies.

Up to date, the Federal Government support has been the only major financial source. This support has been greatly increased in the last two years, as mentioned before.

The national sales of PV systems have passed from 50 kW-peak to about 200 kW-peak in the last three years and they are still growing. Several international sales offices have been installed in Mexico and some engineering firms give technical support.

II.2) Materials research for solar cells

Concerning the second objective, two lines have been explored: low cost processes for the fabrication of solar cells and low cost thin film solar cells.

The pilot production line, described above, began employing the elemental technologies that consist of the common chemical etching and cleaning of silicon wafers followed by impurity thermal diffusion processes using a liquid source (POCl_3) for the formation of the front junction layer. Electrical contacts were deposited with conventional vacuum evaporation of Ti/Pd/Ag and, as antireflecting coating, a spray pyrolysis deposited SnO_2 thin film was used.

Some changes were introduced by using the low cost electroless technique for deposition of the electrical contacts. This technique allows nickel deposition on silicon, followed by Pb-Sn dipping process. It was a decisive step to achieve a higher production rate.

Concerning the thin film solar cells, we work currently in the following materials:

- hydrogenated amorphous silicon
- semiconductor oxides
- GaAs and GaAlAs
- CuInSe_2 and CuInS_2

1) a-Si:H

Two techniques have been used to deposit a-Si:H; glow discharge decomposition of silane and silane-methane mixtures, and rf reactive sputtering of a silicon target. Different analytical techniques have been used to characterize the films obtained, in particular the conductivity, photoconductivity, transmittance, structure, H content and H bonding have been determined.

2) Semiconductor oxides

SnO_2 and ZnO have been deposited in large areas, using the technique of spray pyrolysis. The main application of these oxides has been as antireflecting coatings of the solar cells produced in the pilot line. These oxides improved the absorption of light increasing the efficiency of those cells. For fluorine doped SnO_2 transmittance values around 90% and resistivities as low as 10^{-3} ohm-cm were obtained. The films were characterized by using many different techniques, such as electrical conductivity, structure, microstructure, impurity distribution and segregation, as well as the effect of the substrate temperature on the properties of the films.

3) GaAs and GaAlAs

Gallium Arsenide is a good material for high efficiency solar cells. The technique was used to grow thin films of this semiconductor is the Chemical Vapor Deposition of Organometallic compounds (MOCVD). It has the advantage of its versatility for changing the composition and properties technique, to grow structures suitable for special applications. The structure under study is the following: nGaAlAs/nGaAs/pGaAs/pGaAlAs/GaAs/Si.

4) Ternary compounds

Solar cells with efficiencies as high as 14% have been reported for CuInSe₂. The methods used to prepare the active layers are, however, rather sophisticated. We have started a study to obtain CuInSe₂ and CuInS₂ by spray pyrolysis and electrodeposition, which are cheaper. The advantage of S with respect to Se is that it is much less toxic. We are using resistivity, transmittance, X rays and chemical analysis to characterize these films. Our results indicate that the films obtained by spray pyrolysis are good quality films for photovoltaic applications.

III. Conclusion

The technology developed allowed the installation and operation of photovoltaic prototypes for different applications. The work, developed at the pilot plant, shows a technological dominion in cell and module fabrication. There is not yet, however, industrial response for the transfer of the technology developed at the CINVESTAV.

The study of new semiconductor materials will make the systems produced more competitive by decreasing the fabrication costs and increasing the efficiency.

The potential market of more than eleven million people and the high insolation rates in the country favour the photovoltaic solar energy conversion as an alternative to offer services to the rural communities.

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